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ABSTRACT
Compact, high density and mixed-used urban environments can exert a strong influence on the way people choose to travel. Very few studies, if any, have taken place in the developing world, particularly at the local scale. This paper reports on the relationship between the built environment and modal choice focusing mainly on three of its dimensions: density, diversity, and design. Such associations can provide urban and transportation professionals with valuable tools to assist them in policy appraisal and decision making. In order to analyze the relationship between modal choice and different measures of the built environment we use mobility and associated socio demographic data contained in the household travel survey performed in the city of Neuquen, Argentina during the year 2008. Urban environment variables are characterized for each of the zones in which the city was divided for the O-D survey. Generalized costs are considered as well. Modal split models are applied to assess the influence that built environment variables exert over the individual decision of traveling by car, ride transit, walk or bike. Dense, mixed-used environments favor the decision to walk or bike to nearby destinations, discouraging private car use. Such environments also encourage the use of transit. Theoretical shortcomings, mixed and conflicting results and lack of consensus regarding methodological and variable measurement procedures are the main features of this trend of research. The analysis of a local case helps to clarify some of these points while widening the background for future research in an area that so far is limited to foreign experience. Our findings restate the importance of urban policies with regards to sustainable transportation.

1. INTRODUCTION

Mobility difficulties related with urban growth and sprawl are often linked to large cities and large metropolitan areas. In fact, in this type of locations where getting around proves to be a challenge citizens must face on a daily basis, public agents are continually required to work on mobility strategies. However, small and medium-sized cities also suffer inconveniences derived from strong concentration of activities in their central areas and in many cases insufficient or unsuitable road development and public transport service to satisfy continuous demand growth generated by spontaneous urban sprawl.

Most widely spread solutions performed to deal with these matters have focused mainly on providing new infrastructure, adding routes to existing transit services, or in some cases putting into operation alternative public modes. Other frequently used tools have been traffic management and demand control measures. Among the latter and rather recently, urban environment planning strategies are being considered. This approach comprises urban design schemes that encourage walk travel and the use of other non-motorized modes, performing at the same time some kind of persuasion against car travel. Supporting such schemes we can identify a trend of research that is concentrating on the influence that the built environment wields on the way people choose to travel.

2. BACKGROUND

To date much has been written about the influence of land use on travel behavior. However, almost every piece of research was performed abroad, especially in the United States of America. A few exceptions have been identified in brazilian cities (Amancio, 2005; Grieco and Portugal, 2010) and in the metropolitan area of Santiago de Chile (Zegras, 2004). A great part of these studies have focused on variables that influence motorized travel -mainly by car-, which often include socioeconomic characteristics of travelers and their homes, attitudinal factors and qualities of alternative transportation modes. At the local level no previous research has been acknowledged excluding the work of one of the authors of this article (Riera, 2012) regarding non-motorized generation models for five argentine cities and trip choice model estimation in the city of Cordoba, Argentina (Riera and Galarraga, 2011 and Riera, 2014). Consequently, the available references must be considered with great care since they are based on realities that are completely different from local circumstances.

Zegras (2004) briefly accounts for the state of the art in this branch of research: "The first investigations took place in the United States, initially at a metropolitan scale and more recently at a local or neighborhood scale. More than 50 empirical analysis were reported over year 2000 while very few are known at the local scale"

The impact of local urban form on travel behavior, represented by the three "D's" (Density, Diversity and Design), is the proposition usually set forth. This effect can result in a reduction of motorized trips, a bigger share of non-motorized modes within modal split, smaller trip distances and an increase in shared car trips. Cervero and Ewing (2010) expand the initial three "D's" to six "D's" that have been considered by different authors describing them as follows:

- Population, residential and employment Densities or variables that are computed using these measures.
- Land use mixture or Diversity measures as a result the floor area percentage representing each type of land use.
- Urban Design meaning street network characteristics, block type, walkability indexes, etc
- Accessible destinations in terms of Distances to trip generation centers.
- Distance to public transport stops
- Parking Demand management in terms of available parking places and associated costs.

Some of the work done has considered the influence of the built environment on work trips only (Cervero, 1991; Eash, 1999) or on non work trips (Kockelman, 1996; Greenwald and Boarnet, 2001, Rajamani et al, 2002; Leck, 2006). In other cases no distinction by trip purpose is made or both alternatives are analyzed within the same study (Khattak and Rodriguez, 2005; Shay and Khattak, 2006).

Models have been estimated where the dependent variable has been the total number of trips, vehicle occupancy rates, vehicles-kilometers traveled (Kockelman, 1996) or the odds of choosing between different alternative modes. (Cervero, 2002, Rajamani et al, 2002). The type and number of independent variables varies as well, among the pieces of work revised for this investigation

Cervero and Ewing (2010) conducted a meta-analysis of the built environment-travel literature existing at the end of 2009 in order to draw conclusions that could be generalized for practice. The authors aimed to quantify effect sizes, update earlier work, include additional outcome measures, and address the methodological issue of self-selection. From the methodological point of view, elasticities were computed for individual studies and then pooled to produce weighted averages, drawing the following results and conclusions:

Travel variables are generally inelastic with respect to change in measures of the built environment. Of the environmental variables considered, none had a weighted average travel elasticity of absolute magnitude greater than 0.39, and most are much less. Still, the combined effect of several such variables on travel could be quite large. Consistent with prior work, they found that vehicle miles traveled (VMT) are most strongly related to measures of accessibility to destinations and secondarily to street network design variables. Walking is most strongly related to measures of land use diversity, intersection density, and the number of destinations within walking distance. Bus and train use are equally related to proximity to transit and street network design variables, with land use diversity a secondary factor. Surprisingly, population and job densities were found to be only weakly associated with travel behavior once these other variables are controlled.

The elasticities derived in this meta-analysis may be used to adjust outputs of travel or activity models that are otherwise insensitive to variation in the built environment, or be used in sketch planning applications ranging from climate action plans to health impact assessments. However, because sample sizes are small, and very few studies control for residential preferences and attitudes, the authors could not say that planners should generalize broadly from their results. While these elasticities are as accurate as currently possible, they should be understood to contain unknown error and have unknown confidence intervals. They provide a base, and as more built-environment/travel studies appear in the planning literature, these elasticities should be updated and refined.

3. THE STUDY AREA

The city of Neuquen is located in the argentinian Patagonia and is the capital of the province of Neuquen situated in the border line with the country of Chile. The annual demographic growth rate during the period 1991-2001 between population census' was 1,84%, reaching 203.000 inhabitants by the year 2001. This steady growth has continued at an increasing rate, and by year 2012 the population is estimated in 300.000 inhabitants.

The urban area has natural barriers on all its borders, except on the west. These geographical accidents - Limay River south, Neuquen River on the east and the mountainous formations called "bardas" at the north, limit urban growth shaping the territory. The development of the urban area took place spontaneously generating an atypical distribution of densities with outer high density spots and a weak consolidation of the central area and its surroundings. Within the study area there is considerable amount of scarcely inhabited vacant land, but for which land use regulations have already been established within an urban scheme.

The street network consists of a series of principal streets which work as structural axes and a dense grid of secondary streets of generous dimensions with the exception of the colonial designed central area. Figure 1 shows a conceptual interpretation of the development of the city's structure.

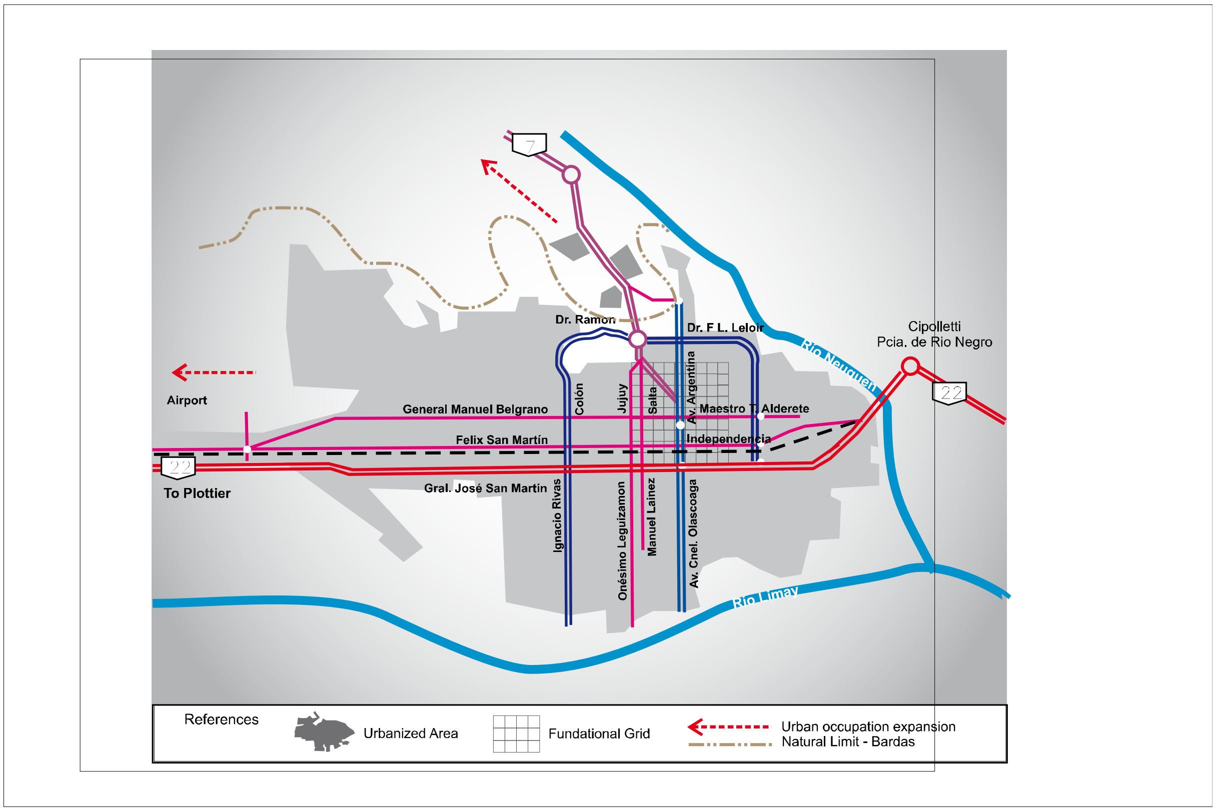

Figure 1 – City structure development

Data obtained from the 2008 O-D survey showed that transit encompasses 41% of daily trips while the private car concentrates 28% of modal share. Bike and walk trip share, with 21% of trips, show that motorized modes use is less than would be expected for a medium-sized city. Figure 2 represents modal share obtained from the O-D survey performed during 2008.

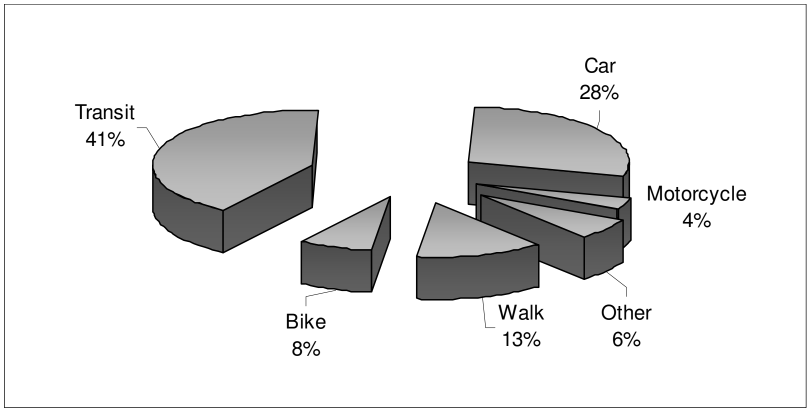

Figure 2 - Modal share / O-D survey 2008

4. EMPIRICAL ANALYSIS

4.1. Travel Survey Data

The main source of information upon which this study is based, is the origin-destination survey that was undertaken by the city of Neuquen during the first semester of the year 2008. The survey was aimed to bid for the city's public bus transport system on the basis of an improved network design and an adequate regulatory scheme. In spite of the specific purpose of the data pick-up, plentiful information was collected during the survey related to trips that were performed on every mode, during work days. So the trip database contains the chosen modal alternative (car, bus, walk, etc), the location of origins and destinations, trip frequency and duration and several individual characteristics of travelers and their homes.

4.2. Measuring the Built Environment

Several tasks were accomplished in order to complete the database by adding the variables chosen to describe the built environment. Population and residential density were obtained composing data of census radios into the transportation zones delimited for the survey. Land use mix within each transportation zone was determined on the basis of previous work performed as part of the urban transport project during which planners made a detailed description of each area. This information was improved using Google Earth tool's historical images, setting them up to the year the survey was performed. In this way a percentage of each land use type was estimated, measuring the amount of vacant land as well. The city's digitally supported cartography, provided by Neuquen's municipality for the transportation project, was used to measure total and partial areas and to locally make counts of the different elements that make up urban design such as the proportion of grid streets, different types of intersections, number of cul de sacs, etc.

4.3. Data Assemble

The data assemble included several steps. The trip database was enlarged by adding each traveler's individual and home characteristics. Travel and socioeconomic data were obtained from the 2008 O-D travel survey performed in the city of Neuquen while zonal built environment variables and its values had to be further introduced into the database.

The final sample included 13.168 trips of individuals who belong to 2.372 homes located in the city of Neuquen. Almost half of these trips - 48% - are return home trips, while 23% are work trips, 11% are for study purposes and 18% for other purposes like health, shopping and sports. The variables that make up the sample used in this study are specified and described in Table 1, and the values adopted are listed in the same table. In some cases data had to be re-categorized in order to be able to proceed with the statistical process.

Table 1: Travel behavior model variables

Variable	Variable type	Description	Values
mochoice	Dependent	Non-motorized, transit or private car choice	Non-motorized = 1 Transit = 2 Private car = 3 Other = 4
Vehicle	Independent	Number of cars at home	Continuous variable
sex	Independent	Traveler's sex	Men = 1 Women = 2
agegroup	Independent	Traveler's age	Continuous variable
workstat	Independent	Work status	Not employed = 1 Student = 2 Housewife = 3 Employed or independent= 4
purpose	Independent	Trip purpose	Work or study = 1 Other = 2
travtime (minutes)	Independent	Time spent traveling	Continuous variable
origdens	Independent	Population density at origin	Continuous variable
destdens	Independent	Population density at destination	Continuous variable
origmix	Independent	Land use mix at origin	Continuous variable
destmix	Independent	Land use mix at destination	Continuous variable
vaclorig (hectares)	Independent	Vacant land at origin	Continuous variable
vacldest (hectares)	independent	Vacant land at destination	Continuous variable

4.4. The Model

By the application of the multinomial logit model which allows modeling more than two alternatives, modal choice between non-motorized, public transport, private car and other modes is appraised. The proposition to be examined is that urban form measures such as density, land use mix and street network connectivity can explain travel behavior. Regarding policy administration this means that an adequate management of these dimensions of the urban environment could contribute as urban mobility enhancement tools.

4.5. Variables Description

The variables that were analyzed in order to appraise their inclusion in the logit model, were grouped within three categories:

- Individual and home socio-demographic characteristics: sex, age, employment status, instruction level and car ownership.
- Trip characteristics: trip purpose, trip frequency's and travel time influences were examined, considering the latter as a generalized cost measure.
- Urban form measures: three main descriptors of the urban environment were considered: population and residential density, land use degree of mixture and street network design. The proportion of vacant land was evaluated as well.

Population and residential density have been frequently used in model specification as a substitute of other built environment variables excluded from models. This has altered the true impact of this variable.

Land use degree of mixture or diversity quantifies the actual variety in land use distribution within each transportation zone. In this case land use was categorized as follows: i. residential - ii. commercial - iii. Industrial - iv. institutional - vi. recreational and green areas.

A preliminary idea of land use mixture by transportation zone was obtained using the urban transport project document as source information. This document contains a detailed description of the 51 transportation zones that were defined for the O-D survey which proved to be a very valuable support to complete the required task. To obtain more detailed data, the Google Earth program was used to calculate the area in hectares of each land use type by contrasting the O-D survey zone limits and the satellite surveys' year historical images. In this way it was possible to identify those areas that are mainly residential, as well as commercial areas, health, educational and administrative buildings, sports fields, plazas, parks and vacant land spaces. Areas were computed employing CAD software. The former data was introduced into the formulae shown in Equation 1 used to estimate a variable that describes land use mix (Rajamani et al, 2002):

$$Land\_Use\_Mixture\_Diversity = 1 - \left(\frac{\left\| \frac{r}{T} - \frac{1}{4} \right\| + \left\| \frac{c}{T} - \frac{1}{4} \right\| + \left\| \frac{i}{T} - \frac{1}{4} \right\| + \left\| \frac{o}{T} - \frac{1}{4} \right\|}{\frac{3}{2}} \right) \qquad (1)$$

where:
r = acres in residential use (single and multi-family housing),
c = acres in commercial use,
i = acres in industrial use,
o = acres in other land uses as institutional, recreational and vacant land, and
$T = r + c + i + o$.

A value of zero for this measure means that the land in the neighborhood is exclusively dedicated to a single use, while a value of one (1) indicates a balanced mixing of the four land uses.

Street connectivity which can be associated to network design can be described by many different indicators. In this particular case the number of squares by hectare was determined for each transportation zone.

4.6. Model estimation

The selection of variables was done intuitively, appraising their possible effects. The variables preliminary chosen were tested by systematically adding them to the initial formulation, i.e. the only constant model, and leaving aside the ones that were not significant or were correlated to another selected variable. In the first place a base model was estimated, which considered only socioeconomic variables. Table 2 contains a comparison between statistics relative to the base model and those relative to an improved model containing the variables of the built environment.

Table 2: Base and improved models statistics comparison

Model	Chi-square	Degrees of freedom	Sig	Pseudo R^2 statistics		
				Cox and Snell	Nagelkerke	McFadden
Base	364,4	18	0,00	0,500	0,545	0,277
Improved	396,7	36	0,00	0,596	0,650	0,365

The likelihood ratio test values for both the base model and the improved model, exceed the critical chi-square value corresponding to 18 and 36 degrees of freedom at any reasonable level of significance. Thus, the hypothesis of no observed variable effects is rejected in both cases. The improvements that can be observed in the values of the log-likelihood ratios and the pseudo-R^2 statistics show that the built environment variables introduced in the model make a contribution towards explaining modal choice. The results of the multinomial logit estimation of the final model specification are presented in Table 3. The parameter estimates in the MNL model indicate the effects of exogenous variables on the latent utilities of three modes (non-motorized, public transport and private car) relative to the "other modes" alternative. The effect of the different variables will be analyzed on the basis of the estimated model.

Table 3: Effect of exogenous variables on mode choice

Variable	Non-motorized		Transit		Private car	
	Parameter	Wald	Parameter	Wald	Parameter	Wald
Intercept	5,349	3,083	6,736	4,511	-0,728	0,051
Household socio-demographics						
Car ownership	-0,775	2,742	-1,229	5,489	2,353	21,084
Individual socio-demographics						
Sex	0,360	0,513	0,621	1,322	-0,733	1,882
Age	-0,500	1,749	-0,432	1,151	-0,086	0,047
Work status	-0,069	0,044	0,363	1,179	0,545	2,723
Trip characteristics						
Trip purpose	0,093	0,096	0,740	3,228	1,044	6,796
Travel time	-1,011	4,381	-2,301	21,233	-0,062	0,015
Urban form measures						
Population density at origin	-0,069	0,02	-0,616	0,014	-0,181	0,132
Population density at destination	1,084	4,270	1,956	12,594	0,748	1,862
Land use mix at origin	-0,476	1,199	-0,498	1,221	-0,963	4,606
Land use mix at destination	0,559	1,537	-0,035	0,005	0,318	0,475
Vacant land at origin	-0,272	3,979	-0,252	3,088	-0,466	10,263
Vacant land at destination	1,278	1,213	1,332	1,317	1,367	1,392

The high intercept value in both the non-motorized and the transit choice alternatives, implies that the model does not explain a great part of the data. Among the household socio-demographics that were tested, car ownership was significant in all cases. An increase in the number of vehicles in the household significantly decreases the likelihood of choosing to walk or bike. The negative utility of this variable towards riding transit is even greater. On the other hand, the car choice parameter shows the greatest propensity to travel by car as the number of cars at home increase. Individual socio-demographic variables were not significant in most cases. The variable “studies” which describes educational status was suppressed from model formulation since it proved to be not significant in every case. Results indicate women’s likelihood to choose riding transit and a negative utility in the case of the car. Meanwhile, the likelihood of choosing to walk or bike diminishes with the rise of age. Finally, among individual characteristics, the effect of work status was tested showing higher chances of traveling by car for individuals who work or study, relative to those who do not. The analysis of trip characteristics reveals a positive utility when riding transit or riding a car for any trip purpose, while the likelihood of doing so increases when the trip purpose is other than work or study. The model estimation results indicate the usual negative impacts of travel time, variable which is representative of generalized costs.

The results indicate that time spent on transit is more onerous than time spent walking or biking and highly significant. Travel time was not significant whereas car choice concerns.

4.6.1. Influence of Built Environment Variables

Four types of indicators of the built environment were tested in the model: population density, land use mixture diversity, connectivity and amount of vacant land. The outcome was not quite as expected for all subgroups, yet a good part of the studied variables likely effects were proved.

The impact of density was appraised by population density while residential density was discarded for being strongly correlated with the former. Results indicate that as population density at the destination is higher, the likelihood of walking or biking becomes greater. This tendency is even stronger in the case of transit choice. As for car choice the direction of the impact is the same but much weaker which is reasonable since highly populated areas may persuade drivers to avoid such destinations if possible.

Land use mix described by means of the diversity index is positive and fairly significant in the case of non-motorized modes, indicating some propensity to walk or bike to this type of environments. At the same time the negative sign of the highly significant coefficient specific to car mode corroborates the effectiveness of mixed uses in discouraging driving. Regarding transit, this attribute was not significant.

The impact of urban connectivity represented by the number of squares per hectare and by the percentage of cul-de-sacs was not significant as expected and the variables were excluded from the model. Probably this city's lifestyle and a still fluent traffic with very limited congested areas and periods, have not created the need for avoiding car use. Further research of this topic would be desirable testing other indicators depicting urban design.

The effect of vacant land had the expected outcome, decreasing the likelihood of walking, biking, riding transit or even driving a car in those cases where the variable coefficient was significant, which applies to the origin. Long non-productive distances discourage trip making, even when a car is available.

5. CONCLUSIONS

The study provides some evidence to prove the importance of built environment variables in the context of modal choice models. The model fit showed that mixed uses and higher densities tend to encourage walking and biking while dissuading the use of the private car. If the goal of diminishing private car modal share is present in urban communities, then the results of this type of research might be used to assess the potential impacts of policy actions. For example they can provide support for urban development policies that put limits on the city's spreading out, favoring densification and land use diversity.

Built environment variables contribute only marginally to the model's fit. In spite of this, the outcome of the obtained estimation gives good reason for giving continuity to this course of research. For this purpose more detailed data at a geographic level would be desirable since the aggregation within transportation zones defined for the O-D survey, inadequately scaled for this study, cause the loss of local effects which are thus not captured by the model estimation process.

In the same way, having available a Geographic Information System would make the acquisition of more detailed data possible as well making feasible the inclusion of other built environment variables that could not be analyzed because of lack of data or of computational resources.

A further limitation regarding models that are estimated in this study area is due to the heterogeneity that is observed when certain built environment variables are measured. This causes difficulties when establishing comparisons between the diverse estimated models and results generalization accomplishment.

Some recommendations for future studies are summarized below:

- The achievement of more detailed, less aggregated data to be able to work at a smaller scale in order to attain a more precise definition of local characteristics.

- Perform different estimations by testing other built environment variables and their possible contribution to model improvement.

- Include in the research agenda the execution of studies at the neighborhood scale which should include trip counts and an exhaustive description and quantification of the characteristics of the areas to be analyzed.

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