

Permeability and Interface Catchment: Measuring and Mapping Walkable Access

Elek Pafka & Kim Dovey

Abstract

The relationship between urban morphology and walkability is central to urban design theory and practice. In this paper we develop new measures for pedestrian permeability and catchment areas, suggesting that their joint use can progress our understanding of the ways urban morphology mediates walkability. Existing measures of permeability do not account for heterogeneous morphologies. Likewise, measures of pedestrian catchment do not account for what it is that is caught. The proposed 'area-weighted average perimeter' and 'interface catchments' together integrate both street width and block size, measuring both walkable access and what one gets access to. What is at stake is not only correlations with health and transport, but also measures of walkable access that are geared to the social and economic productivity of the city.

Keywords: permeability, catchment, interface, morphology, mapping, walkability

Introduction

The broad concept of walkability has emerged as a key theme in urban studies with strong links to health and environmental sustainability outcomes (Forsyth and Southworth 2008, Maghelal and Capp 2011, Frank et al. 2006, Giles-Corti et al. 2003). It is also a key urban design concept and a particular focus for those researching streetlife intensities and transit-oriented urbanism (Cervero and Kockelman 1997, Krizek 2003, Lo 2009). Walkability has been linked to many aspects of the urban environment including permeability, safety, footpath quality, land use mix, density and climate (Lin and Moudon 2010, Moudon et al. 2006, Lee and Talen 2014, Ewing and Handy 2009, Forsyth et al. 2008, Porta and Renne 2005). Many such studies are focused on perceptions or attitudes of residents and users rather than morphologies (Ewing and Handy 2009, Clifton, Livi Smith, and Rodriguez 2007, Páez 2013). While a complex integration of such factors remains a larger task, our goal here is more focused. In this paper we explore the ways in which walkable access is mediated by the urban morphology of public space networks, together with the ways in which such access might be measured and mapped.

'Short blocks' was the phrase Jacobs (1961) used to promote a permeable morphology where multiple choices of public pathways with rich interconnectivity contribute to the synergies of intensive urban streetlife and productivity. She also introduced the related phrase 'pools of use' to refer to the zone within walking distance of a particular urban location measured by distance or time. Such a concept has been developed into the mapping of walkable catchments or 'pedsheds' (Sevtsuk and Mekonnen 2012, Peponis, Bafna, and Zhang 2008, Schlossberg 2006). A range of different measures of such street network properties have been used in walkability research and planning practice, however, there are often inconsistent results for different morphologies (Knight and Marshall 2015, Lin and Moudon 2010, Stangl 2015). There is a need for metrics that can be applied across the vast differences between historic European city centres, the wide streets of colonial cities, the open spaces of modernist urbanism and the intricate labyrinths of informal settlements.

Within this context we seek to explore ways of measuring and mapping these two key concepts of permeability and catchment. Our analysis of the range of metrics shows that they can produce incoherent results for different morphologies and scales. We also seek a better understanding of the differences and relationships between measures of permeability and catchment. How are we to deal with the paradox that permeability and catchments both increase as streets get wider and peak when there is no city and nothing to 'catch'? We will show that block length, diagonal and area are inaccurate measures of permeability and propose an 'area-weighted average perimeter' together with a focus on 'interface catchments' more than catchment areas or 'pedsheds'. These measures incorporate both street width and block size. Any understanding of walkable access must account for both access and some measure of what one gets access to.¹

Permeability

Permeability can be defined as the extent to which a particular urban morphology is permeated by publicly accessible space (Marshall 2005, pp.88-89). It relates to the ease of movement through an urban area as well as the multiplicity of route choices between any two points. Thus permeability relates to the capacity to move and the potential to interact in urban space. There are two general approaches to measuring permeability: one is to measure the degree to which the publicly inaccessible parts of the city obstruct flows and the other is to measure the degree to which public pathways enable them. These are two sides of a coin but they are not the same thing - one measures morphology while the other measures network connectivity. Jacobs used the first of these approaches when writing about the need for small blocks that produce a highly interconnected pedestrian network (Jacobs 1961, pp.178-186). When explaining this principle she shifts from the term 'small blocks' used in the chapter title to that of 'short blocks' and uses them synonymously. What is meant, however, is that no side of a block should be excessively long. Morphogenetic research has found that in urban centres where blocks were planned larger than a hectare there is a tendency for

them to be broken down over time into smaller blocks by the creation of new streets and arcades (Siksna 1997). Normative approaches, based on observation of western cities, generally define good permeability by block length ranging between 60-90 metres (Whyte 1988, p.318) with a maximum of 120 metres (Jacobs 1961, p.184). On the other hand very small blocks have disadvantages in that they constrain possibilities for density, private open space and activation of all frontages. These opposite considerations (not too large but not too small) led Cerdá (1867) to settle for 113 x 113 metres blocks for the extension plan of Barcelona.

Early attempts to quantify Jacobs' small/short blocks principle at the scale of neighbourhoods used the average block area as a measure (Weicher 1973, Schmidt 1977). This does not, however, account for long thin blocks. For example the elongated rectangular blocks of 60 x 240 metres in Manhattan referred to by Jacobs as barriers to neighbourhood vitality have the same area as 120 x 120 metre blocks. The measure of average block perimeter (Fowler 1987) is better than block area, but can be problematic when measuring heterogeneous street networks where many small blocks can obscure the impermeable effect of a few very large blocks. There is also the problem that the same perimeter can relate to variously shaped blocks. Stangl (2015) suggests that the longest diagonal of the block would be a better measure, yet the same diagonal length can relate to a vast range of block sizes and shapes that can be inscribed within a circle of that diameter. A related indicator is the number of blocks within a study area (Southworth and Ben-Joseph 2003), a proxy for average area, yet again this does not take into consideration the effect of elongated or heterogeneous block shapes.² Likewise, the median values for perimeter, area, block length or diagonal would all be misleading since they discount the largest blocks that are such significant barriers to movement.

The second approach to permeability applies to street networks rather than blocks. Berghauer Pont and Haupt (2010, pp.96-98) use the term 'network density' to refer to the total length of streets in a given area. This method does not consider interconnectivity between streets, and thus is only useful for comparing street networks of similar configuration. A better metric is the number of intersections within a given area or 'intersection density'. This measure of interconnectivity is the most common in walkability research (Frank et al. 2006, Maghelal and Capp 2011, Knight and Marshall 2015). A partial measure of intersection density is the number of access points to a study area (Southworth and Ben-Joseph 2003), but this is primarily a measure of the connectivity between a study area and its context. A key problem here is that in real cities at pedestrian scales there can be no clear definition of either an 'intersection' or a 'street'. Do six-way intersections and T-junctions both count as single intersections? How close can two intersections be before they become one? Allan Jacobs (1993, p.202) shows that within one square mile of Venice there are over 1,500 intersections, while in Brasilia there are less than 100, yet can the narrow lanes of Venice and the large open spaces of Brasilia be treated as equivalent 'streets'. A further

issue is that such measures of intersection density will not account for network heterogeneity - serious blockages in the network may be averaged out. We need metrics that will enable us to compare morphological differences between diverse cities.

To summarize, thus far we have pointed out some problems with using measures based on block area, perimeter, diagonal or numbers of blocks and the limitations of using street length or number of intersections. The measure of permeability that we propose is the area-weighted average perimeter (AwaP) of all urban blocks (including impermeable areas such as expressways and water bodies) within a given study area. The perimeter of each block is multiplied by its area and the average is then calculated. This is a method that registers the effect of both block area and perimeter, ensuring that the impact of a large impermeable block is not lost in the average. Any dead-end streets need to be removed from the analysis so that the block perimeter corresponds to the shortest distance around the block, without entering the dead-end. In algebraic terms this can be represented by the following formula:

$$AwaP = \sum_{i=1}^n P_i \times \frac{A_i}{A_T}$$

where n is the number of blocks, P_i and A_i are the perimeter and area of each block i, and A_T is the total area of all blocks. Low AwaP scores indicate high permeability within the measured area, while high scores indicate low permeability.

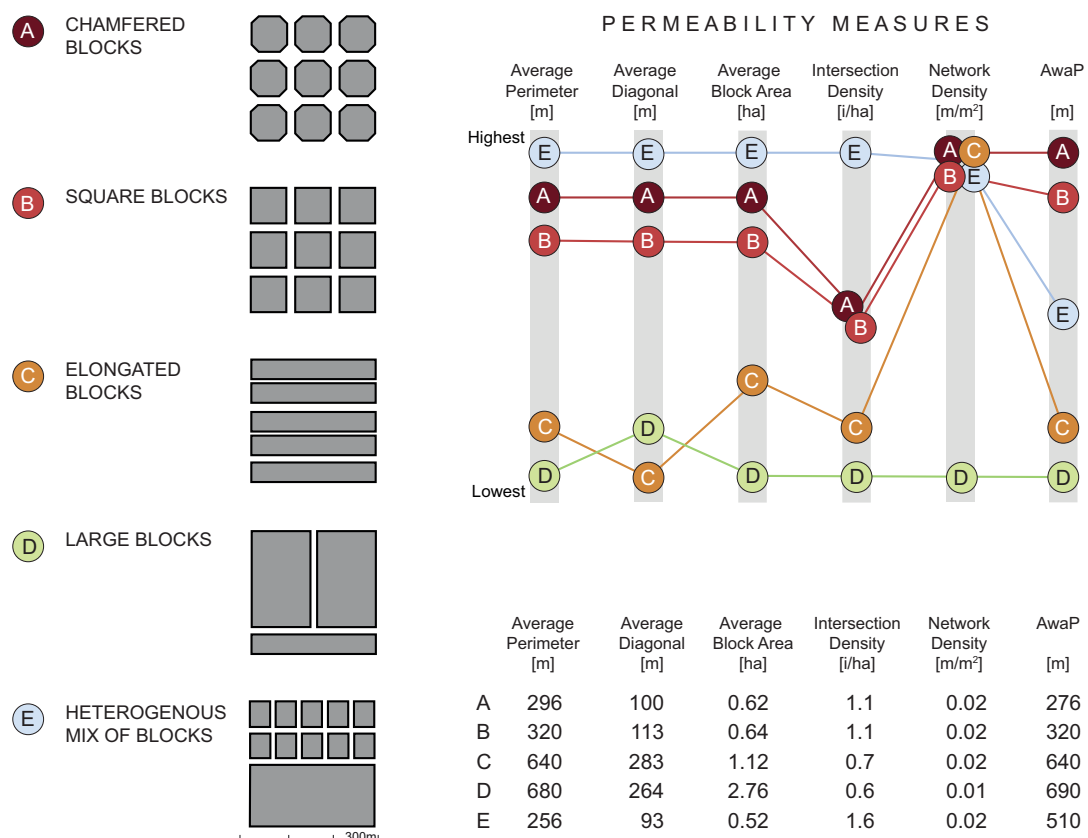


Figure 1. Permeability measures compared.

Figure 1 shows how five distinct basic morphologies for a 9 hectare neighbourhood are differently evaluated by the measures described above and compared with the AwaP measure. These examples are chosen to test the different measures and to cover both homogenous and heterogeneous block size and block shape. They range from a chamfered square grid as used by Cerdá to minimize the block perimeter to area ratio (A) through a non-chamfered square grid (B), elongated blocks (C) and large blocks (D) to a heterogeneous mix (E). The most notable result is that all existing approaches rate example E highly permeable despite the fact that half the area is consumed by a single impermeable block. The measure of intersection density accentuates this effect while network density does not distinguish between four quite different morphologies. Only the AwaP measure is able to account for the heterogeneous mix of block sizes (E). One could suggest that the heterogeneous morphology of example E - with high permeability juxtaposed against a major urban barrier - is an urban anomaly. Yet this condition emerges along most waterfronts, transit lines and the edges of large grain projects.

While we suggest that AwaP is the most effective measure of permeability at this scale, this is not the end of the story. None of the metrics outlined above take good account of street width or open space. If street width were to be doubled on all of the morphologies in Figure 1 then the average perimeter, diagonal and AwaP of each block would be unaffected while all other measures would decline significantly. We now want to expand this discussion to incorporate the different but overlapping measures of the pedestrian catchment, pool of use or 'pedshed'.

Catchment

Catchment refers to a zone of potential access to any particular location; it derives from what Jacobs called 'pool of use' (Jacobs 1961, pp.179-182) and is often called a 'walkable shed' (Hess 1997) or 'pedshed' (Thadani 2010). Catchment measures can be centred on attractions such as shopping centres, schools and public transit stops and can measure the scope of the catchment by land area (Schlossberg 2006), street length (Peponis, Bafna, and Zhang 2008), gross floor area (Sevtsuk and Mekonnen 2012) or numbers of residents (as in transport research). It is usually calculated for an average walking distance or time. The distance people are prepared to walk depends on a wide range of social and spatial factors including age, gender, quality of pedestrian space, distance to key attractors such as public transport stations and trip purpose (Gehl 2010). The average walking distance is generally assumed to be around 400-500 metres, but is shorter for children, disabled and the elderly (Gehl 1987, p.139). Gruen (1965, p.250) suggested that it ranges from 200m (2 min) to 1,500m (20min) depending on the quality of the environment and the degree of weather protection.

While the catchment is often approximated as a circle of a given radius, this is always larger than the actual reachable area within that distance, given that the geometry of the street

network restrains movement. A simple measure attempting to quantify this is that of the ratio between the reachable catchment area within a given distance and the unimpeded reachable area represented by a circle of that radius (Schlossberg 2006). For a grid network the pedestrian catchment will have the shape of a square inscribed in the circle with a Pedestrian Catchment Ratio (PCR) of $2/\pi = 64\%$. Figure 2 shows how 400 metre catchments can be mapped across different block sizes, street widths and levels of heterogeneity. It shows clearly that PCR is not a measure of permeability since the catchments of A and B are identical. Figure 2c shows that large blocks on the edge of the catchment have an impact on the catchment area while those near the centre do not. It follows that any location on the edge of an impermeable fabric such as waterfront or transit line will have its PCR halved. What PCR does not do, however, is give any measure of what a catchment gives access to. Indeed, the less there is to catch the more it will increase, reaching 100% when there is only open space.

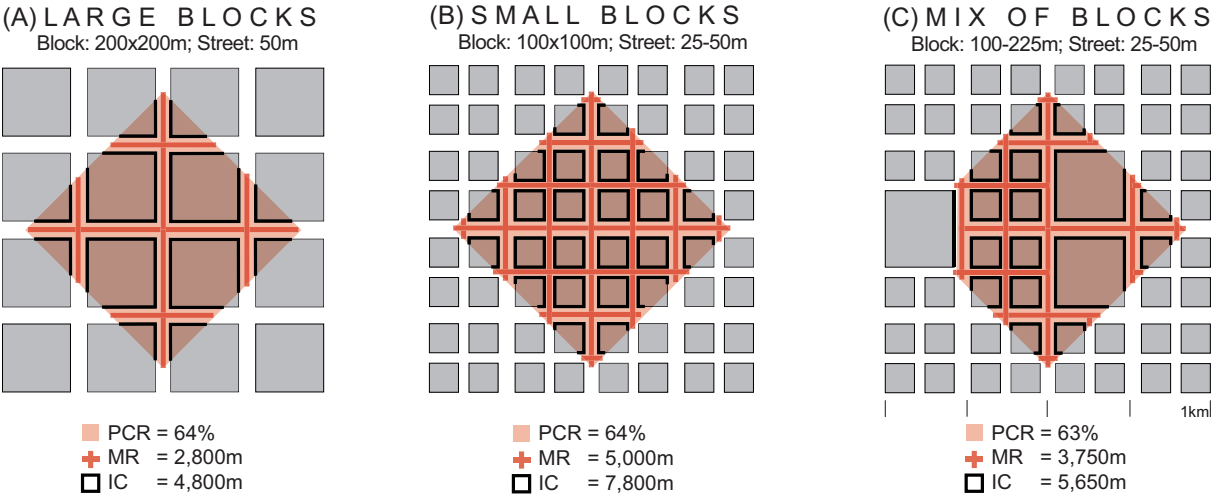


Figure 2. Measuring pedestrian catchments: three methods/three morphologies.

Another measure of catchment is the sum of street lengths reachable within a given distance from any given point within a network, called 'metric reach' (MR) (Peponis, Bafna, and Zhang 2008) or 'network distance'. What is at stake here is the capacity of the network to enable access to and between urban attractions. Here we encounter the same problems as those measures of permeability that focus on streets - how to compare the metric reach along a boulevard and a laneway? We want to suggest an adaptation of this method with a focus on public/private interfaces rather than street lengths. While parts of public space may themselves be attractive, most urban attractions are entered across a public/private interface. It follows that a proxy measure for what is being caught within a catchment involves the length of such interfaces that are accessible from a given point. We call this Interface Catchment (IC), a derivative of metric reach that takes into account the actual morphology of the urban tissue (i.e. street width and open space). IC is less than double the metric reach as the total length of street crossings are subtracted. Interface catchment is the

total of all block perimeters within a catchment. High IC scores indicate high catchment. Figure 2 shows that a 400 metre walkable distance can produce interface catchments ranging from 4.8 to 7.8 kilometres in different morphologies. While interface catchment is not a measure of permeability, there is a level of congruence since a higher permeability will generally produce a greater interface catchment. Interface catchment is an approach that measures more than simply area and is also geared to the capacity for a diversity of entrance types and functions; linked in turn to potential for social and economic exchange (Dovey and Wood 2015).

Contrasting Metrics

The concepts of permeability and catchment relate to different properties of urban morphologies. For each of them the chosen measure can be applied to a particular location within the network or the entire network and at different scales. The way a measure is applied to a network will depend on the research question. To further investigate the differences between permeability and catchment we have applied these measures to a matrix of grid networks of varying block sizes and street widths. Figure 3 shows a matrix of 9 grids at a scale of one square kilometre. Here we have eliminated heterogeneity within each grid in order to test the effects of block size and street width on permeability and interface catchment. Block size is progressively increased from the lower left to top right while street width increases from top left to lower right as indicated in the row of diagrams beneath. While these are not real cities, the sample of grids is designed to cover the range of combinations of street widths and block sizes one finds in real cities. Street widths range from 5m to 80m and block sizes range from 25m to 300m. Unlikely combinations such as 300m blocks with 5m streets and 25m blocks with 80m streets are excluded. The values for permeability (AwaP), and interface catchment (IC) are listed under each grid. The AwaP score peaks in the upper right plan (showing impermeability) and declines towards the lower left commensurate with block size. This measure, as mentioned earlier, is not impacted by street width. Interface catchment peaks in the middle left plan and diminishes towards the lower right, responding primarily to street width but also to smaller block size. The greatest gaps between permeability and interface catchment are found in the lower middle and right where high permeability combines with low interface catchment.

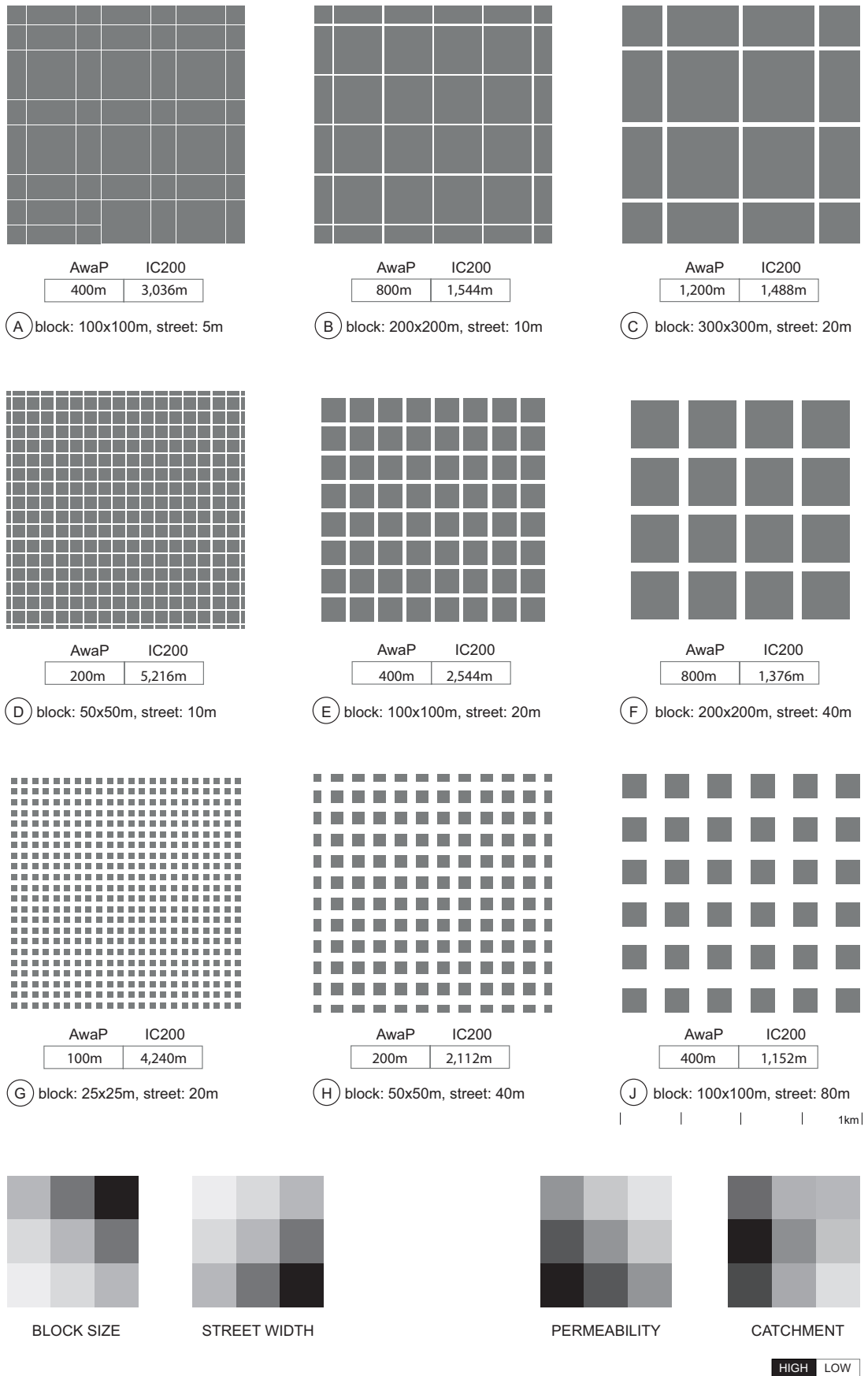


Figure 3. Effects of block size and street width on permeability and interface catchment.

Six Cases

We now apply the measures of area weighted average perimeter (AwaP) and interface catchment (IC) to six case studies of 1 square kilometre, selected to represent a wide range of actual morphologies from Houston and Brasilia to Nagoya and Venice. The aim is not to test AwaP and IC against other measures, but to explore how they together can capture differences between real morphologies. Figure 4 shows the overall morphology for each case and the AwaP scores that range from 1,000 in Houston (low permeability) to 315 in Nagoya (high). Venice shows a low level of pedestrian permeability (AwaP = 860) due to the fact that our map is centred on the Grand Canal which is largely impermeable to pedestrians. We were initially tempted to relocate this frame in order to capture a more ideal 'Venice', however, there is another lesson here in the degree to which these measures can change dramatically within short distances depending on morphology.

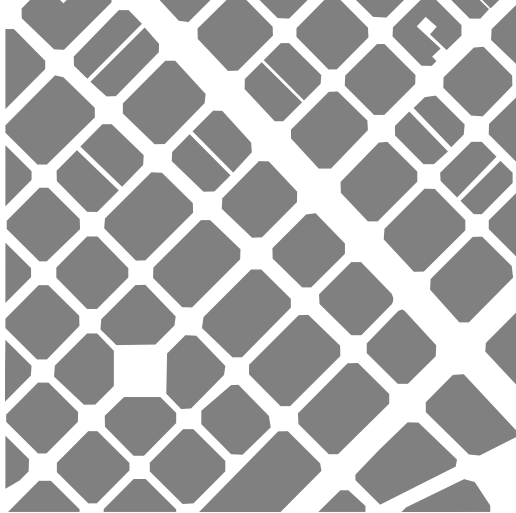
GOKISO, NAGOYA AwaP=315



VENICE AwaP=860



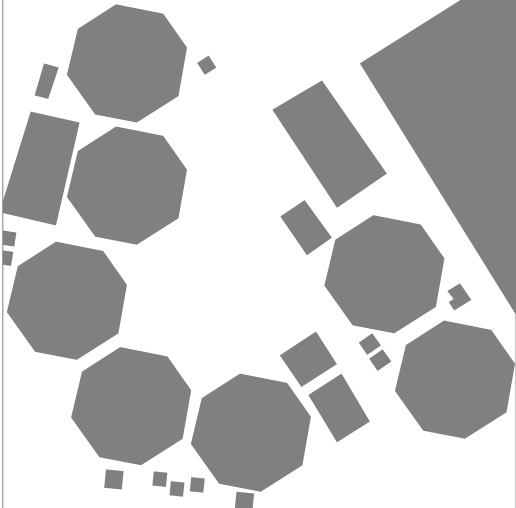
EIXAMPLE, BARCELONA AwaP=450



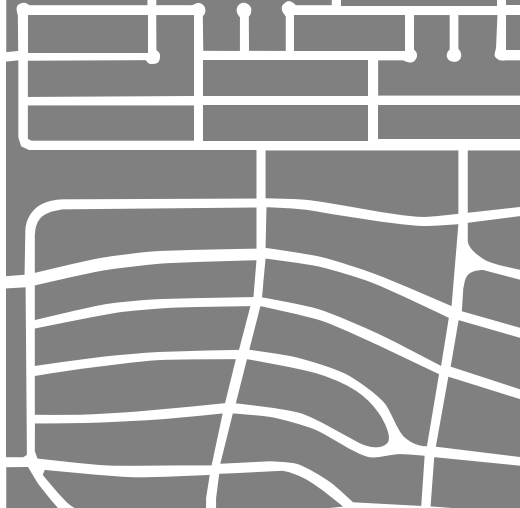
MANHATTAN, NEW YORK AwaP=550



OCTOGONAL, BRASILIA AwaP= 675



OAK FOREST, HOUSTON AwaP= 1,010



1km

Figure 4. Six case studies with different morphologies.

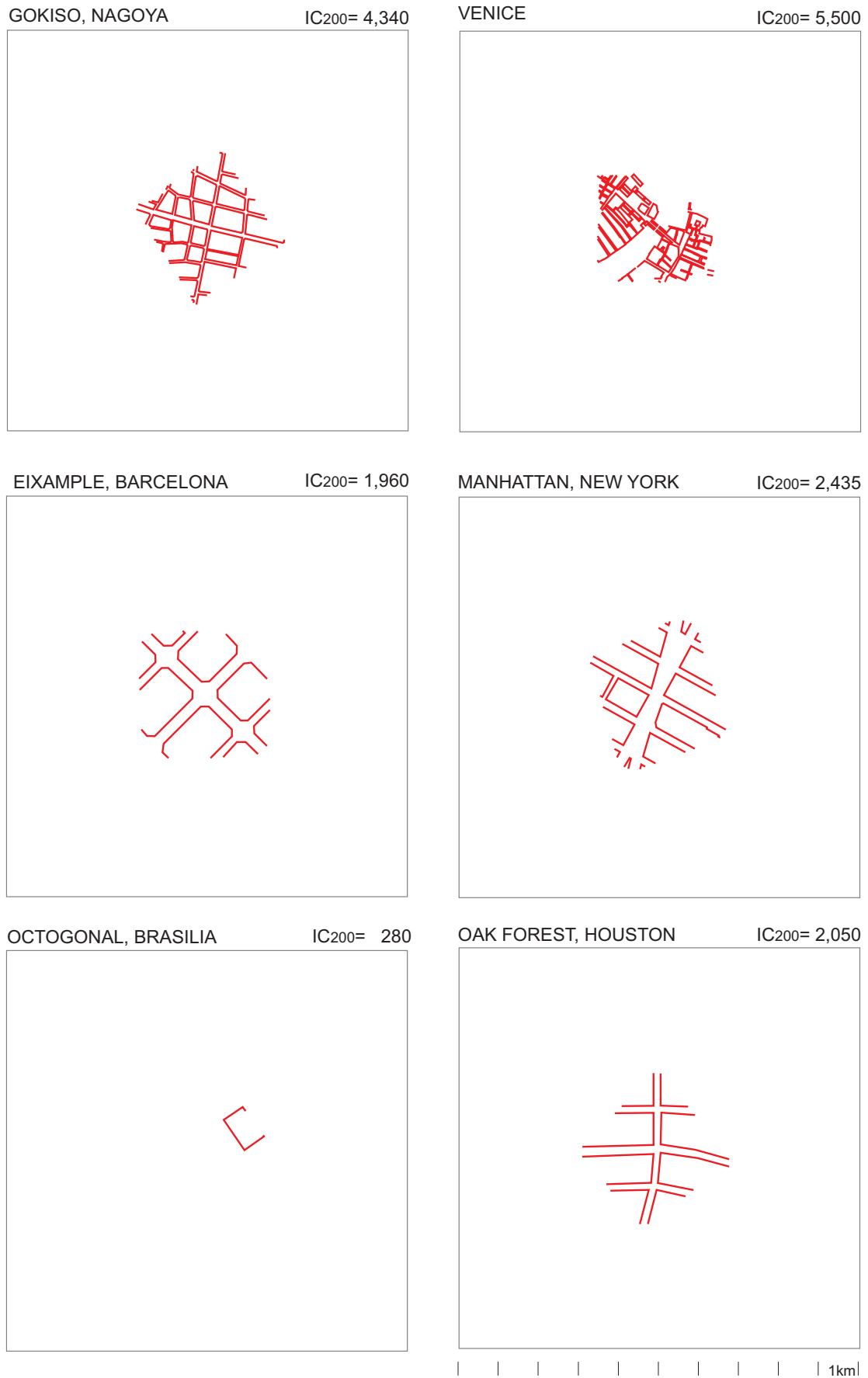


Figure 5. Interface catchment (IC₂₀₀) of the six case studies.

Figure 5 maps the identical sites in terms of interface catchment which, even at a 200 metre interface reach (IC200m), ranges from 280m to 5,500m. The peak is in Venice as result of very narrow streets, lanes and dead-ends, further demonstrating the distinction between permeability and interface catchment. In Nagoya the combination of small blocks and narrow streets leads to high IC in combination with high permeability. In Manhattan and Houston the IC is half that of Nagoya as a result of elongated blocks. The IC is almost equal in Barcelona and in suburban Houston, a result that is produced by the measure being taken in the most permeable location in the latter case. The very low IC in Brasilia reflects the vast open spaces.

Figure 6 superimposes the findings from figures 3, 4 and 5 and graphs them according to axes of interface catchment (vertical) and permeability (horizontal). If it weren't for the anomaly of the Venice canal what we find is a loose curve from the highly permeable small grain morphologies of Nagoya through the mid-range of Barcelona and Manhattan to the modernist morphologies of Brasilia and Houston. Figure 6 also shows these measures superimposed with the abstract morphologies from Figure 3 (labelled A to J). Recall that block size increased from G to C and that street width increased from A to J. It is notable that each of these actual morphologies with the exception of Barcelona lies outside the limits of the results produced by the abstract morphologies labelled A-J, suggesting that measures based on entirely regular street grids have limited applicability.

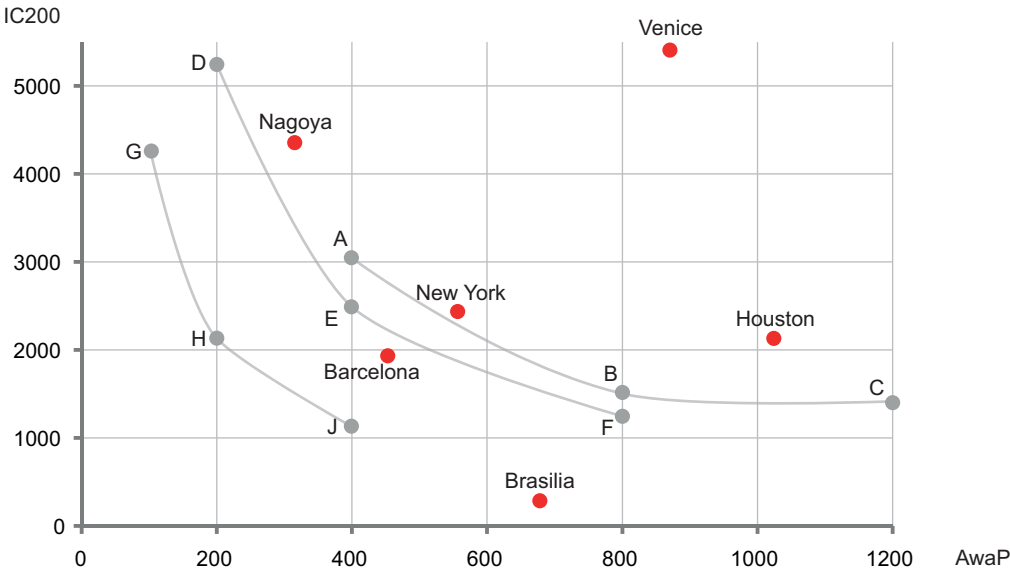


Figure 6. AwaP/IC200 diagram showing the six case studies.

Discussion

We conclude here with a brief summary of the arguments and discussion on how and why this exploration might be useful for research and practice. This work has a key antecedent in the work of Jacobs (1961) who introduced the concepts of 'short blocks' and 'pools of use'. These concepts - now generally labelled pedestrian 'permeability' and 'catchments' respectively - have each become key concerns for research on walkability with a range of metrics emerging in the fields of public health (Frank et al. 2006, Giles-Corti et al. 2003, Moudon et al. 2006) and transport (Cervero and Kockelman 1997, Krizek 2003, Schlossberg 2006) as well as urban design and planning (Hillier 1996, Lee and Talen 2014, Stangl 2015). Morphological properties such as permeability and catchment would appear to be simple measures, yet the metrics used tend to vary according to the morphology being studied, the scale at which it is studied and the research questions. Our goal is to develop better metrics for permeability and catchments, and to better understand their interconnections, as well as to show the limitations of any metrics. What is at stake is not only correlations with health and transport but also measures of walkable access that are geared to the social and economic productivity of the city. The larger task here is to apply a better understanding of walkability in both our diagnoses of the existing city and to codes and critiques that govern the prospective city. We need widely understood measures that can be calculated from urban databases that will enable us to compare walkable access between the whole range of urban morphologies.

Using a combination of mapping and measuring we have developed new methods for analysing permeability and catchment. In the case of permeability we have suggested that AwaP is an approach that deals more accurately than existing measures with heterogeneous urban morphologies and elongated barriers to pedestrian movement. This is shown in Figure 1 which compares AwaP against measures of average block length, area or diagonal as well as those focused on street length or intersection density. While we suggest that AwaP is a more effective measure of permeability at the tested scale, it still shares some of the limitations of other metrics in that it does not account for street width or open space. Furthermore, a focus on permeability alone is insufficient, since any measure of permeability will peak when the blocks disappear entirely - when there is no city to walk to. Jacobs' principle of short blocks was the means to the end of intensive 'pools of use' or catchments. Metrics for catchments are also well-developed - often through measures of the pedestrian catchment ratio (PCR) or metric reach (MR) (Schlossberg 2006, Peponis, Bafna and Zhang 2008). Figure 2 demonstrates that catchments do not measure permeability, but also that PCR is not a measure of what is useful within a 'pool of use'; like permeability, PCR will peak in open space when there is nothing to catch. While metric reach is more useful we suggest that a measure of the total length of public private interfaces within the catchment, or interface catchment (IC), is more useful still. In Figure 3 we show that permeability and interface catchment are closely related since both are geared to block size; yet they are distinguished by the fact that interface

catchment diminishes with increasing street width while permeability does not. In figures 4-6 we have tested this combination of proposed metrics on a range of real cities where the effects of heterogeneous morphologies become apparent - results can vary a great deal with small shifts in location. One example is Venice where the impact of the canal is profound; we were tempted to move the frame but that would simply skew the result towards an ideal and miss the lesson that real cities are not ideal cities. Our analysis here is limited to a single location in just six cities; research on a greater range of cities and morphologies would be useful.

Our focus on the public/private interface as a measure can again be traced to Jacobs for whom the interface is a key to what makes cities tick. Three chapters of her seminal book were entitled 'The uses of sidewalks' to highlight the interface as a site of social and economic exchange with 'eyes on the street' and the performance of 'place ballet' (Jacobs 1961). The public/private interface is a threshold condition that generates attractions, entrances and sites of exchange (Gehl 1987). While often reduced to a formula like the 'active edge', the interface is perhaps the least developed of Jacobs' work and most deserving of further research (Dovey and Wood 2015). The length of reachable interface is important because the interface is a productive interstitial zone that sustains the life of the city. The importance of the catchment lies in access to destinations which are generally found on public/private interfaces. We argue that the interface catchment is a proxy measure of the capacity of the city to sustain differences through a multiplicity of entrances across the public private interface. Indeed the measure of IC we introduce here could be usefully extended to include a metric for the number of entrances - perhaps the 'entrance catchment'. Thus the permeability of the street network is linked to that of the interfaces and ultimately it is also connected to streetlife vitality and urban intensity.

The AwaP and IC as our preferred measures of permeability and catchment respectively are joined at the hip, so to speak, since in general terms the block perimeter is the public/private interface. Of course there are many locations where this is not the case, where interfaces have been privatized within quasi-public space (where public access may be restricted by time of day) or distributed across three-dimensional urban networks. These are conditions that complicate the measuring and mapping of both permeability and interface catchment, but they do not change the key questions for urban design research and practice. How does the urban morphology enable and constrain walkable public access? To how much of the city do we have walkable access from any given location? Both AwaP and IC are measures of the perimeter of private space; they map and measure the extent of public access. The measures we suggest here embody the kind of thinking that needs to be applied in any critique of privatization (Dovey 2016).

Through this interconnected understanding of permeability and interface catchment we begin to approach the broader urban property of 'porosity' a concept that can be traced to an essay

on the slums of Naples in 1924 by Benjamin and Laci (1978). Much more than simply street permeability, porosity is the social and spatial interpenetration of public and private space - socially and spatially. The joint measures of permeability and interface catchment we present here can be construed as one way of measuring/mapping porosity.

Finally we have to discuss the epistemology of measuring and mapping urban morphologies. There is always the danger in quantitative research that we prove the bleeding obvious. The map itself is a form of spatial knowledge that can be designed to show levels of permeability graphically by stripping away all information except the public space network - as in our figures. Any trained urbanist can then see the general range of levels of permeability and connectivity in the maps we have presented, so what is the point of quantification? How to ensure that we do not simply construct a measure that confirms what the map has already told us? While maps of homogenous abstract morphologies are relatively easy to read, real cities are more complex. The comparison of case studies has led to surprising results that did not match our understanding of the morphologies derived from studying the maps.

On the other hand we might ask: if these properties of permeability and interface catchment can be reduced to a number then what is the use of the maps? For many researchers in the field of walkability, permeability is but one index within a complex formula and there is scarcely a use for maps at all - the index that best predicts pedestrian flows or population health is the answer (Cervero and Kockelman 1997, Frank et al. 2006, Giles-Corti et al. 2003). We suggest a combination of mapping and measuring; any study of urban morphology must account for forms of peculiarly spatial knowledge embedded in maps that cannot be reduced to numbers and words. This triangle of relations between maps, words and numbers also bears on the relations between research and practice. We suggest the joint use of both maps and measures - maps that demonstrate the measures - is crucial to gearing practice to research. If walkable access is to be embodied within urban codes then its measures need to be understood in morphological terms.

The metrics we suggest here are measures of capacity; we are not measuring pedestrian flows nor suggesting that permeability or interface catchments will necessarily produce them. This is a mapping of the 'space of possibility' embodied in the urban morphology (DeLanda 2011). The reasons why such measures matter is because they enable and constrain pedestrian flows. Permeability and catchments are properties that enable such desired interconnections, co-functioning and synergies of the city to flow more effectively and adaptably. While we treat permeability as a property of the actual city morphology, the extensive city, the key to its importance is what it makes possible – the synergies and alliances between attractions. We measure this morphology in order to better understand this potential.

Endnotes

1. The relationship between pedestrian movement and street networks has also been explored through spatial syntax research, which studies the links between topological measures of urban networks (such as integration) and urban intensity (Hillier and Hanson 1984, Hillier 1996, Hillier and Vaughan 2007). While network integration is an important form of urban analysis it is not strictly a measure of permeability or catchment and is excluded from this analysis.

2. There are two other mathematical measures of block shape that we have considered but discarded. First is the method used by Louf and Barthelemy (2014) which measures each block in terms of the ratio between the area of the block and that of the circumscribed circle. Second is the ratio between the block area and that of a circle with an identical perimeter, known as the 'isoperimetric quotient' (Colaninno, Cladera, and Pfeffer 2011). In both cases as block shape approaches a circle the ratio approaches 1 and is considered to have maximum permeability. However, neither of these measures is scale based - the measure for a small square block will be identical to that of a large impermeable square block.

References

- Benjamin, Walter, and Asja Lacin. 1978. "Naples." In *Reflections*, edited by Walter Benjamin, 166-168. New York: Harcourt, Brace & Jovanovich.
- Berghauer Pont, Meta, and Per Haupt. 2010. *Spacematrix: Space, Density and Urban Form*. Rotterdam: NAI.
- Cerdá, Ildefonso. 1867. *Teoria General de la Urbanizacion*. Vol. 1. Madrid: Imprenta Española.
- Cervero, Robert, and Kara Kockelman. 1997. "Travel Demand and the 3Ds: Density, Diversity, and Design." *Transportation Research Part D* no. 2 (3):199-219.
- Clifton, Kelly J., Andréa D. Livi Smith, and Daniel Rodriguez. 2007. "The development and testing of an audit for the pedestrian environment." *Landscape and Urban Planning* no. 80 (1):95-110.
- Colaninno, Nicola, Josep Roca Cladera, and Karin Pfeffer. 2011. An automatic classification of urban texture: form and compactness of morphological homogenous structures in Barcelona. In *51st European Congress of the Regional Science Association International*. Barcelona.
- DeLanda, Manuel. 2011. *Philosophy and Simulation*. London: Continuum.
- Dovey, Kim. 2016. *Urban Design Thinking: A Conceptual Toolkit*. London: Bloomsbury.
- Dovey, Kim, and Stephen Wood. 2015. "Public/private urban interfaces: Type, adaptation, assemblage." *Journal of Urbanism* no. 8 (1):1-16.
- Ewing, Reid, and Susan Handy. 2009. "Measuring the Unmeasurable: Urban Design Qualities Related to Walkability." *Journal of Urban Design* no. 14 (1):65-84.

- Forsyth, Ann, Mary Hearst, J.M. Oakes, and Kathryn H. Schmitz. 2008. "Design and destinations: factors influencing walking and total physical activity." *Urban Studies* no. 45 (9):1973-1996.
- Forsyth, Ann, and Michael Southworth. 2008. "Cities Afoot-Pedestrians, Walkability and Urban Design." *Journal of Urban Design* no. 13 (1):1-3.
- Fowler, E. P. 1987. "Street Management and City Design." *Social Forces* no. 66 (2):365-389.
- Frank, Lawrence D., James F. Sallis, Terry L. Conway, James E. Chapman, Brian E. Saelens, and William Bachman. 2006. "Many Pathways from Land Use to Health: Associations between Neighborhood Walkability and Active Transportation, Body Mass Index, and Air Quality." *Journal of the American Planning Association* no. 72 (1):75-87.
- Gehl, Jan. 1987. *Life between buildings: using public space*. Translated by Jo Koch. New York: Van Nostrand Reinhold.
- Gehl, Jan. 2010. *Cities for People*. Washington DC: Island Press.
- Giles-Corti, Billie, Sally Macintyre, Johanna P. Clarkson, Terro Pikora, and Robert J. Donovan. 2003. "Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia." *American Journal of Health Promotion* no. 18 (1):93-102.
- Gruen, Victor. 1965. *The Heart of Our Cities*. London: Thames and Hudson.
- Hess, Paul. 1997. "Measures of connectivity." *Places: Forum of Design for the Public Realm* no. 11 (Summer).
- Hillier, Bill. 1996. "Cities as movement economies." *Urban Design International* no. 1 (1):41-60.
- Hillier, Bill, and Julienne Hanson. 1984. *The social logic of space*. Cambridge: Cambridge University Press.
- Hillier, Bill, and Laura Vaughan. 2007. "The city as one thing." *Progress in Planning* no. 67 (3):205-230.
- Jacobs, Allan B. 1993. *Great Streets*. Cambridge, MA: MIT Press.
- Jacobs, Jane. 1961. *The death and life of great American cities*. New York: Random House.
- Knight, Paul L., and Wesley E. Marshall. 2015. "The metrics of street network connectivity: their inconsistencies." *Journal of Urbanism* no. 8 (3):241-259.
- Krizek, Kevin J. 2003. "Operationalizing Neighborhood Accessibility for Land Use–Travel Behavior Research and Regional Modeling." *Journal of Planning Education and Research* no. 22 (3):270-287.
- Lee, Sungduck, and Emily Talen. 2014. "Measuring Walkability: A Note on Auditing Methods." *Journal of Urban Design* no. 19 (3):368-388.
- Lin, Lin, and Anne Vernez Moudon. 2010. "Objective versus subjective measures of the built environment, which are most effective in capturing associations with walking?" *Health & Place* no. 16:339-348.
- Lo, Ria Hutabarat. 2009. "Walkability: what is it?" *Journal of Urbanism* no. 2 (2):145-166.
- Louf, Rémi, and Marc Barthelemy. 2014. "A typology of street patterns." *Journal of the Royal Society: Interface* no. 11.

- Maghelal, Praveen K., and Cara Jean Capp. 2011. "Walkability: A Review of Existing Pedestrian Indices." *URISA Journal* no. 23 (2):5-19.
- Marshall, Stephen. 2005. *Streets & Patterns*. London: Spon Press.
- Moudon, Anne Vernez, Chanam Lee, Allen D. Cheadle, Cheza Garvin, Donna Johnson, Thomas L. Schmid, Robert D. Weathers, and Lin Lin. 2006. "Operational Definitions of Walkable Neighbourhood: Theoretical and Empirical Insights." *Journal of Physical Activity and Health* no. 3 (S1):S99-S117.
- Páez, Antonio. 2013. "Mapping travelers' attitudes: does space matter?" *Journal of Transport Geography* no. 26:117-125.
- Peponis, John, Sonit Bafna, and Zongyu Zhang. 2008. "The connectivity of streets: reach and directional distance." *Environment and Planning B: Planning and Design* no. 35 (5):881-901.
- Porta, Sergio, and John Luciano Renne. 2005. "Linking urban design to sustainability: formal indicators of social urban sustainability field research in Perth, Western Australia." *Urban Design International* no. 10 (1):51-64.
- Schlossberg, Marc. 2006. "From TIGER Audit Instruments: Measuring Neighbourhood Walkability with Street Data Based on GIS." *Transportation Research Record* no. 1982:48-56.
- Schmidt, Charles G. 1977. "Influence of Land Use Diversity Upon Neighbourhood Success: An Analysis of Jacobs' Theory." *Annals of Regional Science* no. 11 (1):53-65.
- Sevtsuk, Andres, and Michael Mekonnen. 2012. "Urban network analysis: A new toolbox for ArcGIS." *Revue internationale de géomatique* (2):287-305.
- Siksna, Arnis. 1997. "The effects of block size and form in North American and Australian city centres." *Urban Morphology* (1):19-33.
- Southworth, Michael, and Eran Ben-Joseph. 2003. *Streets and the Shaping of Towns and Cities*. Washington: Island Press.
- Stangl, Paul. 2015. "Block size-based measure of street connectivity: A critical assessment and new approach." *Urban Design International* no. 20 (1):44-55.
- Thadani, Dhiru A., ed. 2010. *The Language of Towns and Cities: A Visual Dictionary*. New York: Rizzoli.
- Weicher, John C. 1973. "A Test of Jane Jacobs' Theory of Successful Neighbourhoods." *Journal of Regional Science* no. 13 (1):29-40.
- Whyte, William Hollingsworth. 1988. *City: Rediscovering the Center*. New York: Doubleday.



Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Pafka, E; Dovey, K

Title:

Permeability and interface catchment: measuring and mapping walkable access

Date:

2017

Citation:

Pafka, E. & Dovey, K. (2017). Permeability and interface catchment: measuring and mapping walkable access. *Journal of Urbanism*, 10 (2), pp.150-162.

<https://doi.org/10.1080/17549175.2016.1220413>.

Persistent Link:

<http://hdl.handle.net/11343/230638>

File Description:

Accepted version