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Review of Settlement Form Descriptors – Working Paper

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1.1 Introduction

Research relating to urban form has enjoyed a resurgence since the introduction of GIS related technologies in the late 1990's. This renewed interest has spawned new methodologies for quantifying human settlement, once reliant on cartographic representation, and later MATLAB.

Much less information exists that quantifies "urban form at the metropolitan level than at the intermediate and low geographic levels" (Tsai, 2003). Most of the material is relatively new… having been written since 2001. While many of the ideas presented in the literature (especially Ewing et al, 2002) were quickly translated into local policy in the United States, insufficient time has passed to provide significant case study analysis. Research seeking to measure urban form has reached similar conclusions in most cases, yet each suffers from the desire to ''re-invent the wheel'. Little consistency exists between both methodologies, and the definition of the measured environment. The majority of research is U.S. based and relies on national databases. This provides an added difficulty for outside countries whose data collection and measurement techniques vary.

This review seeks to identify the best measurements of urban form contained within the literature, with the intent of applying them in the New Zealand setting. This is the beginning point for research intending to improve the sustainability of our cities by providing local authorities with suitable planning tools.

1.2 Definitions

There appears to be an inconsistency of separation between the terms 'urban form' and 'urban sprawl' within the literature. Often the terms are thrown together loosely, without consideration of their meanings. Although a major aspect, sprawl is merely one part of the myriad of complexity that is urban form. Those who have used both terms have done so interchangeably, implying that they are indeed one and the same. It is widely agreed that unsustainable urban form is a direct result of urban sprawl – hence, all those who are seeking to quantify urban form, are in fact measuring the various aspects of sprawl. For the benefit of this research, the interchangeable use of both terms should be maintained… however it is recommended that more weight is given to definitions in future research.

Urban Form has been defined as…

- "The spatial pattern of human activities at a certain point in time" (Tsai, 2003).

Sprawl has been defined as…

- "The process in which the spread of development across the landscape far outpaces population growth" (Ewing et al, 2002)

2.0 Methods for Measuring Urban Performance

2.1 Literature Review

To obtain a measure of overall urban form, a number of sub-measures must be quantified. The type of sub-measures involved is dependent on the aspect of urban form for which we are looking. In this case we are measuring overall urban form, with the intent of providing indices that can assess settlements for their social, environmental, and economic performance.

Galster et al, (2001) divide land use into 3 types: residential, non-residential, and un-developable. A ¼ mile grid is then overlaid onto a city, and each cell is measured for eight different land use dimensions: density, continuity, concentration, compactness, centrality, nuclearity, diversity, and proximity. "Each dimension was operationally defined and six of the eight were quantified for 13 urbanised areas" (Ewing et al, 2002). Individual measures are obtained for each aspect. These are weighted and combined to form an overall index. This work changed the face of urban quantification (most previous studies had concentrated their urban form measurements on density) as it utilised a number of different measurements in concert to give the first "composite index of metropolitan sprawl" (Knaap et al, 2005). The new measurement enabled us to distinguish between density and overcrowding, and gave enough spatial information to characterise the form and function of a particular city. According to Ewing et al (2002), Galster et al's (2001) model "was the most complex and multi-faceted sprawl index to date". Most literature since has simply expanded upon, or re-defined and modified the various dimensions used by Galster et al (2001).

The other major groundbreaking paper on quantifying urban form was Ewing et al (2002). This is simpler than Galster et al (2001) in that it measures four factors of sprawl rather than eight. The four factors looked at were; Residential Density, Neighbourhood mix of homes, jobs, services, strength of activity centres and downtowns, and the accessibility of the street network. However, within these four factors are 22 measured variables (increasing the complexity of the method) taken from various U.S. based data providers. Because of this, the application of Ewing et al's work outside the U.S. is difficult, especially since they have factored into the equation just about every possible data measurement available in the United States. While Ewing et al's results are thorough; other countries are unlikely to produce the same data on urban form making repeatability difficult. Still, individual countries can group the datasets they have under one of the four factors outlined, and create their own weightings for each variable dependent on their importance within that particular locality. This gives us the best method for pooling individual dimensions and achieving an overall sprawl rating.

Wolman et al (2003) suggests that (like other recent research on measuring sprawl) Galster et al (2001) and Ewing et al (2002) needed to achieve academic consensus on the area of measurement and the definition of the term 'sprawl'. "When the definition of sprawl is so ambiguous and idiosyncratic, it is impossible to know with any confidence its causes or consequences or the effects of any policies designed to contain it" (Wolman et al, 2003). The flaw in the method is that the location of an urban boundary can determine whether a city is shown to be compact or suffer from sprawl. Indeed, one study shows that Portland is less sprawled than Los Angeles, while another study has the position of the two cities reversed. The question is where exactly is the edge of the city? Bertaud (2001) uses 45 km as the maximum distance for measurement; however this is for cities far larger than any we have in New Zealand. Other methods include: adhering to political/official boundaries; including only nearby towns and secondary cities that have a strong commuter relationship or role within the urban environment in question; and measuring to a point where the urban density becomes indistinguishable from the rural density. Bertaud (2001) has also used density measures to determine the urban boundary. The rural area density outside the city is measured and the line drawn at a point where the urban density drops to within a certain range of the rural density. However, in his Shanghai example, Bertaud uses the 'city proper' as outlined by local authorities as his defined boundary (excluding satellite sprawl). This renders the comparison between this city and other cities irrelevant, and highlights the need for consistency in boundary definition.

Perhaps the best beginning point for establishing measures of urban form within New Zealand is the work by Knaap et al (2005). Five categories are outlined, broadening the scope slightly of the four variables in Ewing et al (2002). These five categories are: metropolitan structure; sub-metropolitan structure; community design; urban design; and landscape ecology. Within each category are a number of sub-categories (35 in total). These include things like density, accessibility, centrality etc. Each sub-category has a short list of the **possible** methods for measuring that particular sub-category. This offers a base for methodology selection as it includes almost all the significant methods from previous studies. Upon selection, an overall measure could be quantified using a weighting (such as used by Ewing et al) for any number of variables across the sub-categories.

In a case study of Portland by Song & Knaap (2004), the importance of forecasting is mentioned with regard to the application of urban form measurements. Within their literature review Galster et al's (2001) work is recognised as providing an abundance of information on urban form, "Yet their measures offer little use to urban residents or policymakers" (Song & Knaap 2004). The policy oriented approach is focused on outcomes rather than on differences in spatial relationships. The point is raised that if a local authority is told it has a high accessibility rating, (e.g.) how would they know how to respond (considering they may not have the tools to prepare policy relevant to their rating)? Incidentally, the case study of Portland highlights what happens to the density of an urban area when development boundaries are adhered to. The results suggest this is a successful tool for reducing sprawl and its associated sustainability deficiencies.

"For making urban land use planning more sustainable, it is essential to have insight into the relationships between urban users and their surroundings" (Van Diepen & Voogd, 2001). Van Diepen & Voogd studied the relationship between urban form, travel behaviour, and sustainable development. They term urban form as "the spatial configuration of the way people employ a parcel of surface, or land use". Their literature review concludes that: fuel consumption decreases with density; high density corresponds with a low energy consumption rate; an increase in localised facilities reduced car trip length but does not generate more walking; the relationship between urban form and travel isn't strong, but is related; and urbanisation reduces mobility and trip length. Their own research concentrates mostly on micro level aspects of urban form that have an influence on travel behaviour and they present a case study on the Amersfoort region in the Netherlands. Van Diepen & Voogd (2001) also experienced consistency issues involving the area of measurement – namely the rural zone. This was because the Amersfoort region has a comparatively densely populated rural area compared to the rest of the Netherlands, making it difficult to distinguish the urban area from the rural area. It was concluded that "even if an ideal form could be envisioned, it is not clear how it could be attained". A notion of development timeframes was alluded to… "we must be aware of the fact that the built environment for the next 50 years largely already exists"; implying that best practice is always changing, and that today's urban environment is merely a product of those changes.

Bertaud (2001) uses a 'centre of gravity' measurement. This is the point within a city where the average distance per person to the CBD is the shortest, and is influenced by the city shape as well as land value. The measure is relevant and interesting when looking at monocentric cities, however not so for those that are polycentric. Bertaud measures Density by "calculating the number of people within each consecutive ring centred on the central business district (CBD), calculating the built up area within the same rings, then for each ring dividing the population by the built up area". This is a good combination for looking at density and centrality; however is not an overall measurement of urban form.

A more mathematical attempt to quantify urban form was made by Tsai (2003). He used four quantitative variables "to measure four dimensions of urban form at the metropolitan level: metropolitan size, activity intensity, the degree that activities are evenly distributed, and the extent that high-density sub-areas are clustered" (Tsai, 2003). To distinguish these dimensions of urban form between those representing compactness from those measuring sprawl, Tsai (2003) advocates the Moran coefficient. The Moran coefficient reads high for monocentricity, intermediate for polycentrism, and low for decentralised sprawl. Tsai (2003) urges caution when analysing variables on differing scales. Even data as commonplace as density can and will show different results on a neighbourhood level than it would on a metropolitan level. For this reason it is deemed that works relating to smaller scale measurements be given less weighting in terms of their relevance in characterising overall urban form in the New Zealand scene. Unlike monocentricity, polycentrism is more difficult to distinguish from sprawl. Polycentric cities operate on a more sustainable basis than decentralised and unstructured sprawl. The most commonly used coefficient (Gini) does not make the required distinction. The *Gini coefficient* is applied to measure inequality of population or employment distribution by spatial units in a metropolitan area. There is no certainty or place as yet for the Gini coefficient as recognised measure of urban form because it cannot distinguish between randomly distributed or clustered spatial arrangements. This is the reason for Tsai's advocacy for the more flexible Moran coefficient (see 2.9)

Not all academics are proponents of new urbanist ideals. Burchell & Mukherji (2003) are sceptical of the actual costs of sprawl. They propose re-development as a serious method for controlling urban sprawl. This literature is a review of a report on the costs of sprawl in the year 2000 and tends to argue that there are also numerous benefits of sprawl from a social perspective. These include: an increased living standard for less cost (assuming that larger homes equate to a higher living standard); unlimited automobile use equals less public transport expenditure; land availability within the core of the city is preserved for other uses; crime rates are lower; and the educational opportunities are greater.

Porta (2001) looks at Sustainable Development Indicators that can assess the relationship between urban form and social sustainability. He argues that "little research, if any, has addressed the impact of city form onto social behaviours as part of the urban sustainability question". Porta's work is mostly concerned with micro level dimensions of urban form, such as building facades and street walls. Still, it gives useful information on social measurements of urban form, and the pitfalls associated with obtaining them.

2.2. Measurement Scales

The best categorisation of urban form measurement scale is presented by Knaap et al (2005). They divide urban form into five different levels. These are:

- Metropolitan Structure (Bertaud, 2001) (Ewing et al, 2002) (Galster et al, 2001) (Knaap et al, 2005) (Tsai, 2003)
- Sub-Metropolitan Structure (Song & Knaap 2004)
- Community Design (Knaap et al, 2005)
- Urban Design (Porta, 2001)
- Landscape Ecology (Knaap et al, 2005)

This review is primarily concerned with the macro aspect of urban form measurement, so only studies containing methods for measuring metropolitan structure will be looked at. Below are the types of measurement contained within the metropolitan structure category within the last four years (since the path-breaking paper by Galster et al (2001) of literature. Minor or small scale types of measurement such as 'clustering' and 'continuity' have been left out of this particular review, yet are still applicable for in depth studies of individual urban environments. Also left out are types of measurement that some studies refrained from using due to difficulties obtaining adequate data.

Metropolitan Structure includes:

Note that next to each form of measurement are the corresponding literature sources. Also, for the purpose of this review, similar methods have been grouped together.

Density - Built Area (Bertaud, 2001)
- Development (Galster et al, 2001)
- Distribution (Knaap et al, 2005)
- Land Use Intensity (Ewing et al, 2002)
- Metropolitan (Knaap et al, 2005)
- Residential (Ewing et al, 2002)
- Variation (Knaap et al, 2005)

Accessibility / Street Network (Ewing et al, 2002) (Knaap et al, 2005) (Song & Knaap, 2004)

Centrality / Compactness (Ewing et al, 2002) (Galster et al, 2001)
Eccentricity / Proximity (Bertaud, 2001) (Tsai, 2003)
Mix / Diversity (Ewing et al, 2002) (Galster et al, 2001) (Song & Knaap, 2004)
Nuclearity / Concentration (Galster et al, 2001) (Tsai, 2003)
Proximity / centre of gravity (Bertaud, 2001) (Galster et al, 2001)
Size / Shape (Knaap et al, 2005) (Tsai, 2003)

2.3 Density

Description

Density is the most common and simplest measure of urban form. As a lone measure, density can tell us a lot about a city, however its flaw is that it can't distinguish between desirable density and overcrowding. Therefore, density measures require additional methods to characterise the more intricate variations of urban form.

Methods (Galster et al, 2001)

- Development density: residential units and employment divided by developed land area.

Methods (Ewing et al, 2002)

- Gross population density: persons per square mile.
- Suburban density: percent of population living at densities less than 1500 persons per square mile.
- Urban density: percent of population living at densities greater than 12,500 persons per square mile.
- Density at the centre of a metropolitan area: derived from estimated population density gradient.
- Gross population density of urban lands: based on data from the USDA Natural Resources Inventory.
- Lot Size: weighted average size of single family lots.

- Population centre density: weighted density of population centres based on a grid system.
- Coefficient of variation: measure of density variation from the mean.
- Density entropy: measure of proportionate density variation.
- Density Gini: measure of difference in density from uniform distribution

Methods (Song & Knaap, 2004)

- Lot size: median lot size of single family dwelling units (SFDU's) divided by the residential area of the neighbourhood; the higher the ratio, the higher the density.
- SFDU density: single-family dwelling units divided by the residential area of the neighbourhood; the higher the ratio, the higher the density.
- Floor Space: median floor space of SFDU's in the neighbourhood; the smaller the floor space, the higher the density.

Methods (Knaap et al, 2005)

- Population density - Total metropolitan population divided by total metropolitan area.
- Minimum density - Density of the census tract with the lowest density.
- Maximum density - Density of the census tract with the highest density.
- Weighted median density - Density of the census tract that contains the medium person.
- Percentile density - Density of the census tract in the *xth percentile*.

Methods (Bertaud, 2001)

- Population divided by built up area = density
- Built up area divided by population (formula based) = average land consumption

Application

The use of development density by Galster et al (2001) does not distinguished between two very different types of density; employment and residential. It is worth knowing the location of employment within the sub-metropolitan urban environment for commuter analysis purposes, yet at the macro level, employment has little relevance as an overall form quantifier. To be fair, employment is the main reason for movement within a city and generally creates issues associated with transportation infrastructure development. However employment is largely influenced by the economic situation of the city, and will often have little to do with urban form.

Ewing et al (2002) compute 10 density measures as part of their *Smart Growth America* measure of urban sprawl. Their choice was dependent on data availability, and they computed as many factors as were possible in the U.S at that time. Overall this analysis used a methodology that is possibly too complex to reproduce easily, and difficult to adapt into policy for local authorities.

When using an SFDU density measure, multi-family dwelling units or apartments in the neighbourhood are not counted. This means that in high density urban environments (that have a minimal amount of SFDU's) a smaller amount of SFDU's will get divided by neighbourhood area – resulting in a low density figure. Therefore, this form of measurement is only suited to monotonous residential suburbs such as those typical of American living, and is not particularly applicable to New Zealand, where residential development occurs on a smaller scale. For this reason Song & Knaap's (2004) density measures should not be used as an urban form measure in New Zealand.

The minimum and maximum density measures used by Knaap et al (2005) are questionable with regard to their consistency. Figures for the low density tracts are generally dependent on the definition of the urban area and location of the measured boundary. Data disparities can also occur when a parcel of isolated unused land is encapsulated by an individual census tract. High density tract measurement is less likely to suffer these inconsistencies, however it is not a fair method because it doesn't take into account levels of density variability within the high density urban centre. Both of these statistics are unlikely to give us any picture of the true form of a city. A better method exists in measuring a radial area from the CBD centre rather than using a census tract.

Bertaud (2001) opted to rely on the more simplistic density measurements. These methods are used in one form or another for most research into urban form. Historically, they have been relied on to the extent that they were the only form of analysis used. Recent literature argues that urban form is far more complex and dynamic than merely area/population, and uses other methods to accompany density and land consumption. Still, they provide reliable and informative figures that should be taken into account when measuring urban form.

Below are the best three density measurements for use in the New Zealand environment. They are the broadest and most simplistic data producers, and are separate enough from one another to be evenly weighted in an overall analysis. The measures not chosen are either; too difficult to obtain data for, have irrelevant meaning with regard to policy formation, or form part of a variable other than density.

Selected Measures

- Persons per square kilometre = Gross population density
- Total Residential Floor Area / Population = Average Floor Area
- Metropolitan Area / Population = average land consumption

2.4 Accessibility

Description

Accessibility can be divided into two distinct types. The first is the level of access the population has to modes of transport, such as the distance to a bus/train station. Secondly, accessibility can be measured by the actual performance of the transportation network. The first is concerned with form, the second with function. Here, we seek to measure form.

Methods (Ewing et al, 2002)

- Average block length (in the urbanised portion of the metro area).
- Average block size (in square miles and excluding blocks greater than one square mile).
- % of small blocks (less than .01 square miles).

Methods (Song & Knaap, 2004)

Distance

- Median distance to the nearest commercial use.
- Median distance to the nearest bus stop.
- Median distance to the nearest park.

(Street Network)

- Internal Connectivity: number of street intersections and the number of cul-de-sacs; the higher the ratio, the greater the internal connectivity.
- Blocks Perimeter: median perimeter of blocks; the smaller the perimeter, the greater the internal connectivity.
- Blocks: Number of blocks divided by the number of housing units; the fewer the blocks the greater the internal connectivity.
- Length Cul-de-sac: median length of cul-de-sacs; the shorter the cul-de-sacs, the greater the internal connectivity.
- External Connectivity: median distance between Ingress/Egress points in feet: the shorter the distance, the greater the external connectivity.

Application

The methods outlined above measure form, however they do not break down accessibility in terms of mode (driving versus walking). For example, measuring block size (Ewing et al, 2002) gives only a vehicular accessibility measure because it does not take into account pedestrian access-ways within the block itself. The methods used by Song & Knaap (2004) are also questionable in that they measure point to point accessibility (such as the centre of a group of residential buildings to the nearest bus station), that does not recognise possible localised advantages and disadvantages caused by the street pattern.

Most work on connectivity and accessibility has given us measures based on the assumption that a better connected street network is the most sustainable way of developing a new urban form. Critics of this theorem argue that the square street pattern associated with greater connectivity reduces density and safety, whilst increasing the land coverage of the paved area (CMHC SCHL, 2002) - creating an urban environment perhaps less sustainable (at least in some respects) than modern cul-de-sac developments.

Due to the debate on street networks and accessibility it is difficult to use the measures based on smart growth; such as Ewing et al (2002), and Song & Knaap (2004). Although, the external connectivity measurement can be adapted to include walkways in order to form an accessibility measure based on walkability (excluding vehicular). This is recommended as one of the variables used to measure urban form in New Zealand.

Selected Measures

- Average Block Size (with walkways included as boundaries)

2.5 Centrality

Description

"The degree to which observations of a given land use are located near the CBD of an urban area. Less centralised urban areas are deemed more sprawl like" (Galster et al, 2001).

Methods (Bertaud, 2001) Ewing et al, 2002) (Galster et al, 2001)

Here, a radial measurement from the CBD core is taken using concentric rings. This has been set at one mile ratios for the empirical study by Ewing et al (2002); however Bertaud (2001) uses 1km rings. The simplest land use variable to use is population, although other variables such as residential and commercial tracts can be looked at. Results are best observed using a density profile (Bertaud, 2001). Galster et al (2001) uses 1 mile grid overlays rather than concentric rings, however this method is more useful when looking at dynamics on a sub-metropolitan level. It also suffers from the inconsistency of grid overlay (Krizek, 2003), whereby tracts may divide clusters of development, giving an inaccurate interpretation of the results. Ring measurements still have this problem, but it is less of an issue due to the reduction of line intersections.

Application

While using employment and residential tracts would result in an interesting graph showing sub-metropolitan density dynamics, it is recommended that overall population centrality be used for a metropolitan scale urban form index. This is best measured in average distance per person to the centre of the urban core; however, this method disadvantages large cities due to their greater spread. To combat this, **the average distance per person to the urban core should be viewed as**

either a percentage distance from the core of the total measured area or by finding the standard deviation. Proportionate centrality is more important than actual distance when obtaining comparative measurements.

Selected Measures

- Percentage distance/standard deviation from the urban core of the average person

2. 6 Eccentricity

Description

"A city's CBD is considered eccentric when it does not coincide with the centre of gravity of the population… an eccentricity below 10% is considered satisfactory, between 10 and 20%... indicates a mild eccentricity, above 20% the city shows a high eccentricity" (Bertaud, 2001).

Methods (Bertaud, 2001)

A cities "centre of gravity" is the point where the average distance per person to the CBD is the shortest. This is then used to find the eccentricity. "Eccentricity… is measured by calculating the percentage of the distance between the CBD and the centre of gravity of the population over the average distance per person to the CBD. The larger is this percentage the more eccentric is its CBD" (Bertaud, 2001).

Application

This measurement is potentially useful for directing the spread of the CBD toward the largest population mass with regard to urban planning. "The optimum position of the CBD to maximise proximity coincides with the centre of gravity of the shape" (Bertaud, 2001).

2.7 Mix

Description

The degree to which land uses are mixed. Galster et al (2001) define this as "The average density of a particular land use (e.g., housing units) in another land use's (e.g. non-residential or employees) area", however, this implies that one particular land use type dominates a particular area. When a true mixed development environment is achieved, this definition becomes obsolete as land uses should be equally dominant.

Methods (Song & Knaap, 2004)

- Mix Actual: acres of commercial, industrial, and public land uses in the neighbourhood divided by the number of housing units; the higher the ratio, the greater the land use mix (Song & Knaap, 2004).

- Mix Zoned: acres of land zoned for central commercial, neighbourhood commercial, office commercial, industrial, and mixed land uses in the neighbourhood divided by the number of housing units; the higher the ratio, the greater the mix (Song & Knaap, 2004).

Methods (Ewing et al, 2002)

- Percent of residents with business institutions within ½ a block of their homes.
- Percent of residents with "satisfactory" neighbourhood shopping within one mile.
- Percent of residents with a public elementary school within one mile.
- Balance of jobs to residents.
- Balance of population-serving jobs to residents. Population-serving jobs include retail, personal services, entertainment, health, education, and professional services.
- Mix of population serving jobs.

Application

The use of 'zoned' and 'actual' land use mix could be a way of splitting up the ideals of past and future development strategies. While the two methods can be used in tandem, mix actual is perhaps more useful than mix zoned. In relation to policy, most local authorities would be aware of how mixed their zoning is, yet one would expect this to be less so for the actual developed urban area.

Ewing, et al's (2002) methods require the definition of employment type and are more difficult to measure because of this. Half block measurements may provide inaccurate results as block size (and therefore walking distance) varies. Interpreting the term "satisfactory" is also challenging considering cultural variation, between and within urban environments, as to what adequately constitutes the term. Overall this research presents us with a complex methodology for achieving a land use mix measurement that is not as easily applied as that of Song & Knaap (2004).

<u>Selected Measures</u>

- Mix Actual (Song & Knaap, 2004) is the most recent and accurate method for measuring development mix – making it the obvious choice if one was to choose a single measure of land use mix (although to be useful in New Zealand it would require a metric conversion). It operates on a neighbourhood scale, so suburban boundaries as defined by local authorities probably provide the best definition of area. An average can then be obtained for the entire city.

2.8 Nuclearity

<u>Description</u>

"The extent to which an urban area is characterized by a mononuclear (as contrasted with a polynuclear) pattern of development" (Galster et al, 2001).

Methods Galster et al (2001)

Galster et al (2001) offers a formula for measuring the monocentricity of urban form. The output is a map of one-mile grid cells in the location of highest density within the urban environment. This can be useful considering most cities have a monocentric form.

Methods (Tsai, 2003)

Tsai (2003) advocates the use of the *Moran coefficient* as the best way to determine the Nuclearity of an urban environment. Its maximum and minimum readings are +1 and -1 respectively. The coefficient reads high for monocentricity (closer to +1), intermediate for polycentricism (closer to zero), and low for decentralised sprawl (closer to -1). This way is very useful as all city types are taken into account, and the output is measured on a decimal index.

<u>The Moran Coefficient:</u>

$$MC = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \sum_{i=1}^{n} (x_i - \bar{x})^2}.$$

<u>Application</u>

Nuclearity as a measure of urban form offers the ability to distinguish clustering from random development. As suggested by Tsai (2003) the Moran coefficient is the best way of determining the monocentricity, polycentricism and decentralisation of an urban area. The dominant theory within the literature suggests that monocentricity is the most sustainable form of urban development, and decentralisation is more typical of unsustainable sprawl. The Moran Coefficient can therefore be included in an overall sustainability measurement.

<u>2.9 Size</u> (Tsai, 2003)

<u>Description</u>

Regarding sustainability, size has an impact. For this reason a land area measure should be included in any analyses. The question is, should it be a separate entity or included as part of a density measure?

Methods (Ewing et al, 2002) (Tsai, 2003)

Size (according to Tsai, 2003) is best characterised by a measure of **land area**. The usefulness of this form of measurement is outlined by Ewing et al (2002) who argue that no measurement of overall form should be completed without taking size into account in some way. This is because land prices, labour markets and real estate value are higher in larger cities – encouraging denser development. Yet, these cities are deemed in the primary examples of sprawl (e.g. Los Angeles) in the publics eyes because they "go on forever". Therefore, "a sprawl index that disregarded this aspect (size) of urban form would never achieve face validity" Ewing et al (2002). However, Tsai, 2003) suggests that land area must only be factored into a measure of form, and is not a measurement of sprawl.

Methods (Knaap et al 2005)

Another possible measurement is the "Oblong Ratio". Oblong ratio: "ratio of diameters between the shortest and longest diameters as if the city was an oblong ellipse" (Knaap et al, 2005). This measure is not particularly suitable for measuring most New Zealand locations. Cities such as Wellington and Dunedin are dictated by topography rather than planning, which may yield an unfair measurement of urban form. Hence this method is not suited to the local context.

Application

As a city becomes larger, land value and rent price grows (accentuated in the CBD). The result is a denser city core, purely from market forces. For this reason, a large city with sprawling suburbs may yield better (higher) density results than a smaller city or town whose relative density is greater. It is recommended therefore that any land area measurement of urban form maintains separate context from density.

Selected Measures

- Land area of the built environment

3.0 Conclusions

3.1 Preferred Measures of Urban Form for the New Zealand Setting

New Zealand Data

The methods outlined in previous sections need to be contextualised for their appropriateness in the New Zealand setting. Prior to this however, a consistent definition of urban area must be settled upon. Statistics New Zealand's definition of urban area appears flawed in that it characterises the Hamilton urban area as larger than any other city, and corresponding statistics give Hamilton a density level considerably lower than any other city in New Zealand. Also, most local authorities observe the urban/rural boundary at the edge of zoned urban areas, rather than the actual edge. This varies between cities so is unsuitable for achieving statistically consistent data.

Scale

In order to achieve fair and correct overall measurements of urban form, a consistent scale must be settled upon. The question is; do we measure singular cities, or larger urban areas (encompassing secondary cities)? It is recommended that for the purpose of the proposed research, each city or town is measured on its own. This limits the impact that selection criteria may have on results. Obviously this recommendation is contradictory to the macro-scale aspect this particular review has focused on. It neglects to recognise the inter-relationships and dynamics that exist between neighbouring cities and towns. For example, Wellington and Lower Hutt measured separately are unlikely to show a true reflection of what is actually happening within the wider urban area. For this reason it is recommended that measurements from individual cities and towns be grouped together within wider urban areas to provide **regional data**. This method has the added advantage of automatically discounting any undeveloped or un-developable land (that falls within the urban region) from the equation.

Further research is recommended to establish the most appropriate density threshold for the urban/rural boundary. U.S. based studies have used a boundary density of 1000 people per square mile. This could be converted to metric, although density levels in New Zealand may warrant a different measurement scale. It is therefore recommended that the appropriate density level for the rural/urban boundary be analysed further.

Within New Zealand, mesh block data on urban areas is easily obtainable and can be used to determine the urban boundary. The first step is to estimate the location of the boundary by simply drawing a line over a map. The density of each mesh block that coincides with this line is then observed. If it is higher (for example) than the density threshold, that particular mesh block is counted as part of the urban area, and the next mesh block (outward) is measured. This process goes on until a mesh block returns a density under the threshold - this point being the location of the urban/rural boundary.

Density

Gross population density

'People per square kilometre' (gross population density) is the most commonly used type of density measurement. Achieved by simply dividing the *population* by the *built up area*, it is an un-complicated statistic that tells us a considerable amount about the city. The widely accepted theory is that density has a positive relationship to sustainability. More recent literature suggests that sustainability is more complex than this, and that density is insufficient as a sole assessor of urban form. Where it lacks is in measuring smaller intricacies within the urban environment that potentially have a larger part to play in establishing sustainable settlement development. However when used in combination with other methods, density is perhaps the most important macro-scale urban form assessor.

Reversing the method to *built up area* over *population* gives us the average land consumption of a city. This requires no extra data - therefore is easily achievable. While the result is neither an ecological footprint nor a reflection on true land consumption (as it neglects the adjacent hinterland), it offers an alternative method for density comparison between cities. This measurement will only yield results that parallel gross population density, so effectively it isn't telling us anything new. It is recommended that this dataset be computed into an overall measure of sustainability purely because it is so simple to obtain.

Average Floor Area is recommended for use as a density measure because it provides a way of assessing house size. Floor area was chosen ahead of other measurements as it includes all types of residential housing. Relying on SFDU based measures can distort the picture of urban form into something it is not, and seeing that this research is concerned with the macro scale, average floor area is an appropriate method. The benefits of this are that average floor area is less concerned with urban boundaries, unlike other measurements, they are more distinguishable. Data availability is also a key reason this methodology was chosen. Quotable Value NZ has data on every household in New Zealand that can be aggregated to mesh block level for comparison with census data. In some locations the dataset is not complete which creates a hurdle, although estimations could attain a reasonable level of accuracy as a last resort.

Accessibility

Average Block Size (with walkways included as boundaries)

Measuring accessibility is perhaps the most contentious aspect of urban form quantification. Within the literature there are various methods involving block size and street intersections. These methods are all very automobile oriented, and because of this are not entirely suitable for measuring sustainability. What sustainable urban form actually consists of with regard to vehicle travel is contestable, and possibly contradictory to what is sustainable for walking. Due to this inconsistency, the average block size measure requires some form of modification. Average block size means a lot to both vehicle travel distance and density, yet little to pedestrian accessibility. It is recommended that block size is modified so it represents the total area inside pedestrian access-ways (rather than the street network). This will give a clear understanding of street network accessibility in terms of walking. Data for this will be difficult to obtain and may require considerable adaptation of existing block size data, therefore further research is required into data acquisition.

Centrality

Average Distance per Person to the CBD Core (as a percentage).

Residential and employment centrality measures have been outlined, however for the macro-scale focus of this review it is recommended that only the broader 'population centrality' method be used. In monocentric cities, the location of most employment is the CBD core. Common theory suggests that the monocentric city has a higher degree of sustainability than other city types, and measuring population centrality is a reflection of this.

Average distance to a CBD core is unable to compare cities or towns of different sizes. This is because there is no scale. In order to achieve a comparative measurement, a modification of the methodology is proposed, by where the distance to the core of the average person is taken as a percentage of the total built radius.

This measurement may be influenced more by topography in New Zealand than in other countries. Therefore, some influence (from this) on results should occur. It would be expected that places such as Wellington (whose development is fragmented by steep hills), would achieve a lower centrality rating than say, Christchurch, where sprawl is directed more evenly. Despite this, Wellington may have a stronger core - evening out the result.

Eccentricity

Eccentricity is a little known, but important tool for measuring sustainable urban form. It is used to establish the distance between the urban core and the population centre (Bertaud 2001). It has relevance to policy development (in respect of town planning) at the local government level as it gives an indication as to which direction of spread is most sustainable.

The main problem with applying the eccentricity measure at a macro-level in New Zealand is again one of scale. For example, a city such as Dunedin may have an eccentricity of 2km when the city edge is approximately 15km away, and a town such as Masterton could have an eccentricity of 1km and an edge 5km away. Dunedin is more eccentric in total distance, while Masterton is more eccentric in proportionate terms - hence a scale is required.

Simply using 'percentage of distance' would not do justice to New Zealand's hilly cities, where unusable land and/or green space occupies large portions of inner city areas. It is therefore recommended that the degree of eccentricity should incorporate the percentage of total built up area inside a circumferential ring drawn from the centre of gravity and compared to the total built area remaining. By turning this into a percentage we are able to gain a fairer measure that can be used to gauge the comparative sustainability of New Zealand's urban areas.

Mix

Mix Actual

Mix Actual is a clear way of distinguishing land use variability and can be employed on a full range of scales. It operates by measuring residential housing units against the spread of industrial, commercial, and other land uses. While this method was intended for operation on a neighbourhood scale, it may be used to quantify overall urban form. The results will reflect positively on less homogenised cities and towns, although the effect of 'secondary cities' on results is a concern due to the .Using the Wellington region as an example, it is well known that a large portion of Wellington City's working population comes from outside the city. Upper Hutt, Lower Hutt and Porirua are the major feeders and have comparatively low levels of employment. This again raises the question; do we measure individual cities, or entire regions? It is recommended that prior to a scale being settled upon, trial research on land use mix needs to be conducted at both scales and analysed to determine which level gives the best overall measure of urban form. At this stage however it is recommended that the scale remain in line with other methodologies for consistency reasons.

Nuclearity

The Moran Coefficient

$$MC = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} \sum_{i=1}^{n} (x_i - \bar{x})^2}.$$

The Moran Coefficient is a mathematical formula for determining the strength and location of a city's nucleus. Put simply, it measures the centrality of the CBD. This method is recommended for its clear, figure based results that will provide relatively easy translation into an overall sustainability index. Strongly advocated by Tsai (2003), the Moran Coefficient is more effective than rival methods as it can better distinguish between sprawl and polycentrism. In the New Zealand setting it is not expected that urban areas will show any indication of polycentrism, as they are possibly below the population threshold required for the pattern to occur. Despite this, the coefficient is recommended for its ability to deduce the varying degrees of monocentric urban form.

Size

Land Area

A size measurement is needed as a means of reducing the impact of scale on overall city quantification. Size is not a clear indicator of urban sprawl, yet needs to be included as such in any macro-scale urban form measurement. The purpose of this is to negate any distortion caused by higher land value (that heighten density) in larger cities, which may give a false perception of density (as outlined by Tsai, 2003).

3.2 The Next Step

The next step in the process is to gauge data availability in New Zealand to determine which of the methods outlined can be used. It is anticipated that a large portion will come from local council GIS databases. Those methods requiring housing information are available from *Quotable Value New Zealand*. The largest potential snag with the collection of data is likely to occur in relation to scale, i.e. data may not conform to the requirements for our preferred measured area.

3.3 Summary

Having read the literature, it is apparent that no single measure or previous work is able to best quantify urban form in the New Zealand setting. What is needed, to a degree, is a combination of all, or part of the methods suggested above. While most literature is from North American studies, the ideas are very recent. Those contained in this review are no more than five years of age (no coincidence as the GIS revolution stimulated a new wave of interest in urban form measurement), which increases their respective relevance. After establishing which measures we can use (data availability), an index can be created (similar to Ewing et al, 2002). Within this, the chosen variables can be given weightings aligned to the New Zealand setting. This will produce an overall measurement of urban form.

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