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What is walkability? The urban DMA

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Abstract
The concept of urban 'walkability' has come to occupy a key role at the nexus of a series of multidisciplinary fields connecting urban design and planning to broader issues of public health, climate change, economic productivity and social equity. Yet the concept of walkability itself remains elusive – difficult to define or operationalise. Density, functional mix and access networks are well-recognised as key factors: density concentrates more people and places within walkable distances; functional mix produces a greater range of walkable destinations; and access networks mediate flows of traffic between them. This complex synergy of density, mix and access – herein called the urban DMA – largely stems from the work of Jacobs. With an approach based in assemblage thinking we show that each of these factors is multiple and problematic to define or measure. Any reduction to a singular index of morphological properties can involve a misrecognition of how cities work. We argue that walkability is a complex and somewhat nebulous set of capacities embodied in any urban morphology, and that it should not be conflated with nor derived from actual levels of walking.

Keywords
assemblage, density, functional mix, permeability, walkability

摘要
城市“步行性”的概念在一系列将城市设计和规划与公共卫生、气候变化、经济生产力和社会公平等更广泛问题相关联的多学科领域中发挥了关键作用。然而，步行性本身的概念仍然难以捉摸—难以定义或操作。密度、功能组合和进入网络被公认为关键因素：密度在可步行距离内集中更多的人和地方；功能组合产生更多的步行目的地；而进入网络则调度目的地之间的流量。这种密度、组合和进入的复杂协同作用（文中称为城市DMA）主要源于雅各布斯（Jacobs）的著作。基于组合思维方法，我们表明这些因素中的每一个都是多重的，并且难以定义或测量。一旦简化为单一的形态属性指标，就可能导致对城市运行的错误认识。我们认为，步行性是一种复杂的、有点模糊不清的能力集合，它体现在任何城市形态中，并且，它不应与实际的步行水平混淆或由实际的步行水平得出。

关键词
组合、密度、功能组合、渗透性、步行性

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Introduction

The 'walkable city' has become a catch-cry in both popular and academic discourses about the future of cities. There is now a well-established literature showing that increased levels of walking have positive outcomes for population health (Stevenson et al., 2016), and that low-carbon cities necessary for climate-change adaptation require walkable transit-oriented neighbourhoods (Ewing and Cervero, 2010; Newman et al., 2009). Walkable cities of intensive face-to-face contact are also more productive in the context of an innovative information economy of idea formation, creativity and knowledge spillover (Storper and Venables, 2004). The cosmopolitan city of shared and walkable public space has also been recognised as a key to achieving equity between differences of social class, ethnicity, gender, age and ability (Massey, 2005; Sennett, 2018).

Our goal here is not to further investigate whether neighbourhoods with high levels of walking are healthy, green, productive, creative or equitable; rather we want to investigate the morphological conditions that comprise the concept of walkability in the first place. While there is a great deal of current research on walkability, this has exposed some deep ambiguities about what the concept means – it is clearly multi-dimensional and requires multi-disciplinary approaches (Forsyth, 2015; Lo, 2009). We suggest that walkability is a set of capacities of any given neighbourhood that is embodied in urban morphologies in three main ways – the densities (concentrations) of buildings and people; the mix of different functions and attractions; and the access networks we use to navigate between them. Density shortens distances between people and the places they need access to – how much activity, population and built form can be concentrated into a given urban area? Mix is fundamentally about differences and juxtapositions between activities, attractions and people. Mix is a means of generating alliances and synergies between functions: between home, work and play; between production, exchange and consumption. Access is about how we get around the city – how do we make connections between where we are and where we want or need to be? What are the access options and to what degree do they include or exclude walking?

While the existing research on walkability generally incorporates measures of density, mix and access, it is also widely understood that the concept is multi-dimensional (Talen and Koschinsky, 2013). In focusing on these dimensions of walkability we are specifically bracketing factors such as topography, micro-climate, safety and aesthetics. Hills, heat, cold, rain, snow, crime, noise, dirt, smell and broken pavements all inhibit walkability, while a comfortable and attractive walking environment enhances it. While such factors are not less important, they will be held in brackets for our purposes in order to focus on the morphological conditions of density, mix and access. For the most part these bracketed factors either cannot be changed or can be ameliorated after the city is developed. Our focus is on those long-term morphological conditions that are a key product of urban design and become highly resistant to change once the city develops.

This synergy of density, mix and access – the urban DMA – has roots in the earliest of urban design theorists. In the 19th century Ildefons Cerdá produced an urban theory based on socio-spatial surveys, morphological analysis and observation of

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cities as complex movement economies with synergistic relations where density, functional mix and street networks were the key components (Soria y Puig, 1999). Yet it was Jane Jacobs, with her deceptively simple description of the ‘need for concentration’, ‘mixed primary uses’ and ‘small blocks’, who established these three factors as central to how cities work (Jacobs, 1961). This has now become part of mainstream urban design theory, often formularised and over-simplified. Jacobs’ work emerged from urban activism; from trying to understand why and how urban life was being damaged by modernist thinking. She was not studying ‘walkability’, rather she took the value of a walkable city for granted as she articulated the principles that make it work and uncovered what we call the urban DMA.

Most of the research on urban walkability begins from questions of health or transport planning. For many of the best researchers in this field the key task has been to reduce urban morphology to a quantitative index (see: Cervero and Kockelman, 1997; Frank et al., 2006; Giles-Corti et al., 2003; Maghelal and Capp, 2011). Such approaches often seek to identify morphological conditions that can be associated with higher levels of walking in order to prove or disprove certain cause–effect relations between different morphologies and higher levels of walking and therefore effects on health and transport – the measure that best predicts pedestrian flows or population health is seen as the answer. If particular morphological factors can be shown to correlate with more walking then in aggregate, they come to define walkability. The limits to aggregating complex factors that work in synergy are widely recognised by most authors in this field; while we make no claim to solve these problems we hope to open a window onto new ways of thinking about walkability.

In this paper we explore these concepts of density, mix and access in more detail and while each may appear to be one thing, they turn out to be multiple. In each case we ask how they might be most effectively defined, measured and mapped. Jacobs’ principles were drawn from detailed observations of everyday urban life; she looked at only one city in detail and the principles of density, mix and permeability are largely derived from her own neighbourhood of Greenwich Village. However, these principles would not have had the sustained impact they had if they were particular to New York. Jacobs argued that her work was inductive rather than deductive, reasoning from the particulars of the city to general principles. She railed against planners who sought to reduce urban principles to numeric formulae, arguing that the city was far too complex for such reductionism and that the task was one of understanding the city as ‘organised complexity’. She suggested that emerging work on cybernetics, complexity and information theory held potential for a better understanding of urban synergies. Our approach here has some parallels but is generally known as an assemblage approach derived from the socio-spatial theories of Deleuze and Guattari (1987) as developed by DeLanda (2006) among others.

Assemblage

While the concept of assemblage has been applied in a variety of ways in urban studies, its application to walking (Kärrholm et al., 2017) and walkability is in an incipient stage. Within the humanities assemblage thinking is variously linked to ‘relational’ thinking for its focus on relations rather than things, and a ‘new realism’ or a ‘material turn’ for its focus on the materialities of the city (DeLanda and Harman, 2017; Rydin, 2014). A very brief introduction may portray this as a way of understanding the city with a focus on relations between material forms and socio-spatial practices – the city as an assemblage of the human and non-human, at once social and material. It pays attention to the relations between different scales without any presumed priority of the large over the small scale; the general order of the city emerges from the particulars as much as vice versa. Assemblage is a critique that sees practices of power operating both top-down and bottom-up; a relation between rhizomic networks and tree-like hierarchies. The identities of particular places (streets, neighbourhoods, districts) emerge from complex interrelations between parts.

Such an approach can be linked to investigations of self-organised learning systems, incorporating theories of emergence, complex adaptive systems and resilience (Johnson, 2001; Walker and Salt, 2006). Assemblage thinking is non-reductionist in the sense that it does not presume specific cause–effect relations – the goal is not to reduce walkability to its causes but to expose it as a multiplicity of interconnections, synergies, alliances and symbioses. Walkability is not one thing but an irreducible multiplicity of properties; we seek to understand it not as a cause of health or transport effects but as a set of properties embodied in any urban morphology. Assemblage thinking is multidisciplinary, connecting humanities to sciences and the disciplines of geography and social theory to practices of architecture, planning and design. Assemblage is an approach that tries to understand the city not only in terms of current properties but also capacities for what it could become, bringing urban design thinking into a research analysis of the city as a space of possibility (Dovey, 2016). Finally, assemblage is not one thing or method but a conceptual toolkit – the goal is not to make a theoretical point but to use these concepts to investigate how cities work and we mostly seek to avoid the jargon.

Based on a series of earlier papers we now unpack the concepts of density, mix and access in turn; we then explore how these parts are related to each other and to walkability.

Density

Urban density is a key property of walkability because it concentrates more people and places within walkable distances. The level of density literacy, however, is low and there is substantial confusion over what it means (Dovey and Pafka, 2014). Do we mean the density of buildings, residents or pedestrians? As perceived or as measured? Do we mean the net density on a particular site or the gross density that includes public space? Net density is generally discussed as part of planning controls and development decisions, yet the amenities and the problems that density brings to a neighbourhood depend on the gross density. Any measure of gross urban density also begs the question – at what scale? The more roads, highways, freeways, carparks, open spaces and water bodies we include, the lower the density becomes. The gross density will often decline to about 10% of neighbourhood measures as we expand in scale to the metropolis. Any comparison of average densities of whole cities depends on the scale of analysis. Population densities also change with daily, weekly and seasonal rhythms. In many cities large portions of the population oscillate from the suburbs to the centre on a daily cycle. Any measure of population begs the question – at what time?

One of the most persistent confusions over density is the conflation of density with building height. A ten-storey building on 10% of the site has the same floor area as a single storey building with 100% site coverage. The ratio between floor area and site area is generally known as the Floor Area Ratio (FAR, also called Plot Ratio and Floor Space Index) and is the most common density measure in urban planning. We have long known that the same FAR can be achieved with very different building types and height (Gropius, 1931), however, confusion persists because building height produces a high perceived density.

The measure of dwellings/hectare is common but particularly blunt as it depends on the functional mix, household size and dwelling size for its relations to building or population densities. Larger houses will produce higher building densities for the same population and larger households will lead to higher populations for the same number of dwellings. In functionally mixed neighbourhoods housing will be just one component of the mix and therefore not a measure of either building or population density. The census-based density of residents/hectare is another common measure but it does not include those who work there. Figure 1 maps three different measures of density in Manhattan and demonstrates how the spatial distribution of densities of floor areas, residents and jobs can differ, and there is always an additional population of visitors where data are more difficult to find.

Finally we come to the question of the degree to which such building and population densities are geared to streetlife and pedestrian densities. This linkage is strongly mediated by car dependency – what proportion of the population drive everywhere and never set foot in public space? Car dependency means that population and building densities are less likely to produce streetlife vitality.

The logic linking density to walkability is deductive – density shortens distances; other factors being equal, higher density brings more destinations within walking distance. In order to measure this, some assumptions about walkable distance are necessary. We begin from the position that a walkable distance is elastic. At a brisk walking speed of 6 km/h (Gehl, 1987), a 5-minute walk will extend to 500 m and produce a pedestrian catchment zone of ~50 ha of urban fabric, expanding exponentially to ~200 ha after 10 minutes and ~800 ha after a 20-minute walk

Figure 1. Building and population densities in Manhattan.

(this of course depends on permeability to which we will return below). In our work we have used the measure of 100 ha (1 km^2) as a useful proxy that sits between the most common 5- and 10-minute measures for healthy people within typical urban environments.

A suburban morphology of detached houses may have a gross FAR of 0.25, which means that from any given location there will be a total of about 25 ha of constructed floor area within the adjacent 100 ha. While internal densities vary enormously, an internal density of 50 m^2/person will generate walkable access to maybe 5000 residents. By contrast, a typical four-storey urban block may have a gross FAR of 2, bringing about 200 ha of floor area and ~40,000 residents within walking distance. Such measures are mediated by other factors including functional mix and permeability, but they demonstrate the effect that density has on concentrating people and places within walkable reach.

Measures of density can differ dramatically for different morphologies and building typologies. Patel (2011) has shown that the informal settlements of Mumbai have more than double the population density of Manhattan despite having a fraction of the FAR and building height. This is largely due to a huge difference in internal density since the dwellings per hectare are similar. We conclude that there is no single density measure that is going to be the most useful in understanding walkability; urban density needs to be understood as a complex assemblage of relations and interdependencies (Dovey and Pafka, 2014).

Mix

Functional mix, like density, shortens the distances between wherever we are and where we need to be. Jacobs (1961) argued that the modernist segregation of the city into mono-functional zones had the effect of preventing close connections of home to work, school, shopping, entertainment and recreation. This insight has been increasingly embraced in urban planning and as a key ingredient of walkability research (Cervero, 1989; Frank et al., 2006; Grant, 2005), yet basic questions about how to define the ingredients of the urban mix and the methods of measurement and mapping remain unresolved. When we list the most common functional categories we find at least 15 different functions and indeed the literature lists over 100 such urban functions (Lee and Moudon, 2006). There are several problems here. First, most of the functional categories we find in urban databases were originally designed to prevent mixing; the very term 'landuse' is based in an ideology where all land has a single use. Second, there are so many overlaps between categories – is a vacant shop a vacancy or a shop; is a stadium sport or entertainment? Third, functions are in no way equal; a shop is much more clearly geared to walking than a house. We suggest that what is necessary to cut through this complexity is a fundamentally different way of slicing the cake that brings mix rather than segregation to the fore (Dovey and Pafka, 2017). Figure 2 shows how 28 common functional categories can be subsumed under a triangular framework of live/work/visit – an adaptation of the Mixed-Use Index developed by van den Hoek and others (van den Hoek, 2008; Nes et al., 2012). Instead of continuing to separate functions we collapse them into just three plus the range of mixes between them – the live/work/visit triangle. This is a relational model that seeks to understand the urban activities and practices not as stand-alone functions but in relation to each other. The live/work/visit triangle cuts through the complexity of overlapping functions and instead of trying to distinguish more and more different functions we seek to distinguish different kinds of mix. The triangle shows three primary kinds

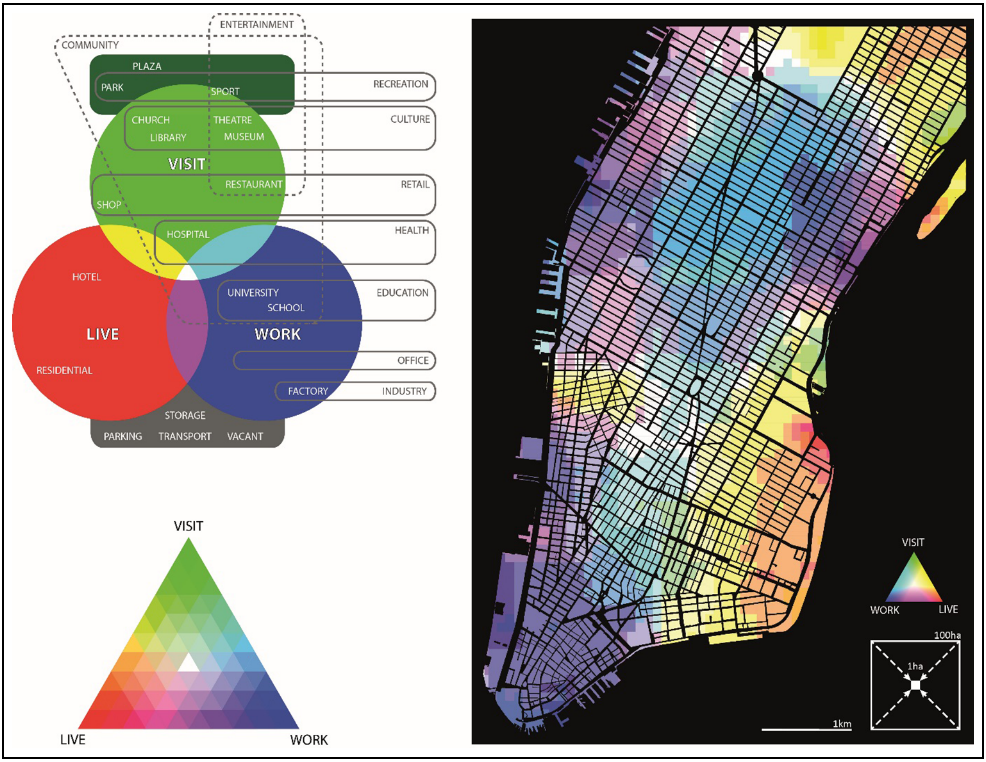

Figure 2. The walkable live/work/visit mix mapped in Manhattan.

of mix: live/visit (yellow) is mostly linked to lifestyle (where we live, shop, eat and play); live/work (magenta) is the commute; work/visit (cyan) is the ways we shop, eat and play in conjunction with work. As live, work and visit all mix the colours become progressively lighter. This reduction of urban life to three primary functions involves a radical simplification that conflates highly disparate functions within broad categories. Figure 2 also demonstrates one way of using this lens to map the ways a walkable mix is distributed across Manhattan based on detailed floor area data (New York City, 2015). In this case each hectare of the city is coloured according to the mix of floor areas within the surrounding walkable catchment of 100 ha.

The live/work/visit triangle constructs a field of possible relations between three primary functions that resonate with what economists have often called reproduction, production and exchange (incorporating social exchange). They also identify primary relations between people and urban space – we become ‘residents’, ‘workers’ and ‘visitors’, respectively, in different locations in everyday life. The key shift here lies in a focus on the mix rather than the functions in themselves. Such mapping offers an empirical understanding of mix that enables us to expose different kinds and levels of mix – the mix of mixes. It is tempting to construct an index for an ideal mix measured by the degree of lightness as the mix approaches the centre of the triangle. However, we suggest that the best cities comprise a mix of mixes and that our attention should focus instead on the corners of the triangle – the dysfunctional parts of cities where one cannot walk between live, work and visit functions. In this regard Manhattan is a rich mix of mixes – note the scarcity of deep blue, red and green. Metrics that reduce functional mix to singular measures of entropy or dissimilarity (Cervero, 1989; Frank et al., 2006) cannot show this mix of mixes.

While the functional mix is crucial to any approach to walkability, it is important to note here that function is itself but one dimension of the urban mix which also includes the formal mix and social mix. A formal mix emerges from the way a city produces different plot sizes which are in turn linked to different building styles, floor plate sizes and building heights. While a small-grain urban fabric is clearly linked to a more mixed neighbourhood there is also a need for large grains because some functions rely on those large grains in order to become part of the mix. The social mix has to do with the ways a good city brings together people of different ages, abilities, ethnicities and social classes. Cities are places where differences rub together in walkable public space and this mix of differences is fundamental to the production of urban vitality. Again, there is no single index for mix in its impact on walkability because the concept is fundamentally relational, both between functions and with the formal and social mix that sustains them (Dovey and Pafka, 2017).

Access

The access networks of the city enable and constrain pedestrian flows; the impact on walkability is both in shortening distances and accelerating flows. Jacobs (1961) originally introduced the concepts of 'small blocks' and 'pools of use'– now generally labelled pedestrian 'permeability' and 'catchments', respectively. These have each become key concerns for research on walkability with a range of metrics in the fields of public health (Moudon et al., 2006), transport (Krizek, 2003) and urban design (Lee and Talen, 2014). Jacobs suggested a maximum block length of about 120 m to ensure an effective pedestrian network, similar to the 113 m blocks calculated by Cerdá in the 19th century. This is not a bad rule of thumb for urban walkability, however the most obvious measures of permeability based on average block-size (length, area, perimeter) can be misleading because a single elongated block (or barrier) can disrupt flows without impacting the average. The most accurate measure is the 'area-weighted average perimeter' where each block perimeter is multiplied by its area and then averaged across a study area (Pafka and Dovey, 2017).

Jacobs 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 widely developed into the mapping of walkable catchments or 'pedsheds' (Schlossberg, 2006). 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 because the geometry of the street network restrains movement. Catchments within urban areas are generally no more than about two-thirds of the inscribed circle and large block sizes or impermeable networks can reduce this much more.

The effectiveness of walkable access networks, however, entails more than simply permeability or connectivity. A crucial paradox here is that permeability will increase as streets get wider and blocks get smaller – in this sense walkability peaks when there is no city to get access to. So we need to incorporate some measure of what we get access to. We suggest that it can be useful to map and measure the 'interface catchment'– the total length of public/private interface (or block perimeters) that can be reached within a walkable distance (Pafka and Dovey, 2017). The interface is a proxy for the way most urban attractions are entered across a public/private interface. The measure of interface catchment increases in relation to a combination of both permeability and narrower streets; it is a measure of pedestrian catchment that incorporates a proxy measure of what is being caught. The length of walkable interface is important because the interface is a productive interstitial zone that sustains the life of the city. This approach derives again from the work of Jacobs whose three opening chapters focused on the importance of sidewalks for urban vitality, social integration and safety. 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. Thus the permeability of the street network is linked to the total length of interface catchments, and ultimately to streetlife vitality. The ways that pedestrian catchments and interface catchments are mediated by permeability and street width are diagrammed in Figure 3 which shows how a 500 m walk in a dense city will give access to between about 7 and 26 km of interface as the average block length decreases from 200 to 50 m and street width narrows from 40 to 10 m. It demonstrates that changes in block size (permeability) and streetwidth have little impact on the size of pedestrian catchments but a significant impact on the interface catchment.

Access networks are also multi-modal and need to be understood from the perspective of those who choose between modes of walking, cycling, public transport and cars. Public transport trips are generally coupled with walkable access to the transit stop. In this regard multi-modal isochrones can be mapped to show how the urban territory accessible within a given time period will expand and contract between different modes and over time (Dovey et al., 2017). A pedestrian isochrone map is a catchment expressed in time rather than distance, enabling us to compare different modes. Isochrones are a proxy for the cognitive maps that we all use to calculate how long it will take to get where we need to go – we choose access modes and plan accordingly. Walking will primarily be chosen up to a limit of about 10 minutes if it is the fastest mode and other factors being equal. Walking has the advantage that it is a much more predictable trip time than public transport or cars where we have to allow for delays caused by poor service, congestion and parking. Walking isochrones can also be expanded through urban design initiatives that make walking more efficient. What is at stake here is the capacity or possibility to walk; we are not suggesting that permeability, interface catchments or expanded isochrones will necessarily produce pedestrian flows, only that they enable greater access. Like density and mix, these are properties that are embodied in urban form and that enable more efficient pedestrian flows.

The urban DMA

So, having explored each of these three properties of density, mix and access independently, what is walkability? Our key arguments are twofold. First is that these properties of density, mix and access are each comprised of a set of interrelated concepts for which there can be no singular measures, and they work together in complex synergies and interdependencies – the urban DMA is an assemblage that cannot be reduced to an aggregation of parts. Walkability is a nebulous term that is best understood as an aspect of urban intensity that is open to interpretation but resists any

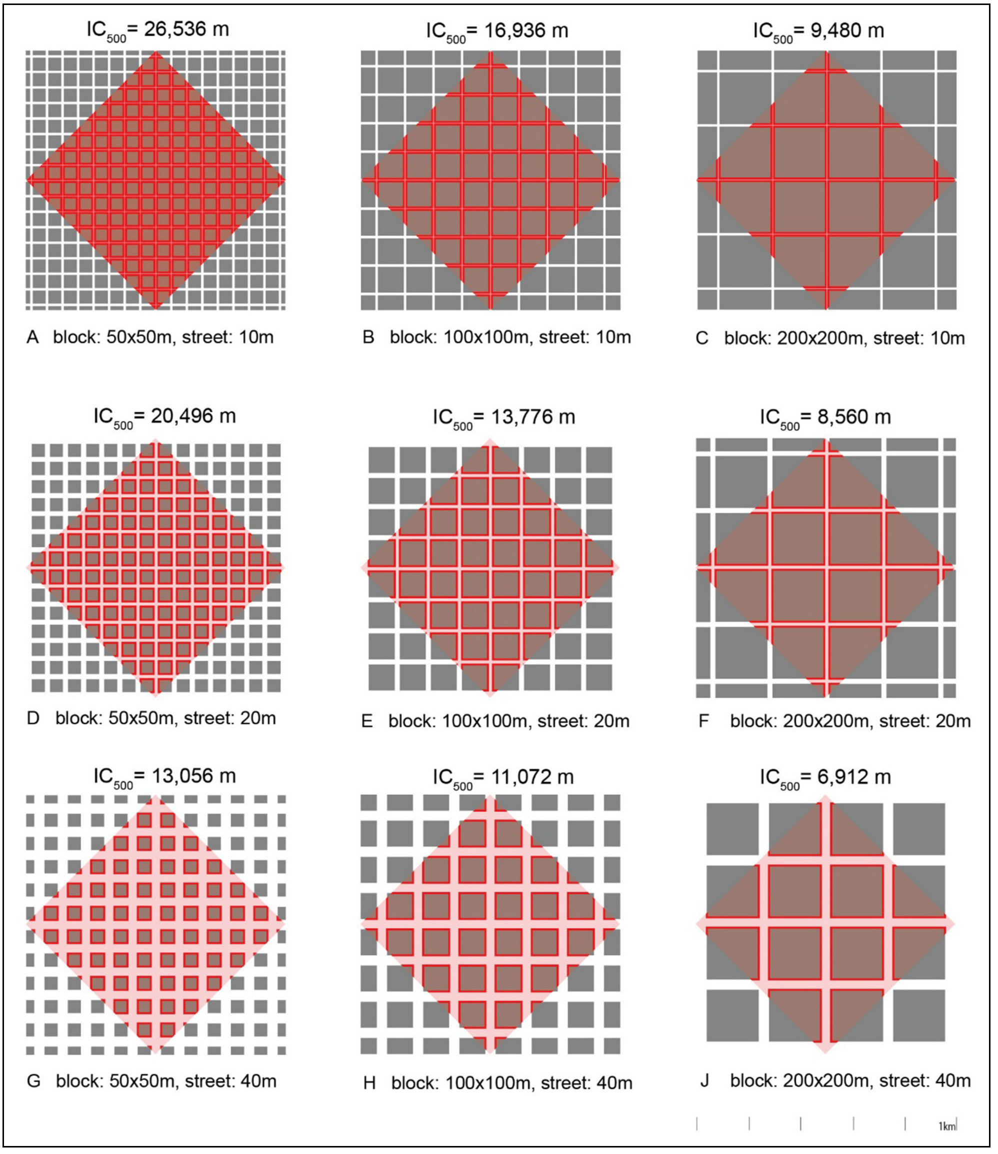

Figure 3. Interface catchment increases as catchment area remains constant.

reduction to its extensive properties. Second, we argue for a key distinction between walkability and walking. The logic connecting density, mix and access to walkability is deductive; these properties are capacities that enable and constrain, rather than directly cause, walking. While the various measures and maps of the DMA can be crucial contributions to knowledge, there are limits to any science of walkability.

Density, mix and access, while often combined with other factors, form the basis of most current measures of walkability from the popular ‘walkscore’ or ‘ratemystreet’

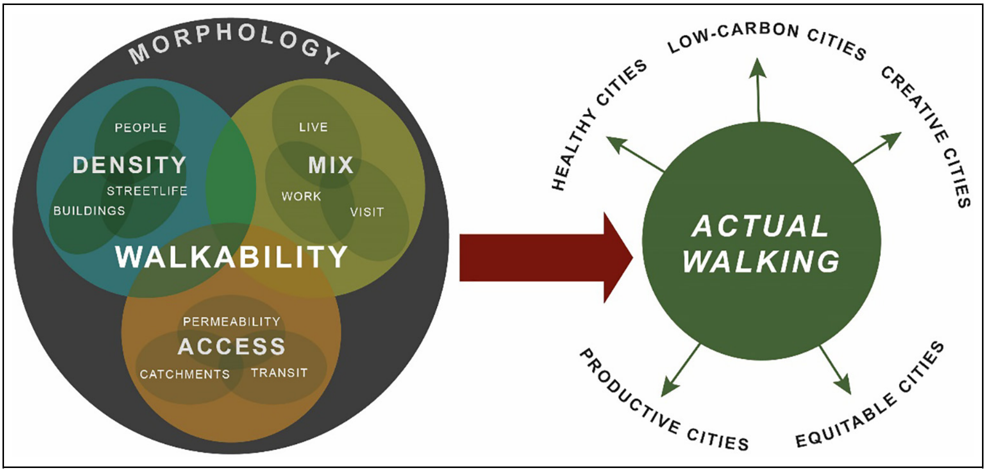

Figure 4. The Urban DMA – Walkability and actual walking.

websites to the more scientific metrics that aim to connect urban morphology with better environmental and health outcomes. However, none of these factors is singular – each turns out to be a set of interdependent relations (Figure 4). Density is an interrelated assemblage of buildings, populations and streetlife that no single measure can capture. A walkable mix is also best understood as a complex set of relations between where we live, work and visit. Rather than an ideal functional mix we suggest a mix of mixes and an interdependency between formal, social and functional mixes. Likewise, walkable access cannot be reduced to any singular measure of connectivity, permeability or catchment but is dependent on destinations and geared to metropolitan access through public transit nodes.

As we explore the interconnections and synergies between these factors the interdependencies multiply further. We argued earlier that any measure of population density depends on the functional mix, and that any outcome in terms of streetlife density depends on the mode of access and car dependency. Any measure of functional mix cannot be understood independently from density – 20 shops in a high-density residential area may register the same mix as a single corner store in a low-density suburb. Without a walkable pedestrian network, density and mix will not work their magic, and a walkable city at metropolitan scale relies on the interdependencies between walking and public transport. Density, mix and access work in synergy, all are necessary and none are sufficient. We call this the urban DMA to indicate the underlying conditions of an emergent urban effect that is more than the sum of its parts. The urban DMA is a set of synergies between the ways cities concentrate people and buildings, the ways they mix different people and activities together, and the access networks we use to navigate through them. Like biological DNA, the urban DMA does not determine outcomes, rather it establishes favourable conditions or limits to what is possible. Once established, the DMA of a neighbourhood can have great inertia and last for centuries with minimal change – for better or worse. Unlike DNA, the urban DMA is not natural but is a design and planning outcome. The synergies between density, mix and access are the key drivers that make the city walkable; the urban DMA is an intellectual framework for understanding and designing a more walkable city.

The term 'walkability' was not part of Jacobs' lexicon. When she outlined the principles we have described here as the urban DMA, she organised them into a section of her book entitled 'The conditions for city diversity'; the four key principles of mixed-use, aged buildings, permeability and density were each chapters within this section. We have collapsed mixed-use and aged buildings into mix because the latter principle is really an argument for a small-grain mix of old and new buildings that work together with functional and social mix. Jacobs' labelling of the larger set of principles as conditions for 'diversity' is confusing because it suggests that a diverse mix is both part and whole, means and end. In Jacobs' deceptively simple language these were the key principles underlying the emergence of urban 'vitality' and 'intensity'– concepts that are much more difficult to pin down than density, mix or access. The urban DMA is primarily a diagrammatic way of understanding how cities work, and wherein walkability is a necessary condition.

The language of assemblage thinking would call this synergy of density, mix and access an 'intensive multiplicity'. It is a multiplicity because the assemblage is essentially multiple and relational – one does not find 'elements' at the heart of it but multiple relations. The concept of 'intensity' is founded in the philosophical and scientific distinction between extensive properties such as volume (which are additive and divisible) and intensive properties such as temperature or stickiness (which are not). For Deleuze and Guattari (1987: 33) an 'extensive multiplicity' is an aggregation of parts that are largely unaffected by new additions. No matter how many ingredients are added it remains a simple aggregation. An 'intensive multiplicity' by contrast is more like a soup with an intensive flavour which is changed by each new ingredient as it enters into multiple relationships. Urban intensity is not a phenomenon that simply increases in a linear manner with building and population densities or network connectivity; it is a concentration of diverse encounters and interconnections. It follows that the urban DMA cannot be reduced to the extensiveness of density, mix or access without losing important aspects of what it is that makes cities tick.

So, to what degree might these factors of density, mix and access be understood through a science of walkability? A key problem with the production of knowledge about the city is that there are no controlled conditions – the city is the laboratory. Jacobs (1961: 441) suggested that her form of logic was inductive: 'reasoning from particulars to the general; not the reverse'. She argued that 'City processes in real life … are always made up of interactions among unique combinations of particulars, and there is no substitute for knowing the particulars'. She was critical of the ways that statistical averages can mislead, and attuned to the ways that the atypical peculiarities of everyday urban life can be vital to understanding how cities work (Jacobs, 1961: 452–453). While Jacobs reasoned from the particular to the general, this was clearly not a form of empirical science and her work is difficult to test. In one early example Weicher (1973) found that dense, permeable, mixed-use neighbourhoods of inner-city Chicago correlated with poor health and high crime outcomes – a finding that may say something about Chicago at that time but little about urban morphology or urbanity.

Jacobs' work was empirical in the broader sense of being based in rigorous observation rather than empirical science, and the general propositions that emerge from her work embody deductive rather than inductive logic. Density, mixed-use and permeable networks reduce walkable distances regardless of the amount of walking that actually takes place. Thus it is important to distinguish between walkability and walking – the capacity and the outcome; a dense, mixed and accessible city will enable but not cause people to walk. One cannot calculate a walkable capacity inductively by measures of walking. It is more the case that dense, mixed and accessible cities have long been produced because they shorten distances. Walkability emerges from the synergies of density, mix and access, but the larger assemblage of relevant factors such as topography, climate, car dependency, safety and so on may leave highly walkable neighbourhoods with low levels of walking and vice versa. Beautiful but barren walking paths in car-dependent suburbs are one example. The opposite is the case in some cities of the Global South where high density and mix lead to intensive streetlife despite highly impermeable and dangerous access networks. Some cities produce 'density without intensity'– mono-functional, car-dependent neighbourhoods where everyone drives because there is nothing to walk to. Then there are counter examples of what might be called 'intensity without density'– neighbourhoods where a small-grain mix of functions and a highly walkable access network produce a vibrant streetlife with relatively low densities. The gated enclave often achieves a mix of residential, retail, sports and entertainment that produces a packaged lifestyle with walkable internal access but sealed from public access – promoting private walking while lowering the permeability of the surrounding city.

The general point here is that walkability as a capacity to walk between urban locations cannot be conflated with actual walking activity, which can be minimal in the most walkable neighbourhoods or very heavy in the least walkable. While it is actual levels of walking that produce positive health and other benefits, and such measures are crucial for urban research, they need to be distinguished from measures of walkability (Figure 4).

While Jacobs referred to her method as inductive, we suggest it is best understood as what Peirce defined as 'abduction'– a form of inference by 'best explanation' where a set of observations leads to a conjecture that explains them. Now a key method for grounded theory (Reichertz, 2010), this is a form of reasoning backwards from effect to cause – observing the ways in which the city works and engaging in educated guesswork about how and why it works that way. While abduction can be used to generate testable hypotheses, it can also open the door to ideology and prejudice. The minimum densities and block sizes proposed by Jacobs were effectively those of Greenwich Village and need to be seen in that context rather than applied as formulae. Urban design knowledge from the early work of thinkers such as Cerdá, Sitte and Geddes through to the 20th century work of Jacobs, Alexander, Lynch and others has always been based on detailed observation of particular cities and neighbourhoods. For Jacobs most of the damage to cities was due to the application of ideal city models such as Garden City and she was critical of the tendency to reduce complex interrelations to formulae.

In her final chapter Jacobs argued that the city is a problem of 'organised complexity' and that the science of complex systems held prospects for a better understanding of how cities function (Jacobs, 1961: chapter 22). This work has developed productively through theories of cybernetics, chaos, complexity and resilience (Levin, 1999; Walker and Salt, 2006). Here the dynamics of complex systems are understood to depend on self-organised adaptive interactions between parts. While detailed outcomes are unpredictable, over time a regime with a set of particular properties 'emerges' and settles down

– walkability is one of these properties. The resilience of a complex adaptive system is defined as its capacity to adapt to change without slipping into a new regime (Walker and Salt, 2006). 'Key slow variables' within the system can be managed to either maintain the regime or drive it across a threshold into a new regime. The various dimensions of density, mix and access can be understood as key slow variables of any neighbourhood that can be managed to create or maintain a walkable regime.

While complex adaptive systems theory can be useful for understanding cities, a city is not systematic in the sense of being reducible to interactions between clearly defined parts with predictable outcomes. There are good reasons to develop better metrics for understanding and mapping those aspects of urban design where measurability is possible. However, the reduction of the city to its extensive components comes at a cost to the unmeasurable lived intensities of everyday urban life. Urban thinking needs approaches that cut across dichotomies between objective and subjective, materialities and representations, sciences and humanities. One way to address this is to join the sciences of complex adaptive systems to the social theory framework of assemblage thinking – to see the city as a 'complex adaptive assemblage' (Dovey, 2016: 263). This is not to oppose the quest for a science of walkability, only to suggest that city science remains a proto-science with no monopoly on urban knowledge (Dovey and Pafka, 2016). While complex digital modelling of urban systems is now common, there simply cannot be any controlled laboratory conditions – the city is the only real laboratory. Jacobs' forensic observational techniques bridge between the humanities and the sciences. While abductive logic is widely used to generate testable hypotheses in science, this is more problematic for walkability. A better understanding of the correlations between various metrics for density, mix and access and actual levels of walking is a key avenue for future research, however, walkability as a capacity cannot be derived from measures of actual walking. The logic linking the urban DMA to actual walking is deductive.

The synergies we are exploring here have been on the urban research agenda for 150 years and we make no claim to have resolved them. While the demand for simple measures of density, mix and access will persist, something distinctly urban is lost when each of these factors is reduced to a simple and partial metric. While the work of Jacobs is not empirical science, it is based in detailed observations of real cities and has largely stood the test of time. Jacobs' observational technique was a form of thick description, with its detailed accounts of everyday urban life steeped in the humanities. While she occasionally used measures where available or useful, her primary currency was words. We suggest that the language of urban thinking also includes the knowledge embodied in diagrams and maps which are central to the discourses of spatial knowledge (Dovey et al., 2018). Diagrams and maps are fundamentally relational rather than reductionist; particular layers of data are selected to reveal general patterns of sociality and spatiality. Like an X-ray, the map opens a window onto the city that represents an empirical reality and opens it up to interpretation. While such mapping may be less useful to those trying to prove cause–effect relations, it may be more useful to designers and planners faced with designing walkable neighbourhoods.

The term 'walkability' was largely invented in the 1960s partly in response to the revolution in urban thought initiated by Jacobs. Google Ngram shows negligible use of the term through the early 20th century, a small boost in the 1960s and then a 20-fold increase since 1990 as problems of obesity and climate change became more apparent. Thus our quest for an understanding of walkability has emerged in part because we have been working backwards from the realisation that walking has positive health and environmental outcomes. We have often been looking at walkability through the lens of the unwalkable car-dependent city. Yet Jacobs, who does not use the term, stumbled upon its key principles because they are also the key principles of intensive urban life. The term 'walkability' has some characteristics of a 'zombie noun', where a verb (walking) or adjective (walkable) is converted to an abstract noun that seems more objective but where the life of the concept we refer to (the walkable city) has been drained (Sword, 2012). While we do not suggest any problem with using what is now a very common concept, the term 'walkability' has been asked to capture an impossibly complex and abstract set of factors and interrelationships. One way to contain this task is to say that walkability is just one aspect of the urban DMA. While the synergies of density, mix and access are also deeply complex, they are at the heart of what makes great cities tick.

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