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Urban built environment analysis: Evidence from a mobility survey in Madrid

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Abstract

Applications involving travel behavior from the perspective of land use are dating from the 1990s. Usually, four important components are distinguished: density, diversity and design (3D's of Cervero and Kockelman) and accessibility (introduced by Geurs and van Wee). But there is not a general agreement on how to measure each of those 4 components. Density is used to be measured as population and employment densities, but others authors separate population density between residential and building densities. A lot of measures have been developed to estimate diversity: among others, a dissimilarity index to indicate the degree to which different land uses lie within one another's surrounding, an entropy index to quantify the degree of balance across various land use types or proximities to commercial-retail uses. Design has been characterized by site design, and dwelling and street characteristics. Lastly, accessibility has become a frequently used concept, but its meaning on travel behavior field always refers to the ability "to reach activities or locations by means of a travel mode", measured as accessibility to jobs, to leisure activities, and others. Furthermore, the previous evidence is mainly based on US data or on north European countries. Therefore, this paper adds some new evidence from a Spanish perspective to the research debate. Through a Madrid smartphone-based survey, factor analysis is used to linearly combine variables into the 3D's and accessibility dimensions of the built environment. At a first step for future investigations, land use variables will be treated to define accurately the previous 4 components.

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Keywords: urban built environment; density; diversity; design; accesbility

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1. Introduction

The last legislations aiming at stricter mobile soured emissions control and planning for dramatic decreases in Greenhouse gas emissions emphasizing the need for integrated land use policies with transportation policies. This integration requires understanding of and changing household residential location and promotes a move to environmentally friendly behaviors.

The influence of land use patterns on travel behavior has been theme of many previous studies, but links between international and Spanish perspectives are rarely dealt. Mitchell and Rapkin (1954) wrote one of the first studies to understand the impact of land use patterns on travel behavior, but since 1990 have appeared the most part of the studies in this field. Some of them have identified relevant links (Cervero and Kockelman, 1997; Lin and Yang, 2009), while others have not found almost any effect (Kitamura et al., 1997; Schwanen and Mokhtarian, 2005a). Apart from using different statistical approaches, the different types of land use explanatory variables included in the research are a possible explanation of that controversy.

Methodologically, reviewing the previous literature it is necessary to take into account these three steps: (1) to define only land use explanatory variables; (2) to control earlier results for socio-economic/demographic variables; and (3) to pay attention on attitudes, lifestyles and perceptions that have an impact on land use or travel behavior. The relationship between socio-economic (2) and perception dimensions (3), and travel behavior have already been studied by the authors using a Structural Equation Modeling (SEM) approach (Comendador et al., 2014). The influence of land use patterns (1) on travel behavior from a Spanish perspective is the real objective at time by the authors. But the lack of agreement in the definition of land use explanatory variables from this Spanish perspective difficult to achieve an accurate analysis of land use and travel behavior interdependences.

Factor analysis (FA) is the name given to a group of statistical techniques that can be used to analyze interrelationships among a large number of variables and to explain these variables in terms of their common underlying dimensions (factors) on travel behavior (Ewing and Cervero (2010); de Abreu e Silva et al. (2012); He and Zhang (2014)). The approach involves condensing the information contained in a number of original variables into a smaller set of dimensions (factors) with a minimum loss of information. Therefore, to reach an approximation of 3D's (density, diversity and design) (Cervero and Kockelman, 1997) and accessibility (Geurs and van Wee, 2004) dimensions of the built Spanish environment, this paper develops a FA with land use variables based on data from a Madrid smartphone-based survey (n=255 respondents) where these variables are calculated with the GPS information of each travel.

The structure of the paper is that follows. First, the relevance of land use on travel behavior is defined. Second, the methodological ways used in different contexts to achieve the urban built environment factors. Afterwards, it gives an overview of the statistical approach used to define factors (FA), while following section describes the panel smartphone data. A synthesis and the results applying this methodology are presented in the sixth section, finalizing with some conclusions and recommendations.

2. The Relevance of Built Environment

Since 1970s the most frequently quoted studies on the impact of the land use patterns on travel behavior have provided important conclusions. Through a regression analysis, Hurst (1970) demonstrated that higher rates of vehicle trip generation were found among retail and office land uses compared with storage and industrial usage. Newman and Kenworthy (1989) found a significant negative statistical correlation between residential density and transportation-related energy consumption per capita.

The impact of density, diversity, accessibility, and percentage of multifamily residential on travel time was study by Ewing et al. (1994). Also Friedman et al. (1994) distinguished two neighborhood types: standard suburban and neo-traditional neighborhoods. To find a study that analyzes different neighborhood design, Hess et al. (1999) demonstrated that urban neighborhoods with small blocks and extensive sidewalk systems were found to generate three times more the pedestrian volumes than suburban sites with large blocks and short. Handy (1996) was among the first to mention the importance of perceptions and attitudes towards land use on travel behavior. But also there are studies point to a higher significance of land use compare to socio-economic and demographic characteristics (Schwanen and Mokhatarian 2003, 2005).

In Europe, the SESAME (1999) research project, studying 57 urban agglomerations in France, Germany, Great Britain, the Netherlands, Switzerland, and Spain, pointed to the existence of several important relationships at an aggregate level among land use patterns, travel behavior, and transit supply. Other European studies also concluded that land use patterns influence travel behavior (Naess, 2005). An exploratory study in this field with a database of Madrid (La Paix et al., 2012) reveals that people living in outskirts areas are likely to multistage tours out of the residence area and the public transport trips decreases with the distance to Center Business Center (CBD).

3. How to measure Spatial Dimension?

Most evidence about how to measure the environmental dimension on travel behavior is based on data stemming from the US as has pointed before. Since 2000s, the research debate has been enriched with European evidence. But there are important differences in urbanization patterns between North-American and European cities. Thus, the great problem is the lack of common point all of the studies in this field to quantify this novelty dimension. In this chapter, the authors review the ways used in different contexts to achieve the target of this paper: a quantification of the spatial dimension in a travel behavior study since Spanish perspective.

3.1. Key dimensions to be into account

Land use characteristics can be measured at several scales, ranging from the local neighborhood to the metropolitan area. Usually, four important components are distinguished: density, diversity and design (Cervero and Kockelman, 1997) and accessibility (Geurs and van Wee, 2004).

Density. The effects of density on travel demand have long been acknowledged (e.g., Levinson and Wynn, 1963) and remain well-studied and understood. Higher densities are associated with more public transport use, more walking and cycling, and less car use. After all, public transport is organized more efficiently (more routes, higher frequency of services) in high density areas and car users may face more congestion. Furthermore, travel distance and time is negatively associated with density (Cervero and Kockelman, 1997; Kitamura et al., 1997; Schwanen et al., 2004).

Diversity. Several measures have been developed to estimate diversity: among others, a jobs/housing ratio (Ewing et al., 1994), an entropy index to quantify the degree of balance across various land use types (Kockelman, 1997) or a dissimilarity index to indicate the degree to which different land uses lie within one another's surrounding (Kockelman, 1997). The effects of more diversity on travel behavior are comparable to the effects of higher densities.

Design. The factor design can be characterized by a general classification of neighborhoods with a standard suburban neighborhood and a neo-traditional neighborhood as extremes (Gorham, 2002). Standard suburban neighborhoods are characterized by low densities, limited diversity, and a car-orientated design. However, design can be characterized more specifically by site design, and dwelling and street characteristics. Studies indicate that neighborhoods characterized by small block sizes, a complete sidewalk system, the absence of cul-de-sacs and limited residential parking encourage walking and cycling (Cervero and Kockelman, 1997; Hess et al., 1999).

Accesibility. Accessibility is a fourth important land use characteristic. Accessibility has become a frequently used concept, but its meaning always refers to the ability "to reach activities or locations by means of a (combination of) travel mode(s)" (Geurs and van Wee, 2004). To measure this accessibility there are two approaches: (i) according to Koenig (1980) it must take into account the distance between the person or place and the destination and the utility of various destinations; but also (ii) according to Simma and Axhausen (2001) accessibility is calculated as the number of reachable facilities. The latter approach is labeled as *intensity* by Krygsman and Dijst (2001). Moreover, most studies agree on the effects of accessibility on travel behavior. For example, Gao et al. (2008) found that households living in residential locations with higher job accessibility are likely to own fewer cars. Several studies also point out that accessibility is negatively associated with travel times (e.g., Ewing et al., 1994; Susilo and Maat, 2007).

3.2. Land use variables tested

The many ways by which urban environment can be measured may be considered as observed characteristics of a neighborhood. Several of these observed characteristics are related. In some cases the relationships are obvious: the average proximity to a transit stop in a neighborhood and transit-based accessibility to opportunities may be correlated in measuring overall transit access of a location. However, as the number of observed variables increases, it is difficult to identify the structure within them. Therefore it becomes necessary to condense these observed variables into a smaller set of variables that accounts for the variance in the data. One such data reduction technique is FA. Factors derived through such data reduction techniques are also referred to as latent variables. Although, as the name latent implies, these variables are not observable, certain effects on measurable (manifest) variables can be observed (Srinivasan, 2001). Thus, FA methods can assess and explain the structure in a set of correlated, observed variables in terms of a small number of latent variables or factors.

Cervero and Kockelman (1997) introduced the idea that "in light of the need to use sets of variables to capture the many-sided dimensions of built environments and to allow for colinearity, the multivariate technique of factor analysis was used". These authors pointed that since the research focused on how the land use shaped travel demand, FA was carried out only for land use variables (not socioeconomic, attitudinal …). Their FA was successful in providing a multi-variable description of two of the 3D's dimensions (density and design) specified each other by six land use variables. Each factor was labeled 'intensity' and 'walking quality', respectively. It was the beginning of several studies in this field that included FA to improve their studies since the multicolinearity among the land use variables could hide the effects of their individual contributions to travel demand.

Since the great goal of this paper is to define new evidence from the Spanish perspective to the land use variables treatment on travel behavior, it is necessary to review how the land use factors have been labeled in other American and European studies following the technique of FA (Table 1).

Table 1. Environmental factors as a result of studies that have used FA

Study	Environmental Factors labeled
de Abreu e Silva, Golob, and Goulias (2006)	(1)'Residence in traditional urban areas'; (2)'Working in traditional urban areas'; (3)'Working in compact and central urban areas'; (4)'Road supply'; (5)'Freeway supply in the residence area'; (6)'Residence in a specialized area'; (7)'Working in a specialized area'; (8)'Freeway supply in the work area'
Van Acker and Witlox (2010)	(1)'Built up index'; (2)'Land use diversity'; (3)'Distance to railway station' ; (4)'Distance to CBD'; (5)'Accessibility by car'
de Abreu e Silva and Goulias (2009)	(1)'Employment in a central and denser area'; (2)'Residence in a central and denser area' (3)'Bus supply in the employment area'; (4)'Bus supply in the residence area'; (5)'Mix'
Ewing and Cervero (2010)	(1)'Density'; (2)'Diversity'; (3)'Design'; (4)'Accesibility'; (5)'Distance to CBD'
de Abreu e Silva, Goulias and Dalal (2012)	(1)'Employment in a central, denser and accessible area'; (2)'Residence in a central, denser and accessible area'; (3)'Employment in a dense area well served with roads'; (4)'Residence in a compact and small area and well served by roads'; (5)'Working in a mixed and compact zone'; (6)'Residence in a mixed and well served by freeways area'; (7)'Mix of land uses in the residence area'
He and Zhang (2014)	(1)'Density'; (2)'Entropy'; (3)'Average block size'; (4)'Distance to CBD'

The six studies above confirm the lack of common point to define built environmental factors (latent variables) that are represented by a group of land use observed variables on transport studies. Among the general conclusions, noteworthy: (i) a density factor defined at least from population density; (ii) a diversity factor defined at least from land use mix value or entropy index; (iii) a design factor but defined on different ways (street quality factor or average block size, for example); and (iv) some accessibility factors defined since different points of view (accessibility by car, distance to transit or public transport, distance to CBD, residence/employment in a specialized area, etc.). Moreover, the variables used to define the factors are scale variables or/and percentage, being greater the number of the first ones. Most part of the previous studies finished with a Structural Equation Modeling approach (SEM) to analyze the relationship between those new land use factors and travel behavior. This type of methodology will be applied by the authors with the results of this paper.

4. Methodological approach: Factor Analysis

The utility of FA hinges on its ability to yield stable, accurate and interpretable estimates of factor loadings. But there are a number of determinants of successful application of FA that have to be taken into account following the next stepped way proposed by the authors:

Step 1. Data suitable. Although sample size is important in FA, there are varying opinions, and several guiding rules of thumb are cited in the literature. Hair et al. (2009) suggested that sample sizes should be 100 or greater. A number of textbooks cite the work of Comrey and Lee (2013) in their guide to sample sizes: 100 as poor, 200 as fair, 300 as good, 500 as very good, and 1000 or more as excellent. Moreover, Tabachnick and Fidell (2007) recommended inspecting the correlation matrix for correlation coefficients over 0.30. Prior to the extraction of the factors, several tests should be used to assess the suitability of the respondent data for FA, as Kaiser-Meyer-Olkin (KMO) index. The KMO index ranges from 0 to 1, with 0.50 is considered suitable for FA.

Step 2. Factor extraction method. The aim of the extraction is to simplify the factor structure of a group of items, or in other words, high item loadings on one factor and smaller item loadings on the remaining factor solutions. There are numerous ways to extract factors: Principal Component Analysis (PCA), Principal Axis Factoring (PAF) and others. PCA and PAF are used most commonly in the published literature (Thompson, 2004; Tabachnick and Fidell, 2007). When the variables have high reliability (Cronbach's alpha) the differences between the two are often insignificant (Thompson, 2004); but PCA is recommended when no priori theory or model exists (Gorsuch, 1983).

Step 3. Rotational Method. Another consideration when deciding how many factors are analyzed the data is whether a variable might relate to more than one factor. Rotation maximizes high item loadings and minimizes low item loadings, therefore producing a more interpretable and simplified solution. There are two common rotation techniques: orthogonal rotation and oblique rotation. Orthogonal rotation first developed by Thompson (2004) is the most common rotational technique used in FA, which produce factor structures that are uncorrelated. In contrast, oblique rotation produce factors that are correlated, which is often seen as producing more accurate results for research involving human behaviors, or when data does not meet priori assumptions (Costello and Osborne, 2005).

Step 4. Number of factors. The aim of the data extraction is to reduce a large number of items into factors. In order to produce scale unidimensionality, and simplify the factor solutions several criteria are available to researchers. However, given the choice and sometimes confusing nature of FA, no single criteria should be assumed to determine factor extraction (Costello and Osborne, 2005). According to Hair et. al (2009) factors should be stopped when at least 50-60% of the variance is explained (for social sciences).

Step 5. Interpretation. Interpretation involves the researcher examining which variables are attributable to a factor, and giving that factor a name or theme. Traditionally, at least two or three variables must load on a factor so it can be given a meaningful interpretation (Henson and Roberts, 2006). Variables with higher loadings are considered more important and have greater influence on the name or label selected to represent a factor. The signs are interpreted just as with any other correlation coefficients. If the researcher is content with these factors, these should be operationalized and descriptively labeled. It is important that these labels or constructs reflect the theoretical and conceptual intent.

5. Mobility survey

The study reported here is a small part of a larger work aimed at assessing what and how variables (levels of service, socio-economics, psychological, land use, etc.) influence on travel behavior (Comendador et al., 2014). The data use in this study originates from first wave (n=255 respondents) of the HABIT project (Habit and Inertia in mode choice behavior: a data panel for Madrid).

5.1. Sample design

During fall 2011 and winter of 2012, a smartphone with a panel-survey application was delivered for one week among two focus groups in order to capture a portion of the population of Madrid most affected by recent changes in transport policy: (1) 91 workers of Regional Health Department of the catchment area of a new Line 2 and Line 9 stations; and (2) 164 workers of the Polytechnic University of Madrid taking advantages of their close relation to the authors, which helped to easily achieve a random sample of 5774 workers (2011 Census data). Since, high costs in terms of time and money are one of the biggest limitations when building data panels (Yáñez et al., 2010). Authors discarded the most common sampling unit in transport survey (i.e. the household), and panel survey used is based on a sample of a worker subpopulation.

For each trip, GPS information was available about travel times, number of transfers, distances recover; and then estimation costs. Regarding the users, the panel gathered information about socioeconomic variables. Lastly, land use variables were calculated with the GPS information of each travel. Table 2 contains a selection of individual and household characteristics of this sample. Despite these restrictions, the sample well represents the Madrid worker population in many aspects.

Table 2. Sample travel behavior and socioeconomic characteristics

Variables		**Worker Population***	**Average**	**St. Deviation**
Endogenous travel behavior variables (daily)	*# trips*	2.6	2.4	0.3
	Travel time (min)	28.6	32.7	5.8
	Commuting dist. (km)	6.0	7.9	3.7
Socioeconomic variables	*Male (%)*	51	52	-
	Age	40	43	9.2
	Income	2500	2100	410

**Source:* INE (2011) and Monzón et al. (2013).

The survey considered two main phases. The first phase consisted in a face-to-face interview registering personal data about the respondent. In the second phase, authors gave the smartphone to the people and asked them to register the daily trips they made during the five workdays (Monday to Friday). The trips recorded were monitored in real time and respondents were eventually contacted at the end of the day to correct or clarify the information. A chart was also given to the participants to manually register those trips not registered by the smartphone. The complete registration of daily trips, took about 20 seconds for a trip by car or by walking and one minute for a public transport journey. At the end of the trip, the data were automatically sent to a server accessible by the monitor of the survey. Both the face-to-face interview and the smartphone trip diary were based on the palm-based Santiago Panel used for evaluating the TranSantiago system in Chile (Yáñez et al., 2010), also covering a wide variety of socio-economic variables.

5.2. Definition of urban built environmental variables

The variables related to the service area have been calculated within the station service area (SSAs). Service areas were obtained using Geographical Information System (GIS), and are based on distances across the transport/road network. The distance threshold considered was 900 meters, which is the maximum distance that most people are willing to walk in order to access the Metro network in Madrid (García-Palomares et al., 2013). Once the SSAs were defined with a GIS, they have been intersected with various urban variables that that hypothetically favor transit use: density, diversity and design (Cervero, R. and Kockelman, 1997); and accessibility dimensions (Geurs and van Wee, 2004).

Population Density and *Employment Density* have been chosen as density variables in the service area. The former was calculated as inhabitants/ha, and the latter as employment/ha. Two indicators of "land use mix" have been used. First, the ratio of employment per inhabitant was computed (*Job Ratio*). This index can contribute to measure the job accessibility. Second, a more general land use mix (*Mix*) was measured using the reciprocal of the variation coefficient of the area covered by different land uses within SSAs (higher values indicate higher diversity in uses). Both measures are easily computable and interpretable. But the rest of the different categories of land uses within SSAs have been also studied separately to improve the knowledge about the diversity and accessibility dimension: hectares (ha) of trade, health and educational (*Equipment*), ha of single-family residential (*Single Residential*), ha of multifamily residential (*Multi Residential*), ha of industry (*Industry*), ha of Offices, ha of infrastructure that promotes economic activity, such as roads, highways, railroads, airports, electricity, telecommunications, water supply and sanitation (*Infrastructures*), ha of parks and recreations (*Green Zones*). To measure the “center accessibility”, the distance of each SSAs to Center Business District (*Distance CBD*) was also included, as well as ha of land available for building (*Brownfield*).

An urban design indicator was calculated using the street network layer *Street Density* within SSAs. This variable was calculated as a ratio between the street length and the service catchment area. *Street Density* can be considered as an indicator of walkability (Zhu and Lee, 2008), since it favors access to stations on foot and increases transit ridership (Cervero, 2002). To achieve a better knowledge of “street network design” dimension was used the inputs of Ravulaparthy and Goulias (2014) that set of centrality measures to spatial systems:

- *Remoteness* centrality: measures to what extent a link is close to all the other links along the shortest paths from one link to another on the network.

- *Betweeness* centrality: is based on the idea that a link is more central when it is traversed by a large number of shortest paths connecting any other two links in the network.

- *Straightness* centrality: represents "efficiency of communication" between two links increases when there is a least deviation of their shortest path from the virtual straight line connecting them – that is, a greater straightness of the shortest-path distance.

- *Reach* centrality: measures the number of other links that can be reached along the shortest path on a network.

This centrality measures complement the classical Multiple Centrality Assessment (MCA) model (Porta et al., 2012) in two ways: (a) accommodate the context of location and its importance through weighted link attributes like roadway capacity, population and opportunities at a place; and (b) accounting for the relative importance of a link in the network across multiple spatial scales and centrality values. To determine at least the small-scale measures for the centrality indices above, it was computed centrality indices for a network radii or network buffer surrounding each link of 2.5km along with measures for the entire Madrid network, which are the 25th percentile, of the pairwise distance distribution.

Table 3. FA results

Factor	Observed variable	Factor loading
Street Network Design	*Straightness*	0.970
	Reach	0.961
	Remoteness	0.947
	Betweenness	0.805
Urban Block Diversity	*Mix*	0.798
	Multi Residential	0.773
	InvLog_Road Supply	0.605
Nonresidential Diversity	*Green Zones*	0.772
	Industry	0.725
	Infrastructures	0.723
Job Accessibility	*Employment Density*	0.898
	Job Ratio	0.675
	Offices	0.561
Center Accessibility	*Brownfield*	0.832
	Distance CBD	0.734
Density	*Population Density*	0.691
	InvLog_Single Residential	0.666

Trying to identify a combination of variables into the 3D’s (density, diversity and design) and accessibility dimensions of the built environment, results above add some new evidence from a Spanish perspective to the research debate. Each factor loading represents the role each observed variable plays in defining each factor:

- as more *Straightness*, *Reach*, *Remoteness* and *Betweeness* values, bigger ‘street network design’.
- as more *Mix*, *Multi Residential* values, bigger ‘urban block diversity’. Conversely, as more ‘road supply’ value, smaller this diversity factor.
- as more Green Zones, Industry, Infrastructure values, bigger ‘nonresidential diversity’.
- as more *Employment Density*, *Job Ratio*, *Offices* values, bigger ‘job accessibility’
- as more *Brownfield* and *Distance CBD* values, bigger ‘center accessibility’, i.e., more difficult to access to the city center.

- as more *Population Density* value, bigger the 'density' factor. Conversely, as more Single Residential value, lower density factor.

6. Factor Analysis Estimation

The goal of a FA is to identify a limited number of underlying (latent) factors responsible for observed variances and covariances. Following the stepped methodology proposed at chapter 4 and the database presented at chapter 5, the authors try to identify dimensions of the urban built environment since Spanish perspective.

Step 1. Data suitable. With an acceptable sample size of 255 respondents, the correlation matrix of the eighteen environmental variables presents a very low (<0.3) correlation factor between Equipment and the rest of the variables; thus we can reject this variable. To assess the suitability of the respondent data for the FA with the seventeen resulting variables we reach an acceptable valuation of KMO index (0.684).

Step 2. Factor extraction method. The statistical program SPSS was used to perform FA through the default method of extraction in other statistical applications: Principal Component Analysis (PCA). Moreover PCA is appropriate when the primary concern is about prediction or the minimum number of factors needed to account for the maximum portion of the variance represented in the original set of variables, and when no priori theory exists.

Step 3. Rotational Method. Reviewing similar environmental-factor-analysis researches based on different case studies (see chapter 3) the factors will be related; thus the oblique rotation method is more suitable.

Step 4. Number of factors. With a first PCA using oblique rotation method, the scree-plot indicates a clear "elbow" with seven factors (scores) meaning that a six-factor-solution can be extracted. Communalities are uniformly high (between 0.6 and 0.9), but two observed variables (Road Supply and Single Residential) have negative factor loadings. Thus, it is useful a transformation of the scale variables. To achieve factor loadings more than 0.5 it is necessary to apply the inverse of the logarithm for both variables. Running a second PCA analysis, six factors with an eigenvalue greater than one explain 72.2 % of the variance.

Step 5. Interpretation. The oblique rotation solution (Table 3) implies that: the first factor concerns street network design (26.4% variance explained); the second factor relates to urban block diversity (13.1%); the third factor consists of a categorization of nonresidential diversity (9.8%); the fourth factor relates to job accessibility (9.1%) or even job intensity; the fifth factor represents the center accessibility (7.8%); and the last factor can be named as density (6.0%).

7. Conclusion

This paper analyzes the existing literature about the relationship between land use and travel behavior, and concludes that a crucial issue on the analysis of these relationship is the definition of latent variables which represent the environmental dimension. Most evidence about how to measure the environmental dimension on travel behavior is based on data stemming from the North-American and North-European cities using a Factor Analysis (FA) approach. Applying this methodology is easy to identify a limited number of underlying environmental factors or dimensions responsible for land use variables. Usually, four important environmental dimensions are distinguished: density, diversity and design (3D's of Cervero and Kockelman) and accessibility (introduced by Geurs and van Wee) but with a lack of common point (see review in Table 1). The different types of land use explanatory variables included in the research are a possible explanation of the controversy. Despite this, the authors have identified general conclusions based on international case studies.

Links between international and Spanish perspectives are rarely deal on transport studies. This paper develops a FA with land use variables based on data from a Madrid smartphone-based survey (n = 255 respondents) where land use variables are calculated with the GPS information of each travel. The results of this case study confirm the 3D's and accessibility underlying dimensions responsible for land use variables, but it is necessary to make comparisons with prior research in this area. The main comparison findings can be summarized as follows (Table 4).

Table 4. Links between previous FA and Madrid case study results

General conclusions of prior research*	Madrid case study
Density factor defined at least from population density	*Density* factor defined from 'population density' and the inverse of 'single residential'.
Diversity factor defined at least from land use mix value or entropy index	Two diversity factors labeled: *urban block diversity* and *nonresidential diversity*. Land use mix value defines the first one and 'green zones', 'industry', 'infrastructure' values the second.
Design factor but defined on different ways (street quality factor or average block size, for example)	A novelty *street network design* factor defined from centrality measures: 'straightness', 'reach' 'remoteness' and 'betweeness'.
Some *accessibility factors* defined since different points of view (accessibility by car, distance to transit or public transport, distance to CBD, residence/employment in a specialized area, etc.)	Two accessibility factors since two different points of view are presented: *job accessibility* (or *job intensity*) and *center accessibility*.

**Source:* de Abreu e Silva et al. (2006); Van Acker and Witlox (2010); de Abreu e Silva and Goulias (2009); Edwing and Cervero (2010); de Abreu e Silva et al. (2012); He and Zhang (2014).

The paper reported here is a small part of a larger work aimed at assessing what and how variables (levels of service, socio-economics, psychological, land use, etc.) influence on travel behavior with introduction of transport policy measures (Comendador et al., 2014). The data use in this study originates from the HABIT project (Habit and Inertia in mode choice behavior: a data panel for Madrid). The contribution of this particular subproject is the definition of land use factors to reach a better understanding of causal relationships between traveler attitudes, socioeconomic characteristics and travel behavior on following studies using different methodologies: structural equations and discrete choice models.

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