LAND USE AND PUBLIC TRANSPORT INTERACTION

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ABSTRACT

In the last years there was a clear and shared evidence that transport in the urban areas creates negative impacts on the society particularly for the congestion, implying an increase of travel times, the increase of air and noise pollution, the accidents, the excessive production of greenhouse gases and the land consumption. Public transport represents a more efficient mode of travel respect to car and so it could play an important role to provide a more sustainable transport system. The present paper wants to analyze the requirements and the needs to provide an effective public transport system, competitive with the private transport, focusing the attention on the relationships between built environment characteristics and the mode choice. In particular the main goal is to find some correlations between built environment and the mode choice in order to know which variables can increase the use of public transport. The applied methodology is based on a statistical analysis of measures of land use and measures of use of public transport including a correlation analysis, a regression analysis, a factor analysis and a cluster analysis. The analysis is carried out considering the real life case of the city of Rome in Italy.

Keywords: sustainable mobility, land use, urban transport, public transport

1. INTRODUCTION

In the last years there was a clear and shared evidence that transport in the urban areas creates negative impacts on the society particularly for the congestion, implying an increase of travel times, the increase of air and noise pollution, the accidents, the excessive production of greenhouse gases and the land consumption. Such occurrences are clearly related to the increasing use of the car for travel, both in developing and developed countries. In addition, the continuous spread of residences and activities, facilitated by the car, have increased the length of trips and the use of motorized private transport and, in many cases, also reducing the possibilities to develop efficient public transport system. Taking into account that public transport represents a more efficient mode of travel respect to car in terms of costs, energy and land consumption, this mode could play an important role to provide a more sustainable transport system. Starting from these remarks, the present paper wants to analyze the requirements and the needs to provide an effective public transport system, competitive with the private transport, focusing the attention on the relationships between built environment characteristics and the mode choice. This is a very controversial topic involving not only public transport/urban planning design and management issues but also a large number of other social, economic and historical elements, often not easy to measure and to compare. The main goal of the paper is to find some explicit and easy to understand correlations between built environment and mode choice in order to know which variables can increase the use of public transport. The analysis is carried out by means of an empirical study of data from the real world case of the city of Rome in Italy. The applied methodology is based on a statistical analysis of measures of land use and measures of use of public transport that includes consolidated techniques such as correlation analyses, regression analyses (single and multivariate regressions), factor analysis and cluster analysis.

This paper is structured in five sections including this introduction; the second section analyses the literature and some remarkable examples of sustainable mobility in the world; the third section shows the adopted methodology; the fourth section the results of the statistical analysis for the case of the city of Rome, in order to find the impacts of different land-use elements on the use of public transport. The fifth section contains observations and final considerations.

2. LITERATURE REVIEW

Sustainability and transportation has been heavily dealt with by the research community in the last twenty years centering the attention on the analysis of the interaction between land-use and the transport system, the role of the land use characteristics in the travel patterns choice and the importance of the public transport to develop a sustainable transport system. About the role of public transport, Vuchic (1999) shows that car dependency is not sustainable, especially analyzing the United States situation, recommending the development of a really intermodal transport systems, involving public transport services of quality. In addition, Vuchic states the importance of planning the evolution of the cities taking into account as driving force the relationship between land use and transportation. Banister (2005) underlines the importance of the implementation of appropriate policies in order to develop high-quality livable cities, also encouraging the modal shift to green modes (walk and cycle) and public transport. This can be achieved through slowing down traffic, parking and road pricing, reallocating space to public transport and making easier the use of public transport. About the opportunities provided by the public transport systems to develop a sustainable mobility, Bernick and Cervero (1997) and Cervero (1998) show, introducing the concept of the "transit metropolis", examples of transit services that provide respectable alternatives to travel by car. All these examples of transit success are characterized by different policies but always a strong interaction between the land use policy and the transport system planning.

Literature review about transportation and land-use interaction can be found in Badoe and Miller (2000) and also in Ewing and Cervero (2001, 2010). The reviews are conducted to understand if travel variables as trip frequencies, trip lengths and mode choices are correlated with the built-in environment in the studies analyzed. The studies provide an example of the complexity of the relationship between land-use and transport system, underling the difficulties to quantify general and strong relationships, effect sizes or outcome measures. The last contribution provides an exhaustive analysis of studies that try to relate, quantitatively, characteristics of land use to measures of travel by grouping the measures of built environment, as often made in literature, with the "five Ds": density, diversity, design, destination accessibility and distance to transit.

Extensive debates are related to the role played by the population and activities densities to explain the level of car and public transport use. Sinha (2003) demonstrates, with the collection of different data from 46 cities in United States, Australia, Canada, East Europe and Asia, that an high urban population density seems to be a primary element to increase transit ridership. About the impact of the density, an important observation is highlighted by Eidlin (2005). According to this contribution, the critical issue is not the average density value, but its distribution within an urban area. This consideration derives from the analysis of the city of Los Angeles that is characterized by an average density of activities and residences higher than many other Americans cities but these values are correlated with one of the lower levels of public transport share. The comparison with the data of New York and San Francisco, characterized by the one of the largest level of public transport use in the United States but by an average value of population density lower than Los Angeles, permits to underline that this condition derives from the low variation of population and activities density within the territory, that is what the author defines as "the worst of all worlds". Mees (2009), from the comparison between urban densities and transport mode shares of Australian, Canadian and United States urban areas, highlights that variations in density are little or no correlated to transport modes share, which seems more closely related to different transport policies. These findings are very different from those on which current urban policies are based and suggest the need for a radical rethinking of those policies. Other interesting contribution about the determinants of the mode choice is from Buehler (2011) with the comparison of the results of national travel surveys in Germany and in the USA. Germans are considerably more likely to walk, bike, and use public transport than Americans even if socio-economic, demographic and spatial development variables are quite similar. Travel behaviour choice seems to be more related with other factors such as transport and land-use policies as well as cultural preferences.

Gori et al. (2012) highlight the importance of density of residences and activities, the need for a good quality access system to the transit services stops and the importance of the configuration of the transit network; however, single actions on these variables demonstrate to be not successful due to the complexity of the analyzed system.

Sung and Oh (2011), analyzing the association between transit-oriented development and transit ridership in Seoul, suggest focusing the attention more than in increasing density in strengthening the transit service network, growing the mixed land-use and creating a more pedestrian friendly surrounding around rail stations working on urban design and street networks. Similar conclusions are made also by Beimborn *et al.* (1992) about the requirements for successful transit. Land use design could be sensitive to transit needs to develop “transit corridors” divided by 0.4-0.8 km from the automobile networks, in order to separate the automobile oriented land-use from the transit oriented land-use. Such areas would have a mix of land uses and higher densities to reach a concentration of trip ends along the transit service, with a high quality access system to transit stops. The importance of a high quality access system to transit stops is underlined also by Schlossberg and Brown (2004). Gori *et al.* (2006) define two possible transit oriented development to make easier the use of rapid mass transit services, characterized by high speed and high capacity transit system, usually a rail system: 1) transit-village, with a strong concentration of activities and residences in an area of about 500 m of radius (considered as the maximal tolerable distance to cover by walking); 2) compact island with lower densities, different possible configurations and a maximum extension of about 300-400 hectares (roughly a 2 by 2 km area), in which the access to the mass rapid transit system is guaranteed by the introduction of an effective feeder public transport service which ensures a large area coverage as well. While the first TOD suggested is the classic transit village, proposed firstly by Calthrope (1993), the second one is proposed by the authors and derived from the analysis of the Italian city of Venice where travel is possible, without particular problems, using ferry services along the main city canal and walking. In both cases the access phase to the mass rapid transit system becomes fundamental. In fact accessibility can penalize the “door-to-door” speed, increasing the total travel time. For the “transit village”, the access phase has to be identified at the pedestrian level working on the configuration of the road network (in fact the road network is also the network used by pedestrians, Schlossberg, 2004), while for the “compact island” the problem becomes to identify the optimal layout of transit routes balancing directness and service coverage.

3. METHODOLOGY

In order to find the requirements and the needs to provide an effective public transport system, measures of land use and measures of the use of public transport will be defined.
About the land use, measures belonging to the “D” concepts have been adopted (Table 1): density, diversity, design, destination accessibility, distance to transit.
Inside density usually measures per areal unit are computed: population/ha, employees/ha but also the sum of population and employees per areal unit named as activity density.
Speaking of diversity, jobs to population ratio is a classical measures of the level of mixed land-use.
Design includes street network characteristics within an area, that is the network used not only by the private transport, but also by the bus system and by pedestrians and bicycles; so it is useful to compute the number of nodes, the number of links and their length (the relation between link length and number of links inside an area can specify the level of curving streets) and the link density of the street network.
Measures of destination accessibility can be computed both for the private and the public transport, for example the distance to reach the central business district (CBD) or the number of zones/employees reachable for a fixed travel time. The number of transfers to reach the

CBD are a clear measures of the penalty related to the structure of the public transport system.

A part from the measures of land-use, some measures describing the level of using the public transport have been adopted (Table 2): transit modal split (both for generated and attracted trips), private demand/ transit demand, total generated trips/population, total attracted trips/employees, total intrazonal trips, total intrazonal trips/total generated trips.

If the previous measures report the word "total", it means that both transit and private demand have been considered.

Table I – Adopted measures to describe the land-use

"D"	**Measures**	**Unit**
Density	Population	[Pop]
	employees	[Emp]
	Area	[ha]
	Population/area	[Pop/ha]
	Employees/area	[Emp/ha]
	Activity density	[(Pop+Emp)/ha]
Diversity	Jobs to population ratio	[Pop/Emp]
Design	Nodes/area	[nodes/ha]
	Link length/number of links	[km/link]
	Link length/area	[km/ha]
	Links/nodes	[links/nodes]
Destination accessibility	Average transit time to reach each destination	[min]
	Transit distance to the central business district	[km]
	Number of zones reachable within a transit travel time of 30 minutes	[zones]
	Number of employees reachable within a transit travel time of 30 minutes	[Emp]
	Number of zones reachable with a travel time (private transport) greater than 60 minutes	[zones]
	Number of employees reachable with a travel time (private transport) greater than 60 minutes	[Emp]
	Number of transfers between public transport lines to reach the central business district	[Transit changes]
Distance to transit	Distance to the nearest transit stops	[km]
	Transit stops/area	[stops/ha]

Table II – Adopted measures to describe the use of public transport

Measures of public transport	**Unit**
Transit modal split (generated trips)	[%]
Transit modal split (attracted trips)	[%]
Private demand/transit demand	[veh/pax]
Total Generated trips/Population	[pce/pop]
Total Attracted trips/Employees	[pce/emp]
Total Intrazonal trips	[pce/h]
Total Intrazonal trips/ Total Generated trips	[%]

Once defined the measures of land use and the measures of use of public transport, the methodology (Fig. 1) follows the following steps:

1. a correlation analysis inside each "D" and inside the measures of the use of public transport in order to remove dependent variables;
2. a correlation analysis between measures belonging to the different "D" in order to derive the most robust links inside land use;
3. a correlation analysis between the two different groups of variables (land use and use of public transport);
4. a regression analysis (including both linear and not linear regressions, single and multivariate regressions) between measures of land-use and measures of the use of public transport;
5. finally a cluster analysis putting together zones with same land-use characteristics based on the main variables derived from the correlation analysis.

In addition, a factor analysis has been conducted in grouping the different variables into the different D´s.

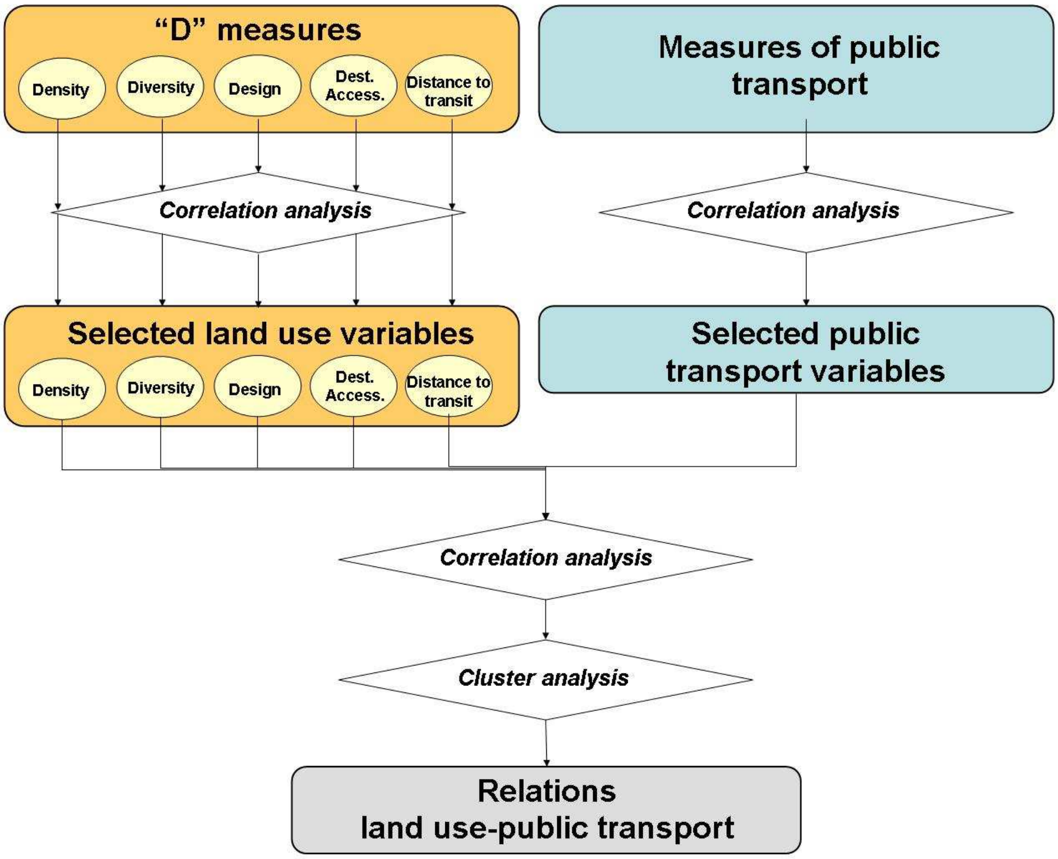

Figure 1 – Methodology of the study

Different approaches can be adopted to deal with the interaction land-use and transport system: the followed approach is clearly a descriptive approach that makes use of

aggregated macroscopic data. Different authors (Biggiero *et al*., 2001, Zhou and Kockelman, 2008, Handy *et al.*, 2005) try to investigate the problem also adopting behavioural methods based on discrete choice analysis, but sometimes these types of approaches can result in an "ecological fallacy".
The analysed problem can be certainly defined as a complex problem due to the huge number of variables concerned, belonging to different research fields (both the land use and the different modal shifts can depend also by economic variables, cultural variables and so on): in this paper the adopted methodology is developed with the goal of being sufficiently intuitive and reliable to fix some fundamental connections between the land-use and the use of the transport system.
Both one to one and one to many relations have been obtained between land use and the use of public transport as a result of the methodology.

4. THE CASE STUDY OF ROME

The urban area of Rome is characterized by a population of 3 millions with 1.1 millions employees, contributing to about 552,000 trips in the morning peak hour. A first division of the city can be done considering areas to be inside or outside the GRA (a circular freeway of approximately 68 km of length). Inside the GRA, the average population density is not high (about 70 persons/ha) and a similar measure is obtained in terms of the average employee density (about 75 employees/ha). Outside the GRA, in a very large area (about 90,000 ha) the density decreases to very low values of 6 persons/ha and 1.5 employees/ha even if the population of this external area is larger than half a million. In terms of employees, about half of the total amount are distributed in the peripheral districts, also situated outside of the GRA.
In regard to the transit system, there are two metro lines extending for a total of 36 km. These lines are radial with a unique interchange in the city centre (Termini rail station). Other seven rail lines connect the surrounding urban areas to the city centre, but these services are actually far from frequent and only three of them present an headway lower or equal than 15 minutes in the morning peak hour. The union of five of these rail lines creates an half circle inside the GRA known as the "rail ring".
Urban bus transport develops for 2,263 km (ATAC, 2009) with 315 frequency service lines, 39 fixed-time service lines, and 11 express lines. The express lines connect peripheral districts to the city centre through a radial service as well. However, corridors used by express lines are usually shared with private traffic or other type of public transport services, thus reducing their operating speed and reliability. The other bus lines are based on an extensive rather than intensive service, with low-medium frequency lines and a very large service coverage.
In regard to private transport, Rome has a very high level of automobile ownerships (more than 700 for 1,000 persons) and the road network is frequently congested. Large part of the historical centre of the city, one of the main point of concentration of activities, is a traffic limited zone (ZTL) and the access in the area is permitted only to the residents cars. In many districts of the inside city, there is a relevant lack of space for parking; this trouble is partially offset by an extensive use of motorcycles.
The transit share nowadays is estimated to be around 30%.

The measures of land use and the measures of use of public transport (Table I and Table II) have been computed for the 126 zones which represent the districts of Rome. These zones are derived from the grouping of the about 500 traffic zones used for the traffic model of the city.
The data on private and public transport demand, for the morning peak hour, as well as other data related to demographic and socio-economic characteristics adopted to compute the measures were obtained from the data bank of ATAC, the mobility agency for the city of Rome.

4.1. Built environment measures statistics

From the analysis of the measures inside each "D" and from the measures of the use of public transport, a set of statistics have been computed: the minimum value, the average value, the maximum value, the standard deviation and the ratio between the standard deviation and the average value. These statistics can be helpful to understand the current situation of the city of Rome respect to the selected measures.
About density and diversity (Table III and IV), the statistics report a high variation of the measures, given by the ratio between the standard deviation and the average value: especially the jobs to population ratio reports a variation coefficient of 2.9 and it means that there is not a clear mixed land-use in the Rome zones, while we can also have purely residential district and purely business district.
About design (Table V), the values of the variation coefficient are lower than values obtained for measures of density and diversity: the measures of link length/number of links and links/nodes report respectively a coefficient value of 0.4 and 0.1 and it implies that in the city of Rome street links are usually 200 meters long and there is a ratio between links and intersections of 1.26 on average (more links respect to nodes means that there are less route choice for transport modes using the street network).

Table III – Statistics of density measures

	Pop	**Emp**	**Area**	**Pop/area**	**Emp/area**	**Activity density**
min	7.00	48.00	46.00	0.02	0.01	0.05
average	17,971.39	7.985,48	754.48	67.67	32.83	100.51
max	77,927.00	57,306.00	6,396.00	255.54	342.47	406.34
stand.dev.	14,775.64	10,251.83	1,178.08	65.14	49.86	94.46
Stand dev/average	0.8	1.3	1.6	1.0	1.5	0.9

Table IV – Statistics of diversity measures

	Jobs to population
min	0.09
average	1.40
max	33.00
stand.dev.	4.03
Stand dev/average	2.9

Table V – Statistics of design measures

	nodes/area	**Link length/number of links**	**Link length/area**	**Links/nodes**
min	0.10	0.05	0.03	0.99
average	1.42	0.09	0.14	1.26
max	3.87	0.26	0.30	1.58
stand.dev.	0.85	0.04	0.07	0.13
Stand dev/average	0.6	0.4	0.5	0.1

Table VI – Statistics of destination accessibility

	Average time to destinatio n	**Distanc e to CBD**	**zones within 30 min (PT)**	**Empl.s within 30 min (PT)**	**zones more than 60 min**	**Empl.s more than 60 min**	**transf. to CBD**
min	48.80	0.00	0.00	0.00	2.00	2,820.00	0.25
average	76.69	12.97	4.02	52,761.35	53.93	457,852.54	1.35
max	183.87	34.86	21.00	311,526.00	116.00	980,525.00	3.70
stand.dev.	20.71	7.78	4.53	67,409.07	30.01	302,367.30	0.64
St. dev./average	0.3	0.6	1.1	1.3	0.6	0.7	0.5

Table VII – Statistics of distance to transit

	Distance to the nearest transit stops	**Transit stops/area**
min	10.63	0.000
average	5,336.75	0.004
max	9,999.00	0.036
stand.dev.	4,745.77	0.007
Stand dev/average	0.9	1.8

About destination accessibility (Table VI), the travel times of 30 minutes, in case of destination accessibility with transit, and greater than 60 minutes, with private transport, have been selected after a sensitivity analysis of the relation between different ranges of travel times and the ratio private transport demand/transit demand. For this set of measures, only the average transit time from each zone has a low variation coefficient (0.3), but it is not a good result in term of use of transit system, because on average these time value are of 1 hours and 20 minutes. Also the numbers of transfers to reach the central business district have not a high variation, but usually 2 changes along the transit system are needed to reach the CBD with a resulting high penalty in using the transit system itself. High variations exist in the measures of zones and employees reachable within a certain travel time with public and private transport modes, especially for the public transport.
Finally also the distance to transit measures (Table VII) report a high variation, with values of 5 km on average for the distance to the nearest transit stop and almost zero values of transit stops/ha (only urban rail and metro network are considered for the computation of transit stops).

About the measures of the use of public transport (Table VIII), on average the transit modal split is about 27% for generated trips and of 19% for attracted trips. The high variation of private demand/transit demand show that there is a high variability in the use of public transport depending on the characteristics of each zone.

Table VIII – Statistics of measures of public transport

	Trans. modal split [gen. trips]	Trans. modal split [attr. trips]	Private demand / transit demand	Total Gen. trips / Pop	Total Attracted trips / Emp	Total Intr.trips / total gen. trips	Total Intrazonal trips
min	0.02	0.00	0.70	0.12	0.06	0.00	0.00
average	0.27	0.19	7.25	0.30	0.52	0.01	69.74
max	0.54	0.62	129.47	7.17	1.55	0.07	720.58
stand.dev	0.12	0.15	14.20	0.63	0.24	0.01	108.43
Stand dev/average	0.5	0.8	2.0	2.1	0.5	1.0	1.6

Also the availability of starting a trip is high variable (variable coefficient of 2.1). About the intrazonal trips, that are a measure of how much a zone is self-sufficient, their values are generally low (70 trips and 1% of the total generated trips on average), but also in this case the variability between zones is quite high.

4.2. Correlation and regression analyses

The correlation analysis has been firstly performed inside each “D” and inside the measures of the use of public transport in order to remove dependent links. The analysis has been conducted considering the dependent links those with a correlation index (Pearson coefficient) R greater than |0.75|.
Starting from land-use variables (Table IX), measures of density are reduced from 6 variables to 3 variables, measures of design are reduced from 4 variables to 2 variables, measures of destination accessibility are reduced from 7 variables to 2 variables, while finally all the measures of distance to transit and diversity are selected.

Activity density is directly correlated to population/area and employees/area (R=0.87 and R=0.76 respectively) and summarize both the measures. The relation between population/area and population reports a R value of 0.6, so while the first one has been represented by using the activity density, the last one has to be selected.
About the design, nodes/area are strongly correlated to Link length/number of links and Link length/area: especially with the last one the R coefficient is equal to 0.97. Also between the level of winding streets (Link length/number of links) and the link density (Link length/area) the correlation is high (R=-0.75), but as an inverse proportion: *i.e.* more the streets are straight and more the density of the street network is high.

The transit distance to the central business district is strictly correlated to the number of zones/employees reachable within a travel time on private transport greater than 60 minutes (R=0.88), and the first one has been selected given the great role of the CBD on mobility especially in the case of Rome (the CBD overlap the unique interchange of the metro lines, i.e. Termini station).

Table IX – Resulting measures of land use after the correlation analysis inside each "D"

"D"	Starting Measures	Selected measures
Density	Population	Population
	employees	
	Area	Area
	Population/area	
	Employees/area	
	Activity density	Activity density
Diversity	Jobs to population ratio	Jobs to population ratio
Design	Nodes/area	Nodes/area
	Link length/number of links	
	Link length/area	
	Links/nodes	Links/nodes
Destination accessibility	Average transit time to reach each destination	
	Transit distance to the central business district	Transit distance to the central business district
	Number of zones reachable within a transit travel time of 30 minutes	
	Number of employees reachable within a transit travel time of 30 minutes	Number of employees reachable within a transit travel time of 30 minutes
	Number of zones reachable within a travel time (private transport) greater than 60 minutes	
	Number of employees reachable within a travel time (private transport) greater than 60 minutes	
	Number of transit transfers to reach the central business district	
Distance to transit	Distance to the nearest transit stops	Distance to the nearest transit stops
	Transit stops/area	Transit stops/area

After performing the correlation analysis for the measures of use of public transport (Table X), only total intrazonal trips are not selected due to the high correlation factor (R=0.83) with the total intrazonal trips/total generated trips.

Table X – Resulting measures of the use of public transport after the correlation analysis

Measures of public transport	Starting Measures	Selected measures
	Transit modal split (generated trips)	Transit modal split (generated trips)
	Transit modal split (attracted trips)	Transit modal split (attracted trips)
	Private demand/transit demand	Private demand/transit demand
	Total Generated trips/Population	Total Generated trips/Population
	Total Attracted trips/Employees	Total Attracted trips/Employees
	Total Intrazonal trips	
	Total Intrazonal trips/ Total Generated trips	Total Intrazonal trips/ Total Generated trips

The next point of the methodology is the correlation analysis between the selected measures belonging to different "D": activity density is directly correlated with both the measures of design (nodes/area: R=0.85 and links/nodes: R=0.75) and these are the most important links inside land-use. Other correlations exist between activity density and the measures of destination accessibility, but they are not selected due to the correlation index lower than 0.75. Passing from the correlation analysis to the linear regression, the relations between activity density and nodes/area and between activity density and links/nodes report respectively a R^2 value of 0.72 and of 0.56.

At this point a factor analysis has been conducted in grouping the different variables into the different D´s: factors are derived (latent variables) by summarizing the information originally contained in a larger number of variables, in particular all the variance of the starting variables is explained by the main components (Principal Component Analysis, PCA). Globally, 6 factors have been identified:

- starting from the first "D", the Density measures, the factor analysis identifies three factors (covering the 89% of the variance):
    a. the first one takes into account mainly the density of population and employees (or their combination, *i.e.* activity density);
    b. the second one takes into account mainly the single density of population or employees (not their combination), as well as the absolute values of population and employees;
    c. finally the third one takes into account the dimension of the area and the absolute value of the population.
- passing to the design measures, only one principal component has been identified (covering the 82% of the variance): this component is a function of all the design measures with the same weight.
- about the destination accessibility measures, two factors have been identified (covering the 86% of the variance):
    a. the first one is quite uniformly explained by all the destination accessibility measures
    b. the second one is explained by the number of zones and employees reachable within a transit travel time of 30 minutes.

For diversity and distance to transit no factorial analysis has been conducted, because of the number of measures inside each "D" (respectively one and two measures). A part from the second factor obtained for the destination accessibility measures, that means and underlines the importance of the transit travel times (we can call this factor as "active transit accessibility"), for the other factors there is not an exhaustive and clear interpretation, that is often the main problem of performing a factor analysis.

So, the next step is to proceed with the correlation analysis between selected measures of land use and selected measures of transit demand, that reports the strong correlation of transit modal split [attracted trips] with the following variables of land-use: the activity density (density, R=0.81), links/nodes (design, R=0.75) and the number of employees reachable within a transit travel time of 30 minutes (destination accessibility, R=0.75). Passing to the linear regression, the most robust relation is between the transit modal shift of attracted trips and the activity density with a R^2 value of 0.65.

About the interaction between the transit modal shift of generated trips with the land-use variables, the higher correlation factors are obtained with the following measures: for the density, with the area of the zones and the activity density (R=-0.56 , R=0.65 respectively), for the design, with both nodes/area and links/nodes (R=0.62 , R=0.69 respectively), for the destination accessibility, with both the transit distance to the CBD and the number of employees reachable within a transit travel time of 30 minutes (R=-0.58 , R=0.55 respectively). However the correlation factors, as reported, are not higher than 0.69 and performing a linear regression the statistics are not suitable to obtain a good representation of the studied phenomena; it depends from the complex relations that link the transit modal shift of generated trips and the selected land-use measures: Figures 2, 3 and 4 show that the most significant interactions between the two types of measures are typically not linear.

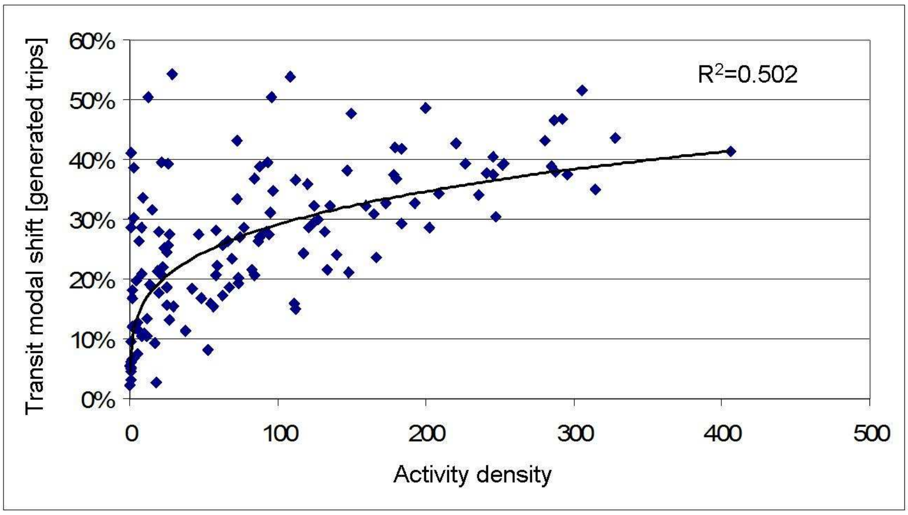

Figure 2 – Transit modal shift of generated trips as a function of activity density

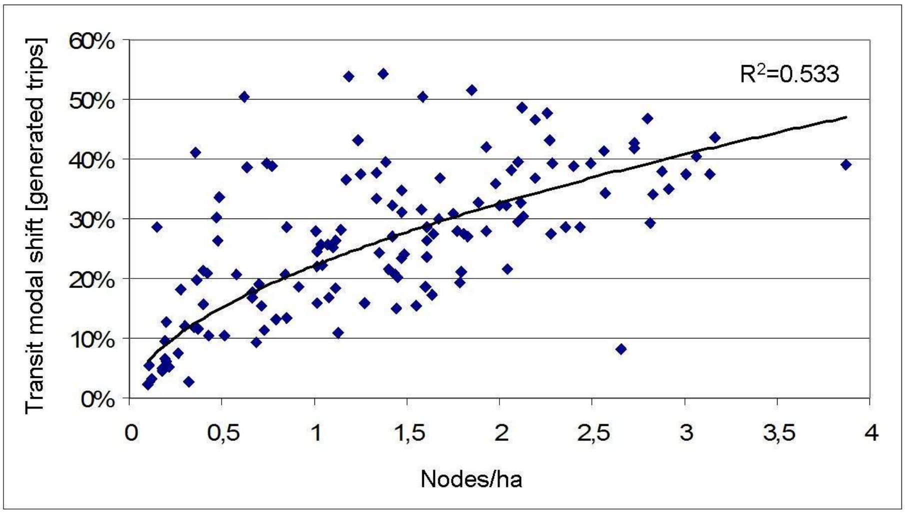

Figure 3 – Transit modal shift of generated trips as a function of nodes/ha

However there is a quite high correlation factor between the two transit modal shifts [generated vs attracted trips] with a R index equal to 0.74: actually, reporting the first measures as a function of the second one (Fig.5) it is clear that there is a common trend more than linear, for value of transit modal shift of attracted trips lower than 40%, and less than linear after this threshold.

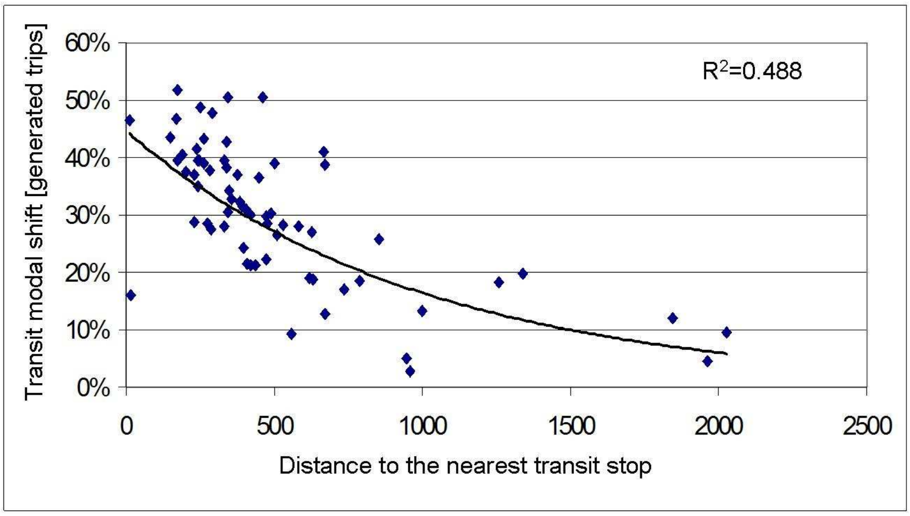

Figure 4 – Transit modal shift of generated trips as a function of distance to the nearest transit stop

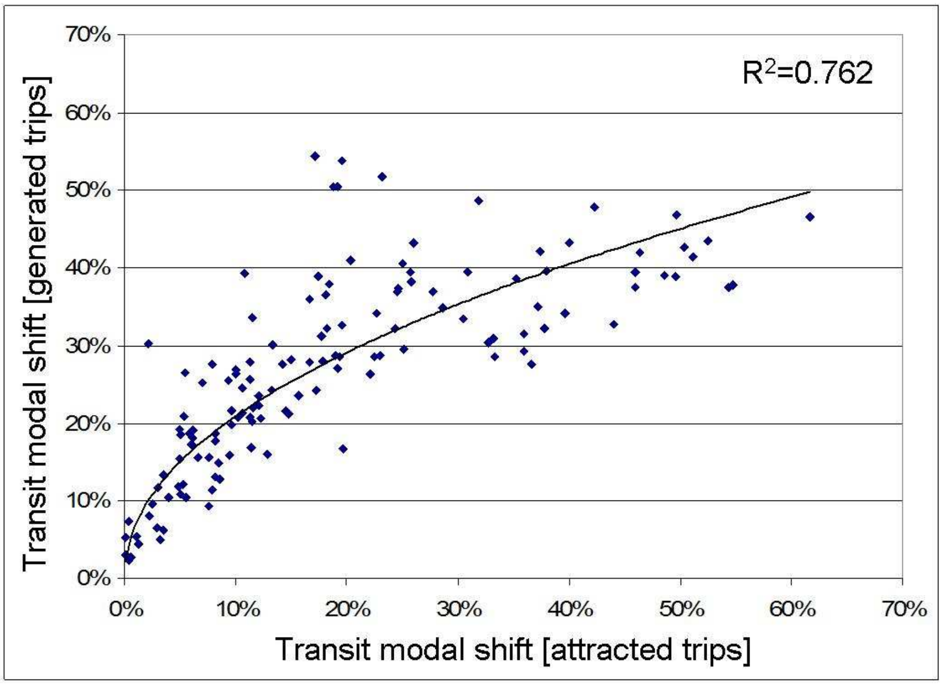

Figure 5 – Transit modal shift of attracted trips versus Transit modal shift of generated trips

The higher significance of the correlation between transit modal shift of attracted trips with the selected land use measures can be explained by the different impact of the access-egress phase to/from the mass transit system. In fact while the access is considered an easy phase, because the trip from the origin zone to the transit stop can be done using different modes (walk, bike & ride, park & ride, kiss & ride etc.), the egress phase from the final stop to the destination is constrained by the transit and pedestrian network defined around the destination zone.

The remaining measures of the use of public transport reports low correlation coefficients with the selected land use variables, except for the total generated trips/Population that is highly correlated with the jobs to population ratio (R=0.82). However this last relation is mainly influenced by few points with a jobs to population ratio of 25÷35 and so hereinafter it will not be considered.

Interesting comments can be extract from the one to one comparison of the ratio between private demand and transit demand with the land use variables: it strongly decreases with the increase of activity density, but is also dependent from the design of an area (more are the nodes per area and higher is the ratio links/nodes, lower is its value). In case of links/nodes there is a high dispersion of the points for high values of private demand/transit demand: it happens also for distance to CBD, the number of transit transfers to reach the central business district and the distance to the nearest transit stops.
Also for the ratio between private demand and transit demand, there are not always simple explainable relations and the following Figures 6 and 7 report some of the most significant not linear interactions with the "D" measures

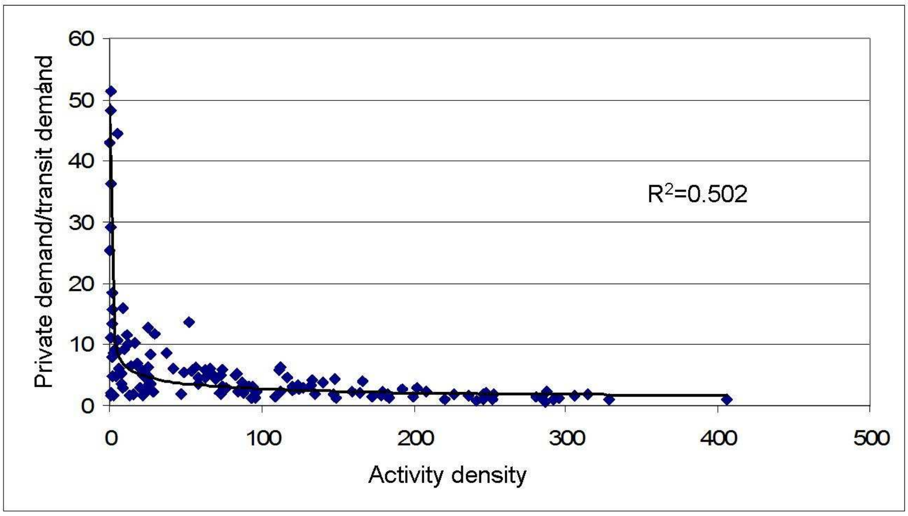

Figure 6 – Private demand/transit demand as a function of activity density

Defined the main one to one relations inside land use and the main one to one relations between the use of the public transport and the land use, also one to many possible functions have been found. Inside the measures of land use there is a linear relation between activity density and the two measures of links/nodes and nodes/area (R^2=0.76); between public transport and land use a linear relation exists between the transit modal shift of attracted trips and the measures of links/nodes, the activity density and the number of employees reachable within a transit travel time of 30 minutes (R^2 = 0.75).
So the use of public transport, represented by the transit modal shift of attracted trips, for the 180 zones of Rome is linearly correlated to the land-use through measures of the design of the street network (links/nodes, nodes/area) and the destination accessibility as a function of

the distribution of employees respect to the shape of the transit network (in order to derive the number of employees reachable within 30 minutes by public transport).

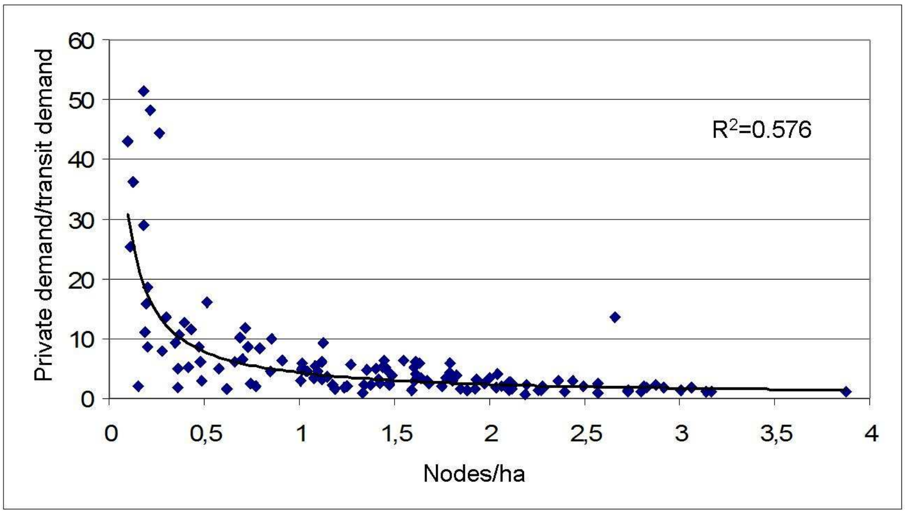

Figure 7 – Private demand/transit demand as a function of nodes/ha

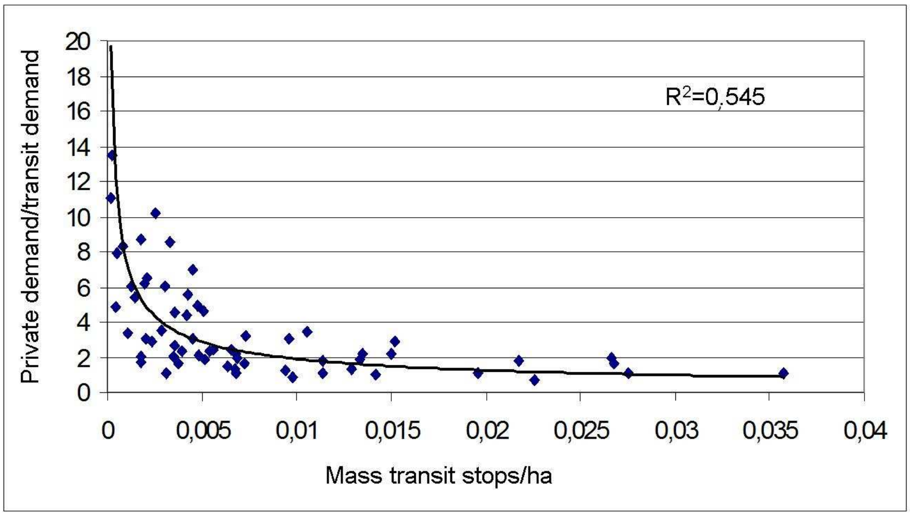

Figure 8 – Private demand/transit demand as a function of mass transit stops/ha

4.3. Cluster analysis

In the previous analysis, all the zones of Rome have been considered together in order to extract the main variables inside the land-use and the use of public transport and the main relationships between the two systems. This last chapter faces with the last point of the methodology of the study, that is a cluster analysis putting together zones with homogeneous land-use characteristics using the Bottom-up technique. In particular the pure land-use measures have been considered (i.e. density, diversity and design) to create the clusters: for density the measures of activity density has been considered, for the diversity the measures of jobs to population and for design the measures of nodes per unit of area. These measures are selected as a result of the correlation analysis. In fact they are the ones with the higher

variation coefficient and the best descriptor of the land use characteristics.
For each of the previous measures, four ranges have been defined in order to reduce the variation coefficient (standard deviation/average value) inside each cluster:

1. Activity density: 0÷20 (very low-low density), 20÷50 (medium density), 50÷100 (high density), >100 (very high density);
2. jobs to population ratio: 0÷0.25 (residential areas), 0.25÷0.75 (low-medium values of activities), 0.75÷1.5 (equilibrium range between jobs and population), >1.5 (business districts);
3. nodes per unit of area: 0÷0.2 (considering the average area, this range defines areas with low values of intersections – lower than 100), 0.2÷0.7, 0.7÷1.5 (about 1,000 nodes), >1.5 (very intersections dense areas).

The results are 20 clusters (if only one zone derives from the clustering, it is not selected), each one composed by zones pertaining to the same class (range of value). The clusters describes the current development of the city of Rome: we can pass from typical suburban districts characterized by very high areas, low density, mainly residential, a road network with few route choices, to typical historical areas characterized by compact nucleus, high density and diversity, a compact road network.
For each zone of each of the 20 clusters, the values of Transit modal shift (both generated and attracted trips) have been analyzed in order to understand if homogeneous land use zones could have the same level of use of public transport. The results are reported as follows:

1. Clusters containing mainly residential peripheral zones of high dimension can have low or high value of transit modal shift of generated trips (the difference can reach on average a value of +30%), depending respectively by the absence or the presence of stops of mass transit systems;
2. Clusters of the same land-use characteristics as in point 1 don't have high variations of transit modal shift of attracted trips, due to the fact that the mass transit system works for the egress phase only if the mass transit stops are located at the final destination of the trips (low egress distance values);
3. Passing to clusters containing zones closest to the central area of the city, the dimensions of the areas decrease, usually there is a mixed land use structure and the transit modal shift is high both for generated and attracted trips; in this case the presence of a mass transit system in a zone implies a difference of transit modal shift respect to zones of the same cluster, but without mass transit systems, of a maximum of +10% (with transit modal shift ranging from 30 to 40%).

CONCLUSION

The present paper analyzes the requirements and the needs to provide an effective public transport system, competitive with the private transport, focusing the attention on the relationships between built environment characteristics and the mode choice. In order to reach this objective, a methodology has been developed based on a statistical analysis of the measures of land use and the use of public transport, including a correlation analysis and a cluster analysis. The methodology has been applied to the city of Rome, that has been divided firstly into 126 zones and after into 20 clusters for fixed range of the main land use variables.

The first result of the methodology is the definition of the main independent variables of land use, in particular the activity density (density), the jobs to population ratio (diversity), the ratio between nodes and area and between links and nodes (design), the distance to the CBD and the number of employees reachable within a transit travel time of 30 minutes (destination accessibility), the distance to the nearest transit stops and the number of transit stops for area (distance to transit).

A linear interaction has been found between the transit modal shift of attracted trips and the measures of activity density, the measures of the design of the street network (as nodes/area and links/nodes) and measures belonging to the design of the mass transit system and the distribution of activities.

The transit modal shift of generated trips seems to be less constrained by the land use characteristics respect to the transit modal shift of attracted trips: this result can be explained by the different impact of the access-egress phase to/from the mass transit system. In fact while the access is considered an easy phase, because the trip from the origin zone to the transit stop can be done using different modes (walk, bike & ride, park & ride, kiss & ride etc.), the egress phase from the final stop to the destination is constrained by the transit and pedestrian network defined around the destination zone.

The difference between the access at the origin point and to the destination point has been underlined also by performing a cluster analysis: moreover the cluster analysis has permitted to quantify the differences of transit modal shift (both generated and attracted trips) between zones belonging to same clusters (and so with common land use aspects) and to understand that these differences are mainly dependent by the presence or not of a reliable mass transit system. In some clusters it can happen that also if the land use characteristics are against the public transport, the existence of a mass transit station can deeply increase the transit modal shift.

The results confirms the importance of variables such as density, particularly the combined density of activities and residences, the need to pay attention to the design of the cities and how much the design is important to increase the use of public transport. However the complexity of the relationship remains and it is clear the need to work jointly on the two systems.

Future developments of the study will imply: 1) to apply the explained methodology in other city contexts in order to understand if the obtained results can be easily extended or if they are specific of the analyzed context; 2) to investigate other type of approaches as behavioral approaches based on discrete choice analysis.

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