The indirect effect of the built environment on travel mode choice: A focus on recent movers

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Abstract

Many studies have demonstrated that the built environment has a strong impact on people's travel mode choice. However, the built environment also influences elements such as travel distance and car ownership, which might be the true predictors of which travel modes are chosen. In this study, we analyse the effects of changes in residential neighbourhood on changes in travel mode (for commute trips and leisure trips), both directly and indirectly through changes in car ownership, travel distances and travel attitudes. This study applies a structural equation modelling approach using quasi-longitudinal data from 1,650 recently relocated residents in the city of Ghent, Belgium. Results indicate that the built environment has strong direct effects on active leisure trips and car use. However, distance (for car use) and attitudes (for active travel) were found to be important mediating variables. In sum, the effect of the built environment on travel mode choice might be more complex than commonly assumed as it partly seems mediated by travel distance and travel attitudes.

Keywords: Travel behaviour; Built environment; Residential location; Travel attitudes; Car ownership; Travel distance

1. Introduction

Since the 1990s, numerous studies from different regions in the world have shown that people living in urban neighbourhoods frequently walk, cycle or use public transport while suburban residents travel mostly by car (see e.g., De Vos, 2015; Ewing & Cervero, 2010; Næss, 2012; Wang & Zhou, 2017; Zhang et al., 2012; Zhao, 2013 for recent work). Variances in travel mode choice according to the residential neighbourhood can largely be explained by the differences in density, diversity and design, the so-called 3 Ds (Cervero & Kockelman, 1997). The low density and diversity of suburban neighbourhoods result in relatively long travel distances. The separation between home and other activity destinations together with a design stimulating car use (ample parking space, large building blocks, cul-de-sacs, etc.) result in a high share of car trips for suburban residents. Since public transport services are limited and travel distances are often too long to cover by active travel, these residents are mostly forced to own a car, which in turn results in even more car trips (e.g., Buehler et al., 2017; Næss, 2006). Urban neighbourhoods, on the other hand, are mostly compact and have mixed land uses resulting in short distances, making it possible to walk or cycle to most destinations (e.g., Ewing & Cervero, 2010). In combination with (mostly) good public transport services and a design discouraging car use (e.g., car-free zones, limited parking spaces), alternative travel modes are used rather frequently in these urban areas. The shorter distances covered, and available public transport services offered make it possible for a household not to own a car when living in an urban area, further stimulating the use of car alternatives. In sum, the chosen residential location can influence travel distances and car ownership, which in turn affects travel mode choice (e.g., Ding et al., 2017).

Partly inspired by the theory of planned behaviour (Ajzen, 1991), travel behaviour studies also found that travel attitudes play an important role in travel mode choice, and that a positive appraisal of a certain mode increases the likelihood of choosing that mode (e.g., Bagley & Mokhtarian, 2002; Kitamura et al., 1997). Furthermore, these attitudes might also affect the residential location choice since people might prefer a residential neighbourhood in line with their travel needs and preferences – referred to as residential self-selection in the literature (Cao et al., 2009; De Vos et al., 2012; Guan et al., 2020; Handy et al., 2005). A person preferring active travel, for instance, might desire a compact, mixed-use neighbourhood to live in, as the short distances enable walking and cycling. Although some studies have argued that attitudes have a stronger effect on travel mode choice than the built environment, most studies still found significant effects of the built environment after controlling for self-selection effects (Cao et al., 2009; Næss, 2009).

Besides effects of travel attitudes on the residential location choice, an opposite effect might also exist. People might develop positive attitudes towards certain travel modes which use is being stimulated by the neighbourhood's physical characteristics (De Vos et al., 2018; Wang & Lin, 2019). For instance, a person moving to / living in an urban neighbourhood might (eventually, after potentially changing attitudes) experience positive feelings towards active travel and public transport as this person can easily travel by these modes in urban areas. These attitudes – which are consistent with travel modes encouraged by the neighbourhood – can stimulate the use of these modes even further. According to Lin et al. (2017), the residential environment mainly affects travel attitudes when the residential location choice was not based on travel attitudes. In such case, travel attitudes might not be consistent with the travel patterns stimulated by the new built environment (e.g., a car lover living in an urban environment). This vein of thought is aligned with the cognitive dissonance theory (Festinger, 1957), indicating that people tend to change attitudes when an inconsistency exists between attitudes (e.g., travel attitudes) and behaviour (e.g., residential location choice).

The above discussion indicates that the built environment, car ownership, travel distance, and travel attitudes affect travel mode choice. Studies have also shown that the built environment has indirect effects on modal choice through car ownership and travel distance. However, despite an understanding that the built environment affects travel attitudes, and travel attitudes affect mode choice, no studies have analysed the indirect influence of the built environment on mode choice through travel attitudes. In this study we will analyse the effect of changes in people's residential neighbourhood (resulting from a residential relocation) on changes in travel mode use, directly and indirectly through changes in travel distance, car ownership and travel attitudes. While most previous studies use cross-sectional data to analyse (direct and indirect) effects of the built environment on travel mode, this study uses quasi-longitudinal data making it possible to examine this link in a more robust way. Furthermore, this is – as far as we know – the first study that simultaneously analyses the mediating effects of (changes in) car ownership, travel distance and attitudes on (changes in) travel mode choice. Results from this study can consequently provide new insights on the effect of the built environment on travel behaviour. This paper is organised as follows. Section 2 gives an overview of existing studies analysing relationships of car ownership, travel distance and travel attitudes with the built environment and travel mode choice. In Section 3 we discuss the collected data and used methodology (i.e., a structural equation modelling approach). The main results from the models are shown in Section 4, while a discussion and conclusion are provided in Section 5.

2. Relationships of car ownership, travel distance and travel attitudes with the built environment and travel mode choice

2.1 Car ownership

A number of studies have indicated that car ownership is lower in urban neighbourhoods compared to suburban neighbourhoods (Bhat & Guo, 2007; Cao et al., 2007a, 2019; Dargay, 2002; Ding & Cao, 2019; Ding et al., 2016; Guiliano & Dargay, 2006; Senbil et al., 2009; Zegras, 2010), and that car ownership positively influences car use (Bagley & Mokhtarian, 2002; Cervero, 2002; Dieleman et al., 2002; Krizek, 2003; Schwanen et al., 2002; Senbil et al., 2009). However, studies analysing the indirect effect of the built environment on travel behaviour through car ownership are limited. In order to examine this mediating effect, structural equation modelling approaches have occasionally been used. These studies indicate that the built environment exerts both a significant direct effect on travel mode choice (car use and public transport use in particular), and significant indirect effects on these elements through car ownership (Aditjandra et al. 2012, 2016; Cao et al., 2007b; Ding & Lu, 2016; Ding et al., 2017; Van Acker & Witlox, 2010). In sum, the effect of the built environment on travel behaviour seems partly mediated by car ownership. After accounting for car ownership, the effect of the built environment on travel behaviour is still significant, yet less strong compared to when disregarding car ownership.

2.2 Travel distance

Similar to car ownership, travel distance might be an important intermediating variable in the effect of the built environment on travel behaviour, since travel distance is affected by the density and diversity of the built environment but could itself also influence how people travel (Dieleman et al., 2002; Holz-Rau et al., 2014; Næss et al., 2017; Scheiner, 2010; Schwanen et al., 2001). Ding et al. (2017), for instance, found that employment density has a direct positive effect on walking, cycling and public transport use, but also an important indirect effect through travel distance; employment density negatively affects travel distance, which in turn has a negative effect on active travel and public transport use. De Abreu e Silva et al. (2006, 2012) found that the built environment of the residential location and work location has a significant effect on commute distance, which in turn affects travel mode choice. They also found significant direct effects from the built environment on travel behaviour. Travel distance consequently seems to have an intermediate role in the link between the built environment and travel behaviour, similar to car ownership. After accounting for travel distance, the effect of the built environment on travel behaviour remains significant but becomes less strong.

2.3 Travel attitudes

Although studies have indicated that travel attitudes have an important influence on how we travel (e.g., Bagley & Mokhtarian, 2002; Kitamura et al., 1997), the idea that travel attitudes can be affected by the built environment is rather new. Most studies suggest that travel attitudes have an effect on the choice of where to live, and that people partly choose a residential neighbourhood based on their travel preferences (i.e., transport-related residential self-selection (Cao et al., 2009)). The opposite effect has been analysed less frequently. Four studies using a structural equation modelling approach found significant bidirectional relationships between travel attitudes and the built environment (de Abreu e Silva, 2014; Ewing et al., 2016; Lin et al. 2017; Van Acker et al., 2014). Kamruzzaman et al. (2013, 2016) – using a two-wave panel study in Brisbane (Australia) – found that around 25% of respondents significantly changed their travel attitudes between 2009 and 2011, in most cases becoming more consistent with the residential location. Two recent studies found that mode-specific attitudes considerably changed after respondents moved, becoming more in line with travel encouraged by the new built environment (De Vos et al., 2018; Wang & Lin, 2019). Furthermore, the built environment might also affect travel attitudes indirectly via travel patterns encouraged by the built environment (De Vos et al., 2020). Up till now, no studies have analysed the effect of the built environment on travel behaviour taking into account the (potential) mediating effect of travel attitudes.

In this study we will examine the influence of the built environment on travel mode choice considering the mediating effects of car ownership, travel distance and travel attitudes. In particular, we will focus on variations in these elements by using 1,650 recently relocated residents. In other words, we will analyse how changes in the residential neighbourhood result in changes in mode frequency, both directly and indirectly through changes in car ownership, travel distance and travel attitudes (Figure 1).[1] We will not take into account possible self-selection effects of travel attitudes on the residential location choice since this is not the focus of this study and this cannot be measured with the available date (see Section 3.2).

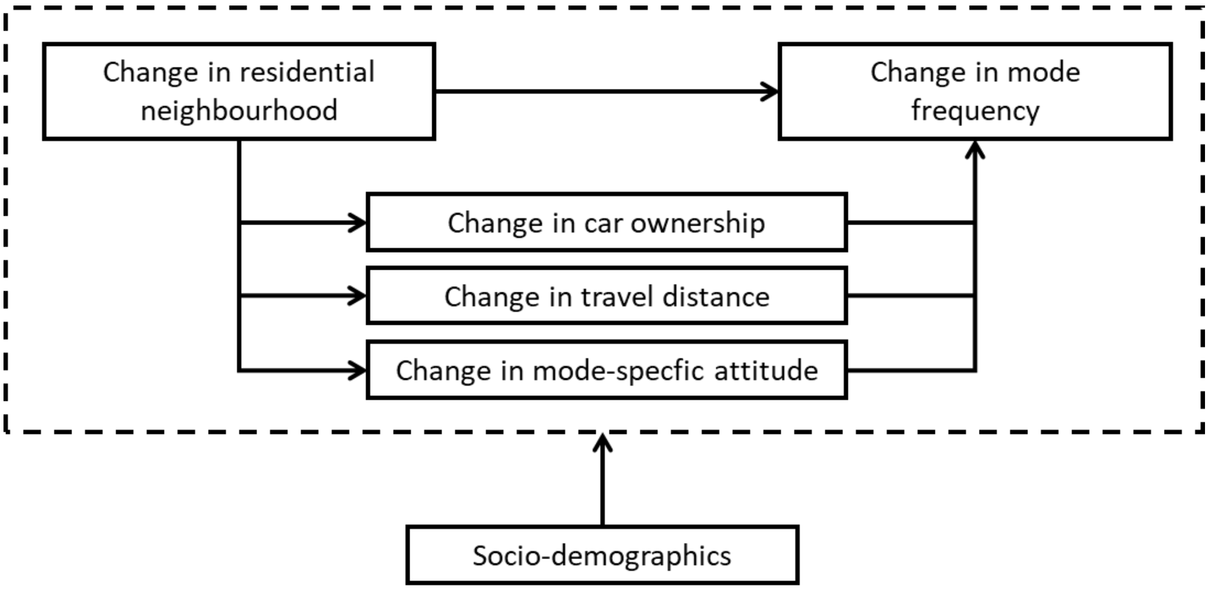

Figure 1. Conceptual structural model.

3. Data and methodology

3.1 Data

In February 2017, 9,979 invitations to participate in an online survey on travel behaviour (changes) were distributed to all households within a group of selected (urban and suburban) neighbourhoods in the city of Ghent (Belgium; 258,000 inhabitants). For this study, recently relocated residents were targeted and addresses of households moving to these neighbourhoods in the last two years (i.e.,

[1] Although bidirectional effects between changes in car ownership and travel distance can be expected (i.e., longer average travel distances resulting in a possible purchase of a car, and owning a car resulting in longer travel distances), we did not include these in the models, in order not to unnecessarily complicate the models.

between January 2015 and December 2016) were provided by the city of Ghent. The cover letter of the survey invited all the adult household members that participated in the residential location choice to fill in the survey. In the end, 1,842 individuals participated, of which 1,650 respondents completed the survey.

Table 1 shows the socio-demographic characteristics of the respondents. Most respondents live in urban neighbourhoods (67.4%), are highly educated (77.2%) and are – mainly full-time – employed (83.5%). There are somewhat more men than women in the sample (52.1% versus 47.9%) and most respondents live together as a couple without children (37.3%), or are single (29.9%). Somewhat more than half of the respondents (53.2%) lives in a household with a monthly net income lower than €2,500.[2] Young adults are overrepresented in our sample; almost half of the respondents (49.5%) are younger than 30 years old. This might be explained by the fact that the (life) event of a residential relocation is often linked or even induced by other life events (Müggenburg et al., 2015), which mostly take place in people's twenties and thirties. This is also the case in Ghent, where most people relocating are between 20 and 40 years old (City of Ghent, 2020).[3] Respondents indicated that the following life events were important reasons for relocating: Moving away from parents (31.9% of respondents), formation of a household with partner (29.1%), purchase of dwelling (16.4%), new job (location) (13.6%), family expansion (e.g., child birth) (6.1%), and reduction of household size (e.g., children moving out) (2.7%). Although we might not have a fully representative sample of the total population in the selected neighbourhoods, our sample is probably representative for the group of people relocating to these neighbourhoods (since all movers in these neighbourhoods were invited to participate). Nevertheless, we do have a relatively large sample size, making it possible to estimate relationships with sufficient certainty. For more details on the data sampling, see De Vos et al. (2018, 2019).

[2] We do not have information on whether respondents are homeowners or renters. However, in the selected neighbourhoods, 47.1% of the residents rents a home, while 52.9% are homeowners (www.gent.buurtmonitor.be, situation in 2018).

[3] Those moving to Ghent are mainly between 20 and 35 years old, while those moving within Ghent are mainly between 30 and 40 years old.

Table 1. Respondents' socio-demographics (N = 1,650)

Socio-demographic	%
Age distribution	
18-29	49.5
30-44	29.1
45-59	13.4
60+	8.0
Gender	
Male	52.1
Female	47.9
Education	
High education (University (college) degree)	77.2
Low education (secondary school degree or less)	22.8
Job status	
Full-time employed	72.8
Part-time employed	10.7
Retired	6.9
Unemployed	6.4
Student	3.2
Residential location	
Urban neighbourhood	67.4
Suburban neighbourhood	32.6
Household composition	
Couple without child(ren)	37.3
Couple with child(ren)	14.6
Single	29.9
Single parent	5.9
Other (e.g., living with parents, with friends)	12.3
Household net income/month	
< €1,500	13.5
€1,500 - €2,499	39.7
€2,500 - 3,499	19.2
€3,500 +	27.6
Household car ownership	
0	25.5
1	54.3
>1	20.2

3.2 Key variables

In this study, we will not focus on respondents' current residential neighbourhood, car ownership, travel patterns and attitudes, but we will analyse changes in these elements resulting from a residential relocation. A residential relocation is an interesting opportunity to examine changes in mode frequency since a residential move is often accompanied by changes in neighbourhood type, car ownership and travel patterns (Scheiner & Holz-Rau, 2013). We will measure the effects of changes in the type of residential neighbourhood on changes in mode frequency (for car use, public transport use, cycling and walking and this for both commute and leisure trips)[4], both directly and indirectly through changes in car ownership, travel distance and mode-specific attitudes. Finally, we also take into

[4] Since retired and unemployed respondents do not perform commute trips (trips to job or school location), these respondents were excluded from the models focusing on commute trips. As a result, the models on commute trips include 1,430 respondents, while the models on leisure trips include 1,650 respondents.

account respondents’ socio-demographic characteristics by including them as exogenous variables in the models. Table 2 shows the key variables used, indicates how we measured them, and provides the average values of these variables. On average, respondents relocated to more urbanised neighbourhoods, and lowered their car ownership and travel distance.[5] Compared to before their relocation, respondents now drive less and walk and cycle more and especially see an improvement of their attitudes towards active travel (for a detailed overview of changes in respondents’ travel attitudes and behaviour, see De Vos et al., 2018). It is worth noting that differences in the key variables between respondents relocated in 2015 (49.1% of the respondents) and those relocated in 2016 (50.9% of the respondents) are limited, suggesting that changes in car ownership, travel distance, travel attitudes and mode frequency happen rather fast after the relocation and do not change a lot afterwards.

The used variables are ideal for measuring the direct and indirect effects (through car ownership, travel distance and travel attitude) of the built environment on travel behaviour since they measure changes in residential neighbourhood, car ownership, travel patterns and attitudes after respondents relocated. As a result, the data would not have been suited to test self-selection effects from travel attitudes on the residential location (since the residential location choice is (partly) based on attitudes before the relocation). In a parallel study using the same data, De Vos et al. (2020) measure a similar model but with effects from changes in mode frequency to changes in mode-specific attitudes. Also a model with reciprocal relationships between changes in travel attitudes and behaviour would be plausible, but turned out not to be identifiable, making it impossible to measure it. Most variables included in the models (except for socio-demographics and changes in car ownership) capture self-reported, retrospective changes in residential neighbourhood, travel attitudes and behaviour measured by a five-point Likert scale. As a result, these (directly observed) manifest variables are ordinal in nature and can be regarded as subjective and rather crude measurements, making it difficult to truly capture the magnitude of (relationships between) changes in the built environment, changes in attitudes, and changes in travel behaviour. Retrospectively measuring changes in attitudes is rather rare, and to the best of our knowledge this is the first travel behaviour data set doing so. Although this measurement method is subject to memory and consistency biases (i.e., unreliable attempts to recall one’s attitudes and confounding previous attitudes with current one’s, respectively), retrospectively measuring attitudes can be considered as reliable and results are often similar with longitudinal measurements of attitude change (Jaspers et al., 2009). Ideally, more precise and continuous measures, preferably longitudinal and latent (unobserved) variables should be used.

[5] A reduction in travel distance can partly be explained by the fact that people often relocate to live closer to certain destinations. In our sample, 29.9% of the respondents indicated that living closer to their (current) job or living closer to family/friends was an important reason to relocate.

Table 2. Key variables

Variable	Survey question / used measurement	Average value
Change in residential neighbourhood	"To what extent is your current neighbourhood less or more urbanised compared to your previous neighbourhood?" on a scale from -2 (far less urbanised) to +2 (far more urbanised).	0.43
Change in car ownership	Difference between current household car ownership and household car ownership just before the relocation (i.e., current ownership - previous ownership)	-0.13
Change in travel distance	"To what extent did the distance to your job/school location / the average distance to out-of-home leisure activities change after you moved?" on a scale from -2 (a lot shorter) to +2 (a lot longer).	Commute trips: -0.27 Leisure trips: -0.25
Change in mode-specific attitude	"To what extent did your attitude towards car use / public transport use / cycling / walking change after you moved?" on a scale from -2 (far more negative) to +2 (far more positive).	Car attitude: 0.09 PT attitude: 0.12 Cycling attitude: 0.32 Walking attitude: 0.44
Change in mode frequency	For both commute trips and leisure trips: "To what extent did your frequency of car use / public transport use / cycling / walking change after you moved?" on a scale from -2 (far less frequent) to +2 (far more frequent).	Commute: / Leisure: Car use: -0.21 / -0.26 PT use: -0.18 / 0.06 Cycling: 0.13 / 0.20 Walking: 0.00 / 0.35
Socio-demographics	Age (in years), gender (0 = male; 1 = female), educational level (0 = low education (secondary school degree or less); 1 = high education (college or university degree)), household net income/month (0 = low income (< €2500); 1 = high income (€2500+)), and non-adult children living at home (0 = no; 1 = yes).	See Table 1

3.3 A structural equation modelling approach

In this study we apply a structural equation modelling approach. A structural equation model (SEM) specifies a series of simultaneously estimated structural relationships. Such an approach is useful for measuring multiple relationships among a set of variables, in which a certain variable can be the outcome (or dependent variable) in one set of relationships, and a predictor of outcomes (or explanatory variable) in other relationships. Unlike regression, a SEM can measure both direct effects between variables and indirect effects through mediating variables. Since we want to analyse the effect of (changes in) the built environment on (changes in) mode frequency, both directly and indirectly (through (changes in) car ownership, travel distances and attitudes), a SEM approach is a suitable methodology. Two types of SEMs exist, i.e., a measurement model and a structural model. A measurement model (also known as confirmatory factor analysis) specifies the relationships between latent variables and their observed indicators, while in a structural model relationships between the latent variables are modelled (Golob, 2003; Mokhtarian & Ory, 2009). Since our variables are directly observed (manifest variables), we only estimate a structural model.

In travel behaviour analysis, SEMs have occasionally been used since the 1980s (Golob, 2003), whereas the approach has gained ground in the past two decades. Studies have used the SEM approach to analyse relationships between travel behaviour, built environment, car ownership, travel distance and travel attitudes. Some studies have used this approach to examine the indirect effect of the built environment on car use, through car ownership (Aditjandra et al., 2012; Ding & Lu, 2016; Van Acker & Witlox, 2010). De Abreu e Silva et al. (2006, 2012) analysed the effects of land use characteristics on travel behaviour, directly and indirectly through commuting distance. Ding et al. (2017) measured the effect of the built environment on travel mode choice considering the mediating effects of both car ownership and travel distance. SEMs have also been applied for measuring links between travel attitudes and the built environment. Both Bagley and Mokhtarian (2002) and Cao et al. (2007b) found that travel attitudes have a significant effect on travel behaviour, both directly and indirectly through the residential location choice. Some studies also included direct links from the built environment to travel attitudes in their SEMs (Bagley & Mokhtarian, 2002; de Abreu e Silva, 2014; De Vos et al., 2020; Ewing et al., 2016; Lin et al., 2017; Van Acker et al., 2014).

The maximum likelihood estimation (MLE) approach, a commonly used estimation technique, was chosen to develop eight SEMs (using IBM SPSS Statistics 26), i.e., for car use, public transport use, cycling and walking, and this for both commute trips and leisure trips. MLE is based on normal theory and is therefore not strictly theoretically appropriate when the data are not multivariate normal. The variables we used in the eight models do not have the multivariate normal distribution. Although our models deviate from the multivariate normality assumption, the influence of non-normal data is reduced when using MLE with a large sample size, namely a sample size larger than 500 or a ratio between sample size and the number of observed variables of at least 15 (e.g., Cao et al., 2007b). Our sample size is around three times as large as recommended (i.e., 1430 for the commute models and 1650 for the leisure models), and the ratio between sample size and variables is clearly higher than 15 (i.e., 143 for the commute models and 165 for the leisure models). As a result, we do not expect that the non-normality of the data will be a serious problem in this study.

4. Results

4.1 Goodness-of-fit

We analysed how well the models fit the used data by examining various goodness-of-fit measures. Since the values of these measures were not satisfactory, we decided to remove insignificant paths (i.e., paths with a p-value larger than 0.1) from socio-demographics to the endogenous variables in the models.[6] As a result, we still measure the essence of the model as shown in Figure 2, while discarding insignificant paths from socio-demographics to endogenous variables (which can be considered as conceptually less important).[7] Doing so resulted in satisfactory goodness-of-fit measures (Table 3), indicating that the (adjusted) models fit the data well.

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[6] Paths with the highest p-values were removed one by one (i.e., backward elimination) until all p-values of paths from socio-demographics to endogenous variables were lower than 0.1.

[7] Although a SEM approach is often considered as confirmatory, it is often a combination of confirmatory and exploratory purposes. Studies often apply a SEM, find it to be inadequate, and then test an alternative model based on the output of the original model. Since we cannot be certain of relationships before testing them, we still need considerable exploration to identify the relationships that best fit the data (Garson, 2015).

Table 3. Measures of fit for the SEMs[8]; recommended values shown in brackets

	Commute models (N = 1,430)				Leisure models (N = 1,650)			
	Car	PT	Cycling	Walking	Car	PT	Cycling	Walking
χ^2/df (<5)	2.48	1.21	2.89	3.21	2.06	2.52	3.75	4.65
GFI (>0.9)	0.99	1.00	0.99	0.99	1.00	0.99	0.99	0.99
NFI (>0.9)	0.95	0.97	0.95	0.95	0.96	0.95	0.95	0.94
CFI (>0.9)	0.97	0.99	0.97	0.96	0.98	0.97	0.96	0.95
IFI (>0.9)	0.97	0.99	0.97	0.96	0.98	0.97	0.96	0.95
RMSEA (<0.08)	0.03	0.01	0.04	0.04	0.03	0.03	0.04	0.05

4.2 Estimation results

Tables 4 – 11 show the standardized direct effects of the eight models. Most effects of socio-demographics on changes in car ownership, travel distance, attitudes and mode frequency were removed due to insignificance, while most socio-demographics significantly influence a change in neighbourhood and were therefore retained in the model. Older respondents living in a high-income household with children tend to move to more suburban-style neighbourhoods, while highly-educated respondents often move to more urban-style neighbourhoods. Changes in car ownership are positively affected by household income, while men – compared to women – seem to have a somewhat higher chance to increase their travel distances after relocating. In terms of changing attitudes, we found that income negatively affects walking attitudes, having children positively influences cycling attitudes, and that being highly-educated negatively affects public transport attitudes. Age positively affects attitudes towards car and (even more so) public transport. Effects of socio-demographics on changes in mode frequency are rather diverse. Older respondents, for instance, tend to decrease their car use frequency, while members of a high-income household tend to travel more by car after they moved. Highly-educated respondents mainly seem to cycle more often.

Results indicate that moving to a more urban neighbourhood negatively affects car ownership and travel distances (especially distances of leisure trips), while positively affecting attitudes towards public transport, cycling and especially walking. An increase in car ownership positively affects car use, while negatively affecting public transport use, cycling and walking for both commute and leisure trips. An increase in travel distance positively influences driving and negatively influences walking and cycling. The effect of changes in travel distance only has limited effects on changes in public transport use. The increase in frequency of public transport, cycling and walking is strongly affected by improved attitudes towards these respective modes. Changes in car attitudes only have limited effects on changes in car frequency. This might suggest that car use is often habitual and only affected by changes in attitudes to a limited extent.

[8] χ^2/df = Discrepancy between observed and model-implied variance–covariance matrices corrected for degrees of freedom; GFI = Goodness-of-Fit Index: An absolute fit index that estimates the proportion of variability explained by the model; NFI = Normed Fit Index: Proportion of baseline (independence) model χ^2 explained by the model of interest; CFI = Comparative Fit Index: Assumes a non-central χ^2 distribution for the baseline model discrepancy; IFI = Incremental Fit Index: Incremental improvement of the model of interest over the baseline (independence) model; RMSEA = Amount of error of approximation per model degree of freedom, correcting for sample size and penalizing model complexity. Descriptions retrieved from Mokhtarian and Ory (2009).

Tables 4 – 7, focusing on commute trips, show that changes in the residential neighbourhood only have significant direct effects on mode frequency for car use. Moving to a more urban (or suburban) neighbourhood has a significant positive (or negative) direct effect on car frequency for commute trips. For public transport, walking and cycling, changes in the built environment do not have a direct effect on changes in mode frequency of commute trips. The direct effects of (changes in) the built environment on (changes in) mode frequency for leisure trips are considerably stronger (Tables 8 – 11). Moving to a more urbanised neighbourhood has a negative direct impact on the frequency of car use and a positive direct impact on the frequency of public transport use, cycling and especially walking.

Table 4. Standardized direct effects for the model on car use and commuting (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in commute distance	Change in car attitude	Change in car frequency
Age	<u>**-0.09**</u>	–	–	<u>**0.09**</u>	<u>**-0.14**</u>
Gender	–	–	**-0.06**	–	–
Income	<u>**-0.10**</u>	<u>**0.08**</u>	**0.05**	–	0.05
Education	<u>**0.08**</u>	–	–	–	–
Children	<u>**-0.14**</u>	–	–	–	–
Change in neighbourhood	–	<u>**-0.16**</u>	<u>**-0.21**</u>	**0.06**	<u>**-0.08**</u>
Change in car ownership	–	–	–	–	<u>**0.17**</u>
Change in commute distance	–	–	–	–	<u>**0.24**</u>
Change in car attitude	–	–	–	–	-0.02

Table 5. Standardized direct effects for the model on public transport use and commuting (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in commute distance	Change in PT attitude	Change in PT frequency
Age	<u>**-0.09**</u>	–	–	<u>**0.12**</u>	–
Gender	–	–	**-0.06**	–	–
Income	<u>**-0.10**</u>	<u>**0.08**</u>	**0.05**	–	–
Education	<u>**0.08**</u>	–	–	<u>**-0.07**</u>	–
Children	<u>**-0.14**</u>	–	–	–	–
Change in neighbourhood	–	<u>**-0.16**</u>	<u>**-0.21**</u>	<u>**0.14**</u>	-0.03
Change in car ownership	–	–	–	–	**-0.05**
Change in commute distance	–	–	–	–	**0.06**
Change in PT attitude	–	–	–	–	<u>**0.17**</u>

Table 6. Standardized direct effects for the model on cycling and commuting (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in commute distance	Change in cycling attitude	Change in cycling frequency
Age	**<u>-0.09</u>**	–	–	**<u>0.08</u>**	–
Gender	–	–	**-0.06**	–	–
Income	**<u>-0.10</u>**	**<u>0.08</u>**	**0.05**	–	–
Education	**<u>0.08</u>**	–	–	**0.05**	**<u>0.09</u>**
Children	**<u>-0.14</u>**	–	–	**0.06**	–
Change in neighbourhood	–	**<u>-0.16</u>**	**<u>-0.21</u>**	**<u>0.18</u>**	-0.05
Change in car ownership	–	–	–	–	**<u>-0.11</u>**
Change in commute distance	–	–	–	–	**<u>-0.19</u>**
Change in cycling attitude	–	–	–	–	**<u>0.30</u>**

Table 7. Standardized direct effects for the model on walking and commuting (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in commute distance	Change in walking attitude	Change in walking frequency
Age	**<u>-0.09</u>**	–	–	–	0.05
Gender	–	–	**-0.06**	0.05	–
Income	**<u>-0.10</u>**	**<u>0.08</u>**	**0.05**	**-0.06**	–
Education	**<u>0.08</u>**	–	–	–	**<u>0.07</u>**
Children	**<u>-0.14</u>**	–	–	–	–
Change in neighbourhood	–	**<u>-0.16</u>**	**<u>-0.21</u>**	**<u>0.35</u>**	0.01
Change in car ownership	–	–	–	–	**<u>-0.10</u>**
Change in commute distance	–	–	–	–	**<u>-0.18</u>**
Change in walking attitude	–	–	–	–	**<u>0.16</u>**

Table 8. Standardized direct effects for the model on car use and leisure trips (bold = 0.01 ≤ p < 0.05; bold and underlined = significant at p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in leisure distance	Change in car attitude	Change in car frequency
Age	**<u>-0.07</u>**	–	–	**0.06**	**<u>-0.17</u>**
Gender	–	–	-0.04	–	–
Income	**<u>-0.08</u>**	**<u>0.07</u>**	–	–	**<u>0.06</u>**
Education	**<u>0.07</u>**	–	–	–	**0.05**
Children	**<u>-0.15</u>**	–	–	–	–
Change in neighbourhood	–	**<u>-0.17</u>**	**<u>-0.35</u>**	**0.06**	**<u>-0.15</u>**
Change in car ownership	–	–	–	–	**<u>0.22</u>**
Change in leisure distance	–	–	–	–	**<u>0.20</u>**
Change in car attitude	–	–	–	–	**-0.05**

Table 9. Standardized direct effects for the model on public transport use and leisure trips (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in leisure distance	Change in PT attitude	Change in PT frequency
Age	**-0.07**	–	–	**0.16**	**0.06**
Gender	–	–	-0.04	–	–
Income	**-0.08**	**0.07**	–	–	–
Education	**0.07**	–	–	**-0.07**	-0.04
Children	**-0.15**	–	–	–	–
Change in neighbourhood	–	**-0.17**	**-0.35**	**0.14**	**0.07**
Change in car ownership	–	–	–	–	**-0.05**
Change in leisure distance	–	–	–	–	0.03
Change in PT attitude	–	–	–	–	**0.28**

Table 10. Standardized direct effects for the model on cycling and leisure trips (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in leisure distance	Change in cycling attitude	Change in cycling frequency
Age	**-0.07**	–	–	–	**-0.05**
Gender	–	–	-0.04	–	–
Income	**-0.08**	**0.07**	–	–	0.04
Education	**0.07**	–	–	–	**0.08**
Children	**-0.15**	–	–	**0.09**	**0.05**
Change in neighbourhood	–	**-0.17**	**-0.35**	**0.15**	**0.08**
Change in car ownership	–	–	–	–	**-0.07**
Change in leisure distance	–	–	–	–	**-0.08**
Change in cycling attitude	–	–	–	–	**0.41**

Table 11. Standardized direct effects for the model on walking and leisure trips (bold = 0.01 ≤ p < 0.05; bold and underlined = p < 0.01)

Endogenous variables → Explanatory variables ↓	Change in neighbor-hood	Change in car ownership	Change in leisure distance	Change in walking attitude	Change in walking frequency
Age	**-0.07**	–	–	–	**0.05**
Gender	–	–	-0.04	–	–
Income	**-0.08**	**0.07**	–	**-0.05**	–
Education	**0.07**	–	–	–	–
Children	**-0.15**	–	–	–	–
Change in neighbourhood	–	**-0.17**	**-0.35**	**0.35**	**0.19**
Change in car ownership	–	–	–	–	**-0.07**
Change in leisure distance	–	–	–	–	**-0.11**
Change in walking attitude	–	–	–	–	**0.35**

Figure 2 gives a more detailed view on the (direct, indirect and total) effects of changes in the residential environment on changes in mode frequency. For car use, leisure trips in particular, moving to more urban neighbourhoods has strong direct negative effects on changes in car use. Also the indirect effects through changes in car ownership and especially travel distances are strong. When moving to more urban (or suburban) neighbourhoods, people will most likely decrease (or increase) their car ownership and travel distances, which in turn will negatively (or positively) affect car use. Indirect effects through changes in car attitudes are negligible. For public transport use we only see significant direct effects of (changes in) the built environment on (changes in) public transport frequency for leisure trips. The strongest indirect effects – though being insignificant – are through changes in public transport attitudes, while indirect effects through car ownership and distance are limited. A more urban residential environment might improve public transport attitudes, which in turn can positively affect public transport use. Similar, yet stronger effects can be found for cycling and walking. Moving to a more urban neighbourhood has a direct positive effect on cycling and (especially) walking for leisure trips. Rather strong indirect effects through travel distance and especially attitudes are also noticeable. Higher levels of urbanisation result in shorter distances which in turn increase active travel frequencies, but also improve attitudes towards active travel, which (mainly for leisure trips on foot) in turn result in higher levels of walking and cycling. The indirect effect through car ownership is rather limited for active travel.

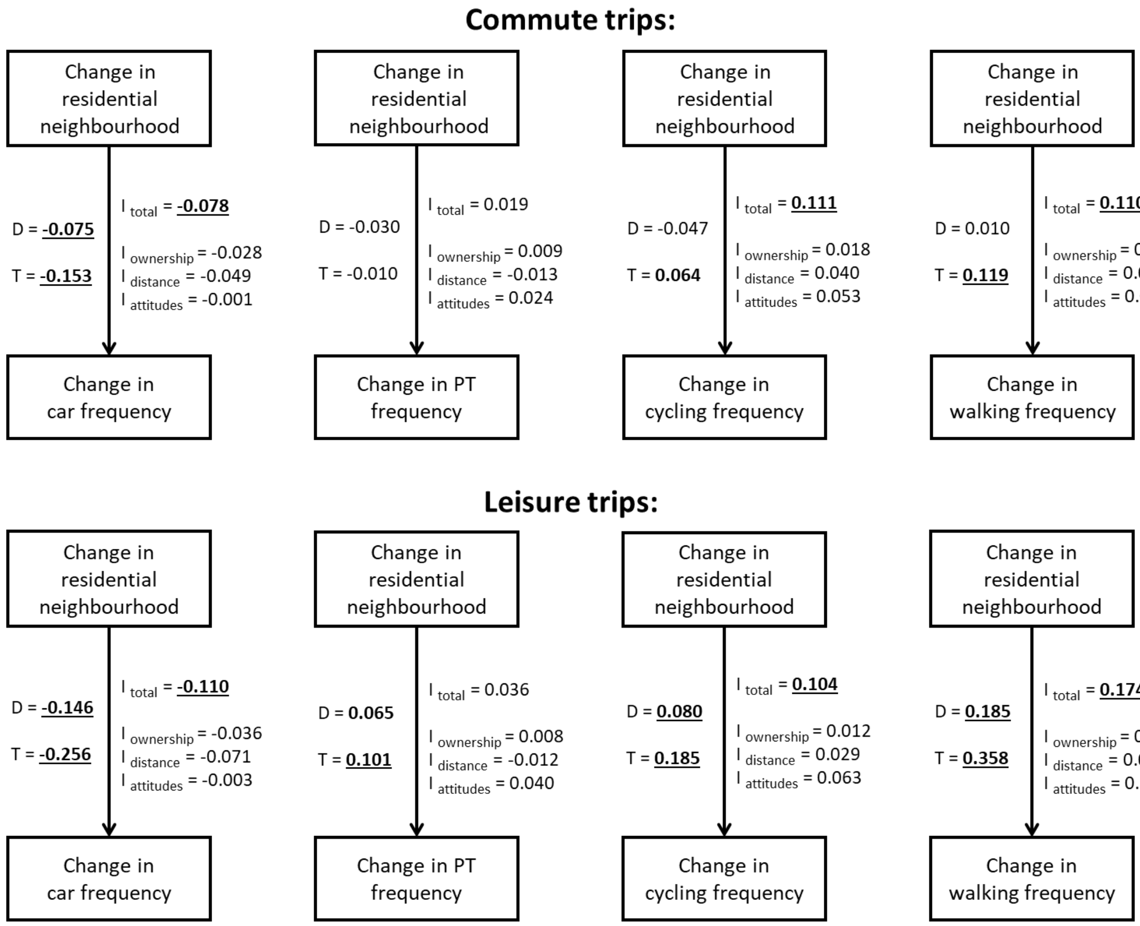

Figure 2. Direct (D), Indirect (I), and total (T) effects of the changes in the residential neighbourhood on changes in mode frequency (bold = 0.01 ≤ $p < 0.05$; bold and underlined = $p < 0.01$).[9]

Changes in mode frequency are explained quite well by the models, indicating that changes in the residential neighbourhood have important (direct and indirect) impacts on changes in mode use. Especially for leisure trips the explained variance in changes in mode frequency is substantial (squared multiple correlations (R^2s) are 0.19, 0.11, 0.23 and 0.26 for changes in car frequency, public transport frequency, walking frequency and cycling frequency, respectively). For commute trips, changes in mode frequency (especially public transport frequency) are less affected by changes in the residential neighbourhood (R^2s are 0.12, 0.04, 0.15 and 0.09 for changes in car frequency, public transport frequency, walking frequency and cycling frequency, respectively).

5. Discussion and conclusion

In this study we analysed the direct and indirect effect of changes in the residential neighbourhood on changes in mode frequency, applying a SEM approach of quasi-longitudinal data. This is the first study that simultaneously examines the mediating effects of car ownership, travel distance and travel attitudes in the relationship between the built environment and travel mode choice. Doing so, we found that (changes in) the residential neighbourhood has strong indirect effects on (changes in) mode

[9] The significance levels of the indirect effects (all indirect effects combined) and the total effects are obtained by performing a bootstrapping procedure. Note that significance levels of indirect effects through car ownership, travel distance and travel attitudes separately cannot be measured.

frequency. Changes in car ownership have noticeable mediating effects on car frequency, while changes in travel distances have considerable mediating effects on the frequency of car use, cycling and walking. Indirect effects through changes in travel attitudes are notable for changes in public transport frequency and strong for changes in active travel frequencies. Although we found strong indirect effects from changes in the neighbourhood to changes in mode frequency (except for public transport), changes in the neighbourhood still have significant direct effects for car use and leisure trips of public transport and active travel. The fact that changes in the residential neighbourhood have stronger (direct and indirect) effects on mode frequency for leisure trips compared to commute trips might be explained by people often performing leisure activities within their (new) residential neighbourhood, while still going to the same location for work/school (often outside the residential neighbourhood) compared to when living in their previous neighbourhood. As a result, (changes in) residential neighbourhood might have stronger effects on (changes in) leisure trips than on (changes in) commute trips.

Although the results from this study provide new insights into how the built environment can influence travel behaviour, it does not clearly indicate the processes through which the built environment influences travel mode choice in a direct and indirect way. In Figure 3 we provide an overview of how these processes might work. First of all, changes in car ownership and travel distance might be the outcome of changes in density and diversity as a result of a relocation (link A). Moving to a more urban-style neighbourhood will most likely result in higher densities and diversities, resulting in shorter distances and lower car ownership and consequently in lower car use. Second, direct effects of changes in the residential location on changes in mode frequency might be the result of changes in design (link B). Urban neighbourhoods (in Ghent but also in most other regions) have a design that can stimulate active travel and discourage car use, for instance by the presence of separated cycling lanes, wide and well-lit sidewalks, car-free or car-reduced areas, and limited car parking. Finally, changes in travel attitudes, which strongly affect public transport use, cycling and walking (see Tables 4 – 11), might be the result of changes in the ease of travel (link C). If, for instance, walking and cycling becomes more convenient when moving to a more urban neighbourhood (e.g., due to shorter distances and a design stimulating active travel), then attitudes towards active travel might improve, resulting in more frequent walking and cycling. Changes in density/diversity, design and ease of travel might be related with each other as, for instance, the ease of travel might be affected by density, diversity and design.

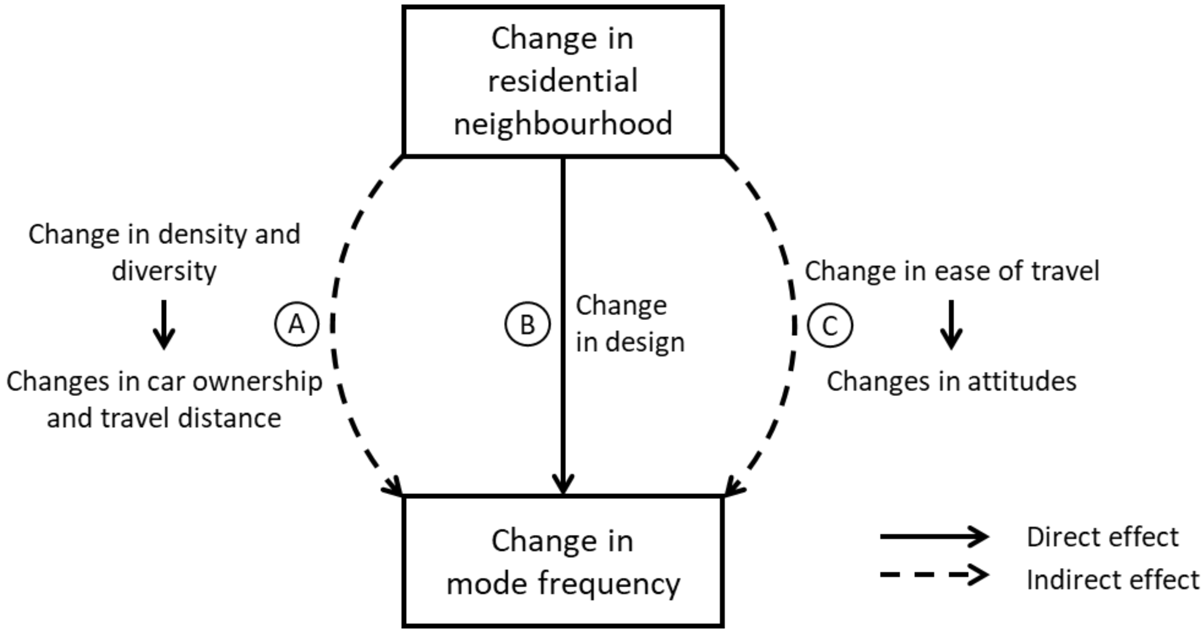

Figure 3. Possible processes of direct and indirect effects of changes in the residential location on changes in mode frequency.

Note that the various processes of how the built environment might affect travel behaviour as shown in Figure 3 are subject to debate (partly because of the subjective and rather crude measurements used) and future research should further elaborate on – and disentangle – the different (direct and indirect) ways of how the built environment can affect mode frequency. Due to the complexity of these relationships, longitudinal and qualitative studies – performing in-depth interviews or focus groups – seem most appropriate. In this regard, Guan et al. (2020) suggest a panel household survey with multiple waves, i.e., pre-relocation, directly after the relocation, and (one or more) post-relocation. Each wave could consist of a survey that collects objective information regarding the built environment, car ownership and distance, and a qualitative part that focuses on the timings and reasons of changes in the residential location, attitudes, and travel behaviour. Furthermore, future studies might also analyse the direct and indirect effects of changes in the built environment on changes in travel behaviour in case of physical changes in the built environment, e.g., due to densification and land use mixing of neighbourhoods. Doing so, a representative sample of a neighbourhood's population can be analysed instead of movers which are mainly young adults.

Although this study found that the direct effect of the built environment on travel mode choice might be overestimated in previous studies, the total effects of the built environment on travel mode use – taking into account indirect effects through car ownership, travel distance and attitudes – are still significant and strong (except for commute trips by public transport). As a result, the focus of policy makers and urban planners should remain on stimulating people to move to urban neighbourhoods, or on creating compact, mixed-use neighbourhoods with a design stimulating public transport and active travel.

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