Land use patterns and access in Mexico City

ACSP-AESOP Fourth Joint Congress, Chicago, Illinois
July 6-11, 2008

Track 8: Methods for Spatial and Planning Analysis

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Abstract

The problem of distribution of land uses in urban space in Latin American cities has been examined under different perspectives. Most authors tend to model patterns of population and land use as a consequence of social and economic processes alone, failing to address urban space as an intrinsic variable. Instead, the theory of cities as movement economies argues that land use patterns are influenced by movement flows, which are in turn strongly affected by the urban grid. As a result, land uses such as retail would seek highly accessible locations to take advantage of such flows while residential uses would avoid them. However, space syntax techniques traditionally used to point out this relationship do not seem to reveal it so easily in non-organic cities like Mexico. This paper addresses the relationship between patterns of accessibility and land use in the first ring of Mexico City as a spatial strategy. A new functional description of the city where plots are nodes connected to flows that represent the street network is adopted. This model enables us to measure accessibility at the level of plots. Following this, we focus on the occurrence of land use types in highly or low accessible locations using cumulative distribution functions. If the distribution of land uses was random, the proportion of land use types would be more or less uniform throughout the area. It is shown that the relationship between accessibility and land use is not linear and is guided by movement economy forces. It is suggested that the understanding of these relationship is key to plan for sustainable growth objectively.

1. Introduction

The problem of urban land use distribution in Latin American cities has been examined by a number of authors in the field of urban geography who have addressed it with ecological zoning models (Griffin & Ford, 1980; Ward, 1990; Crowley, 1995; Ford, 1996) **(FIGURE 1)**. These offer a comprehensive overview of the way a city is organised. However, they tend to model patterns of population and land use merely as a consequence of economic processes ignoring socio-cultural values (Pacione, 2005). Another problem is that they reflect a specific moment whereas in reality the processes they deal with are dynamic. One reason for this might be that they fail to address urban space as an intrinsic and constantly-changing variable that can influence land use patterns.

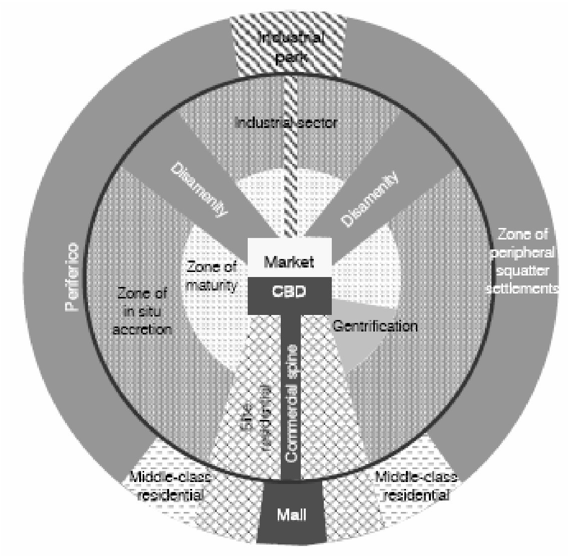


FIGURE 1. A model of Latin American city structure by Ford (1996), modified from Griffin and Ford (1980).

Anas et al (1997) suggest that agglomeration economies generate centripetal forces in cities that cause people to cluster to facilitate interaction with consequent economic and social benefits. These are balanced by centrifugal forces that limit the extent of clustering by limited space supply, congestion or other disamenities. The balance between these forces then determines a certain pattern selection (Krugman, 1996) in the spatial structure so that proximity facilitates specific transactions.

Hillier et al (1993; 1996a) propose that urban layout --space syntax-- strongly influences movement so it has the potential to determine the *location* of clusters of specific activity. Movement-dependent uses, like retail, tend to cluster in the most accessible locations which consequently have higher levels of movement, thus creating 'live centres'. Residential uses seek less accessible, quieter locations (Hillier, 1999). On the latest of these studies the shops formed distinct concentrations of the kind associated with London's urban villages which could be easily correlated with the spatial variables of their location **(FIGURE 2)**. In some cities, like Mexico, shops appear dispersed almost everywhere and where concentrated they occupy large areas of the urban grid. Therefore, to explore the land use/space relationship becomes more complex than it may seem. **(FIGURE 3)**

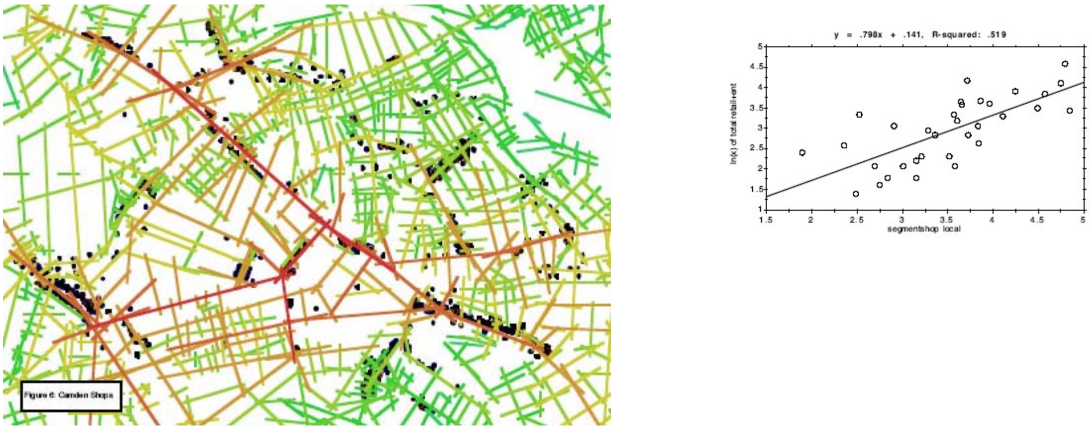


FIGURE 2. Location of shops on axial map of Camden and scattergram correlating local integration and scale of shopping segments from the work of Maria Gebauer-Muñoz (Hillier, 1999).

FIGURE 3. Location of shops on axial map of Mexico City.

Mexico City developed over the geometry and organisation imposed by the *ordenazas* of Philip II of Spain in 1576, a series of regulations that determined how the territories of the Spanish overseas Empire should be organised. Among other things, these regulations clearly stated the way in which the new settlements were to be laid out: a main *plaza* in the centre from which perpendicular roads would begin, smaller *plazas* scattered at short distances from the centre and 'zoning' areas starting from the main *plaza* --the main church as well as the authorities' administrative buildings should be located on the plots next to the main *plaza*, shops and businesses, on plots next to these, etc. (Garcia-Ramos, 1983) These, together with wide roads --*calzadas*-- that were built over existing water canals, as well as later interventions like destruction of nuclei of convents and monasteries and opening of new streets in 1859-1860 with the Laws of Reform, guided later development of Mexico City's urban grid. Another fundamental change in the city's geometry was the construction of *Paseo de la Reforma*[1] in 1864, an important avenue running north-west, cutting diagonally the orthogonal layout. (Luiselli, 2003) **(FIGURE 4)**

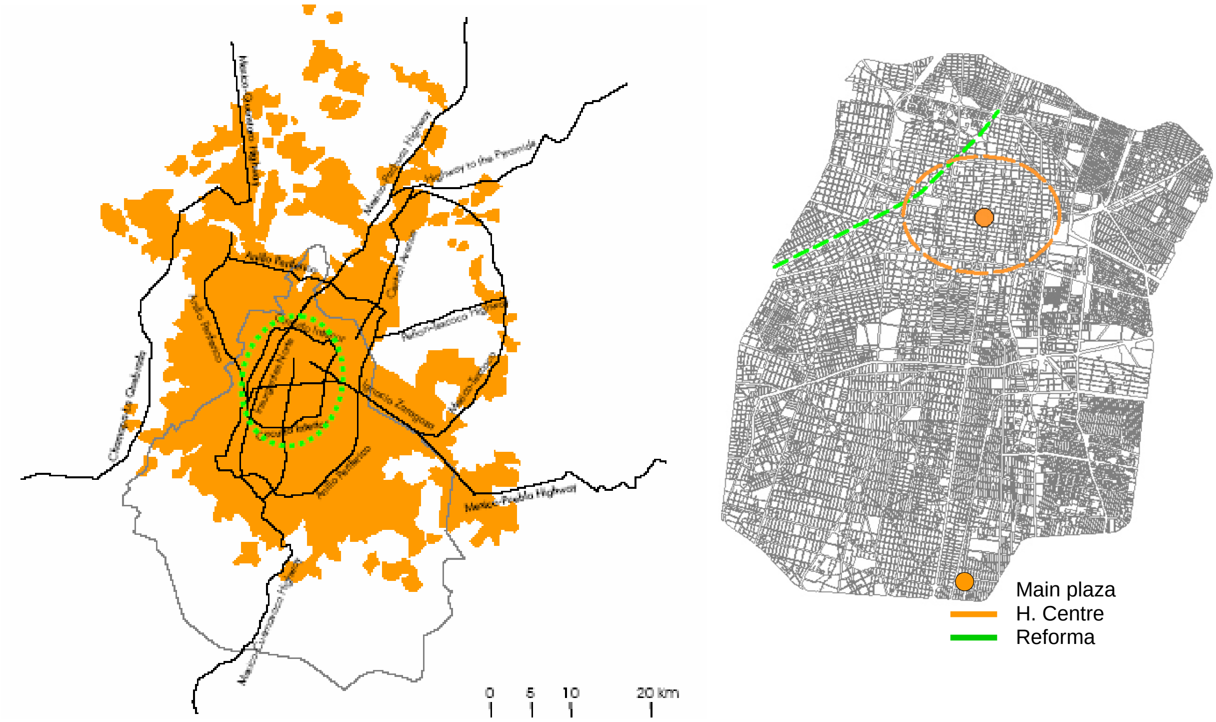


FIGURE 4. Mexico City's urban sprawl and main roads, first ring in green circle (left); and detail of the grid in the first ring of the city (right).

Unplanned, uncontrolled growth started slowly with centralisation policies in the Porfirian era (1876-1910) and boomed with economic growth from the 40s to the 70s (Luiselli, 2003). During this period and after, many new neighbourhoods -- for all social strata and both, legal and illegal-- were developed, usually by aligning new grids to the nearest main road. One of these roads was *Paseo de la Reforma* next to which well-off areas were aligned and built. The inner geometry of the added grids would vary in terms of size, compactness, density, etc. Non grid-like patches added included those reflecting specific 'design' ideologies, squatter settlements that developed over a long period of time thus showing a more organic inner pattern (Cymet, 1992), and old indigenous *pueblos* that were absorbed by the sprawl. Yet, non-grid areas are not frequent in the first ring of the city; offset grids are the predominant morphology

This paper presents part of ongoing doctoral research. It proposes a methodology, combining space syntax with cumulative frequency distribution, to explore the relation between spatial accessibility and land use in Mexico City at the micro-level of plots. The use of space syntax provides a relatively straightforward way to deal quantitatively with the forces that shape land use distribution --i.e. accessibility, therefore, movement and potential interaction. Cumulative distributions allow to look at this patterns at a very fine scale without having to group the data in bins that, on the one hand are arbitrary and, on the other, might lose any information contained in individual values. The result is a detailed picture of how global and local access influence the location of certain land uses, namely retail, offices and housing.

The aim of the study is to contribute to the understanding of the spatial structure of Mexico City and other Latin American cities with similar layouts and background. We believe that understanding of urban space and its relationship with land use has key implications in planning with positive consequences like microeconomic development, sustainable growth and, in general, more inclusive institutions.

2. Cities as movement economies

The ideas of space syntax (Hillier & Hanson, 1984) explain the dynamics of social processes that happen in space through the understanding of urban structure. Hillier et al (1993) propose the idea of 'natural movement' defined as *'the proportion of urban pedestrian movement determined by the configuration of the grid itself'* (p.32). He then suggests that the 'living city' –the city, comprising areas with more and areas with less movement-- is determined by this space-to-function process which influences land-use distribution, allowing certain functions like retail in the areas with the most natural movement, and others like housing where the natural movement is low. This, he says, is the 'movement economy' process (Hillier, 1996a).

Such distribution then leads to the process of centrality (Hillier, 2001): movement-dependent uses attract even more movement to those areas with already high rates of movement that introduce new changes in the land-use patterns, creating an ever-changing process of multiplier effects where configuration generates attraction. Globally, 'live centres', or concentrations of this kind of activity associated with the 'hearts' of centres and sub centres --usually mixed uses with retail predominance--, are to be found in highly accessible locations from the settlement as a whole. Locally, they will tend to maximise accessibility within the live centre with conditions like grid intensification --smaller block size.

Urban space potential to attract movement is quantified through its accessibility. A model is used to analyse the connections and relations between its components as the nodes of a graph. A widely used representation for this kind of analysis is the *axial map* of an open space structure, defined as the least set of straight lines which pass through each bi-dimensional space and make all the links possible in a system (Hillier & Hanson, 1984, p. 91-92). In an axial model, each axis of movement represents a node while each relation or connection between axes/spaces represents a link **(FIGURE 5)**. Two types of accessibility can be calculated: integration and route choice. *Integration*, equivalent to 'shortest path closeness' in network analysis, refers to the shortest topological or relational distance from a node *to* all others.[2] R*oute choice*, or 'shortest path betweenness', indicates the nodes that are at the shortest topological distance *between* other nodes.[3] Both can be calculated globally --in relation to all the nodes in the system-- or locally --considering only those nodes up to a certain number of connections or *radius*.

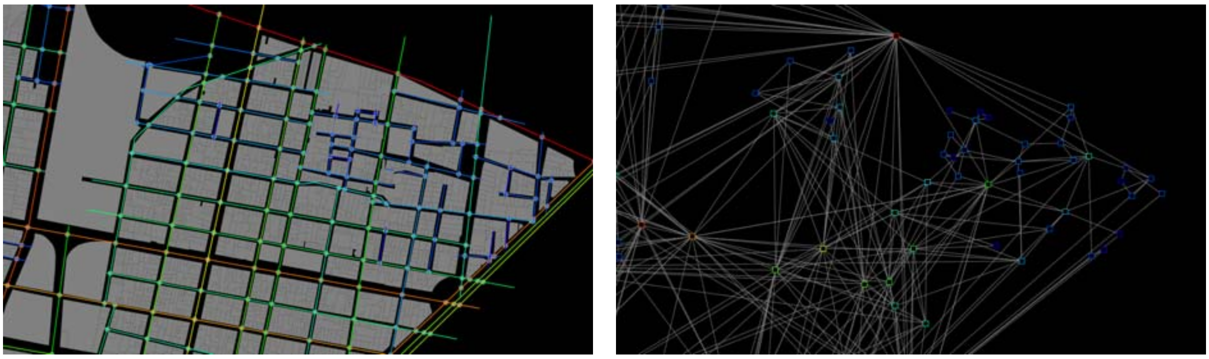


FIGURE 5. Axial map and its transformation to graph (Figueiredo, 2004): each axis represents a node while each relation or connection between axes represents a link.

3. Plot accessibility

To explore the nature of the space-function relation in Mexico City, the area encircled by the first ring road, *Circuito Interior*, was defined as study area. It covers a rough 12 by 9 km. It was chosen as it is the smallest area that could be defined by a 'natural boundary', that is, an element --normally a river, railway or motorway-- that physically divides the system. An arbitrary limit could bias the accessibility model by increasing the 'edge effect'[4]. The area was modelled as an axial map and it comprised 4773 axes. The 2000 cadastre[5] in CAD format was transformed into a GIS environment generating a dataset of 159,608 plots with their land-use classifications. From these, the location of big and small retail, and housing was of particular interest, although the location of office uses was also explored.

Next, an interface between the street network representation --axial map-- and the land-use data --in this case, plots-- was needed. Usually, a *rate*, some value such as number of shops or of any particular use per axial line or street segment, is calculated to compare with different spatial conditions. The problem with rate is that, even with all other conditions being equal, the longer the line or the higher the number of plots on a street segment, the higher the opportunity of that event, for example shop, to occur. If we try to normalise, say by dividing by line length, the problem will remain, only now it will be inverted: a random shop in a short street will be assigned a higher rate than one on a long line, though both may be equally chance events. Rate would thus give a false picture of an event/use actual opportunity to happen. An alternative is to group the data in bins. Unfortunately, some information contained in the individual values is sometimes lost when using this technique.

To avoid this problem and given that land-use data is always arranged in plots or buildings, a new functional description of the city was adopted where plots also become nodes and are connected to the lines of movement that represent the street network **(FIGURE 6).** It was created in Mindwalk (Figueiredo, 2004), a stand-alone application for spatial analysis. This model enables us to measure accessibility at the level of plots: *plot accessibility*. It resembles the pioneering work of Krüger (1979), especially where the latter refers to the relation between road network connectivity and built form[6]. Another similar description is the interface map (Hillier & Hanson, 1984) that combines open space description and its relation of adjacency and direct permeability to buildings. A later development of these kind of descriptions are the maps generated with place syntax (Stahle, Marcus, & Karlstrom, 2005). This is a GIS tool that can 'load' space with a specific weight or geographic content of buildings or plots --i.e. population density or the presence of an attraction-- before calculating the accessibility of the network. The association is done geographically with building entry points.

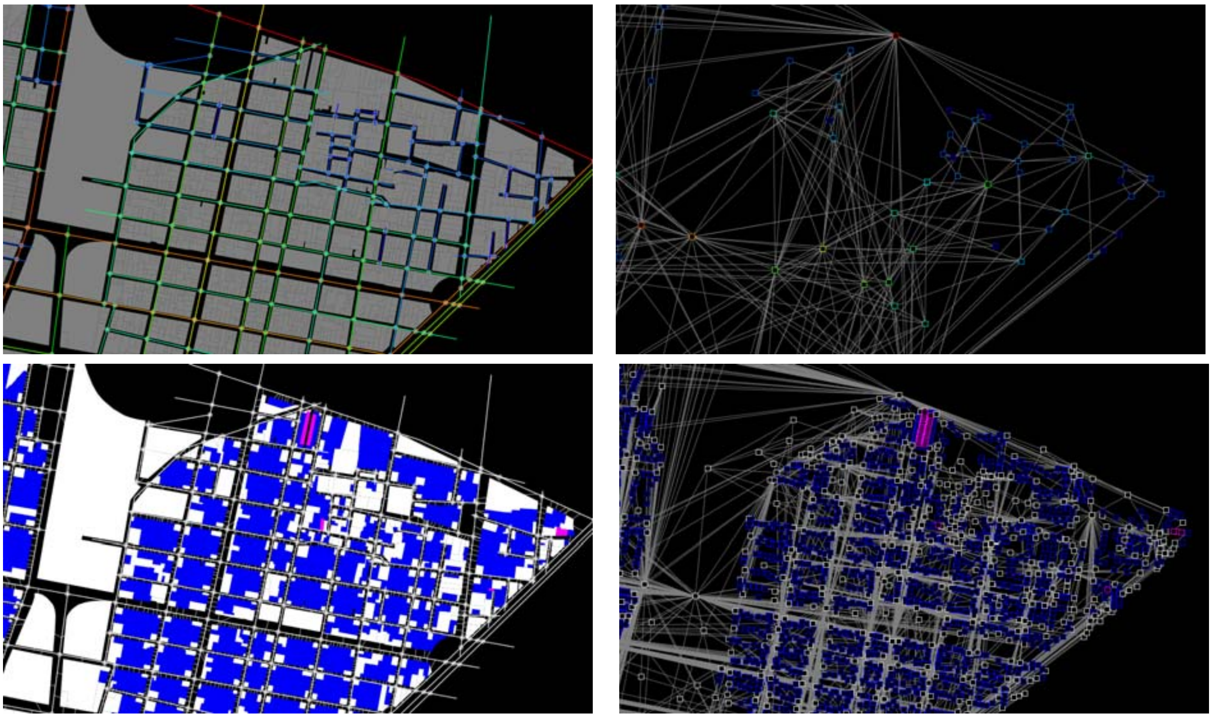


FIGURE 6. Construction of the plot accessibility model: axial map (top left), axial graph (top right), interface map or links between axes and plots (bottom left) and complete graph (bottom right) (Figueiredo, 2004).

The plot acessibility interface relates axis and polygon geometry by their vicinity. This, particularly in the absence of entry point information, entails the underlying assumption of potential, rather than actual, access from the public realm. The majority of buildings/plots in Mexico City have only one façade/side facing the public realm. This means one side of the plot to access it and one connection. However, for corner plots, for example, the assumption for this representation is at least two sides of potential access and movement. The consequence is that, unlike one-access plots which turn into dead-end nodes in the graph, a corner plot becomes a loop, assuming that one can move from one street or space of the corner to the other through that plot. Consequently, plots on or close to the crossing of several axes and large plots occupying whole blocks turned to be 'hyper-connected' as they created several loops around them. Some of these plots might be loops in reality if they allow pedestrian movement through them.

In order to explore the system locally and globally, radius 2 (R2), radius 3 (R3), radius 4 (R4) and radius infinity (RN) --or all the nodes in the system-- were used. These radii were thought of as representing street, crossing, area and entire system respectively, considering that both, axes and plots, become connected nodes in this representation. **(FIGURE 7)** Another important consideration was the geometry of the study area made up of a series of offset grids at different angles with several long lines often crossing most of the system.

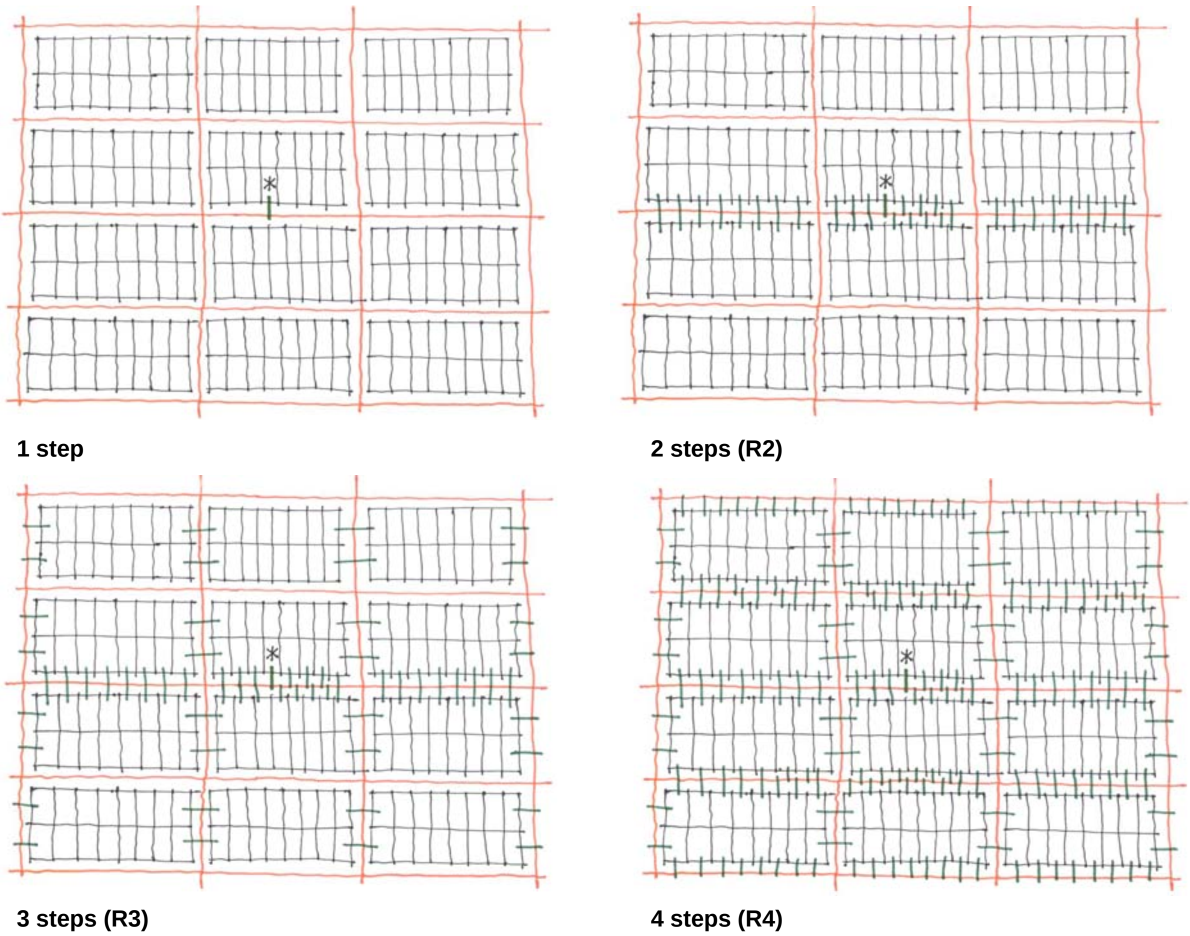


FIGURE 7. Different radii in a perfect grid using the plot accessibility model.

4. Cumulative frequency

If the distribution of land uses was random, any part of the map would be likely to contain the same proportion of uses as the whole map. However, if the movement economy process (Hillier, 1996a) was influencing the patterns of land-use in Mexico City, the occurrence of uses like retail should increase with high accessibility while residential uses would tend to seek less accessible locations. These relations between accessibility and land use were first examined numerically as variations in the proportion of specific uses in four portions of the ranked data/map --the 25%, 50%, 75% most accessible plots, and the entire area. The uses studied were big and small retail, housing and offices. Accessibility was quantified as integration R2, R3, R4, RN and choice RN.

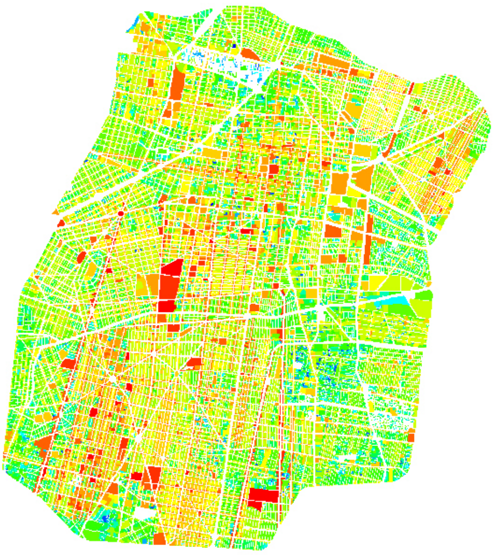
Next, the *cumulative distribution function* (Newman, 2005) or *cumulative frequency* --also known as rank-frequency plot-- was adapted to illustrate the occurrence of land uses for every plot in the database. The cumulative frequency *P(x)* is the probability, or the *proportion,* of observations *x* with a reference value greater than or equal to *x*. In this study, *x* were plots of specific use *U* and the reference values were given by the same five definitions of accessibility as above. The proportion of plots of use U was determined for each ranked plot *(x)* as in the four ranked sections that were examined previously --for the top *n*, that is, for plots with accessibility greater than or equal to x. Twenty use-access combinations were plotted and eight were explored in detail --global and one local access variable for each land use.

5. Patterns of land use in Mexico City

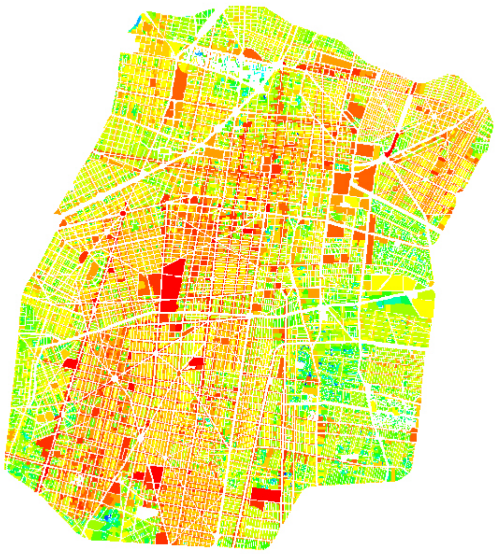
The following maps of the first ring of Mexico City illustrate the plot accessibility of the area **(FIGURE 8)**. Table 1 shows the first results on the frequency of land uses in different plot accessibility situations. Integration varied from the most local level, street (R2), to crossing (R3), area (R4), and system (RN). Choice was only calculated for RN. These accessibility measures were ranked and decreased from left to right as the ranked sections of the database grew.

It became clear that as accessibility, in all its variations, increased, the proportion of retail uses also increased whereas residential uses decreased. The frequency of office uses increased with higher accessibility too, except for a slight decrease with the highest values of local integration (R2 and R3).

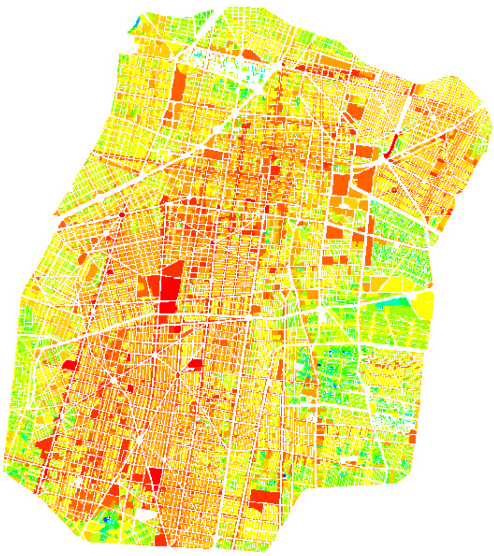
On the second stage, as explained before, the cumulative frequency of each of the 159,608 plots on the database was computed and plotted for each of the four uses and five definitions of accessibility proposed **(FIGURE 9)**. The patterns shown by the measure of choice did not seem to give clues about its relation with land use distribution so this variable was not further studied after this stage. This could be related to the nature of the plot accessibility model as nodes on the routes *between* other nodes are streets and 2- or more-connected plots which form loops of potential movement --refer to section 4-- but the majority of plots are one-connected dead-ends. The rest of the functions plotted strongly confirmed the influence of accessibility on land use distribution pointing to a non-linear relation**.** This contrasts with the linear correlation observed in space syntax work on organic cities (Hillier et al., 1993; Hillier, 1996a, 2001)



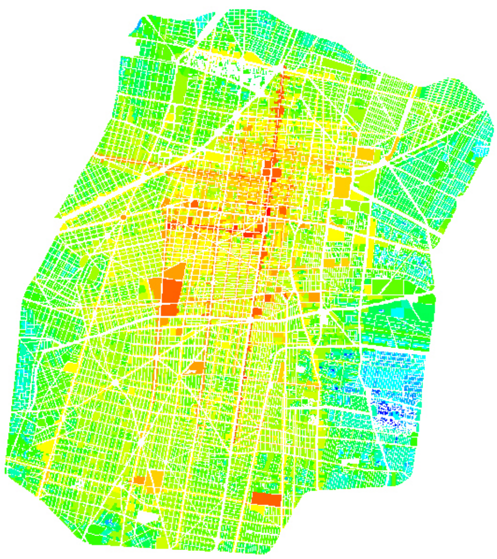
Integration R2



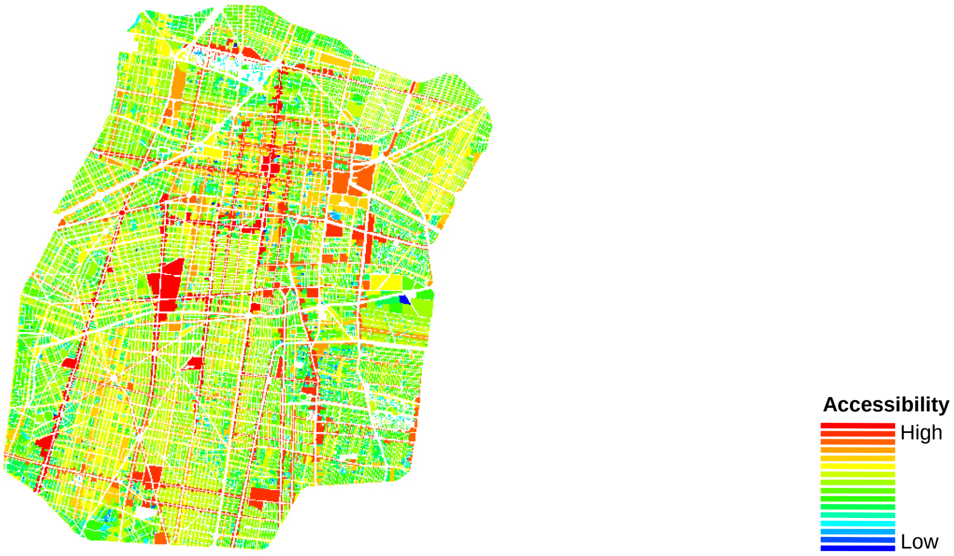
Integration R3



Integration R4



Integration RN



Choice RN

FIGURE 8. Plot accessibilities of the first ring of Mexico City showing the measures of integration at street (R2), crossing (R3), area (R4) and system (RN) level, and choice.

Table 1. Frequency of land uses in ranked plot accessibilities.

Accessibility	*frequency* (%)	*in top* ***25%*** HIGH	*in top* ***50%***	*in top* ***75%***	*in* ***100%*** LOW
Int R2 (street closeness)	*big retail*	4.35	3.56	3.11	2.68
	small retail	22.85	20.05	17.70	15.41
	housing	54.63	59.10	63.33	66.84
	offices	3.45	3.51	3.30	3.01
Int R3 (crossing closeness)	*big retail*	4.35	4.05	3.29	2.68
	small retail	22.85	21.14	18.13	15.41
	housing	54.63	56.89	62.17	66.84
	offices	3.45	3.88	3.49	3.01
Int R4 (area closeness)	*big retail*	5.40	4.02	3.26	2.68
	small retail	25.00	20.69	17.87	15.41
	housing	48.96	57.59	62.74	66.84
	offices	4.68	3.88	3.42	3.01
Int RN (urban system closeness)	*big retail*	6.69	4.31	3.34	2.68
	small retail	26.07	19.97	17.43	15.41
	housing	44.91	57.49	62.20	66.84
	offices	4.73	3.97	3.67	3.01
Choice (urban system betweenness)	*big retail*	5.52	3.97	3.12	2.68
	small retail	23.83	20.39	17.69	15.41
	housing	49.66	57.38	63.36	66.84
	offices	4.41	3.77	3.26	3.01

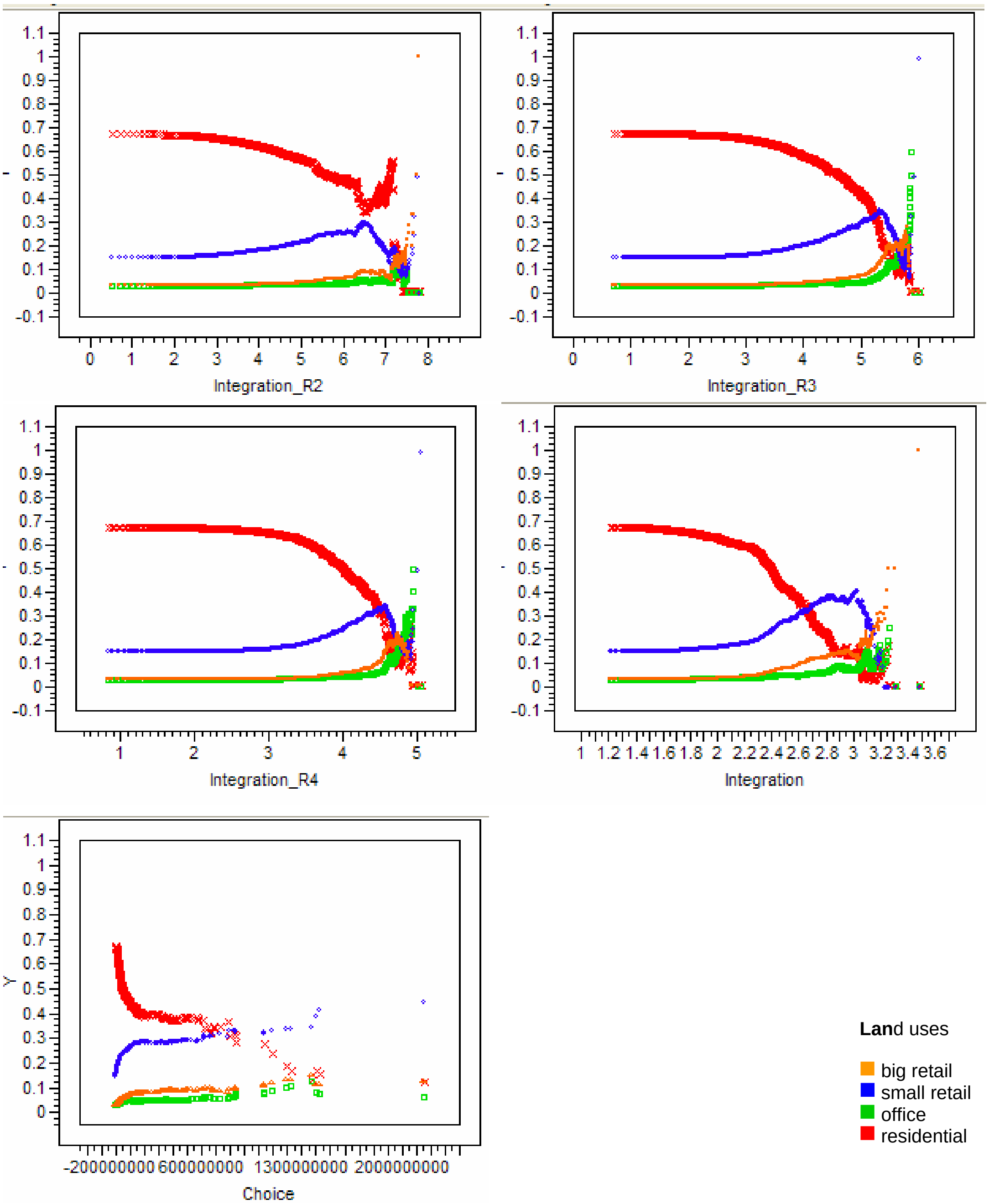


FIGURE 9. Cumulative frequency distributions of the first ring of Mexico City showing four land uses as functions of integration at street (R2), crossing (R3), area (R4) and system (RN) level, and choice.

The use-access curves showed similar behaviour --in line with the hypothesis of the movement economy guiding land use patterns-- with all the different radii used. The functions of each use were examined in more detail for global integration (RN) and local integration R3 **(FIGURE 10)**. R2 was discarded for further exploration because it shows the most distortion on the tails of the curves, presumably due to its short topological reach up to the street level. The patterns of integration R3 and R4 looked almost the same, though R3 was preferred because R4 has theoretical and, potentially, an amount of actual similarity with global integration. The former as four connections would cover a theoretically perfect grid system, i.e. R4 = RN **(see FIGURE 7)**. The latter as Mexico City has a degree of grid-likeness as well as a number of long axes across it.

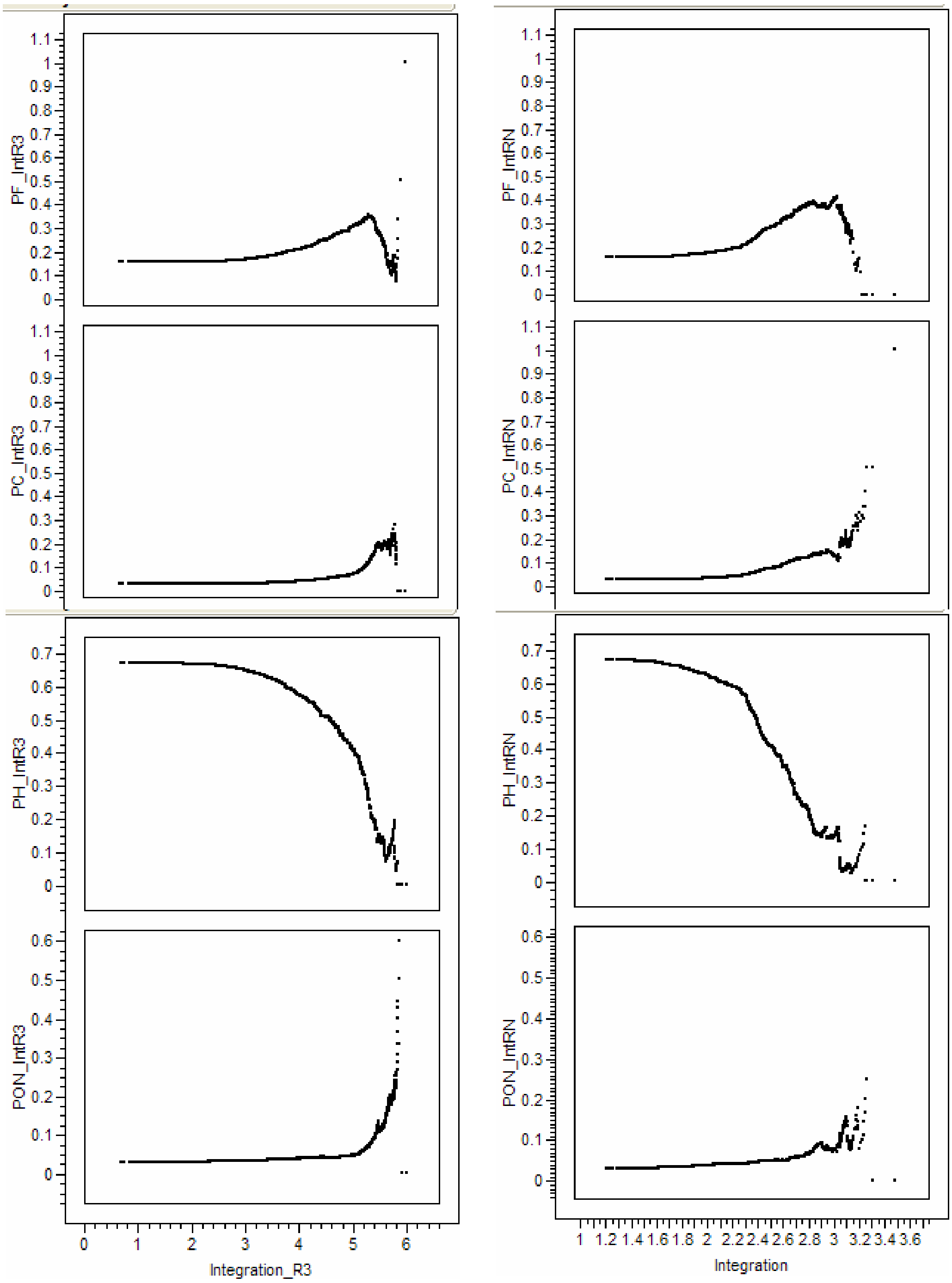
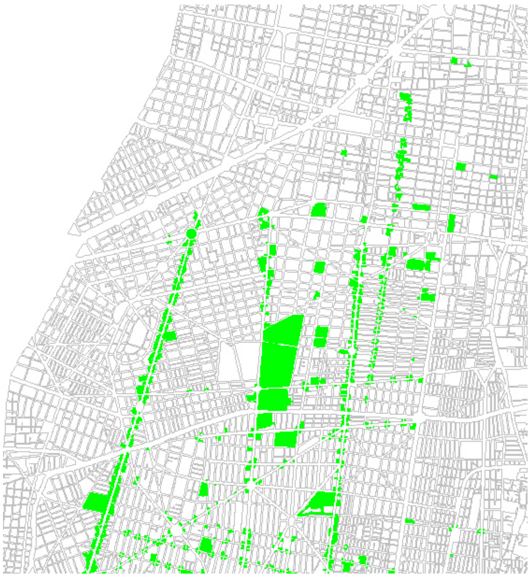
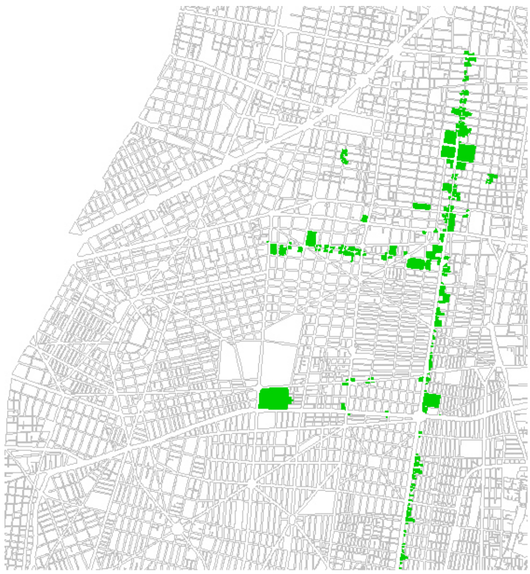


FIGURE 10. Cumulative frequency distributions of the first ring of Mexico City showing, from top to bottom, small retail, big retail, housing and office uses as functions of local (R3) integration and global (RN) integration.

Examination of these curves gave further information about land use patterns and the model. For example, it was observed that the tails of the curves either just 'fell' --like in small retail-- or became 'noisy'. This always happened around the top 1-2% of the ranks. The dots on this range correspond to hyper-connected plots --those with more than one side of access, i.e. corners and half- or one-block large plots-- on the most integrated --accessible-- axes, locally and globally respectively **(FIGURE 11)**. Moreover, there is a small number of dots at the end of the tails, especially on the local accessibility functions (<0.01%), that separate slightly from the main shape. The outlier behaviour of these can also be partly attributed to their extreme hyper-connectivity. Besides their location on the most locally integrated axes, as the rest of the plots on the tail, they lie by the junction of 4 or more axes. For global integration, outlier dots (0.005%), besides their location on the tail of the curves and therefore on the two most integrated lines of the system as a whole, have 3 or more sides of street access.



P(big retail)-local integration



P(big retail)-global integration

FIGURE 11. 'Noise' (<1% top of ranks) in cumulative frequency distributions of big retail as a function of local (R3) and global (RN) integration.

Noisy tails aside, some functions seemed to have steeper increase of curves after an inflection point. Small retail and housing against global integration are clear cases, both with inflections at about 50% of the number of plots/dots. This indicates a stronger influence of higher values of accessibility in the distribution of activities which would be positive for retail and negative in the case of housing. Slight slope changes could be claimed around approximately the top 5% of the big retail, housing and office-local integration relation but these, being a short proportion on the top of the ranks, are still affected by the hyper-connectivity effect, though to a lesser extent.

6. Discussion

Although not as easily pointed out as in organic cities, land use distribution seems to respond to the network effects of the *movement economy*. Accessibility exerts a positive influence, both globally and locally, on the location of uses that benefit from movement, that is commercial uses such as retail and offices, and a negative influence on residential uses. It is *a bottom-up process*. The complexity of this relationship, depicted in the lack of visual correlation between land use and access maps, and the patterns observed in the cumulative frequency distributions, could be related to the forces underlying the morphology and, as a result, the configuration of the grid and its accessibility.

Localised clusters of movement-dependent uses that relate visually to accessibility mappings and can be analysed using linear correlations are not rare in organic cities (Hillier, 2001; Strano, Cardillo, Iacoviello et al., 2007). That could be explained by the fact that their morphologies are the product or by-product of a 'natural' process of growth over time, *a bottom-up process where underlying forces have also been predominantly economic* --to facilitate movement within the centre and to/from the centre from/to the edges, that is, network effects or the movement economy process. Even when there are partial top-down planning interventions along an organic city's growth process, as it is often the case, they inherit the precedent of the original grid.[7]

This is not the case for most Latin American cities, including Mexico. Grid morphology has been driven mainly by a 'planned' *top-down process where underlying forces have been driven by political decisions* that have distorted market forces. First and foremost, the impositions of the Spanish Empire's orthogonal grid laid down tacit rules, embedded in the geometry itself, that would guide its development from then on. New neighbourhoods, although developed without much governmental control and faster than they could be planned responding to economic boom, happened in the context of the existing implicit structure laid out by the original orthogonal geometry, hence the predominance of offset grids and the resulting 'patchwork' morphology of the city. The only processes that could be regarded as more ‘naturally’ developed or organic are adaptations and subdivisions that have occurred in the original Spanish grid of the Historic Centre, squatter settlements and prevailing indigenous *pueblo* cores, but they are minimal, especially in the first ring.

Mexico City's land use pattern selection developed driven by bottom-up movement economy forces regardless of its top-down growth and resulting patchwork morphology. Market forces adapted to the city's 'unnatural' grid causing the complexity and at-first-glance distortion of the space-land-use relation. The city developed a spatial hierarchy similar to that of organic cities. These findings support urban economics ideas of agglomeration economies and network effects.

The aim of this paper was to contribute to the understanding of spatial structure in Mexico City and parallel Latin American cities. Use of the plot accessibility model and cumulative distribution function resulted in a powerful methodology to support the hypothesis that accessibility, through movement, operates as an important driving force in the process of land use distribution and quantify its effect. It also shows the potential of large blocks to enhance movement and even become nodes of centrality when they become part of the network of public space instead of interrupting it. This potential is illustrated by their occurrence in top ranks as a consequence of hyper-connectivity.

The method provides an important tool to foster economic development at the micro scale and plan for sustainable growth objectively. The work could be extended to include other uses and compare them with the social distribution of the city to explore asset provision and promote inclusive development.

Acknowledgements

The author wishes to thank Lucas Figuereido for all the time invested in discussions that lead to this methodology, Marios Michael for his invaluable expertise in programming, Jorge Gil for his help with technical difficulties, and Bill Hillier, research supervisor.

This research is funded by a CONACyT scholarship.

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[1] This still prominent avenue was built on the orders of Emperor Maximilian I in 1864 to connect the city centre with the Palace of Chapultepec in a straight line.
[2] For details of how integration is calculated see Hillier and Hanson (1984, chapter 3).
[3] For a deeper explanation of betweenness and its calculation see Freeman (1977).
[4] The tendency for the edges of a spatial system to be different from interior area because they are close to the edge (Hillier, 1996b, p. 163).
[5] The cadastre was kindly provided by the Ministry of Urban Development and Housing (SEDUVI) of the Federal District.
[6] In his work, this relationship is addressed as graphs type 3 and 4.
[7] For organic cities, this consists of the 'deformed wheel' (Hillier, 1989), an integration core and a number of integrated spikes that link it to the edges of the settlement like a rim. This is usually the main public space structure. The less integrated interstices become residential areas.