Urban Sprawl and Fragmentation in Latin America: A Comparison with European Cities. The myth of the diffuse Latin American city.

Luis Inostroza, Rolf Baur and Elmar Csaplovics

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Abstract

South America is one of the most urbanized continents in the world, where almost 84% of the total population lives in cities, more urbanized than North America (82%) and Europe (73%). The future of the continent will be dominated by urban development and driven by urban systems. However, the spatial behavior of most Latin American cities, their structure, driving forces, main features, comparability and others remain mostly unknown.

To quantify and assess urban sprawl and fragmentation we address certain patterns for 10 Latin American cities over a period of 23 years. Using satellite imagery we quantify the main parameters of expansion and fragmentation, land consumption rates, spatial arrangement and densities, identifying key factors leading the process and spatial ways to characterize urban development and sprawling features under certain indices, using European urban development as a comparison. The aim is to address relevant spatial metrics, all measured with GIS tools, to achieve policy relevant indices of urban form.

By identification of those factors, together with the quantification of the sprawl as a tool for monitoring development patterns, we aim at contributing to better understanding urban form in Latin America, towards an improved spatial urban development and land policy.

In a pervasive urban expansion context, Latin American cities are more compact and less fragmented than in Europe. There are also important differences in the rates, densities and degrees of fragmentation. The need to redefine the role of Latin American urban planning appears in a scenario where urban expansion is not possible to control, and where trends of sprawl, fragmentation and discontinuity may result intensified by the interaction of economical operations.

Urban Sprawl/Latin America /Fragmentation/GIS metrics/Land Policy

About the Authors

Dr Luis Inostroza Pino (corresponding author) Architect-Urbanist of University of Chile, with over 15 years experience in Urban Planning, Land Management and use of GIS technologies. Doctor in urban development University of Madrid. Postgraduate degree in Human Settlements, University of Chile. Certificated in Proficiency in Land Use Change Management and Remote Sensing, Technische Universitat Dresden. International Diploma in Urban Management and Sustainable Development, ECLAC. Specialization in GIS Analysis and Modeling, Codazzi, Colombia. Valuer Universidad de Chile. City Planner Punta Arenas 2001-2009. Professor University of Magallanes 2006-2007. ARCADIS Consultant 2003-2009. Expert valuator. Private consultant. Former Director Collegium of Architects Magallanes region, Chile. International award academic essay Adriana Schiffrin 2009, first mention. International award academic essay Observatory on Latin America (OLA) of New School University, New York 2008.

At present is an independent researcher on issues of urban planning, GIS and Remote Sensing, Landscape Ecology and Social Metabolism.

Address: Nezamyslova #274/10, Praha 2 Nusle
Praha, 12800 The Czech Republic
Telephone: +420-732-61-67-61
Email: inostroza@urbansprawlproject.com, inostroza@seznam.com

Dr Rolf Baur Since November 2005, Dr Rolf Baur is the managing director of the Centre for international postgraduate studies of environmental management, TU Dresden. He studied at TU Berlin, IIT Madras and obtained his first degree in civil engineering (Urban engineering) from Wuppertal University. After his Phd at TU Dresden, he has been working as a researcher at INSA Lyon (France), and again at TU Dresden in the position of a senior researcher, and a freelance engineer (Baur & Kropp) consulting urban utilities in their asset management. His research focused on the rehabilitation of ageing infrastructure and the asset management of technical infrastructure networks, with working and teaching experience in Europe, North America, Africa and China.

Prof Habil Dr Elmar Csaplovics is Director of the Institute of Photogrammetry and Remote Sensing, TU Dresden and Chair of Remote Sensing at the Institute of Photogrammetry and Remote Sensing, TU Dresden with a broad experience on Remote sensing Technologies which includes: Remote Sensing for Multi-Scale Environmental Monitoring, Geographical Information Analysis for Multi-Scale Environmental Monitoring, Landcover Change Detection, Digital Terrain Modelling, Tropical Deforestation Mapping, Appropriate Technologies in Remote Sensing and GIS, Transnational Networking with Spatial Information Systems. PhD in Remote Sensing at the Technical University of Vienna (Austria), Post-doc scientist at the Institut National de la Recherche Agronomique (INRA) Montpellier, Post-doc scientist at the Department of Geology, Geophysics and Geoinformatics, Free University of Berlin (Germany), Habilitation in Remote Sensing at the Technical University of Vienna (Austria). Professional experience: Transdisciplinary Projects, e.g. in Bangladesh, Ethiopia, India, Mali, Sudan, Syria, Yemen and in different regions of Europe.

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Acronyms and abbreviations

CDB	Central Business District
ED	Edge density
EU	European Union
LA	Latina America
MPS	Mean patch size

Introduction

Is the Latin American city diffused, sprawled and fragmented, as Latin American planners and policy makers use to think? What are the spatial patterns of its expansive processes? What similarities exist between the behavior of European and Latin American cities? What are the trends of densities in the expansion process? Where the higher degrees of fragmentation can be found? What would be the role of spatial planning in this context? Is there a relationship between growth rates and different degrees of fragmentation? What factors could explain greater or lesser fragmentation of expansive processes?

In this essay we try to address urban sprawl as specific spatial development pattern in ten Latin American cities and then compare those results with what we know from European cities. Addressing the general expansion scenario for cities and by using certain metrics our aim is to improve our understanding of sprawl and fragmentation in Latin America and their characteristics: cities will grow, it is unavoidable, but how to manage this urban development in the most compact way is a matter of land policy. Characterizing sprawl and fragmentation would open new ways to drive urban development under market conditions, where adequate legal and tax treatment are necessary.

Expansion is not an equivalent to sprawl. Sprawl means a large area of buildings that are spread out in an untidy and unattractive way (Longman Dictionary 2006). Expansion is when something increases in size, range, amount, etc. (Longman Dictionary 2006). As a matter of fact, cities expand as a result of demographic and economic growth[1]. But sprawl is a specific pattern; a kind of increasing trend of the undesired effects of expansion: fragmentation as a spatial pattern of discontinuity.

Whether urban areas sprawl, and to what extent they do so, depends on the land policy and other spatial strategies to control the urban development towards a more efficient and smarter growth. Land is a scarce resource; land suitable for urban development is even scarcer. Thus, an efficient urban growing process is an important issue for regional planning where markets are normally leaving behind sprawled and fragmented spatial configurations in their search for profits:

Sprawl is no more or less than the efficient operation of the land market, and in this sense, is the outcome of a competitive process. (Batty et al, 2003:6)

Under the current scenario of constant urban expansion an important question is what the acceptable degrees of fragmentation for urban planning are. This moves the concern to the specific shape and spatial arrangement that urban expansion is taking place in.

The pattern of dispersion of urban sprawl expresses the adaptation of factors as spontaneous tendency in the short-term economic maximization. What is the relationship between this dispersive tendency and the aim for a better land policy, regional planning, infrastructure, transport and investment? Where do we find more scattered (fragmented)

[1] Both driving forces are out of the scope of the urban or regional planning, thus not a matter of land policy.

expansive patterns, in what kind of land policy contexts are the patterns less tight or tighter? Is sprawl a natural broken response of an economic adjustment of the urban system asymmetries? Or is it a negative effect of urban planning that introduces market failures and prevents land markets from operating freely and efficiently?

From the perspective of public policy, and sharing ideas of Angel (Angel 2010), if we want to deal effectively with urban sprawl it is clearly an imperative to define it rigorously and measure it systematically. It is difficult to lead urban development from sprawled patterns to smart growth if the underlying dynamics remain unknown. At the same time it is necessary to separate expansion from sprawl by defining certain thresholds with general criteria but with specific spatial application to every city.

In this comparative perspective on urban sprawl, Latin American cities are in better condition than planners and policy makers usually think. Average population densities remain higher and cities are less fragmented than European ones, discounting the effect of geography. However, Latin America is following similar transformations, but with a time lag that could give us the chance to face the expansion and sprawl in better ways.

The first aim of this research is to quantify the processes of urban sprawl and fragmentation in ten major Latin American cities and then compare those results with European cities. We demonstrate that Latin American cities are more compact and less fragmented than European ones. To address this issue we built a platform of categories, concepts and methodology for comparing urban sprawl and fragmentation with the European reality. By using common spatial classification criteria we quantify the degree of fragmentation of urban sprawl (compactness and continuity), characterizing fragmentation (determining densities of the expansive vectors, etc.) and comparing the Latin American urban fragmentation with the European one. In this comparative study we determine differences in the fragmentation of expansive processes. This allows for a general analysis of the regulatory frameworks to contrast it with the processes and their effects. Finally we draft explanatory factors and the role that urban planning might play in the struggle against sprawl and fragmentation.

We aim to address the problem with the use of appropriate analytical tools. At the same time, land policy needs appropriate parameters for better evaluation and a long-term perspective in the triangle of economy, ecology and social implications related to the increasing segregation and inequality in our cities. It is necessary to analyze and compare factors that are driving urban form, sprawl and density, in order to better anticipate their occurrence, which could lead to less fragmented expansion patterns and open the discussion about the role of urban planning in Latin American continent in the 21st century.

Defining sprawl and fragmentation

We understand urban sprawl as a spatial phenomenon. As cities are, at a certain scale, physical objects, they behave according to the rules of physics, following some common patterns that lie beyond political, legal or cultural context. For instance, larger cities grow more and faster than smaller ones, in a kind of "inertial behavior". A similar phenomenon has been observed with population growth rates (Rozenfeld et al 2008) – a so called "development attracts further development." All this behavior is mainly spatial and physical. It has been suggested that the urban growth mechanisms result in self-organized-criticality, independently from the fact that urban development is planned and executed at all levels (Andersson et al 2002).

Cities are growing in size and population and this expansion is a common urban challenge. However, sprawl implies certain spatial behavior with specific characteristics, topology, densities and relationship with the preexisting urban system (core city, spatial structure, infrastructure, land use, distribution of social economic classes, etc.). Spatial structure and spatial interaction are mutually determined (Andersson et al 2002).

Under this spatial understanding, the sprawling is an expansion pattern where the new growth is often discontinuous, low dense and extensive. The European Environment Agency has described sprawl as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas[2]. Sprawl is the leading edge of urban growth and implies little planning control of land subdivision and urban development, which is patchy, scattered and strung out, with a tendency for discontinuity. It leap-frogs over areas, leaving agricultural or open space enclaves behind. Sprawling cities are the opposite of compact cities, full of empty spaces that indicate the inefficiencies in development and highlight the consequences of uncontrolled expansion (EEA 2006).

Urban sprawl normally has been studied as a matter of degree (Schneider & Woodcock 2008). However, cities also grow according to their size. Land consumption rates are highly correlated with the size of cities, more than with the size of their population. The amount of land consumption which characterizes urban sprawls, in a conceptual dimension, depends on the density of the new developments outwards the cities and the efficiency in revitalizing obsolete urbanized areas, to improve density or to avoid population decline.

Understanding sprawl mainly as a spatial pattern allows us to separate simple urban expansion from sprawled patterns. Spatial continuity is one of the main factors to assess in order to achieve the trend of compactness. Density is another important factor, together with speed and level of fragmentation.

[2] This fact links urban sprawl to food security. In some cases like in Bogotá this is already an issue for urban planning.

An urban core expands in an "oil stain" pattern. While such continuous expansion over the edges is a physical behavior present in all cities, the shape of that stain certainly varies from one city to another. Urban development tends to take place along the boundaries of already urbanized areas and implies "how growth attracts further growth" (Andersson et al 2002). It usually advances in an asymmetric radial direction[3] around the city centre or in a linear direction along the road network, on the urban fringe, at the edge or close by an existing urban area or along the highways. We call this an "infrastructure principle" and it is the main criterion to determine core areas of continuous urban fabric and a key factor for further development also: lacking infrastructure is a strong constraint for urban development, thus any new developments will tend to follow naturally a city edge. This is a kind of centripetal force dragging urban development to the city core. Benefits arise from being part of the infrastructure network, however the land price is generally inversely related to development density (Andersson et al 2002). Thus it is possible to observe at the same time a centrifugal behavior, a tendency to escape from the city and spread urban development over hinterlands.

Fig. 1. Brussels and Bogotá.

Specific features of development patterns differ among cities: speed change, the rate change, the spatial vectors, etc., due to particular features. We address certain parameters for quantifying and assessing urban sprawl, identifying the key factors that lead the process. Combination of the identification of those factors and the quantification of the sprawl might feed with certain facts the land policy towards a better spatial urban development.

In this spatial perception the gaps in the urban fabric suggests lack of efficiency in the urban development due to inorganic growing process (Batty 2003:4).

[3] Although it is radial, it is possible in most cases to identify certain expansion vectors.

Since comparisons among cities are useful, we compare Latin American sprawling patterns with the European ones. But it is also necessary to assess properly the phenomenon of sprawl within the urban structure itself, avoiding just overall measures for comparison. This could be relevant to achieve policy relevant indices of urban form, expansion and sprawl. That is, policy makers can use those indices to inform zoning and subdivision regulations that control density, street network connectivity, and the location of key land uses as schools, businesses and others. Describing sprawling features by using certain indices, all measured with geospatial tools (GIS), could give to the land policy the possibility to monitor those development patterns. For instance in Europe some continental initiatives are being developed like MOLAND, CORINE and URBAN ATLAS projects. They aimed at creating a common framework to allow comparisons among cities and regions across the continent by using similar definitions. This is the first step to lead desirable parameters to achieve a compacter city trend[4], and certainly further than just knowing the ranking of cities.

We attempt to measure the urban sprawl as land cover change process which is setting the change in the spatial structure of cities over time. To find out patterns of urban sprawl we focused on land cover changes over an average of 23 years period of time[5], estimating the amount of new land transformed from non-urban to urban cover/uses, including five quantifiable spatial characteristics: density, spatial configuration, built-up area ratio, speed and fragmentation.

Density measured as population per hectare (or square kilometers in some cases) is a key metric showing important differences not just among cities but also into the structure of each city itself. As densities vary between cities but also within the urban structure. This may have substantial implications for social segregation and quality of life of unprivileged. Also must be a key factor for land policy and regional planning.

Spatial configuration classifies new development into three categories: infill, axial and isolated, according to the spatial relationship they have with the pre-existing city.

Built-up area ratio was used to measure land cover changes, i.e. the quantity of land converted from non-urban to urban over the period of time under analysis.

To assess speed of sprawl, we measured *speed* in meters per year for the fastest expansion vector. This shows the dynamics of cities in the context of persistent urban expansion.

Finally, *fragmentation* was measured by using edge density, mean patch size and compactness of the largest patch, which are good explanatory metrics for fragmentation in European cities (Schwarz 2010).

[4] Urban development is a continuous process. Under this perspective the “goal of compact city” is a trend, not a final result, as it is sometimes misunderstood in urban planning.
[5] Depending on the availability of satellite images for each city.

Methods

In order to make possible a comparison between different cities it is necessary to address what "urban" means and what geographical area should be considered.

Normally urban planners divide descriptions of urban areas into both spatial (or physical) and functional definitions; ours is mainly spatial. First we determined core area, the urban continuous fabric under the continuity principle (infrastructure principle) to separate it from the fringe, the hinterland where the influence of the city is direct and strong. We followed spatial criteria to establish the extension of the cities, cores and fringes.

As our understanding of sprawl is mainly spatial we avoid metropolitan definition of areas of influence because they are basically functional assumptions. By determining a spatial area of influence we analyze direct effects and relationships of cities in that area. Functional definitions of the scope of influence of cities like metropolitan or others are also important, but that kind of consideration might be included in further research.

This spatial criterion is however not absent of difficulties and sometimes fuzzy whenever the function is hard to separate completely from the spatial definition. What we understand as urban lies in the continuity of the urban fabric and by consequence where that continuity is interrupted, whenever this continuity of the urban tissue finishes, whether by a geographical barrier, a sudden or smooth interruption of urban fabric, etc., the city core will find its edge. Spatial continuity is the main criteria to separate city from its hinterland. This continuity was determined by using spectral behavior, shapes and textures of the LANDSAT images in T1 and T2. We support this definition with our field excursions where we did certain transects from the very center towards the hinterland. Under a perceptual assessment it is more or less clear where the city ends. That kind of continuity is following the urban spatial-physical structure – roads and infrastructure - and these are important vectors leading expansion of cities.

The core urban area was delineated for each city based on the on-screen segmentation process. To support the determination of city's edge we complemented the analysis with very high resolution images by using the ARCWORLD tool of ArcGIS10©. For some cities this analysis was supported by aerial photography and other ancillary data. As we know that sprawling is hiding under suburbanization processes we included low density urban fabric in the core area, to avoid underestimations.

Following the spatial criteria we used the MOLAND database method (Kasanko et al 2005) to calculate the fringe area around the cities, by using the formula:

$$W = 0.25*\sqrt{A}$$

where W is the thickness of the buffer and A is the surface of the core area. This determination implies that bigger cities have thicker fringe. This assessment of the city's expansion towards the hinterland is spatially explicit. Also this assumption makes easier the comparisons between European and Latin American cities, avoiding administrative definitions.

To improve the accuracy of the image classification we run separated routines of classification for fringe and core. We defined 4 main classes: built-up or sealed surfaces (core and fringe), open spaces (only in the core area), geographical constraints which include all areas where urban development could not take place as rivers, lakes, mountains, etc., and developable area including either agricultural or natural land representing all land susceptible to receive further urban development.

To make our measures comparable with the European ones we used most of the definitions of the CORINE project to determine our classes. Categories of land cover are directly comparable.

GIS modeling

The GIS modeling has followed four main steps: imagery pre-processing, determination of spatial units of analysis, imagery processing and vector integration and overlay. We used LANDSAT imagery as main source (table 1), complemented with ancillary vector and raster data.

1. LANDSAT Imagery pre-processing
    1.1. Band stacking
    1.2. Spatial enhancement (georeferencing, reprojections, calibration with vector files, etc.)
    1.3. Preliminary radiometric and spectral enhancement
2. Determination of spatial units of analysis (vector)
    2.1. Delimitation of core area by on screen segmentation (city edge)
    2.2. Determination of fringes: buffers to core areas
    2.3. Determination of major geographical constraints
    2.4. Integration of core and fringe into AOI T1 and T2
3. LANDSAT Imagery processing
    3.1. Enhancement
        3.1.1. Core enhancement (histogram equalization and principle component)
        3.1.2. Fringe enhancement (histogram equalization and principle component)
    3.2. Classification (Bands 742 and 542)
        3.2.1. Core classification (built up and open space)
        3.2.2. Fringe classification (suburban or built up in fringe)
        3.2.3. Interpretation and editing
4. Vector data integration and overlaying (land covers in T1 and T2, census data)
    4.1. Spatial differentiation of expansion patterns: infill, axis and isolated for T1 and T2,
    4.2. Quantification of sprawling patterns and determination of rates (measuring and density)

	City	Country	Coordinates Latitud	Longitud	IMAGE T1 Date	IMAGE T2 Date	Projections UTM, m
1	Asunción (south)	Paraguay	25° 16' 00" S	57°40'00"W	03.01.1987	29.01.2010	WGS 21 S
	Asunción (north)	Paraguay			03.03.1987	29.01.2010	WGS 21 S
2	Bogota	Colombia	4° 35' 56,57" N	° 04' 51,30" W	22.03.1988	22.01.2010	WGS 18 N
3	Brasilia	Brasil	15° 46' 0" S	47° 55' 0" W	24.07.1988	18.07.2009	WGS 23 S
4	Buenos Aires	Argentina	34° 36' 14" S	58° 22' 54" W	25.11.1988	18.10.2009	WGS 21 S
5	Cordoba	Argentina	18° 28' 00" N	69° 54' 00" W	22.06.1985	12.09.2009	WGS 20 S
6	La Paz	Bolivia	16° 30' 00" S	68° 09' 00" W	02.08.1987	11.04.2010	WGS 19 S
7	Lima	Perú	12° 03' 00" S	77° 03' 00" W	05.03.1987	02.04.2009	WGS 18 S
8	Montevideo	Uruguay	34° 53' 1" S	56° 10' 55" W	20.02.1985	17.08.2009	WGS 21 S
9	Santa Cruz de la Sierra	Bolivia	10° 30' 00" N	66° 55' 00" W	11.01.1985	04.06.2010	WGS 20 S
10	Santiago	Chile	33° 26 '16" S	70° 39' 01" W	11.10.1986	19.03.2010	WGS 19 S

Table 1. Cities and imagery.

Measuring sprawl as a dynamic process

First aim of this research is quantifying urban sprawl in 10 Latin American cities over a period of 23 years time (T1 and T2 see table 1). The objective is to analyze and measure the urban sprawl patterns in those cities, to understand its dynamics and to draw implications for land policy. We used European sprawling patterns as reference.

With our method of classification, one of the first objectives was to include, as much as possible, urban development around the edge of the city in low density. The suburbanization process in most cases is a substitution of agricultural land and in some cases it implies the subdivision into smaller plots or other kind of new suburban rural neighborhoods with or without minimal infrastructure (as roads, equipment, etc). To have a good understanding of sprawling patterns we need the capability to see their typical morphological typologies as suburbanization.

We know that densities fall towards the urban edge. This spatial pattern is a gradient starting in the central business district (CDB) and decreasing at certain amount while getting away from the city center (Clark 1956). The question is where the cutting point is, where that density is small enough to find the city edge. This issue is connected to methodological aspects, such as the resolution of our approximation or source. But it also depends on certain concepts about what we consider as urban and what not. It is necessary to have a clear picture of this before setting the methods and tools for measuring. If an important amount of new urban development is taking place in a scattered and low dense way we will need certain level of adjusted perception to catch intra-cities differences in development patterns. We know that suburbanization of new developments look like rural pattern or it is just invisible for certain remote sensing technologies. On the other hand to address urban classes just after spectral signatures leaving out land use could lead to confusing the technologization of the agricultural land with urbanization, including new and sometimes big areas of greenhouses, sheds and barns as urban patches. In cities like Bogotá for instance the new development of the hinterland under rural land uses, which is a respond to the increased demand for flowers and other agricultural products, is bigger than the urban development taking place in the same area.

The second important aspect is the assessing of sprawl as a dynamic process. For that we classified all development between T1 and T2 into three categories: infill, axial and isolated. This allows identifying spatial patterns of new urban development between T1 and T2. Quantification of those patterns gives us a picture of the specific spatial arrangement cities are taking in time.

To measure the urban sprawl and characterize trends across cities and nations, we use a set of indicators. Five quantifiable spatial characteristics we used were: density, spatial configuration, built-up area ratio, speed and fragmentation.

Density and data population

We use data census from each country[6] as main sources for the analysis of population growth and density. However as census data are indexed to administrative boundaries, which in most cases are not comparable among countries - administrative denominations are very different across the continent even for the census areas and they differ too much in size also - the estimation and measuring of population and densities represent an issue by itself.

We believe that the incongruence between spatial tools and methods to measure urban development with the enormous differences and inconsistencies with administrative assumptions census data are taking, produces distortions in the estimation of populations and densities, despite of making direct comparisons complicated. Population dynamics are clear just at certain scale, according to administrative levels, but within those areas at smaller scale the spatial process of populations, as deconcentration, lost of density, suburbanization and others, are not clear. Accumulated statistics for the city area or for the whole urban regions suggest that large urban regions are rather growing into prosperous regions while not being affected by the demographic ageing and decline. Such conclusions do not consider developments at a smaller scale (Kroll & Kabisch 2011).

To address a better population and density measuring we worked with census data indexed to spatial units (districts or municipalities) smaller than the extension of the city[7]. However we had to face the methodological problem of addressing the shared population in periphery districts, because their population is shared between the city and the countryside, where the assumptions of “urban” used by the census methodologies are usually fuzzy or just not comparable.

The aim was to get a realistic estimation of density in the specific spatial arrangement the new urban development is taking place in the city edge, by considering the real extension of urban developments with their respective population data, where normally census spatial units are too big in comparison with the inner city census districts.

[6] A complete report of web sites is listed in the bibliography.
[7] As small as possible with respect to the data availability. See Annex 2 density files.

To solve this situation we assigned population data only to built up areas in the periphery districts. As our methods catch all built up pixels we assumed that all population in the districts lives in the built up pixels, which means that we considered zero population value for the agricultural land[8] and we also assumed that built up area within the specific districts has homogeneous spatial distribution. Despite of its weaknesses this spatial assignation of population is methodologically more robust than the administrative density or another modeling starting from already estimated densities[9].

With these criteria we calculate core area density, estimating the amount of population living in the city core; this represents gross city density. We also calculate net core density which corresponds to the built up area density in the core, discounting open spaces. For the whole area (AOI) we estimate urbanized density, which is the ratio of population living in the core plus all built up area into the fringe.

To adjust the population data set from census to the times of our imagery we used official estimations. When official estimations were not available we interpolated/extrapolated the census data to match T1 and T2 times using linear or exponential demographic models (see example fig. 2 and table 2).

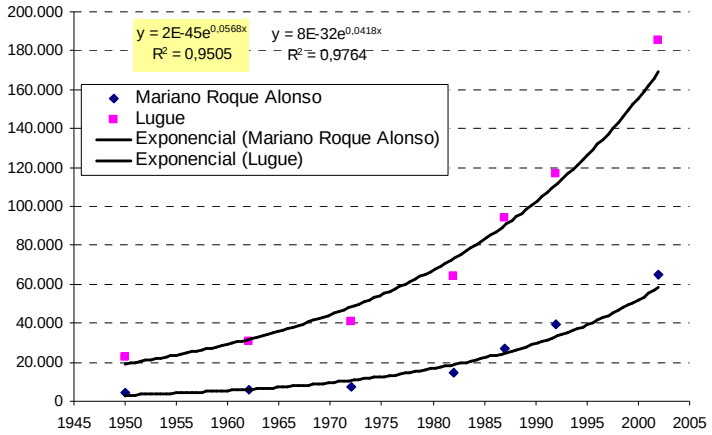

Fig. 2. Population estimation for two districts in Asuncion.

[8] For this assessment we run classification for the whole districts, thus further than just the fringe.
[9] Further analyses of this assumption are in discussion.

City	CENSUS 80`s	IMAGERY T1	METHOD	CENSUS 00´s	IMAGERY T1	METHOD
Asunción	1982	1987	INTRAPOL	2002	2010	EXTRAPOL
Bogotá	1985	1988	OFICIAL	2006	2010	OFICIAL
Brasilia	1991	1988	EXTRAPOL	2010	2009	CENSUS
Buenos Aires	1991	1988	EXTRAPOL	2010	2009	CENSUS
Córdoba	1991	1985	EXTRAPOL	2010	2009	CENSUS
La Paz	1992	1987	EXTRAPOL	2001	2010	OFICIAL
Lima	1981	1987	INTRAPOL	2007	2009	OFICIAL
Montevideo	1985	1985	CENSUS	2004	2009	EXTRAPOL
Santa Cruz de la Sierra	1992	1985	EXTRAPOL	2001	2010	OFICIAL
Santiago	1982	1986	INTRAPOL	2002	2010	OFICIAL

Table 2. Imagery and census dates.

Spatial configuration

We defined a spatial configuration of new urban development. As our definition of sprawl is an opposite pattern to compact, we defined the area of maximum compactness of every city in T1 as the opposite (negative) buffer to the fringe using the same value of W (see MOLAND definition above) and considering that area as the maximum feasible optimization of the urban edge possible to achieve in T2. All new urban fabric into that area was classified as infill. All new urban fabric physically connected with that area, but out of the infill area, was classified as axial. This kind of development was normally located following the main axis roads. Isolated patches were all discontinued tissues floating in the fringe.

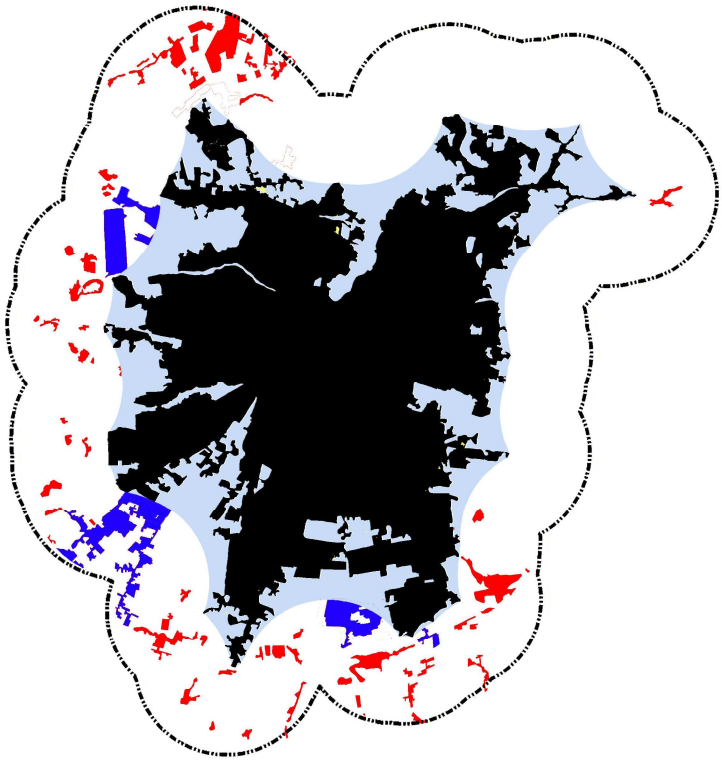

Fig. 3. Spatial characterization of new development.

This measuring allows us to calculate the relative and net spatial efficiency of new urban fabric by calculating the participation of the new built up pixels in those three kinds (infill light blue, axial blue and isolated red, fig. 3) (see also infill files Annex 1) and the net use of infill and axial as the ratio of built up over all infill and axial. It is a dynamic assessment of fragmentation, which is different from the common static fragmentation assessment using landscape ecology metrics.

This configuration of new urban fabric is showing spatially explicit trends of urban expansion by their relationship with the preexisting city. Moreover, this classification is giving light into priorities towards new urban development and some possibilities for differentiate their legal or tributary treatment, towards indications to land policy.

Built up area

With LANDSAT as a main source we cannot estimate the capture of open space in the fringe without controversial assumptions. All free space being used for new urban development in the fringe, as playgrounds, sport fields, etc., is invisible for remote sensing without very high resolution imagery or high quality of ancillary data as property structure for instance. Even though there are some general assumptions in the literature reviewed they are all indirect mechanisms. In this research we preferred direct measuring of urban phenomena. Thus our classification focuses on the quantification of built up area, leaving the consideration of open spaces being captured by urban development for further research.

Speed

Speed refers to the rates of land conversion. We used a common metric for speed: the per capita ratio of land consumption per year.

At the same time we proposed a new metric: the speed of the expansion of the fastest vector in meters per year. This was calculated by measuring the length of core areas expansion vectors from the city center (CBD) in T1 and T2, choosing the longest one and dividing its extension by the years of difference between images.

Fragmentation

Fragmentation reflects the morphological efficiency of the sprawling process. Metrics to assess scattered development were: changes in edge densities, mean patch size and compactness of the largest patch.

All these metrics were applied to the spatial extent of urban areas defined above (AOI).

Results: Sprawl and fragmentation among two continents. The myth of the compact European city v/s the high dense Latin American city.

Europe is a highly urbanized continent, with more than 73% of the population living in urban areas (UN 2009). Spatially speaking the European model of urban development has been largely situated as opposite to the scattered and sprawled North American model. However the European urban form is more diffuse (European Environment Agency report No. 10/2006: 15) than the common perception. The expansion process shows an important morphological management of edges as the main result of urban planning, with a clear control of the urban form in the periphery in a tidy way of growing. Nevertheless it is more diffuse and scattered in the territory, more fragmented and less dense than in the case of the Latin American city (fig 1). This picture would be due to the higher level of income and economic performance and therefore could become a reality in LA in the future.

The population in EU is almost steady, there is also hardly any poor population settled in informal settlements; these were eradicated long time ago. Nevertheless European cities continue to sprawl. The phenomenon of sprawl is common to all cities independently of their geographical, economic or administrative characteristics (EEA 2002). In this urban development two factors play an important role: the intensive development of infrastructure (roads and highways, urban equipment, etc.) which is increasing the amount of available land for development by reducing the distances, and the absence of major geographical complexities (as mountains, sloppy territories, etc., despite some highly anthropogenic river basins). The conjugation of those factors with the fact of the permanent increase in the level of income of the population and the consequent desire for a detached house[10] outside of the city are changing the historical urban form in the continent.

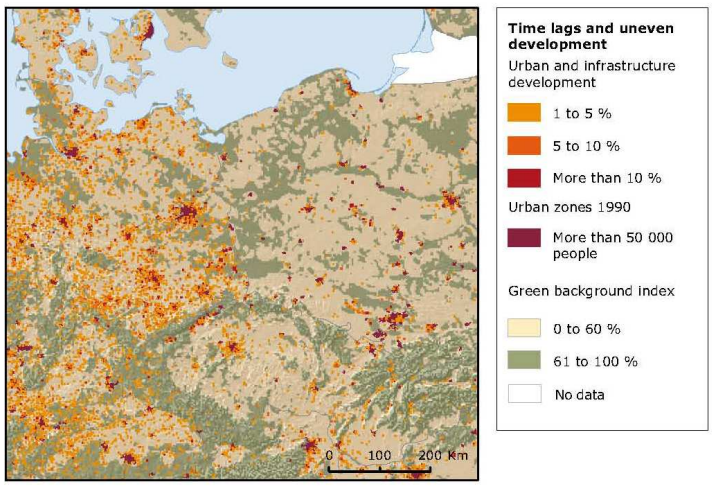

Fig. 4. Sprawl in EU. Source: Galster et al 2001. Source: EEA Report No 10/2006: 11.

[10] In general one of the perceptible effects of economical development is the increase in space demand per person.

European cities are losing compactness and urban sprawl is now a common phenomenon throughout EU with no apparent slowing down in these trends (EEA 2006). An average between 30% and 40% of built-up areas in the total urban area seems to be quite typical for most of European cities (Kansako 2005 et al), whereas South American cities have 70%.

In former socialist countries of Central and Eastern Europe, clusters of compact cities with high densities were common, reflecting strong regimes of central planning with public transport substantive unit prevailed during the communist era. Today these same cities face similar threats rapidly expanding like in southern Europe liberated land markets, and lower residential preferences evolved without planning controls. (European Environment Agency report No. 10/2006: 15). A better understanding of this urban expansion phenomenon driven by economic growth can be drawn from the comparison between former East Germany and Poland in 1990-2000. After reunification in 1990, the eastern part of Germany benefited from substantial monetary contributions coming from the western part and consequently became one of the most rapidly developing European regions. Poland on the contrary, only recently joining the European Union, was less developed in the same period of 1990-2000; the different levels of urban sprawl between the two countries are evident (fig. 5) (European Environment Agency report No. 10/2006: 10). The trend indicates the imminent European polymerization of urban development, indexed to higher economic development. Due to this reason, paradoxically, Latin American cities are more compact than European ones. The scattered urban development around the city core - polymerization of the territory - takes place only in the most dynamic LA economies such as in Chile and Argentina, where it is however often concealed as a suburbanization of agricultural land: the suburban-rural plot.

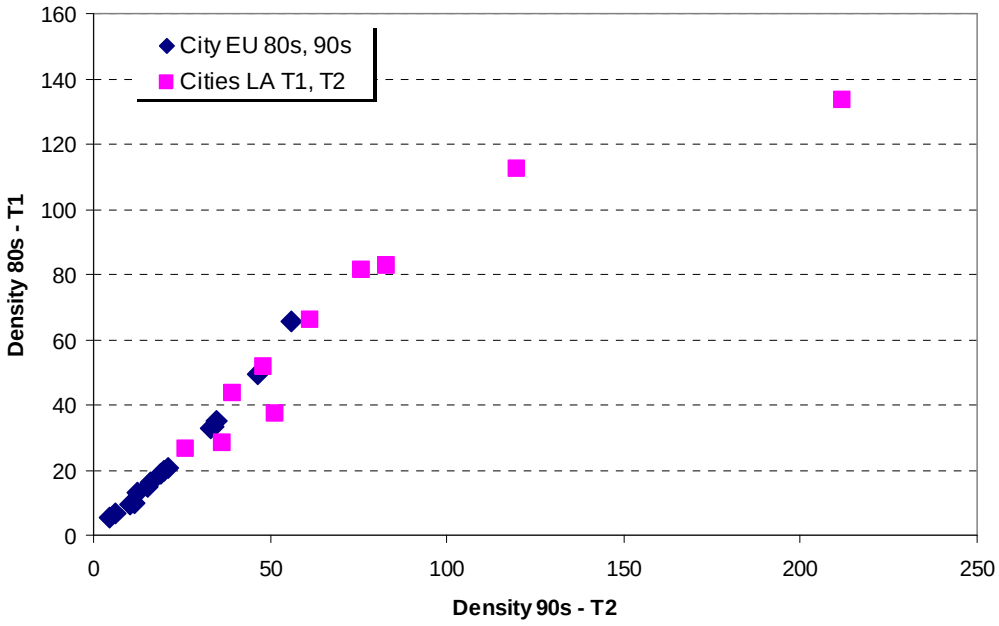

Fig. 5. Changes in density EU and LA. Source: EU cities Kasanko 2005, LA cities Inostroza et al.

The evidence shows that European cities are following a more scattered development pattern than cities in Latin America. This fact contrasts with the existing perception, even though from an economic perspective this behavior is reasonable: ... sprawl is no more or less than the efficient operation of the land market, and in this sense, is the outcome of a competitive process. (Batty et al, 2003:6, Traffic, Urban Growth and Suburban Sprawl). The empirical evidence contrasts with the perception, commonly prevailing in LA, of a highly compact European city, with developed models of effective planning guided by technical and competent institutions.

Higher density cities in EU found their point of comparison just with lower density cities in LA. While the average built up density of European cities in the middle of 1990s was 22 inhabitants per hectare, in LA it was 96 inhabitants per hectare. Despite the trend of declining densities of Latin American cities, the average remains high for 2010, above 104 inhabitants per hectare[11] (fig. 6).

In EU the general trend over the 50-year long study period shows a clear trend towards less intensive residential areas. Only in Palermo, Prague, Munich and Bilbao more than 50% of new residential development has been continuous. In all other cities the growth of discontinuous, less intensive residential development has clearly outpaced the growth of continuous housing areas. This is linked to the rapid decentralization trend which has characterized urban development in Western Europe since WWII. Although there is some evidence that the decentralization has slowed down, stopped and even turned into recentralisation in the 1980s in Northern Europe, if measured by population development (Cheshire, 1995), it does not seem to have reached yet the land use dynamics. Making cities more compact has already been for a while at the top of national (Williams, 2000) and European policy agendas (CEC, 1990, 1996). However, yet these policy efforts do not seem to yield visible results in the light of ongoing growth of discontinuous residential areas in most European cities (Kansako et al 2005).

In Europe, population and built-up areas have been growing at the same rate during 1950-1990. The other reasons for the growth of built-up areas are manifold and can be identified with rising living standards (more space per person), developing commercial and transport services (which require more buildings), changing living preferences (single houses preferred over blocks of flats) and changing land use policies (attitude towards compact/sprawled city ideal, etc.) (Kansako et al 2005).

On average the growth of built-up areas has been 87% from the mid-1950s to the late 1990s. The built-up area in most European cities has almost doubled during the past 50 years. The most rapid growth of built-up area took place from the 1950s to 1960s (Kansako et al 2005). French cities had doubled their built-up areas in only 15 years, between 1975 and 1990 (Kansako el al 2005, Clement and Guth 1995).

[11] Built up core density.

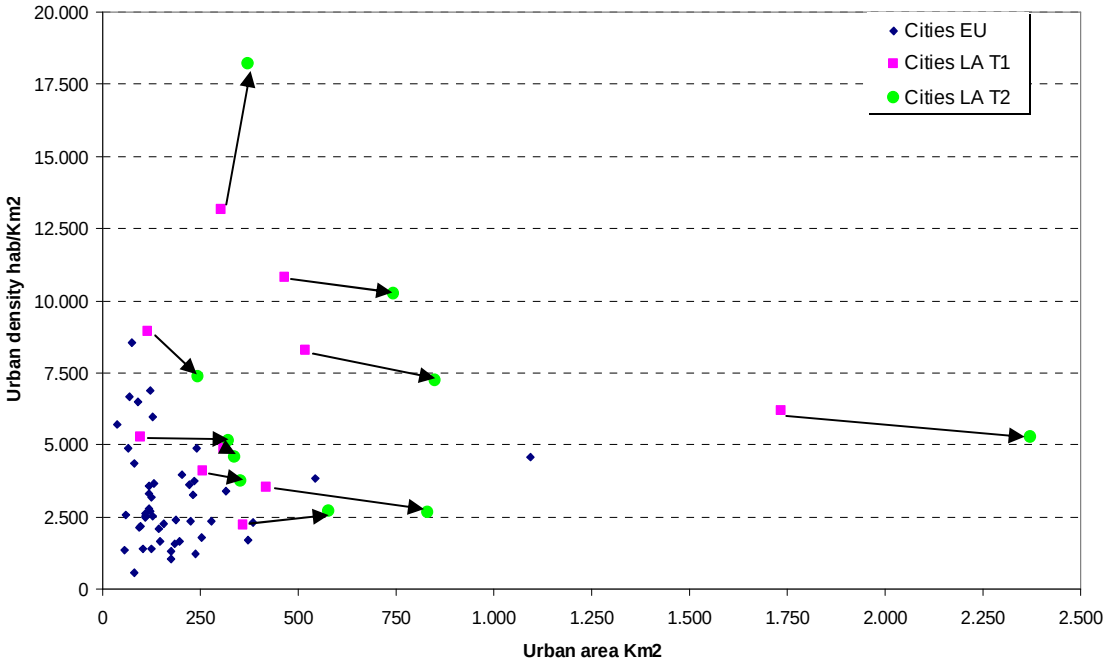

Fig. 6 Density and size in EU (1990s) and LA cities (T1 and T2).

To asses trends of density and fragmentation we used a set of 53 cities with population over 500,000 inhabitants[12]. The urban area of those cities tends to cluster bellow 400 km^2 with an average density of 31 inhabitants per hectare. Latin American cities are bigger, with sizes up to 800 km^2 and higher densities: Buenos Aires is the only city outside this cluster. At the same time, the average density/size distance beetwen cities is smaller in the European cluster than in Latin American one. This means that despite of the countries, cultural and other differences, the studied EU cities over 500,000 inhabitants tend to behave similar in the relationship density/size, than the behavior we observed in cities in LA (fig. 6).

When analyzing the urban form by the metrics of urban patches, it is also possible to distinguish those two clusters. Edge density (ED) tend to be higher in EU, despite the smaller mean patch size (MPS), which is the other metric used to asses fragmentation. LA cities have lower edge density and larger size of the mean patch (fig. 6).

In most studied cities in EU the land use dynamics have slowed down considerably towards the end of the 90s. During the 50s-60s the average yearly growth rate was 3.3%. It then dropped to 1.7% in 80s and when coming to the 1990s further down to 0.75%. Urban land use dynamics have reached a certain degree of maturity in EU because the yearly growth rate has dropped down drastically (Kansako et al 2005).

[12] An extraction from Schwarz 2010 original database.

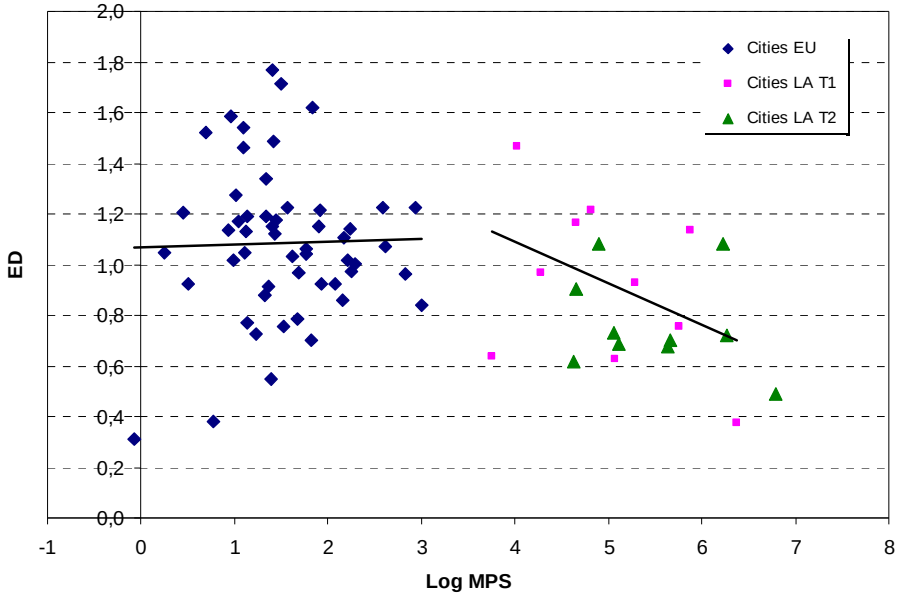

Fig. 7 Fragmentation: edge density and mean patch size.

Latin American sprawling processes

South America is one of the most urbanized continents in the world, where almost 84% (UN 2009) of the total population lives in cities. Thus, it is more urbanized than North America (82%, UN 2009) and EU (73%, UN 2009). Certainly the destiny of the subcontinent will be lead by urban development and driven by urban systems.

In 1950 three cities in South America were in the ranking of the 30 most populated cities of the world (UN 2009), where EU had nine. For 2005 South America counted four cities in the ranking and EU just two. For 2025 five South American cities and just one European will be in the ranking.

Among the studied cities in terms of population[13] we observe three clusters: Buenos Aires the biggest city as outlier[14], Santiago, Lima and Bogotá in the center cluster with populations in T1 about 4 M which reach around 7 M in T2 and the rest of the cities in the range of about 2 M in T1 and T2 (fig. 8).

If we add core density into consideration, the cluster of small lower dense cities (Asuncion, Brasilia, Córdoba, La Paz, Montevideo, Santa Cruz) remains, while Bogotá is taking distance from Lima and Santiago with almost double density (fig. 8). The Colombian city is the density outlier of the continent with values just comparable with most populated cities of Asia and also with an important increase (59%) during the study

[13] Core population.
[14] In the beginning of XX century Buenos Aires was the only Latin American city in the world ranking of 30 major cities. This feature has remained till nowadays.

period. At the same time Asuncion has increased its still low density up to 29%. This densification dynamic of both cities is completely different: whereas Asuncion was the lowest density city in the middle of 80s, Bogotá had got the highest density. In the case of Asunción, which is still under an important migration processes from the countryside, the suburban type of development is achieving better standards and higher densities, similar to the most developed cities of the continent where this migration process has already ended.

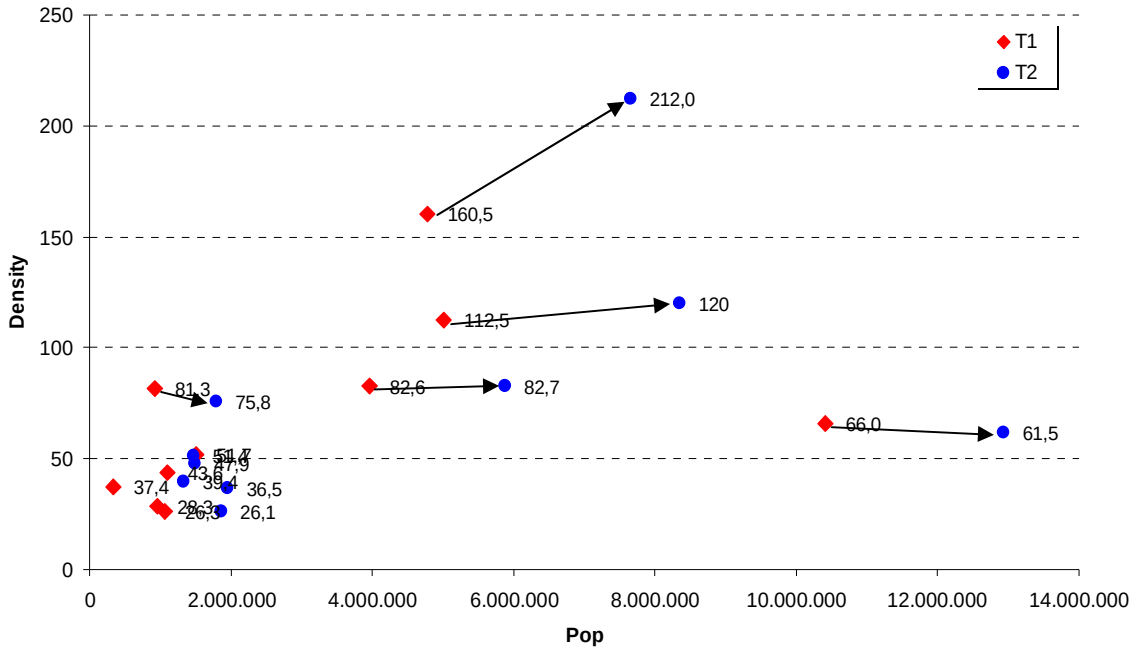

Fig. 8 Three clusters of population and density.

On the contrary, the cores of other six cities have lost built up density at an average of 14% from the middle of 80s till nowadays (fig. 8).

At the same time, beyond this general process of density decline, the population is losing weight as growing factor for cities. Major changes in the size of core area are no longer related to population increase (fig. 10 and 11). Cities in LA are growing in a lower density way not under the pressure of the urbanization process or population growth. This behavior was also observed in EU cities, mainly due to increases in the population level of income and the strong development of transport systems and infrastructure.

Clearly urban expansion is diverging from population growth; population and core size were correlated in 0.92 in the middle of eighties, in 2009-2010 the correlation reduced to 0.80. Cities in LA are growing fast whereas population is losing weight as a driving force, in similar way that European cities already did. Lack of density and increase in the GDP are playing an important role in this trend. The first factor is a matter of land policy whereas the second one is just a matter of fact.

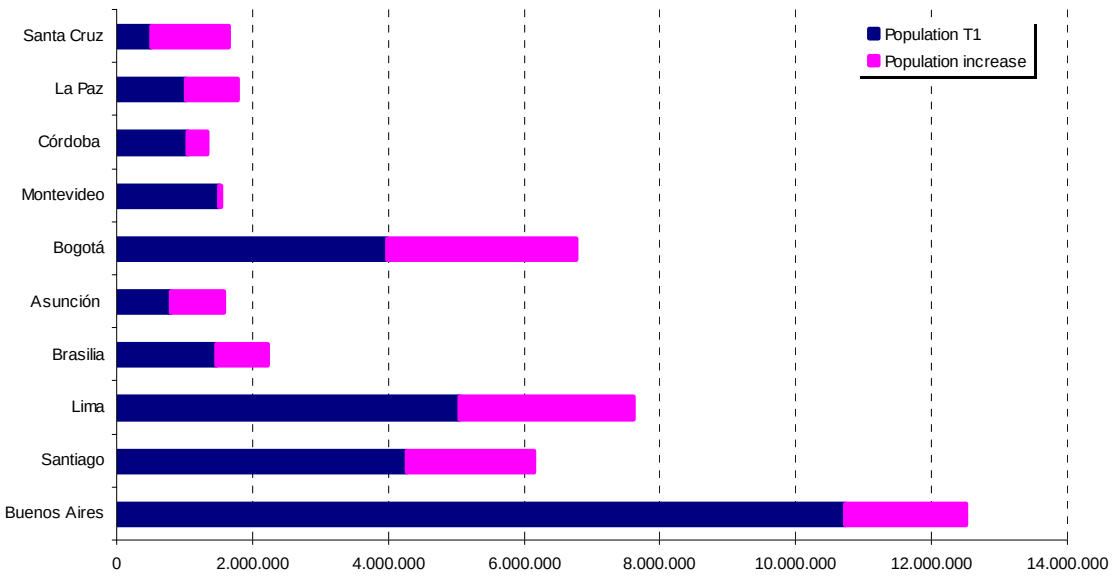

Fig. 9 Population size and increase.

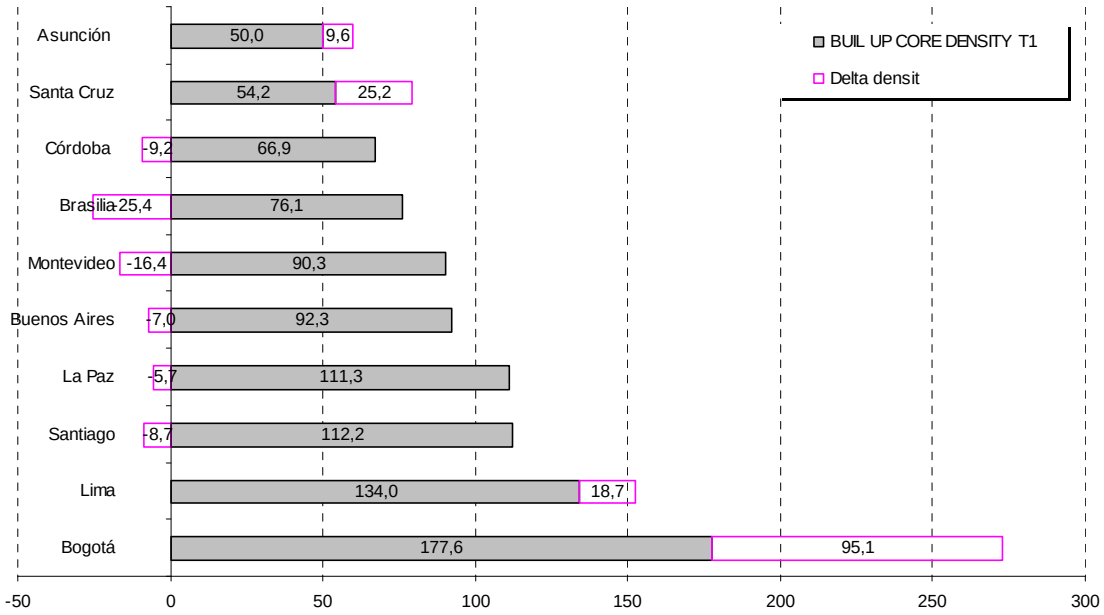

Fig. 10 Core densities in T1 and changes.

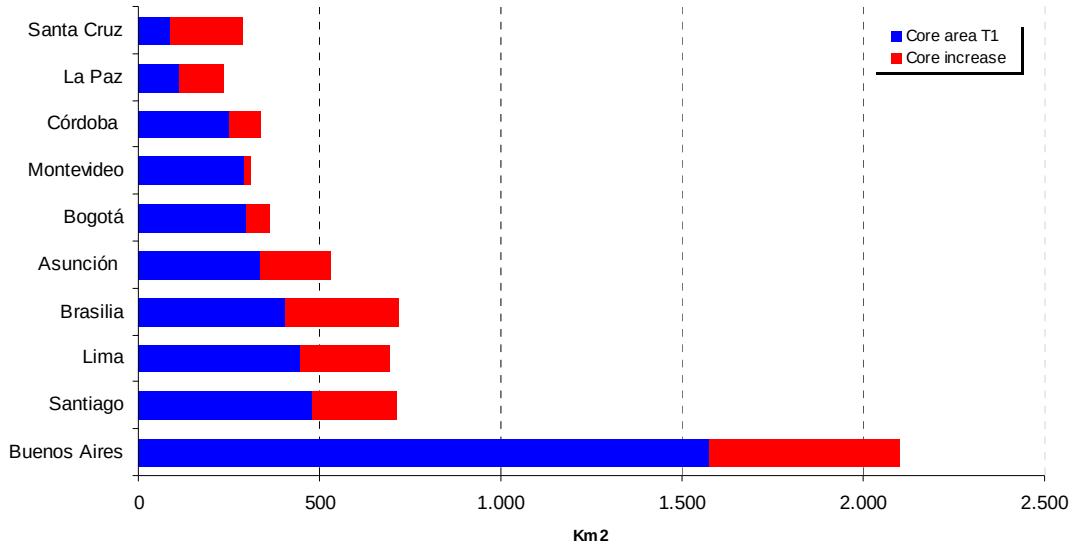

Fig. 11 Core area size and increase. Correlation between city size and core increase is 0.83. Cities are growing according to its size in a kind of inertial behavior: bigger cities grow more and faster than smaller ones. Correlation between city core size in T2 and speed of the fastest vector is 0.7.

In all the Latin American cities studied, the average core population growth was 55%[15] between T1 and T2. The average core area growth was 67%, urbanized area 73% and built up in fringe 240%. The spatial pattern of the increasing urban areas is clear: core areas are growing in size on average similar to the increase of population, but suburban areas (i.e. the built up area in the fringe) almost doubled their amount not following demographic behavior. The core area is matching the population increase by growing an average of 2.9% per year. All development of the built up in the fringe is sprawl, in some cases very strong: Brasilia 711%, La Paz 536% and Santa Cruz 356%; in Montevideo 44% the minimum change.

Urban development after population growth was a relevant issue since the second half of XX century among LA continent: the so called urbanization process (ECLAC). The urbanization process was led by emigration from rural areas to the cities and it was the main factor to explain the fast growing performance of LA cities. Nowadays the demographic dimension is very diverse: demographic transition and other major changes vary between countries determining sprawling process with very different realities. In cities with lower economic performance, as La Paz and Asunción, the rural migration to the cities is still taking place. These cities are growing after urbanization process produced by people coming from the agricultural-farm areas more than the urbanization after population growth rate. Cities in Argentina, Chile, and Brazil, experienced that phenomena 50 and 40 years ago and now are facing a different stage, more similar to the

[15] Not considering Santa Cruz, the outlier, with the growth of 346%.

performance of EU cities. In Montevideo or Santiago the demographic transition is in the advanced stage already and the both cities are losing net population (Rodriguez 2009).

Nevertheless according to the UN estimations population is strongly growing: for 2050 urban population will increase 34% in the South American continent. In most urbanized countries as Argentina, Uruguay and Chile this increase will be close to the average (34%), in others will be very high, like in Bolivia (84%) and Paraguay (99%). Despite of the divergence in the population size and urban expansion this increase will have an important impact in the territory. The effect could be even worse if the trend of sprawl and diminishing densities persist.

Expansion of core areas has been relevant during the past two decades; increases in built up areas of cores have showed an average of 77%. Just Montevideo is steady, both in size and population (fig. 10, 11). On the contrary Bogotá, Lima and Asuncion have increased their population more than the size of the core, thus are still in a densification of the inner city process, Bogotá with the highest built up core density among the continent, 272 inhabitants per hectare. In the case of Lima most of this densification process is the result of serious land availability restrictions and despite of the lack of density of some very central districts (see density files).

Even though core and urbanized densities are still high in the continent, with an average over 75 inhabitants per hectare in T2, they are decreasing (Fig. 10). Six cities are decreasing their built up core density on an average of 14% since middle of 80s, some of them like Brasilia and Montevideo at important rates (-34%, -18%). This decreasing might show a spatial divergence process which is changing the population distribution into the urban structure (see below density structure and changes).

Under this persistent urban expansion scenario the way the cities will expand could make a big difference - or not. If the average land consumption continues at the same annual rate as it has during the past twenty years the urban core area of major cities in South America will be duplicated by 2035. This would be even more dramatic if densities persist to decline at similar annual rates as now. Urban expansion is a matter of fact, falling densities and the very diverse land consumption ratio a matter of land policy.

Not just urban areas are growing faster than their populations (73% v/s 55%, both not considering Santa Cruz); also the amount of the per capita land consumption is high. Here again we found enormous differences: with an average per capita land consumption of 316 m^2 per year in the ten cities, Bogotá consumed just 23 m^2 meantime Montevideo 1,378 m^2.

The changes in the population growth rate does not bring by itself any decrease in the amounts or rates of land consumption: Montevideo with the lowest demographic change and the highest per capita land consumption is an example. Therefore those parameters must be lead by land policy.

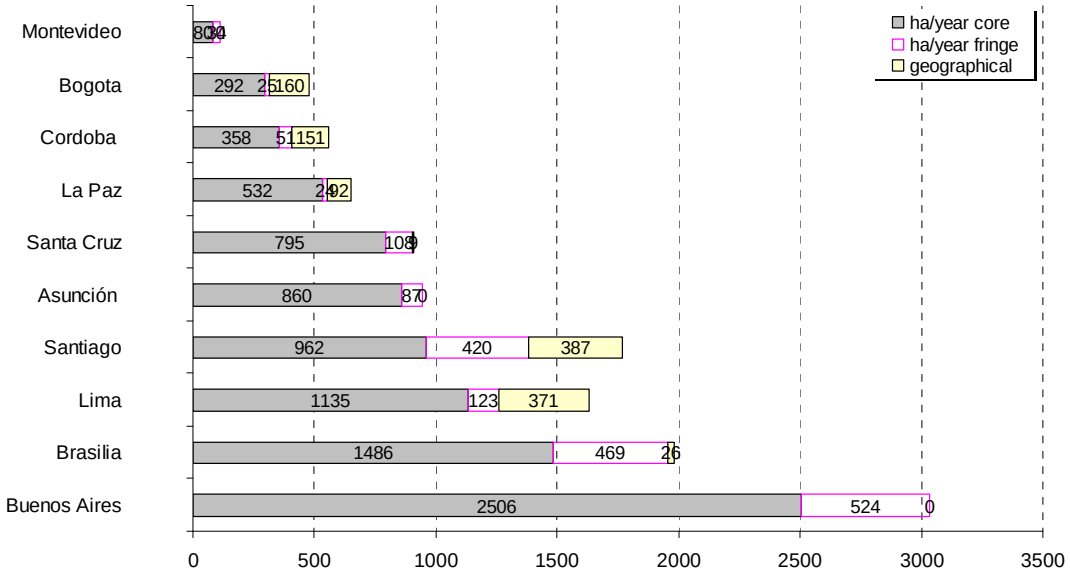

Fig. 12 Per year land consumption amount.

Spatial behavior of LA cities

To achieve a better understanding of urban sprawl it is necessary to have a closer approximation to the specific spatial behavior of every city looking also at the densities configuration into the urban structure. The aim of a compact development will be difficult to achieve if we cannot adjust those differences into the inner city spatial structure. Besides of the social consequences of the observed spatial density divergence which is highly related to socio-economical status.

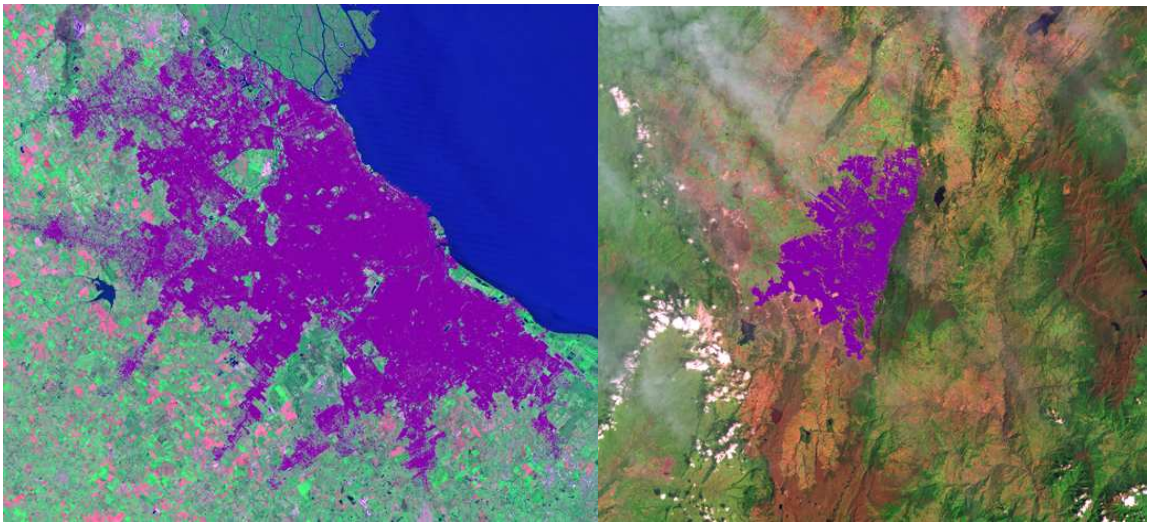

Fig. 13 Buenos Aires and Bogotá Sprawl v/s compact in LA. From the two images above, it is immediately evident that Buenos Aires is more sprawled and scattered than Bogotá, which is more compact. Buenos Aires core area is 6 times larger than that of Bogotá

(2,103 Km^2 vs. 361 Km^2), while its population is only two times bigger (12.9 million v/s 7.6 million). The images are at the same scale.

To asses the spatial evolution of the studied cities we compared the share of infill, axial and isolated built up area between T1 and T2. We also estimated absolute and net efficiency of infilling and axial patches while considering open spaces in new built up areas. All fringes in LA are growing faster than cores at an average of 249%[16]; Brasilia has got nowadays 711% more isolated built up area in the fringe than it had in the middle of 1980s. Montevideo has increase in 44%, the lowest change of all the studied cities.

These changes are presented in fig 14. All cities have experienced an increase in the ratio of built up area in the fringe over all built up area: the average of built up area in the fringe was 8% in T1 and 12% in T2. Brasilia for instance had 9% of all the built up area in the fringe (isolated) during the middle 80s, and that percentage has more than doubled up to 23% nowadays. The average for studied European cities is 27%.

The rate of increase corresponds with the spatial configuration of new development in every city (see Annex 1).

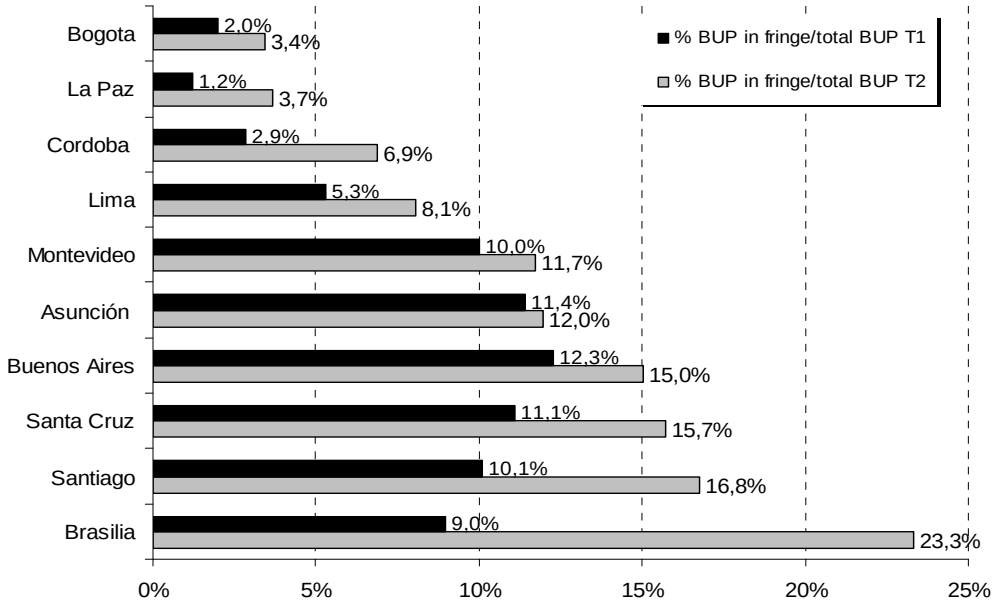

Fig. 14 Changes in the percentage of built up area in the fringe over all built up area.

Not just the ratio of built up area is moving towards fringes – which means by itself as sprawling process - also the net efficiency of this process is low: the average net use of infill[17] is only 36%. Despite the fact that all cities are fulfilling their infill areas, the growth into axial and isolated areas is more prominent. This is placing the trend of urban

[16] Cores growth an average of 67%.
[17] This is the ratio of built up in the infill area over all infill area discounting geographical constraints.

development in LA towards increasing sprawling behavior: growing by adding small, patchy areas of newly developed land located further from the established core, instead of growing by adding plots at the edge or adjacent to the urban core, mostly in the infill area aiming to reduce fragmentation.

The efficiency in the use of infill is led by percentage of increase of the core area, with a correlation of 0.7, followed by surface of geographical constraints with 0.5 and finally by population growth with 0.28 of correlation. This low spatial efficiency shows the inertial urban spatial behavior under market conditions: the cities are growing by using just 1/3 of the available land in the infill area and leaving the rest as fragmented open space. This spatial assignation shows the basic adjustment of economical factors in their search for profits – the best and more profitable land for development – and leaving the rest behind as a residue. At the same time this low efficiency in the use of the infill area is inversely correlated to the motorization rate[18] in -0.59; thus transport system is playing an important role in this sprawling pattern: major availability of vehicles allows less efficiency in the use of infill area.

Urban sprawl is strongly connected to economical factors as GDP or the weight of the construction sector in the economy. The correlation between rates of investment[19] and amount of land consumption in ha/year is 0.6[20]. As the profits of the construction sector increase, further sprawling patterns might be expected. Such patterns emerge following the economic performance of countries and cities. As the population rate is declining the city grows as a business.

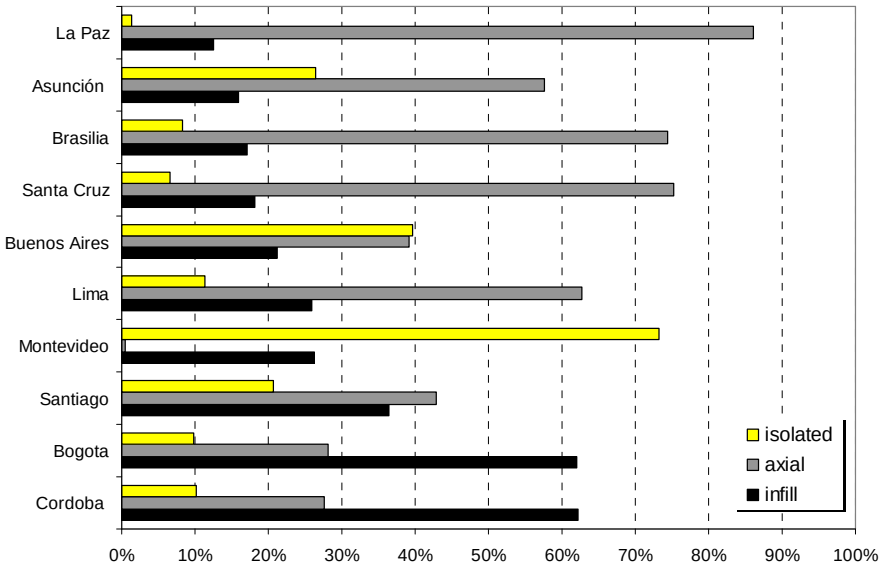

Fig. 15 Spatial arrangements of newly built up areas.

[18] Vehicles per 1,000 inhabitants.
[19] As a percentage of GDP. Direct correlation between GDP and land consumption is smaller, 0.43.
[20] Buenos Aires and La Paz were not considered in this calculation.

INSERT HERE ANNEX 1 INFILL FILES

Density structure and changes

Density is by far the least homogeneous parameter to characterize cities. Thus, it seems necessary to have a more detailed assessment into the inner densities of cities. Similar differences to those we found between European and Latin American densities are also taking place within the same urban areas. According to specific measures there is evidence that suggests some characteristics of development patterns differ significantly within and across cities and over time. Asuncion, Bogotá, Lima and Santa Cruz increased their built up core density, while the cores of other cities were losing population. We calculated gross and net density ratios for T1 and T2 to show those differences (see Annex 2).

One common and well known phenomenon is the lack of residential density of the CDB due to land use changes and/or deteriorating conditions which are expulsing people from historical centers. But similar asymmetries to those that can be found when comparing rich countries with poor ones are taking place in new urban areas. This fact is connected with two asymmetries, the social and the economical: the social asymmetry corresponds to the inequity of societies where high classes are building low density environments, with high level of land consumption, facilities, high demand of infrastructure and open space and pulling out the edges of cities dragging development behind them, meantime the unprivileged are accessing either public housing solutions or just illegally occupied land but commonly in highest densities without minimal conditions. In South America, high classes are trying to build a kind of American model of low dense city for themselves, while an organic crowded development of slums is a common solution for the unprivileged. Both are informal developments, both are either jumping over or avoiding urban regulations.

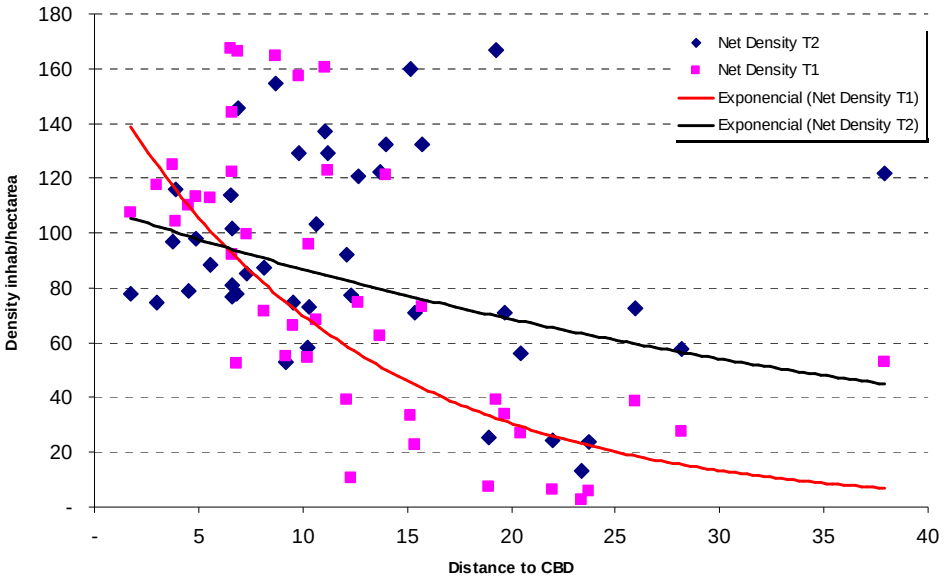

Fig. 16. Changes in the built up densities and distance to city center in T1 and T2 in Santiago.

INSERT HERE ANNEX 2 DENSITY FILES

At the same time, the divergence of densities might be interpreted as an economical asymmetry, where the differences in densities among the periphery are the physical expression of the process of grabbing profits by developing instant new urban tissue. Where the density used to be a smooth gradient from a city center towards a periphery, reflecting both the diminishing population and the size of the plots changing from the small urban plot towards the big rural plot, the pattern is now shifting towards a kind of polymerization of the periphery where we can find areas of urban density surrounded by characteristic large rural plots. Spatial fragmentation is a typical expression of that density/plot size asymmetry in the periphery.

This fact is changing the spatial arrangement of densities. The well known exponential curve from the CBD towards the periphery (red line fig. 17) is changing its slope: while city cores are loosing density, peripheries are increasing it (fig 18).

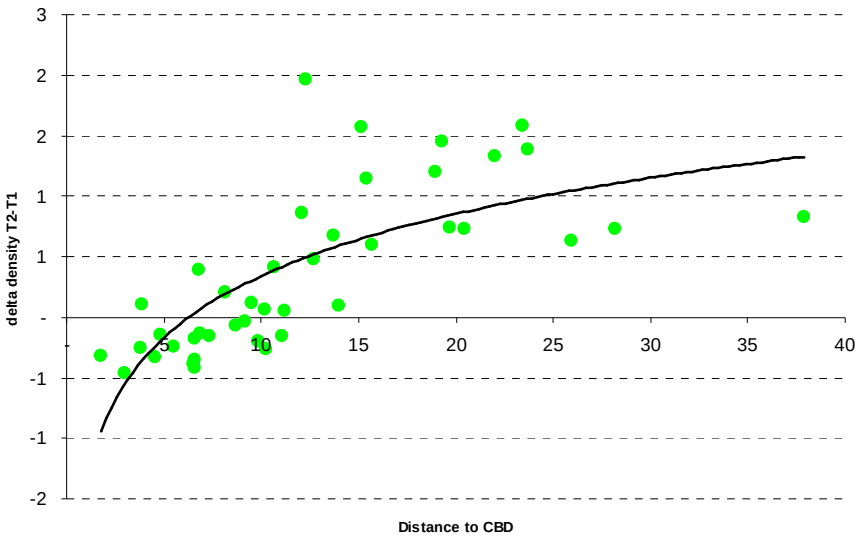

Fig. 17. Changes in density in Santiago T1 and T2.

This new spatial arrangement of cities is showing a new scenario: in Santiago in T1 the correlation between density and distance to city center was -0.65; in T2 decreases to -0.21. The trend seems to be that density is not longer depending on the CBD distance as it was in the middle of 20th century following Clark´s findings. In the beginning of 21st century this spatial pattern seems to be changing; these are a symptoms of the fragmentation process of the peripheries. However, more empirical studies are needed to proof this hypothesis.

This phenomenon is also raising another question: Is it possible that cities as a whole (core areas) are losing density while peripheries are in a densification process? Our evidence seems to show the existence of a spatial divergence process of density differentiation which is not longer depending on the distance from the city center (see annex 2 density files). However, this ongoing process of building up new urban development with asymmetries in the distribution of densities seems to follow market rules.

Another changes

Productivity differentials do not coincide systematically with differential migration (rural-urban migration) as it used to be the case in the past. The rural areas close to the big cities have become attractive to families of middle and upper classes to grab the benefits of suburbanized metropolitan areas but avoiding its disadvantages. Intra-metropolitan migration has become a powerful force for the expansion of cities and depends on this endogenous centrifuged urban migration but not on the rural-urban migration as in the past. This new kind of migration has crucial implications in the use of urban infrastructure producing saturation either underutilization (Rodríguez 2009).

For instance in the metropolitan area of Buenos Aires, and also in some other large Latin American cities, the industry has shifted from the central areas to the outskirts of suburban municipalities. A specific set of diseconomies of agglomeration arising in the urban system determine this migration: high cost of land, restrictive environmental laws, costs and timing of intra-metropolitan transport, higher salaries, and so on; public policy towards diconcentration works in the same direction (Marquez and Pradilla, 2008 in Pradilla 2010:519).

It is also necessary to consider the spatial integration of metropolitan processes (conurbation), which is taking place across political administrative boundaries and is not yet being recognized by official statistics in Asuncion, Bogotá, La Paz, Lima, and Montevideo.

This entire panorama is changing the very inner structure of cities. This polarization is bringing an important stress to the urban systems as the divergence in the densities has clear social attributes: higher classes are running away from the cities, using new and modern infrastructure (paid in many cases), and increasing land availability ratio per person, while at the same time unprivileged groups struggle to find a place in the city.

Transport: the suburbanization of the population

Transport is certainly a key factor to understand urban sprawl which is led by this suburbanization process. We can analyze the urban transport dimension under the demand supply perspective. The supply refers mainly to the infrastructure provision, which has been completely different across the continent with specific and sometimes asymmetric differences. Demand refers to the use of that infrastructure as motorization ratio for instance.

Historically, the structure of the Latin American capitals developed from a colonial military headquarter and administrative centre of the civil and clerical power. From and to this orthogonally designed mono-centre, the land was developed along radial axes. This principle structure left its footprint on the urban areas investigated until today, with Brasilia being a historic exception.

A certain distinction can be made with respect to natural boundaries, i.e. oceans, rivers, mountain ranges, which give a half symmetric structure to most of the cities: these are Bogotá, Buenos Aires, Montevideo, Asuncion, Lima and Santiago.

The urbanization process in most cities developed in the period between 1930s and 1970s. From 1970s until the 1990s an acceleration of rapid urbanization and growth can be observed with various intensities. Drug and civil wars and the different economic developments were drivers of urbanization in these decades. Suburbanization took place from the 1980s, and in its early phase, it was an almost uncontrolled process of illegal housing, in which infrastructure development was only reactively following the new settlements. Development of road infrastructure takes about 10-15 years after settlement, and costs tend to be up to 5 times higher if the infrastructure follows instead of being developed ahead. Today, commerce and industry in most cases are main drivers of the suburbanization process, determining land-use and infrastructure.

Along with the increasing degree of motorization from the 1980s on, traffic tended to collapse within the historic centers, due to the unfavorable structure of the road network with few radial arteries and lack of concentric connections.

An exception is Buenos Aires, where this development was some 50 years ahead before it started to stagnate in the 1990ies. The city has been served by a rather efficient radial rail-based public transport system. After subventions being cut by the military government in the late 1970s, urgent maintenance of the system has not been carried out, initiating an accelerated deterioration of the system, which continues until today.

Montevideo responded to the increased traffic by developing a ring road at a distance of approximately 30 km from the city centre. This has recently led to an increase in land prices that at some parts of the hinterland became even higher than in the centre areas in Montevideo city. This has been determined by the strong harbor role of the city which is increasing land demand for warehousing. In some areas favorable for logistics, land prices increased up to 7 times after the development of this ring road.

Asuncion, being built on an erosion prone area has an orthogonal network rather unsuitable for its topography and the concentric structure. The city has a very low density, and therefore limited potential for public transport. Asuncion is facing a degradation process of the historic city centre that lost its economic and political administrative role. Whereas the CBD functions moved into a neighboring residential area without adequate infrastructure upgrade, industry and commerce develop in the northern part around the airport, and administration moves towards eastern suburbs. The CBD shift initiated a slow displacement process of residents in the area. Traditional suburban settlement does not develop from a rural nucleus, but along the radial connections to the hinterland. There is political will to strengthen the developed radial structure and the concentric connections, and at least the administrative suburb in the east shall get BRT connected in 2013. Lack of significant investments into public infrastructure over the past 20 years has led to a non-existing public space, and resulted in a legitimacy problem of the city.

The municipality of Bogotá has been investing into the development of the Transmilenio BRT system since the late 1990s. Extensions in 2005 and 2010 were co-financed then by the national government. Bogotá achieved much higher degree than the other cities in that accessibility of the city and its opportunities for large parts of the citizens. Here, the public transport system creates democratic public spaces which can not be found as such to be developed recently in the other cities.

Similar to the infrastructure provision, motorization ratios also differs across the continent. However, we found a high correlation (-0.59) between vehicles ownership and fragmentation (spatial efficiency of new urban development, see page 29 and fig. 19). In the growing process of cities, the less use of the infill area is taking place in the cities with higher amount of vehicles per inhabitant.

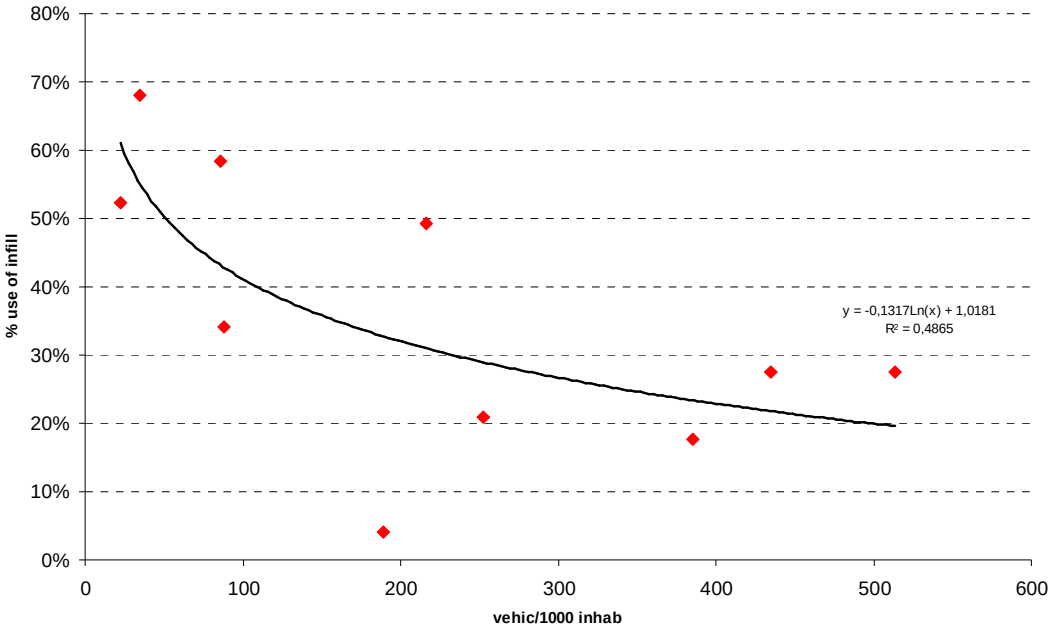

Fig. 18 Correlation between motorization rate and use of infill.

This correlation reflects the link between the commuting possibilities and the spatial arrangement of new urban areas. Preferences of people are following what housing markets supply, while these are offering again what people prefer, in a kind of vicious circle. In the actual situation, rather than the provision of infrastructure the car ownership seems to be the driving force of this fragmented spatial arrangement.

From the economical point of view the argument of the economical efficiency of the people's preferences has been largely promote. Some economists argue that if the people are taking specific options it is a rational decision which is not possible to cut off (Balmaceda in Galetovic et al. 2006):

"If customers decided to locate themselves in the periphery despite of everything it is just because the benefits are higher than the costs, including those due to new infrastructure

needs… if properly fee charged all the city and even though the customers decided locations in the periphery it is just because they prefer this location despite of the savings they could achieve by seizing the city slack…" (Balmaceda pp 155-156 in Galetovic et all 2006).

Economists believe that three underlying forces — population growth, rising household incomes, and transportation improvements — are responsible for the spatial growth of cities. As the nation's population expands, cities must grow spatially to accommodate more people. In addition, rising incomes affect urban growth because residents of the city demand more living space as they become richer over time. By itself, the greater demand for space causes the city to expand spatially as dwelling sizes increase. In Santiago for instance even though the core density remains steady, the built up core density falls by 8%. This effect is reinforced by the residents' desire to carry out their greater housing consumption in a location where housing is cheap, namely the suburbs. Thus, the spatial expansion due to rising incomes is strengthened by a price incentive favoring suburbanization (Brueckner 2000). A similar phenomenon occurs in response to investment in freeways and other transportation infrastructure. Because such investment makes travel faster and more convenient, thus reducing the cost of commuting, consumers can enjoy cheap housing in the suburbs while paying smaller commuting-cost penalties. As a result, suburban locations become increasingly attractive as commuting costs fall down, which spurs suburbanization and leads to spatial growth of the city. Does the invisible hand, which guides the conversion of land to urban use, push too hard in the direction of bigger, low dense cities just for those willing to pay? (Brueckner 2000).

In fact, economists have identified several market failures that may affect the urban growth process, encouraging the asymmetric competition between urban and agricultural uses which outcome has increasingly tipped in favor of urban use, leading to substantial spatial growth of cities. Market failures may lead to excessive spatial growth of cities.

Economists use the term *market failure* to describe a situation in which the invisible hand fails to allocate resources in a socially desirable manner, so as to maximize aggregate economic well-being. A market failure arises when economic agents face incentives that are distorted because of institutional failings or some other reason, leading to economic outcomes that are unfavorable from society's point of view. The classic example of a market failure is air and water pollution, where a factory has little incentive to take account of the environmental damage it causes and, thus, ends up polluting too much. Is a similar market failure involved in the spatial expansion of cities? If so, the criticism of urban sprawl is justified, and measures are needed to restrict urban expansion (Brueckner 2000). In this uncertain situation, city planners lack tools to measure, monitor, and understand urban sprawl processes. On the other hand development appears artificially cheap from the developer's point of view, encouraging excessive urban growth.

Discussion

In this part, two methodological aspects of our research will be discussed: estimation of population in the periphery, and quantification of open space being captured by urban development.

We are measuring population increases among specific spatial units on one hand, and the continuous urban fabric – and its density – of each city on the other hand. We know that assumption differs if we consider the urban function. Also to have good spatial estimations among different sizes of census units is complicated. Under this complexity it is normally accepted the gross density for the whole administrative city, or smaller estimations for smaller spatial units, where in many cases mainly in the periphery are mostly rural land and bigger districts resulting in underestimated population density. This is particularly important in order to assess densities in new urban developments, however we depend on the data availability and the possibilities to come up with a common frame for different countries. We tried to settle densities in the smaller scale available, but here is still much work to be done for future research. Gross density estimations and big census districts in the periphery are hidden the sprawling process.

We assumed that all population in the districts lives in the built up pixels, which means that we assumed null population value for the agricultural land. This implies that we are using partially population scattered distributed in all rural area within the district (over estimation). Second assumption was that built up area within the specific districts has got homogeneous spatial distribution of population, thus homogeneous density. This spatial assignation of population is methodologically more robust than just using the administrative density or another modeling starting from already estimated densities. However a smaller level of disaggregation of the population data (blocks, smaller districts) might help to better spatially address population and density.

Second aspect to be discussed is the scope of the quantification of open space being captured by urban development. As we explain in the methodology we developed a method to catch suburbanization in the periphery by using the continuity concept. However after the continuity of the urban fabric is interrupted we cannot directly measure the capture of open space in the fringe, not with LANDSAT imagery as main source. Without appropriated ancillary data or land use maps it is not possible to directly measure how much open space is being capture by new development into the fringe. Thus, we measure just built up pixels, which is in fact an underestimation because we are not considering all land being transformed into urban use, such as playgrounds, cemeteries, sport facilities and all others land uses invisible to remote sensing technologies. Even though there are some possibilities of estimation we preferred the direct measuring in this research. With appropriate ancillary data (from cadastre or similar) and very high resolution imagery it would be possible to measure more accurately the amount of urban open space in the fringe. With such measure the impact of urban sprawl will be certainly bigger than it was address in this research and this topic opens the need for further research to better understand this issue.

Conclusions

The hypothesis of this research is that the Latin American city is more compact and less fragmented than the European one. Densities are higher in LA and peripheries are less fragmented when the geographical context is taken in consideration. The lack of maturity in the Latin American economies explain this surprising fact, however the cities are expanding fast and in significant rates. Urban sprawl should be an important matter of land policy, where markets might increase the fragmentation in new developments. Stakeholders are competing to grab the land rent and seriously affecting the possibility for better social and spatial arrangements under the long term perspective.

In the current scenario of constant urban expansion, the question for the urban planning is what the acceptable degrees of sprawl and fragmentation are. Urban expansion will inevitably take place, most cities in Latin America will duplicate its size by 2035, and thus the main concerns should be about its spatial configuration. The expert perception in LA sees cities extending endlessly across the hinterland in a deregulated and chaotic continuum. However our empirical analysis shows a different reality: Latin American cities are more compact than European ones.

Urban sprawl as specific spatial development pattern is being led by economic dynamics of both the city itself and the country, while the factor of population dynamics is losing its importance. The weight of the construction sector in the economy, as the percentage of the GDP in investment, is also playing an important role: the city behaves as a business, it is not longer - and only - responding to the spatial needs of the society as it was in the past but following a kind of hunt for profits led mainly by the importance of the construction sector in the economy[21]. At the same time higher levels of sprawl and fragmentation are correlated with higher motorization rates.

In spite of its bad reputation, the urban expansion in LA is quite compact and continuous, regardless of its high speed and amount. However, as urban systems evolve and the national economies reach stronger performance, cities will certainly expand more and faster.

The comparison allows for drafting certain expectable scenarios for the urban development in the continent. The cities seem to follow some similar spatial behaviors under certain scale, which overcome local differences.

The infrastructure and the increase in land availability under expansion scenario are playing an important role in both continents. This dispersion pattern of urban sprawl expresses the adjustment factors as the spontaneous tendency is short-term economic maximization. When the geographic variable is losing weight, a more diffuse expansion appears which is directly correlated with income and investment in infrastructure (GDP).

[21] The Madrid (Spain) real estate bubble in the last economic crisis is a good example of that.

Addressing the general expansion scenario for cities and by using certain metrics our aim was to improve our understanding of sprawl in LA and it characteristics: cities will grow, it is unavoidable, but how to manage this urban development in the highest compact way is a matter of land policy. Characterizing expansion and sprawl would open new ways to manage urban development under market environments, where the different kinds of urban developments should not receive same legal and tax treatment.

Our spatially explicit classification is aimed to give some light to priorities for new urban developments and some possibilities for differentiate their legal or tributary regime. As land is a scarce resource, one possible discussion is the feasibility of spatial differentiation for legal and tax treatment.

Urban planning is normally understood as a matter of "physical planning", which is necessary but not sufficient. Under market conditions it seems to be necessary to include also economical regulations for urban development. However, when talking about spatial development, an appropriate spatial addressing of those patterns seems to be necessary.

Local governments are constantly in a fight for gaining new and better incomes, in most of the cases being a partner of sprawl instead of taking control of it. This is a rational behavior: the governments receive regular payments from the new urban development and they postpone (for future administrations) all its undesirable effects: "the money speaks". On the other hand regulations to the supply seem to be complex as they appear as *restrictions to the desirable development* or, as the orthodox economics normally asserts: the people know what they want: preferences rules. If people decided for a specific kind of housing with specific features it is certainly a rational decision; and it is correct, the preference for detached houses with gardens is a rational decision, but those who are taking this decision are not paying the major costs of such kind of development; this is being paid and prorated by the society as a whole, meantime those new dwellers enjoy what they could choose as a way of life.

However this has got other implications. The first is that the question whether to allow or to regulate sprawling development is not just a matter of money or internalization of its higher costs. It is also a matter of sustainable development where all societies should contribute to achieve better performance of our urban systems. Especially in the case of Latin American continent, with its higher levels of biodiversity, uncountable ecosystem services providing welfare to the people and so on, it is certainly a matter of public interest to manage sprawl over the territory at the scale urban sprawl is taking place. Sprawling impacts, into and out of the cities, result from the absolute values of land consumption and not from the overall rates of the sprawling, which means that even under a scenario of diminishing rates the impacts of urban sprawl will be important. On the other hand, Latin American cities are facing an enormous problem of poor informal settlements. Inhabitants of those settlements lack other options and their housing solution normally appears as an emergency that eventually becomes the permanent solution.

If we can characterize sprawl under certain metrics, and reach a kind of quantitative agreement on which spatial development is not desirable, next steep is to assess better ways to include those results in the regional urban planning. As it is said above, it is

necessary to include economic tools in this planning process. One option is to try to influence personal decisions of the new dwellers by spatial differences according to the locations and features of new developments. If we succeed in addressing certain thresholds to control urban sprawl then it would be also possible to apply a differentiated tax policy for densification and infilling, thus encouraging developers and dwellers towards smarter and more efficient options of city's growth.

Nowadays the trend is paradoxically the opposite one: municipalities are charging higher taxes in historical consolidated areas which are suffering from the process of expulsion of population and deterioration, while at the same time the suburban developments in rural areas seize the benefits of lacking urban regulations and lower land taxes.

The way cities expand matters.

City data sheets

INSERT HERE ANNEX 3 CITIES DATA SHEETS

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