Generation Y's Travel Behavior and Perceptions of Walkability Constraints

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The aim of this study was to investigate the interrelationship between urban environment and walking to school and how teenagers' perceptions of walkability (i.e., how friendly an area is to walking) constraints affected their mode choice. An advanced hybrid mode choice model was developed in which the utilities of the alternative modes depended on the mode characteristics, teenagers' socioeconomic characteristics, weather conditions, and built environment characteristics, as well as a latent variable referring to walking constraints. The indicators of the latent variable included perceptions regarding the existence of stray animals, poor lighting, narrow sidewalks, parked cars that obscure visibility, unsignalized intersections, and probability of attack and safety en route. A questionnaire survey that took place at high schools of three distinct geographic areas in Greece (an urban area, a rural area, and an insular area) during 2011–2012 was the basis for a case study; 1,988 high school students aged 12 and 18 years old participated in the survey. Adolescents in rural areas walked a greater distance than did urban and insular adolescents. Model estimation results showed that teenagers from each geographical area were affected in different ways by weather conditions and they also perceived the built environment in different ways; this perception indicates how significant the sense of place is. The incorporation of the latent variable enhanced the explanatory power of the model, and the results of the study provide insights on policies that may help Generation Y to keep walking.

Half of the trips in developed countries and urban areas can be completed within a 20-min bike ride, and a fourth of the trips are within a 20-min walk. Currently, the vast majority of these short trips are conducted by using motorized vehicles (*1*). However, trends are changing, and the latest reports show that the "future belongs to walking and cycling" (*2*); young people (14 to 30 years old) are choosing active transport and avoiding obtaining a driver's license in much greater numbers than in the past (*3, 4*).

Active transportation is the missing piece in the transportation system. Walking and bicycling can improve public transportation by providing quick access to the destination. Given the availability of safe and convenient infrastructure and the right built environment, more people will choose walking or bicycling for short trips (*1*).

Against this background, the research on active commuting has expanded rapidly in the past decade; researchers are trying to determine which factors affect this behavior. Some of the identified factors are socioeconomic characteristics (e.g., gender, age, and income), and attitudes toward and perceptions of ecological issues, car addiction, and the built environment (*5–9*). With the scope narrowed down to young children (5 to 11 years old), a growing body of researchers is trying to identify school transportation mode choice behavior and, having largely drawn their variables from studies of adults, have suggested that neighborhood factors such as distance to school, land use mix, parental perceptions, and the characteristics of the built environment may influence this behavior (*10*).

However, the majority of these surveys refer to elementary students by analyzing data of their parents' activities and leaving the adolescent age group's travel behavior underexamined. Teenagers are a special age group with distinctive travel behavior and special travel needs. On the one hand, teenagers' participation in activities and mobility is constrained by parental consent and age restrictions on driving. On the other hand, their burgeoning maturity enables them to make independent decisions and spend time without adults' supervision (*11*). Furthermore, because of rapid technological adaptation and changes in socioeconomic characteristics of the developed countries, this generation (Generation Y) exhibits completely different travel behavior from that of Baby Boomers (*3, 4, 12*). Thus a generational gap is developing; this gap is making imperative the study of the travel behavior of this generation. In addition, the propensity of an individual to choose a specific transport mode is highly subjective, since different people perceive the built environment in different ways. Thus, a number of unobserved variables regarding the built environment affect this choice (*13*). The existing work on minors' travel behavior focuses on urban areas; little work has focused on rural and especially on insular areas, where the built environment is completely different.

With these points in mind, the researchers investigated Generation Y's mode choice behavior for the trip to school, the effect of actual and perceived built environment characteristics on walking choice, the impact of weather, and the possible differences between three distinct environments (urban, rural, and insular). More specifically, an advanced hybrid mode choice model was developed for each area; the utilities of the alternative modes (active transport, public transport, escorted by parents, and driving) depended on the built environment's characteristics, weather conditions, teenagers' socioeconomic characteristics, and a latent variable referring to walking constraints. The indicators of the latent variable included perceived built environment characteristics regarding the existence of stray animals, poor lighting, narrow sidewalks, parked cars that obscure visibility, unsignalized intersections, the probability of an attack, and safety en route. The case study was based on a questionnaire survey specifically designed for teenagers, which took place in three distinct areas in Greece (one urban, one rural, and

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one insular) in the 2011–2012 school year. The sample consisted of 1,988 high school students from 12 to 18 years old.

After a review of the literature, the modeling framework and associated mathematical formulations for incorporating the attitudes into the choice process are described. Then the case study, the sample's descriptive statistics, and the indicators of the latent variable—walkability constraints (henceforth WalkCon)—are presented. The model estimation results follow.

LITERATURE REVIEW

The traditional travel patterns to school and after-school activities have changed; children have become reliant on automobiles for their trips (*10*). This shift has contributed to greater congestion and has decreased the quality of life while depriving children of the noted health benefits of physical activity. Schools are also a significant generator of localized congestion, with morning and afternoon peaks similar to those seen in commuting behavior (*14*). Driven largely by this situation, research on children's active commuting to school has expanded rapidly during the past few years and has indicated that the distance between home and school is the most important variable in determining the mode of travel to school and that the built and social environments also play an important role in the choice of travel mode.

For example, McMillan, using data from 16 elementary schools in California, examined which factors affected students' caregivers' decisions about transport mode to school (*14*). Binomial logit regression probability models were developed to examine the likelihood of a child's walking or bicycling to school versus traveling by private vehicle or neighborhood carpool. The results of the analysis support the hypothesis that urban form is important but is not the sole factor that influences a caregiver's decision about a child's trip to school. Other factors, such as neighborhood safety, traffic safety, household transportation options, caregiver attitudes, social and cultural norms, and sociodemographics, may be equally important.

Another survey examined the travel behavior of 614 students from 11 to 13 years old in London, Ontario, Canada (*15*). A geographic information system was used to link survey responses from students who lived within 1 mi of their school to data on the social and physical characteristics of the environment around their home and school. Logistic regression analysis was used to test the influence of environmental factors on mode of travel (motorized versus active) to and from school. The results showed that the likelihood of walking or biking to school was positively associated with shorter trips, the male gender, a greater land use mix, and the presence of trees on the street. Active travel from school to home was also associated with lower residential densities and lower neighborhood incomes.

Mode-to-school choice behavior was also investigated by Mitra and Buliung (*16*). The sample that they examined consisted of 11-year-old children who lived within 3.2 km of their schools. The data about their travel behavior were provided by their parents. A discrete choice modeling approach was adopted to explore the correlates of four travel modes (walk, transit, school bus, car). Distance was the most important factor in explaining the mode choice for school transportation, followed by variables related to intrahousehold travel interactions. The built environment near the home and school, in terms of personal and traffic safety and neighborhood aesthetics and walkability, explained some of the variation in mode choice, even when the distance traveled and the household activity–travel relationships were taken into account, whereas the effect of street connectivity on mode choice was less clear.

As mentioned earlier, the majority of these studies focus on young children, and only a few look at adolescents. At the same time, the majority use data on students' travel behavior as reported by their parents and not collected directly from the students. However, despite the prominent role that the caregiver likely plays in the travel decision for elementary school children, teenagers typically want to avoid parental supervision by making trips without being controlled or supervised, and recent reports show that as teenagers reach the age of 18, they less often place importance on a driver's license or the purchase of a car (*3, 4*). Also, most of these studies were conducted in urban areas, and little was known about the travel behavior of rural or insular adolescents. A review of the samples and methodologies used in various surveys of school transportation and the built environment is presented in Table 1.

TABLE 1 Review of Literature

Reference	Sample	Modes Examined	Environmental Attributes Examined	Methodology
McMillan, 2007 (*14*)	N = 1,128 Age = 6–10 years old Reported by parents California	Active transport, private motorized vehicle	Sidewalks; houses with windows facing street; land use mix	Binomial logit regression probability models
McDonald, 2007 (*24*)	N = 6,508 Age = 5–13 years old Reported by parents NHTS	Car, bus or transit, walking	Distance; population density	Multinomial choice model
Timperio et al., 2006 (*19*)	N = 235 Age = 5–6 years old and N = 677 Age = 10–12 years old Reported by parents Melbourne, Australia	Walking, bicycle	Traffic; concern about strangers; concern about road safety; traffic lights; need to cross several roads; availability of public transport	Odds ratios
Larsen et al., 2009 (*15*)	N = 614 Age = 11–13 years old Reported by parents London, Ontario, Canada	Walking alone, walking accompanied, bicycle or scooter, skateboard or rollerblade, school bus, city bus, driven in automobile	Street trees; distance; land use mix	Stepwise logistic regression

(continued)

TABLE 1 *(continued)* **Review of Literature**

Reference	Sample	Modes Examined	Environmental Attributes Examined	Methodology
Mitra and Buliung, 2012 (*16*)	*N* = 945 Age = 11 years old Data from 2006 Transportation Tomorrow Survey Reported by parents Toronto, Ontario, Canada	Walking, transit, school bus, car	Crossing a major street; ratio between network distance and straight line distance; land use mix; number of street blocks; proportion of four-way street intersections; dead ends; intersections that are signalized	Multinomial choice model
Schlossberg et al., 2006 (*20*)	*N* = 292 Age = 11–13 years old Reported by parents Oregon	Walking, bicycle, bus, car	Distance; intersection density; dead-end density, route directness; major road en route; railroad tracks en route	Logistic regression models
Kerr et al., 2006 (*17*)	*N* = 259 Age = 5–18 years old Reported by parents Seattle, King County, Wash.	Active transport	Aesthetics; walking and biking facilities; street connectivity; neighborhood walkability; land use mix; access	Logistic regression models
Grow et al., 2008 (*21*)	*N* = 87 parents of children and *N* = 124 matched pairs of parents and adolescents Boston, Mass.; Cincinnati, Ohio; and San Diego, Calif.	Active transport	Land use mix; street connectivity; pedestrian infrastructure; aesthetics; traffic safety; crime threat; city; proximity	One-way random-effects single-measure intraclass correlations
Mota et al., 2007 (*18*)	*N* = 705 (only girls) Age = 12–17 years old Aveiro District, Portugal	Active transport, passive transport	Access to destination; connectivity of the street network; infrastructure for walking and cycling; neighborhood safety; social environment; aesthetics; recreation facilities	Logistic regression model
Kamargianni and Polydoropoulou (*22*)	*N* = 4,147 high school students Age = 12–18 years old Cyprus	Walking, bike, public transport, private motorized modes	Sidewalks; existence of bike lanes; distance	Hybrid Choice Model with stated preference data
Yoon et al., 2011 (*23*)	*N* = 3,483 Age = <16 years old Reported by parents 2001 post-census travel survey (SCAG) Southern California	Independent mobility, active transport, father escorting child	Population density, accessibility, relative locations of parents' residences and jobs	Binary logit models (one for each alternative)
Zhu and Lee, 2009 (*25*)	*N* = 2,695 Age = 6–10 years old Reported by parents Austin, Texas	Walking	Distance; safety concerns; highways or freeways; convenience stores; office buildings; bus stops en route	Multilevel correlations
Wen et al., 2008 (*26*)	*N* = 1,603 Age = 9–11 years old Trips recorded by kids, socioeconomic characteristics by parents Sydney, Australia	Walking, car	Distance; safety	Bivariate analyses and multiple logistic regression
Seraj et al., 2011 (*27*)	*N* = 1,000 Age = <16 years old Reported by parents 2009 NHTS, California	Walking, bicycle	Distance; violence or crime rate; speed; traffic; weather	Multivariate ordered response model
Noland et al., 2012 (*28*)	*N* = 1,573 Age = 5–13 years old Reported by parents New Jersey	Car, carpool, school bus, walk	Existence of parks; connectivity; length of sidewalks; speed limits; planting strips	Mixed logit model
Samimi and Ermagun, 2012 (*29*)	*N* = 3,441 Age = 12–17 years old Tehran, Iran	Walking	Population density; number of parks; road density; green spaces; mountainous versus flat	Binary logit models

NOTE: SCAG = Southern California Association of Governments; NHTS = National Household Travel Survey.

MODELING FRAMEWORK

On the basis of the literature review, it is hypothesized that the built environment characteristics of the route between home and school and socioeconomic characteristics of teenagers affect their mode choice behavior. But to take into account that each individual anticipates the built environment characteristics in a different way, a latent variable—walkability constraints (WalkCon)—is defined. It reflects how each individual perceives the built environment characteristics. This latent variable incorporates indicators and perceptions about sidewalks, bike lanes, parked cars that obscure visibility, unsignalized intersections, the existence of stray animals, poor lighting, and the probability of attack and safety en route. The latent variable is also affected by the individual's socioeconomic characteristics and actual built environment characteristics. Then, a hybrid choice model (HCM) is developed to ensure that the latent variable enters directly into the mode choice process (*30, 31*).

More specifically, this research seeks to investigate the effect of teenagers' perceptions of walkability constraints on their mode-to-school choice behavior. To do so, an HCM setting is constructed. Perceptual indicators about built environment characteristics (I_{WalkCon}) are taken, and then the latent variable WalkCon, which enters directly into the choice process, is defined. The explanatory variables (X_n) are actual characteristics such as socioeconomic and actual built environment characteristics. The utility obtained from choosing a particular mode is a function of the explanatory variables, the latent variable, and the actual characteristics of the built environment. The utility is measured by the choice indicator (y_n). The modeling framework is presented in Figure 1, where the ovals represent the latent variables, the rectangular boxes represent the observable variables, the dashed arrows indicate the measurement equations, and the solid arrows indicate the structural equations.

The mathematical formulations for modeling the latent variable are presented in the following equations [for more information, see work by Ben-Akiva and Lerman (*31*)]. For the latent variable model, the structural model (Equation 1) and the measurement model (Equation 2) are as follows:

$$\text{WalkCon} = X_1\theta + \sigma\omega \quad \omega \sim N(0, \Sigma_\omega) \tag{1}$$

where

WalkCon = latent (unobservable) variable,
X_1 = explanatory observed variables,
θ = vector of unknown parameters used to describe effect of observable variables on latent variables,
$\sigma\omega$ = vector of random disturbance terms, and
Σ_ω = covariance of random disturbance terms.

$$I_{\text{WalkCon}} = \alpha + \lambda\text{WalkCon} + \upsilon \quad \upsilon \sim N(0, \Sigma_\upsilon) \tag{2}$$

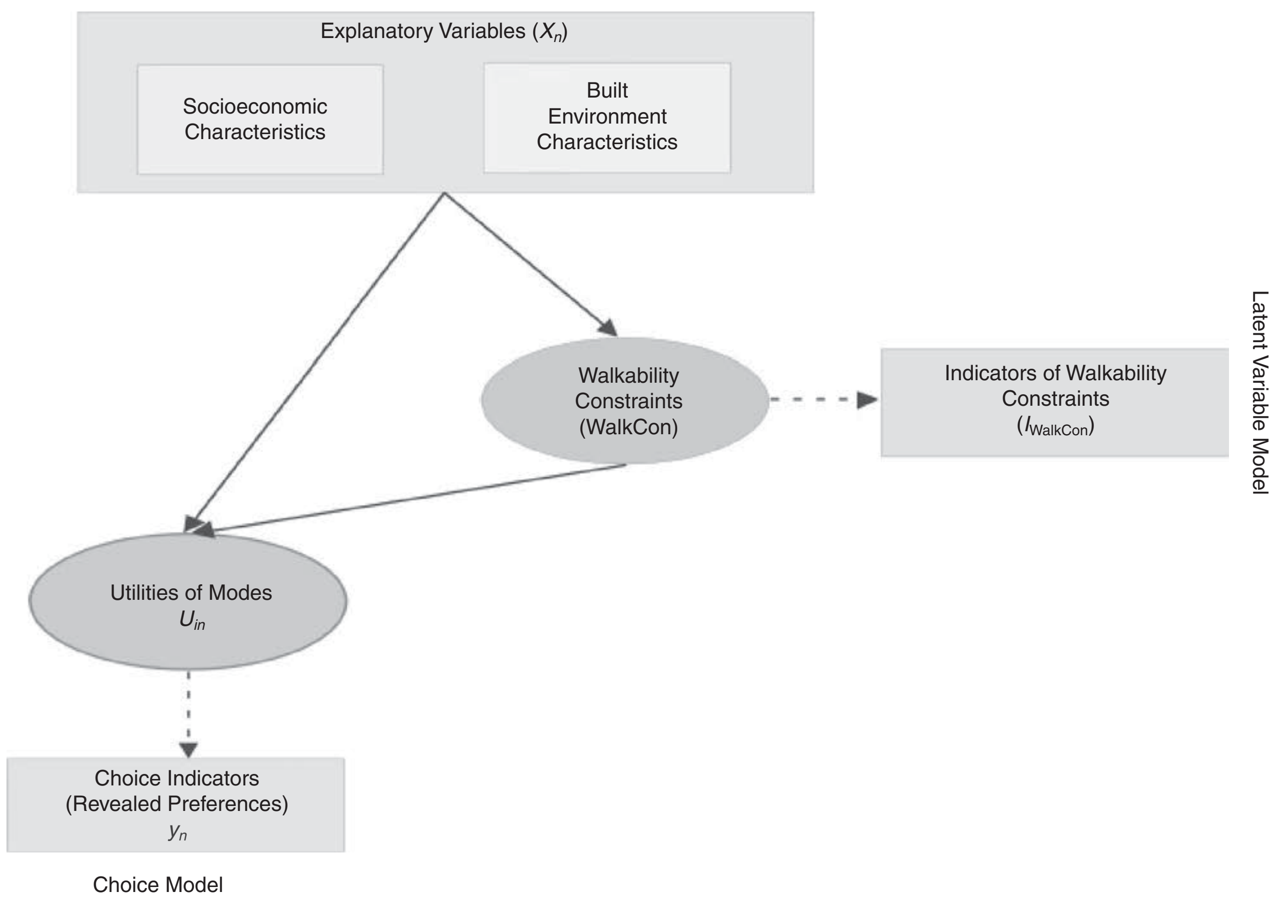


FIGURE 1 Modeling framework.

where

I_{WalkCon} = vector of perceptions,
α = vector of unknown parameters that indicate associations between responses to scale,
λ = vectors of unknown parameters that relate latent variable to indicators,
υ = vector of random error terms, and
Σ_υ = covariance of random disturbance terms.

The choice between the alternative modes is assumed to be based on maximizing one's utility. The choice model is as follows:

$$U = X_2\beta + \gamma\,\text{WalkCon} + \varepsilon \quad \varepsilon \sim N(0, \Sigma_\varepsilon) \tag{3}$$

$$y_i = \begin{cases} 1 & \text{if } U_i = \max j\{U_j\} \\ 0 & \text{otherwise} \end{cases} \qquad i = \text{ACT, PT, DRIVER, ESC} \tag{4}$$

where

U = vector of utilities of all alternatives,
X_2 = matrices of explanatory variables,
β = vector of unknown parameters associated with X_2,
γ = diagonal matrix of unknown parameters associated with latent variable WalkCon,
ε = vector of random disturbance terms associated with utility terms,
Σ_ε = covariance of random disturbance terms,
ACT = active transport,
PT = public transport,
DRIVER = driver of motorized vehicle,
ESC = escorted by parents, and
y_i = choice indicator taking value 1 if mode i is chosen, and 0 otherwise.

The likelihood function for a given observation is the joint probability (P) of observing the choice and the attitudinal indicators:

$$\begin{aligned} f(y_i, I|X;\delta) = \int_{\text{WalkCon}} & P(y|X, \text{WalkCon}; \beta, \gamma, \Sigma_\varepsilon) \\ & f_{I_{\text{WalkCon}}}(I|\text{WalkCon}; \lambda, \Sigma_\upsilon) \\ & f_{\text{WalkCon}}(\text{WalkCon}|X; \vartheta, \Sigma_\omega)\, d\,\text{WalkCon} \end{aligned} \tag{5}$$

where the term δ designates the full set of parameters to estimate ($\delta = \{\beta, \gamma, \lambda, \theta, \Sigma_\varepsilon, \Sigma_\upsilon, \Sigma_\omega\}$). The first term of the integral corresponds to the choice model. The second term corresponds to the measurement equation of the latent variable model, and the third term corresponds to the structural equation of the latent variable model, where d is a function of the integral. The latent variable is only known to its distribution, and so the joint probability of y, I_{WalkCon}, and WalkCon is integrated over the vector of latent constructs WalkCon.

CASE STUDY

Survey Design and Data Collection

For the purposes of this survey, a questionnaire that takes into account the special needs of this age group was designed by transport planners, psychologists, and economists [for more information about the structure and data collection, see authors' earlier work (*22*)].

The data collection took place from September 2011 to May 2012 (school year 2011–2012). The research team in cooperation with the secondary education departments of each area worked together closely to define the sample of schools and the grades (years) from each school that would be asked to participate in the survey in order to obtain a representative sample of each area and school. During the data collection, the researchers visited the high schools in order to assist with any questions regarding the completion of the questionnaire. The questionnaire was available in both paper and online formats. If the high school gave the research team access to the informatics classroom, the online version was used; otherwise the paper questionnaire was used.

Data were collected from three environments (Table 2). Eight public high schools from the greater Athens area (capital city of Greece, an urban area), six high schools in Alexandroupolis (a rural border city), and eight high schools in Chios (an insular border area) participated. Of the schools in the Athens area, four were in the Korydallos neighborhood and four in the Peristeri neighborhood (from now on, this area will be referred to as Athens). These three areas were completely different in terms of their local culture and built environment. Table 2 presents the characteristics of each area (*32*).

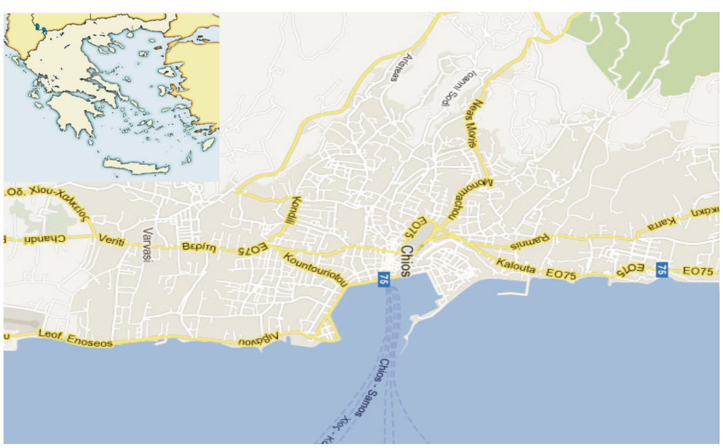
Students in all of the foregoing areas could use cars, motorcycles, public transport, bikes, and walking as their means of transport to school. The difference between the urban and rural areas was that in Athens there were a number of alternative public transport choices, such as tram, metro, train, and bus, whereas in rural areas only buses were available, and their frequency was reduced in the afternoon.

Sample Characteristics

The characteristics of the participants from each area are presented in Table 3. The total sample consists of 1,988 students, between 12 and 18 years of age, from public high schools: 36% of the participants in the urban area, 29% in the rural area, and 35% in the insular area. The average age was 15.7 years old, and 52% were girls. The average number of trips in a typical school day were 4.5, and 17 travel patterns were identified for the trip to school, with the majority of the participants conducting a simple trip from home to school and back again. The main transport mode for this type of trip was walking, with 40% of the participants walking from home to school and back again; only 3% cycle. Of those who were pedestrians, 56% walked to school with their peers. The maximum distance walked was 1.6 km for the students from the urban area, 2.0 km for those from the rural area, and 1.0 km for the insular area.

Table 4 presents the characteristics of the built environment along the route between home and school. Because the actual built environment characteristics of the cities were not available through any other source, the researchers carefully examined each individual's route between home and school and used a geographic information system coded the built environment characteristics. The route characteristics in the urban area differed greatly from those in the rural and insular areas. Only 6% of the urban adolescents faced poor road conditions (potholes in roads and sidewalks) on their way to school. In the urban area, no parts of the route to school were without sidewalks, whereas 27% of the insular adolescents were found to follow a route on which at least one part had no sidewalks. Forty percent of the rural students followed a route with wide sidewalks, whereas only 9% of the insular students followed a route with this characteristic. The characteristics presented in Table 4 are the actual characteristics

TABLE 2 Characteristics of Sampled Areas

Area	Characteristics
	Urban area. Korydalos and Peristeri are located within the greater Athens area, 12 km southwest of Athens' city center. They are in a heavily urbanized area with many buildings per square kilometer. There are narrow, highly congested streets, with parked cars at a capacity that obstructs the road users' visibility. There are high schools in every neighborhood. Population density: 7,361/km² (high).
	Rural area. Alexandroupolis is a border coastal city surrounded by agricultural fields. The landscape consists of five-story buildings, wide streets with low traffic levels, and generally a low population density. In the city four main bicycle corridor link the center of the city with the high schools. All high schools are situated in the southern part of the city. Population density: 35.21/km² (low).
	Insular area. Chios is the fifth largest of the Greek islands, situated in the Aegean Sea. The quality of life is relatively high, as it is the fourth Greek county in terms of savings, with €16,570 per capita, and has the third highest cars per capita ownership in Greece and the highest motorcycle ownership (*32*). There are narrow streets and pavements with parked cars at a capacity that obstructs the road users' visibility. There are high schools in every neighborhood. Population density: 59.06/km² (low).

NOTE: €1.00 = US$1.30 in 2012.

TABLE 3 Socioeconomic Characteristics of Sample

Characteristic	Urban Area[a]	Rural Area[b]	Insular Area[c]
Gender [dummy variable (%)]			
Male (value = 0)	44	52	49
Female (value = 1)	56	48	51
Age: (string variable) [mean (SD)]	16.4 (2.59)	15.0 (2.93)	15.6 (2.05)
Income (%)			
Low (< €2,000)	44	64	31
Medium (€2,000–€4,000)	35	46	45
High (> €4,000)	21	37	24
Car ownership (string variable): [mean (SD)]	2.3 (1.23)	1.7 (1.46)	1.8 (1.53)
Motorcycle ownership (string variable): [mean (SD)]	0.9 (1.92)	0.7 (1.32)	1.4 (1.74)
Number of siblings (string variable): [mean (SD)]	1.7 (0.84)	1.4 (0.93)	1.3 (1.02)
Mode to school (mode used to go to school day before they participated in survey) (%)			
Walk	36	50	34
Cycle	2	4	2
Public transport	30	12	20
Drivers	3	4	13
Escorted by parents	29	30	31
Number of trips (SD)			
Morning	2.3 (0.53)	2.1 (0.74)	2.2 (0.98)
Total	4.2 (1.24)	4.4 (2.15)	4.9 (1.94)
Knowledge of traffic code[d]: yes (%)	63	45	63
Time period in which survey took place (%)			
December–March (cold weather)	68	76[e]	49
September–November and April–May (mild weather)	32	24	51

NOTE: SD = standard deviation.
[a]N = 716 observations.
[b]N = 576 observations.
[c]N = 696 observations.
[d]The participants were requested to indicate whether they knew the traffic code. Afterward, pictures about traffic regulations and yield rules that applied at intersections and driveways were presented; the student had to choose the road user who had priority. Those who answered that they knew the traffic code (perceived knowledge) and also gave the right answers to the questions (actual knowledge) were recorded as being cognizant of the traffic code.
[e]In the week when this survey took place, the highest temperature was −6°C and the lowest −17°C. Despite the bad weather conditions, the majority of the participants still walked to school.

of the built environment and were used in the development of the latent variables and the mode choice models described later.

The participants were requested to indicate their level of agreement or disagreement with various statements regarding the walkability constraints of the built environment that they perceived in their route from home to school (Table 5). These statements were used as indicators of the latent variable WalkCon. The response scale ranged from 1 to 7; a response of 1 indicated that the participant completely disagreed with the statement, and a 7 indicated that they completely agreed. The urban adolescents showed a high level of agreement with the statements about parked cars obscuring their visibility and the possibility of being attacked en route. The insular participants agreed somewhat with the statement that a lack of sidewalks was a constraint on the choice to walk, and both the rural and insular students somewhat agreed that poor lighting was a constraint on the choice to walk.

TABLE 4 Characteristics of Built Environment on Route Between Home and School

	Percentage Experiencing, by Area		
Built Environment—Related Issue	Urban[a]	Rural[b]	Insular[c]
Poor condition of road network (potholes in roads and sidewalks)	6	36	41
Traffic lights at major roads or intersections	78	28	18
Part of route without sidewalks	0	3	27
More than 50% of route has wide sidewalks	28	40	9
Aesthetics (existence of greenery, trees, and flowers)	3	17	20

[a]N = 716.
[b]N = 576.
[c]N = 696.

MODEL SPECIFICATION AND ESTIMATION RESULTS

Model Specification

To investigate the effect of perceived and actual built environment characteristics on mode choice behavior of teenagers and the differences between the three environments, one mode choice model was developed for each area. The alternatives are

1. Active transport (ACT),
2. Public transport (PT),
3. Driver of motorized vehicles (DRIVER), and
4. Escorted by parents (ESC).

TABLE 5 Indicators of Latent Variable WalkCon

	Score, by Area					
	Urban		Rural		Insular	
Indicator	Mean	SD	Mean	SD	Mean	SD
I_{WalkCon1}: There are stray animals.	2.0	1.946	3.7	2.251	3.1	2.360
I_{WalkCon2}: There is a possibility of attack.	5.6	1.508	3.6	2.193	3.1	2.241
I_{WalkCon3}: There is poor lighting.	2.7	1.287	4.8	2.280	4.9	2.326
I_{WalkCon4}: There are no sidewalks.	1.8	0.964	3.4	2.163	4.4	2.135
I_{WalkCon5}: There are no traffic lights.	2.0	1.347	3.2	2.168	3.9	2.433
I_{WalkCon6}: There are parked cars that obscure my visibility.	5.2	2.129	2.9	2.152	3.7	1.893

NOTE: Likert scale: 1 = completely disagree; 7 = completely agree.

Because only a small percentage of the participants were found to cycle to school, the walking and cycling options were merged into one, active transport (ACT). The sample was carefully examined and filtered in order to put constraints on the options available to certain students. For example, students living more than 2.0 km away from their school were not given the option of selecting ACT. The car option was available to all participants, since all of the households owned at least one car or motorcycle. Regarding the option DRIVER, no age limits were set because of the fact that some students drove motorcycles without having a driver's license (72% of the drivers in the insular area were unlicensed).

First, for comparison purposes, a multinomial logit (MNL) model was estimated [see work by Bierlaire (*33*)]. At the same time, the latent variable WalkCon, which reflected the perceived constraints of the built environment on the use of active transport, was postulated to have had a significant impact on mode choice. Specifically, it was assumed that the latent variable would decrease the probability of choosing active transport (walking or cycling) and increase the probability of choosing the option ESC. With these assumptions in mind, the latent variable WalkCon was incorporated into the utilities of the ACT and ESC alternatives in the MNL model.

The utility of choice was a function of socioeconomic and built environment characteristics, the latent variable, and alternative-specific constants for the alternatives ACT, PT, and ESC. The variable distance was interrelated with income and weather variables to enable a better interpretation of the estimation results. For example, distance was interrelated with income, since it could be hypothesized that households with higher incomes would choose to reside near their children's school. However, it might be surmised that families with higher incomes usually live in suburban areas and that therefore their children would not have the option of walking to school. Also, distance was interrelated with weather in order to check the effect of weather on the distance traveled. The utility specification also contained the effect of the latent variable WalkCon. The latent variable was not considered for the PT and DRIVER alternatives. The equations for the choice model are as follows:

$$\begin{aligned}\text{ACT} = {} & \beta_{\text{ACT}} + \beta_{\text{GEN1}} * \text{FEMALE} + \beta_{\text{AGE1}} * \text{AGE} \\ & + (\beta_{D1} + \beta_{\text{INC}} * \text{INCOME} + \beta_{W1} * \text{WINTER}) * \text{DISTANCE} \\ & + \beta_{*\text{WS}} * \text{WIDESIDEWALK} + \beta_{\text{NC}} \\ & * \text{NETWORKCONDITION} + \beta_{\text{TL}} * \text{TRAFFICLIGHTS} \\ & + \beta_{\text{GR}} * \text{GREEN} + \gamma_{\text{WC1}} * \text{WalkCon} + \varepsilon_{\text{ACT}}\end{aligned} \tag{6}$$

$$\text{PT} = \beta_{\text{PT}} + \varepsilon_{\text{PT}} \tag{7}$$

$$\begin{aligned}\text{DRIVER} = {} & (\beta_{D3} + \beta_{\text{INC3}} * \text{INCOME}) * \text{DISTANCE} + \beta_{\text{GEN}} \\ & * \text{FEMALE} + \beta_{\text{AGE3}} * \text{AGE} + \varepsilon_{\text{DRIVER}}\end{aligned} \tag{8}$$

$$\begin{aligned}\text{ESC} = {} & \beta_{\text{ESC}} + \beta_{\text{GEN4}} * \text{FEMALE} + \beta_{\text{AGE4}} * \text{AGE} \\ & + (\beta_{\text{D4}} + \beta_{\text{INC4}} * \text{INCOME}) * \text{DISTANCE} + \beta_{\text{CARH}} \\ & * \text{CAROWNERSHIP} + \beta_{\text{SIB}} * \text{SIBLINGS} + \gamma_{W4} \\ & * \text{WalkCon} + \varepsilon_{\text{ESC}}\end{aligned} \tag{9}$$

where

GEN = gender;
D = distance;
INC = INCOME;
W = WINTER;
WS = WIDESIDEWALK;
NC = NETWORKCONDITION;
TL = TRAFFICLIGHTS;
GR = GREEN;
WC = WalkCon;
SIB = SIBLING;
CARH = CAROWNERSHIP;
FEMALE = 1 if participant is female, 0 otherwise;
AGE = age of participant (minimum value = 12 years old, maximum value = 18 years old);
INCOME = monthly family income in euros (continuous variable);
DISTANCE = distance between home and school (continuous variable);
WINTER = 1 if survey took place during winter (December to March), 0 otherwise;
CAROWNERSHIP = number of cars in household (continuous variable);
SIBLINGS = number of siblings who are students under 18 years (continuous variable);
WIDESIDEWALK = 1 if at least 50% of route from home to school has wide sidewalks, 0 otherwise;

NETWORKCONDITION = 1 if condition of sidewalk network is good, 0 otherwise;
TRAFFICLIGHTS = 1 if there are traffic lights at major intersections or roads along route from home to school, 0 otherwise;
GREEN = 1 if there are trees, flowers, or parks on route from home to school, 0 otherwise;
WalkCon = latent variable walkability constraints; lower value indicates that individual is more likely to choose active transport; and
$\varepsilon_{ACT}, \varepsilon_{PT}, \varepsilon_{DRIVER}, \varepsilon_{ESC}$ = vectors of error terms.

The available indicators may refer to walkability constraints regarding safety, aesthetics, or other type of constraints. On this basis, one may assume that different latent variables could be included in model estimations. At the beginning of the modeling effort, a factor analysis model was estimated with the indicators presented in Table 5. The factor analysis gave as a result only one component; thus in all further modeling one latent factor was used: WalkCon.

The perception of walkability constraints was modeled as a function of the socioeconomic and built environment characteristics. The structural equation linked teenagers' characteristics with the latent variables through a linear regression equation based on the individual's gender, grades, pocket money, parents' level of education, parents' mode use patterns, household income, and the characteristics of the built environment that existed on the route from home to school. The equation is as follows:

$$\begin{aligned} \text{WalkCon} = {} & \theta_{\text{WalkCon}} + \theta_{\text{GEN}} * \text{FEMALE} + \theta_{\text{AGE}} * \text{AGE} \\ & + \theta_{\text{WS}} * \text{WIDESIDEWALK} + \theta_{\text{NC}} \\ & * \text{NETWORKCONDITION} + \theta_{\text{Green}} * \text{GREEN} \\ & + \theta_{\text{TL}} * \text{TRAFFICLIGHTS} + \theta_{\text{TC}} * \text{TC} + \omega_{\text{WalkCon}} \end{aligned} \tag{10}$$

where TC is the traffic code, which takes the value 1 if the student gave the right answers to the questions about traffic regulations, 0 otherwise; and ω is a random error term.

Estimation Results

Mode Choice Model

The estimation results of the choice model are presented in Table 6 and discussed in this section. As explained earlier, an MNL model was estimated and then an MNL model with the WalkCon latent variable. Because of space limitations, only the results of the MNL model with the latent variable (HCM) are presented here. The models were estimated with the Pythonbiogeme software [see work by Bierlaire and Fetiarson (*34*)].

Female students in the urban area seemed to walk and cycle less; these students preferred to be escorted to school by their parents. These results are consistent with those of previous surveys, such as work by Larsen et al. (*15*). Although the sign of the FEMALE variable is negative for the rural and insular areas, the variables are not statistically significant at the 95% level of confidence; this finding indicates that there are minor differences between male and female students in these areas. The possibility of driving to school increases for male students of all three areas. As teenagers grow up, they prefer active transport, and the possibility of being escorted decreases significantly for urban and rural teenagers. This result reflects the fact that teenagers tend to conduct more independent, unsupervised trips when approaching the age of 18.

As income increases, the probability of choosing active transport decreases, but this variable is significant only for insular areas. Also, income affects positively the choice of driving a motorcycle for their trip to school. Teenagers from urban and insular households with higher incomes prefer being escorted to school, but the negative sign of this variable for rural teenagers indicates a negative impact on this choice. Taking into account the fact that the average income of the examined rural area is quite low and homogeneous across the population since the majority of the residents are public servants, this result sounds logical. However, in the other two areas studied there are residents with various types of occupation; thus income varies significantly across the population. As the number of siblings under 18 increases, participants in the urban area tend to be escorted to school by their parents, whereas in the rural and insular areas that circumstance affects this choice negatively. This finding means that when parents in urban areas have more than one school-age child, they tend to escort their children to school.

In regards to the characteristics of the built environment, distance plays the most significant role in mode-to-school choice, a fact that other surveys have verified as well (*14, 20*). Distance affects the choice of driving to school negatively; this finding indicates that drivers do not make long-distance trips. The maximum distance that participants cover on their motorcycles is 3.1 km in insular areas, 2.8 km in rural areas, and 1.6 km in urban areas (almost half as compared with insular areas). The variable DISTANCE is interrelated with INCOME in order to explain more clearly the location of the wealthy households. Generally the results for the urban and insular areas confirm that as both distance and income increase, teenagers prefer to be escorted to school and prefer neither active transport nor motorcycles. This finding reflects the fact that households with high incomes choose to live in areas that may be more prestigious despite their not having a school nearby. At this point it is worth recalling the fact that all the participants in the survey go to public schools. In contrast, the negative sign of INCOME for rural teenagers indicates that although in their case income and distance increase, they do not prefer to be escorted to school. Once again, this result reflects the homogeneity in income among the residents of the rural area, the fact that in Alexandroupolis there are no prestigious areas in which to live, and the additional fact that all the high schools are situated in one specific location, close to each other.

The existence of wide sidewalks affects the choice of active transport in urban and rural areas significantly, whereas in the insular area this variable is statistically significant at the 90% level. When the condition of roads and sidewalks is good, teenagers in rural and insular areas tend to prefer more active transport. However, this variable is not statistically significant at the 95% level for teenagers in urban areas because the road and sidewalk network there is in better condition, with few potholes and obstacles. The existence of traffic lights at major intersections is significant for the choice of active transport in urban areas, whereas this variable does not affect that choice significantly in rural and insular areas. Since the urban area is more congested and its traffic flows are higher, especially in the morning during the commute to school, traffic lights are necessary for walking or cycling to school safely. As for the aesthetics of the route between home and school, the existence of trees and flowers increases significantly the possibility of active transport in all areas. Bad weather (WINTER) affects significantly and negatively the choice of active transport in urban and insular areas only. These areas usually have a mild climate, so the inhabitants are not used to

TABLE 6 Mode Choice Model Estimation Results

	Statistic, by Area					
	Urban[a]		Rural[b]		Insular[c]	
Variable	Coeff.	*t*-Statistic	Coeff.	*t*-Statistic	Coeff.	*t*-Statistic
Vector						
β_{ACT}	8.23	2.28	8.05	2.58	2.28	2.02
β_{PT}	12.7	4.20	*−0.29*	*−0.43*	7.43	2.92
β_{ESC}	3.59	1.08	3.63	2.73	7.20	3.11
Socioeconomic						
FEMALE						
Specific to ACT	−2.67	−2.81	*−1.08*	*−1.33*	*−0.83*	*−1.08*
Specific to DRIVER	−2.6	−3.36	−1.72	−2.65	−0.97	−2.96
Specific to ESC	2.22	5.25	0.94	2.30	*0.15*	*0.61*
AGE						
Specific to ACT	0.44	2.77	0.38	1.98	1.07	2.37
Specific to DRIVER	0.50	3.53	*0.14*	*0.81*	0.75	4.36
Specific to ESC	−0.36	−3.92	−0.78	−2.65	*0.10*	*0.73*
INCOME						
Specific to ACT	*−0.158*	*−0.47*	−0.22	−1.28	−0.84	−2.25
Specific to DRIVER	1.32	3.80	*0.33*	*1.24*	0.27	2.97
Specific to ESC	3.46	10.66	−0.25	−2.46	0.08	1.16
Car ownership, specific to ESC	1.00	4.04	0.85	3.38	1.08	7.54
No. of siblings who are students (<18 years old), specific to ESC	0.20	4.09	−0.34	−2.21	−0.30	−2.24
Built Environment Characteristics						
DISTANCE						
Specific to ACT	−1.26	−7.40	−2.56	−8.22	−4.03	−5.71
Specific to DRIVER	*−0.12*	*−1.31*	−0.46	−3.19	−0.76	−8.31
Specific to ESC	0.33	4.76	−0.49	−5.84	−0.41	−6.09
WIDESIDEWALKS, specific to ACT	4.55	3.55	2.14	2.56	*0.54*	*0.57*
Road and sidewalk condition (1 = good, 0 = otherwise), specific to ACT	*0.48*	*0.39*	−1.92	−2.53	2.07	2.28
Existence of trees and flowers, aesthetics (1 = yes, 0 = otherwise), specific to ACT	1.28	2.30	1.91	2.36	3.78	3.71
Existence of traffic lights at major intersections and roads (1 = yes, 0 = otherwise), specific to ACT	4.02	4.03	*0.19*	*0.26*	*1.38*	*1.21*
WINTER, specific to ACT	−0.72	−2.4	0.65	1.96	−0.34	−1.99
Latent						
WalkCon, specific to ACT	−0.52	−2.28	−0.91	−2.69	−1.63	−2.39
WalkCon, specific to ESC	0.85	10.09	0.52	3.26	0.51	4.82

NOTE: Values in italics are not statistically significant at 95% level. Coeff. = coefficient; no. = number.
[a] $N = 716$; no. of draws = 1,000; $R^2 = .425$.
[b] $N = 576$; no. of draws = 1,000; $R^2 = .492$.
[c] $N = 696$; no. of draws = 1,000; $R^2 = .479$.

worsening weather conditions. As a result, they do not like walking in bad weather but prefer private motorized vehicles. However, this variable is not statistically significant for the rural area, since the weather in winter is usually bad and residents are used to it. Worsening weather conditions do not cause significant changes in their daily activities.

Unsurprisingly, the incorporation of the latent variable improved the explanatory power of the model; it provided insights about perceived urban characteristics. WalkCon enters significantly into the choice model specification. Thus, the latent variable discourages the choice of walking and cycling (WalkCon) to school in all areas through a negative impact on the choice of this alternative. Also, the latent variable has a positive effect on the choice of a car; this finding indicates that individuals who face walkability constraints prefer to be escorted to school by their parents. WalkCon has the highest effect on the ESC choice in the urban area; it appears that walkability constraints affect the choice of ESC more in the urban area than in rural and insular areas.

Structural and Measurement Models

Table 7 presents the estimation results of the structural and measurement models. All variables used in the structural model are statistically significant at the 95% level, but some of them affect the latent variable in different ways. Female students from all areas perceive the walkability constraints more strongly than male students do. As

TABLE 7 Structural Model Estimation Results

Variable	Urban Area Coefficient	Urban Area t-Statistic	Rural Area Coefficient	Rural Area t-Statistic	Insular Area Coefficient	Insular Area t-Statistic
Structural Model						
$\theta_{WalkCon}$	5.46	7.05	4.85	13.19	3.36	10.09
$\sigma_{WalkCon}$	2.38	15.25	1.27	8.30	1.23	6.71
FEMALE	0.645	3.29	1.10	8.34	0.436	4.12
AGE	–0.172	–3.62	–0.125	–5.22	–0.259	–5.78
Knowledge of traffic code (1 = yes, 0 = otherwise)	–0.946	–4.86	–0.409	–3.48	–0.11	–1.96
WIDESIDEWALKS (1 = yes, 0 = otherwise)	–0.486	–2.36	0.835	–1.64	–0.39	–3.07
Road and sidewalk condition (1 = good, 0 = otherwise)	–3.24	–1.58	–0.715	–8.20	–0.316	–2.83
Existence of trees and flowers, aesthetics (1 = yes, 0 = otherwise)	–0.22	–1.68	–0.569	–4.09	–0.44	–3.76
Existence of traffic lights at major intersections and roads (1 = yes, 0 = otherwise)	–0.532	–2.57	–0.189	–1.46	–0.159	–1.37
Measurement Model						
α_1	0	na	0	na	0	na
α_2	0.362	6.18	0.694	1.96	0.207	0.9
α_3	0.315	0.72	0.475	2.12	0.406	2.61
α_4	0.331	5.62	0.375	2.75	0.216	2.85
α_5	0.213	4.2	0.311	1.46	0.38	1.59
α_6	0.203	3.0	0.522	2.45	0.321	1.42
λ_1	1	na	1	na	1	na
λ_2	0.954	56.5	1.22	19.49	1.22	16.12
λ_3	0.975	78.21	1.24	18.8	1.43	17.12
λ_4	0.963	56.98	1.08	17.15	1.32	15.76
λ_5	0.965	66.19	1.09	17.32	1.39	17.54
λ_6	0.92	47.15	1.15	18.26	1.31	17.51
σ_1	0.632	26.19	1.62	31.11	1.9	35.84
σ_2	0.985	32.74	1.09	24.58	1.44	33.42
σ_3	0.603	25.65	1.2	26.48	1.18	29.43
σ_4	0.99	33.71	1.35	29.04	1.59	33.75
σ_5	0.794	30.58	1.34	28.45	0.889	25.05
σ_6	1.21	34.43	1.19	27.22	0.9	26.42

NOTE: na = not applicable.

teenagers grow up and reach the age of 18, they tend to perceive the walkability constraints less, especially in rural and urban areas. The knowledge of the traffic code has a negative sign for all three areas; this finding indicates that when teenagers know how to stay safe as road users, the perceived walkability constraints decrease.

In regards to the built environment characteristics, the existence of wide sidewalks affects significantly and negatively the perceived walkability constraints in urban and insular areas, although in the rural area this variable is statistically significant at the 90% level. When the condition of roads and sidewalks is good, teenagers in rural and insular areas tend to perceive fewer walkability constraints. However, this variable is not statistically significant at the 95% level for teenagers in the urban area because of the fact that in urban areas the road and sidewalk network is in better condition and there are few sidewalks and roads with potholes and obstacles. Existence of traffic lights at major intersections affects the latent variable in the urban area significantly, whereas this variable does not significantly affect this choice in rural and insular areas. Because the urban area is more congested and the traffic flows are higher, especially in the morning during the commute to school, traffic lights are necessary for safe walking or cycling to school. As for the aesthetics of the route between home and school, the existence of trees and flowers reduces significantly the perceived walkability constraints in the urban area.

CONCLUSIONS AND FURTHER RESEARCH

The aim of this research is to investigate the effect of teenagers' perceptions of walkability constraints and actual built environment characteristics on the choice of mode to school between an urban, a rural, and an insular area. To the authors' knowledge, it is the first time that such a survey regarding travel behavior to school has taken place that focuses only on teenagers and compares the effect of characteristics of different urban forms on the choice of mode to school.

With data collected directly from teenagers, an HCM was developed and applied to explain the effect of actual built environment characteristics and perceived walkability constraints in a mode choice context. This specification is consistent with the new trend in discrete choice modeling toward incorporating unobservable (perceptual and attitudinal) factors into the behavioral representation of the decision process. The HCM offers an attractive improvement in modeling mode choice behavior because the choice model is only a part of the whole behavioral process in which an individual's perceptions are incorporated, and thus yields a more realistic model. The latent variable WalkCon enriched the choice model and provided insights into the importance of unobservable individual-specific variables in modal choice; this result indicates that this type of model is a powerful tool for improving the understanding of travel behavior.

In general, the results indicate that each urban environment has its own characteristics that affect mode choice. The model for urban adolescents is consistent with the results of previous surveys that also took place in urban areas, such as those by Mitra and Buliung (*16*) and by Grow et al. (*21*), but individuals in rural and insular areas exhibit different behaviors. The results confirm that distance plays the most significant role in choice of mode to school for all three areas. The existence of wide pavements, flowers and trees, and traffic lights at major intersections affects positively the choice of active transport to school; thus the two first characteristics are more significant for adolescents in rural and urban areas, and the last one is more important for high school students in urban areas. Bad weather decreases the probability of choosing active transport, but this variable is not significant for rural areas.

The results of the HCM showed that teenagers' attitudes toward walkability constraints are very important and significant; this finding ensures that unobservable variables about how individuals perceive built environment characteristics should be implemented in the choice process in order to have more realistic econometric models and in doing so to implement better cut-and-tailored policies. As expected, the latent variable WalkCon works against WALK and CYCLE (active transportation), whereas it affects the choice of being escorted by their parents positively.

The results of the structural model indicate that teenagers perceive the various characteristics and the constraints of the built environment in different ways. The most significant walkability constraint for urban teenagers seems to be the safety issue, whereas for rural and insular students it is poor lighting and the absence of sidewalks.

These results would be without any meaning if they could not be translated into policies and measures. City plans should encourage more innovative types of development that support active transport and discourage car use. Policy makers in urban areas should deal with safety issues in order to improve active transport. In rural and insular areas, they should focus on the improvement of sidewalk conditions. Construction of wider sidewalks and bike lanes, which costs less than road construction, will enhance active transport and at the same time will improve the connectivity of walking routes (for example, to the bus stop or to school). Cities should take into consideration the needs of the new generation and adapt their plans accordingly.

In addition, the estimated models could be incorporated into activity-based models for better behavioral representation of the drivers of activities. The estimated models offer significant insights about the effect of perceived and actual built environment characteristics on travel behavior. Also, the incorporation of these models into activity-based models would allow transport planners and policy makers to better understand adolescents' travel and in doing so to design the appropriate policies that will cover the next generation's travel needs.

The innovative data collection and modeling methodology could be of great importance to researchers who are dealing with this age group or modeling the demand for nonmotorized modes. Moreover, the investigation of teenagers' travel behavior could provide significant findings for policies, strategies, and campaigns in order to shape the desired travel behaviors, which may be retained in adulthood.

Future work includes the estimation of mode choice models that will incorporate the indicators of the latent variable WalkCon as constraints to the choice set (latent choice sets). Also, further research will focus on modeling bicycle usage demand and how the built environment in combination with teenagers' attitudes and perceptions affects this choice.

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