Citation: Dovey, K. & Pafka, E. (2017) 'What is Functional Mix?',
Planning Theory & Practice, 18 (2): 249–267
doi: 10.1080/14649357.2017.1281996

WHAT IS FUNCTIONAL MIX?
An assemblage approach

Kim Dovey & Elek Pafka
Melbourne School of Design
University of Melbourne

ABSTRACT

Functional or land-use mix has been seminal to urban design and planning for over 50 years - mixed-use reduces the need for travel, increases walkability and generates streetlife intensity. In this paper we review existing methods of measuring functional mix and rethink the ways in which it might be conceived, measured and mapped within a framework of assemblage thinking. We suggest a live/work/visit triangle as a promising method with a focus on the interconnections between functions rather than functions in themselves. Mapping techniques are developed to reveal the ways functional mix changes at different scales from streetscape to walkable neighbourhood. This approach is tested on detailed floor area databases from the cities of New York, Barcelona and Bogotá. Rather than reducing mix to an index, such mapping reveals each city as a mix of different mixes. These maps can be understood as urban x-rays that enable interpretation and diagnosis of urban functional mix.

Keywords: functional mix, land use, urban mapping, assemblage, walkability

INTRODUCTION

Over fifty years ago Jacobs (1961) argued that a mix of functions and the various forms of co-functioning between them was key to understanding how cities work. She noted 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. An effective mix shortens the distances between wherever we are and where we need to be. For Jacobs the value of mix was in a general contribution to the social and economic vitality and intensity of the city. She distinguished between primary functions that attract people to a given neighbourhood and secondary uses that are sustained by the primary uses (Jacobs, 1961, pp. 160-161). Jacobs' work has been increasingly embraced in urban planning, including the new urbanism movement (Grant, 2005). More recently the question of functional mix has become an important focus in the fields of health and transport planning. Functional mix is a key ingredient of walkability and higher levels of walking correlate in turn with lower levels of cardio-vascular and other diseases (Frank et al., 2006; Stevenson et al., 2016). Transport flows are similarly enhanced by functional mix and in this case the benefits accrue at every scale from the walkable neighbourhood to the metropolis (Cervero, 1989). There are thus three main drivers of the demand for a better understanding of urban mix that will apply across different morphologies and scales: urban vitality/productivity, health and transport. A key problem here is that the theory remains fragmented and undeveloped; basic questions about how to define the ingredients of the urban mix and the methods of measurement and mapping remain unresolved. It is the goal of this paper to move this debate a step forward.

The task of categorizing, measuring and mapping functional mix has been plagued by the fact that there are an infinite number of possible functions within the city. There have been numerous ways of defining the mix of uses; some simple ones include living/working/leisure (Le Corbusier, 1957), primary/secondary attractors (Jacobs, 1961) and residential/non-residential (Hoek, 2008). Clearly, the city is a field of differences wherein functions are not found but constructed. Standard categories can include residential, industrial, commercial, retail, education, entertainment, recreation, health, transport, government, community, parking, vacant and hospitality. This is already fourteen categories and each of them could be usefully subdivided, yet no map with more than about seven categories will be easily legible (Miller, 1956). The research literature shows the use of over 100 different categories (Lee and Moudon, 2006). A related problem is whether to include public open space as a function since parks and plazas are significant urban attractions. These problems are relatively easily dealt with in strictly modernist and formal cities where functions largely conform with planning zones. Traditional and informal cities, however, are a very different matter where 'grandfathered' functions (legacies of an earlier mix) and informal adaptations prevail. The more mixed the city is then the more difficult it becomes to measure and map.

There is also the problem of consistency of categorization since the boundaries of many of these categories overlap and one can easily become the subset of another - is a vacant shop a vacancy or a shop; is a stadium sport or entertainment? Functional mix is highly scale dependent and will produce different results at different scales of building, plot, neighbourhood, district and metropolis. While the terms 'land-use mix' and 'functional mix' are largely used synonymously we will use functional mix because 'land-use' embodies the notion that each plot of land has a singular use and privileges the larger over the smaller scale. In the best of cities land parcels often have multiple functions. The term 'functional mix' encompasses this intra-cadastral mix, whether vertical or horizontal and is thus more amenable to a multi-scalar analysis. Then there is the problem of data availability; many studies are based on census and land-use data where functional mix patterns are averaged across large territories (Hess et al., 2001; Song et al, 2013). The increasing availability of cadastral and floor area data changes this and makes new forms of quantification and mapping possible.

The key contributions of this paper are to identify some limitations of existing metrics for functional mix, and to explore a different way of understanding functional mix through mapping. Existing metrics that stem from a desire to link urban design to health and transport outcomes often reduce the mix to a single index; the desire is to establish cause-effect relations between urban design variables (of which mix is only one) to outcomes such as walking. While this is an understandable focus for a science of cities, we argue that a reduction to numbers can entail a disregard for the ways functional mix has particular urban effects geared to grain-size, vertical mix and so on. We also suggest that functional mix categories should not be derived from the very modernist system of separating functions that has largely caused a loss of walkability and transport connectivity in the first place. Residential, industrial, retail, recreation and office are all modernist planning zones that have governed the collection of data that are now available for GIS analysis. We will first critique a range of different metrics for land-use mix. We then develop a particular approach to the mapping of functional mix, based on assemblage thinking, which we will test on the cities of New York, Barcelona and Bogotá. We conclude with a discussion on the epistemology of mapping and argue that maps are the urban design and planning parallel of x-rays, that reveal the inner workings of a city. We argue that mix is inherently multiple and that cities work as a mix of mixes.

MEASURING MIX

There are many approaches to the measurement of functional mix that have emerged over recent decades, often as a part of studies of walkability, transport or urban character (Maghelal and Capp, 2011). While often combined with other measures such as density and connectivity, our focus here is on functional mix and we suggest five general approaches as follows.

Entropy

The most widely used metrics for functional mix are 'entropy' measures first introduced by Cervero (1989) in the field of transport and developed by Frank and others in the field of public health (Frank and Pivo, 1994; Frank et al., 2005; Frank et al., 2006). Entropy is a concept borrowed from physics that measures the degree to which different functions occur equally within a given territory. For Frank, each location generates a score between 0 and 1 as the degree to which floor areas devoted to primary functions are equal within a 1 km 'walkable buffer' ('pedshed' or 'catchment') (Frank et al., 2006). Functions that don't exist in that location or are not considered to contribute to walking (such as industrial) are omitted. In a parallel vein Cervero and Duncan (2006) have measured the entropy scores at scales of an 800 metre walking distance and 5-15 km commuting distance. For all such approaches the number of functional categories and the scale of catchment area are key variables.

Entropy scores produce clear comparisons between neighbourhoods when measured at the same scale but some problems have long been noted. First, entropy is not strictly a measure of functional mix but of the 'balance' between functions that happen to exist (Kockelman, 1997). An equal mix of two functions will deliver the same result as an equal mix of six; paradoxically, adding a small amount of a new function will reduce the mix because it throws them out of balance (Brown et al., 2009). This can be addressed by using a constant number of categories, including categories that have no floor area when calculating entropy (Hajna et al., 2014). A second problem is that entropy treats all functions as equal - as Krizek (2003) points out: "a neighborhood with 10 percent residential and 90 percent commercial would rank the same as if the proportions were reversed" - yet the urban effects are fundamentally different (Hess et al., 2001, p. 18). Finally, there is a problem with the way most entropy measures ignore industrial functions because they are not seen to be walkable destinations. Highly mixed neighbourhoods often emerge within the largely industrial precincts of the inner-city where small-scale industry remains an important ingredient of the mix.

Dissimilarity
While entropy measures have been useful to establish broad connections of mix to walkability, they are relatively blunt metrics. Cervero and Kockelman (1997) also developed a 'dissimilarity index' wherein each hectare of the city is scored according to its degree of functional difference from the eight neighbouring hectares of a 3 x 3 grid. Like the entropy measures this index will deliver a score from 0 to 1 - if half the surrounding hectares have a dissimilar function then the index is 0.5 and if they all do then the score is 1. This is a measure of difference rather than balance, as Hess et al. (2001) point out: "the index is a measure only of whether adjoining squares are different (or not) from the central square and therefore is insensitive to the number of uses that are different from that of the central square". Further, there is the paradox that a consistent fine-grain mix of retail, office and residential within all 9 hectares would produce a score of 0.

Destinations
Destination-based measures are those that seek to deal with the problem that functions are not equal. Mix is conceived as a set of destinations within accessible distance but with different levels of attraction. The range of destinations that correlate with increased walking, if within walkable distance, include schools (McCormack et al., 2008), recreation (Giles-Corti et al., 2003), public transport (Rundle et al., 2007; Brown and Werner, 2009) and food stores (Forsyth et al., 2008). Moudon et al. (2006) develop an index for walkable access to possible destinations that are diagrammed according to threshold distances that can be shown to attract people to walk. Destination-based thinking is of most value in recognizing that functions do not have equal levels of attraction, yet reducing this to a metric is problematic. Retail floorspace attracts far more visitors than office or residential space. A park may attract similar numbers to a small shop but floor area measures are incomparable. Public transit nodes are the most attractive of destinations yet they are not functions per se - they are portals that grant access to the larger scale of the city. In sum destination-based approaches are attractive but deeply complex, and when they are reduced to studies of particular attraction types then they cease to be measures of mix.

Proxies
Proxy measures of functional mix are those that index or map certain properties of the city that are not functions but are geared to the functional mix and can serve as proxies (Brown et al., 2009). For instance the ratio of jobs to the residential population can be read as a proxy. The jobs-housing balance at larger scales has long had currency in urban planning practice yet there is no reason to consider an equal number as an ideal mix. The age of buildings is another proxy measure that derives originally from Jacobs (1961) who noted how the retention of old, obsolete and dilapidated buildings adds diversity to the building stock and therefore to the functional mix. This is linked to another proxy measure of lot-size. Plots or lots are the primary increments of urban change; a small-grain urban fabric ensures incremental change while large lots enable wholesale change. Unless there is strong functional zoning, average plot size is an inverse measure of the capacity for functional mix. Large lots, by contrast, generally reduce diversity of ownership and function. Some studies have shown that the most functionally mixed areas are those with a mix of both lot sizes and building ages (Wood and Dovey, 2015). A primary dimension of Jacobs' definition of mixed use is a mix of primary and ancillary functions which often means a mix of large lots with primary functions and smaller lots housing ancillary functions. While such proxy measures can be useful where better data is unavailable, they are not reliable indicators of functional mix.

Mixed-Use Index

In a study of Amsterdam, Hoek (2008) has developed a Mixed-use Index (MXI) that measures the ratio of residential to non-residential functions by floor area. It compares a series of neighbourhoods with different grain-size, mix and period of development; the MXI ranges from 1 to 100 depending on the percentage of total floor area devoted to residential use. Hoek found that in the historic sections of the city the MXI ranges from 40-60, rising to 70-85 in the areas of nineteenth century expansion and then 90-96 in the modernist areas further out - a very succinct mapping of the impact of modernity on functional mix. Hoek (2008, p.8) argues that "the proportion between residential and non-residential uses should be 50-50 in order to create urbanity" but there is little rationale for this ratio. The most interesting aspect of this approach is that it is linked to the development of a triangular model of functional mix that we have developed below as a basis for our mapping of functional mix.

ASSEMBLAGE THINKING

The existing metrics for functional mix as outlined above are generally devoted to the reduction of mix to an index that can then be correlated with outcomes such as walkability, transport and health. These are worthy goals, but we want to ask a little more about what it is that is being measured here? Our approach is framed by assemblage thinking derived from the philosophy and social theory of Deleuze and Guattari (1987). This is heavily jargon-ridden work and we will rely here on a relatively simple account. An assemblage is a dynamic set of relationships rather than a cluster of things; assemblage thinking in relation to cities involves a quest to understand how urban alliances, synergies and symbioses work. It has been developed as theory by DeLanda (2006, 2016) among others and applied in a burgeoning (often bewildering) variety of ways in geography, urban planning and design (Dovey, 2106; Farias and Bender, 2010; McFarlane, 2011; McGuirk et al., 2016; Müller, 2015; Rankin, 2011; Simone, 2011; Wood, 2009). It has been variously identified with 'relational' (Jacobs 2012), 'material' (Rydin, 2014) and 'non-representational' (Thrift, 2007) thinking. Assemblage is a means of engagement with the world more than a formal theoretical discourse. It is an approach that connects sciences and humanities, objectivity and subjectivity. Assemblage thinking is multi-scalar and multi-disciplinary; connecting geographic and social theory with practices of urban planning and design.

An assemblage defies any reduction to essence, to textual analysis or to materiality. An urban neighbourhood is neither a thing nor a collection of things. While buildings, functions, streets, cars, pedestrians and so on all comprise the neighbourhood, it is the assembled connections between them and to other neighbourhoods that are crucial. An assemblage is dynamic — it is the flows of life, traffic, goods and money that give a neighbourhood its intensity and emergent sense of place identity (Dovet, 2010: ch.2). From an assemblage perspective the city is a dynamic field of differences - relations are primary, the identities of places, neighbourhoods and districts emerge from the mix. Assemblage thinking can be understood as a resuscitation not only of the work of Jacobs but also of Alexander's (1996 [1965]) seminal insight that 'a city is not a tree' which emerges in Deleuze and Guattari in the concept of the 'rhizome'. There is a key distinction between the horizontal rhizomic and networked interconnectivity between parts and the vertical tree-like hierarchies that are used to organize the city. Functional zoning is a tree-like system of categories imposed upon the city; walking is a fundamentally rhizomic practice of finding pathways through urban networks as we explore the urban mix.

To understand why such an approach is suited to the study of functional mix we return to the seminal work of Jacobs (1961) whose argument was focused on the ways in which different activities co-function to form alliances and synergies. In this view the mix of primary and secondary functions is geared to a morphological mix of old and new buildings and then in turn to a socio-economic mix of high and low rents. This 'mix of mixes' is interconnected within Jacobs' theory as a complex set of co-functioning principles that operate in synergy. She accused planners of misunderstanding the city as if it were a simple problem of establishing ratios between two variables such as open space to population or housing to jobs (Jacobs, 1961, p. 447). She also suggested that the then emerging work on complexity theory held potential for a better understanding of the synergistic effects of cities that cannot be reduced to cause-effect relations. This is the work that has evolved into complex adaptive systems, emergence theory and resilience thinking (Gunderson and Holling, 2002; Walker and Salt, 2006) with considerable influence in urban analysis (Portugali, 2000; Batty, 2013). While such work emerges from the sciences it has many parallels with assemblage thinking.

One of the distinctions that Deleuze and Guattari (1987) borrow from physics is that between extensive and intensive properties. Distance, area and volume are all extensive properties while temperature, gravity, density and connectivity are intensities. Intensities are indivisible - if we divide an urban land parcel in half then the (extensive) area is halved yet the (intensive) density remains the same (DeLanda, 2005). The functional mix of a city is an intensive property that is based in relations between differences. This is another way of describing the problem of using entropy as a measure of urban mix - it reduces an intensive property to an extensive quantity.

In calling for complex and non-linear thinking about the city, Jacobs was railing against the tree-like thinking of modernist zoning; and in flagging the importance of mixed-use she was focused on the productive nature of co-functioning relationships. There is a connection here to the influential work of Sennett who has long suggested that random encounter with difference in public space is the key source of urban experience, productivity and identity formation (Sennett, 1970). The concept of functional mix goes to the heart of what makes a city tick; not only what makes it walkable but what makes it work and what makes it urban. The many ways in which 'mixed-use' has been turned into formulae suggests that our thinking often remains stuck in linear and tree-like modes of thought. One key prospect for non-linear thinking appropriate to understanding the city lies in the practice of mapping and diagramming. For Deleuze and Guattari (1987) mapping is defined in opposition to the simple 'tracing' of a territory, rather it is a creative practice that analyses the hidden forces within a territory to produce an abstract and diagrammatic understanding of how an assemblage works. Such an approach was first explored by Corner (1999, p. 214) but remains relatively undeveloped (Dovey and Ristic, 2015). Our goal here is modest - simply to use this framework to rethink the ways in which we map and measure functional mix.

THE LIVE/WORK/VISIT TRIANGLE

A key goal of mapping functional mix is to better understand productive differences between attractions. In order to do this we want to return to the problem of the categorization of functions introduced earlier - if urban functions are an infinitely complex field of differences then what kind of categorization makes sense? Figure 1 (left) shows how the range of most commonly used functions might overlap in a Venn diagram. Most categories incorporate aspects of others and 'community' is a catch-all that can include 'health', 'education', 'recreation', 'sport', 'culture' and 'entertainment'. Such category systems are inherently unstable with new functions and distinctions emerging depending on whether we hope to understand walkability, transport, health, creativity or streetlife rhythms. A key problem with the mapping of functional mix has long been that the greater the mix the harder it is to map - suburbs are easy but intensive cities are complex. What to do about shophouses and mixed-use developments unless we give them additional categories? If there are 5 primary functions then there will potentially be 10 categories of bi-functional mix between them and for any complex city the map will become unreadable. The approach we want to discuss here is adapted from the work of Hoek and the Delft-based research team (Nes et al., 2012; Hoek, 2008). Here urban functions are divided into just three primary categories of housing, work and amenities, organized as a triangle to capture different levels of mix between them.

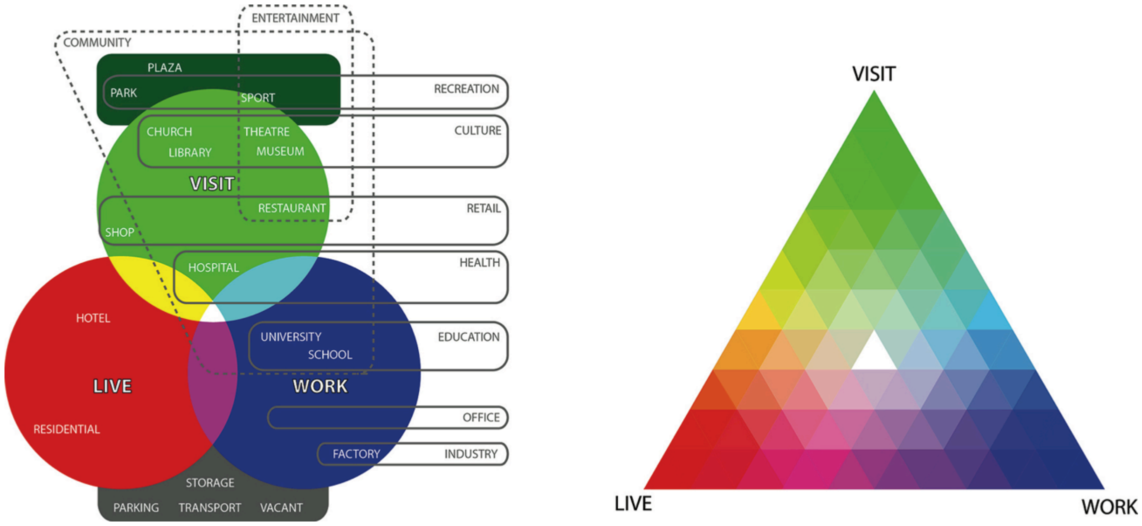

Figure 1: Overlapping functions (left) and the Live/Work/Visit Triangle (right) (adapted from Hoek (2006))

The category of 'amenity' is a catch-all that incorporates everything that is not housing or workplace. The value of this triangular scheme is that it is focused not on primary functions but on the mix and flows between them. If we ask why anyone might be in any given urban location at a given time, then it makes sense to say that they 'live' there, 'work' there or are 'visiting' some kind of facility or amenity. In our view the third category is better labelled 'visit' because 'amenity' is a more generic term that could include housing and work. This mapping index is represented as the live/work/visit triangle (Figure 1 (right)) with three primary colours plus various forms of mix between them, fading towards white for the mix of all three functions.[1] The triangle shows three primary kinds of mix: live/visit (yellow) is mostly linked to lifestyle (where we live, shop, eat and play); live/work (magenta) mix is the commute; work/visit (cyan) is the ways we shop, eat and play in conjunction with work.

The case for constructing visitation as a primary category is twofold. First this framework is geared to the question of why we are attracted to different parts of the city - we live there, work there or are visiting. The places we visit are largely ancillary to, and based on, decisions on where we live and work. Second, we need a robust framework that can contain overlapping categories of 'recreation', 'retail', 'entertainment', 'community' and so on (Figure 1 (left)). The obvious weakness is that this category conflates highly disparate functions from shops to parks and theatres with very different levels of attraction and temporal rhythms. Visitation is always already a multiplicity; the triangulated mapping method disguises this internal mix between visitation functions. There is a case for deeper analysis here but there will be no stopping rule; each sub-category will be multiple and the overlaps between entertainment, health, sport and so on will be impossible to unravel. A further problem with such a typology is that nearly all sites in a dense city can be construed as a mix of all three corners of this triangle - some people work in places of visitation and living, there are visitors to housing and offices places, and some people live in places of visitation and work. Our response here is to assign each function to one of the three categories on the basis that these effects will largely cancel each other out.

THREE CITIES

Effective functional mix mapping requires a database that quantifies floor areas for diverse functions at cadastral scale. Such databases are rarely but increasingly available and publicly accessible (Hoek, 2008; March et al., 2012). For this paper we have mapped three cities with very different histories and morphologies: New York City, Barcelona and Bogotá.[2] Certain data filtering protocols have been necessary. All functional categories other than residential, office, education and industry are combined to create the category of 'visit'. Education has been included with office and industry functions to comprise the 'work' category, on the basis that both students and staff are attracted as a place to work and with similar daily and weekly rhythms. Categories such as vacant and parking have been excluded. While parks and plazas are not part of the floor area databases, they are major attractors. We have coloured them with a darker green to distinguish them from other attractions such as shops and theatres. Transport nodes have been omitted - while they are major attractors they are primarily a means of access to the larger city and not part of the functional mix.

Since floor area is not a good indicator of the level of attraction, the different functions need to be weighted differently. A small store in a residential neighbourhood contributes far more to the mix than an apartment of the same size and its effect will be lost unless the visitation areas are weighted accordingly. While there is little data on this, an early survey in New York (Pushkarev and Zupan, 1975) showed that retail floor area generates 20 times more trips than the same area of residential space; for office space the result was 1.5 times greater than residential. This is a rather vague indicator as interior densities vary a good deal between cities and over time. To ensure that the mix is evident in the maps and after some experimentation we have settled on a 1:2:5 ratio of live/work/visit; in other words the floor area data for workplace and visitation sites is multiplied by 2 and 5 times respectively to determine the colour represented in the maps. The ratio is thus a filter that makes the extent to which different functions contribute to the functional mix legible on the map. Clearly this ratio is crucial and while weighting is not common, other approaches have emphasised visitation by either using multiple categories of visitation (Giles-Corti et al., 2003) or by only considering ground floor functions (Hoek, 2008).

For reasons of both data availability and readable scale we have confined these maps to a 5 x 8 kilometre frame for each of the three cities. At this scale, the three case studies are not entirely comparable because the live/work commute for New York and Bogotá extends well beyond this scale while this is much less so in Barcelona. The percentage of total floor area devoted to each of the three primary functions, differs for each of these three cities. There is a greater percentage of workspace in Manhattan (37%) and central Bogotá (33%) with a much lower proportion in Barcelona (17%). The proportion devoted to living space is conversely much higher in Barcelona (72%) than in Bogotá or Manhattan (both 52%). The proportions of visitation space (excluding public open space) are relatively similar at 11-15%.

We have chosen to study mix with a focus on three scales of analysis. First is what we will call the 'experiential mix' at a scale of a hectare. This is the scale at which we are potentially aware of other functions within our immediate sensory environment - we can see, hear and smell them for better or worse. This is the sensory dimension of the streetscape and of face-to-face encounter (Degen, 2008; Gehl, 2010) and incorporates the vertical and intra-cadastral mix of high-density living. At this scale a functional mix enables an immediate co-functioning; it is also the scale at which functional mix causes problems - when a noisy or pollutant function is mixed with residential - the very problems that modernist planning was partly invented to solve. The primary territory here is the cadastre or plot and any mapping needs to identify multiple functions occurring on the same plot, either vertically or horizontally. Figures 2-4 are cadastral maps that show the experiential mix at streetscape scale; they need to be seen at large scale in order to read sharp distinctions between neighbourhoods and buildings.

Figure 2: Manhattan (cadastral)

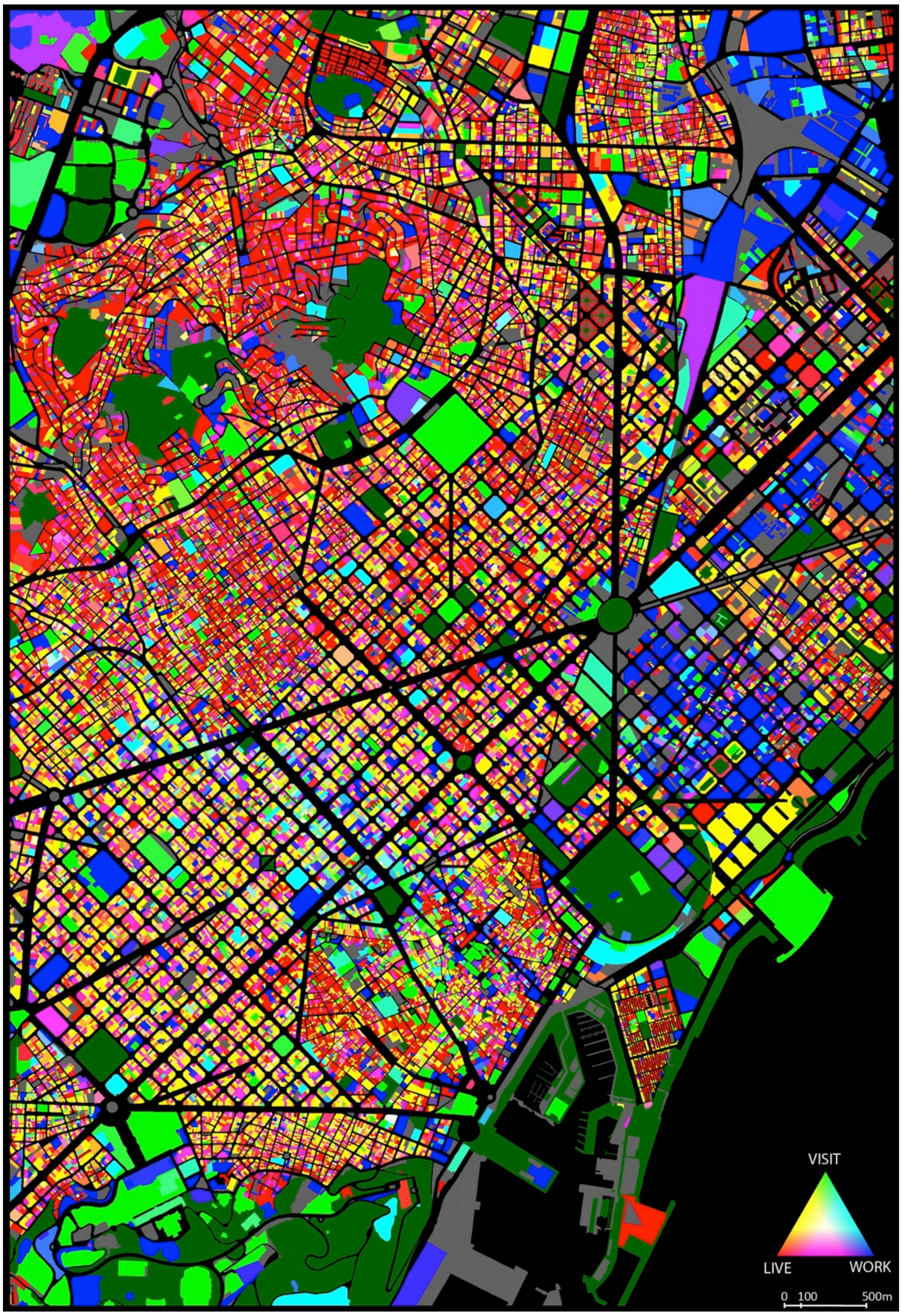

Figure 2: Barcelona (cadastral)

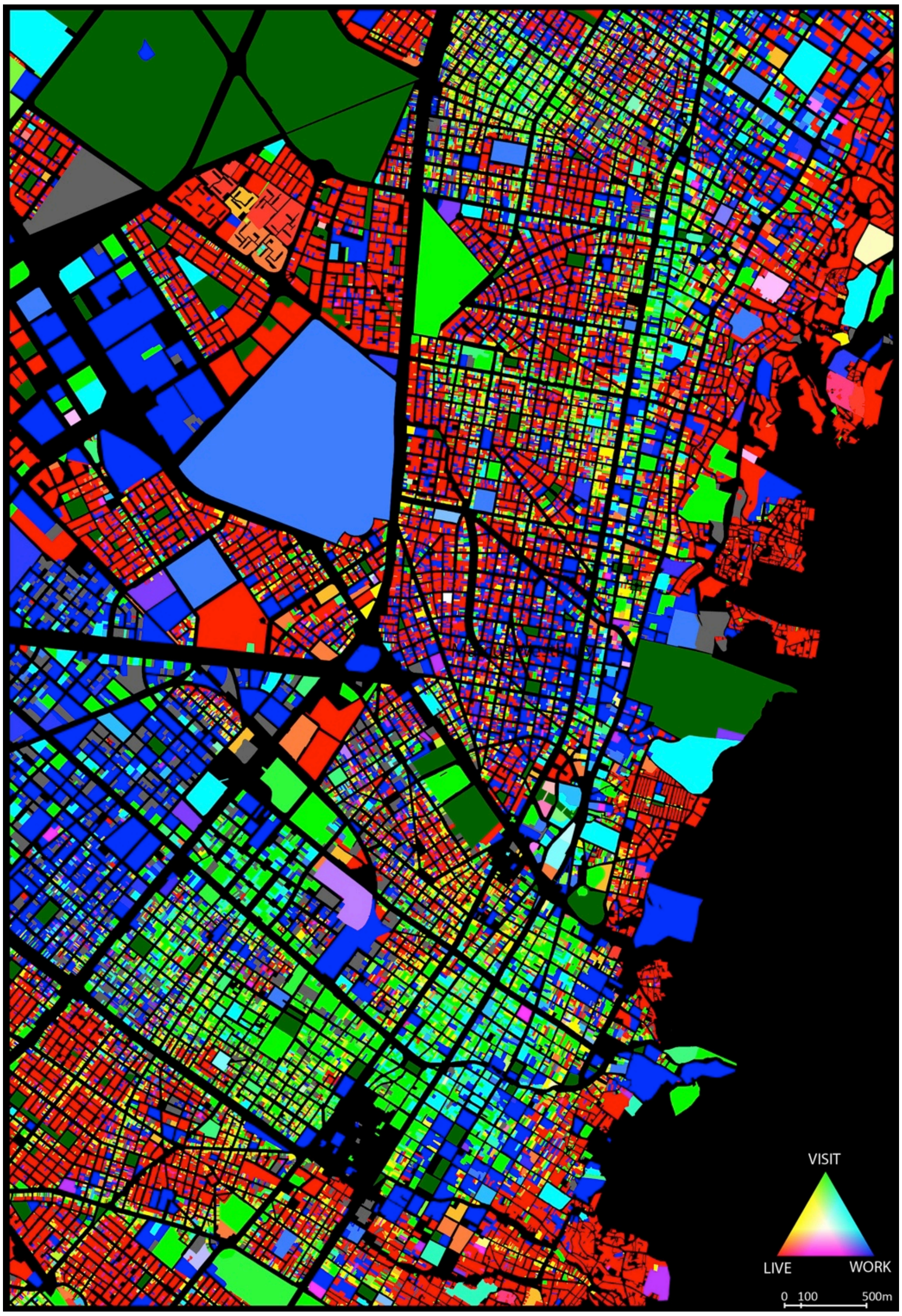

Figure 4: Bogotá (cadastral)

Figure 2 shows a cadastral mapping of Manhattan and parts of Brooklyn. Since the lot-size shows clearly, we can read an inverse correlation between lot-size and functional mix. We can also see the way in which the mix changes from the live/visit mix (orange, yellow) of the Upper East Side, through the work/visit mix (cyan) of mid-town - a loose thread that continues along Broadway to lower Manhattan. What is most apparent is a multiplicity of different kinds of mix. The map for Barcelona (Figure 3) is also very mixed but this is a far more uniform mix with a greater degree of redness since the proportion of residential space is higher. Here we find almost every kind of mix - magenta, yellow and cyan - in most parts of the city. This is particularly the case in the strip from the waterfront to Vila de Gràcia, lining La Rambla and Passeig De Gràcia. Bogotá (Figure 4) shows a similarly rich mix lining the major north-south artery of Carerra 14 from Chapinero in the north to the centre of government and zones of visitation in the south. With a far lower density, Bogotá shows far less intra-cadastral mix (yellow, cyan) than the other cities. Residents from these cities, or scholars who study them, could no doubt add much more depth to such interpretation but that is not our purpose here. The point is to demonstrate that the live-work/visit framework with a floor area database at cadastral scale can give an insight into the functional mix of the city that has not been possible with other frameworks and databases.

The maps in figures 2-4 show the mix for each cadastre and can be used to interpret what we called the 'experiential' mix. Urban mix, however, needs to be understood at multiple scales - beyond the 'experiential' to the 'walkable' and ultimately the mix that is accessible by cycling, cars and public transport (Dovey and Woodcock, 2014). Our approach here is limited to walkable scales. The method is to calculate the mix for each hectare according to the data drawn from a larger hinterland or catchment as diagrammed in Figure 5. In other words the mix for any given hectare is calculated according to the functions that are accessible within a larger spatial catchment. We have done this at two scales - first for a catchment of 500 metres squared (25 hectares) and then for a square kilometre (100 hectares). These calculations have then been applied to data from each of the three cities to produce subsequent maps that show the walkable mix at increasing scales. While walkability is a very elastic concept that encompasses much more than just distance, these scales of 25 and 100 hectares are rough proxies for a 250 metre and 500 metre walk.

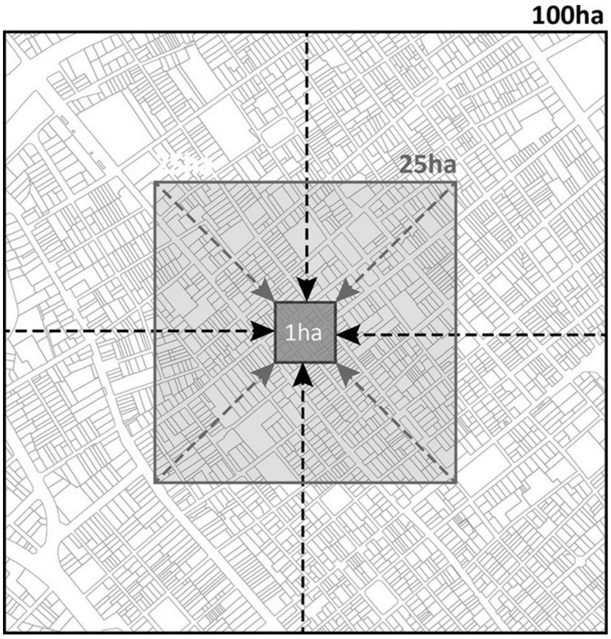

Figure 5: Multi-scale analysis

Figure 6 juxtaposes maps at all three scales from left to right: cadastral maps followed by those based on 25 hectare and then 100 hectare catchments. The increasing levels of lightness emerge because the hinterland or catchment expands to encompass a greater range of functions and the colours approach the more mixed centre of the triangle. A progressive blurring also occurs because as the catchment area increases so the difference in accessible mix between adjacent locations diminishes. The colours shift from the red/blue/green of singular functions on each lot towards the different kinds of mix: work/visit (cyan), work/live (magenta) and live/visit (yellow). Only those neighbourhoods that are monofunctional across the entire 100 hectare catchment will remain deep red, blue or green through all three maps. The degree of lightness represents the intensity of mixing and the shade of colour represents the type of mix, thus the map represents both the quantity and quality of the mix. While whiteness is a rough measure of an equal mix (after weighting), we should resist reading whiteness as a simple measure of the best mix. The map of Manhattan produced from the 100 hectare catchment shows whiteness around Washington Square and Lincoln Square but the patchwork of light mixes extends from live/visit (light yellow) of Greenwich Village, and the Lower East Side to the work/visit (light cyan) of Midtown and Soho to the work/live (light magenta) of Chelsea. This 'mix of mixes' adds another layer of complexity to any quest for an ideal or maximum mix. In Barcelona the deep colours of monofunctional areas have completely disappeared; while it has white, cyan and magenta patches it is also a more uniform city - much less a mix of mixes. Bogotá is more difficult for us to read, again a patchwork of every kind of mix where monofunctional areas disappear at the 100 hectare scale.

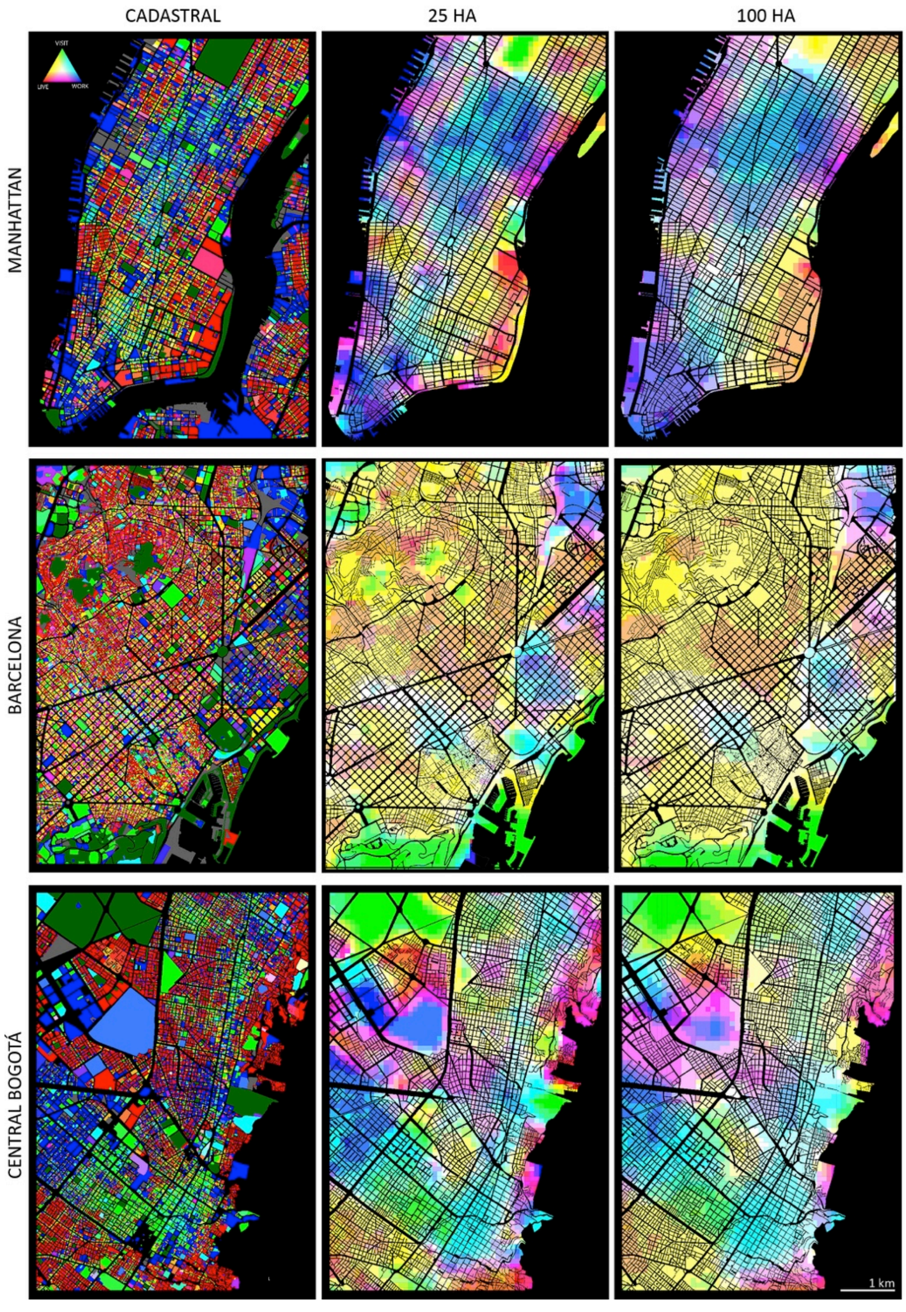

Figure 6: From Cadastre to Walkable Catchment

Our final analysis here is to produce ternary graphs of the data from these three cities to understand how their many neighbourhoods are distributed across the live/work/visit triangle. The data from the third set of maps in figure 6 has been used to generate a diagram of the mix of mixes for each city. Figure 7 is produced by marking a translucent dot for each hectare according to its mix based on the 100 hectare catchment - thus a superimposition of dots produces increasing blackness. Here some important differences between these three cities become more apparent in the diagrams. Manhattan is primarily aligned along an axis from work to the live/visit mix - the corners of the triangle are relatively vacant. For

Barcelona both the high degree and uniformity of the mix shows in the heavily clustered live/visit mix - note the absence of either residential neighbourhoods or exclusive work zones. The neighbourhoods of Central Bogotá are distributed across almost the entire triangle, showing a far greater range of mixes but also many relatively unmixed areas in the corners of the diagram.

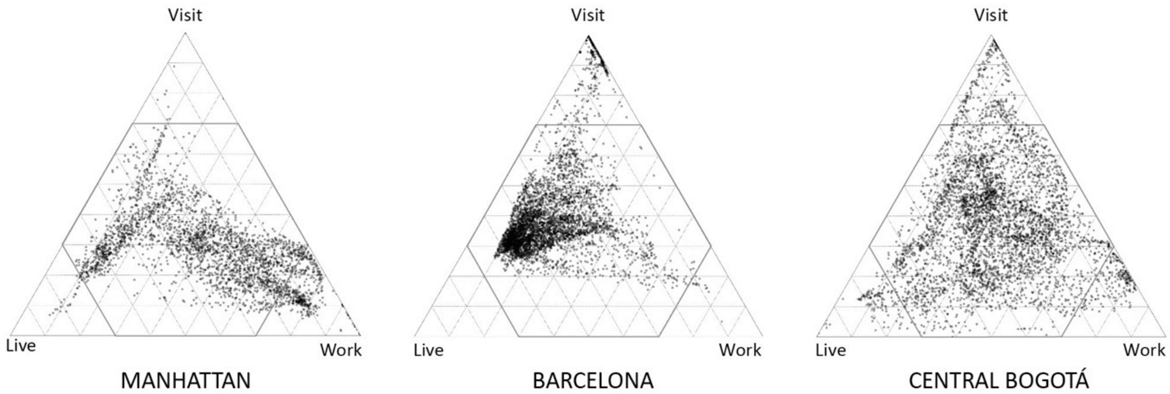

Figure 7: Ternary graphs showing aggregated mix of each hectare using a 100 hectare catchment

DISCUSSION

The study of functional mix has long been, and will remain, a key issue for understanding how cities work. Mix has become a 'holy grail' of urban planning and design research in the sense that we know that functional mix matters fundamentally to how cities work in terms of walkability, health, transport and urban vitality but key questions remain tantalizingly difficult - a mix of what functions and in what proportions? Our goal in this paper has been to move such research a step forward. We will conclude with some key points of discussion that we hope might open some debate in this regard - on the assemblage approach and the live/work/visit triangle, on the role of maps and diagrams, and on the limits to this study.

The triangulation of live/work/visit functions we have developed here is not a better method of reducing functional mix to an index. Rather, the triangle constructs a field of possible relations between three primary functions. At one level these are the relations between production, exchange and reproduction. They also identify primary relations between people and the city - we become 'residents', 'workers' and 'visitors' respectively in different locations in everyday life. While any division of functions will remain somewhat arbitrary the key shift here lies in a focus on the mix rather than the functions in themselves. As Figure 6 shows, such mapping of the city at walkable scale is essentially a mapping of different kinds of mix rather than particular functions. While it might be tempting to give every location a score in accord with its closeness to the centre of the triangle (the degree of whiteness), this would be to ignore differences between various kinds of mixes and the fact that mix changes with the scale of the catchment area (Figure 6). We suggest that the mapping of functional mix using the live/work/visit triangle offers an empirical basis for a better understanding of mix; it enables us to expose different kinds and levels of mix in a non-linear manner.

While studies of functional mix can be usefully harnessed to instrumental research on walkable and low-carbon cities, this is not our intent here. Rather it is to open up the concept of mix 'in itself'. Our approach is non-reductionist; we seek to understand the multiplicity and complexity of mix rather than extract cause-effect relations; to reveal differences that more instrumental research does not. For instance the same database that we used for Bogotá was used by Cervero et al. (2009) who concluded that mix could be disregarded as a factor for walkability because it was relatively uniform throughout the city; yet our mapping shows a diversity of different kinds of mix.

Another key point is about the role of maps and diagrams. These are forms of spatial knowledge that embody an empirical understanding of the city as much as words or numbers do (Dovey and Pafka, 2015). Maps work in a manner that parallels the use of the x-ray in medicine or security screening. The x-ray is a technology that represents selected layers of data to produce an image from which we can read the ways in which something is working or to identify problems. Like urban maps, x-rays are empirical evidence, but what they are evidence of is not self-evident and experienced interpretation is required. There are guidelines for the interpretation of x-rays but if this were a technical task then it would have been mechanized. Good maps are like x-rays of the city; they have an empirical base but cannot be easily reduced to numbers and need interpretation to reveal how the city works. Just as x-rays are cross-sections of a body of evidence, so maps are cross-sections of the city. The metaphor of the x-ray is not a new idea for urban planning (Fooks, 1946) but it is one whose time has come due to the capacities opened by GIS technologies, cadastral databases and new theoretical frameworks.

In figure 7 we convert the data from the maps into triangular diagrams (or ternary graphs) that show the mix for each neighbourhood throughout each city at walkable scale. While there is no ideal mix, we have inscribed a hexagon within the triangle to indicate where the most effective urban mixes will fall. The task for urban design and planning is not so much to lighten the map as to identify the range of mixes as well as any dysfunctional districts in the corners of the triangle.

There are important limits to the kinds of mapping we are experimenting with here and some indications for future research. First, the 1:2:5 ratio that we have used as a multiplier for live/work/visit floor areas is somewhat arbitrary. This ratio is loosely geared to typical levels of attraction but also to the imperative of revealing the functional mix on the maps - if a shop, library or theatre has the same weight per floor area as housing then its impact on urban flows will not be visible. Our use of the multiplier is a loose correlate for tuning an x-ray machine in order to render particular distinctions visible. The question of how different functions produce different volumes and rhythms of visitation is an important one for future research.

A second key limitation is that any measure or map of functional mix is but one dimension of the city. For instance twenty restaurants within a square kilometre of residential Manhattan may register the same mix as a single restaurant in a low-density suburb - the difference is density. Likewise, some neighbourhoods have better pedestrian access networks and larger pedestrian catchment zones. Functional mix is but one part of a synergy between density, mix and access that we have elsewhere termed the 'urban DMA' (Dovey, 2014, 2016).

Thirdly, there are some serious limits to the reliability of data that is collected by formal census. Informal functions that transgress formal codes will always remain relatively hidden to the state. Many people work at home while some live in the studio or sleep in the park; informal street trading in Bogotá comprises a major part of the retail sector. A census can only capture a frozen moment in the life of a city that will always be a changing mix of formal and informal functions that no database can capture fully.

The imperative to better understand the ways that cities work in terms of walkability, transport, health and economic vitality ensures that a better understanding of functional mix at neighbourhood scale will remain on the urban research agenda. While the demand for a simple metric for mix will persist, something distinctly urban is lost when mix is reduced to a number. While the modes of mapping we have developed here may be less useful to those trying to prove cause-effect relations, we suggests that they may be more useful to designers and planners faced with diagnosing and transforming the ways cities work. We have tried to show that while functional mix is deeply complex, it goes to the heart of what makes a city tick - great cities are cities of difference and we need better means of understanding how such differences work together.

Notes

1. In exploring these maps we have experimented with different colours in the apexes. It is attractive to use yellow, blue and red for each apex with green, orange and purple as the mixed colours and these colours have been used in previous publications both by ourselves and the initiators of the scheme (Dovey and Ristic, 2015; Nes et al., 2012; Hoek, 2008). However, given the need to use GIS tools for data management we have opted to correlate the triangle with the RGB (Red/Green/Blue) colour wheel that dominates most digital representation schemes. Those who grew up mixing pigments must learn to read yellow as a mix of red/green, magenta as red/blue and cyan as blue/green.

2. There are very few cities that currently make comprehensive cadastral data available in a comparable format. Our data sources for New York City derive from the Department of City Planning (New York City, 2015); for Barcelona we have used a conversion of Spanish cadastre data (Valls Dalmau et al., 2014) and for Bogotá there is an online cadastral database (IDECA, 2015). Some cleaning and correcting of data has been necessary, we have assigned hospitals, theatres and cultural facilities to 'visit'. An inconsistency among the three datasets relates to storage and car parking space: such space could not be disaggregated for New York and had to be included, while in Bogotá this was a stand-alone category that could not be allocated. While such space is a significant portion of floor area (ca. 10-15%), it is distributed across all functions so the effects will largely cancel out.

Acknowledgements

We thank Stephen Wood and Mirjana Ristic for their reviews of an earlier version of this paper. This work stems in part from Australian Research Council project LP100200590: Intensifying Places: Transit-Oriented Urban Design for Resilient Australian Cities.

References

Alexander, C. (1996 [1965])). A City is Not a Tree. In R. LeGates and F. Stout (Eds.), The City Reader, London: Routledge, 118–131.
Batty, M. (2013). The New Science of Cities. Cambridge, MA: MIT Press.
Brown, B. & Werner, C. (2009). Before and After the Light Rail Stop. Journal of the American Planning Association, 75(1), 5-12.
Brown, B., Yamada, I., Smith, K., Zick, C., Kowaleski-Jones, L. & Fan, J. (2009). Mixed land use and walkability. Health & Place, 15(4), 1130-1141.
Cervero, R. (1989). America's Suburban Centres: The land use-transportation link. Boston: Unwin Hyman.
Cervero, R. & Duncan, M. (2006). Which Reduces Vehicle Travel More: Jobs-Housing Balance or Retail-Housing Mixing?. Journal of the American Planning Association, 72(4), 475-490.
Cervero, R. & Kockelman, K. (1997). Travel Demand and the 3Ds: Density, Diversity, and Design. Transportation Research Part D, 2(3), 199-219.
Cervero, R., Sarmiento, O., Jacoby, E., Gomez, L. and Neiman, A. (2009). Influences of Built Environments on Walking and Cycling: Lessons from Bogota. International Journal of Sustainable Transportation, 3(4), 203-226.
Corner, J. (1999). The Agency of Mapping. In Cosgrove, D. (Ed.), Mappings (pp. 213-252), London: Reaktion.
Degen, M. (2008). Sensing Cities. London: Routledge.
DeLanda, M. (2005). Space: Extensive and Intensive, Actual and Virtual. In Buchanan, I. and Lambert, G. (Eds.), Deleuze and Space (pp. 80-88). Edinburgh: Edinburgh U.P.
DeLanda, M. (2006). A New Philosophy of Society. London: Continuum.
DeLanda, M. (2016). Assemblage Theory. Edinburgh: Edinburgh U.P.
Deleuze, G. (1968). Difference and Repetition. New York: Columbia U.P.
Deleuze, G. & Guattari, F. (1987). A Thousand Plateaus. Minneapolis, MN: University of Minnesota Press.
Dovey, K. (2010). Becoming Places. London: Routledge.
Dovey, K. (2016). Urban Design Thinking. London: Bloomsbury.
Dovey, K. & Pafka, E. (2016) 'The Science of Urban Design?' Urban Design International, 21 (1) 1-10. doi:10.1057/udi.2015.28
Dovey, K. & Ristic, M. (2015). Mapping Urban Assemblages. Journal of Urbanism Advance online publication: doi:10.1080/17549175.2015.1112298
Dovey, K. & Woodcock, I. (2014) Intensifying Melbourne (Research Report), Melbourne: Melbourne School of Design. Retrieved 7 December 2016 from: www.msd.unimelb.edu.au/sites/default/files/docs/Intensifying%20Melbourne%202014_180dpi.pdf
Farias, I. & Bender, T. (Eds.). (2010). Urban Assemblages. London: Routledge.
Fooks, E. (1946). X-ray the city!. Canberra: Ministry of Post-War Reconstruction.
Forsyth, A. (2015). What is a walkable place?. Urban Design International, 20(4), 274-292.

Forsyth, A., Hearst, M., Oakes, J. & Schmitz, K. (2008). Design and destinations: factors influencing walking and total physical activity. Urban Studies, 45, 1973-1996.
Frank, L. & Pivo, G. (1994). Impacts of Mixed Use and Density on Utilization of Three Modes of Travel. Transportaion Research Record, 1466, 44-54.
Frank, L., Sallis, J. , Conway, T., Chapman, J., Saelens, B. & Bachman, W. (2006). Many Pathways from Land Use to Health. Journal of the American Planning Association, 72(1), 75-87.
Frank, L., Schmid, T., Sallis, J., Chapman, J. & Saelens, B. (2005). Linking Objectively Measured Physical Activity with Objectively Measured Urban Form. American Journal of Preventive Medicine, 28(2), 117-125.
Gehl, J. (2010). Cities for People. Washington, DC: Island Press.
Giles-Corti, B., Macintyre, S., Clarkson, J., Pikora, T. & Donovan, R. (2003). Environmental and lifestyle factors associated with overweight and obesity in Perth, Australia. American Journal of Health Promotion, 18(1), 93-102.
Grant, J. (2005). Mixed use in theory and practice: Canadian experience with implementing a planning principle. In Stiftel, B. and Watson, V. (Eds.), Dialogues in Urban and Regional Planning 1 (pp. 15-36). London: Routledge.

Gunderson, L. & Holling, C. (2002). Panarchy: understanding transformations in human and natural systems. Washington, DC: Island Press.
Hajna, S., Dasgupta, K., Joseph, L. & Ross, N. (2014). A call for caution and transparency in the calculation of land use mix. Health & Place, 29, 79-83.
Hess, P., Moudon, A. V. & Logsdon, M. (2001). Measuring Land Use Patterns for Transportation Research. Transportation Research Record, 2512, 17-24.
Hoek, J. v. d. (2008). The MXI (Mixed-use Index) as Tool for Urban Planning and Analysis. Corporations and Cities, Delft University of Technology, 1-15.
IDECA (2015). Mapa de Referencia de Bogotá [Dataset]. Retrieved 8 October 2015 from http://www.ideca.gov.co/index.php?q=es/content/cat%C3%A1logo-de-datos-geogr%C3%A1ficos
Jacobs, J. (1961). The Death and Life of Great American Cities. New York: Random House.
Jacobs, J.M. (2012) Urban Geographies I: Still Thinking Cities Relationally. Progress in Human Geography, 36(3) 412–422.
Kockelman, K. (1997). Travel Behaviour as Function of Accessibility, Land Use Mixing, and Land Use Balance. Transportaion Research Record, 1607(1), 116-125.
Krizek, K. (2003). Operationalizing Neighborhood Accessibility for Land Use–Travel Behavior Research and Regional Modeling. Journal of Planning Education and Research, 22(3), 270-287.
Le Corbusier (1957). La Charte d'Athènes. Paris: Éditions de Minuit.
Lee, C. & Moudon, A. V. (2006). The 3Ds+R: Quantifying land use and urban form correlates of walking. Transportation Research Part D, 11(3), 204-215.
Lo, R. (2009). Walkability: what is it?. Journal of Urbanism, 2 (2), 145-166.
Maghelal, P. & Capp, C. (2011). Walkability: A Review of Existing Pedestrian Indices. URISA Journal, 23(2), 5-19.
March, A., Rijal, Y., Wilkinson, S. & Firidin, Ö. (2012). Measuring Building Adaptability and Street Vitality. Planning Practice & Research, 27(5), 531-552.
McCormack, G., Giles-Corti, B. & Bulsara, M. (2008). The relationship between destination proximity, destination mix and physical activity behaviors. Preventive Medicine, 46(1), 327-332.
McFarlane, C. (2011). Learning the City. Oxford: Wiley-Blackwell.
McGuirk, J., Mee, K. & Ruming, K. (2016). Assembling Urban Regeneration? Geography Compass, 10 (3), 128-141.
Miller, G. A. (1956). The Magical Number Seven, Plus or Minus Two. Psychological Review, 63(2), 81-97.
Moudon, A. V., Lee, C., Cheadle, A., Garvin, C., Johnson, D., Schmid, T., Weathers, R. & Lin, L. (2006) Operational Definitions of Walkable Neighbourhood. Journal of Physical Activity and Health, 3(S1), S99-S117.
Müller, M. (2016). Assemblages and Actor-networks. Geography Compass, 9 (1), 27-41.
Nes, A., Berghauser Pont, M. & Mashhoodi, B. (2012). Combination of Space Syntax with Spacematrix and the Mixed Use Index, in 8th International Space Syntax Symposium, Santiago de Chile.
New York City, Department of City Planning (2015). PLUTO [Dataset]. Retrieved 22 June 2015 from http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml#pluto

Portugali, J. (2000). Self-Organization and the City. Berlin: Springer.

Pushkarev, B. & Zupan, J. M. (1975). Urban Space for Pedestrians. Cambridge, MA: MIT Press.
Rankin, K. (2011). Assemblage and the Politics of Thick Description. City, 15(5), 563-569.
Rundle, A., Diez Roux, A., Freeman, L., Miller, D., Neckerman, K. & Weiss, C. (2007). The urban built environment and obesity in New York City. American Journal of Health Promotion, 21(4), 326-334.
Rydin, Y. (2014). The Challenges of the “Material Turn” for Planning Studies. Planning Theory and Practice, 15 (4), 590–595.
Sennett, R. (1970). The uses of disorder: personal identity & city life. New York, NY: Knopf.
Simone, A. (2011). The Surfacing of Urban Life. City 15 (3–4): 355–364.
Song, Y., Marlin, L. & Rodriguez, D. (2013). Comparing Measures of Land Use Mix. Computers, Environment and Urban Systems, 42, 1-13.
Stevenson, M., Thompson, J., Hérick de Sá, T., Ewing, R., Mohan, D., McClure, R., Roberts, I., Tiwari, G., Giles-Corti, B., Sun, X., Wallace, M. & Woodcock, J. (2016). Land Use, Transport, and Population Health. The Lancet, Advance online publication, doi.org/10.1016/S0140-6736(16)30067-8
Thrift, N. (Ed.). (2007). Non-Representational Theory. London: Routledge.
Valls Dalmau, F., Garcia-Almirall, P., Rendondo Dominguez, E. & Escudero Fonseca, D. (2014). From Raw Data to Meaningful Information. Future Internet, 6(4), 612-639.
Walker, B. & Salt, D. (2006). Resilience thinking: sustaining ecosystems and people in a changing world. Washington, DC: Island Press.
Wood, S. (2009). Desiring Docklands: Deleuze and Urban Planning Discourse. Planning Theory, 8 (2), 191-216.
Wood, S. & Dovey, K. (2015) Creative Multiplicities: Urban Morphologies of Creative Clustering. Journal of Urban Design, 20(1), 52-74.
Ye, Y. & Nes, A. v. (2013). Measuring urban maturation processes in Dutch and Chinese new towns. The Journal of Space Syntax, 4(1), 18-37.