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# The influence of the built environment on mode choice – evidence from the journey to work in Sydney

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## Abstract

The Five Ds of the built environment – density, land use diversity, pedestrian oriented design, destination accessibility and distance to transit – are suggested by Ewing and Cervero (2010) as the built environment factors that can reduce car use in favour of public transport, walking and cycling. This paper examines the strength of these effects by analysing whether built environment factors can be shown to influence journey to work transport mode share in Sydney.

GIS and multivariate regression analysis of mode share and built environment data in 1553 Travel Zones across the Sydney metropolitan area shows that each of the Five Ds of the built environment are statistically significant determinants of mode share for the journey to work, with the exception of pedestrian oriented design. The degree to which each built environment factor influences mode share is expressed as an elasticity, allowing the strength of each factor to be compared. Destination accessibility by public transport and population density appear to be the most important factors. However the elasticities of the Five Ds were much lower than the control variables of car ownership, income and workplace location.

Results suggest that the design of local urban areas can influence non-car mode share by residents. This gives support to planning controls that support transit-oriented design. However, the effect of the built environment should not be overstated and consideration should also be given to more strongly associated variables such as car ownership and workplace location.

## 1. Introduction

The demand for travel within major cities creates a significant impact upon the liveability, sustainability and economic performance of the regions in which they are located. In particular, growth in the use of private cars has led to increasing road congestion, greenhouse gas emissions and reduced amenity in urban areas.

Transit-oriented development (TOD) has been identified as a strategy to accommodate increasing urban populations with reduced impacts on transport networks and the environment. TOD is defined as a mixed use community within walking distance of a transit stop and commercial area (Calthorpe 1993). By providing a range of local services within walking distance and access to regional destinations (such as employment centres) by rapid public transport links, it is thought that residents will be less reliant on private vehicles for common trips. This can lead to a lower impact on the city's transport infrastructure and urban environment.

However TOD is not prescriptive in either its design or outcomes. While there are broad principles which can be ascribed to TOD and related New Urbanist development (Congress for the New Urbanism 2001), in practice the design of each development will differ depending on site characteristics, market demand and planning context. Some aspects of a 'typical' TOD may not be readily achievable on a given project, such as a particular level of density, mix of land uses or close proximity to a rail station. To what extent could we expect that such a development will achieve the same transport outcomes as those as successful TODs?

Studies of travel behaviour of residents in TOD sites show significant variability in public transport use. For example, Lund, Cervero & Willson (2004) found that public transport mode share at TOD sites varied from 45% at San Francisco's Pleasant Hill BART station to 3% at Los Angeles' Long Beach Metro station with an average mode share across all surveyed sites of 27%. More detailed research is required to understand why transit mode shares vary to this degree. However studies need to be consistent and rigorous in their methods if they are to be comparable. After reviewing the available evidence of TOD transport impacts, Crane (1996) found that "the literature on transportation impacts of neotraditional or other new urbanism designs has yet to employ a strong conceptual framework when investigating these issues making both supportive and contrary empirical results difficult to compare or interpret". More detailed and rigorous analysis of the likely contributing factors is therefore required to be able to understand the underlying reasons for travel behaviour and subsequently predict travel outcomes of future TODs.

To bridge this gap, a growing number of researchers have investigated how the built environment – the land use and transportation characteristics of a city or suburb – can affect travel demand. While early research focussed on the role of density (Newman & Kenworthy 1989), a broader framework of built environment factors and methods of research has now been defined (Cervero 2002; Cervero & Kockelman 1997; Ewing & Cervero 2010). This research has begun to provide an improved understanding of how various aspects of the built environment, together with socio-economic factors, combine to influence transport use.

# 2. Built environment factors that may influence travel choice

In a seminal study of land use and transport characteristics of world cities, Newman and Kenworthy (1989) established a strong relationship between a variety of density indicators with public transport use and petrol consumption. The research indicated that metropolitan density was negatively correlated with per capita petrol use, with identifiable groupings of North American, Australian, Western European and Wealthy Asian cities along a scale of increasing density and lower levels of car use. The authors noted that the influence of density on transport use was most pronounced for areas where the population density is greater than 30 people per hectare and recommended a program or re-urbanisation to increase metropolitan densities above this threshold (Newman and Kenworthy 1991).

These studies have spurred some twenty years of debate on the importance of density. For example, Mees (2009) recently re-analysed the relationship between metropolitan density and journey to work mode in 50 metropolitan areas, using with consistent definitions of metropolitan areas. Mees's comparison showed little correlation between metropolitan population density and journey to work by car. Mees concludes that density does affect travel behaviour, when "all other factors are equal" but "the effect of density is outweighed by other factors" (Mees 2009).

Analysing the impact of local density, rather than metropolitan density, Brunton and Brindle (1999) undertook a comparative study of travel behaviour in different types of suburbs in Melbourne. The authors concluded that accessibility to destinations and financial resources were more important determinants of public transport use than density. More recently, Rickwood and Glazebrook (2009) analysed journey to work mode share at the Collection District level in Sydney, Melbourne, Brisbane, Perth and Adelaide. The effect of local population density, distance from the CBD and car ownership were analysed in a multi-variate regression. Local density was found to be a minor determinant of public transport use, but was found to be highly correlated with several other indicators (car ownership, public transport accessibility, and local employment), thus serving as a proxy for these factors when data is not available.

In the United States, Cervero has identified a broader set of built environment factors that may influence travel behaviour (Cervero & Kockelman 1997; Ewing & Cervero 2001; Ewing &

Cervero 2010). These built environment factors categorise different characteristics of urban areas into the 'Five Ds', namely:

- Density – how many residents and/or employees are located within a unit of area (such as hectares), indicating potential trip origins and destinations;
- Land use diversity – the degree to which different land uses are located within close proximity of each other, reducing the need to travel outside of the area for common trip purposes;
- Pedestrian oriented design – a range of measures which describe how conducive an area is to walking, variously described by the quality of footpaths and road crossings, the connectivity of the road network, and the quality of the pedestrian environment (noise, safety, visual interest, weather protection);
- Destination accessibility – reflecting the proximity or ease of access to regional trip opportunities such as employment, which can be measured by distance or time; and
- Distance to transit – how far an area is from the nearest public transport stop or station.

These built environment factors have been adopted as the basis for the subsequent case study of transport mode choice in Sydney as described below.

# 3. Case study analysis of the Sydney metropolitan area

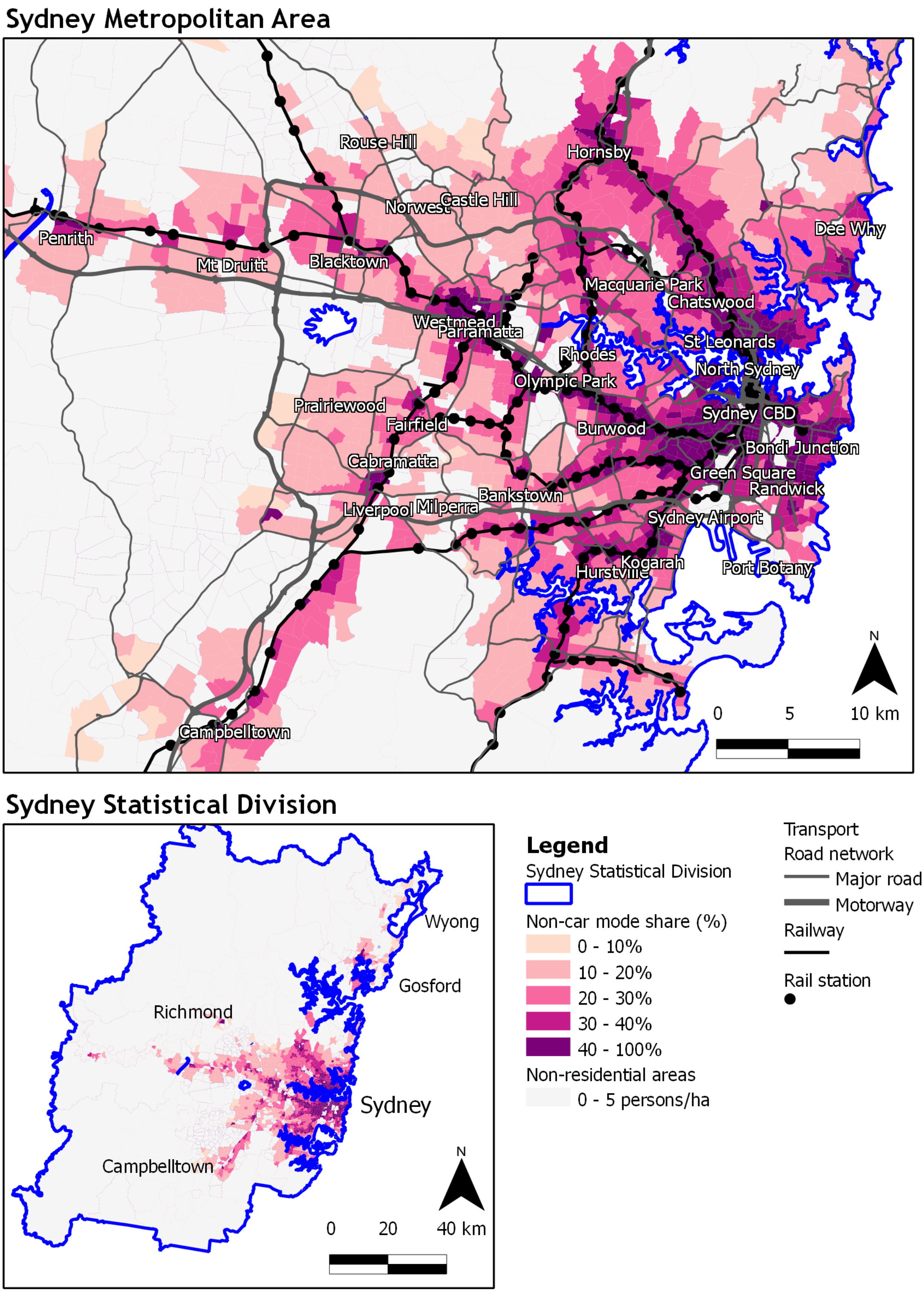
## 3.1 Study area

The case study analysed built environment and travel data for the greater Sydney region. The extent of Sydney considered was the Sydney Statistical Division, which is defined by the Australian Bureau of Statistics (ABS). The geographic unit selected is the Travel Zone, defined by the Bureau of Transport Statistics, a division of the NSW Department of Transport. Travel Zones are generally larger than the ABS Collection Districts (CD), but are smaller than Statistical Local Areas (SLA), with a total of 2,690 Travel Zones defined within the Sydney Greater Metropolitan Area.

As the purpose of the case study was to identify travel behaviour within existing residential areas, certain thresholds for population density were considered appropriate. At the lower population density threshold, a boundary of 5 residents per gross hectare was defined. This threshold is consistent with recent research by Rickwood and Glazebrook (2009). Review of the data also showed certain Travel Zones at very high population and employment densities clustered within Sydney CBD. These Travel Zones constituted a very small percentage of the data set, but due to the small area and very high population, skewed the data analysis substantially. Therefore, Travel Zones from Sydney CBD, defined as the Inner Sydney Statistical Local Area (as defined by the Australian Bureau of Statistics) were excluded from the case study analysis.

Finally, a total of 32 Travel Zones had zero outbound trips recorded in the 2006 Census (and therefore no mode share data) and were excluded from further analysis. A total of 1553 Travel Zones then remained for analysis in the case study. The selected areas are shown (with associated journey to work mode share) in Figure 1.

**Figure 1: Journey to work non-car mode share in the Sydney study area**




## 3.2 Variables analysed

### *3.2.1 Dependent variable*

The dependent variable for the analysis was defined as 'non-car mode share', which is the sum of public transport and 'other' mode shares (or alternatively [1 – car mode share]). This measure includes all public transport use and trips where walking and cycling is the primary mode of travel.

Non-car mode share provides a better representation of the potential benefits of TOD than public transport mode share, as it includes walking and cycling trips. Non-car mode share for the Sydney metropolitan area and Sydney Statistical Division is illustrated in Figure 1.

### *3.2.2 Independent variables*

Data was sourced for each independent built environment variable shown in Table 1. The analysis used data types that are consistent with a recent meta-analysis of over 50 published studies of the relationship between built environment and travel (Ewing & Cervero 2010).

**Table 1: Built environment variables and data sources**

| Built environment characteristics | Built environment variables and units of measurement | Source |
|---|---|---|
| Density | Residential density (residential population per hectare).<br>Employment density (jobs per hectare). | Analysis of 2006 Census data (Bureau of Transport Statistics 2010) |
| Diversity | Proximity to local shops (retail, accommodation and food services jobs per hectare).<br>Jobs/housing diversity (index of 0-1 where 0 = single land use (100% residential or employment) and 1 = equal population and jobs). | Analysis of 2006 Census data (Bureau of Transport Statistics 2010) |
| Design | Street density (metres of streets per hectare)[1]. | Analysis of Open Street Map 'Highway' dataset (Open Street Map Australia 2010). |
| Destination accessibility | Percentage of jobs in Sydney accessible by car within 30 minutes.<br>Percentage of jobs in Sydney accessible by public transport within 30 minutes. | Sydney Strategic Travel Model output (Transport Data Centre 2009). |
| Distance to transit | Distance (in kilometres) to the nearest CityRail station. | Analysis of distance between rail stations (Geoscience Australia 2006) and Travel Zone centroids (Bureau of Transport Statistics 2010) |

*Notes:*

*1. The 'street density' measurement includes all streets within the Open Street Map Highway dataset, excluding motorways.*

### *3.2.3 Control variables*

Control variables are required to isolate the effect of major contributing factors to mode choice that are not captured by built environment variables (Frank & Pivo 1994). Typically, control variables that are introduced to similar studies include socio-economic factors, attitudinal variables, crime variables, socioeconomic variables and workplace variables amongst others (Ewing & Cervero 2010). They allow the strength of the built environment variables to be measured while discounting the confounding effects of the characteristics of the residents.

The control variables selected for the case study were weekly income, car ownership and percentage of work trips with a destination in Sydney CBD, as outlined in Table 2.

**Table 2: Control variables and data sources**

| Independent variables | Source |
|---|---|
| Weekly income per person | Analysis of 2006 Census data (Bureau of Transport Statistics 2010) |
| Car ownership per household | Analysis of 2006 Census data (Australian Bureau of Statistics 2006) |
| Percentage of work trips to Sydney CBD | Analysis of 2006 Census data (Bureau of Transport Statistics 2010) |

## 3.3 Data analysis method

A two stage analysis was used to understand whether each independent (built environment) variable is correlated with increased non-car mode share and to determine the extent of that relationship.

Firstly, each built environment variable was plotted against non-car use in a bivariate analysis as an XY scatter plot. This allowed visual inspection of the data relationship. A trend line was added to the plot to provide the equation and R-squared correlation of determination for the data. Each of the variables was assessed for the correlation strength and direction of the observed relationship (positive or negative). The analysis was used to determine suitability for each variable to be considered in the subsequent multivariate analysis. At this stage, the jobs-housing diversity index was excluded from further analysis on the basis that this variable did not have an observed relationship with non-car mode share.

Secondly, the data was analysed in a multivariate analysis. By analysing all variables at once, as well as introducing control variables, confounding factors were minimised and the strength of each built environment variable could be identified. A stepwise regression with backward elimination of variables was developed. This process commenced with the variables selected from the bivariate analysis, while progressively removing insignificant variables one at a time. Insignificance was determined by a p-value of $>0.05$ (at the 95% confidence level), with one variable removed per model run chosen by the smallest t-statistic. Insignificant built environment variables which were removed from the regression model through the stepwise process were (in order) street density and local shop density. All remaining variables were significant at the 95% confidence level.

The adjusted R-squared value for the multivariate regression model was 0.89, showing that 89% of the variability within the mode share data is explained by the regression model. This provides a high level of confidence that the built environment variables selected in the case study are useful in explaining the differences in mode share observed between different parts of Sydney.

Following from the multivariate regression, the elasticity of each variable was calculated. The elasticity describes by how the dependent variable (non-car mode share) would change with a 100% increase or decrease of the independent (built environment) variable. Elasticities for built environment variables were compared against data observed in similar studies and inferences were drawn regarding the consistency of the results.

## 3.4 Results

The results from multivariate analysis showed that the built environment variables that influenced mode share to the greatest extent were destination accessibility, density, land use diversity and distance to transit (in decreasing order of magnitude) as shown in Table 3. Pedestrian oriented design was found to be not statistically significant.

The multivariate analysis also indicated that built environment factors were relatively weakly correlated to non-car mode share compared to the control variables of car ownership, proportion of workers travelling to Sydney CBD and income (in declining order of importance). The significance of these control variables indicates that studies of the built environment that rely solely on bivariate data analysis and ignore socio-economic factors risk over-emphasising the influence of the built environment.

**Table 3: Elasticity of built environment variables with respect to non-car mode share**

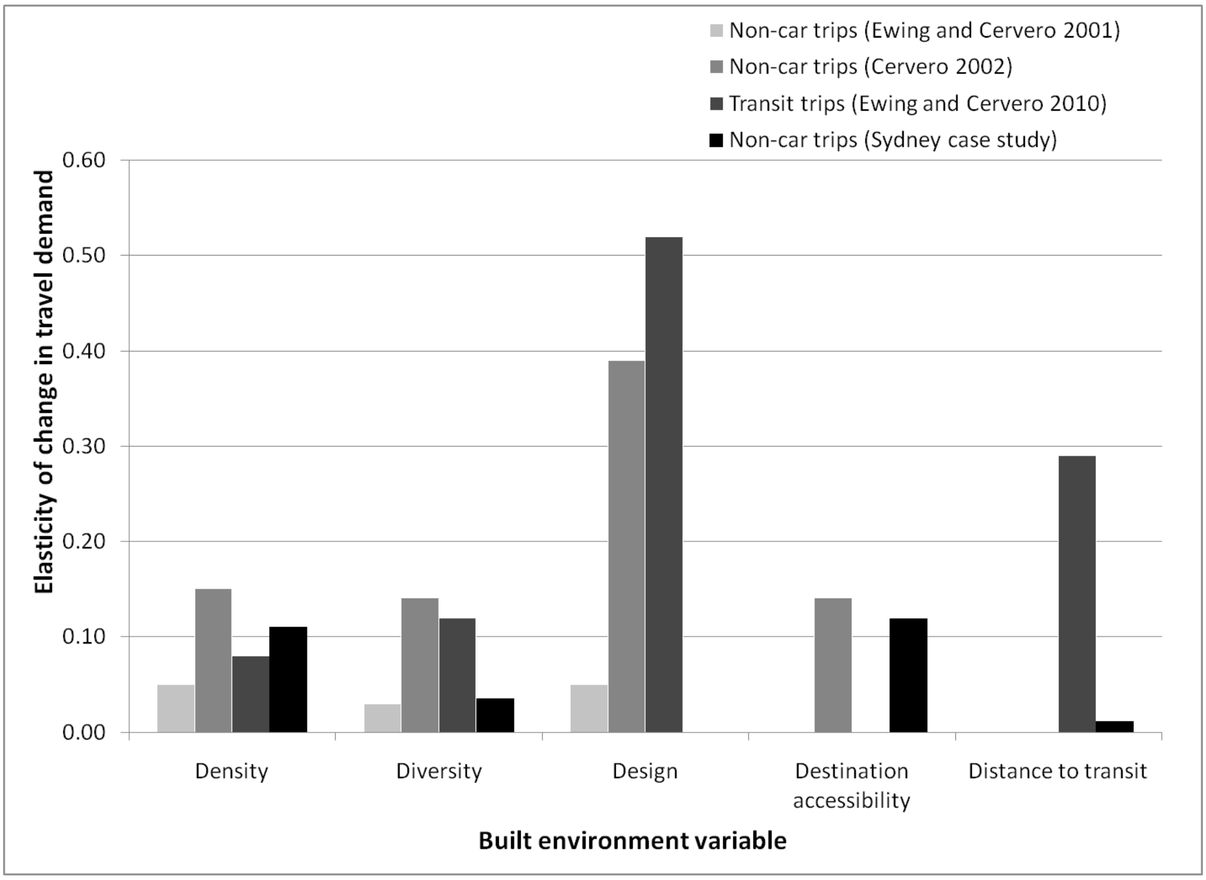
| Category | Built environment variables | Model coefficient | Elasticity |
|---|---|---|---|
| Density | Residential density (pop/ha) | 0.0004 | 0.05 |
| | Employment density (jobs/ha) | 0.0003 | 0.02 |
| Diversity | Jobs/housing diversity (0 = single use, 1 = mixed use) | 0.0247 | 0.03 |
| Design | Street density (m/ha)<br>*Not statistically significant* | - | - |
| Destination accessibility | % of jobs accessible by public transport in 30 mins | 0.4019 | 0.11 |
| | % of jobs accessible by car in 30 mins | -0.1044 | -0.05 |
| Distance to transit | Distance to the nearest CityRail station (log km) | -0.0537 | -0.02 |
| Control variables | Weekly income per person ($ per week) | 0.0001 | 0.17 |
| | Cars per household | -0.2216 | -0.98 |
| | % workers travelling to Sydney CBD | 0.5415 | 0.24 |

*Note: The model intercept coefficient was 0.4313. The number of locations (Travel Zones) analysed was 1553.*

The summary elasticities from the Sydney case study have been compared against three key studies identified in the literature. The studies selected were two meta-analyses (Ewing & Cervero 2001; Ewing & Cervero 2010), which combined a large number of studies into a consistent set of results, as well as a key study which studied destination accessibility in Montgomery County, Maryland – a suburban district of Washington D.C. (Cervero 2002). It should be noted that not all studies included analysis of each of the Five Ds of the built environment, and therefore may overstate the relative importance of those factors that were included.

A comparison of the elasticities reported by the case study and published results is shown in Figure 2.

**Figure 2: Comparison of case study and published results**




*Note: Negative elasticities (e.g. distance to transit) have been converted to positive values to consistently indicate increasing likelihood of non-car mode share.*

Key findings from the case study analysis compared to published results from other studies are discussed further below.

### *3.4.1 Density*

In the Sydney case study, density was found to have only a moderate influence on transport mode share when controlled for other aspects of the built environment. The results provided an elasticity of 0.05 for population density and 0.02 for employment density.

As suggested by Rickwood and Glazebrook (2009), it is likely that population density has served as a useful proxy for several built environment and socio-economic factors in earlier studies. This was demonstrated in the analysis through relatively high rates of correlation between population density and several other factors shown to reduce car use: accessibility by public transport (0.60), cars per household (-0.63) and percentage of workers travelling to Sydney CBD (0.62).

### *3.4.2 Diversity*

Diversity was found to be a relatively weak determinant of non-car mode share for the journey to work, with the jobs-population diversity variable providing an elasticity of 0.03. This is broadly consistent with the published results shown in Figure 2 and supports earlier work by Cervero (1996) which found that land use diversity at the trip origin had little impact on the choice of car or public transport for work commutes.

However other studies have shown that jobs-population diversity and land use diversity generally are stronger predictors of reduced vehicle kilometres travelled (-0.09) and increased walking trips (0.15) when non-work trips are included (Ewing & Cervero 2010). A probable reason for this is provided in Cervero's earlier work (1996) which found that a combination of higher density and land use diversity results in lower rates of car ownership, which in turn reduces car use for all trip types.

It therefore seems likely that diversity is more important in reducing the need to own a car (or multiple cars) rather than influencing journey to work mode choice. This is important if considering the impacts of traffic generation outside of traditional peak hours, such as weekend travel, and the sustainability implications of dependence on motor vehicles.

#### *3.4.3 Design*

The built environment factor of pedestrian-oriented design, measured in this study by street density, was found to be statistically insignificant. This shows that street density does not have a significant impact on transport mode share for the journey to work in Sydney. Similarly to land use diversity, it is likely that pedestrian-oriented design influences non-work trips to a greater extent than work trips, particularly for local shopping and recreational trips.

The insignificance of the design factor could be due a number of reasons. Pedestrian oriented design is a difficult aspect of the built environment to measure, being a mixture of both qualitative and quantitative qualities that can vary significantly at the local scale. Equally differences in study methodologies, either including or excluding correlated variables, could influence the results.

#### *3.4.4 Destination accessibility*

The results show that destination accessibility is the most important aspect of the built environment affecting journey to work transport mode share. The elasticity of accessibility to employment by public transport was 0.11, and the elasticity for accessibility to employment by car was -0.05. This shows that if all other factors are equal, the greater the destination accessibility provided by public transport, the higher the non-car mode share will be. However it also shows that the quality of public transport access relative to car access is important, and that improving car access (for example through road widening or construction of freeways) without associated public transport improvements is likely to result in increased car use. This result is similar to the elasticity published by Cervero (2002) as well as some of the studies analysed by Ewing and Cervero (2010).

#### *3.4.5 Distance to transit*

Distance to transit was found to be a statistically significant but minor factor in determining transport mode choice in the case study. The elasticity of -0.01 indicates that people living further from a train station are less likely to use public transport, but only by a small margin. The analysis shows that that distance to the nearest train station was not a large determinant of transport mode choice when the destination accessibility that the train station provides is taken into account. In other words, being located near a train station is a small incentive to catch a train, but where the train can take you is more important. The relative weakness of this variable in comparison to the destination accessibility variable also shows that the public transport mode (train, light rail, bus or ferry) is not a key factor in determining public transport use.

Comparison of the results for the case study shows a marked difference to published results. Further investigation showed that there is limited data available for this built environment factor in the literature studied. Analysis of the source data utilised by Ewing and Cervero (2010) showed that the results were determined from three studies, which varied widely from 0.02 to 1.0. Furthermore these studies did not control for the destination accessibility provided by public transport. Therefore the case study results are not directly comparable with published results shown in Figure 2.

### *3.4.6 The role of car ownership*

In contrast to the built environment variables, the high elasticities reported for the control variables, and in particular car ownership, indicate that these factors will have a significantly greater impact on mode choice.

Car ownership is often presented as a socio-economic variable by the literature, as rising car ownership has been correlated with rising incomes (Dargay 2001). However there is evidence that in wealthy OECD countries car ownership is reaching saturation and that the relationship with income is no longer tied to increasing incomes (Dargay, Gately & Sommer 2007).

A comparison of income and car ownership for the Sydney case study showed that there is no observable relationship between income and car ownership in Sydney from the data presented. Comparisons of car ownership with population density and destination accessibility provide R-squared correlations of 0.33 and 0.36 (respectively) in a negative log relationship. These relationships indicate that as potential destinations are located within closer proximity (density) and public transport access improves (destination accessibility), car ownership declines. Therefore it is plausible that car ownership in wealthy cities is a response to perceived transportation needs rather than being associated with income or social status.

This discussion gives support to Ewing and Cervero's recent suggestion that 'demand management', incorporating parking supply and cost, should be considered the sixth D of the built environment (Ewing & Cervero 2010).

# 4. Conclusion

The research described in this paper has investigated which aspects of the built environment have the potential to affect mode share for the journey to work. In doing so it has provided further evidence of the built environment characteristics that can contribute to the success of transit-oriented development.

The Five Ds of the built environment – density, land use diversity, pedestrian oriented design, destination accessibility and distance to transit – are suggested in the literature as the necessary ingredients of urban areas that help to reduce car use. However many guidelines and practitioners have not been able to describe the extent to which built environment factors can be expected to reduce car use individually and in combination.

The research has found the each of the Five Ds of the built environment has different levels of influence on transport mode share for the journey to work. All were found to be significant by the case study analysis, with the exception of pedestrian oriented design. It is possible that further study of this built environment factor for non-work trips, or with a different method of measurement, would result in a finding of significance.

Destination accessibility by public transport and population density appear to be the most important built environment factors in influencing mode share. However the elasticities of mode share for these factors of approximately 0.11 and 0.07 are significantly less than the control variables of car ownership, income and workplace destination. In particular, the large negative elasticity of car ownership to non-car mode share (-0.98) shows that measures to reduce car ownership will be required to maximise the benefits of transit-oriented development.

Claims that transit-oriented development will result in large shift towards public transport use should be moderated based on the relatively low elasticities reported. The research indicates that a doubling of residential density alone would be expected to increase public transport use in the area by 5%. Transit-oriented development opportunities should instead be seen as an opportunity to focus population growth in highly accessible areas, which is likely to lead to higher public transport use compared to more distributed or greenfield development.

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## About the author

Matthew McKibbin is a transport planner and project manager with Manidis Roberts, a leading Australian consulting firm serving the energy, property, transport, water and industrial sectors. Matthew has ten years of professional experience with a focus on planning, analysis and design of public transport and urban development. With qualifications in engineering and planning, Matthew aims to integrate land use and transport planning to improve the liveability, sustainability, and efficiency of our cities.