Journal Article

Quantifying diversity
An assessment of diversity indices and an application to Singapore

Author(s):
van Eggermond, Michael A.B.; Erath, Alexander L.

Publication Date:
2016-05

Permanent Link:
https://doi.org/10.3929/ethz-b-000118467

Rights / License:
In Copyright - Non-Commercial Use Permitted
Quantifying Diversity
An assessment of diversity indices and an application to Singapore

Attractive urban settings are easily recognised, but quantifying them is a bit harder. An easy analogy is drawn with Galster (2001) on neighbourhoods: “neighbourhoods are treated in much the same way as courts of law have treated pornography: as a term that is hard to define precisely, but everyone knows it when they see it”. Characterising and quantifying the built environment remains an elusive concept with many pitfalls. Commonly, diversity is judged by land-use plans and categorised by broad descriptions, such as ‘commercial’ and ‘industrial’. In this article, we present a newly developed concept to measure the unmeasurable, compare it to existing diversity measures, and critically assess its relevance for both urban science and city master planning.

An attractive built environment can promote active mobility and moderate motorised travel demand. It has been shown that the built environment influences travel behaviour, health outcomes and even happiness. To describe the built environment, researchers have long employed measures describing the built environment. Cervero and Kockelman (1997) coined these measures ‘density’, ‘diversity’, and ‘design’ - the three ‘D’s’. Measures that fall in these categories include: population density, intersection density, jobs-housing balance, distance to the nearest transit stop, and travel time to work. While these measures might describe whether an area possesses urban characteristics, they fall short of describing a vibrant and diverse environment. Also, the level of resolution on which characteristics of the built environment are measured differs, and similar data sources are not available for the different study regions, making comparison between regions difficult, if not impossible. In this article, we introduce a diversity and destination index that can be easily applied across regions and that describes the built environment from the pedestrian’s point of view. Before that, however, we take a step back and provide a background to the measurement of diversity and the subsequent application to land use.

Fig. 01 Combined diversity and density for Singapore. Dark colours indicate a high combined diversity and density, light colours a low combined diversity and density.
Measuring diversity

Ecologists have traditionally employed a range of diversity indices to describe the contribution of biodiversity to the functioning of ecosystems. In order to describe the diversity of an ecosystem, different structural characteristics of the system can be considered: the number of different species in the system, the characteristic features of the different species, and the relative abundance with which individuals are distributed over different species (Baumgärtner 2006). Examples of diversity measures include the Berger-Parker Index, the Shannon-Wiener Index, and the Simpson Index. To highlight these measures and their differences, a number of ecosystems are shown in Figure 01. Table 01 shows the composition of each system in detail and the resulting diversity indices. Diversity indices, such as the Shannon-Wiener Index and the Simpson Index yield a value starting at 0 up to 1. A value of 0 indicates an area with no diversity, whereas a value of 1 indicates a perfect mix of diversity in the area. However, the absolute number of each species hardly plays a role in the results that these indices yield. Often, the value is normalised to a value between 0 and 1.

Table 01 Hypothetical examples of ecosystems and resulting diversity indices. A visualisation can be found in Figure 01.

<table>
<thead>
<tr>
<th>Indices</th>
<th>System A</th>
<th>System B</th>
<th>System C</th>
<th>System D</th>
<th>System E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># (%)</td>
<td># (%)</td>
<td># (%)</td>
<td># (%)</td>
<td># (%)</td>
</tr>
<tr>
<td>Species 1</td>
<td>5 (33%)</td>
<td>10 (33%)</td>
<td>10 (33%)</td>
<td>15 (50%)</td>
<td>30 (50%)</td>
</tr>
<tr>
<td>Species 2</td>
<td>5 (33%)</td>
<td>10 (33%)</td>
<td>10 (33%)</td>
<td>10 (33%)</td>
<td>15 (25%)</td>
</tr>
<tr>
<td>Species 3</td>
<td>5 (33%)</td>
<td>10 (33%)</td>
<td>9 (30%)</td>
<td>3 (10%)</td>
<td>10 (33%)</td>
</tr>
<tr>
<td>Species 4</td>
<td>10 (33%)</td>
<td>10 (33%)</td>
<td>7 (23%)</td>
<td>5 (17%)</td>
<td>7 (23%)</td>
</tr>
<tr>
<td>Species 5</td>
<td>10 (33%)</td>
<td>10 (33%)</td>
<td>1  (2%)</td>
<td></td>
<td>1 (2%)</td>
</tr>
<tr>
<td>Total</td>
<td>15 30</td>
<td>30 30</td>
<td>23 7%</td>
<td>10 10%</td>
<td>60 8%</td>
</tr>
</tbody>
</table>

Measuring diversity in urban planning

An analogy with urban planning is easily drawn: land-use types can be seen as the number of species in the systems, while the square footage per land-use type within the system can be seen as the number of organisms. The diversity can then be calculated on many spatial scales, varying from traffic zones to buffers around dwellings. Variations exist in the ways land-use categories are used. For instance, Cervero and Kockelman (1997) consider the following land-use categories in their diversity index: residential, commercial, office, institutional, industrial, parks, and recreation.

The most commonly applied diversity index is the Shannon-Wiener Entropy Index, which has been used in urban planning for at least as far back as the work of Frank and Pivo (1994). We have calculated this index for approximately a thousand areas in Singapore and will highlight the outcome for two distinctly different areas. Little India is an area that is well known to residents and tourists alike and is characterised by mainly commercial and residential zoning (Fig. 03). Impressions of Little India can be found throughout this issue. Serangoon Gardens is located in the north-east of Singapore and is characterised by a small centre that contains a selection of shops, a popular food centre, a park, and several schools and residential streets with semi-detached housing. Figure 04 highlights the planned land-use for the Serangoon Gardens. This area is split into different zones. Different land-use types can be considered when calculating diversity. Figure 05 and 06 highlight the results, if the land-use types of commercial, business, religious, and park are included in the calculation of diversity.

To enable easy comparison of the results, the numbers represent percentiles. Serangoon Gardens ranks 10th, whereas Little India ranks between 5th and 6th. These percentile rankings reveal that 90% of the areas rank lower than 10. If residential land usage is added to the calculation (Fig. 07 and 08), Little India ranks 8th, whereas the Serangoon Gardens ranks between 5th and 10th, depending on the area of residential space in the zone.

Fig. 02 Examples of eco-systems. The number indicates the species number. Indicated between brackets is the absolute abundance of each species. Table 1 shows a range of diversity indices for each of these systems.

Fig. 03 Selected planned and existing land uses in Little India, as they can be found in the URA Masterplan.

Fig. 04 Selected planned and existing land uses in Serangoon Gardens, as they can be found in the URA Masterplan.
These outcomes illustrate a range of shortcomings of the use of diversity indices. In this case, the most obvious shortcoming is the failure of land-use descriptions to capture the diversity within one land-use type. Tenants using commercial property can include tailors, specialised food shops, and florists – distinctly different amenities catering to different needs and population segments. Furthermore, the index weighs all categories of land use equally: an area with office and industrial usage will have the same diversity as an area with retail and residential usage (Hess et al. 2001). Second, there is the issue of ‘missing land uses’: determining which land uses should be included in the measure, and which should be left out. In this case, we highlighted this issue by evaluating the effects of residential land usage. A third issue is that an even land-split is considered ‘perfect’: a key point that lacks theoretical basis (Manaugh and Kreider 2013). An area split of 50/50 between two land-uses is considered better than an area split of 60/40. Furthermore, the measure does not reflect ideal land uses per category. Depending on the location of an area in the city, it is questionable whether 50% residential land usage is able to support 50% retail usage. Finally, dense urban environments are characterised by a mix of building heights and the presence of mixed-use buildings. A two-dimensional aerial view of land uses will not provide an accurate description of a true three-dimensional mixed-use environment.

Shouldn’t destinations matter more?

The application of common descriptions of land use, such as residential, commercial, and religious, in diversity indices is fuelled by data availability on one hand, and the relevance of these descriptions to policy makers and planners of future land use plans on the other. However, these descriptions reflect their economic and social functions rather than their behavioural characteristics (Banerjee and Baer 1984). These broad categories fail to capture the diversity within a single category. Descriptions of amenities, such as convenience store, supermarket, gas station, and neighbourhood park, provide better descriptions of how individuals categorise, describe, and use their neighbourhood. After all, the aim is to reach destinations. The ease with which these destinations are reached is referred to as accessibility. A larger variety and number of destinations, and lower travel times, results in higher accessibility. We take this perspective as a starting point for our study on Singapore. As a first step, we obtained amenity location data from a variety of sources: points of interest from Google Places, the Land Transport Authority, and the Ministry of Education; the road network from the readily available Open Streetmap; and building outlines from the Singapore Land Authority. Figure 09 provides an impression of these data sources. We then calculated a number of accessibility measures for each building in Singapore. The distance to each amenity is calculated using network distances, on the basis that amenities located further away are valued less than amenities located nearer to an origin. This perception of distance is captured by means of a distance decay function. Distance decay functions come in a variety of forms and are usually derived from observed behaviour. However, especially for trips made on foot, data is notoriously hard to obtain, as these trips are commonly underreported in travel surveys. For Singapore, we applied a combined rectangular and Gaussian distance decay function, as opposed to other, more commonly used functions, such as the exponential or rectangular function (Fig. 10). With this function, we assume that people are indifferent to a five-minute walk, but that destinations located more than five minutes away are valued less. A destination located 10 minutes away is valued half as importantly as a destination located within five minutes. The effect of this distance decay function is highlighted in Figure 11. In this figure, the shortest paths from a single origin to each destination within 1,200 meters are calculated.

The calculated accessibility per building is used in two ways. First, we calculate the diversity based on the accessibility to five amenity categories. Second, we calculate a destination index, where each amenity category is weighted differently. These weights are determined by the relevance of each amenity to serve an individual’s daily needs. For example, supermarkets, pharmacies, and grocery stores score higher than a shoemaker or carpenter. By combining the diversity and destination indices, a value that represents the quantity and quality of destinations is obtained. This process...
can be extended to calculate the density and diversity of each building in Singapore to all destinations (Fig. 12). A different scenario emerges when destinations are used instead of land-use types. On a smaller scale, the effects of this are clearly visible in Serangoon Gardens, located at the top of Figure 12 and indicated by ‘SG’. Buildings located near the centre are assigned a diversity and destination index. On a larger scale, the diversity of downtown areas of Singapore – such as Little India (‘LI’), Rochor, and Orchard, but also local suburban centres, such as Tanjong Katong and mature HDB (public housing) towns like Bedok – is reflected through the combined diversity and destination index.

Diversity in and of itself is of relevance; the effects of the built environment on happiness, health, and travel outcomes are just as important. These indices prove to be significant, but have a modest effect in predicting vehicle ownership in Singapore, after controlling a range of socio-demographic variables. In the case of Switzerland, we have calculated identical destination and diversity indices, and have found that a more diverse neighbourhood leads to lower vehicle ownership and fewer kilometres driven. Evaluating such images and indices of a city provides insights into the usage of space based on openly available data sources. However, these top-down images do not take away the need to verify these figures with ground-truths, and certainly do not describe the character of an area. We are the first to admit that urban character cannot be captured by a mere number. In addition to these constructed indices, we calculate a range of other measures, including, but not limited to, population density, job density, intersection density, and public transport accessibility. Ultimately, the city is about people, their interactions, and transactions. However, measuring the unmeasurable can support discussion about urban form and its implications.

References

Fig. 10 Example of distance decay functions. The most frequently used functions are the exponential function and the rectangular function.
Fig. 11 Shortest paths from a random origin. Dark blue indicates that the destination is perceived as near; lighter colours indicate destinations are further away.

Fig. 12 Combined diversity and density for Singapore. Dark colours indicate a high combined density and diversity; lighter colours indicate a low combined density and diversity. Serangoon Gardens is indicated by ‘SG’, Little India is indicated by ‘LI’.

Image Credits
Fig 01-02, 05-08, 11-12: Michael van Eggermond
Fig 03-04: Urban Redevelopment Authority
Fig 09: Michael van Eggermond, with data from Open Streetmap, Singapore Land Authority, Ministry of Education, Google Places