EXPLORING THE ROLE OF SOCIO-ECONOMIC AND BUILT ENVIRONMENT DRIVING FACTORS IN SHAPING THE COMMUTING MODAL SHARE: A PATH-ANALYSIS-BASED APPROACH

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Abstract: This paper explores the role of the built environment and socio-economic drivers in shaping the modal share of commuting. For this, we have identified through our literature review 67 potential variables categorised into two groups; the built environment and the households' socio-economic characteristics. We have considered the city of Djelfa as a case study and used the questionnaire as a data collection tool. The questionnaire processing of the 700 questionnaires provided to the households allowed us to select 184 questionnaires for our analysis. The sensitivity analysis protocol is designed for two stages; (i) an exploratory stage, conducted by principal component analysis and bivariate correlation analysis; (ii) and a confirmatory stage conducted by a path analysis. The first step allowed us to hypothesise several causal pathways that could explain, directly or indirectly, the modal share of commuting. The results of the path analysis show that the modal shares of walking, private car and public transit are controlled by 13, 16 and 12 explanatory variables, respectively. Overall, the socio-economic characteristics of households discourage walking and transit use, and encourage private car commuting. On the other hand, the variables identified in this paper related to the built environment discourage walking, but encourage the use of public transit rather than private cars for commuting.

Keywords: commuting, questionnaire, sensitivity analysis, path analysis, Djelfa (Algeria)

Abbreviations: VKT – Vehicle kilometre travelled; Da – Algerian dinar; SNAT – Schéma National d'Aménagement du Territoire (National Spatial Planning Scheme); CFI – *Comparative fit index;* NFI – *Normal fit index;* SEM – Structural equation modelling; PCA – Principal component analysis; PNME – Plan national de maitrise de l'énergie (National Energy Management Plan); KMO – Kaiser-Meyer-Olkin test; SMART – Specific, Measurable, Achievable, Relevant and Time-bound.

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Introduction

Cities today consume three-quarters of the world's energy and are the sources of at least three-quarters of global pollution (Rogers et al. 2008: 47). As a direct consequence of the population growth and the resulting needs, the phenomenon of climate change has manifested itself and has been confirmed by several studies (IPCC 2007, 2014). Sustainable development has come to

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frame growth and human development by introducing the notion of need and its limits, and its preferred mode of appropriation is 'assessment indices'(Boutaud 2005). Within this framework, Algeria, a signatory of the Kyoto Protocol, has committed itself to this lineage by initially producing inventories (MEAT and IPCC 2001; MATE 2010) to assess its greenhouse gas emission rates resulting from main activities, namely, residential, transport, agricultural and industrial activities (APRUE 2007, 2014, 2015, 2017). The concretisation of these main orientations was mainly materialised by the promulgation of the framework law 99-09 on energy management. This was followed by legal measures that provide a framework and facilitates energy management activities

Fig. 1. Location of the city of Djelfa on highlands band (Benslimane et al. 2009).
Source: own elaboration.

Fig. 2. Djelfa in images, composed by authors.

in the four main consumer sectors (Boukarta, Berezowska-Azzag 2018b). This same law gave rise to the National Energy Management Plan (PNME) aimed at reducing energy consumption for every 5-year period through the planning of timetables. However, certain dates could not be achieved just like in the case of the realisation of the 600 HPE (high energy performance) housing programme for all climatic zones. (Boukarta, Berezowska 2017). The residential and mobility sectors alone account for more than 70% of energy consumption in Algeria (Boukarta, Berezowska-Azzag 2018a), so focussing on these two sectors could help reduce energy consumption and *ipso facto* the resulting greenhouse gas emissions. In order to achieve these objectives, knowing and analysing the drivers of energy consumption is a distinct step. To this end, the paper explores the modal share of commuting. We have chosen to focus on commuting because of its recurrent and important nature in the volume of Algerian household transport. Other modes of travel could have been considered, such as shopping and leisure travel. Our review has shown that the methods used to identify the drivers of mobility differ based on the nature of the trip (Boukarta 2019). In order to achieve more impact by our study, we chose the city of Djelfa as a case study because it is located in the highlands area and the government is committed through the SNAT horizon 2030 (Official Journal no. 61) to urbanise this area in the coming years. The results of our study could well be used by urban planners and decision-makers to reduce the use of private cars for commuting in the context of future urbanisation (Figs 1 and 2).

Literature review and research gap

The literature review focuses on the impacts of the socio-economic and built environment driving factor on commuting. So, we have organised our review based on Table A1 in Appendix which contains 27 peer reviewed papers on different countries across the world indexed all in Scopus and Web of science database. Table 1 contains the number of the selected papers by country.

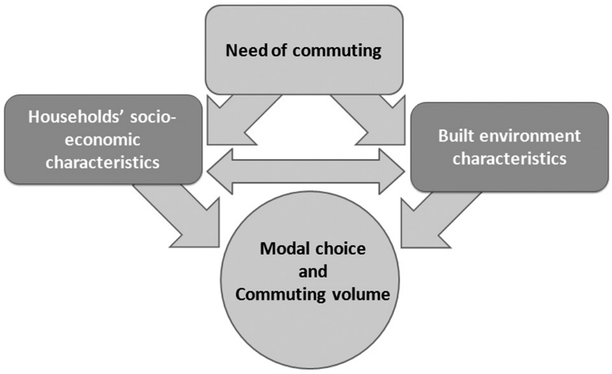

Fig. 3. Conceptual model explaining the need of commuting.
Source: own study.

Basically, a conceptual model was identified to explain the need for mobility through the following two registers; (a) socio-economic characteristics of households; and (b) built environment characteristics (Fig. 3). Each register includes a battery of potential drivers that can explain the volume of mobility and modal choice.

To assess the impact of the different determinants in our review, we have retained, for each driver, the maximum value of its explanatory potential as presented by the values of the standardised *Beta* coefficient. This coefficient explains the variation in distances travelled by car per standard deviation of the driver considered. The results are presented in Figure 4, which combine together 67 determinants of the built environment and the socio-economic characteristics of households. These values are considered only as an indication to estimate the importance of each driving factor by comparison. At first sight, it emerges that certain drivers have a variable impact based on the studies, and it is found that sometimes the estimate is negative and sometimes it is positive with the distances travelled by car. According to the socio-economic data panel, it seems clear that the cost of buying a car is more important than the price of fuel. Moreover, the size of households and the number of children per household seem to have a contrasting effect. This can be explained by the children's schooling and household occupation as well as the proximity of schools. In our review, car ownership contributes to a maximum of 22.4% of the vehicle kilometres travelled (VKT),

Table 1. Number of studies selected per country.

Country	Algeria	Belgium	Canada	China	Denmark	international	Norway	Netherlands	UK	USA
Number of studies	1	2	1	6	1	2	1	3	2	9

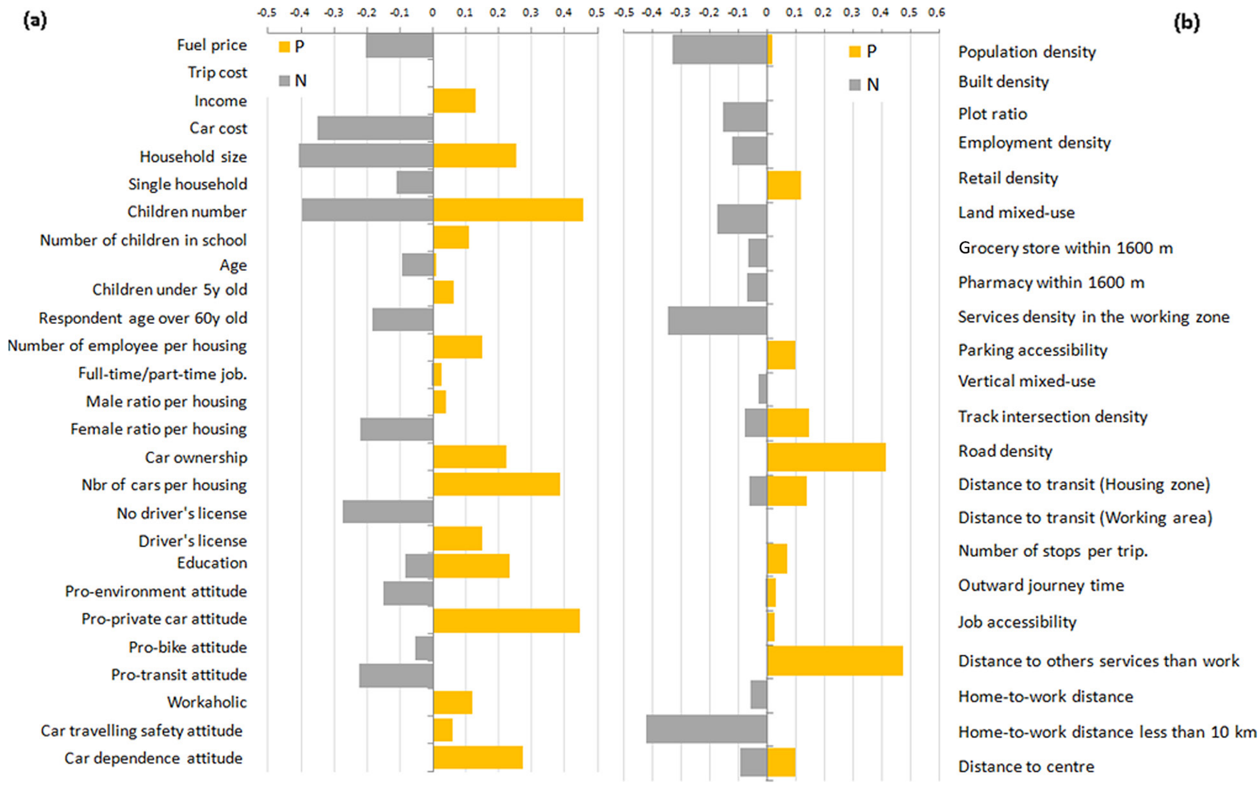

Fig. 4. Maximum values (*B* standardised) for the impact of the drivers related to: (a) – socio-economic characteristics of households, (b) – the built environment. P – positive; N – negative.
Source: own compilation.

while the number of cars per household explains up to 38.7% of the VKT.

The drivers of the built environment most moderating VKT are distance to work exceeding 10 km (−42.1%), population density (−33%), density of services in the work area (−34.5%) and diversity (−17.3%). And among the drivers encouraging the use of the car for travel are the density of roads as a proxy for accessibility by car (41.5%), and the distance to non-employment destinations (47.63%). Depending on the maxima of the effects of commuting drivers, the density of roads' intersections can have an impact that is more of an incentive than a disincentive (14% and −7%).

It is also worth noting that it is important to consider the both registers, the built environment and the socio-economic characteristics when modelling commuting because of the importance of the interaction between them. Manaugh et al. (2009) have performed two models. In the first one, they considered only the socio-economic characteristics of households and found that the explanatory power of the model performed is weak (R^2 = 0.06). But, when the socio-economic and built environment characteristics are considered in the same model, the explanatory power of the model rises up to 40%. It means that it is very important to consider the interaction between the two registers. In another study, Acker et al. (2010) found that all built environment variables are not statistically significant when they are considered alone except for density (−0.173). However, by introducing the socio-economic variables into the first model, the non-significant built environment variables in the first model become significant in the second model. This result highlights the importance of the interactions between the variables of socio-economic and the built environment.

The explanatory power in the models, when considering both the socio-economic and built environment drivers, varies significantly between 11.5% in China and 12.4% in the Netherlands (Feng et al. 2013), 20.1% (Acker et al. 2010) and 45.7% (Marique 2013) in Belgium to nearly 56.48% in Massachusetts (Calabrese et al. 2012). The difference given to the importance of one register compared to another is also shown and observed. Stead (2001, reported by Banister et al. 2007) explains that in the UK, socio-economic drivers are the most important drivers responsible for 23 to 55% of VKT, while the built environment is responsible for 27% of VKT. In another study, Ewing and Cervero (2002) in the United States found that the built environment is more significant than socio-economic drivers in explaining VKT and less significant in explaining trip frequencies and modal choice.

Based on the review of the literature, we note that the knowledge shaping commuting is established mainly in developed countries and the research gap seems to lie in the comparison of the results of our paper with the actual state of the knowledge. Following on these lines, we will focus on developing our method of analysis in order to be able to make a comparison of our results with those already obtained in developed countries. The conclusion of this work could respond to the hypothesis which underlies the possible transposition of knowledge structuring home-to-work mobility from studies established in developed countries to developing ones.

Method

We selected the municipality of Djelfa for our case study because the SNAT's (2030) orientations aim at the urbanisation of the highlands, and the study of the city of Djelfa could serve as a reference for future studies in the same geographical area. Also, the scale of our study area covers the main agglomeration area as shown in Figure 5.

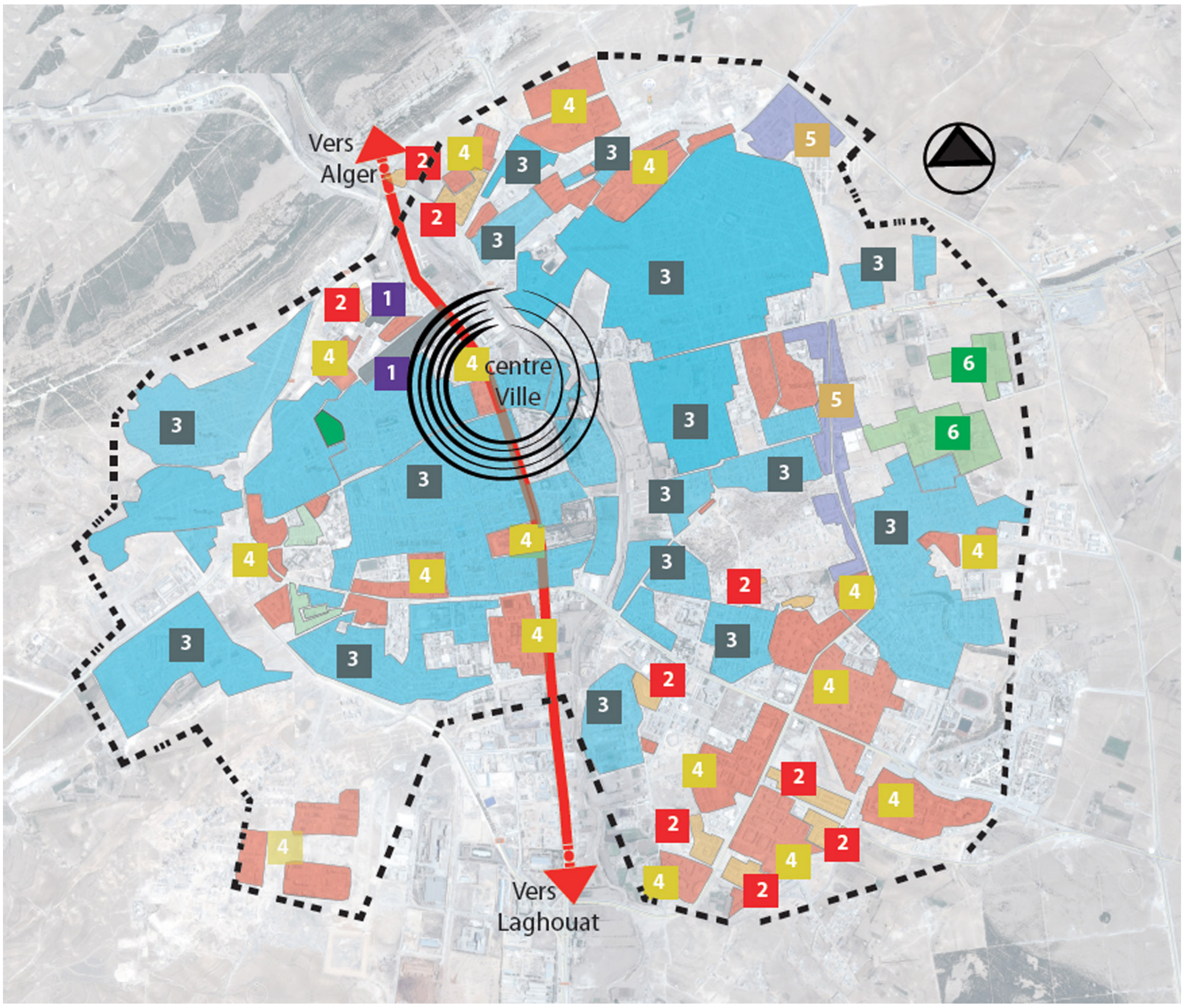

Fig. 5. Study area and types of housings in the municipality of Djelfa. 1 – Very compact individual housing, 2 – Identical individual housing, 3 – Individual housing of housing estate type, 4 – Discontinuous collective housing, 5 – High continuous collective housing, and 6 – Village housing. The discontinuous line represents the study area.
Source: own study.

Given the lack of data on the volume of commuting in the city of Djelfa, we chose to conduct a household survey while having a scanning and homogeneous distribution over the study area as a reference in order to assess the different cases of situations related to the built environment. We then designed a questionnaire aimed at collecting data related to mobility volumes, mode of travel and socio-economic characteristics of households and the built environment. The 67 potential drivers identified during the review of the scientific literature were adapted according to local conditions and we retained only 23 potential variables (Table 2). It should be noted that the city of Djelfa is located in Algeria, a developing country, and moreover not all the factors existing in the developed countries could be transposed to Algeria, for example: for the built environment, it is not common to see the variation in the price of energy or the quality of insulation of the buildings envelope because these variables are fixed over time; thus for socio-economic parameters, the ownership of dishwashers, dryers, or solar panels are absent variables in Algeria. Before performing the analysis, we adapted the 67 variables identified in the literature review to the context of the city of Djelfa based on the SMART criterion approach which limited the number of variables to 23.

The questionnaires were distributed through a network of interviewers composed of architects and students. Among the 700 questionnaires

Table 2. Descriptive statistics.

Variables	N	Type	Min	Max	AVG	Std dev
	Accessibility					
Outward journey time (min.)	175	Continuous	2	200	20.59	18.26
Home-to-work distance (m)	162	Continuous	50	18,000	2,206.91	1,966.96
Number of bus rotations	150	Continuous	0	3	1.20	0.556
	Density					
Plot ratio*	139	Continuous	0.17	1.00	0.59	0.32
Built density*	139	Continuous	0.60	3.20	2.02	0.74
	Design					
Distance to centre (m)*	148	Continuous	17.59	2,659.18	1,219.54	696.57
Distance from national road (m)*	151	Continuous	25.62	2,569.23	1,163.83	629.94
Average number of floors (*n*)*	139	Continuous	2.00	6.00	3.79	1.08
Block's area (m^2)*	139	Continuous	770	36,061	7,398.83	9,150.32
Housing type (1: collective, 2: individual)	184	Nominal	1	2	1.54	0.50
	Distance to public transit					
Distance to public transit (housing zone) (0: < 300, 4: > 1 km)	173	Ordinal	1.00	4.00	2.3237	0.98
Distance to public transit (work zone) (0: < 300, 4: > 1 km)	172	Ordinal	0.00	4.00	1.6919	0.97
Bus frequency	184	Continuous	0.00	5.00	2.4620	1.56
	Diversity					
Mixed use index (from 5 to 40)*	175	Continuous	12	36	24.23	5.38
	Households' socio-economic characteristics					
Household's average age*	42	Continuous	16.33	43.80	27.1681	8.44
Respondent age	120	Continuous	27	70	43.95	10.82
Round trip frequency	172	Continuous	1	4	1.66	0.51
Household's education level	46	Continuous	2.00	5.00	3.5230	0.77
Respondent's education level	174	Ordinal	0	4	3.26	1.06
Number of cars owned	184	Continuous	0	2	0.60	0.57
Profession (1: public, 2: liberal)	181	Nominal	1	3	1.19	0.52
Income (from 15,000 to +60,000 Da)	181	Ordinal	1	4	2.15	0.95
Occupancy rate per housing	139	Continuous	2	12	5.34	1.87
	Modal share					
Public transit (1: TC, 0: others)	184	Nominal	0.00	1.00	0.31	0.46
Car (1: vehicle, 0: others)	184	Nominal	0.00	1.00	0.26	0.44
Walking (1: MAP, 0: others)	184	Nominal	0.00	1.00	0.42	0.49

Source: own compilation.

distributed between April and May (2015), we received 300 with a return rate of 42% which is within the return rate between 15 and 40% observed in the literature review. The analysis of the questionnaires helped us to select 184 cases for our study. We were unable to use the other questionnaires because the respondents had not answered either one or both of the two mandatory questions related to housing and/or work location.

For our study, we designed a two-stage approach (Fig. 6): an exploratory stage using bivariate correlations and principal component analysis, and a second confirmatory stage using path analysis than a SEM because all the variables are observable. The first analysis step will allow us to hypothesise causal pathways between variables and the second step allows us to confirm or invalidate the hypotheses made. The path analysis is a statistical approach which avoids multicollinearity contrary to linear regression analysis (Chen, Lei 2017) and summarise the covariance with a high degree of statistical robustness (Chen et al. 2013), while allowing decomposing the causality in terms of the direct and indirect effect by revealing the interactions between driving factors in the same time. This method is a graphical path-based approach representing a set of hypotheses which could explain the relationship between factors of the phenomenon observed, and it is based on factor analysis and regression techniques. To validate a path analysis, a set of the following indices is required: (1) Root mean square error of approximation (RMSE) has to be smaller than 0.06 or 0.08 with a confidence interval (Schreiber et al. 2006; Hooper et al. 2008), (2) Normal fit index (NFI) has to be > 0.95 (Hu, Bentler 1999), and (3) Comparative fit index (CFI) has to be close to or > 0.95 (Schreiber et al. 2006; Lacobucci 2010) or > 0.80 (Hooper et al. 2008). Once the model fits these required indices, it is considered a good one and we can estimate the total, direct and indirect effect of each factor. The sample size required performing a path analysis or a SEM is 10 times the amount of the parameters considered in the model (Kline 1998).

Results and discussion

Data description

Before performing our analysis, the data obtained from our survey (2015) are compared with the census data (2008) and it is observed that our data fits the census data (Fig. 7). The questionnaires distributed enabled us to establish a database that can be used as a basis for characterising commuting in the municipality of Djelfa and Table 2 includes a description of the data collected from the questionnaire. Table 2 contains the socio-economic characteristics of households and the built environment data organised based on the 5D nomenclature (Density, Diversity, Distance to transit and Destination access) developed by Ewing and Cervero (2010).

Figure 8 shows the mesh obtained from home-to-work trips and in that two main mobility trends can be observed: axial mobility from north-east

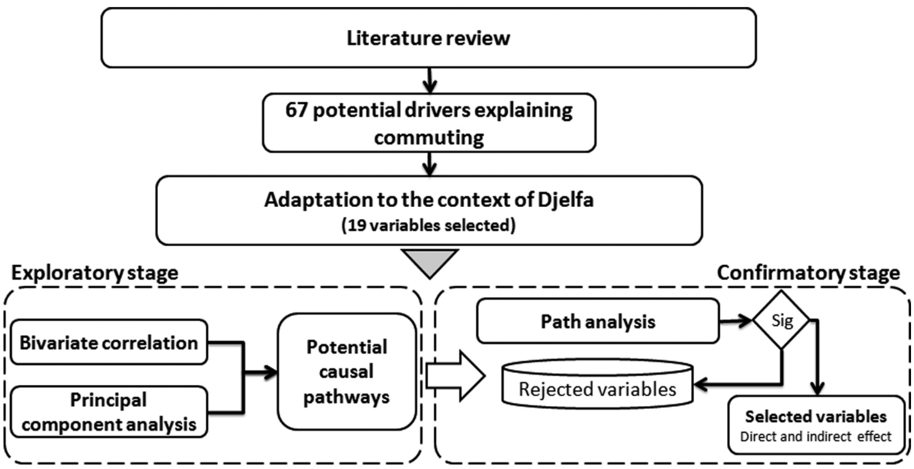

Fig. 6. Method framework.
Source: own study.

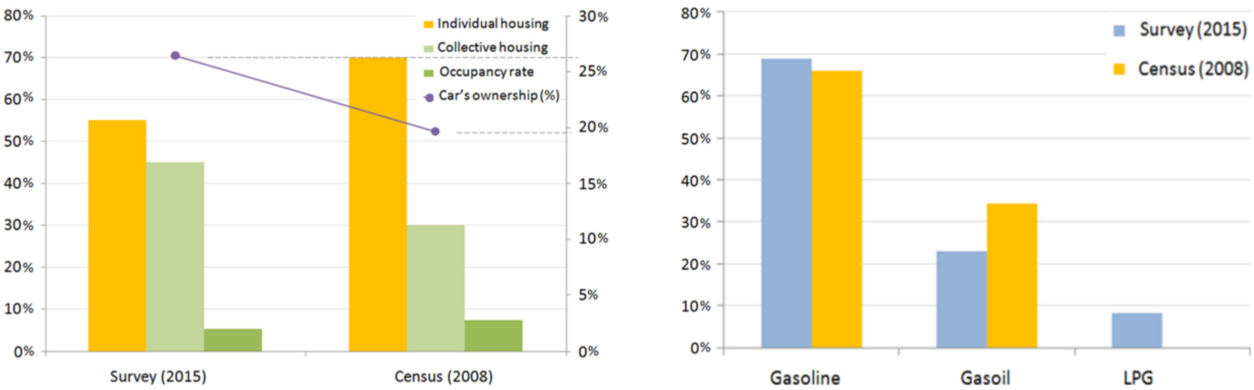

Fig. 7. Comparison between survey's and census data.
Source: own compilation.

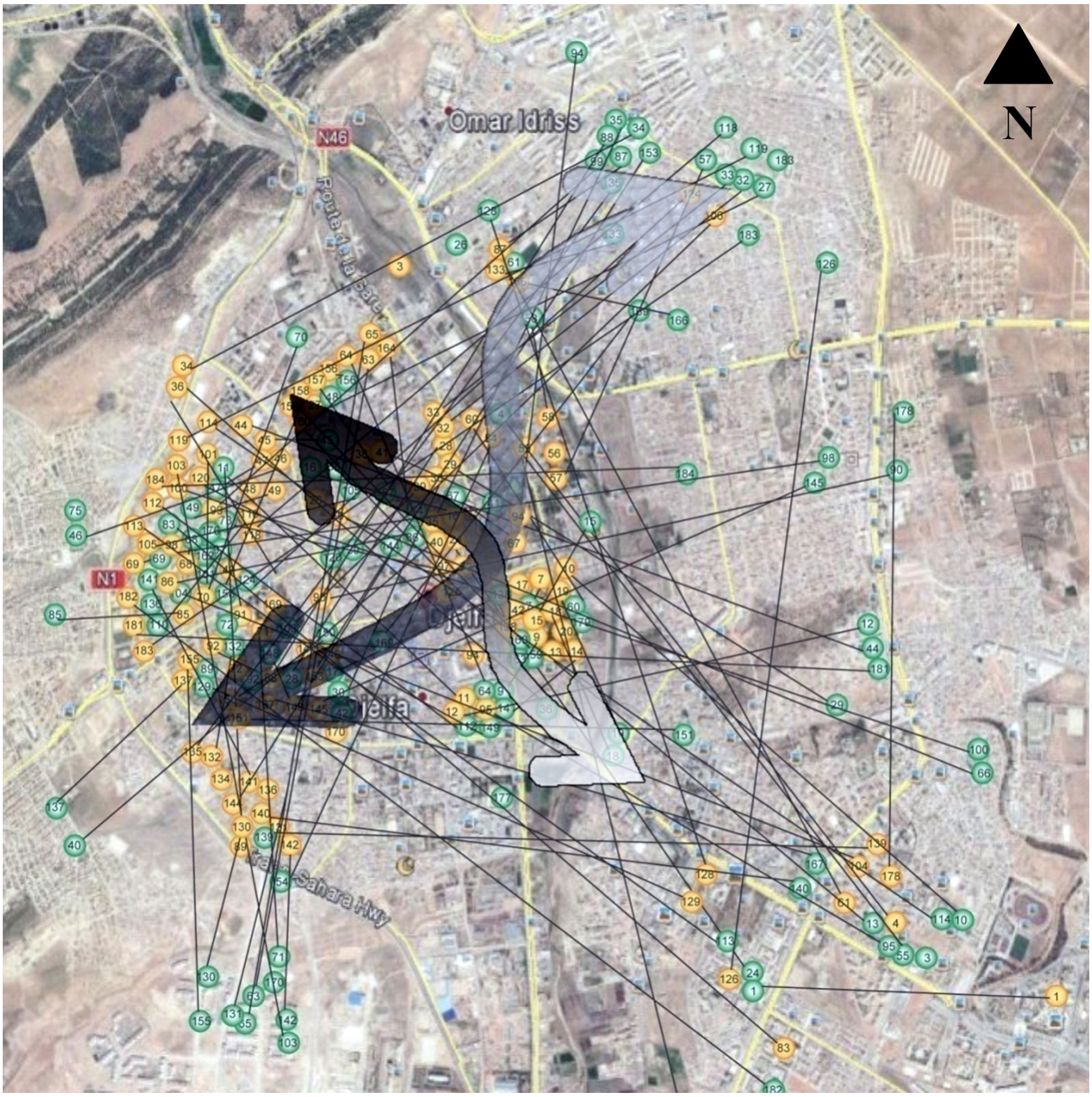

Fig. 8. Mesh representing home-to-work trips. Green colour – homes; yellow colour – workplaces; grey arrows – the main directions for commuting. Markings are carried out in Google earth (2015).
Source: own study.

to south-west (grey arrows), and along the north-west and south-east axis (grey arrows). Further, the national road dividing the city to east and west parts and the city centre seems to be important in structuring commuting. Also, the density of employment of our sample is concentrated in and around the centre. New extensions are less dense in terms of functions.

Bivariate correlation analysis

The results of Pearson's bivariate correlation are presented in Table 3.

Through the bivariate correlation analysis, the explanatory drivers that could impact the modal choice of home-to-work trips directly and indirectly are identified (Fig. 9).

Table 3. Results of Pearson's bivariate correlation.

	Car		Walking		Public transit	
	Correlation	Sig	Correlation	Sig.	Correlation	Sig
	Accessibility					
Home-to-work distance (m)	0.247**	0.002	−0.407**	0.000	0.214**	0.006
Outward journey time (min.)	−0.100	0.187	−0.308**	0.000	0.431**	0.000
Number of bus rotations	0.128	0.118	−0.329**	0.000	0.237**	0.004
	Density					
Built density (COS)	−0.071	0.408	0.087	0.306	−0.026	0.757
Plot ratio (CES)	−0.037	0.662	0.082	0.336	−0.052	0.546
	Design					
Housing type	0.021	0.802	0.035	0.673	−0.055	0.501
Distance from national road	0.205*	0.011	−0.287**	0.000	0.111	0.175
Distance to centre	0.149	0.072	−0.336**	0.000	0.212**	0.010
Block's area	0.140	0.100	−0.280**	0.001	0.164	0.054
Average number of floors	0.047	0.584	−0.119	0.162	0.082	0.339
	Diversity					
Mixed use index	−0.069	0.362	0.126	0.096	−0.064	0.399
	Distance to public transit					
Distance to public transit (housing)	−0.125	0.100	0.008	0.914	0.099	0.194
Bus frequency	−0.070	0.343	0.113	0.126	−0.051	0.492
Distance to public transit (work zone)	0.045	0.559	−0.010	0.898	−0.031	0.687
	Households' socio-economic characteristics					
Profession	0.198**	0.008	−0.115	0.123	−0.060	0.421
Respondent age	−0.086	0.349	0.158	0.084	−0.079	0.388
Respondent's education level	−0.004	0.962	−0.037	0.628	0.079	0.302
Income	0.204**	0.006	−0.086	0.247	−0.124	0.097
Number of cars owned	0.459**	0.000	−0.182*	0.013	−0.267**	0.000
Occupancy rate per housing	−0.086	0.310	0.077	0.368	−0.004	0.967

Source: own compilation.
*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
n = 184.

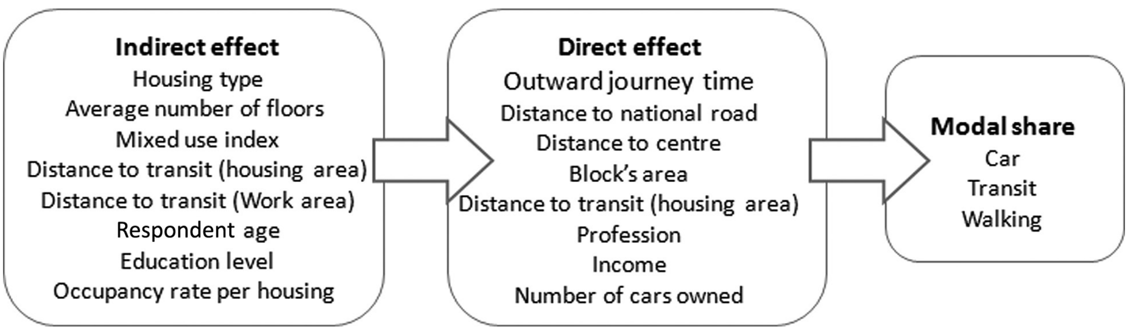

Fig. 9. Hypothetical causal pathways between variables and modal share.
Source: own compilation.

Principal component analysis

We have performed two principal component analyses, one for the modal share of the car and the other for the modal share of walking and transit, since the threshold of the KMO index is not reached (0.45) for considering both of them. Whereas the KMO for the PCA for the modal share of car is 0.59 and that for transit and walking considered together is 0.572.

Principal component analysis for the modal share of the car

The values of all the communalities of the explanatory variables after extraction are > 0.32, which is the threshold value above which a variable has to be excluded from the PCA (Tabachnick, Fidell 2001). The variance explained by the PCA is 77%.

From the projection of the explanatory variables in the PCA on Table 4, the projection of the modal share of the car on three axes (columns of the Table) of the PCA, axis 2, 3 and 5 shows that the values are > 0.32. All variables projected on these three axes are variables which potentially have a direct effect on the VKT. The other variables projected on axes; 1, 4, 6 and 7 may have an indirect effect on the modal share of the car. This PCA allows carrying out the potential causal pathways explaining the VKT (Fig. 10).

Principal component analysis for the modal share of walking and transit

The variance of the PCA for the modal share of walking and transit is 75% and all the communalities of the variables after extraction are well above the threshold value of 0.32. The explanatory variables do form a system. The projection of the variables on the first three axes of the PCA clearly shows a distinction between the modal share of transit and walking, with the two variables projected in a conflicting manner in the PCA space. This can be interpreted by the fact that the variables encouraging transit tend to reduce the modal share of walking. The full projection of the variables in PCA space consists of seven axes, over which all variables are projected. The modal share of walking is projected on axis 2 and transit on axis 7 (Table 5).

Based on the projection of the variables in the PCA, we can distinguish the explanatory variables of the modal share of walking and transit.

Table 4. Projection of variables in PCA space.

	Axes						
	1	2	3	4	5	6	7
Home-to-work distance	0.253	**0.651**	0.074	0.036	−0.263	0.131	**−0.394**
Outward journey time	0.259	0.181	**−0.391**	**0.505**	0.218	**−0.499**	**−**0.085
Number of bus rotations	0.168	**0.536**	**−0.396**	0.274	0.096	−0.298	**−0.495**
Built density (COS)	**−0.833**	0.295	0.187	0.056	−0.158	−0.183	0.075
Plot ratio (CES)	**−0.889**	0.295	0.145	0.113	−0.110	−0.193	0.083
Housing type	**−0.829**	0.258	0.246	0.212	0.021	−0.004	0.153
Distance from national road	**0.436**	**0.597**	0.174	0.274	−0.304	0.220	0.222
Distance to centre	**0.677**	**0.450**	0.081	0.245	−0.177	0.211	0.276
Block's area	**0.709**	−0.057	0.018	0.214	−0.053	−0.065	0.237
Average number of floors	**0.870**	−0.115	−0.057	−0.004	−0.041	0.253	−0.093
Mixed use index	**0.452**	**−0.424**	0.283	−0.226	0.074	−0.292	0.021
Distance to public transit (housing)	−0.297	0.202	**−0.629**	**0.344**	0.098	0.237	0.055
Bus frequency	**−0.459**	0.063	−0.197	0.165	0.291	**0.571**	0.248
Distance to public transit (work zone)	0.131	−0.044	**−0.395**	0.194	**0.707**	0.015	0.165
Profession	−0.218	−0.182	−0.114	−0.279	0.270	0.263	**−0.352**
Respondent age	−0.065	**−0.596**	−0.026	**0.654**	−0.217	0.119	−0.025
Respondent's education level	0.287	0.471	−0.041	−0.318	0.148	−0.292	**0.465**
Income	0.096	−0.308	**0.483**	**0.596**	0.274	−0.180	0.201
Number of cars owned	0.032	0.234	**0.616**	0.161	**0.532**	0.070	−0.204
Occupancy rate per housing	−0.079	**−0.327**	0.165	**0.551**	**−0.331**	0.016	−0.230
Car's modal share	0.194	**0.334**	**0.633**	0.059	**0.398**	0.177	−0.232

Extraction method: Principal component analysis.
Source: own compilation.

Those values projected on axes 2 and 7 of the PCA, respectively, show a potentially direct impact on the modal share of walking and transit. The other variables, on the other hand, have potentially an indirect impact on commuting modal choice. Also, some variables may have both a direct and indirect effect moderated by other variables. The variables are classified in Figure 11 on the basis of their hypothetical effect, may be either direct or indirect.

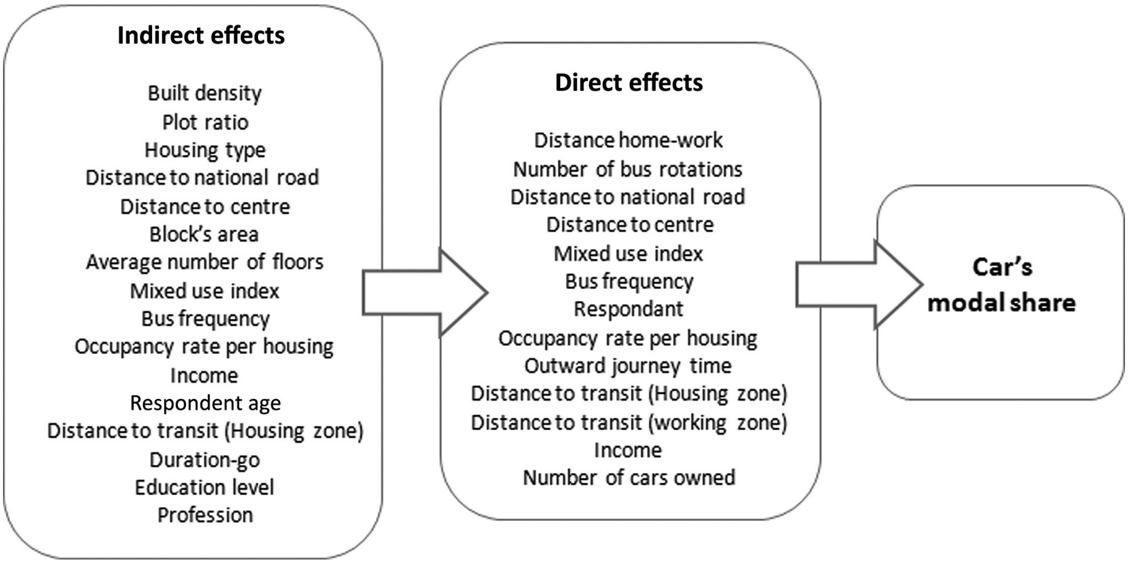

Fig. 10. Hypothetical causal pathways between variables and the modal share of the car.
Source: own compilation.

Table 5. Projection of explanatory variables for the modal share of walking and transit.

	Axes						
	1	2	3	4	5	6	7
Home-to-work distance	−0.019	**0.787**	−0.122	−0.079	0.198	−0.252	−0.022
Outward journey time	−0.113	0.032	0.058	0.046	**0.837**	0.305	−0.062
Number of bus rotations	−0.018	0.318	−0.114	0.053	**0.827**	−0.231	0.002
Built density	**0.935**	0.027	−0.003	0.043	−0.061	−0.022	−0.020
Plot ratio	**0.974**	−0.022	0.014	0.109	−0.012	−0.010	−0.005
Housing type	**0.885**	0.016	0.088	0.239	−0.103	0.076	0.141
Distance from national road	−0.167	**0.779**	−0.135	0.146	−0.067	0.308	0.053
Distance to centre	**−0.447**	**0.676**	−0.160	0.133	−0.017	**0.394**	0.044
Block's area	**−0.576**	0.201	0.029	−0.114	0.079	**0.479**	−0.063
Average number of floors	**−0.874**	0.283	0.035	−0.085	−0.012	0.028	0.017
Mixed use index	**−0.406**	−0.220	0.007	**−0.565**	−0.095	0.189	0.128
Distance to public transit (housing)	0.147	−0.003	0.068	**0.715**	**0.324**	−0.075	−0.273
Bus frequency	0.228	−0.092	0.045	**0.773**	−0.193	−0.062	0.124
Distance to public transit (working zone)	−0.279	−0.391	−0.170	**0.478**	**0.403**	0.177	0.244
Profession	−0.009	−0.220	0.024	0.093	−0.037	**−0.524**	0.122
Respondent age	−0.091	−0.173	**0.855**	0.141	−0.026	0.201	−0.119
Respondent's education level	−0.046	0.141	**−0.733**	−0.085	0.090	0.399	−0.075
Income	0.001	−0.111	**0.470**	−0.102	0.058	**0.609**	**0.470**
Number of cars owned	0.098	0.213	0.004	−0.077	0.069	0.019	**0.880**
Occupancy rate per housing	0.070	0.100	**0.752**	−0.094	0.022	0.063	−0.039
Walking's modal share	0.009	**−0.724**	−0.100	0.132	−0.198	−0.238	0.025
Transit's modal share	0.018	0.382	0.179	−0.021	0.221	0.245	**−0.695**

Extraction method: principal component analysis.
Source: own compilation.

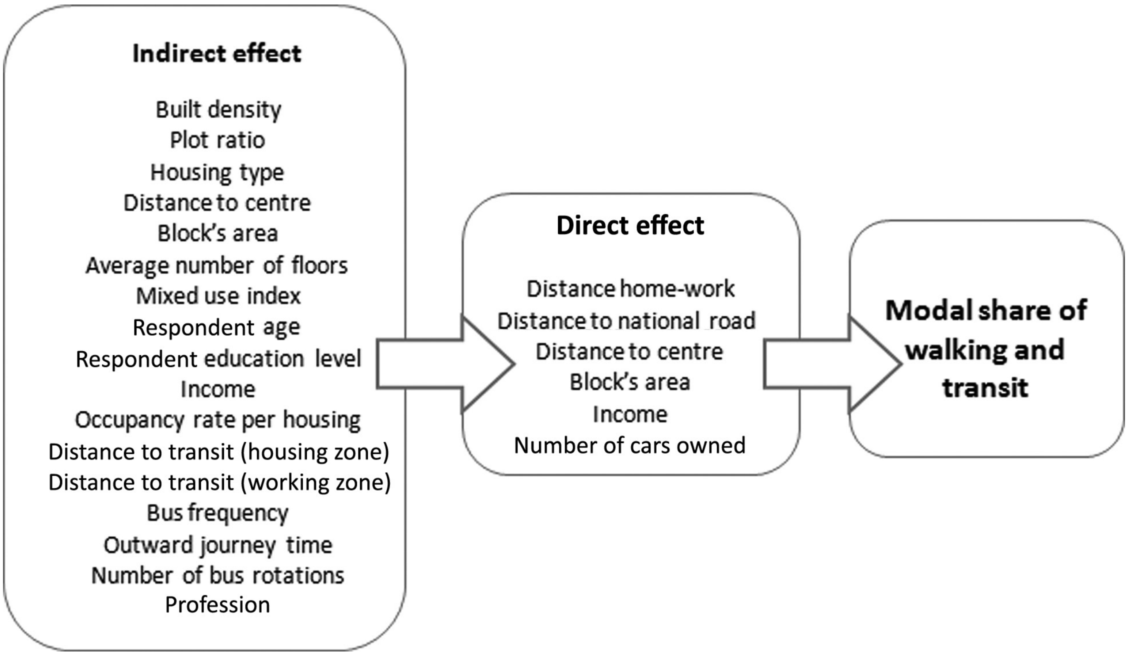

Fig. 11. Hypothetical causal pathways between variables and the modal share of walking and transit.
Source: own compilation.

Path analysis

Based on the hypothetical causal pathways obtained from the first stage of bivariate correlation analysis and principal component analyses, the total of three path analysis models was carried out. Table 6 shows that all the conditions for fitting the models are verified.

Figures 12–14 show the three models that explain the modal share of walking, transit and cars. Every driving factor has a direct or indirect effect on the modal share.

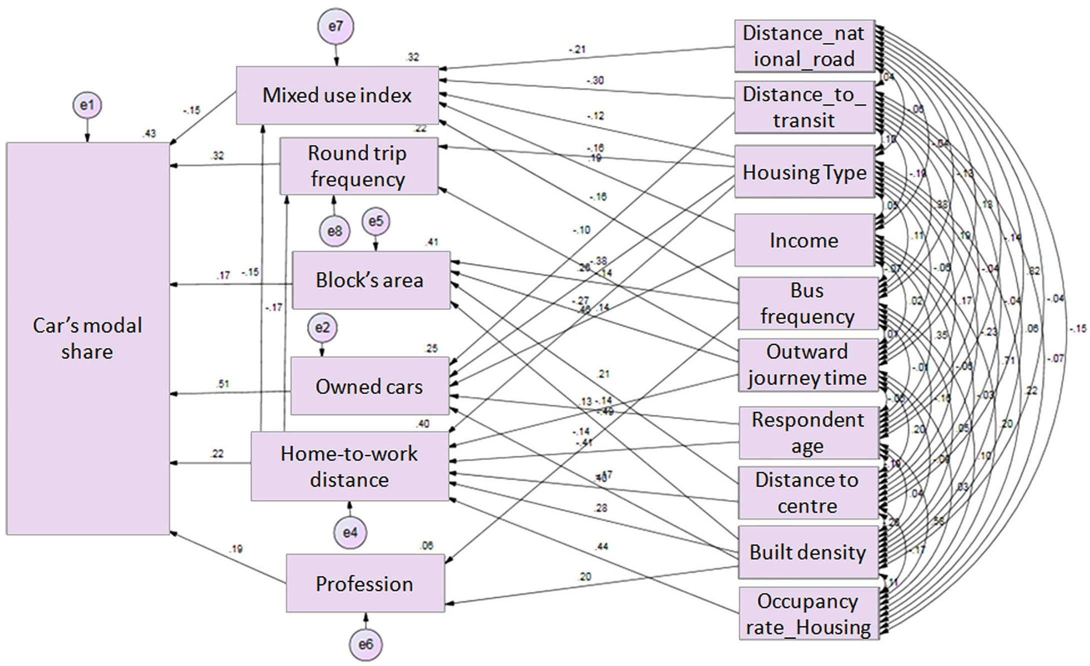

Fig. 12. Path analysis of the modal share of the car.
Source: own compilation.

Table 6. Models fit indices.

Modal share	*df*	χ2	Probability level (> 0.05)	RMSE (< 0.06 or 0.08)**	NFI (> 0.9 or > 0.95)***	CFI (> or closer to 0.95)***
Car	59	39.35	0.977	0.000	0.954	1.000
Transit	34	21.20	0.957	0.000	0.964	1.000
Walking	34	28.03	0.755	0.000	0.949	1.000

*Schreiber et al. (2006) and Hooper et al. (2008).
**Hox (2000), Huand Bentler (1999).
***Schreiber et al. (2006).
Source: own compilation.

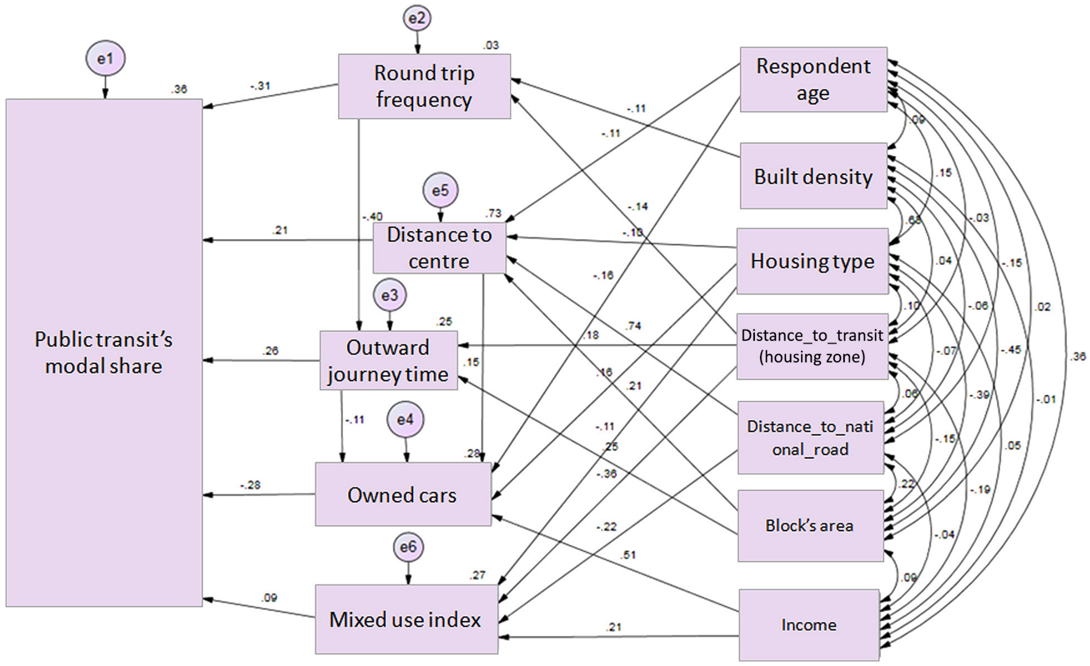

Fig. 13. Path analysis of the modal share of public transit.
Source: own compilation.

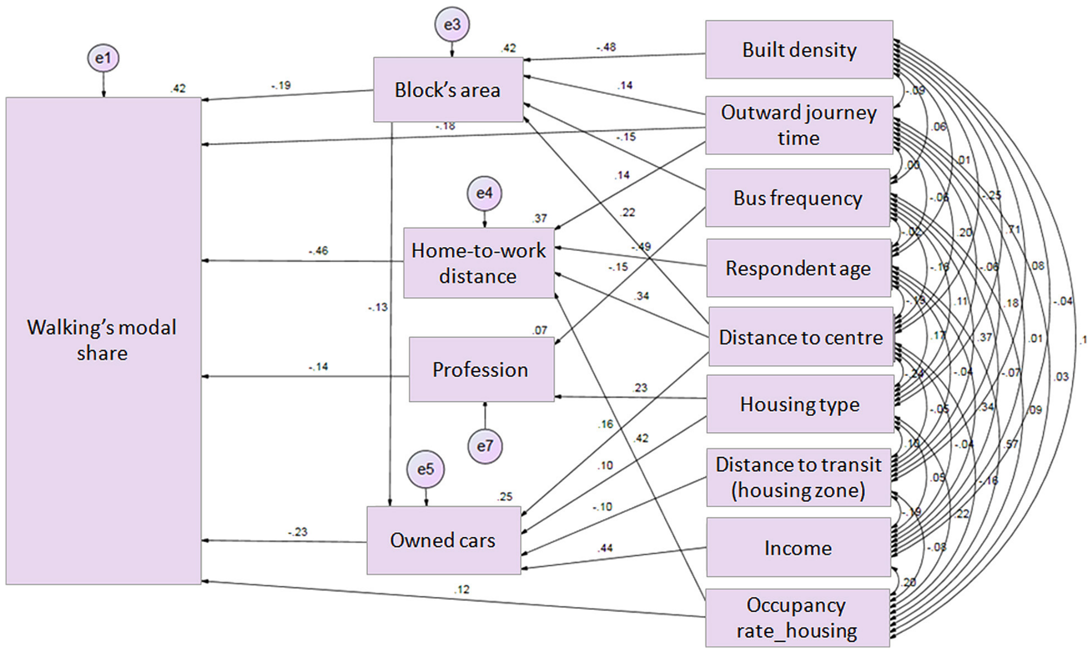

Fig. 14. Path analysis of the modal share of walking.
Source: own compilation.

Discussion

In order to summarise the results obtained from the analysis of Figures 12–14, Figure 15 is presented incorporating all the significant variables with their total effect and per unit of variation.

From the register of the built environment, 10 significant variables were identified. The mixed-use index has a positive effect by encouraging the modal share of public transit by 3.14% while reducing the modal share of private cars by 4.80%. Feng et al. (2013) have found a similar effect of the mixed use index on the modal share of the use of private car in their studies in which there is a reduction of 7.4% in China and 4% in the Netherlands. However, Calabrese et al. (2012), Ding et al. (2017), Holden and Norland (2005) and Zhang et al. (2014) did not find a statistically significant effect of the mixed-use index on the modal share. When analysing further, the block's area reduces walking by 8.66% because the largest blocks are mainly located in the new extensions of the city and are less dense with a low rate of land mixed-use. The surface area of the blocks encourages private car use and the public transit use by 8.07% and 5.38% respectively.

The distance between home and working zone has a low effect in encouraging the use of private cars (4.16%). A similar effect was found by Chen et al. (2007) in their study. The number of bus stops grows with the distance to the working zone and it increases the modal share of private cars by 7.1%. Also, in our study, we found that the frequency of buses in the residential area encourages walking mainly by 1.46%. This conclusion may seem contradictory, but it turns out that

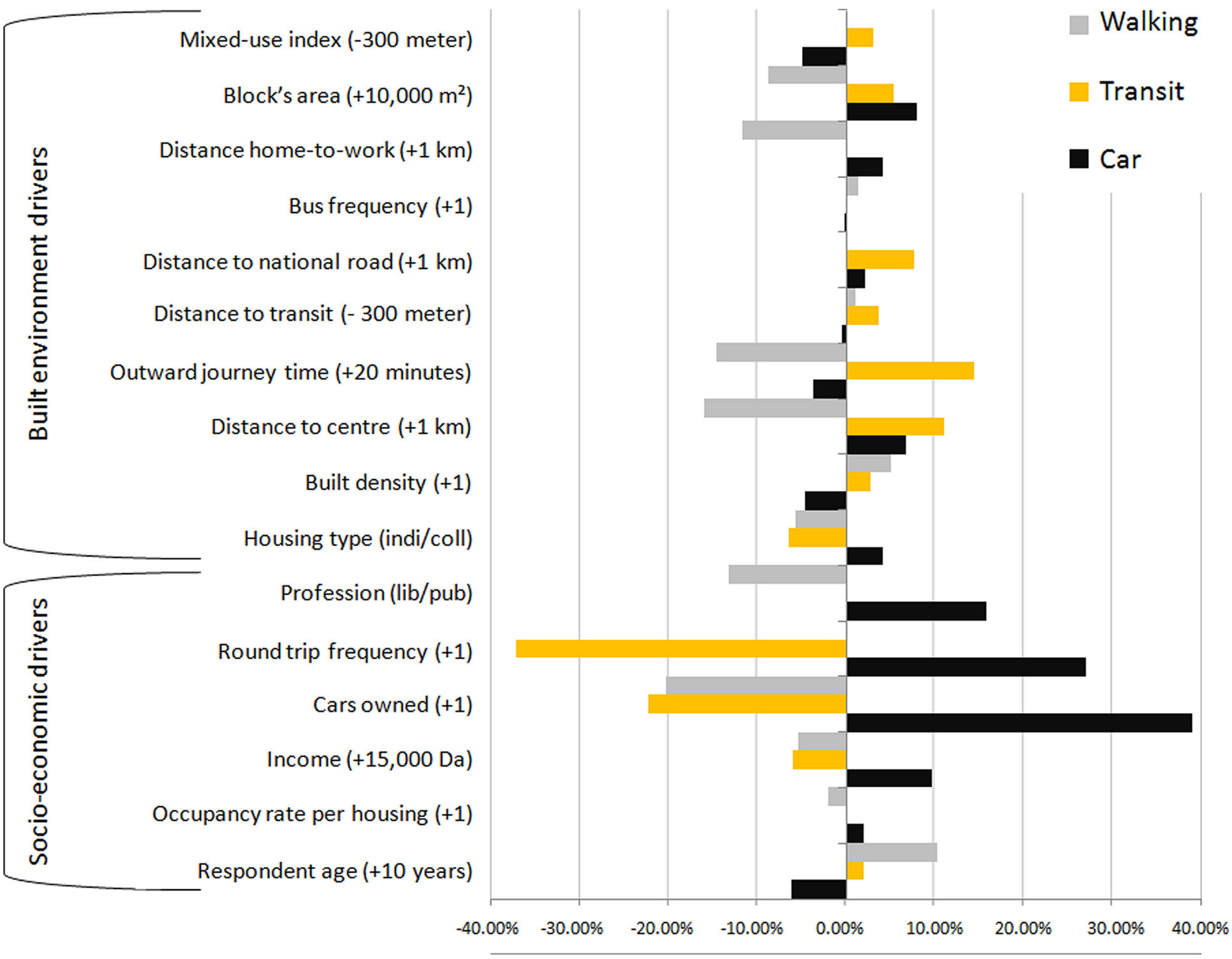

Fig. 15. Synthesis of the effects of the built environment and socio-economic drivers in shaping the modal share of the car, public transit and walking.
Source: own compilation.

the highest frequency of buses is concentrated in the central zone (the main employment pole) of the city compared to the periphery.

The distance to public transit reduces the modal choice of private cars slightly and encourages walking more by 1.20% for every additional km. Most studies have found that the distance to transit is positively correlated with motorised travel, which means the greater the distance, the greater the use of the car for travel. Acker and Witlox (2010), Calabrese et al. (2012), Khan et al. (2014) and Ding et al. (2017) found that doubling the distance to transit causes the distances travelled by car to increase by 3.4%, 3.04%, 13.2% and 4.7% respectively. We have also found that the distance between housings and national road n01 encourages the use of public transit by 7.66% and private cars and walking to a lesser extent. National road n01 divides the city into east and west and thus provide a link between the two parts. Further, most of the buses passes through this road which explains the increase in the use of public transit in the nearest areas to the national road. The distance to national road n01 has a higher impact on the modal share than the distance to transit since more buses move around this road frequently and with a high functional diversity.

Outward journey time is a more important variable than home-to-work distance since it reduces walking by almost 14.47%. Further, it also encourages the modal choice of public transit by 14.5% and reduces the modal share of the car by 3.56% for every additional 20 minutes of travel time. Pan et al. (2009) found that the choice of the car as a means of travel increases by 1.03 times for every additional minute in the journey time, while at the New York region, Chen et al. (2007) found a relatively weak impact (−0.32%) of trip duration on car use in trips. But, when chains of trips instead of a single trip are considered, Ma et al. (2014) found that the people tend to make fewer trips (−0.529) in China when the duration of the single trip is important.

The distance to the centre of the city is also an important variable in shaping the modal choice, as the centre is characterised by its high land mixed-use and its central position gives it the role of a connecting point between the different parts of the city. So, it reduces walking by almost 16%, and it encourages the use of public transit and private cars by 11.8% and 6.88% respectively for each additional kilometre. Acker and Witlox (2010) found that the distance to the business centre of the city of Ghent, Belgium, is associated with a low increase (1.3%) in the distances travelled by car. In the Netherlands, Holden and Norland (2005) found that for every additional kilometre to the centre of Oslo, travel energy consumption will increase by 108kWh/person per year. Further, Næss (2010) also found that distance to the centre is positively associated with the energy consumption generated by motorised travel (9.8%).

The type of housing has a clear impact on the modal choice. When compared to the collective housing, the individual type is associated with more car use (+4.22%), low use of walking (−5.64%) and public transit (−6.44%). This result could be explained by the difference in terms of the built density and *ipso facto*, the density of employment. In fact, in this study, the built density has a reducing effect of 4.6% on the modal share of cars and encourages public transit and walking by 2.75% and 5.08% respectively for every +1 increase in the built density. Brownstone and Golob (2008) found that in California, a household residing in an urban area would travel 1,171 miles less annually than the same household residing in a less dense area of 1,000 homes. The authors explain this difference is due to a lower car ownership rate in dense areas compared to less dense areas. In another study, Holden and Norland (2005) found no statistically significant correlation between housing density and energy consumption per person in Norway for every day car travel. Acker and Witlox (2010) argue that all determinants of the built environment are statistically insignificant except for the built-up index, which is negatively correlated with car use (−0.699) and car ownership (−0.038).

In the register of socio-economic variables, six driving factors are identified. The number of cars is the most important variable with an encouraging effect of 39% on car use in commuting, and a reducing effect of 20% and 22% on the modal share of walking and public transit respectively. The car ownership increases also the round-trip frequency. In fact, because of more round-trip frequency the car use increases by 27% and the modal choice of public transit reduces by 37%. Regarding the influence of car ownership on mobility, Chen et al. (2007), Acker and Witlox (2010) found that car ownership at least per household is associated with 10.2% and 22.4% of distances travelled by car. While Holden and Norland (2005), Næss (2010) and Jahanshahi et al. (2015) found that car ownership would account for an additional 1,727 kWh/person, 5.65 km and 4 miles/week of mobility respectively. Similarly, Ding et al. (2017) and Zhang et al. (2014) found that car ownership would reduce the modal share of public transport and walking by 9.74% and increase the use of cars for travel by 17.7 times respectively.

Similarly to the effects of number of cars, the income tends to encourage motorised commuting by almost 10%, while reducing the modal share of public transit and walking by almost 6% and 5.5% respectively for every 15,000 Da (113 Euro, 2015 exchange rate) additional income. In a study on Belgium, Acker and Witlox (2010) found that an income above 3.1K€ is responsible for almost 13% of motorised mobility, while in Seattle, Khan et al. (2014) and Dieleman et al. (2002) in the Netherlands found that income has an impact of 6.21% and 2.9% respectively.

Further, the profession is considered as a variable based on the relation to the sector of attachment. Liberals tend to move almost 16% more to the workplace by car and to walk less by up to 13.2% compared to the public sector employees. This is due to the higher income of liberals than those working in the public sector.

The occupancy rate per housing has an encouraging effect for all modal choices, but high on walking. But, household size has been negatively correlated with motorised mobility by most studies. Cervero and Radisch (1995) found that household size is related to the use of non-car means of transport (transit, bicycle and walking) which is around 30.67%. Also, Ding et al. (2017) from a study on Baltimore and Pan et al. (2009) on China found that the determinant household size reduces the modal share of car use by 0.561 times compared to public transit. Ma et al. (2014) found a negative correlation between household size and chain travel (−6.3%). While in Seattle, Khan et al. (2014) found that household size positively impacts the distances travelled by car by up to 25%. The authors explain this trend by the presence of infants and children without a driving licence in the households. Some researchers have found no statistically significant relation between the household size and the use of the car (Chen et al. 2007; Manaugh et al. 2009).

Finally, the age of the respondent affects modal choice by reducing the modal share of cars by up to 6.02% and increasing the walking and public transit by up to 10.33% and 2% respectively for every additional ten years to the respondent's age. This result could be explained by the fact that older people live in or close to the centre of the city where the density of employment is higher than in the new urban extensions. The age of the respondent is negatively correlated with the car use in most studies. Its impact on motorised mobility varies from –6.4% in Belgium (Acker, Witlox 2010) to –9.4% in California (Handy et al. 2005). In Montreal, Manaugh et al. (2009) found that older people tend to live closer to their workplaces. Also, Chen et al. (2007) found a weak positive correlation with car use (+1%) in New York. The authors clarify that this relation is due to the fact that the older people tend to use cars more than younger people, as car ownership is higher among the older people. Though, Holden and Norland (2005) found that age does not have a statistically significant effect on travelling by car in Oslo.

The review of the 16 driving factors enabled us to realise the important effect that socio-economic characteristics play in shaping the modal choice of home-to-work trips, particularly with income and the number of cars. Also, it emerges from this study that there is a clear difference in the quality of the built environment between the centre of the city and its periphery, which is expanding in response only to the housing demand. The resulting volume of motorised commuting is accentuated by several parameters: low functional diversity, low built density, large distance to the centre, large distance to the national road, low bus frequency and the importance of almost monofunctional and large blocks. These factors reduce the modal share of walking and public transit, and encourage more motorised commuting.

Conclusion

This paper explored the role of the built environment and the households' socio-economic characteristics in shaping the modal share of commuting in the city of Djelfa in order to identify and analyse the most important driving factors. To perform this analysis, we used a household survey conducted through closed questionnaires, from which 16 variables are identified that could explain the modal shares of the means of commuting, namely private car, public transport and walking. Each modal share was explored under two stages; (i) an exploratory stage conducted through bivariate correlation analysis and principal component analysis to explore the possible pathways that could explain the commuting in the city of Djelfa; and (ii) a confirmatory stage conducted through a path-analysis-based approach. This latter allows identifying the direct and indirect effects that the driving factors might have on modal choice. At this stage, it appears that the urban form as a physical container has an important influence on the modal share of commuting, however, the socio-economic characteristics of households play a predominant role in determining the modal choice and the volume of motorised commuting and that it would be prudent for city designers and decision-makers alike to take decisions on improving the built environment in current and future urbanisation areas based on built density, diversity of the land use and the public transit accessibility in order to reduce the use of private cars and *ipso facto* reduce the energy resulting in low greenhouse gas emissions.

Finally, the results obtained are similar to the results of studies in developed countries, and the difference in results is mainly related to households' lifestyle. So, we can conclude that the current state of knowledge acquired in developed countries can be used in developing countries. Also, it would be advisable to include other type of mobility such as mobility for shopping and leisure in the future research.

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Appendix

Table A1. Presentation of the papers chosen for the literature review.

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type			Drivers		Explanatory power of modal
							C	S	L	SE	BE	
Acker and Witlox (2010)	Belgium	2000–2001	Survey on behaviour of travellers in Ghent on people aged 18 and over	City	Structural equation modelling	2,500 households	X	X	X	X	X	R^2 = 20.1%
Breheny (1995)	Wales, UK	1961–1991	Aggregated data from Ecotec project (1993)	National	Interpolation from data from Ecotec project (1993)	Ecotec project sample (1993)	X	X	X		X	–
Brownstone and Golob (2008)	California, USA	2001	National Household Transportation Survey. Aggregate data	National	Structural equation modelling	2,079 households	X	X	X	X	X	R^2 = 0.37 and 0.42
Calabrese et al. (2012)	Massachusetts, USA	2011	Deducted by detecting signal of mobile phones carried out by AirSag	Metropolitan area	Multiple linear regression	1,101 households	X	X	X	X	X	R^2 = 49.40% and 56.48%
Newman and Kenworthy (1989)	32 cities of different countries	1980	Collection of fuel consumption data and calculation of density excluding rural areas. Urban planning agency of different countries. Aggregate data	City	Bivariate correlation analysis	32 cities	X	X	X	X	X	/
Cervero and Murakami (2010)	USA	2003	Data collected from Highway Statistics. Department of Commerce	National	Structural equation modelling	370 urban areas	X	X	X		X	CFI (>0:900) 0.969 NFI (>0:950) 0.961 NNFI (>0:900) 0.942
Cervero and Radisch (1995)	USA	1990–1991	Bay Area Travel questionnaire survey	Neighbourhood	Binary logistic regression	2 neighbourhoods: 620 households for non-commuting and 840 households for commuting	X	X	X	X	X	Pseudo R^2 = 0.29, Predicted cases = 88.6%
Chen et al. (2007)	NY, USA	1997/1998	Household survey	Metropolitan area	Structural equation modelling	2,089 trips	X			X	X	R^2 = 0.45 and 0.58
Dargay (2004)	UK	1970–1995	Survey of family spending	National	Semi-logistic regression	256 pseudo panels	X	X	X	X	X	R^2 = 0.989

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type			Drivers		Explanatory power of modal
							C	S	L	SE	BE	
Dieleman et al. (2002)	Netherlands	1996	National Mobility Survey in Netherlands	National	Multinomial logistic regression	70,000 households	X	X	X	X	X	$R^2 = 0.31$
Ding et al. (2017)	Baltimore, USA	2001	Household survey	Metropolitan area	Structural equation modelling	3,519 households	X			X	X	/
Feng et al. (2013)	China and Netherlands	2008	Household survey on mobility in both countries	City	Multiple linear regression	2,989 respondents for 10 districts in China and 1,322 respondents for Randstad	X	X	X	X	X	China: $R^2 = 0.115$ Randstad: $R^2 = 0.124$
Handy et al. (2005)	California,USA	2003	e-mail questionnaire carried out on 8 neighbourhoods	District in metropolitan area	Linear regression	1,466 respondents				X	X	$R^2 = 0.16$ R^2 adjusted = 154
Holden and Norland (2005)	Oslo, Norway	2003	Questionnaire distributed by mail	Regional	Linear regression	650 for daily trips, 778 for leisure travel, and <100 respondents per zone (eight zones selected for the study)	X		X	X	X	$R^2 = 0.231$ for commuting
Karathodorou et al. (2010)	42 countries	1995	Millennium Cities Database for Sustainable Transport (1999) for 100 countries and car occupancy from Mobility in Cities database (2006)	Cities	Linear regression	84 cities	X		X	X	X	$R^2 = 0.61$
Khan et al. (2014)	Seattle, USA	2006	Questionnaire/Puget Sound Regional Council	Metropolitan area	Regression modelling	10,510 respondents of 4,741 households	X		X	X	X	/
Kitamura et al. (1997) Attitude is very important more than the others.	San Francisco, USA	1994	Questionnaire. And land use information is obtained from Metropolitan Transportation Commission	Neighbourhood	Multiple linear regression	5 neighbourhoods, 640 respondents	X		X	X	X	$R^2 = 0.2125$
Limtanakool et al. (2006)	Netherlands	1996	National Mobility Survey conducted by telephone interview and questionnaire	Regional	Binary logistic regression	Commuting:2,326 Shopping: 932 Leisure: 3,072	X	X	X	X	X	

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type			Drivers		Explanatory power of modal
							C	S	L	SE	BE	
Ma et al. (2014)	China	2007	Questionnaire	Neighbourhood	Logistic regression	60 households, 699 trips of 10 neighbourhoods	X	X	X	X	X	Pseudo $R^2 = 0.16$
Manaugh et al. (2009)	Montréal, Canada	2003	Origin-destination survey	Neighbourhood	Linear regression	17,000 trips	X			X	X	SE: $R^2 = 0.06$; SE + BE modal: $R^2 = 0.40$
Marique (2013)	Belgium	2001	2001 Socio-economic survey	National	Multiple linear regression	966,247 respondents	X			X	X	$R^2 = 0.457$
Næss (2010)	Hangzhou, China	2005	Qualitative interview and questionnaire in 40 urban areas	Urban zone	Multiple linear regression	28 interviews 3,150 questionnaire respondents	X			X	X	$R^2 = 0.189$
Naess (2014)	Hangzhou, China and Copenhagen, Denmark	2005	Interview and questionnaire	Regional	Linear regression	1,932 questionnaires for Copenhagen and 3,150 for Hangzhou	X			X	X	Copenhagen: $R^2 = 0.233$ Hangzhou: = 095
Pan et al. (2009)	Shanghai, China	2001	Questionnaire	Neighbourhood	Multiple logistic regression	1,709 respondents in 4 neighbourhoods	X		X	X	X	Pseudo $R^2 = 0.2714$
Zhang et al. (2014)	Zhongshan, China	2010	Questionnaire	Neighbourhood	Linear regression	25,618 respondents	X	X	X	X	X	Pseudo $R^2 = 0.2823$
Baouni et al. (2013)	Algiers, Algeria	2013	Questionnaire	Regional	Bivariate correlation	175 respondents						–
Bakour (2016)	Algiers, Algeria	2004	Household survey conducted by an organisation	City	Linear regression	1,200 respondents	X					$R^2 = 0.5–0.9$

C – commuting; S – shopping; L – leisure; SE – socio-economic; BE – built environment.
Source: own compilation.