Changes in Urban Density: Its Implications on the Sustainable Development of Australian Cities

Brian H Roberts
Emeritus Professor and Research Associate CSIRO Sustainable Eco Systems
Email: Brian.Roberts@canberra.edu.au
Phone: 0416041837

Abstract

This exploratory paper seeks to develop a deeper understanding of the phenomenon of urban density and its effects on the sustainability of urban development, functionality and management of Australian cities. The paper explores different attributes of urban density and presents a conceptual framework to explore the relationship of these to sustainability criteria. The work presented in the paper is confined to an exploration of urban density demographic and urban residential development. Other dimensions of density will be explored in future research. The paper presents simple time series measurements of change in urban density for selected Australian cities drawing upon ABS and satellite imagery data. It shows since 1990 the urban areas of Australia's largest cities (Sydney) are growing at over 2.4% per annum, while the population growth rate is around 1.2%. The population densities of Australian cities have been falling at about 0.8% per annum. If these trends continue, the implications on the sustainability and development of Australian cities could be significant. The paper examines some environmental impacts of urban density on the sustainability of urban systems. It concludes with a brief discussion on the challenges to achieving sustainable urban development in Australian cities.

Urban Density: Its impact on the Functionality and Sustainability of Australian Cities

One of the most significant sustainability issues facing the development of Australian cities is urban sprawl. Urban sprawl is synonymous with the spread of cities and their characteristics of low-density suburban residential development, the predominance of detached housing and open streets and landscapes. These features of cities have given rise to concerns by governments in all states and territories that urban sprawl is not sustainable and should be prevented or slowed down. Most state governments have moved to curtail urban sprawl by adopting planning policies to encourage greater urban consolidation and higher density residential development (Infrastructure, 2002; Management, 2005). However, urban consolidation is not the only aspect of urban density that must be addressed if we are to make our cities more sustainable in the future.

In Australia, there is a wide and polarized debate over issues related to urban density, urban sprawl and sustainability. Advocates of low density cities (Cox, 2002; Moran, 2007; Troy, 1996) argue they provide a greater choice of living locality, offer access to more affordable housing, and provide the space necessary for privacy and raising families. While others (Newman, Kenworthy, & Vintila, 1992) contest that low urban density is inefficient, limits the viability of public transport and increases the ecological footprint and economic transaction costs in cities. It is unlikely a consensus view will be reached on what an appropriate, size, population density and urban form for Australian cities in the short-term.

Cities are complex systems and policies related to urban density and form significantly affect the functionality, economics and sustainability of cities (Munda, 2006; Newton, 1997). Historically, cities which have higher population and development densities have proved the wealthiest, most dynamic, innovative, diverse and ecologically sustainable (Hall, 1998; Mumford, 1961). However, lower density cities have attributes which it can be argued are sustainable: spacious living environments, clean air, privacy, and land to build a house and outdoor space to raise a family (EEA 2006). Perspectives on urban density and sustainability of cities thus vary significantly from country to country and even between cities within countries. The relationship between urban density and sustainability of urban development is, therefore, complex and embraces many, physical, environmental, social and behavioural factors, many of which are poorly understood.

The term urban density is multifaceted and covers a broad range of urban characteristics. Most studies on urban density are confined to demographic and other features of human settlement. However, there are many other features of urban density, which will be described later, which have a significant impact on the sustainability of cities. The paucity of knowledge about the relationship between urban density and sustainable development raises many questions for debate about whether compact cities function better or are more sustainable than dispersed cities. Is there a range or mix of urban development densities which generate more sustainable development outcomes for cities than others? If so, how do we change the patterns of urban density in cities, and how long will the process take? These are important research questions about cities which require exploration if we are to understand more about how to develop and maintain sustainable cities.

This paper reports on exploratory work by CSIRO Sustainable Ecosystems Urban Systems Program to develop a deeper understanding of the relationship between urban density and the effect it has on the sustainability, functionality and management of Australian cities. The paper commences with a brief discussion on the urban density/sprawl and its effect on sustainability. The paper then explores different attributes of urban density in relation to factors which are having and impact upon the sustainability of our cities.

The scope of this paper is limited to an exploration of urban density issues related to demographic and dwelling change in Australian cities since 1991 and how these factors impact upon the sustainability of urban development. Simple time series data showing changes in urban density for selected Australian cities, drawing upon statistical, census and satellite imagery data, are presented and discussed. The relationship between changes in urban population and dwelling density and their impacts on the sustainability of Australian cities is then discussed. The paper concludes with a brief discussion on the need for a more long-term approach to increase urban density which is necessary for Australian cities to become more sustainable.

Urban Sprawl, Density and the Sustainability Debate

Concerns about city size, density, overcrowding, rates of development and urban sprawl are not new. History provides many examples of attempts by rulers and governments to constrain the development of cities or introduce measures to constrain population growth and reduce overcrowding in cities. Queen Elizabeth I issued a proclamation in 1592 to constrain the growth of London, which failed. Measures to support decongestion in inner city areas and absorb population growth have involved the building of new and satellite towns, the adoption of green belts and urban growth boundaries. With few exceptions, urban growth management policies and plans designed to limit the growth of cities have failed or been challenged (Millward, et al 2004). Several, urban growth management strategies in the US have come under challenge in the court system (Michael Lewyn, 2002).

The low-density city is a phenomenon of the 20th century. The main drivers of low-density developed cities are the automobile and low fuel prices; population and economic growth; rising living standards, competition for development between fringe municipalities, changes in household income and formation; housing preference, environmental and social problems associated with inner-city areas. Globalization and competition also are driving factors leading to economies of scale and other major changes in the retail sector especially the emergence of subregional shopping and business centres which have fundamentally changed employment patterns and consumer purchasing practices. Industrial, commercial and transport service activities now occupy on average one third of urban land, compared to 25% in the mid-20th century (EEA 2006)

On the other hand, the debate over urban consolidation has been driven strongly by sustainability issues associated with urban sprawl; high agriculture land loss; land development costs; the lack of public capital to provide adequate social and community infrastructure; increased travel times, and congestion. The availability of better inner city public transport and the emergence of the urban village are also attractive to couples without children and single persons. These changes have brought about a shift in attitude and support for medium density inner city living. For singles and childless couples, high density living in inner urban areas associated with mixed development offers economic, and social advantages by lowering transaction costs, and create greater opportunities for face-to-face social interaction, engagement and knowledge exchange. Some argue denser living environments generate higher levels of productivity (Carlino et al. 2007).

Urbanization, globally, has led to a general perception that cities are becoming more dense and overcrowded places. While the urban form and land-use activities in the centre of cities have increased significantly, globally the population density of cities is falling. Research by the World Bank (Angel, Shepherd, & Civco, 2005) of 120 cities around the world indicates urban populations over the past two decades have been growing at more than 1.7% per annum, while the population density of cities has been falling by 2.2% per annum, with the urban footprint of cities growing at more than 3.3% annually. The implication of this pattern of development continues on the future management and sustainability of cities will be very significant (Roberts & Kanaley, 2006).

In developed countries, the situation concerning falling density is not much different to the faster growing cities of the developing world. The European Environmental Agency (EEA 2006) report on Urban Sprawl notes, “Historical trends show European cities have expanded their urban footprint area on average by 78% over the past 50 years, whereas the population has grown at 33%”. This represents an annul fall in population density of around 1.25 % annum. The rate of expansion in the urban footprint of Australia cities (see discussion later in the paper) is greater than that of European cities.

The argument that compact cities are more sustainable than low-density cities has been studied and argued extensively. The conclusions are inconclusive. Compact have significantly lower ecologic footprints (Newman 2006; Muñiz & Galindo 2005) and GDP per capita is generally higher in more densely populated cities in developed countries. A study by WS Atkin (2001) suggests that urban density has a significant impact on per capita GDP. Cities like Munich, with a population density of 4320 people per km^2, have a GDP per capita more than three times that of Manchester, which has a density of 2012 people per km^2. It is not easy make international comparisons between cities of similar size because there are significant differences in the level of economic development between countries. However, more densely developed cities tend to have more highly developed social networks, higher levels of knowledge development, learning and innovation (Castells 1989).

How to make the development of cities more sustainable is one of the most challenging issues facing the human race since we first began to build and live in cities. Cities have existed for more than eight millennia and they remain one of man’s greatest collective achievements. Many argue cities are not sustainable; however, from their very beginnings they have experienced environmental problems associated with overcrowding, air, water and noise pollution; poor sanitation and housing (Haughton & Hunter 2003:2). Despite the many problems cities have faced in the past, they have demonstrated a remarkable resilience to overcome shocks and adversities to rejuvenate into dynamic places for people to live and work.

Urban Density

The term ‘density’ has scientific and social meanings. The Oxford Dictionary defines density as the ‘closeness of substance, crowded state, and in physics, the ratio of mass to volume or by quantity of matter in unit of bulk’. In the spatial sciences, density is a measure of the concentration, grain, tightness of pattern, cluster or intensity of beings or substance within a defined space or territory. However, urban density has attributes of behaviour or flow; for example, density can be a measure of perception related to overcrowding or congestion. Measuring attributes of spatial density is important in estimating the nature and scale of activities in total populations, environmental impacts and in modelling other phenomenon associated with cities, rural and natural habitats.

Urban density is a term used to describe the dimensions of relationships between attributes of urban substance and being; for example, dwellings or persons per hectare. The measure of urban density is plagued by definition problems. The primary problem is jurisdictional and relates to the definition of what constitutes an urban area. An urban area is defined generally as a community of people of a certain size living in close proximity to each other. However, what area of land or population constitutes as urban varies between countries.

There is also a definition issue over the minimum size of an urban area. When is an area urban as distinct from rural? The UK Department of Environment National Land-use Classification (Environment., 1975) provides one of the most useful guides. Generally, an urban area is defined by population size and specified urban land-use activities. An urban area in the UK includes built-up areas over 20 hectares, comprising buildings, and transport utility and other structures. It also includes vacant areas of land-used for future urban use which are separated by less than 50 metres.

A more general definition of urban is land which has undergone or is undergoing change from a predominantly rural/natural to an urban use. A problem with this definition is that there are large areas of land on the fringe of cities which are undergoing a transition from rural/non-urban to urban use. Should these areas be considered urban in the measurement of urban density? US research suggests 43% of land in urban fringe areas intended for residential use is undeveloped, a figure has changed little in 30 years (Burchfield, Overman, & Puga, 2005). These vacant areas are 'dormant lands', which have access to services and form part of the patchwork of the urban fabric of cities. The so-called dormant lands are a major contributing factor to urban sprawl. Many of these areas are also included in density estimates of urban areas resulting in significant differences between measured and actual density.

Some of Australia's leading social scientists (Hugo 1986; Stillwell, 1992; Troy 1995) have studied demographic changes in the density of Australian cities extensively. State and federal government enquiries also have examined the impact of urban density on sprawl, development costs and sustainability of Australian cities.

The rapid growth in lifestyle residential areas, so-called peri-urban, further complicates the measurement of the urban density. Australia, Canada and the United States have cities with very large peri-urban areas used primarily for residential-lifestyle living. These are commuting zones located up to 50kms away from the urban fringe of large metropolitan and regional cities. People living in peri-urban areas are just as dependent on the city or regional centres and industrial areas for employment and other needs as those living within the city boundaries. Thus, while the density in peri-urban areas is low (less than 1 dwelling or 3.5 persons per ha) these areas, essentially, are part of the urban footprint of modern cities. It is the growth of rural residential in the peri-urban areas that has contributed to the overall reduction in urban population density of cities in Australia and other countries in the last 30 years (Agency, 2006)

The issue of what constitutes 'urban' and 'rural' is thus blurred, leading some to question if the term urban has real meaning (Champion, 2004; Champion & Hugo, 2003). In assessing densities in Australian cities, it is important to make clear the distinction about which land-use activities should be included in the definition of urban areas and in the calculation of urban density. As discussed later in this paper, there are significant differences in estimates of urban density produced by the ABS and other researchers. Depending on the method of calculation used, the conclusions about what changes are occurring in urban density in Australian cities are misleading, especially in relation to the achievement of public policies on urban consolidation.

Attributes of Urban Density

The measurement of different attributes of urban density provides useful information for planning, developing and managing cities. Measurements of urban density also provide important baseline information for monitoring and evaluating the performance of urban plans, sustainability targets and impacts of development on environmental, social and economic systems. Urban density has many dimensions. These can be measured and provide useful insights into the intensity of land-use activities in urban space and time. Dimension of urban density that can be measured include:

Urban Demographic Density (UDD) is a measure of population concentration in an area (usually people/households but can include other species). There are two commonly used measures of urban population density.
Urban Land-use Density (ULD) is a measurement of the ratio of the intensity of use of land-use features for a geographic area. ULD may include the measure of the intensity of dwellings, structures or ground surface cover.
Urban Mass Density (UMD) is a volumetric measurement of urban structures. It is a three dimensional measure of land-use intensity, usually measured as the floor space ratio of site. As cities undergo redevelopment, urban mass density increases.
Urban Resource Density (URD) is a measurement of the resource concentration, especially demand for and waste generated spatially by land-use activities.
Time-Space Density (TSD) is a duration/intensity measure of urban space.
Perceived Urban Density **(PUD)** is a behavioural or perceptual measure of density. Perceived density relates to measuring crowding, complexity, aural and visual privacy and sense of spaciousness.

What makes a Sustainable City?

It is imperative we find answers to the question of how urban density affects the sustainability of development in cities if we are to make them better places for people to live. This begins by defining what we mean by a sustainable city. The terms 'sustainablity' and sustainable development are embodied in a broad set of principles developed through international fora and a global engagement process which have been running for more than three decades. Sutainability, when applied to the context of cities, has dimensions which are constantly being shaped and reshaped by the interaction of global, natural and human systems and forces.

The term sustainable city, however, is almost an oxymoron. There are many theories on how to achieve it, but perhaps it is something that may never be attained. Central to all thinking on urban sustainablity is the belief that future generations living in cities are entitled to have secure access to essential resources needed to live, and that urban systems must be designed and developed to have the capacity for resilience. Sustainable cities will be those which are dynamic, manage their limited resources efficiently and effectively, have good governance, respond well to shocks and other adversaries, innovate and adapt quickly to economic, social, cultural, environmental and physical change and upheaval (Roberts & Kanaley 2006).

Sustainability is very much concerned with matters of process and choice. The way we take decisions about making, doing, changing and consuming things now affects the choices and options available to others in the future. Sustainability not only affects the environmental factors (economic, social and natural) which shape the actions of humans, but also the way human actions shape environments, choices and options for the future. Sustainable urban development is thus a process that is ceaselessly dynamic and concerned with managing and responding to changing economic, environmental, governance and social pressures and circumstances. Developing a model to manage the dynamics of sustainability is impossible, as we do not know the entire dimension and the future is an unknown variable. However, some dimensions of urban systems, especially the physical dimension of urban form, are fixed in space and time. This constrains available options and choices concerning the future utility of cities. Making sustainable cities is, therefore, very much about designing cities that enable greater choice, and are capable of responding positively to future shocks and changes to natural and human systems and conditions.

Conceptually Linking Urban Density to Sustainability

To link urban density to sustainability is difficult. A way to do this is to link the different dimensions of urban density described above to the five principal elements of urban systems: built, economic, governance, natural and social environments. From these relationships, it is possible to derive a range of useful indicators to measure the performance and impact these different dimensions of urban density have upon the sustainability of urban systems.

In a way, this is what triple bottom line accounting attempts to do (Elkington, 1998), but in this case the model is a quintuple bottom line. Table 1 shows different types of sustainability indicators that can be derived from an analysis of the relationships between the dimensions of urban density and environmental systems. Specific indicators could be developed under these broad headings in the cells of the matrix. Some indicators will apply to more than one dimension of urban sustainability; for example, person per household provides a behavioural measure of overcrowding as well as an intensity of land-use.

Table 1: Urban Density and Sustainability Indicators

Environment Density Dimension	Built	Economic	Governance	Natural	Social
Demographic	Settlement	Incomes	Accountability	Consumption	Cohesion
Spatial	Form	Employment	Representation	Diversity	Ethnographies
Mass	Space	Investment	Democracy	Concentration	Community
Utility	Serviceability	Productivity	Rules/Values	Replenishment	Logistics
Time Space	Accessibility	Efficiency	Responsiveness	Resilience	Activity
Perceived	Habitability	Profitability	Accountability	Beauty	Wellbeing

Table 1 above provides the author's initial thinking for a conceptual framework to explore and measure changes to different dimensions of urban density and to link these to indicators of sustainability for the five urban environmental systems described above. Further work is necessary to develop this conceptual framework and indicators to derive a more robust set of meaningful measures and indicators of urban sustainability.

Assessment of Some Impacts of Urban density on Sustainability

The discussion tries to put a practical bent upon the conceptual framework to explore some dimensions of urban density and sustainability related to population and spatial change in Australian cities. The analysis will examine demographic, spatial and utility on the built, social and economic environments.

Social Environmental Impacts

There are two measures of urban population density estimated for Australian cities: (i) population based on ABS statistical areas (ii) population of built-up areas. As noted earlier, statistical areas often include significant areas of vacant land so that measurements of population density trends using ABS data tend to be much lower than estimates derived using built-up areas. The following analysis shows changes in urban density for Australian capital cities and selected local governments using the two estimate methods.

Statistical Area Density

The ABS produces measures of urban population density based on census and other data. The technique used by the ABS to estimate density for urban areas was developed by Hugo (1985) and used to measure urban density of Australian capital cities presented in the Social Atlas of Australia (ABS 2006). ABS urban density measures are represented as a ratio of housing, people, household income etc on a hectare/km^2 basis for a statistical local or divisional area.

Table 2 Change in Urban Density Australian Cities 1991-2001

	Pop 1991	*Urban Area 1991*	*Density PP Km^2*	*Pop 2001 Census*	*Urban Area 2001*	*Density PP Km^2*	% An Change Area	An % Change Density
Adelaide	957,000	671	1426.23	1,025,864	781.91	1,312	1.5%	-0.80%
Brisbane	1,145,000	1,146	999.13	1,490,475	1602.66	930	3.4%	-0.70%
Canberra-Queanbeyan	313,744	262	1197.5	339,595	377.33	900	3.7%	-2.80%
Darwin				89,199	87.71	1,017		
Hobart				153,244	164.6	931		
Melbourne	2,762,000	1,643	1681.07	3,203,088	2141.1	1,496	2.7%	-1.20%
Perth	1,019,000	875	1164.57	1,302,126	1172.03	1,111	3.0%	-0.50%
Sydney	3,098,000	1548	2001.29	3,455,110	1687.89	2,047	0.9%	0.20%
Total				11,058,701	8015.23	1,379.7		
Excluding Darwin& Hobart	9,294,744	6,145	1512.57	10,816,258	7,763	1,393	2.4%	-0.8%

ABS Social Atlas 2003 series 2030.1 -7 & **NSW EPA** **Core Indicator 5C: Urban areas**
http://www.epa.nsw.gov.au/soe/97/ch5/7_3.htm#7_3t1.htm

Table 2 shows the change in urban density of Australian capital cities between 1991-2001 using ABS Social Atlas and NSW EPA data derived from census data. Average density fell from 1512 persons per km^2 in 1991 to 1393 person per km^2 in 2001 or about – 0.8% per annum. The overall rate of decline in population density is faster than most European countries (-0.6%), but above that of US cities (Minneapolis -1.98%, Pittsburgh -1.76% and Springfield -3.92% cited Angel et al 2005).

There are significant changes in the rate of decline of urban population density between Australian cities. Canberra/Queanbeyan had the fastest decline, which can be explained by the growth in rural residential lifestyle-living in Queanbeyan and increased open space provision in the ACT. Adelaide, Brisbane and Melbourne had population density declines ranging between 0.7% and 1.2% per annum. Only Sydney appears to have had an increase in net density. The data used in the table only covers the capital city statistical divisions, and excludes many peripheral development areas, suggesting the figures many be underestimated, as will be discussed later.

Built-up Area Density

ABS estimates of urban population density are very accurate for fully developed urban areas. In fringe urban areas the measurements become less reliable since collector districts and SLAs on the fringe and can lead to significant reductions in gross area urban density estimates for cities. The most reliable means of defining urban density is to measure the built-up area of cities. Satellite imagery is used widely internationally to measure the built-up areas and density change in cities (Angel et al 2005); however, it is not used widely in Australia. By overlapping time-series satellite imagery, rates of land conversion/consumption can be analysed very accurately.

In 2006, GeoScience Australia (Holzapfel et al, 2006) undertook pilot work to explore the extent the urban built-up areas of selected cities and local governments. The results of this analysis is shown in table 3. The data is a random sample of SLA and population for different times. Population data derived from ABS estimates for the dates of the satellite imagery of the selected SLAs, and excludes population for non-urban area collector districts.

Table 3 reveals significant differences in urban density change for the selected SLA for the dates of available imagery. The images selected were those offering the highest level of clarity. The figures in the table show declining rates in urban population density which are slightly higher than those shown for the capital cities in Table 2. Areas undergoing the most rapid urbanization are those where densities are falling the fastest. The larger cities like Melbourne and Brisbane show much slower declines in urban population density. ABS 2006 census data was not available to conduct an analysis of the most recent situation, where overall population density in Melbourne and Sydney may have stabilised and be on the rise. On-going research will enable up-dated information to be produced once the 2006 ABS collector district census data becomes available.

Table 3: Actual and Percentage Change in Build up Urban Area, Population and Density for Selective Australian Local Governments

Local Govt	*Date (1)*	*Date (2)*	*Km² (1&2)*		*% /Yr*	*Pop (1 &2)*		*% /Yr*	*Pers/Km² (1&2)*		*% /Yr*
Gold Coast City	Jan-79	May-02	66.9	214.3	5.20%	147,000	448,554	5.00%	3281	2093	1.90%
Brisbane City	Jan-82	Jul-02	262.7	374.6	1.80%	732,463	914,296	1.10%	2788	2441	0.70%
Redland Shire	Jan-82	May-02	21.2	67.3	5.90%	60,231	120,494	3.50%	2842	1791	2.30%
Maroochy Shire	Jan-81	Oct-02	21.6	62.2	5.20%	49,953	108,209	3.60%	2315	1739	1.40%
Caboolture Shire	Jul-91	Jul-02	18.3	58.4	5.70%	41,428	117,296	9.90%	2265	2009	0.80%
ACT	Jan-87	Aug-02	145.2	190.0	1.80%	287,907	365,027	1.60%	1983	1921	0.20%
Greater Geelong City	Dec-91	Jun-03	65.7	102.6	3.80%	147,461	162,637	0.80%	2244	1586	2.90%
Logan City	Jan-82	Jul-02	45.0	81.0	3.00%	92,747	165,606	2.90%	2063	2044	0.00%
Cairns City	Jan-84	Sep-01	28.8	63.7	4.80%	69,465	117,531	3.10%	2410	1845	2.20%
Metropolitan Melbourne	Jul-91	May-03	1297.6	1544.5	1.50%	3,155,576	3,555,321	1.00%	2432	2302	0.50%
Ballarat City	Jan-81	May-03	34.3	50.6	1.80%	71,930	85,851	0.80%	2097	1697	1.00%
Greater Bendigo City	Jan-84	Jun-03	28.0	50.6	3.20%	61,200	81,906	1.00%	2185	1620	1.60%

Source: Geosciences Australia 2006

Spatial Environmental Impacts

Housing Density in Urban Areas

While urban population densities in Australian cities have continued to fall since the 1980s, there is a belief that the ratio of dwellings per hectare has been rising as the result of an increase in the housing density green-field and in inner-city redevelopment areas. ABS estimates suggests that residential densities have changed little between 1991 and 1996 (1301.0 – Year Book Australia, 2001). The 2006 State of the Environment Report, using ABS Census data, also suggests overall dwellings per hectare (1991-2001) appears to be falling as the floor space area of dwellings rise, except for Sydney (See Table 4). This trend supports the SOE indicator data for average block size for detached housing in Australia. These fell from 802m² in 1994 to 702 m² in 2000. Since 2000, block size has risen sharply to 736 m² (2004) in response to the significant rise in average dwelling size.

Table 4: Change Area Per Dwelling Per Hectare for Australian Cities 1991-2001

	2001				*1991*				
	Dwell (1000)	Area Km²	M²/ Dwell	Dwell/Ha	Dwell (1000)	Km2	M²/ Dwell	Dwell/Ha	% Change Dwell/Ha
Sydney	1438.4	1687.89	1173.4	8.52	1216.0	1548	1273.0	7.86	8.5%
Melbourne	1243.4	2141.1	1722.0	5.81	1048.2	1,643	1567.5	6.38	-9.0%
Brisbane	601.1	1602.66	2666.2	3.75	454.2	1,146	2522.9	3.96	-5.4%
Adelaide	430.2	781.91	1817.5	5.50	378.8	671	1771.5	5.64	-2.5%
Perth	511.2	1172.03	2292.7	4.36	402.8	875	2172.2	4.60	-5.3%
Hobart	76.1	164.6	2162.9	4.62					
Darwin	38.2	87.71	2296.1	4.36					
Canberra	114.7	377.33	3289.7	3.04	92.5	262	2831.1	3.53	-13.9%
Total	4453.3	8015.23	1799.8	5.56	3592.5	6145	1710.5	5.85	-5.0%

Sources: Australia State of the Environment 2006 ABS Social Atlas 2003 series 2030.1 -7 & ***NSW EPA Core Indicator 5C: Urban areas*** *http://www.epa.nsw.gov.au/soe/97/ch5/7_3.htm#7_3t1.htm*

Over the two decades since 1984-2003 the floor area of new houses Australia's capital cities increased from 162m^2 to 227m^2 (Year Book 2005). ABS data for the first three quarters of 2003-04 indicates the average size of new houses is still increasing to reach 239 m^2. This trend runs parallel with the rate of increase in block size per dwelling.

Data on the total area of land converted annually to urban use in Australian cities is not readily available. State planning agencies have very good data on blocks of land produced on a quarterly or more frequent basis. Currently the demand for urban land is in the order of 150 km^2 per year for the capital cities. Much of this will be developed for low-density detached housing at around 5.5 blocks per hectare. More accurate data on land conversions are required to monitor changes to urban footprint areas of Australian cities.

Urban Mass

Urban Consolidation

In response to concerns about urban sprawl, most states have attempted to impose or encourage higher density residential development on the urban fringe, in the inner city and around transport nodes. The Victorian government used a ministerial direction in the early 1990s to require a minimum lot size of 15 per hectare. This was removed in 1993, but was subsequently restored under the Melbourne 2030 Plan (McDougall 2007). The Queensland SEQ2001 Regional Growth Management Framework (RGMF) (1995) proposed 15 lots per hectare as an average dwelling density for the region. This target represented a 50% increase in dwelling densities per hectare, prior to the release of the RGMF. The target is unlikely to be met. SEQ 2021 sets targets of 15 lots per hectare net residential.

The New South Wales government, through a series of plans and policies, has sought to increase residential density on the urban fringe. Dwelling density figures for urban release areas in Sydney show an increase in average net residential density from 11.6 to 12.09 dwellings per hectare between 1992 -1996. With the supply of broad hectare development land on Sydney's outer suburban fringes now constrained, a recent study of Sydney suggests the city is achieving an overall increase in residential development densities on the urban fringe (BIS Shrapnel Pty Ltd 2006).

What is apparent from available data is that targets to increase dwelling densities on the urban fringe in most capital cities are proving difficult to achieve. Some master planned communities on the fringe of the capital cities are achieving an increase in residential dwelling density, but these are exceptions. New master planned communities tend to have more generous open-space provision which offsets the gain from higher density residential development. The desire of many Australians to own a large house on a large block of land is still very strong and, short of a radical planning policy change, achievement of higher density development in urban fringe areas will continue to be difficult. Recent concerns about housing affordability will bring pressure upon governments to release land for development on the fringe to be developed as traditional low-density residential developments.

There is a growing trend towards medium and higher density development in inner areas of Australian cities. There are many reasons for this change, but Australians are showing less reluctance to live in medium and higher density housing (Urban Development Institute Australia 2005). ABS data indicates inner city populations are growing at rates of over 3%

in the major capital cities. Inner city dwelling stock in Melbourne is growing at rates over 6.3% per annum. Similar rates are being experienced in Sydney, Brisbane and Perth.

The effect of these trends is that ultimately Australian capital cities can expect overall urban densities to stabilize and increase. However, this will take some time to occur. While cities like Sydney are moving towards 60% of building approvals for medium and higher density residential development, the annual increase in dwellings is less than 2.5% of the total existing urban dwelling stock. With urban fringe development densities not likely to change significantly in future and household size falling, what is occurring is a redistribution of population, not a marked overall intensification of residential populations and development densities. The effect, over time, is that time density space concentrations will rise in the more densely populated areas of Australian cities, and fall significantly in less populated areas. The implications of this trend pose significant challenges to ensuring efficient use of urban assets in all the capital cities.

Urban Density and Micro Climate

There is a general perception that low-density development has less impact on the microclimate of cities – especially heat concentration. However, the opposite appears to be the case. A study conducted in Melbourne found surface energy balance related to heat does not show a clear pattern that increased housing density results in warmer and more unpleasant local microclimates (Coutts et al. 2004). The authors found, during the warmer part of the day, medium density developments showed higher amounts of surface heating compared to higher density developments. Higher density residential development can help improve street microclimate by offering greater shade areas, particularly when combined with tree cover. This is a feature of Middle Eastern housing that has been a practice for thousand of years. Johansson (2006) found that housing in Morocco with tight streetscapes had street temperatures 6 – 10 degrees lower than exposed locations.

On the other hand, Skinner (2006) in a study of Melbourne found that higher urban density has negative impacts on the microclimate and the hydrology of the city, but there are strategies to minimise these adverse effects, including the widespread use of rooftop gardens. Roof-top gardens are now actively promoted as part of sustainability planning policy in Chicago and other US cities.

The change in urban form resulting from the increase in average house size and ground surface cover is having an impact on the microclimate of suburban areas. This increase in surface cover, combined with the decline in tree and vegetation cover, has increased the level of thermal radiation per hectare - especially in outer urban areas of Australian cities. The implications of these changes on urban microclimate, especially if future climate change is taken into consideration, will be significantly increased demand for energy for air conditioning. The paving-over of Australian cities presents a formidable challenge in identifying ways to cool our cities, particularly in suburban areas.

Utility

The changes in the form, density and demography of Australian cities over the past two decades have been significant. Unfortunately, from a sustainability perspective, most of these changes have not been positive. The impact of current development practices, if continued, on the natural, social, economic, physical and governance environments of Australian cities will be significant. The following describes some impacts current development trends have, or may have, on the demographic and spatial, mass, utility and time-space dimensions of sustainable urban development in Australian cities.

Urban Density and Energy Demand

Almost half of Australia's total greenhouse gas emissions and two thirds of emissions from energy are generated in urban areas, or through energy conversion for urban use (Pears 1995). Urban form and density also have a significant impact on energy consumption and greenhouse gas emissions; however, the relationship between urban density, energy consumption and sustainability is complex. Generally, higher density cities have lower energy demand per capita than more densely developed and populated areas. Energy demand, however, is affected by many factors such as the level of national economic development, disposable incomes and the use and the age of technology.

Two types of energy consumption should be considered in relation to sustainability of urban development. Embodied energy is the amount of energy used in the construction of houses and buildings. The Australia Greenhouse Office estimates the embodied energy in a dwelling can amount to around 40% of the household's operational energy demands over a hundred-year period (Australian Greenhouse Office, 1999). In commercial buildings, embodied energy may be in the range of 10-15% of total energy costs over the life time of the building. Energy consumption is the measure of the total energy consumed for the operation of a building. The Australian Building Codes Board (ABCB) estimates that energy used in buildings accounts for almost 27% of all energy related greenhouse gas emissions (Holloway & Bunker, 2005). However, for residential land-uses, transportation costs need to be added to household energy consumption. These costs are significantly greater for people living in urban fringe areas than in the inner city.

Many studies have been conducted on embodied and household energy consumption in Australia (Australian Greenhouse Office, 1999; Troy et al 2002; (Perkins, 2003); (Holloway et al., 2005). Holloway and Bunker (2005) found in a survey of 4572 households in the southern and eastern areas of Sydney that houses produce 15.9 tonnes of greenhouse gases compared to 12.0 tonnes for multi-unit developments. Two studies conducted in Adelaide found house energy consumption was slightly higher in the outer suburbs than inner city areas (Perkins (2002; 2003) citied Holloway and Bunker (2005)); however, overall energy consumption was almost twice that of the inner city when energy used in travel was included.

Newman and Kenworthy (1999) argue that there is a strong relationship between urban density and energy (fuel) consumption; however, Mindali et al (2004) suggest there is no direct impact of total urban density and energy, but that several other relationships between energy consumption and density attributes can be identified, such as increases in the concentration of subregional employment. On the other hand, Pears (2005), argues that higher density development may not result in reduced household energy requirements if estimated on a per capita basis, reasoning that energy consumption is greater in higher density developments because of increased demand for energy to run lifts, and communal facilities.

There is not a simple relationship between urban density and energy consumption. The evidence that high-density residential development is more energy efficient than lower density development is not conclusive, partly because the variables used to derive total energy use are different in the studies conducted to measure this. The rapid increase in house size since 1990, suggests that low density housing urban energy use (including fuel) is rising on a per capita basis, but that improved energy efficiency will help to reduce this in the long term. Medium density residential development in the form of town houses and low-rise apartments appear to provide the most efficient energy consumption (Wright 2006) on a household and per capita basis. It is this direction that Australian housing policy should be directed if policies related to urban consolidation are to have any meaningful impact in the long-term on the sustainability of Australian cities.

Urban Density and Travel

Urban form and density have a significant influence on travel patterns in Australian cities. Australian cities were designed for and are heavily dependent on the use of motor vehicles. Australia has one of the world's highest vehicle ownership rates per capita at 632 vehicles per 1000 population (Dargay et al. 2007). Australian cities have one of the longest length of road per capital and the biggest road user rates measured as vehicle person kilometres travelled (VKT) per year. Our cities also have some of the lowest population and residential development densities in the OECD. Canberra, has one of the lowest residential development density in the OECD for a national capital.

Table 5 shows 2002 and predicted 2020 VKT per year for Australian capital cities. The Bureau of Transport and Regional Economics predicts metropolitan total VKTs to rise by 33% by 2020 or 1.6% per annum (Gargett & Gafney 2004). VKT rates per capita are expected to increase overall by almost 12% from 7400 km to around 8280 km in the metropolitan regions. This compares with a predicted growth of 1% VKT for the same period in Canadian cities. VKT per capita in cities like Toronto and Vancouver are projected to fall (Delcan Corporation 1999). The implication of increased VKTs per capita on the sustainability of Australian cities will be significant, not just in terms of increased traffic congestion and emissions, but in the level of investment needed in road infrastructure to service the projected increase in road space demand.

Table 5: Car Traffic Projections for Australian Cities

City	2002			2020			%
	Car VKT/ Person(000)	Pop (a) (000)	Car (b) VKT(m)	Car I VKT/ Person(000)	Pop (a) (000)	VKT(m) Car	change 2002-2020
Sydney	7.035	4207.5	29,600	7.858	4999.0	39300	+33%
Melbourne	8.089	3556.8	28,770	9.035	4058.4	36700	+28%
Brisbane	6.903	1681.8	11,610	7.711	2188.0	16,900	+46%
Adelaide	7.474	1111.9	8,310	8.348	1170.4	9,800	+18%
Perth	7.163	1430.9	10,250	8.001	1798.1	14,400	+41%
Hobart	7.155	193.0	1,381	7.992	187.7	1500	+9%
Darwin	6.041	93.2	563	6.748	127.2	860	+53%
Canberra	8.962	318.0	2,850	10.011	354.9	3,550	+25%
Metro	7.412	12,593	93,334	8.279	14,884	123,200	+33%
Rest Aust	8.886	7,026	62436	9,994	7,885	78,800	+26%
Total Aust.	7.94	19619	155,770	8.87	22769	202,000	+30%

(a) BTRE(2003) p320-321

(b) BTRE(2003) pp.3-30

I The Australia level per cent increase from 7.94 to near saturation at 8.87 is assumed to apply to each city. At the level of the 8 capitals, the increase from car travel per person is 12%, and from population 18.5%. The overall increase in Australia Metro car traffic is then (1.12 * 1.185-1.0)*100 or about 33% in 18 years

Source: Gargett & Gafney 2003

Urban form and population density have a significant influence on transportation demand as expressed through VKT. VKT transportation demand is influenced significantly by density factors. Higher density cities tend to have reduced per capita VKT and emission exposure per capita (Marshall et al. 2005). However, this may be misleading as emission standards for vehicles have a significant impact on particle level concentrations. If Australian cities are to become more sustainable, it is imperative that VKT rates of increase are stabilized, but this can only be achieved by a fundamental shift in policies related to urban density, design and public transport.

Urban Density and Ecological Footprint of Australian Cities

A useful measure of the relationship of urban density and sustainability is the ecological footprint (Rees 1995; Girardet 1999). The ecological footprint is a conceptual measure of the human demand on nature and compares human consumption of natural resources with the earth's ecological capacity to regenerate them. The measure of the ecological footprint is gross area of land-used to support an individual based on his or her consumption of natural resources. The global average is 1.9 gross hectares per person. In 2004, Australia ranked as the country with the sixth highest ecological footprint in the world, at 6.6 global hectares person (Sydney, 2005). International research suggests that more densely populated cities have significantly lower ecological footprints (Gilson & Gelb, 2004). The ecological footprint for the UK is around 5.6 gross hectares per person (ghpp) and 4 ghpp for Switzerland.

Several studies have been conducted to measure the ecological footprint of Australian cities. The ACT's ecological footprint in 1998-99 was 5.73 ghpp. This compares with Sydney's of 5.2 ghpp, Melbourne's 4.71 ghpp and the Australian average of 5.65 ghpp (Lenzen & Dey, 2004). Research undertaken for the Adelaide City Council's Strategic Management Plan 2004-2007 found that an outer suburban household in a low density environment of predominantly single storey detached houses is likely to consume up to 90% more energy than their inner urban counterpart (Perkins 2003a). A study of the ecological footprint has also been conducted for Southeast Queensland (Simpson et al. 1998). The conclusion drawn from these studies is that there is a relationship between urban density and the ecological footprint of Australian cities. Cities with the highest ecological footprint have the lowest density of development. Reducing the ecological footprint of Australian cities is one of the most significant challenges facing the nation.

Conclusion

This paper set out to develop a framework for a preliminary exploration of different dimensions of urban density and their impact on sustainability. Urban density has many dimensions, which shape and impact of five key elements of urban systems related to natural, built, social, economic and governance environments. Some relationships between different dimensions or urban density and their impacts on urban systems were explored briefly in the paper. More research is required to define benchmarks which set limits on the level of impact that changes to these dimensions of urban density will have on the sustainability and resilience of urban systems.

The paper presented evidence of the effect that urban density has had on the efficiency, functionality and sustainability of Australian cities. The population density of Australian cities is falling, while the urban footprints of our capital cities are growing at rates that are not sustainable. The long-term impact if these trends in urban density continue, is that the cost of building, operating and maintaining Australian cities will rise significantly. Stabilizing urban population density and reducing the growth of urban footprints is one of the most important goals in the achievement of sustainable urban development.

The future development of Australian cities faces a paradox. Some researchers and the development industry argue strongly that lower density residential development offers a better lifestyle for families, more affordable housing, open space and amenity. This is the traditional Australian way of life. It can be argued that some of the less sustainable aspects of low-density urban development can be improved through better urban design and the adoption of improved technologies to reduce resource consumption and greenhouse gas emissions. However, the evidence from many studies citied in this paper suggests a more compact form of urban development and density is necessary to ensure our cities become more sustainable in future. This does not mean that we should prevent the outward growth of cities: it means improving the management and utilization of urban assets and systems; ensuring cities consume fewer resources; add value to natural, as well as social, physical and economic capital stocks, and are made more liveable places.

The challenge facing Australian cities is how to develop pathways that will ensure sustainable forms of urban development. Central to this challenge is the issue of urban density. Urban density, as the paper has described, has many dimensions, which impact upon urban sustainability. Much of the debate on density has centred upon population and development. Comparatively little research has been undertaken linking urban density to mass, utility and time-space dimensions of sustainability. These are important issues for future research as they will help to inform decision-makers on how to improve the efficiency of urban form and development which will ensure more sustainable use of urban resources.

The sustainable city of the future will be very different to the cities of today. For the first time in human history cities globally are facing resource constraints. Cities must become denser places to create opportunities for the achievement of economies of scale and scope, to ensure more efficient use of limited resources and to encourage the creation of new capital needed to support future generations. This will involve identifying and adopting ways for developing, recycling and rebuilding our cities which do not follow the traditions of the past.

For Australian cities to become more sustainable, planning policies must become more long-term and use a lifecycle approach to the development and redevelopment. This is essential if Australian cities are to respond to changes occurring globally which affect the metabolism of cities. The average age of Australian cities' infrastructure and building stock is more than 35 years. Most of this stock will need replacement or major refurbishment in the next 25 years. The cost of rebuilding and rejuvenating Australian cities will necessitate government involvement in land rationalisation, using eminent domain powers and in extracting rent from the redevelopment process to fund the replacement infrastructure needed to sustain Australian cities into the next century.

In conclusion, urban density is an issue which will have a profound impact on the future development and sustainability of Australian cities. The paper has sought to explore different dimensions of urban density and to link these to measures of sustainability within the realm of environmental, governance, economic, social and built-form systems. Critique and further thinking is required to explore the dimensions and measurements of urban density and relate these to the urban development process. The paper and framework has provided a useful insight into the way urban development and population density impacts on transport, energy and the ecological footprint of Australian cities. The challenge is to translate these findings into a policy agenda for changing the approach to the development, recycling and redevelopment of Australian cities. The introduction of planning policies, technology and urban design that will increase urban density and improve the sustainability of urban systems is relatively easy. It is changing the beliefs and aspirations of Australians about the continuance of a way of development and living that has prevailed for almost a century that will be difficult.

References

Australian Bureau of Statistics (ABS)
ABS Social Atlas 2003 series 2030.1 -7
1301.0 - Year Book Australia, 2005

Agency, E. E. 2006. Urban sprawl in Europe: The ignored challenge: European Commission.

Angel, S., Shepherd, S. C., & Civco, D. L. 2005. The Dynamics of Global Urban Expansion: 200. Washington, DC: World Bank.

Australian Federal Government, 2005, Sustainable Cities Report,

Australian Greenhouse Office (1999) *Australian Residential Building Sector Greenhouse Gas Emissions 1990-2010,* Australian Greenhouse Office, Canberra.

BIS Shrapnel Pty Ltd. (2006). *Medium & High Density Dwellings in Sydney suburbs* (BIS Shrapnel Pty Ltd). Sydney

Burchfield, M., Overman, H. G., & Puga, D. 2005. Causes of sprawl: A portrait from space.

Carlino, G., Chatterjee, S., & Hunt, R. (2007, May). Urban density and the rate of invention. *Journal of Urban Economics, 61*(3), 389-419.

Castells, M. (1989). *The information city, economic restructuring and urban and regional process.* Oxford: Information Technology, Basil Blackwell.

Champion, T. & Hugo, G. 2003. New Forms of Urbanization: Beyond the Urban-Rural Dichotomy. In T. Champion & G. Hugo (Eds.). Aldershot: Ashgate: Publishing Company for IUSSP.

Champion, T. 2004. Are ‘urban’ and ‘rural’ outmoded terms?, Panel Contribution to the PERN Cyberseminar on Urban Spatial Expansion Newcastle upon Tyne: Politics & Sociology University of Newcastle Newcastle upon Tyne.

Coutts, A., Beringer, J., Tapper, N. J., & Cleugh, H. A. (2004, Tuesday, 24 August 2004). *The influence of housing density and urban design on the surface energy balance and local climates of Melbourne, Australia, and the impact of Melbourne’s 2030’s vision.* In *Session 5, the energy and water balance of cities (parallel with session 6).* Fifth Conference on Urban Environment, Melbourne.

Cox, W. 2002. Property, Prosperity and Poverty: Trends and Choices in Land-use Policy. London: Institute of Economic Affairs.

Dargay, J., D. Gately, and M. Sommer, 2007, “Vehicle Ownership and Income Growth, Worldwide: 1960–2030” New York University, Department of Economics.

Delcan Corporation. (1999). *Strategies to Reduce Greenhouse Gas Emissions From Passenger Transportation in Three Large Urban Areas* (National Climate Change Process – Urban Passenger Transportation Sub-Group). Ottawa: Transport Canada.

Elkington, J (1998) *Cannibals with Forks: the Triple Bottom Line of 21st Century Business,* Vancouver, New Society Publishers

Department of the Environment (UK) 1975. National Land-use Classification. In DOT

Environment (Ed.): HMSO.
European Environmental Agency (EEA) (2006) Urban sprawl in Europe: The ignored challenge: Brussels, European Commission
Gargett, D., & Gafney, J. (2004). Bureau of Transport and Regional Economics. Canberra: Department of Transport and Regional Services.
Gilson, S. & Gelb, R. 2004. <u>The Influence of Development Characteristics on the Ecological Footprint of an Urban Household</u>.
Girardet, H. (1999). Sustainable Cities: A Contradiction in Terms. In D. Satterthwaite (Ed.), *Sustainable Cities* (pp. 413 -425). London: The Earth Scan Reader.
Gradel, T. and Allenby B., 1995, Industrial Ecology, Upper Saddle River, NL, Prentice-Hall.
Hall, P. 1998. <u>Cities in civilization : culture, innovation and urban order</u> London: Weidenfeld & Nicolson.
Haughton, G., & Hunter, C. (2003). *Sustainable Cities.* New York; London: Routledge.
Holloway, D. & Bunker, R. 2005. Planning, Housing and Energy Use, <u>National Housing Conference – Building for Diversity</u> Perth: City Futures Research Centre, University NSW
Holzapfel M. J., Costello S., Levett B. (2006) The Benefits of Raster And Vector Change Detection to The National Mapping Program, Unpublished Paper**,** National Mapping and Information, Geoscience Australia, Canberra.
Hugo, G., Griffith, D., Rees, P., Smailes, P., Badcock, B. and Stimson, R. 1997, *Rethinking the ASGC: Some Conceptual and Practical Issues*, Monograph Series 3, National Key Centre for Social Applications of GIS, University of Adelaide, Adelaide.
Hugo, G.J. 1986, *Australia's Changing Population: Trends and Implications,* Oxford University Press, Melbourne.
Infrastructure, D. o. 2002. Melbourne 2030: Planning for Sustainable Growth. In D. o. Infrastructure (Ed.): 192: Government of Victoria.
Johansson, E. (2006, October). Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco. *Building and Environment, 41*(10), 1326-1338.
Kenworthy, J. R. & Laube, F. B. 1999. Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy. <u>Transportation Research Part A: Policy and Practice</u>, 33(7-8): 691-723.
Lenzen, M. & Dey, C. 2004. The Ecological Footprint of Canberra, Canberra, Australian Capital Territory's Office of Sustainability).
Marshall, J. D.; McKone, T. E., Deakin, E.; Nazaroff, W. W. (2005) Inhalation of motor vehicle emissions: effects of urban population and land area, Atmospheric Environment, 39,283–295
McDougall, A. (2007, June). Melbourne 2030: A preliminary cost benefit assessment. *Australian Planner, 44*(2), 16-25.
Michael Lewyn. 2002. Sprawl, Growth Boundaries and the Rehnquist Court. Utah: Utah Law Review.
Millward, H. 2006. Urban containment strategies: A case-study appraisal of plans and policies in Japanese, British, and Canadian cities. <u>Land-use Policy</u>, 23(4): 473-485.
Mindali O.; Raveh A.; Salomon I. (2004) Transportation Research Part A: Policy and Practice, Volume 38, Number 2, February , pp. 143-162(20) Elsevier
Moran, A. 2007. <u>Land regulations, Housing Prices and Productivity</u>. Paper presented at the Agenda.

Mumford, L. 1961. The city in history: its origins, its transformations, and its prospects. New York: Harcourt, Brace & World.
Munda, G. 2006. Social multi-criteria evaluation for urban sustainability policies. Land-use Policy, 23(1): 86-94.
Muñiz, I., & Galindo, A. (2005, December). Urban form and the ecological footprint of commuting. The case of Barcelona. *Ecological Economics, 55*(4), 499-514.
Newman, P. (2006). The environmental impact of cities. *Environment and Urbanization, 18*(2), 275-29.
Newman, P. 2006. The environmental impact of cities. Environment & Urbanization 18(2): 275-295.
Newman, P. and J. Kenworthy (1999) Sustainability and Cities: Overcoming Automobile Dependence, New York: Island Press
Newman, P. W. G., Kenworthy, J., & Vintila, P. 1992. Housing, transport and urban form Canberra: Australian Govt. Pub. Service.
Newton, P. W. (Ed.). 1997. Re-shaping cities for a more sustainable future : exploring the link between urban form, air quality, energy and greenhouse gas emissions: Australian Academy of Technological Sciences and Engineering
Office of Urban Management. 2005. Southeast Queensland Regional Plan 2005-2026. In P. Queensland Department of Local Government, Sport and Recreational Services (Ed.): Queensland Government.
Pears, A. (2005) Does Higher Density Really Reduce Household Energy Requirements? It Depends…, *Urban Policy and Research*, 23, 3, 367-369.
Perkins, A. (2003, December). *How Significant an Influence is Urban Form on City Energy Consumption for Housing and Transport?*. Presented at the State of Australian Cities National Conference, Parramatta.
Perkins, A. 2003. The Significance of Urban Form in Creating More Greenhouse – Friendly Cities, National Planning Congress: Leading with Diversity. Adelaide
Australian Productivity Commission (2003) First Home Ownership Public Inquiry Report, Canberra, Australian Productivity Commission
Rees, W.E. (1995), "Reducing our ecological footprint'", *Siemens Review*, Vol. 2 pp.30-35
Roberts, B. & Kanaley, T. (Eds.). 2006. Urbanization and Sustainability in Asia:Case Studies of Good Practice. Manila, Philippines: Asian Development Bank Cities Alliance (World Bank).
Stimson, R., Petroeschevsky, A., & Lowe, I. (1998). *The ecological footprint of Australia, with a focus on the South-East Queensland region.* Brisbane: Griffith University.
Skinner, C. J. (2006, September). Urban Density, Meteorology and Rooftops. *Urban Policy and Research, 24*(3), 355-367.
Stilwell, F. (1993) *Reshaping Australia: Urban Problems and Policies*. Sydney: Pluto Press.
Sydney, G. F. N. 2005. The Ecological Footprint of Victoria Assessing Victoria's Demand on Nature: EPA Victoria
Troy, P.N. 1996, *The perils of urban consolidation: a discussion of Australian housing and urban development policies*, Federation Press, Leichhardt, NSW.
Troy, P., Holloway, D., Pullen, S. and Bunker, R. (2002) *Toward Sustainability: An Adelaide Case Study,* Research Paper No.14, Urban Frontiers Program, University of Western Sydney, Campbelltown.
Troy, P.N. (ed.) 1995, *Australian cities: issues, strategies and policies for urban Australia in the 1990s*, Reshaping Australian institutions, Cambridge University Press, Cambridge, Melbourne.

Wright, K. (2006) 'The Relationship Between Residential Density and Non-Transport Energy Use' Australian Planner, Vol 43, No 4, 12-13
WS Atkins. (2001). *European Best Practice in the Delivery of Integrated Transport:* (Tech. Rep. No. 1 - Benchmarking). Epsom Surrey: WS Atkins Transport Planning.