Metropolis :A Measure of the Spatial Organization of 7 Large Cities

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A city is a very complex object. Its complexity is compounded by its constantly evolving shape and structure. To try to understand a city's inner mechanisms we have to develop models that are simple enough to be easily understandable but accurate enough to be operationally useful. This paper attempts to present this type of simplification. Our objective is to provide a tool that planners can use to implement municipal development strategies. These strategies may concern the quality of the environment, the efficiency of infrastructure network, the growth of employment, or housing affordability. The job of the urban planner is to identify the type of spatial organization that is compatible with the municipal strategy, and the regulatory tools and infrastructure investments that will allow a city to evolve from its current spatial organization to the one implied by the strategy.

The complex economic and social relations that gave rise to the emergence of large cities produce a physical outcome – the urban built-up space – which can be mapped and measured. While we may never know with precision the nature of the forces that produced the built-up space we are at least able to measure the end result. The new technology developed during the last 30 years – satellite imagery, digital mapping and geographical information systems – allow us to have a much better knowledge of the urban shape than was the case in the past. At the same time, because the number of megacities in the world is increasing rapidly, monitoring and managing their spatial expansion is much more complex than in the past.

A. How to define a city's spatial structure?:

The spatial structure of a city can be defined by two complementary components: first, the spatial distribution of population as recorded by census data and second, the pattern of trips made by people when they go from their residence to their place of work, to schools, shops, social gatherings and to any other places where they will have a productive or social activity. The spatial distribution of population is therefore a static representation of the city when its people are at home, while the pattern of trips is a schematic view of the complex trajectories that these same people will follow during the time they are not at home.

1. Distribution of population

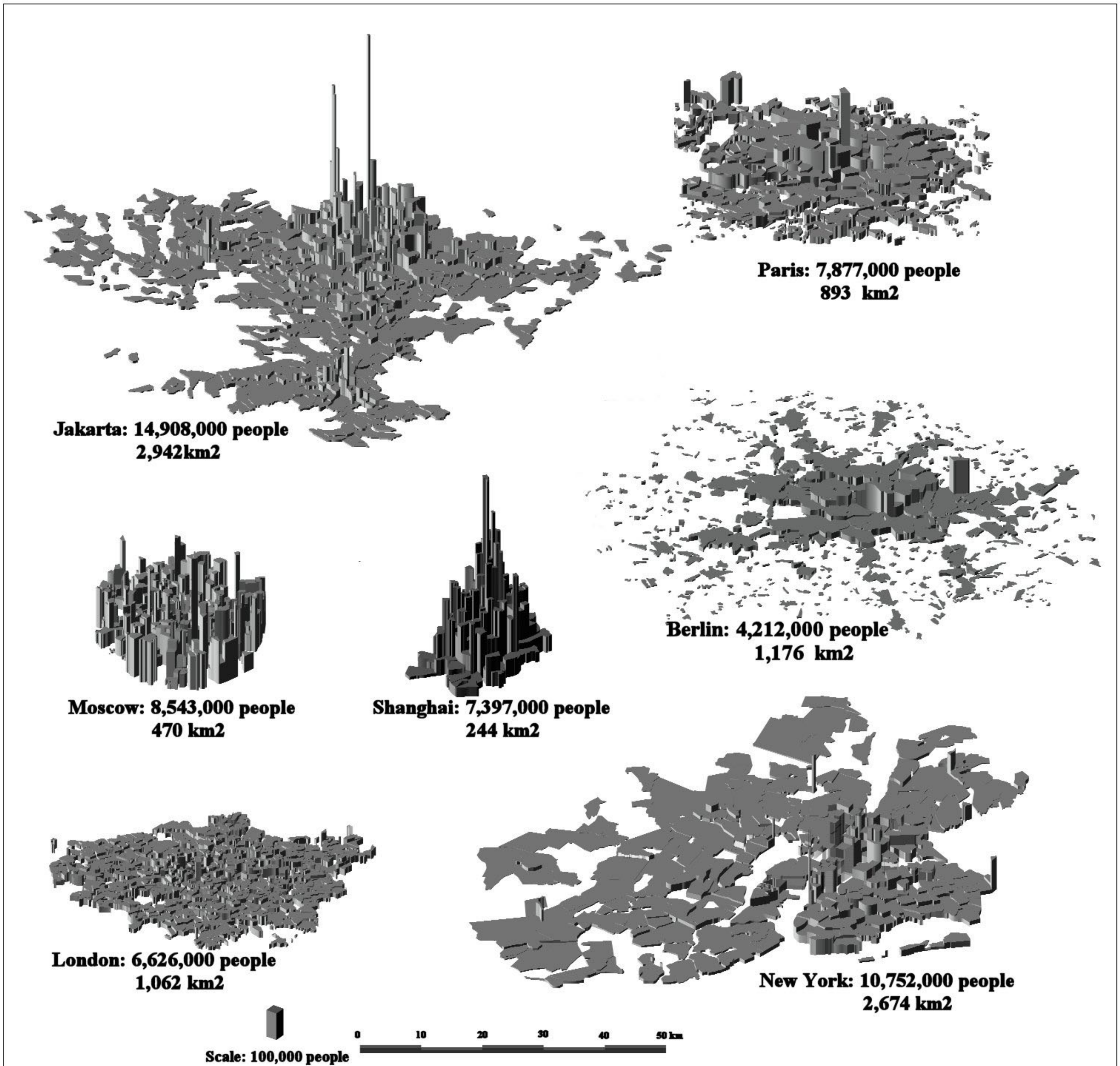
While some cities claim to be alive 24 hours a day, the reality is that most people are at home between midnight and 6 in the morning, with the exception of relatively few night shift workers and night clubs patrons. Where people are between midnight and 6 in the morning is important because it is the starting point of the daily trips toward the meeting places. What I will call the spatial distribution of population is therefore an image of the location of the majority of a population of a city between about midnight and 6 in the morning. It is important to note that when urban planners show density maps they are of course showing the densities around midnight, not the density during the day.

We can represent graphically the spatial distribution of the population by combining census data and land use maps to construct a 3 dimensional object where the map of the built - up area is in the XY plane and the population density within the built-up area is shown in the Z dimension. To understand better a city spatial structure we must analyze the geometrical properties of this 3 dimensional object. For instance, we can calculate the position of its center of gravity. The center of gravity will be the point to which the average distance per person is the shortest. We can also identify on this 3 dimensional object special areas of the city like for instance its central business district (CBD). We will be able then to calculate what is the average distance per person to the CBD and whether the CBD and center of gravity coincide. In other words, we will be able to analyze the geometric property of this 3 dimensional object and compare it to other similarly constructed ones representing different cities. The only constraint will be to make sure that the conventions used to build this 3 dimensional representation of population is consistent across cities.

Figure 1 shows the spatial distribution of the population – at midnight – of 7 large world cities. the built-up area and the population of the 7 cities are represented at the same scale. The isometric view is from the South at a 30^{o} angle with the horizontal plane.

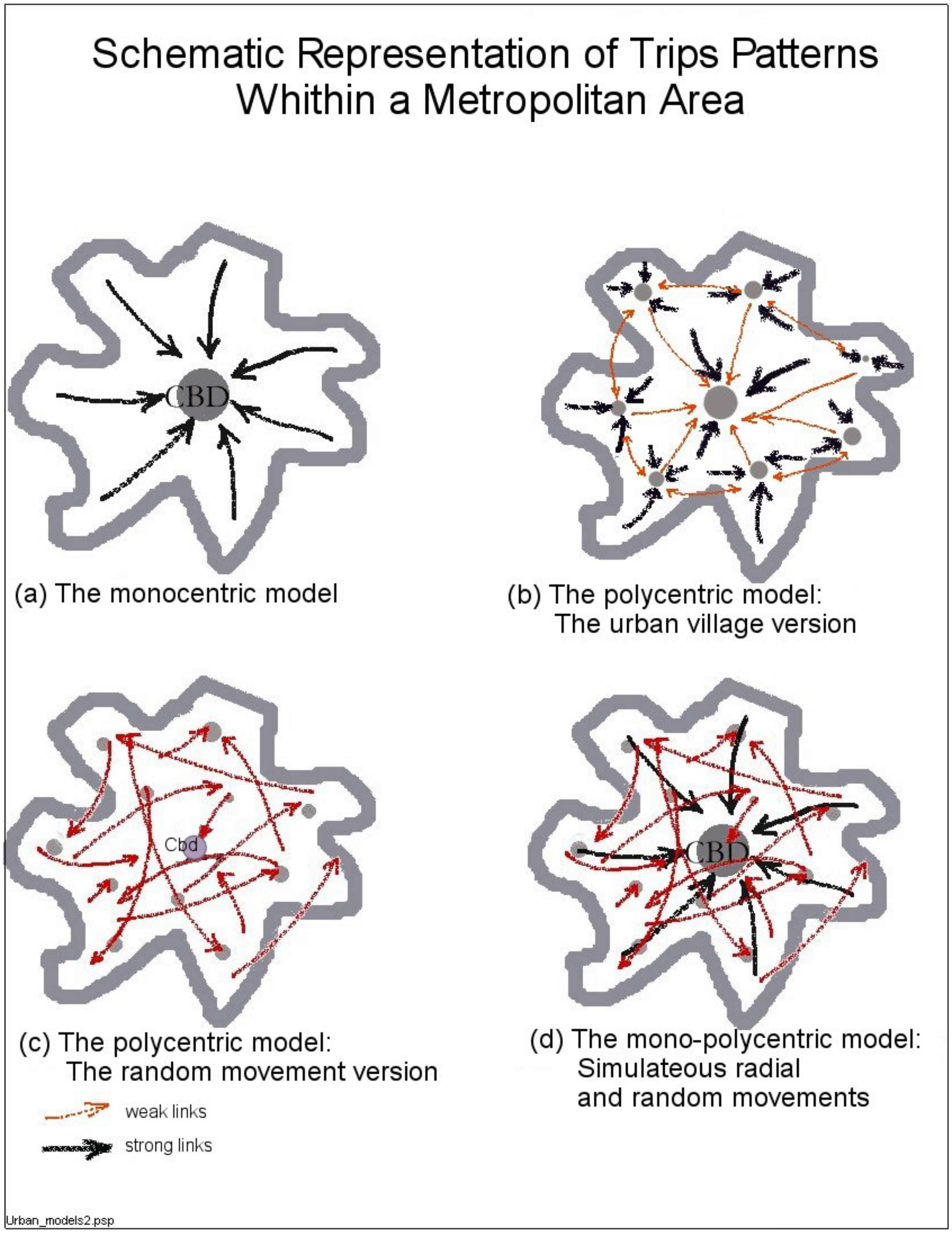
The spatial structure of the cities shown on Figure 1 appears complex and is dramatically different. We are going to try to develop indicators that would allow us to find out first in what measurable way these spatial structures differ and second, whether some structures might be performing better than other in meeting some simple criteria.

Figure 1: The spatial structure of 7 cities



2. Pattern of trips: Monocentric and polycentric cities

Figure 2: Pattern of trips in monocentric and polycentric cities



a) definition of trip patterns

Every day the inhabitants of a city move from their place of residence to other locations in the city that include their place of work, shopping areas, cultural and social facilities. They also move to visit each other residence. Many jobs involve more than one location within the same day, for instance the lawyer moving from office to court, or the UPS driver delivering its packages. In a modern American city the number trips generated by commuting from residence to job is in most cases less than 50 % of the number of total trips. One should therefore resist the simplistic view that trips pattern are generated by daily return trip from residence to place of work. To avoid this confusion I will call "meeting places" the place where people go when they leave their home. The definition of "meeting places" covers therefore job locations, shopping places, cinemas, schools, other people home, etc.

Trip pattern will therefore depends on the relative location of residences and meeting places within the metropolitan area. In a monocentric city the location of the majority of these meeting places is heavily concentrated in a central area. In a polycentric city, the majority of the meeting places is distributed in clusters around the metropolitan areas. The number of clusters could range from 3 or 4 to several hundred.

To understand the pattern of trips in monocentric and in polycentric cities, it is necessary to look briefly at the economic justification of cities.

b) ***The size of labor and consumer markets is the base of the economic success of cities***

A large unified labor and consumer market is the raison d'être of large cities whether they are monocentric or polycentric. A large literature treats cities as labor markets like Ihlandfeldt, (1997) and the classic Goldner (1955). Prud'homme (1996) provides a convincing explanation for the growth of megacities in the last part of the twentieth century: Large cities become more productive than small cities when they can provide larger effective labor markets. Megacities' capacity to maintain a unified labor market is the true long run limit to their size. Market fragmentation due to management or infrastructure failure should therefore result initially in economic decay and eventually in a loss of population[1]. Spatial indicators should therefore indicate if a city current structure favor or disfavor the functioning of unified labor and consumer markets. In this paper, I am considering the spatial structure of a city as possible factor for labor markets consolidation or fragmentation. It is obvious that the fragmentation of labor markets might be due to many different other non spatial factors, for instance, the rigidity of labor laws or racial or sex discrimination.

c) **Pattern of trips in monocentric and polycentric cities**

A monocentric city can maintain a unified labor market by providing the possibility of moving easily along radial roads or rails from the periphery to the center (see Figure 1 (a)). The shorter the trip to the CBD, the higher is the value of land. Densities, when market driven, tend to follow the price of land, hence the negative slope of the density gradient from the center to the periphery observed in most world cities.

The growth of polycentric cities is also conditional on providing a unified labor and consumer market. Some urban planners often idealize polycentric cities by thinking that a self-sufficient community is likely to grow around each cluster of employment. According to

[1] I am certainly not implying here that the quality of infrastructure creates urban growth or that an infrastructure break down is the only reason why a city would shrink in size. Exogenous economic factors are of course determinant. But if infrastructure is not a sufficient reason to explain growth the lack of it may explain stagnation in spite of favorable exogenous economic conditions.

them, a number of self-sufficient "urban villages" would then aggregate to form a large polycentric metropolis (Figure 1, (b)). In such a large city, trips would be very short; ideally, everybody could even walk or bicycle to work[2]. Nobody has ever observed this behavior in any large city. A metropolis constituted by self sufficient "urban villages" would contradict the only valid explanation for the existence and continuous growth of large metropolitan areas: the increasing returns obtained by larger integrated labor markets[3]. The urban village concept is the ultimate labor market fragmentation.

Although there are many polycentric cities in the world, there is no known example of one formed by an aggregation of small self-sufficient communities. The urban village concept flies in the face of common sense. It assume that in a large metropolis most people will not look for work beyond a radius of few kilometers from their home, or that they would select a home only within the restricted boundaries limited by a given radius from their work.

In spite of not being encountered in the real world, the utopian concept of a polycentric city as a cluster of urban villages persists in the mind of many planners. For instance, in some suburbs of Stockholm urban regulations allow developers to build new dwelling units only to the extent than they can prove that there is a corresponding number of jobs in the neighborhood. The satellite towns built around Seoul and Shanghai are another example of the urban village conceit. The majority of the inhabitants of these towns work and commute daily to the main part of the city, and most jobs in the satellite towns are performed by who commute from the main city.

In reality, a polycentric city functions very much in the same way as a monocentric city: jobs, wherever they are, attract people from all over the city. The pattern of trips is different, however. In a polycentric city each sub-center generate trips from all over the built-up area of the city (see Figure 1 (c)) Trips tend to show a wide dispersion of origin and destination, appearing almost random. Trips in a polycentric city will tend to be longer than in a monocentric city, ceteris paribus. However, for a given point, the shorter the trip to all potential destinations, the higher should be the value of land. A geometrically central location will provide trips of a shorter length to all other location in the city. Therefore, we should expect polycentric cities to also have a negatively sloped density gradient, not necessarily centered on the CBD but on the geometric center of gravity of the urbanized area. The slope of the gradient should be flatter, as the proximity to the center of gravity confers an accessibility advantage that is not as large as in a monocentric city. The existence of a flatter but negatively sloped density gradient in polycentric cities can be observed in cities that are obviously polycentric, like Los Angeles.

d) Monocentric cities tend to transform themselves as they grow into polycentric cities

Traditionally, the monocentric city has been the model most widely used to analyze the spatial organization of cities. The works of Alonso (1964), Muth (1069), and Mills (1972) on density gradients in metropolitan areas are based on the hypothesis of a monocentric city. It has become obvious over the years that the structure of many cities departed from the mono-centric model and that many trip-generating activities were spread in clusters over a wide area outside the traditional CBD. Consequently, many have questioned whether the

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[2] This is an extreme version of views expressed in, for example, by Cervero (1989)

[3] Many papers such as Carlino (1979) and Sveikauskas (1975) document these increasing return to size.

study of density gradients, which measures density variations from a central point located in the CBD, has any relevance in cities where the CBD is the destination of only a small fraction of metropolitan trips.

As they grow in size, the original monocentric structure of large metropolises tends with time to dissolve progressively into a polycentric structure. The CBD loose its primacy, and clusters of activities generating trips are spreading within the built-up area. Large cities are not born polycentric; they may evolve in that direction. Monocentric and polycentric cities are animals from the same specie observed at a different time during their evolutionary process. No city is ever 100% monocentric, and it is seldom 100% polycentric (i.e. with no discernable "downtown"). Some cities are dominantly monocentric, others dominantly polycentric and many are in between. Some circumstances tend to accelerate the mutation toward poly-centricity – historical business center with low level of amenities, high private car ownership, cheap land, flat topography, grid street design –; others tend to retard it – historical center with high level of amenities, rail based public transport, radial primary road network, difficult topography preventing communication between suburbs.

3. the development of spatial Indicators

a) ***Can the same spatial indicators be used for monocentric and polycentric cities?***

To compare and analyze the spatial organization of cities I will use a number of spatial indicators. Some of these indicators require a central point, in this case the CBD or the center of gravity of the population. The measure of population distribution from a central point is usually associated with monocentric cities, i.e. in cities where the CBD is the destination of the large majority of daily trips. It could be argued that some of the cities in the sample presented in this paper are polycentric – i.e. cities where the destination of the majority of trips are spread in clusters around the metropolitan area – and that therefore the indicators I have selected – based on a privileged central point – are inadequate to measure their shape. In the following section, I will show that indicators based on central points are relevant to both monocentric and polycentric cities.

Density gradients, and other indicators linked to a central geometrical point, therefore constitute very useful tools to reveal and compare the spatial structure of cities, whether they are monocentric or not. In many cities, the center of gravity and the historical CBD coincide, in particular in cities with few topographical constraints. When in a polycentric city these two points do not coincide, the center of gravity should be selected instead of the CBD to calculate the density gradient. In most large cities, some trips are following the monocentric mode – from a random point to a central point—while others are following the polycentric mode – from random point to random points (Figure 1 (d)). In this case on could select either the CBD or the center of gravity of the population as the reference point for density gradients.

In addition to the density gradient, I will use the "dispersion index " to compare the shape of various cities. The dispersion index was defined in Bertaud and Malpezzi (1999):"All else being equal, a city shape which decreases the distance between people's residence and the main place of work and consumption will be more favorable to the functioning of labor and consumer markets. For a <u>given built-up area</u>, the shorter the average distance per person to the main place of work or to the main commercial areas, the better would be the performance of the city shape.

b) The location of the CBD and the center of gravity of the city shape

As we have seen, the average distance per person to the CBD would be a good measure of proximity for a monocentric city. However, the CBD is a real estate concept, not a geometric one. The location of the CBD within the city shape have an effect on the measure of proximity that is independent of the shape itself. We need therefore first, to define a way to measure proximity within a shape independently from CBD location, and then to introduce the measure of the location of the CBD within a shape as an additional shape parameter.

We have defined a city shape as a 3 dimensional solid in which the horizontal plane contains the base of the prisms corresponding to the outline of the different neighborhoods constituting the built-up area, while the population density in these same neighborhoods constitute the height of the prisms. The complex solid formed by the aggregations of neighborhood prisms possesses a center of gravity whose location can be calculated. This center of gravity is by definition the point from which the average distance to all the points of the solid is the shortest. Therefore, for a given shape, the optimum position of the CBD to maximize proximity coincides with the center of gravity of the shape. We will define below another shape indicator, relevant only for monocentric cities, which measures the distance between the CBD and the center of gravity.

c) Variations in distance to the CBD and in distance between random points for various spatial structures of identical area and average density

Before going further in defining a proximity index that would allow us to compare cities of any size and density, let us just test the variation in proximity for a fictional city of constant area and population (therefore constant average density) when the spatial structure varies. I will measure the variations of the average distance per person to the CBD and between random points for a number of shapes while keeping the built-up area and population constant. Therefore, our measure could be applied to either a monocentric or a polycentric city. For this exercise, we will assume that the CBD coincide with the center of gravity of the shape.

Let us assume an imaginary city of 1 million people at an average density of 100 people per hectare, i.e. a built-up area of 100 square kilometers. To limit the number of possible shapes the variations will be limited to those who are inscribed within a square of 12 by 12 kilometers. Let us then test the variation of distance per person to the CBD and the average distance per person between random points for 20 variations of typical spatial structures, keeping the average density, population and built-up area constant. The variables are the density of sub-areas, the location of sub-areas with different densities and the shape of the built-up area within the limit of a square of 12 kilometers side. The results are shown on <u>Figure 3</u>.

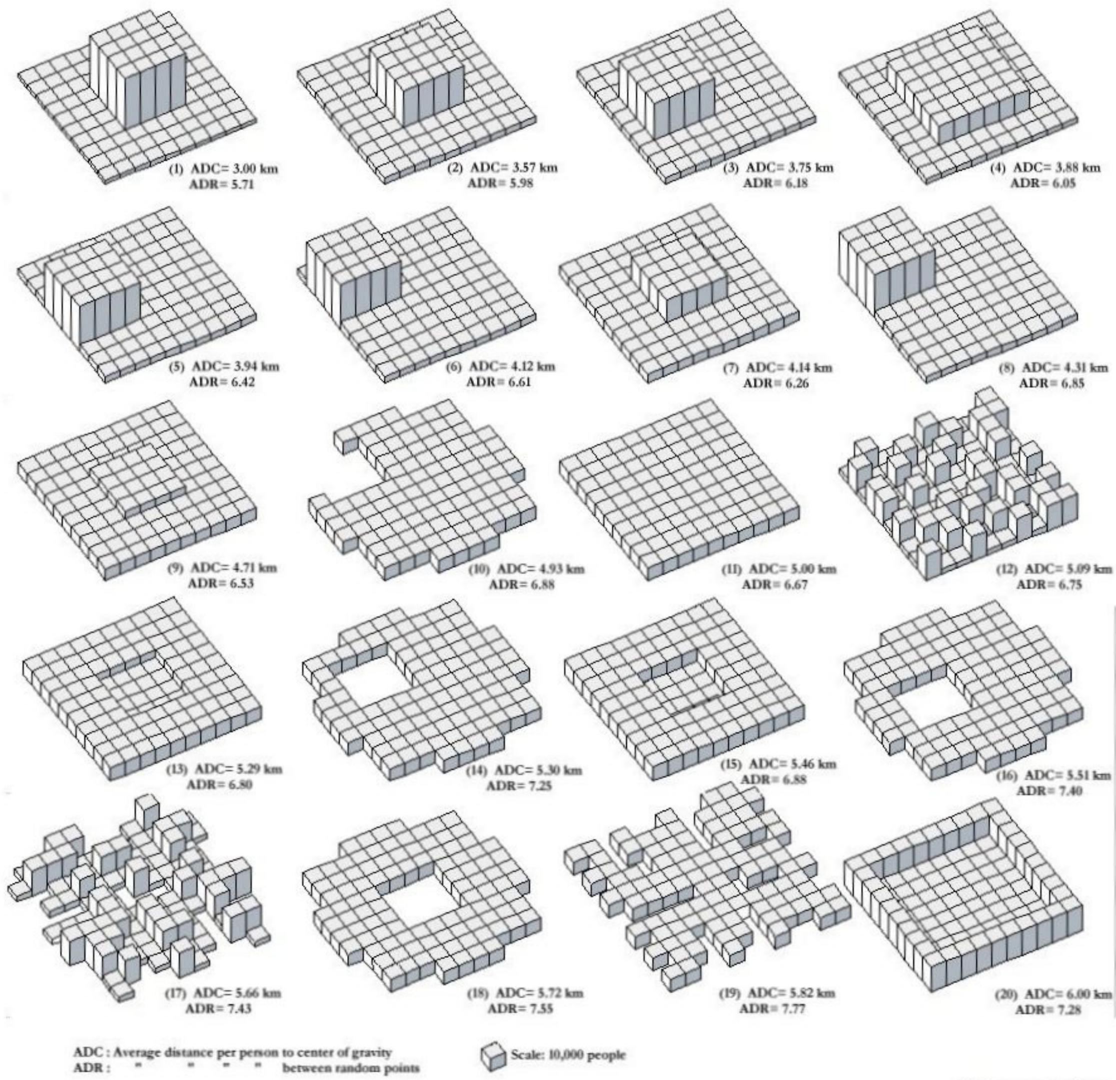
The spatial organization types shown on <u>Figure 3</u> are presented by order of decreasing performance for average distance to the CBD. The results allows us to draw 3 observations:

a) The variation of performance between types is large. The distance to the CBD double between layout 1 to layout 20 (from 3 to 6 kilometer, although the shape itself stay inscribed within a square of 12 by 12 km). Between cities of identical average density, Shape is therefore a very important factor in allowing markets to function and in affecting the length and the costs of networks.

b) The variation in the distance to the CBD is much larger between different spatial arrangement than between the distance to the CBD and the distance between random points for a given shape. Shape itself is more important in city performance than whether the city function as a monocentric city or a random movement city.

c) While a poor performer for the distance to the CBD will generally be a poor performer for average distance between random location, the correspondence is not linear. Some types of spatial arrangements, which are favorable to monocentric movements, are not favorable to random movements. For instance, layout ranked 13 for distance to CBD performs better for random movement than the layout ranked 8.

Figure 3: Variation of average distance per person to center of gravity and between random points for various spatial structures



4. Urban Spatial structures matters for economic and environmental reasons

We can summarize the points made above in the following manner:

a) Urban Spatial structures have an impact on the functioning of labor and consumer markets

Because the length of trips – and hence their time and costs – from residence to meeting places varies with different type of spatial organization, spatial structures have therefore an impact on the economy of cities. Cities with a more favorable type of spatial organizations, will possess a decisive economic competitive advantage over cities with a less favorable spatial structure.

b) Urban Spatial structures have an important impact on the environment

Urban spatial structure have two ways to have an impact on the environment. First, because some spatial organizations shorten trips, they also reduce the need of cities for energy and therefore pollution. Second, because some spatial forms are more compact than others , they put less pressure on the natural environment surrounding cities.

But cities' structures evolve constantly with time. A structure initially favorable to the economy and to the environment may eventually deteriorate into a less effective structure. Conversely, an inefficient urban structure might be guided to evolve into a more efficient one. It is therefore important that urban planners constantly monitor the evolution of cities' structures with relevant indicators and establish targets for the future.

B. The use of spatial indicators to analyze and monitor spatial organization in 7 large cities

To illustrate the points made above I have selected 7 large metropolis from different parts of the world representing vastly different culture, climate and economic systems. These cities were shown on Figure 1. There are from East to West: Shanghai, Jakarta, Moscow, Berlin, Paris, London and New York. It has to be acknowledged that the selections of these 7 cities has been neither random nor unbiased and therefore no statistically valid conclusions should be derived from this paper. The observations contained here should be considered as case studies and not as statistical evidence.

The basic data concerning the 7 metropolis is presented on Table 1.

Table 1: Built-up Area, Population, and average density

Table 1 - Selected Cities: Built-up Area, Population and Average Density

	Built-up Area	Population	Average density in built-up area		Built-up land per person
	Km2		people/Ha	People/sq.mile	m2/person
Berlin	1,176	4,212,400	36	9,279	279
Jakarta Metropolitan Area (Jabotabek)	2,942	14,908,400	51	13,124	197
London	1,062	6,626,300	62	16,167	160
Moscow (Municipality)	503	8,497,200	169	43,711	59
New York Metropolitan area	2,674	10,752,900	40	10,414	249
Paris Metropolitan area	937	7,998,100	85	22,098	117
Shanghai (City proper)	244	7,397,200	303	78,483	33

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The parameters of Table 1 are defined as follows:

Built-up area: (A_b): expressed in square kilometers, measures the land area consumed by urban activities within a metropolitan area across administrative boundaries. It does not include large parks of more than 4 hectares, airports, agricultural land, and undeveloped vacant land and water bodies. However, the limits of a metropolitan area are themselves subjective. I have consistently tried to limit the boundary of the built up areas to where additional population corresponded to a density that was not significantly higher than the prevailing density in adjacent rural areas. While some might disagree in the way I have delimited the metropolitan built-up area, the advantage of this approach is its internal consistency. All the data presented here are derived from primary sources: census tract and land use maps or satellite imagery.

In the case of Shanghai, some settlements in the northwest suburbs have not been included due to a limitation in data availability. Shanghai data, however, corresponds to the area called "The City Proper" by the municipality.

<u>Population</u>: (*P*):Number of people within the built-up area defined above as given by census tracts within or intersecting the built-up area. All data are from the 1990 census, except for Shanghai population data, which corresponds to a census taken in 1987 by adding up data from street committees.

<u>Average Population density</u>: (*D*) expressed in people per hectare): Population divided by built-up area expressed in hectares (there are 257 hectares in a square mile)

<u>Built-up area per person</u>: (A_b $.10^6/P$), Built-up area expressed in square meters divided by population.

1. Average density and land consumption

Figure 4: Average density of 7 cities

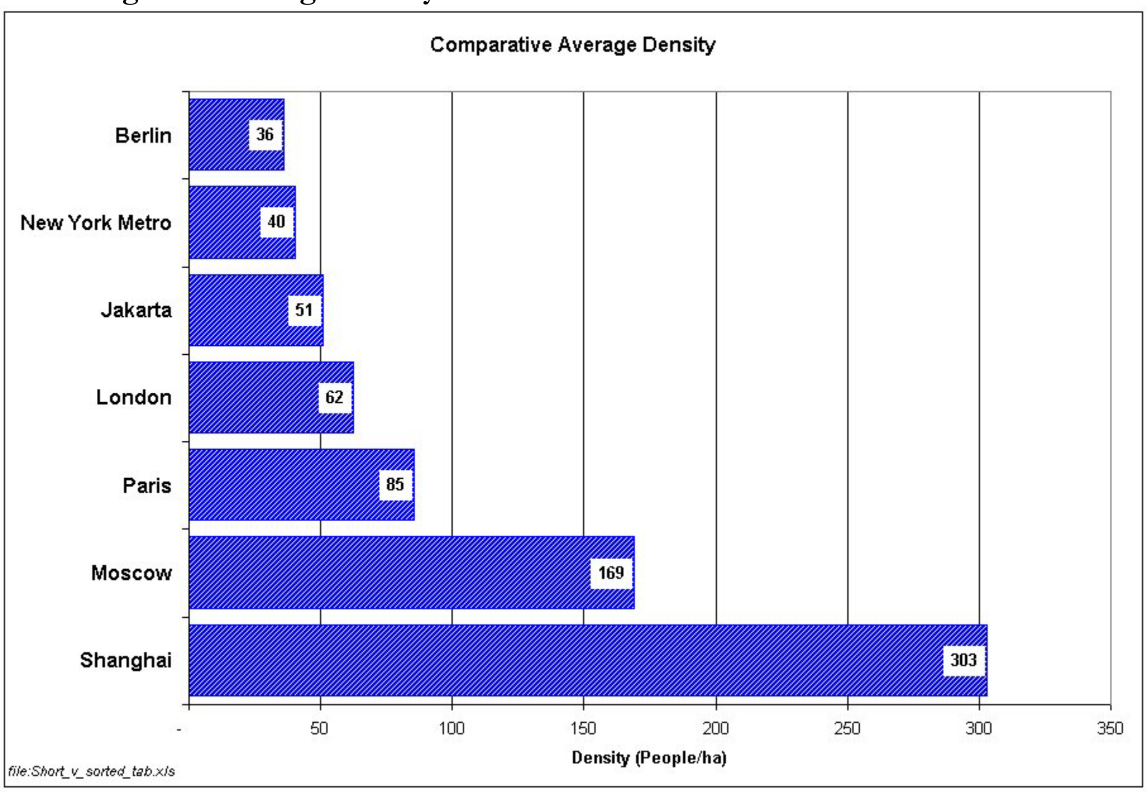
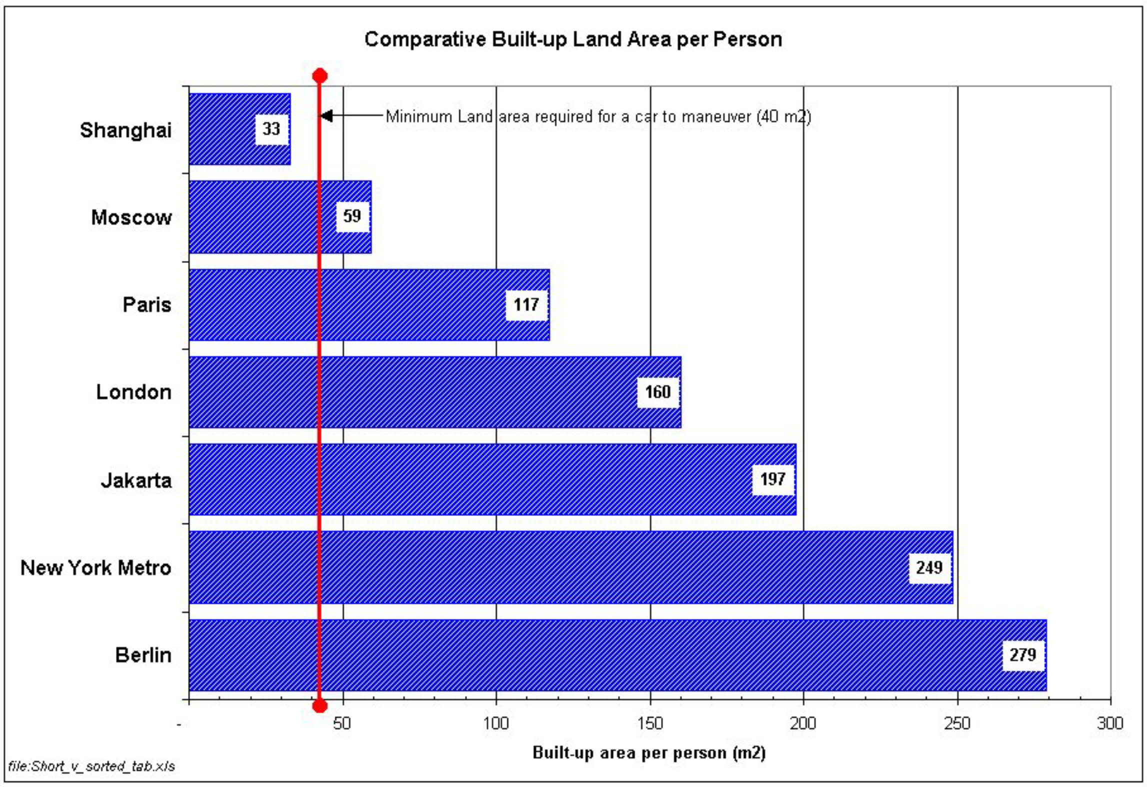


Figure 4 shows the wide range of density which are possible for a successful metropolis. The average density is an ambivalent parameter for the environment. A high density preserve the environment outside the city but is not necessarily conducive to a pleasant environment inside the city.

One should note the lack of correlation between poverty and density or between crime and density. Jakarta is much poorer than Shanghai or Moscow but has a much lower density than either city. Shanghai and Paris have less violent crime per inhabitant than New York but have a much higher density. We will see below, however, that the average density is a rather crude spatial indicator. The way density is spatially distributed within a metropolitan area is much more important for its shape performance than the average density. For instance, as we have seen above on Figure 3, trip length are not directly related to average density but to the way densities are distributed across the metropolitan area.

2. Average Land consumption per capita

Figure 5: Average land consumption per capita



The land consumption per capita is directly derived from the density. Figure 5 shows the wide range of land consumption that are possible in a metropolitan area. There are no good or bad figures for land consumption. There are only trade-off between spatial features and for instance transport options. The red line on figure 5 shows the amount of land space required by a car to park and to maneuver. One can see that the area required by a car is a small fraction of the land consumed per person in New York or in Berlin but it is a significant portion of it in Moscow and in Shanghai a car consumes more space than a person!

The implication of this is clear, the smaller the consumption of land per capita, the more disruptive will be the use of the individual car as a mean of transportation. While a few years ago, trips in Moscow were mostly done by public transport (about 95%) in 1996 public transport use had fallen to about 70% of trips. In Shanghai, in 1987 about 65% of the trip were using bicycle and about 30% buses. In both cities the rate of car ownership is growing very fast every year, the number of trips using private cars is following car ownership with a lag of few years. It is clear that in cities with a very low land consumption per capita, such as Shanghai, Moscow and to a certain extent Paris, the car is directly encroaching on people space. The impact of cars on the environment just in spatial term (not including pollution) is of course much more disastrous in very dense cities. In the long run these cities will be confronted with a decision to either decrease densities – i.e. destroy a lot of their city core – or to severely regulate the use of cars within the densest area of the city. Strangely enough, only Singapore, which by world standard is not particularly dense, has taken serious measures to limit car traffic within the city core.

3. Density Profile

Figure 6: Density profile

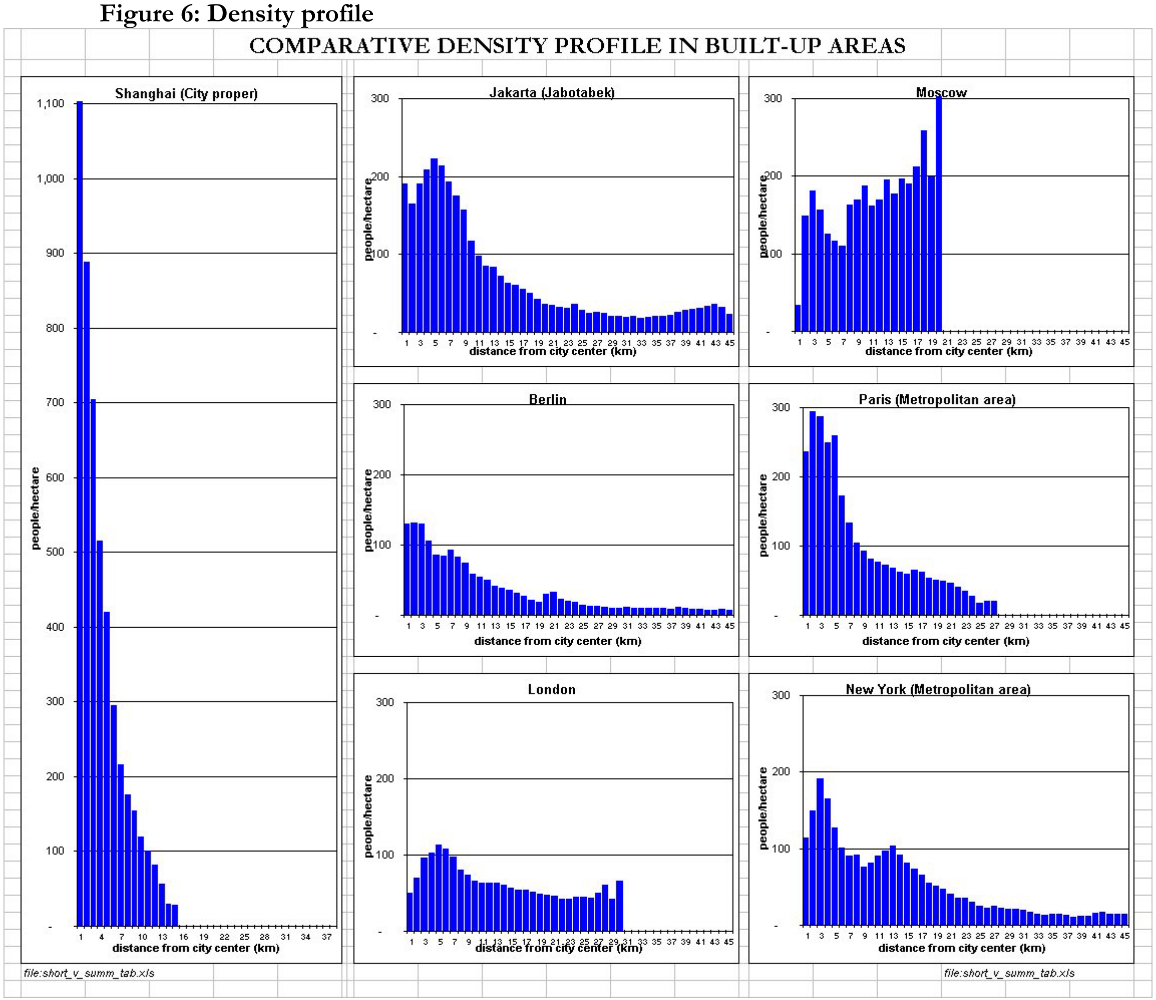


Figure 6 shows the density profile of the 7 sample cities. The horizontal axis shows the distance from the city enter at 1 km interval from 0 to 45 km. The vertical axis shows the population density expressed in people per hectare. The horizontal and vertical scale is the same on all graphs of Figure 6. However, the vertical axis range from 0 to 300 people/hectare for all cities except for Shanghai where vertical axis range from 0 to 1,100 people per hectare.

This profile is established by calculating the number of people within each consecutive ring centered on the central business district (CBD), calculating the built-up area within the same rings, then for each ring dividing the population by the built-up area.

This graph shows that the spatial distribution of densities follows approximately the same pattern – a negatively sloped exponential curve – for all cities except Moscow. This is consistent with what urban economists – Alonzo (1964), Muth (1969) and Mills (1972) – tell us about the effect of land prices on densities. Moscow did not have a land market for 70 years so we should expect its density profile to be different from cities in market economies[4]. But what about Shanghai? This city did not have a land market for 45 years but shows a density gradient much steeper than cities like Paris or New York where land markets exerted their pressure without interruptions for several hundred years. The only convincing explanation I can find for this puzzle is that the dominant use of the bicycle as a mean of transportation during 45 years shaped the density profile in the same way as the land market would have done it. Shanghai density profile, as shown on Figure 6, corresponds to a census taken in 1987. At that time, much of the city's housing stock had been built in pre-Revolutionary time. Very little new housing was added in the fifties because the national priority was the development of people's communes in rural areas then from the mid sixties to the end of the seventies came the cultural revolution during which time many cities lost population sent to the country side and no new housing was built. The city absorbed additional population by densification and subdivision of the existing pre-revolution housing stock. New traditional socialist housing started being built in significant numbers only in the eighties, a period too short to significantly affect the density profile. That would explain why the density do not rise in the Shanghai's suburbs like it does in Moscow, but it does not explain the extremely steep negative gradient as compared to other cities in the sample. In my opinion, the dominant use of the bicycle as a mean of urban transportation is the only explanation for the steep gradient. When people use a bicycle to commute in a big city like Shanghai, every kilometer counts. Houses located close to the center would have received a much higher pressure to densify than houses located in the periphery. Hence subdivisions and densification must have happened in a much more intensive way in the center than in the suburbs. The effort made to bicycle in the hot Shanghai summer and the cold and damp winter acted as a substitute for land price.

An additional observation could be made concerning the density profile of London. Between 26 and 30 kilometer from the center the London density rise slightly. This is the green belt effect. Although London's green belt is nowadays hard to detect on the ground, it did exist for a long time and it has the effect of raising density, first, because the reduction in land supply brought by the green belt's regulatory restrictions and second by the "amenity effect" offered by the green belt. Both factors contributed to an increase of land prices in the vicinity of the green belt, and as a consequence to an increase in density.

The density profile of a city is similar to the rings of a tree: it shows the history of a city, many events of the past which have affected the spatial structure are leaving their mark on it.

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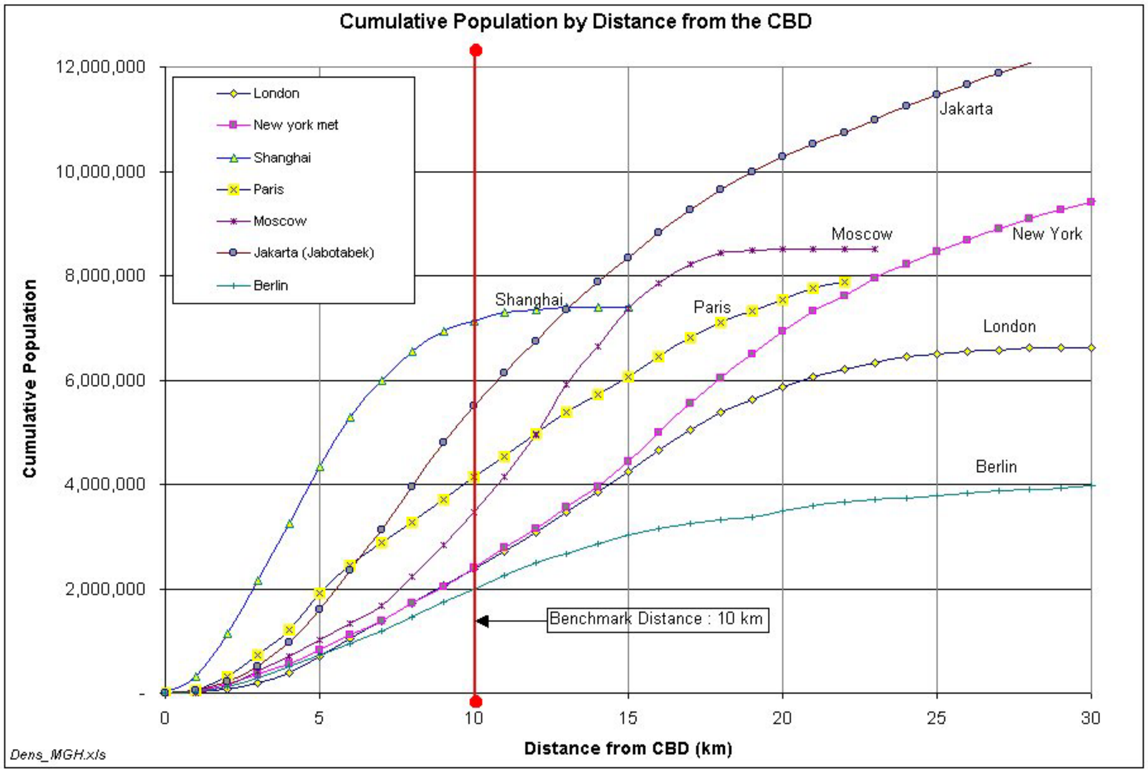
[4] For a full explanation of why densities increases with distance from the center in socialist economies, see Bertaud and Renaud (1997).

4. Population by distance to center of gravity or to the CBD

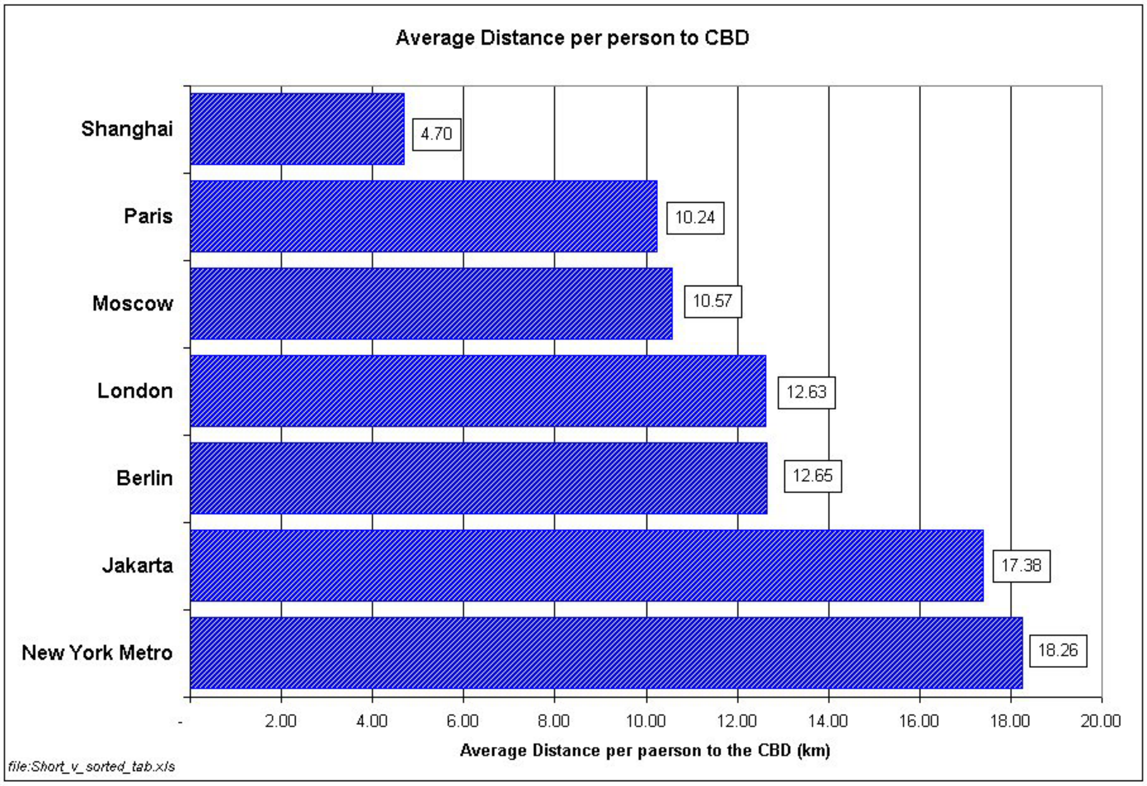
Figure 7: cumulative population per distance to the CBD



The graph of Figure 7 is particularly relevant for cities which are dominantly monocentric (which is the case for the 7 cities in our sample). On the graph, the horizontal axis shows the distance from the city center in kilometers and vertically the cumulative number of people. For instance, in a radius within 10 kilometers from the center Shanghai has more than 7 million people, Jakarta 5.5 million, Paris 4.1 million, Moscow 3.5 million, New York and London 2.5 million, and Berlin 2 million. The benchmark distance of 10 km is interesting as it is a distance that, in urban area, can easily be covered by bicycle in about 40 minutes and about 15 minutes with a tramway. We should note that he number of people which can have easy access to the center is very much related to the density profile shown on Figure 6. The steeper the gradient of the density profile, the higher is the accessibility of the center. We should note that while Moscow average density (169 p/ha) is about twice higher than Paris' density, about 600,000 more people than in Moscow are located at less than 10 kilometers from Paris center. The spatial structure of Paris give it a decisive advantage over Moscow in terms of accessibility. This advantage is easily translated into an advantage in the functioning of labor and consumer markets and in environmental cost.

5. Average distance per capita to the CBD

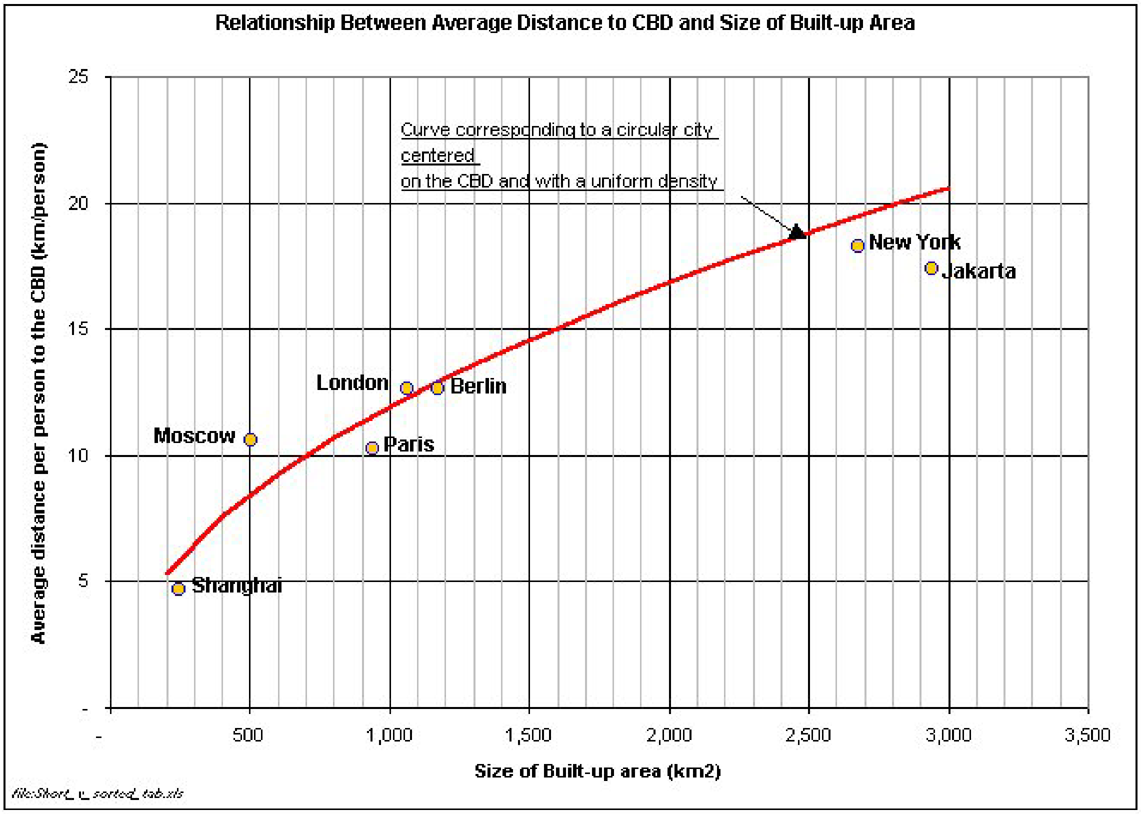
Figure 8: Average distance per capita to CBD



The average distance per person to the CBD is directly linked to the spatial structure. The distance is directly linked the cost of getting to the city center and is proportional to the length and costs of random trip across the metropolitan area. It would be expected that the average distance per person will increase with the size of the built-up area. But we can see from the graph of Figure 8 that this is not necessarily the case. The built-up area of Paris (937 km2) is nearly twice the size of the built-up area of Moscow (503 km2) but the average distance per person to the center in Paris is slightly less than in Moscow. This apparent paradox is due to the distribution of densities within the built-up area, as seen on the density profiles for each city shown above on Figure 6. In this case the practical consequence of the positive density gradient of Moscow (density increasing with distance to the center instead of decreasing like in the other cities in our sample) is to lengthen the distance to the center, and this in spite of Moscow's compact aspect on Figure 1.

6. Relationship between average distance per person to the CBD and built-up area

Figure 9: relationship between average distance and size of the built-up area



The graph of Figure 9 shows horizontally the size of the built-up area expressed in square kilometers and vertically the average distance per person to the CBD. The red line on the graph shows the relationship between the size of the built-up area and the average distance per person for a fictitious city whose shape would be a circle and that would have a uniform density. This is useful to se how the average distance per person would varies when the shape stay constant but when the size of the built-up area become larger. On the graph, the relative vertical distance from the point representing each city and the red line gives an indication of shape performance. The further below the line is the point representing a city the better is the shape performance. The further it is above the line the worst is the performance. For instance, we can see more clearly the relative performance of the spatial organization of Paris and Moscow as discussed above.

7. Dispersion index

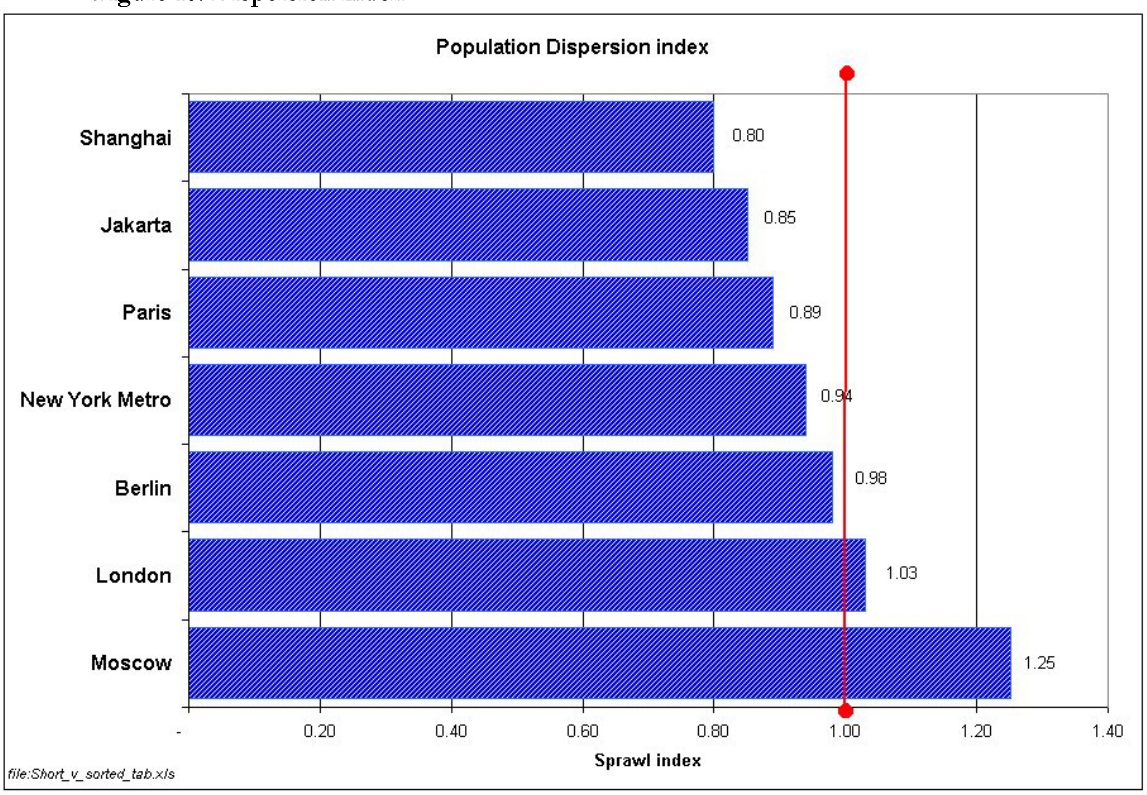
The measure of the average distance per person to the CBD – in case of a monocentric city – or to the center of gravity – in case of a polycentric city – provides a good indicator of dispersion for a given city over time or between alternative spatial options. However, to have a comparative measure of shape performance between cities, it is necessary to have a measure of dispersion independent of the area of the city. Everything else being equal, in a city with a small built-up area the distance per person to the center will be shorter than in a city with a larger built-up area. To correct for the area effect, the index of dispersion ρ, used in this paper is the ratio between the average distance per person to the CBD, and the average distance to the center of gravity of a circle whose area would be equal to the built-up area:

$$\rho = \frac{\sum_i d_i w_i}{\frac{2}{3}\sqrt{\frac{A}{\Pi}}}$$

Where ρ, is the index, d is the distance of the *i*th tract from the CBD, weighted by the tract's share of the city population w_i; and A is the built-up area of the city.

The index of dispersion, ρ, is therefore independent from the area and from the density of a city; it reflects only the shape performance. It is therefore possible to use ρ to compare cities of very different sizes and of very different densities. A city of area X for which the average distance per person to the CBD is equal to the average distance to the center of a circle of area equal to X would have an index of dispersion of 1. Of course, I am not arguing here that a circular city is somewhat optimal, merely that some cities will be more compact that this baseline (have a lower value of ρ) and some will be less compact (have a higher value of ρ).

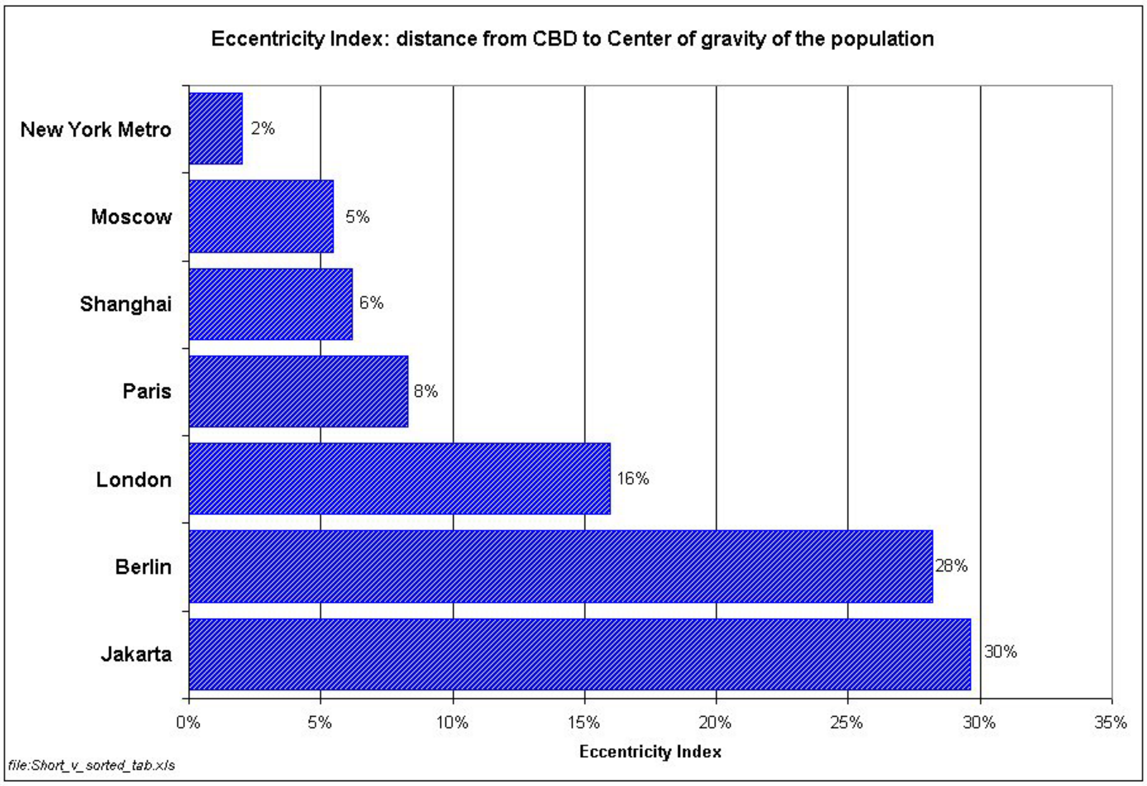
Figure 10: Dispersion index



The dispersion index give us an interesting insight in the importance of a city spatial structure in reducing trip length. We can see that high density itself does not necessary reduce trip length.

8. Eccentricity index

Figure 11: Eccentricity index



A city CBD is considered eccentric when it does not coincide with the center of gravity of the population The eccentricity index shown on Figure 11 is measured by calculating the percentage of the distance between the CBD and the center of gravity of the population over the average distance per person to the CBD. The larger is this percentage the more eccentric is its CBD. An eccentricity index below 10 % is considered satisfactory, between 10 and 20% the index indicate a mild eccentricity, above 20 % the city shows a high eccentricity.

. In a dominantly polycentric city, this indicator is not relevant, as only very few trips are directed to the CBD. By contrast in a city predominantly monocentric, a large distance between the center of gravity and the CBD increases trip length significantly. On the graph of Figure 11, only Berlin and Jakarta are showing a high eccentricity. Berlin up to 10 years ago, before the fall of the wall, had in fact 2 CBD one on West Berlin the other in East Berlin. The CBD used in this calculation is the CBD of West Berlin because land value are higher here than in the old East Berlin CBD. However the center of gravity of the city is in between the 2 centers in an area formerly occupied by the infamous wall, and precisely at the location of the new Postdamerplatz that is currently being built as the new business center of Berlin. When the new office buildings and shopping areas of the Postdamerplatz will be completed and operating the new this will be the location of the new CBD of Berlin and Berlin will then have an eccentricity close to 0.

Jakarta high eccentricity is due to its location along the sea. Most sea ports are eccentric because the port area constituted originally at the time of the city creation the major center of activity. As the city develops, other services also develop and the port becomes an ancillary activity. Because of the asymmetry imposed by the proximity of the sea, the center of gravity of the population is constantly moving as the city area growth. In the case of Jakarta, the CBD has been moving away from the port since a number of years and has been following the center of gravity but with a lag of a few years. The CBD of Jakarta has been moving by 12 kilometers in the last 15 years, always following the same path as the center of gravity, increasing thus the performance of the city shape. This displacement was not due to the initiative of urban planners but to market forces. Locations of higher accessibility became more valuable and attracted new businesses.

C. Conclusions: urban planners should monitor constantly the evolution of urban spatial structure and eventually try to modify it

Because of the impact of a city spatial structure on its economic and environmental performance, urban planners should constantly monitor its evolution. They may use the basic indicators described above and additional ones more specific to their city. In particular, by mapping the location of new building permits and real estate investments, they can easily monitor development trends. The use of Geographical Information Systems greatly facilitates this work..

Master plans usually include broad municipal objectives that need to be translated into spatial terms. For instance, a municipal objective to increase the use of public transport implies a more compact city, maintaining a high degree of monocentricity and relatively high density. On the contrary, a policy aimed at increasing the consumption of housing by making it more affordable would imply an extension of the city and the opening of large peripheral areas for development. A policy aiming at improving the environment inside the city will require using more land for open space and for public facilities, thus increasing the foot print of the city at the expense of the agricultural or undeveloped areas in the periphery. By contrast, a policy aimed at protecting the natural environment outside the city would require higher density and a more compact development probably implying a lower standard of floor and land consumption and higher housing prices. There are no win- win urban spatial strategies. Most urban development policy involves painful trade-offs, which can be done only through an accountable democratically elected municipality. No land use optimization can be performed from a sole technical point of view, political objectives are needed to set the goals to be reached.

Urban planners have to design the tools that will help implement the spatial strategy derived from the municipal objectives. Planners dispose of only 3 types of tools to help shape an urban spatial structure: (i) land use regulations, part of which will be a zoning plan, (ii) primary infrastructure investments and (iii) property taxation. The impact of these tools will only be indirect. The real estate market, reacting to the constraints and opportunities provided by regulations, infrastructure and taxation, will in reality shape the city. Planners design and master plans will not have much direct influence. This is the reason why spatial indicators need to be constantly monitored to verify that the city is evolving in the spatial direction consistent with the municipal objectives. Many regulations and infrastructure investments have spatial side effects are often unexpected. For instance, green belts have a tendency to increase the price of land and housing and to increase commuting distance as households and firms are looking for cheaper land on the other side of the green belt. Low density zoning designed to preserve more green areas have a tendency to generate sprawl by forcing land user to consume more land than they would otherwise have done in the absence of zoning. New light rail and metro lines do not necessarily increase demand for public transport if densities are too low or the city structure is dominantly polycentric.

Urban planning is not an exact science but has to proceed by trial and errors. That makes it all the more important to monitor the constantly evolving spatial organization of cities.

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