Don't Be So Dense: An Alternative Approach to Measuring Urban Structure and Form

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Abstract: Global commitments to make urban areas more sustainable coincide with debate over the type of urban form required to achieve this outcome. Much of the debate centres on the merit of broadly increasing residential densities across the metropolitan area in the name of sustainability. I argue that the focus on density in such debates is problematic. My recently completed PhD thesis explains that urban density calculations are an inaccurate proxy for representing urban structure and form differences across large metropolitan areas like Sydney. Describing urban structure and form as either high or low density tells us little about its location, accessibility and design characteristics. The focus on density in urban research has contributed to an unsophisticated policy response of poorly located and designed high-rise (and detached dwelling) development across the metropolitan area. To more accurately compare the sustainability credentials of different urban structure and form types, my research project adopts a typology approach to representing urban structure and form difference, using Sydney as a case study. Although such an approach has implications for quantifying urban structure and form's influence on a variety of sustainability data variables (including transport mode choice, energy consumption and water consumption) my thesis argues that the use of density measures flaws urban research regardless of the methodology chosen to quantify statistical relationships. My presentation will detail the alternative urban structure and form typology adopted for our research project and explain why statistical tests that encapsulate categorical urban structure and form variables, like those developed in our typology, are appropriate within an urban planning framework.

INTRODUCTION

"The way cities are planned, built and function can promote more efficient use of resources, including water, energy and land, minimise the production of waste and encourage more reuse and recycling, reduce greenhouse gas emissions, and support biodiversity in and around urban areas through better management of open and green space." (Commonwealth of Australia, 2010: 3).

This quotation, from the 2010 Australian State of the Cities Report, reinforces a popular view that urban design and planning are important influences in achieving sustainable outcomes. This belief has more or less held sway since the release of the United Nation's seminal document "Our Common Future: The Brundtland Report" in 1987. The Brundtland Report was the first far-reaching UN report of its type to consider the impacts of global development on the environmental health of the Planet. It also introduced the concept of sustainable development, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987: 41). The report was a trigger for government agencies around the world, including Australia, to move away from a period of uncoordinated and parochial urban planning policies to reassert support for environmental planning objectives (Gleeson et al 2004; Anderson et al 2006, Forster, 2006). Metropolitan strategies, in particular, became "pivotal instruments in the application of the governance hypothesis to the achievement of urban sustainability" (Gleeson et al 2004: 350), with urban consolidation becoming the prime planning object in most states and territories throughout the 1980s (Gleeson et al 2004: 352).

The Brundtland Report was the impetus for urban architectural, planning and design practices around the world to be "green and global". As a consequence, there was a resurgence of interest in compact city theories and policies (Burgess, 2000: 9-10). Peter Hall suggests, however, "that like most fixed ideas; this one has a small element of truth and a much larger element of myth" (1997: 214). It is apparent that those supporting compact city policies place significant value on the environmental benefits that containment and consolidation supposedly bring. As Hall alluded to, compact city proponents argue that higher-density urban forms are the most sustainable because they facilitate lower energy outputs, especially transport related energy use (see Talen, 2011; Newton, 2011; Ewing and Fong, 2010; Rickwood, 2009; Perkins, 2009). Other urban researchers, like Hall, assert that such compact city claims are misleading (Gray et al, 2008; Neuman, 2005; Troy, 2004).

From a methodological standpoint, Neuman (2005: 23) states that compact city research has generally been lacking:

"Form, as biologists and geologists understand it, is an outcome of evolution. Form is a snapshot of process. It is a fixed condition at any point in time. Form, in and of itself, is not measurable in terms of sustainability. Asking whether a compact city, or any other form of the city, is sustainable is like asking whether the body is sustainable. The proper question is not if the body is sustainable, but rather, does the being that inhabits the body live sustainably?"

The resource use and environmental impacts of private household consumption are key aspects of sustainable development (Holden and Norland, 2005: 2145), yet it appears that there has been little accompanying research into the direct links between the built environment and areas of household consumption and behaviour (Gray et al, 2008: 17). And even if there is relevance to investigating household behaviour, Neuman (2005) suggests that the methodological premium placed in most previous urban form research on a single operational measure when measuring urban form differentiation, namely population density, tends to reduce a complex entity (the city) to one criterion (density), thereby constraining research and biasing action.

My recently submitted thesis tests the hypothesis that planning and design decisions contribute in some way to achieving sustainable outcomes by testing a different methodology for measuring associations between urban structure and form and sustainable data. I develop alternative approaches to representing urban structure and form and using sustainability data to address some the issues that researchers such as Neuman raise. This Paper's primary focus is on the urban structure and form component of my research. My aim in this Paper is to show that an urban structure and form typology approach can represent the characteristics of Australian urban areas better than density measures do. The Paper then goes on to provide a brief overview of how an urban structure and form typology can be used to statistically test the strength of association with some key sustainability data.

THE PROBLEM WITH DENSITY MEASURES

Density calculations are commonly used in urban form research as a way of quantifying differences in urban form type (e.g. to represent an area as either high density or low density). Churchman (1999) provides a useful overview of the common density measures used and the issues pertaining to them. Churchman states that among a number of ways of measuring density, the most popular are dwellings per hectare; population per hectare; and people plus jobs per hectare.

Newman and Kenworthy appear to be the most influential researchers who apply density calculations to promote high density as the most sustainable urban form (1989, 1999 and 2001). In their work, Newman and Kenworthy calculate average population densities for most major North American, Australia, European and Asian cities and correlate these with car and energy use. Newman and Kenworthy show that car use and, as a result, energy use, increases exponentially once densities fall below approximately 30 persons per hectare. Newman and Kenworthy showed that Sydney's car use, for example, was higher in outer urban areas of Sydney because densities, on average, fell below the 30 dwellings per hectare benchmark. Newman and Kenworthy state that density calculations help explain why relatively high car use exists in Australian and North American cities and why relatively high public transport rates exist in Europe and Asia.

Newman and Kenworthy's research results have garnered much support (Rickwood, 2009b), with Mees (2009) suggesting that their widely used graph showing the relationship between density and car use has significantly influenced metropolitan planning strategies that promote urban consolidation policies in order to increase public transport use and reduce car use. Mees argues that Newman's and Kenworthy's density calculations are flawed, however, because the urban area boundaries they use to calculate urban density for each city around the world are inconsistent – some areas include surrounding suburban areas and some do. Mees goes to the extent of recalculating Newman and Kenworthy's work based on a supposedly more accurate and consistent urban area definition that incorporates previously left out surrounding suburban areas. Mees concludes, after recalculating every North American and Australian cities considered by Newman and Kenworthy, that density does not have the influence on transport patterns that Newman and Kenworthy assert.

But should density calculations be used at all to represent a certain urban form ideal? Practitioners at the planning and design level tend to use dwellings per hectare so as to translate the perceived need for higher densities into specific built form outcomes that facilitates such change (Griffiths, 2009). An example of this approach is Sydney's Metropolitan Strategy 2005 which defines high density housing as over 60 dwellings per hectare and generally five storeys or more (in other words high rise apartments). Medium density is defined as generally between 25 to 60 dwellings per hectare and not usually more than three or four storeys in height (walk-up apartments, townhouses and terrace houses). Low density, obviously, is anything below 25 dwellings per hectare and would comprise predominantly detached dwelling stock (Griffiths, 2009: 4). The problem with such categorisations is that different built form types can represent a variety of different population density categorisations. Griffiths (2009: 3) explains when comparing NSW Urban Design Advisory Service density guidelines, that the same number of people (168) can be housed by providing medium density three storey apartments (69 dwellings/hectare and 2.6 people/hectare) as high density 4-9 storey apartments (141 dwellings/hectare at 1.4 people/hectare). In other words, it is easy to show that the same population density can result in very different dwelling and built form outcomes. Griffiths (2009) and Bamford (2009) state that that the assumed correlation between higher population densities and higher residential building density is misleading.

Michael Neuman in his article the Compact City Fallacy (2005: 21) is critical of those researchers using density calculations in urban form research. He states that as a representation of urban form, average density ignores variations in density within aggregated areas and it does not reflect variations in built form, transport service levels and community linkages across land uses in urban settings. Several other authors have also highlighted the negative impact that the focus on density has had on Australian urban planning policy (McLaughlin 1991, Forster 2006, Bamford, 2007, Griffiths, 2009 and Mees, 2009). This is not to say that increased population density does not play some role in delivering environmental, economic and social benefits (Newman and Kenworthy, 1989; Bramley, 2009; Perkins, 2009; Jones et al, 2010; Florida, 2012) but, as Rickwood and Glazebrook show (2009: 184), there are likely to be other important factors at play. It is argued, however, that the inaccurate application of density measures in urban research has resulted in an unsophisticated urban consolidation policy response in many of Australia's largest cities, especially Sydney. In other words, there has been an unnecessary broad application of multi-level apartment buildings across the metropolitan area (Randolph 2004 and Randolph et al 2006, 2007).

The question then arises as to why density calculations are used at all to represent urban form and structure differences? The answer is simple: statistically, density calculations make it easier to quantify the strength of a causal relationship by calculating the linear regression (r^2) of a dependent variable (e.g. public transport patronage or energy consumed) against an independent variable representing urban form (e.g. density). Yet, what is the point of the calculation if the independent variable does not validly represent urban structure and form difference? Not only can the same density correspond to different built or urban form outcomes (as explained by Griffiths, 2009 above), but densities calculated over large aggregated urban areas do not capture variations in land use patterns, physical design, social characteristics, and ecological conditions (Neuman, 2005: 21). Figure 1 shows that the same density calculations (calculated at the CCD level) can exist within different geographical contexts with different accessibility and socio-economic characteristics. Figure 1 also shows that the State Government's map showing density variations across Sydney is misleading. There are five different density categories mapped, with areas containing over 25 dwellings per hectare all lumped into the one broad category. This category contains a variety of high and medium density built form types (terrace and semi-detached housing, walk-up apartments and high-rise apartments). Yet, four categories are developed to represent essentially one built form type: detached dwellings.

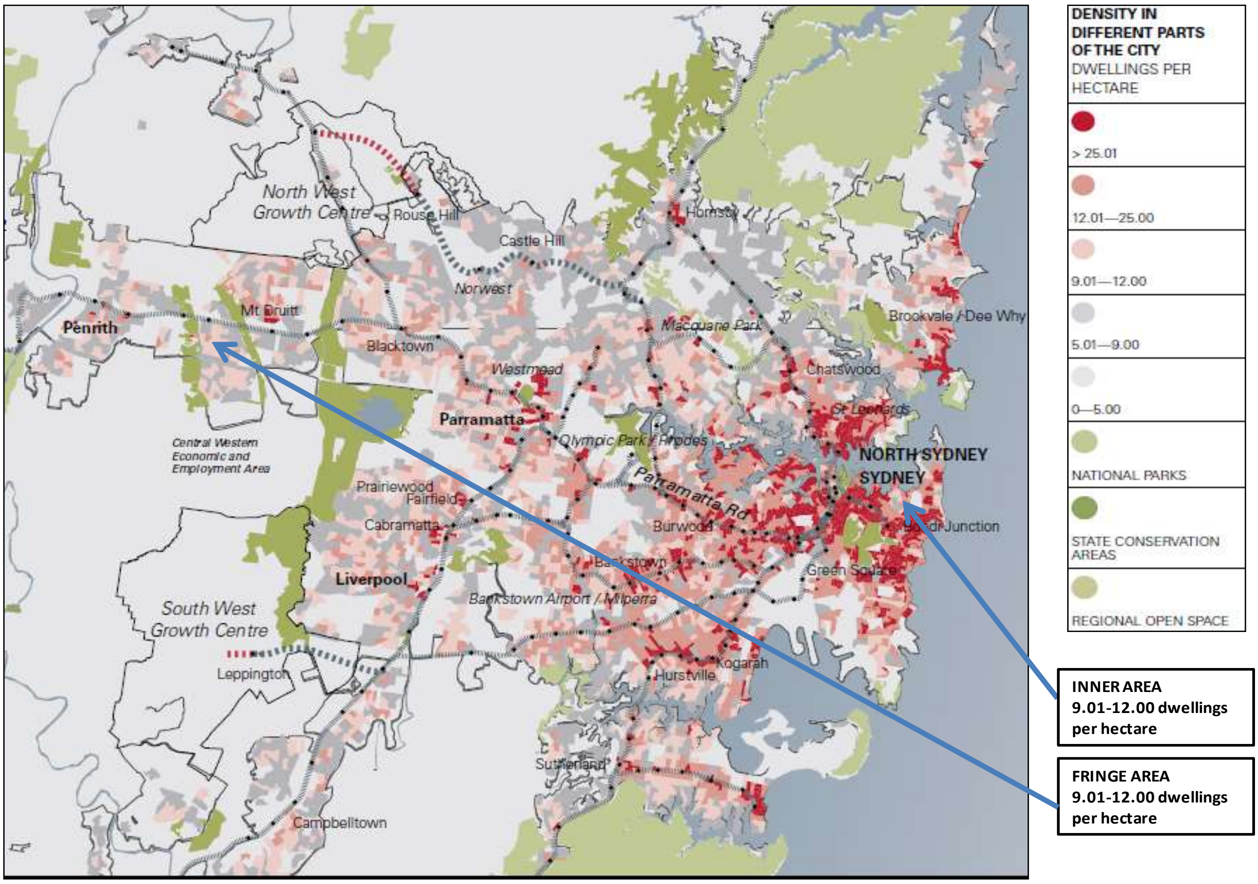

Figure 1: Comparison of area with same density – Sydney metropolitan area (adapted from NSW Department of Planning Metropolitan Strategy, 2005)

Even though the inaccuracies associated with using density calculations to represent differences in urban structure and form are evident, density measures continue to be used because they enable researchers to assess the level of causal inference between two or more sets of numeric variables. Although it could be argued that calculating lineal regression is the statistically correct approach to showing correlation and possibly causality, a counter argument would question the need to show causality when we know from previous research that there are many potential influences on sustainable outcomes, only one of which is urban structure and form. In reality, it is extremely difficult to show causality between two correlated factors in any research, particularly urban research. It could be argued that attempting to prove causality between, say, high density and low energy use, when so many other behavioural influences are at play, is futile. In contrast, there are other statistical tools available to establish statistical association without implying causality, depending on the type of variables being investigated. These can then be compared to other potential sustainability influences/associations, including levels of education, beliefs and attitudes, and a range of socio-economic variables. I assert that urban researchers that continue to use density measures as a proxy to represent urban structure form difference and quantify its lineal relationship with transport mode share or other environmental and social data implies to planners and policy makers that density is the critical variable responsible for achieving sustainable outcomes.

Possibly as a result of the criticisms of density calculations, an increasing number of researchers are developing urban structure and form typologies unique to the city or country being investigated as an alternative to representing differences in urban structure and form. Such typologies encapsulate variables such as urban structure, residential type, public transport accessibility and land use mix (Newton, 2000; Holden and Norland, 2005; Jenks and Jones, 2010). For example, Ghosh and Vale (2009) develop a taxonomy for Auckland, New Zealand, that encapsulates five scales to describe the range of urban change that occurs in large metropolitan areas (see Figure 2): metropolitan/regional scale; sub-metropolitan/city scale; community/neighbourhood scale; local/residential block scale; and house/micro scale. If Ghosh and Vale's taxonomy was applied to Sydney, an area located on the fringe with little public transport access would be placed in a different urban structure category than an area located adjacent to a rail corridor with good public transport access, even though they might have the same residential densities (as shown in Figure 1 previously). The transport modal choices, for example, of residents living in these two situations are likely to be different. Indeed, Owens (2005) shows this to be indeed the case by documenting hundreds of neighbourhoods across the US that experience enormous variation in environmental quality between areas of similar density and land use.

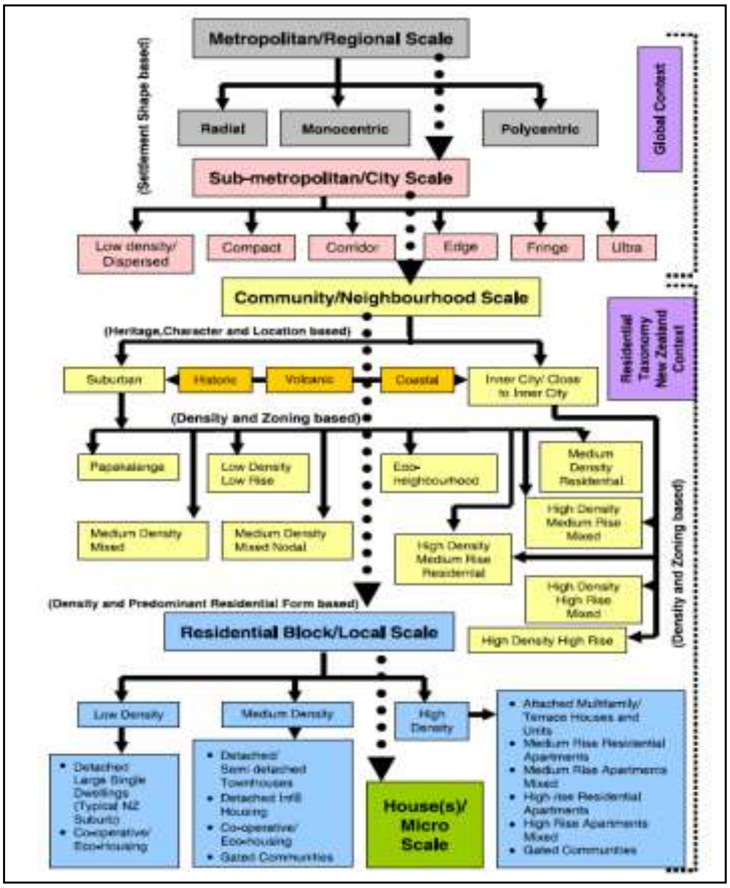

Figure 2 Ghosh and Vale's Urban Structure Form/Taxonomy Scale, 2009: 514

APPLYING AN URBAN STRUCTURE AND FORM TYPOLOGY FOR SYDNEY

Some researchers who use density measures to represent urban structure and form difference recognise there are issues in accurately capturing the obvious structural differences that occur in large metropolitan areas. Urban structure is the manner in which land uses are distributed throughout a city and urban form is the characteristic morphology of settlement of a city. The former could be considered the macro structural context within which micro examples of urban form operate. The measure many researchers have used to represent urban structure, especially those researching the relationship between density and transport, is the distance to CBD measure. They do so because they recognise that urban structure has a strong influence on transport choice (Rickwood and Glazebrook, 2009: 184; Mees, 2009: 11) and a new measure is required that enables the researcher to continue to calculate lineal causality. I argue that such an approach simply compounds the original problem by continuing to validate the density variable. As well, in some large cities like Sydney, the distance to CBD is problematic because it does not capture the unique urban structure differences apparent across a polycentric metropolitan area.

Sydney contains many centres of varying size located along these radials – ranging from larger employment centres like Parramatta and Chatswood to sub-regional centres like Bankstown and Liverpool. Its broad metropolitan scale context provides the setting for applying a unique urban structure and form typology for the Sydney metropolitan area.

Newton (2000) is one of the few Australian researchers to apply an urban structure typology to a large metropolitan area (Melbourne) to test the energy and greenhouse gas emission implications of different urban structures. Newton nominates six different urban structure types, based on “archetypal urban geometries” identified by others (including Pressman, 1995 and Minnery, 1992) to describe current and possible future urban growth: the dispersed city; the compact city, the multi-node city; the corridor city; the fringe city and the ultra city (Newton, 2000: 47). These are similar to the categories nominated by Ghosh et al in their New Zealand-based typology for the sub-metropolitan/city scale (see Figure 1 earlier). Although Newton uses density to describe each category, it is not the only consideration – location relative to the CBD and accessibility are also important. Table 1 below describes each of Newton’s categories.

Urban Structure Category	**Newton’s Description (Melbourne Context)**
Compact City	Increased population and density in the inner group of suburbs surrounding CBD.
Multi-Node City	Increased population, housing densities and employment at selected nodes across the metro area, with key infrastructure linking the nodes.
Corridor City	Growth along linear corridors emanating from the CBD and supported by upgraded transport infrastructure
Dispersed City	Outward random suburban expansion at relatively low densities with connections to a the central city as the key economic node.
Fringe City	Additional growth beyond the dispersed suburban context.
Ultra City	Additional growth accommodated primarily in provincial cities within 100km of the principal city and linked by high speed rail.

Table 1 Newton’s urban structure categories. Source: Newton, 2000: 47

In his Melbourne-based research, Newton showed that these different urban structure categorisations have relevance from a sustainability perspective (Newton, 2000; Australian Academy of Technological Sciences and Engineering, 1997). After testing each urban structure type in relation to indicators such as energy consumption and vehicle kilometres travelled, Newton concluded that urban structure – when represented by the above categories – does matter. He stated that a trend to a more compact city, however defined, will lead to significant environmental improvements compared to the business-as-usual dispersed city model (Australian Academy of Technological Sciences and Engineering, 1997: 170; Newton, 2000). This conclusion supported previous research that used similar approaches to understanding the impact of urban structure and form:

“Although no one form can provide all the environmental, social justice, liveability and economic efficiency conditions required for Australia, it is clear that the increasingly dominant dispersed urban form is unsatisfactory” (Minnery 1992: 106).

To further test this typology approach to describing urban structure and form differences, we need to determine whether Newton’s urban structure categories are applicable to Sydney.

Mapping Sydney’s Urban Structure and Form

My research project uses the Australian Bureau of Statistics (ABS) geographical classification for Urban Centre/Locality to define the Sydney metropolitan area, which corresponds to the Sydney metropolitan region boundary used by the NSW Department of Planning in Figures 3 and 4. It is apparent when viewing the geography of Sydney’s historical urban growth that each urban structure category described by Newton can be broadly applied to different parts of the Sydney metropolitan area. The NSW Government’s Metropolitan Plan for Sydney 2036 (NSW Department of Planning, 2005) contains a map showing Sydney’s urban growth history which broadly reflects the type of urban structure categories Newton describes (reproduced in Figure 3). The suburbs shown in dark red are areas developed before 1917 containing the type of inner-area compact city, multi-node and corridor city characteristics described by Newton. These areas of Sydney contain much of Sydney’s older apartment, semi-detached, terrace and mixed use land use stock, as well as newer high-rise apartment buildings, especially in and around the CBD and in the multi-node locations. The compact city, multi-node and corridor city areas also have excellent levels of walking and public transport accessibility. Areas developed between 1917 and 1945 are shown in lighter red and represent the dispersed city category, where Sydney's early detached dwelling dominated suburbs started to appear beyond Sydney's rail corridors. The lighter pink areas represent the fringe city categories, which contain new large-sized detached dwellings well away from any railway lines. New master-planned residential estates have dominated in these areas. The yellow areas are areas already planned for future fringe growth.

Although Sydney's historical urban growth pattern can be considered a good guide for placing Newton's urban structure categories, we require a more detailed examination of potential urban structure category boundaries so that every CCD within the Sydney metropolitan areas can be placed within an appropriate urban structure category using Geographical Information Systems (GIS). Figure 4 and Table 2 specifies where each urban structure category has been placed, using local government area boundaries, public transport walking catchments, major road corridors and natural area boundaries.

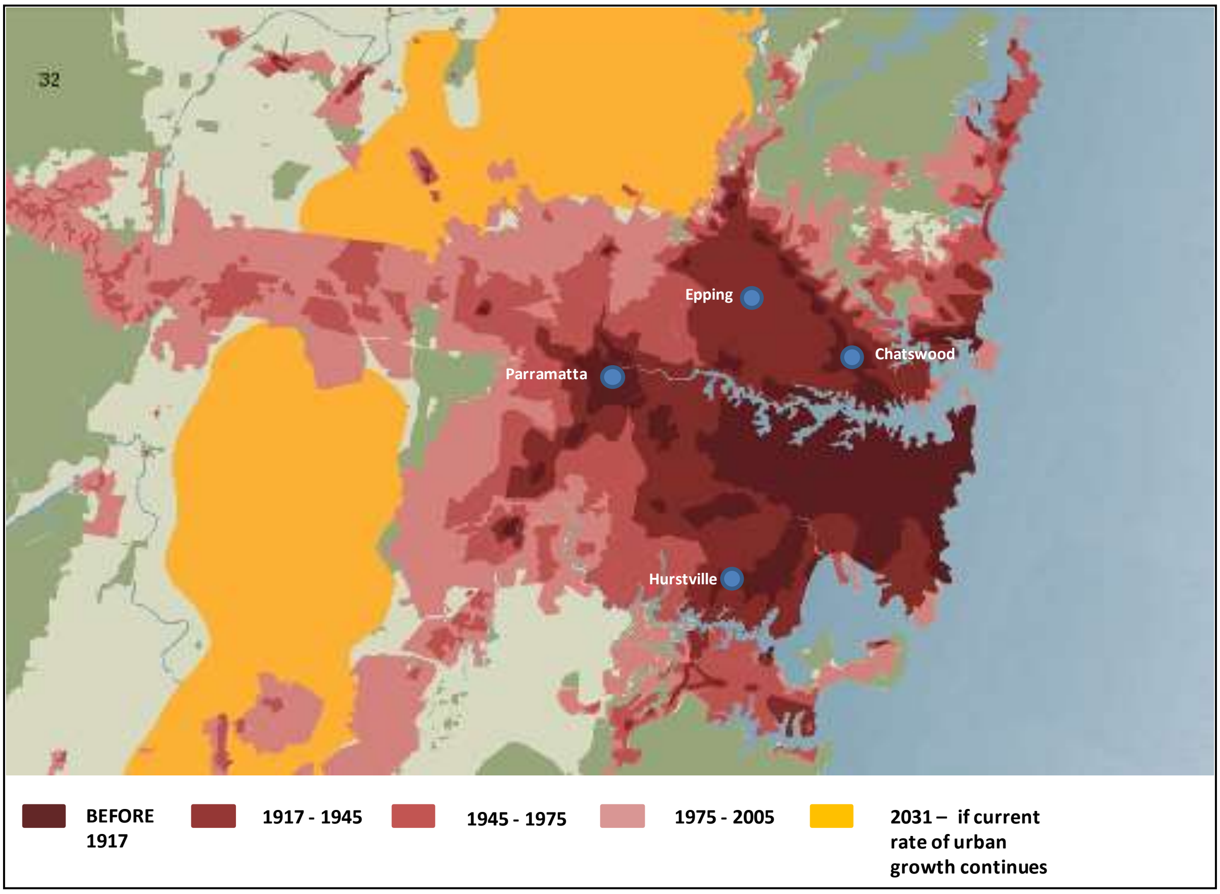

Figure 3 Sydney's Urban Growth History. Source: 2005 City of Cities Metro Strategy, NSW Department of Planning, 2005

In applying Newton's urban structure categories to the Sydney context, it became clear that one additional urban structure category was required. A "secondary centre" urban structure category was added to reflect the polycentric structure that exists within the Sydney metropolitan region. The state government's metropolitan planning strategy promotes a "city of cities" approach (NSW Department of Planning, 2005), which has resulted in the strengthening of sub-regional employment and retail centres located on rail corridors and major bus corridors in the Sydney metropolitan region. The secondary centres, namely Burwood; Ashfield; Hurstville; Bankstown; Penrith; Kogarah; Blacktown; Dee Why; and Sutherland, are smaller than the larger multi-node city category centres which have been established for some time (Parramatta, Chatswood, Hornsby, Liverpool and Campbelltown), but larger than the village-like centres located within the corridor city structure.

Category	Where Applied
Compact	CCDs located within Sydney's inner urban LGA's - City of Sydney, Leichhardt, Waverley, Marrickville and Randwick (north of Gardener's Road). These LGA's are generally highly accessible to public transport, employment, retail and essential services with a mixture of housing choice.
Multi-Node	CCDs located within 800m of railway stations (proxy for centroid) located within designated (by Planning NSW) high-order centres: Chatswood, Parramatta, Hornsby, Liverpool and Campbelltown. Similarly accessible to public transport, employment, retail and essential services as the Compact City but dominated by four-storey and above apartments.
Sub-Regional	CCDs located within 800m of railway stations (proxy for centroid) located within designated (by Planning NSW, 2005) secondary centres: Bankstown, Ashfield, Burwood, Blacktown, Penrith, Sutherland, Dee Why, Kogarah and Hurstville. In the case of Dee Why, it is all CCD's within 800m of Pittwater Rd and Dee Why Parade intersection. Sub-regional centres have similar characteristics to the Multi-Node City but on a smaller scale with less employment opportunities.
Corridor	Any CCDs outside the previous categories that are located within 800m walking distance of a railway station or 400m of a high-order bus corridor (Anzac Pde and Pittwater Rd). Characterised by good accessibility to local shopping precincts with a mixture of housing choice (other than four-storey and above apartments).
Dispersed	Areas constituting Sydney's traditional suburban environment (see Figure 3– suburban areas developed between 1917 to 1976). Generally comprises a mixture of old and contemporary detached dwellings dominated by car access and local bus services.
Fringe	Designated areas beyond the traditional dispersed suburban environment. Primarily consists of contemporary build with poor public transport and local service accessibility.

Table 2 Urban structure locations in Sydney metropolitan region. Reference: Department of Planning, 2005

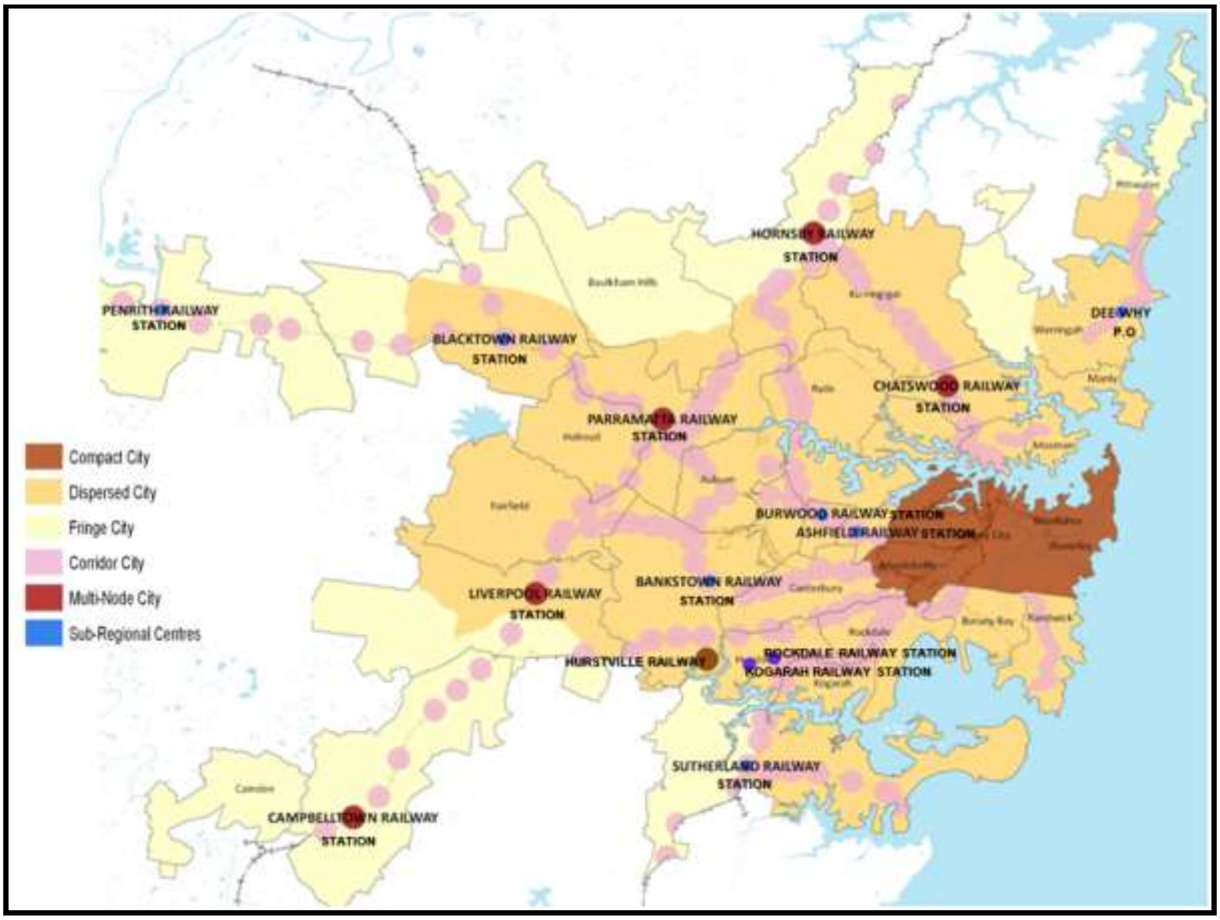

Figure 4 Sydney's Urban Structure Locations. Map source: UWS Urban Research Centre, 2012

With our urban structure categories in place, we now consider dwelling type characteristics within each urban structure category to better understand the level of urban form differentiation that exists within them, representing the residential block/local scale as per Ghosh and Vale's typology (Figure 1 earlier). Each urban structure category contains examples of different housing types to varying degrees. We have grouped all housing types listed by the ABS into the following categories (Table 3): detached dwellings; semi-detached or terrace style dwellings; up to three-storey walk-up apartments; and four-storey and above apartments. Table 3 shows that there are notable differences in the proportions of these dwelling type contained within each urban structure category. Notable differences include detached dwellings being predominant in the fringe (86 percent of all dwellings provided) and dispersed categories (66 percent of all dwellings provided) and walk-up and four-storey and above apartments predominating in the multi-node (64 percent of all dwellings provided) and sub-regional centre (72 percent of all dwellings provided) categories.

	Detached		**Semi-Terrace**		**Walk Up Apts**		**Four-Storey Plus Apts**		**Other**		**Total**	
Category	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Compact	40892	22	40771	22	47707	26	50651	28	1968	1	181989	100
MultiNode	4079	30	675	5	3708	27	5086	37	20	0	13568	100
SubRegional	2773	20	1046	8	6897	50	3119	22	61	0	13896	100
Corridor	148514	52	32020	11	70794	25	34361	12	1843	0	287532	100
Dispersed	168703	66	28357	11	43237	17	15969	6	760	0	257504	100
Fringe	45884	86	4057	8	2433	5	530	1	180	0	53084	100

Table 3 – Sydney's Urban Structure Categories – Number of Dwellings and Percentage of Housing Type. Source: ABS Census, 2006

In order to analyse the combination of urban structure and dwelling type (representing urban form) for our research project, we isolated those CCDs that contain one dominant housing type. The sustainability data collected for this research project is aggregated to the CCD level. As such, analysis of the influence of dwelling type on the sustainability data can only take place when one dwelling type only is counted for the whole of the CCD. Therefore, we do not seek to compare different dwelling types within every CCD located in the Sydney region but rather seek to compare CCDs within different urban structure categories that contain a dominant dwelling/urban form type. Table 4 shows that there are a sufficient number of CCDs with one dominant housing type (where a CCD contains above 95 percent of one particular dwelling type) to enable dwelling type to be analysed and compared across the metropolitan region.

	Detached	**Semis-Terraces**	**Walk Up Apts**	**Four-Storey Plus Apts**	**Total**
Compact	13	9	11	71	104
Multi-Node	8	0	9	13	30
Sub-Regional	1	0	4	3	8
Corridor	303	4	24	19	350
Dispersed	581	10	21	4	616
Fringe	531	6	0	0	537
Total	1429	29	68	110	1645

Table 4 – Sydney's Urban Structure Categories – Number of Predominant Housing Type CCDs (above 95 percent). Source: ABS Census, 2006

STATISTICAL TESTS USING AN URBAN FORM TYPOLOGY

The requirement to calculate lineal relationships between density and different sustainability indicators in urban form research is questioned. Rickwood states (2009a: 64) that the complexity of urban systems often does not easily enable theoretical models to be developed, resulting in descriptive statistical and econometric approaches being used to obtain insights from available data. Rickwood concludes that the reliance on easily computable metropolitan-scale variables (such as density calculations) leads to difficulties in devising a representation of urban form differences. Yet, even though Rickwood still maintains that results from such studies can be informative, I have argued earlier that the continued emphasis on density implies to planners and policy makers that density is the critical variable responsible for achieving sustainable outcomes.

Descriptive variables such as the urban structure and form categories developed for this research project cannot be sequentially ordered or differentiated from each other using a mathematical method (Ludford, 2012). They are therefore categorical. On the other hand, the secondary sustainability data used in my research project to compare different urban structure and form categories are differentiated numerically, so are defined for statistical purposes as continuous. Ludford develops a table (Table 5) to guide researchers in choosing the correct statistical test to use based on whether variables as categorical or continuous.

		Dependent Variable	
		Categorical	Continuous
Independent Variable	Categorical	Chi-Square	t-test, ANOVA
	Continuous	LDA, QDA	Regression

Table 5 Choosing the Correct Statistical Test. Source: Ludford, 2012. *Note: LDA = Linear Discriminant Analysis and QDA = Quadratic Discriminant Analysis*

Table 5 shows that there are only two statistical tests available when calculating the level of association between our categorical variable (urban structure and form categories) and the variety of continuous data available that represent sustainability behaviours: t-tests or Analysis of the Variance of Means (ANOVA). If our urban structure and form typology contained only two categorical independent variables (e.g. compact city and dispersed only), then a 2-sample t-test would be the correct statistical test. However, because the categorical independent variable has more than 2 variables (there are six urban structure categories), ANOVA should be applied. Even though ANOVA does not assist in explaining the cause of difference that might exist across urban form categories, it is an approach that is appropriate in urban form research for assessing statistically significant patterns of difference (Sobhani, 2009; Handy, 1996). If statistically significant patterns of difference emerge across the urban structure and form categories and across the three secondary sustainability variables, then further research can take place to understand potential causes of such differentiation.

Our research did show there were statistically significant associations between our sustainability data (electricity consumption, water consumption and car ownership rates) and the urban structure categories (see Figures 5, 6 and 7)

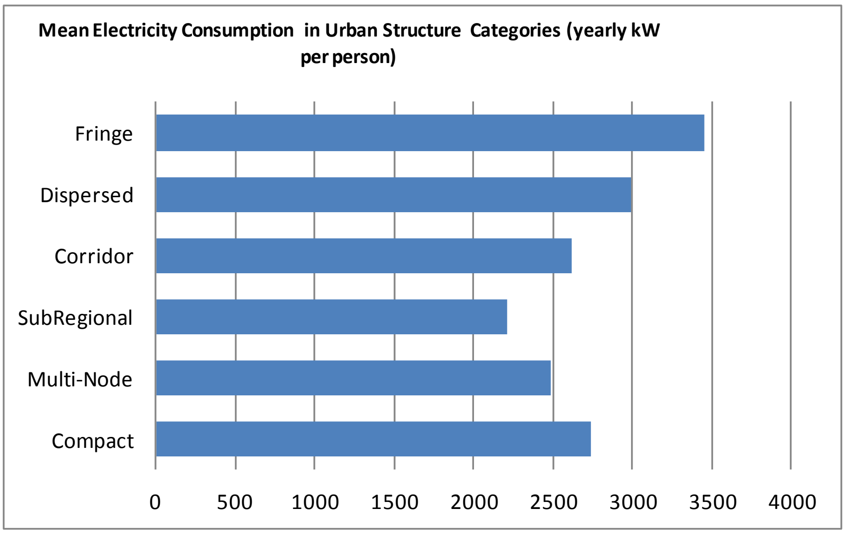

Figure 5 2006 Electricity Consumption per person by Urban Structure. Data Source: AusGrid, 2011..

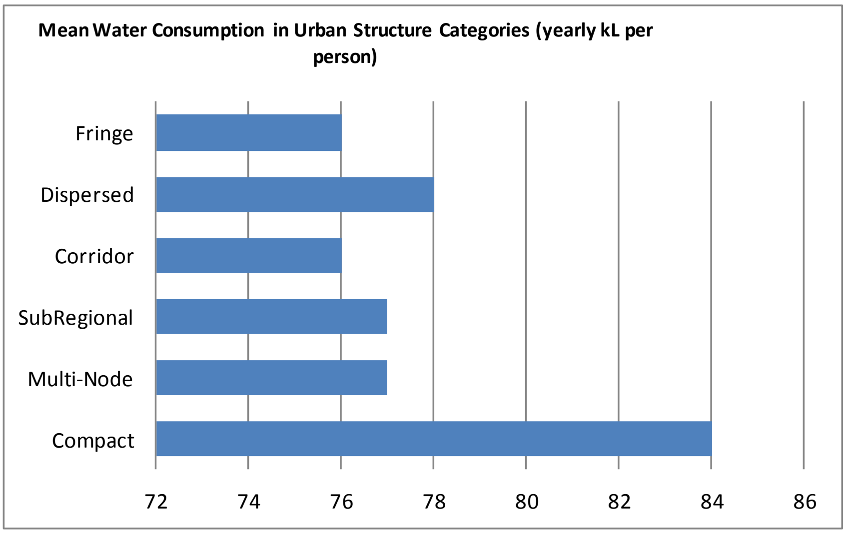

Figure 6 Water Consumption by Urban Structure. Source: Sydney Water, 2011

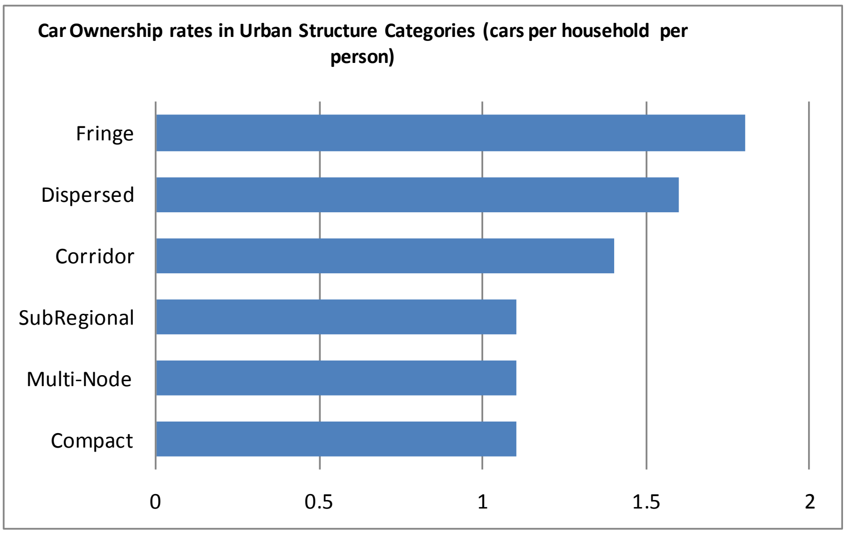

Figure 7 Car Ownership by Urban Structure. Source: ABS, 2006

For electricity use, ANOVA one-way tests showed there are significant differences in the means between most urban structure categories except between the compact city and multi-node categories, the multi-node and corridor categories, and the multi-node and sub-regional categories. For water use, there is statistically significant difference in the means between compact city and every other category. For car ownership there is significant difference in means between most urban structure categories, except between the compact city and sub-regional and multi-node categories.

On the surface, the urban structure variable appears to have an influence on the three key sustainability indicators in different ways. Yet, can it be assumed that it is the urban structure category itself is responsible for generating statistically significant difference in the means for each of the indicators or are there other factors contributing to the results? From the relevant literature it is apparent that two potential influences on the three indicators are dwelling type (representing urban form difference in this research project) and socio-economic status (Randolph and Troy, 2007, 2008). With regard to dwelling type, the different heating and cooling requirements of different building structure types, in particular, can have a marked impact on electricity use. Socioeconomic factors are also believed to be associated with energy consumption, with Randolph and Troy (2007) showing in the Sydney context that higher income low density suburbs record much higher per capita electricity consumption than lower and moderate income low density suburbs.

Water consumption rates are also affected by dwelling type, with those living in detached dwellings with backyards having a greater capacity to recycle and reduce the amount of water consumed (Randolph and Troy, 2008). Moreover, dwelling type and levels of home ownership may be more important than socio-economic factors in influencing water consumption patterns (Randolph and Troy, 2008: 453). With regard to car ownership, socio-economic factors and dwelling type may also have an influence on transport modal choice, although urban structure is identified as having a more significant influence on transport modal choice than these factors (Mees, 2009; Rickwood and Glazebrook, 2009).

What we can do to understand the level of influence of one category (urban structure) over another (dwelling/urban form or SEIFA) is to perform a two-way ANOVA test. Tables 6 and 7 show the results of two-way ANOVA tests when the effect of urban structure is assessed for both the dwelling/urban form variable and SEIFA index variable.

	Electricity		Water		Car Ownership	
Dwelling Variable	F value	Sig.	F value	Sig.	F value	Sig.
Detached Dwelling	17.885*	0.00	21.722*	0.00	33.793*	0.00
Semi or Terrace	0.399	0.67	0.138	0.94	2.125	0.10
WalkUps	0.551	0.70	2.839*	0.02	3.36*	0.01
FourStorey Above	1.938	0.10	7.827*	0.00	6.034*	0.00
Each F tests the simple effects of UrbanForm within each level combination of the other effects shown. These tests are based on the estimable linearly independent pairwise comparisons among the estimated marginal means.						

Table 6 –Two-Way ANOVA testing for electricity, water and car ownership considering Urban Structure and Dwelling. * indicates statistical significance. Source: PASW SPSS Statistics 18

	Electricity		Water		Car Ownership	
SEIFA Variable	F value	Sig.	F value	Sig.	F value	Sig.
Ranking 1	0.39	0.68	21.526*	0.00	32.241*	0.00
Ranking 2	1.52	0.21	2.334	0.04	13.936*	0.00
Ranking 3	21.532*	0.00	1.46	0.20	17.152*	0.00
Ranking 4	19.535*	0.00	1.171	0.32	28.606*	0.00
Ranking 5	0.50	0.73	1.826	0.10	45.07*	0.00
Ranking 6	1.39	0.24	3.902*	0.00	69.227*	0.00
Ranking 7	4.328*	0.00	4.472*	0.00	95.872*	0.00
Ranking 8	3.815*	0.00	6.192*	0.00	112.103*	0.00
Ranking 9	13.611*	0.00	3.97*	0.00	221.606*	0.00
Ranking 10	48.436*	0.00	9.355*	0.00	497.877*	0.00
Each F tests the simple effects of UrbanForm within each level combination of the other effects shown. These tests are based on the estimable linearly independent pairwise comparisons among the estimated marginal means.						

Table 7 –Two-Way ANOVA testing for electricity, water and car ownership considering Urban Structure and SEIFA index. * indicates statistical significance. Source: PASW SPSS Statistics 18

Table 6 shows that urban structure has a statistically significant influence on mean electricity consumption in detached dwellings, while mean electricity consumption does not vary significantly for the other dwelling types across different urban structure contexts. In other words, electricity consumption has the potential to vary significantly in detached dwellings when placed in different urban structure contexts. The table also shows that urban structure has a significant influence on water consumption in three of the four dwelling types, with the semi-detached and terrace dwelling type being the only exception. As well, urban structure influences car ownership for all dwelling types except semi-detached and terraces.

Table 7 also shows that urban structure has a statistically significant influence on electricity usage and water usage across many of the SEIFA index ranking categories, and for all SEIFA rankings when it comes to car ownership. In fact, Table 5.9 shows that for every SEIFA ranking above 7, urban structure has a statistically significant influence over electricity consumption, water consumption and car ownership.

These results led us to choose case study locations around Sydney representing different urban structure and form (dwelling) types so as we could attain primary data from households to interrogate why such associations might exist. The survey of case study areas generated responses regarding behavioural choices that are also defined as categorical for statistical purposes (i.e. they are not continuous or ordinal). Whereas Table 5 above shows that t-tests or Analysis of the Variance of Means (ANOVA) are most appropriate when determining the level of association between a categorical variable (urban structure and form) and continuous or ordinal data (the sustainability data), the table shows that chi-square tests should be used when testing two categorical variables.

The categorical responses from our questionnaire survey were divided into dependent or independent variables in order to develop cross-tabulations. The chi-square cross-tabulations then enabled us to quantify the most statistically significant associations between urban structure and form and the variety of sustainable behaviour data we were able to collect. The chi-square testing showed that urban structure and form has a strong association with transport behaviours, especially when compared to other potential influences like attitudes and beliefs and a range of socio-economic factors. On the other hand, urban structure and form is one of several factors (including attitudes and beliefs) that are statistically associated with reduced electricity and water consumption. The chi-square results suggest that the case study locations representing different urban structure and form categories may be statistically associated with other independent variables such as belief in human-induced climate change, level of education and a variety of socio-economic factors, which manifest as geo-political differences across large metropolitan areas. This then might explain differences in detached dwelling electricity consumption across the urban structure categories. The nexus between urban structure and form and the combination of political values, level of education and socio-economic factors is an area of further research worth exploring.

CONCLUSION

This Paper presents two different approaches to representing urban form difference: density calculations and urban structure and form typologies. Given the inherent inaccuracies involved in using density calculations to represent different urban form types when assessing their relationship with sustainability data, it was decided to develop and test a typology approach as a way of more accurately representing urban structure and form difference. In developing an urban structure and form typology for our case study location, the Sydney metropolitan area, we relied on Newton's (2000) urban structure categories and adapted these to the Sydney context. We developed six distinct urban structure categories that we found existed in various parts of the Sydney metropolitan area and mapped these as accurately as possible with the assistance of GIS. We then placed every CCD within the Sydney metropolitan area into an appropriate urban structure category and highlighted those CCDs with a dominant housing type to enable a comparison of different combinations of urban structure and dwelling type (urban form).

Applying an alternative descriptive typology for representing urban structure and form difference did not permit us to infer causal relationships between our urban structure and form categories and the sustainability data we used. I argue, however, that employing alternative statistical approaches that calculate relative levels of association between categorical urban structure and form variables and a variety of sustainability data is more appropriate within an urban research context. When we undertake 2-way ANOVA testing to ascertain the extent to which the urban form (represented by different dwelling type) and the SEIFA index (representing socio-economic differences) variables affect urban structure's influence over the three sets of data, it becomes evident that urban structure, as a separate statistical variable, does influence household behaviours, especially car ownership, regardless of dwelling type (urban form) or socio-economic ranking. However, further case study results suggests that other variables such as belief in human-induced climate change, level of education and a variety of socio-economic factors may manifest as geo-political differences across large metropolitan areas and explain the level of association the urban structure variable has with electricity and water consumption. Such results would not be possible by using density calculations alone to represent urban structure and form difference.

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