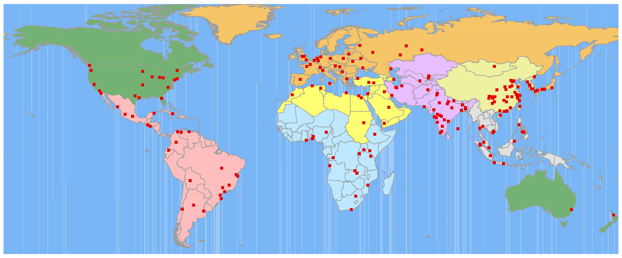
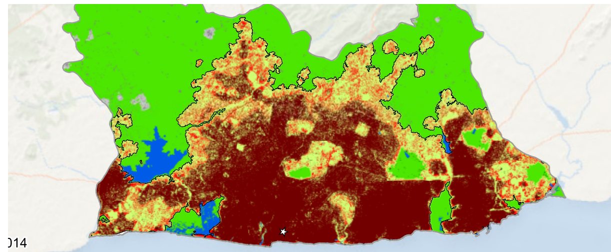
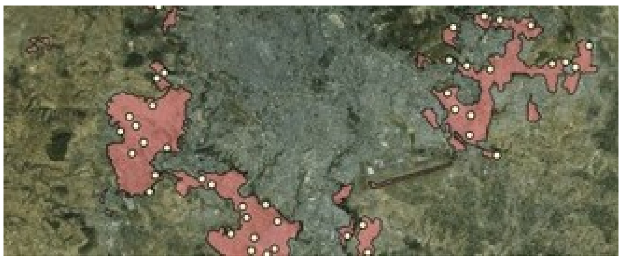


WORKING PAPER #24/SEPTEMBER 2015

MONITORING THE QUANTITY AND QUALITY OF GLOBAL URBAN EXPANSION

+ SHLOMO ANGEL, ALEJANDRO M. BLEI, DANIEL L. CIVCO, NICOLAS GALARZA SANCHEZ, PATRICK LAMSON-HALL, MANUEL MADRID, JASON PARENT, AND KEVIN THOM[1]

ABSTRACT

This paper reports on current progress in estimating the dimensions and attributes of global urban expansion. Monitoring global urban expansion is undertaken by a partnership between the NYU Urban Expansion Program, the United Nations Human Settlements Programme (UN Habitat), and the Lincoln Institute of Land Policy. Results are expected in time for Habitat III, the United Nations Conference on Housing and Sustainable Urban Development, now scheduled for October 2016. The monitoring effort focuses on a global stratified sample of 200 cities, selected from a universe of 4,245 cities that had 100,000 people or more in 2010. It consists of a four-phase research project. Phase I focuses on the mapping and measurement of global urban expansion in the sample of cities, 1990-2014, using *Landsat* satellite imagery; Phase II on the mapping and measurement of urban layouts in the sample, 2014-2015, using high-resolution satellite imagery; Phase III on a land and housing survey focused on the regulatory regimes and on land and housing affordability using city-based researchers in the global sample of cities; and Phase IV, to be completed later, on the mapping and estimation urban extent in the entire universe of cities to 2045.

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1 *The NYU Urban Expansion Program, The NYU Stern Urbanization Project and the NYU Marron Institute of Urban Development, New York University. Several phases of the monitoring program are undertaken in partnership with the United Nations Human Settlements Programme (UN Habitat) and the Lincoln Institute of Land Policy.*

Monitoring the Quantity and Quality of Global Urban Expansion

Shlomo Angel, Alejandro M. Blei, Daniel L. Civco, Nicolas Galarza Sanchez, Patrick Lamson-Hall, Manuel Madrid, Jason Parent, and Kevin Thom[2]

Introduction

This paper reports on current progress in estimating the dimensions and attributes of global urban expansion, focusing on two simple questions. First, what is the physical extent of urban areas on our planet today, what are its key attributes, how are they changing over time, why, and why should it matter? Second, how well laid out are recently built urban peripheries, how are layouts changing over time, why, and why should it matter? We believe that answers to these two important questions, provisional as they may be, may make us all less fearful of the rapid expansion of the urban peripheries of our cities; and hence better able to confront this expansion in a meaningful way, and to engage with laying out urban peripheries in a timely, pragmatic, and realistic manner in the years to come.

T*he Urbanization Project*—the movement of people from village to cities and towns—began in earnest in 1800, when less than 10 percent of the planet's population lived in cities. It reached a peak in 2000 when half the world's urban population lived in cities and the world's urban growth rate began to slow down; and is likely to come to an end by 2100, when world population growth is now expected to come to a halt and when as many as three-quarters of the worlds' population will live in cities. In a short span of 12 generations, humanity as a whole has consciously decided that living closer to one another is preferable to living closer to the land, and has acted—and is still acting—quite emphatically on that decision. The coming decades thus offer us a window of opportunity, short as it may be, to make minimal preparations for the coming urban population growth and its concomitant urban expansion. Romantic as it may seem to some, efficient, equitable, and sustainable cities are not self-organizing. They do not come about as the result of the spontaneous actions of the multitudes of individuals, groups, or firms. They come about as the result of these multitudes acting in unison as a *public* to lay out areas of expansion in an orderly, efficient, equitable, and sustainable manner before they are occupied: reserving adequate lands for public works and public open spaces in advance of the construction of homes, workplaces, and public facilities on the remaining lands.

Cities, our largest and most complex artifacts, thus come into being as a result of both public and private actions, with the important qualification that some minimal public actions must take place *before* any private actions materialize. Examples—both good and

[2] The NYU Urban Expansion Program, The NYU Stern Urbanization Project and the NYU Marron Institute of Urban Development, New York University. Several phases of the monitoring program are undertaken in partnership with the United Nations Human Settlements Programme (UN Habitat) and the Lincoln Institute of Land Policy.

bad—abound, but our knowledge as to both the quantity and the quality of global urban expansion is meager and unsatisfactory. The two-pronged strategy of the *NYU Urban Expansion Program—monitoring global urban expansion* on the one hand, and starting *country urban expansion initiatives* that support rapidly growing cities in preparing for their coming expansion on the other—is aimed at improving that knowledge and in using it to inform local, national, and international actors that can make a difference in coming to terms with the inevitable expansion of our cities in the coming decades. This is, of necessity, work in progress, and in this chapter we report on the current state of our monitoring work.

By now, it should already be abundantly clear that we cannot hope to slow down the urbanization process or to shift populations among cities. People are free to move within their own countries and their right to move is enshrined in the *Universal Declaration of Human Rights*.[3] Population growth in cities large and small, we know, cannot be effectively guided by policy. But the conversion of land from rural to urban use is very much guided and influenced by policy.

When cities grow in population and wealth they expand and as they expand they need to convert and prepare lands for urban use. Stated as a broad policy goal, cities need adequate lands to accommodate their growing populations and these lands need to be properly serviced and yet affordable to be of optimum use to their inhabitants. To meet this goal, cities need concerted public action that must precede and guide the operations of the free market on the urban fringe. In the absence of concerted public action—action that can secure adequate lands for public works and public open spaces, *in advance of development*—land and housing markets, efficient as they may be in theory, will fail to perform properly in practice.

And yet, there is reluctance to engage with the prospects of urban expansion, perhaps for perfectly understandable reasons. Many people have come to believe that cities consume enough land as it is, and that all future construction should take place within existing urban footprints. Others oppose expansion so as to conserve municipal infrastructure budgets, to ameliorate traffic congestion, to help decaying central cities thrive again, to conserve energy and to reduce air pollution, or to protect precious cultivated lands at the urban fringe. This reluctance, reasonable as it may seem, keeps the prospects of urban expansion rather obscure and prevents us from addressing them in a clear and forthright manner.

Empirical data on actual urban expansion and its key attributes, in many cities around the world over long periods of time, can provide a much-needed basis for understanding the global and historical contexts of urban expansion. Coupled with theories that could explain the underlying forces that propel and shape urban expansion, these data could provide the evidence needed to assess and address our concerns: that it would be very difficult, if not futile to resist urban expansion in the face of rapid population growth; that ignoring it or denying it in the hope that it will not occur will simply allow it to take place unhindered and in a more costly and destructive way; that acquiring a better understanding of it will make it

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3 UN General Assembly, *Universal Declaration of Human Rights*, *Article 13,* 10 December 1948, 217 A (III), available at: http://www.un.org/en/documents/udhr/ [accessed 13 August 2015].

less formidable and more manageable; and that making minimal yet effective preparations for it is the right way, and certainly the only responsible way, to proceed.

The city as a unit of analysis and the universe of cities

We focus our monitoring efforts on cities of 100,000 people or more. Different countries have adopted different thresholds for a human settlement to be considered a 'city', but there is near universal agreement[4] that a settlement of 100,000 people or more constitutes a city. We also focus our attention not on single municipalities but on entire metropolitan areas: contiguous urban areas that may contain many municipalities are considered to be a single city.[5]

We define cities by the extent of their built-up area, rather than by their administrative or its jurisdictional boundaries. The *extrema tectorum*—the limit of the built-up area of the city, as it was referred to in Ancient Rome—defines the city, and the city thus defined is our unit of analysis.[6] We have now identified 4,245 cities on our planet that were homes to 100,000 people or more in 2010. These 4,245 cities constitute our *Universe of Cities* (see figure 1). The total 2010 population of this universe of cities amounted to 2.5 billion, or 70 percent of the world's 2010 urban population of 3.6 billion.[7] The remaining urban population lived in cities and towns that had less than 100,000 people.

It is important to note that three-quarters of the cities in the universe of cities are in developing countries. More precisely, 3,130 cities out of the total 4,245 (74%), housing 1.85 billion people out of a total 2.5 billion (also 74%) are in developing countries. The share of projected urban population growth in coming decades in the developing countries is much greater. Between 2015 and 2050, the world's urban population is now expected to increase by 2.38 billion people.[8] Only 5% of that increase (130 million) will be in developed countries. The rest, 95% or 2.25 billion, will be in the developing countries. In other words, the increase in the city populations in developing countries will be 18 times that of the

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4 With the important exception of China where there were only 657 officially designated cities in 2015, where there were hundreds of settlements of 100,000 people or more that we have counted as cities.

5 There are a few exceptions to this convention. In countries where many large cities have combined to create elongated conurbations that stretch for hundreds of kilometers—e.g., the Northeast cities in the United States or the Rhein-Ruhr cities in Germany—we have separated the major cities along administrative boundaries. We have also adopted a formula for the inclusion of towns that are not contiguous to large urban agglomerations, where the distance to the agglomeration is a function of its area.

6 The populations of cities are, and should, be calculated using data on the populations of the administrative districts containing the built-up areas of these cities. Where these administrative units are large and contain other built-up areas that are not part of the city, we allocate a population to the city that is equivalent to its share of the built-up area within the set of administrative districts containing its built-up area.

7 United Nations, Department of Social and Economic Affairs, Population Division 2014, File 3: Urban Population at Mid-Year by Major Area, Region and Country, 1950-2050 (thousands), available at: http://esa.un.org/unpd/wup/CD-ROM/ [accessed August 13, 2015].

8 Ibid.

increase in the city populations of developed countries. The challenge for city planners, municipal officials, central government officials, international organizations, civic sector leaders, students of cities, and interested citizens in the coming decades is therefore largely a challenge facing cities in developing countries, not cities in developed countries. And these cities, on the whole, have fewer fiscal resources, weaker rule of law, higher levels of corruption and less experienced public servants, but also higher built-up area densities, more reliance on public transport, and lower levels of energy use. It may well be that the urbanization agenda for developing-country cities may be quite different than the urbanization agenda of developed-country ones. Still, from the point of view of monitoring urbanization in general and urban expansion in particular, we believe that it is important to study both developed-country cities and developing-country cities using the same conceptual framework and the same methods for data collection and analysis.

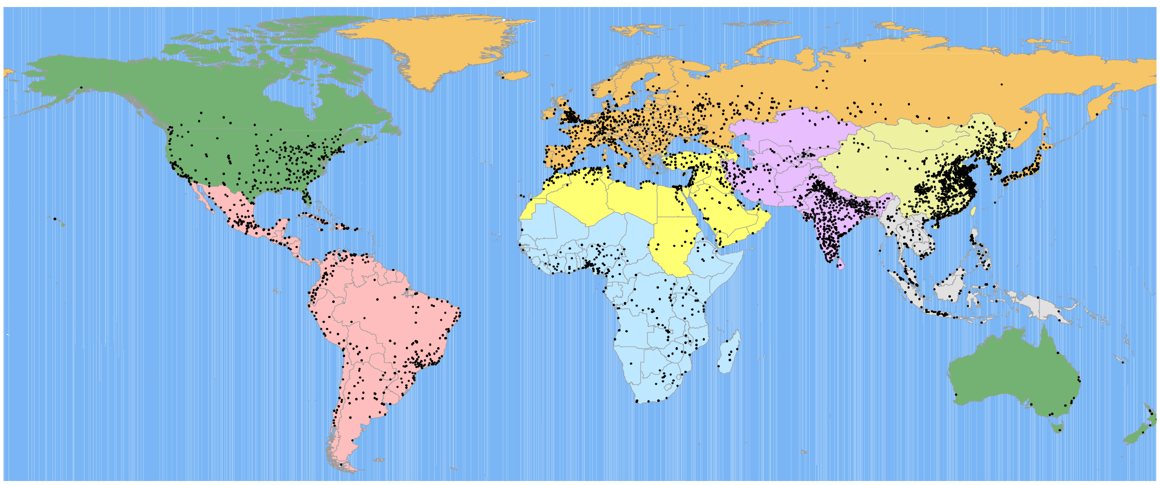

Figure 1: The universe of cities and metropolitan areas that housed 100,000 people or more in 2010

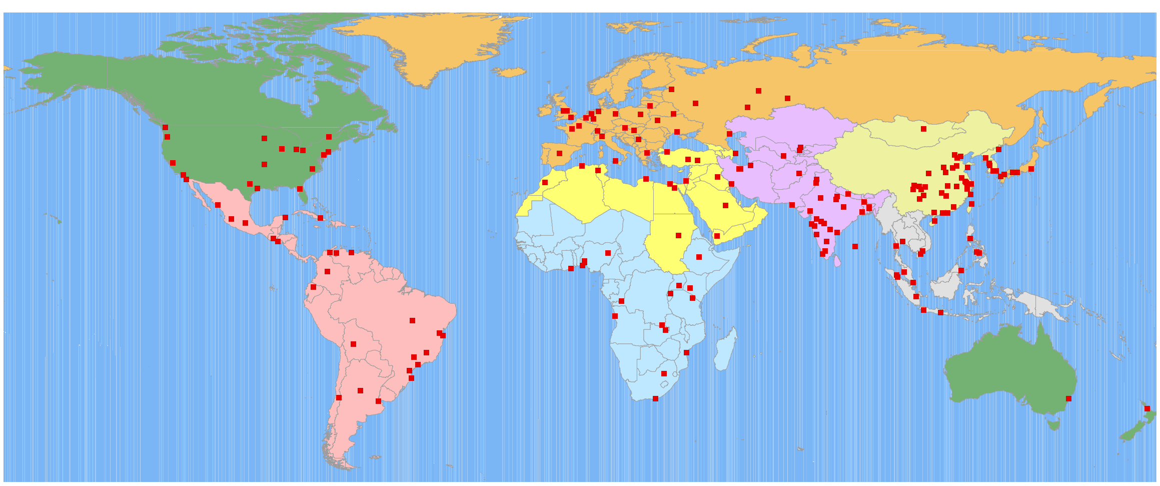

Figure 2: The global stratified sample of 200 cities selected from 8 world regions, 4 population size classes and 3 categories pertaining to the number of cities in the country

The global sample of cities

We can study the universe of cities by studying a carefully selected sample from this universe, selected with a view to obtaining results that can be generalized to the entire universe. We have selected a stratified global sample of 200 cities, roughly 5 percent (4.7%) of the 4,245 cities in the universe in 2010 (see figure 2 and table 1).

Regions	Universe				Sample			
	Number of Cities	% of total	Total Urban Population	% of total	Number of Cities	% of total	Population in Sample	% of total
East Asia and the Pacific (EAP)	1,089	26%	645,356,592	26%	42	21%	154,459,839	21%
Southeast Asia (SEA)	232	5%	128,492,546	5%	15	8%	37,995,438	5%
South and Central Asia (SCA)	693	16%	392,876,899	16%	32	16%	121,380,230	17%
Western Asia and North Africa (WANA)	300	7%	180,525,762	7%	15	8%	62,177,236	9%
Sub-Saharan Africa (SSA)	331	8%	186,626,671	7%	18	9%	50,018,112	7%
Europe and Japan (E&J)	781	18%	396,157,559	16%	34	17%	127,216,190	18%
Land-Rich Developed Countries (LRDC)	334	8%	240,725,842	10%	18	9%	68,421,847	9%
Latin America and the Caribbean (LAC)	485	11%	320,102,523	13%	26	13%	98,805,345	14%
Grand Total	4,245	100%	2,490,864,393	100%	200	100%	720,474,238	100%
City Population Groups	**Universe**				**Sample**			
	Number of Cities	**% of total**	**Total Urban Population**	**% of total**	**Number of Cities**	**% of total**	**Population in Sample**	**% of total**
100,000 - 425,677	3,150	74%	622,400,949	25%	56	28%	12,585,331	2%
425,678 - 1,559,789	814	19%	622,296,461	25%	50	25%	41,719,128	6%
1,561,742 - 5,556,200	227	5%	619,845,757	25%	54	27%	171,482,632	24%
5,718,232 +	54	1%	626,321,226	25%	40	20%	494,687,146	69%
Grand Total	4,245	100%	2,490,864,393	100%	200	100%	720,474,238	100%
Number of cities per Country Categories	**Universe**				**Sample**			
	Number of Cities	**% of total**	**Total Urban Population**	**% of total**	**Number of Cities**	**% of total**	**Population in Sample**	**% of total**
1-9	370	9%	184,155,422	7%	23	12%	39,166,655	5%
10-19	307	7%	154,896,704	6%	18	9%	35,382,060	5%
20 +	3,568	84%	2,151,812,267	86%	159	80%	645,925,523	90%
Grand Total	4,245	100%	2,490,864,393	100%	200	100%	720,474,238	100%

Table 1: A comparison of the universe of cities and the sample of cities, stratified according to regions, city population groups and number of cities per country categories

The sample was selected with three criteria in mind: (1) having cities from 8 world regions, in proportion to the urban population in each region; (2) having one-fourth of the cities drawn from 4 population-size categories, each category containing one-quarter of the total population of the cities in the universe; and (3) selecting cities from three country categories—those with 1-9 cities, those with 10-19 cities, and those with 20 or more cities, with a slight bias towards the first two categories (e.g. only 9% of the cities in the universe but 12% of the cities in the sample are in countries with 1-9 cities).

The division of the world into regions largely follows that of the United Nations with a few important differences. First, Western Asia and Northern Africa were unified into one region. Second, Japan was included in Europe, largely because of its similar levels of urbanization and development. Third, the United States, Canada, Australia and New Zealand were grouped into a region titled *Land-Rich Developed Countries.* All have large agricultural hinterlands and their cities have large expanses of low-density suburban developments that distinguish them from European or Japanese cities.

It is also important to note that the second criterion—dividing the cities into four population size groups, each containing the same total population—biases the sample toward larger cities: The four population size groups contain the same total population, but there are as many as 3,150 cities in the first group (100,000-425,000) and 56 of them are in the sample, but there are only 54 cities in the fourth population size group (5.6 million +) and 40 of them are in the sample. As a result, the 200 sample cities constitute only 4.7% of the number of cities in the universe, but have a population of 720 million, 29% of the total population of the universe. Data on the universe and the sample is given in table 1.

We tested the representativeness of the sample in the following manner: We know the 2000-2010 population growth rates of all cities, both the cities in the universe and the cities in the sample. We compared their averages—both weighted and un-weighted—and found that they were not statistically different from each other at the 95% confidence level.

That said, there are still last minute changes in the sample and—as a consequence—in the universe of cities as well. The results of the analysis of satellite imagery, in conjunction with the population data associated with administrative districts, sometimes reveals that (1) a city that may have been on its own in earlier periods is now included in a larger metropolitan area; or (2) that although its administrative district contains more than 100,000 people, the built-up area associated with the city contains less than 100,000 people. It both cases, we replace this city with a new city selected at random from the same regional, city size, and the number of cities in the country grouping.

Monitoring global urban expansion

The NYU Urban Expansion Program—supported by the NYU Stern Urbanization Project and the NYU Marron Institute of Urban Management, in partnership with the United Nations Human Settlements Programme (UN Habitat) and the Lincoln Institute of Land Policy—has initiated a multi-phase research effort to monitor the quantitative and qualitative aspects of global urban expansion. This effort is a continuation of an earlier project by the authors and their colleagues that resulted in the *Atlas of Urban Expansion* (Cambridge MA: Lincoln Institute of Land Policy, 2012). The monitoring program now has four interdependent phases in different stages:

- Phase I—*The Mapping & Measurement of Global Urban Expansion*—focuses on the mapping and measurement of key *attributes* of global urban expansion—urban extent, average built-up area density, the fragmentation of the built-up area of the city by open spaces, and the compactness of the shape of city footprints—in the global sample of 200 cities in three time periods: Circa 1990, circa 2000, and circa 2014. This phase requires the classification and analysis of medium-resolution *Landsat* satellite imagery as well as census data associated with administrative districts that contain the built-up areas of these cities.

- Phase II—*The Mapping and Measurement of Urban Layouts*—focuses on (1) how well laid out are recently-built urban peripheries (areas built between 1990 and 2014) in the global sample of 200 cities; (2) how well laid out are urban areas built before 1990 compared to areas built between 1990 and 2014 in the global sample of 200 cities; and (3) how well laid out are city areas built in five different time periods—before 1900, between 1900 and 1930, between 1930 and 1960, between 1960 and 1990, and between 1990 and 2014—in a representative sample of 30 cities. This phase requires digitizing and analyzing high-resolution *Bing* and *Google Earth* imagery.
- Phase III—*The Land and Housing Survey in a Global Sample of Cities*—includes two separate surveys. The first, *a Survey of the Regulatory Regime Governing Land and Housing*, seeks to capture land ownership patterns, land-use planning practices, and the development of new subdivisions in expansion areas of cities. The second, *the Affordability Survey*, seeks to measure the prices as well as the key attributes of different types of residential plots, houses, and apartments available for sale or rent in the 200 cities in the global sample and to compare them with household incomes in these cities. This phase requires the engagement of City-Based Researchers in the 200 cities in the global sample, as well as Regional Coordinators based at NYU.
- Phase IV—*The Mapping and Estimation Urban Extent in the Universe of Cities to 2045*—focuses on assembling population data for administrative districts that contain all cities in the universe, as well as satellite imagery of the built-up areas of these cities, for two or more recent time periods. These data, together with additional information on these cities will then be used to map projected urban expansion in the coming decades in each city in the universe.

The remaining sections of this chapter describe the progress to-date and the preliminary results now available in each of the four phases of monitoring global urban expansion. Results for the first three phases are expected to be complete and available online on the websites of the NYU Urban Expansion Program, The United Nations Human Settlements Programme (UN Habitat), and the Lincoln Institute of Land Policy during Habitat III—The United Nations Conference on Housing and Sustainable Urban Development—now scheduled to take place in Quito, Ecuador, in October 2016.

Phase I: The mapping and measurement of global urban expansion

We have been mapping and measuring global urban expansion since 2003, starting with *The Dynamics of Global Urban Expansion*, and continuing with the *Atlas of Urban Expansion* and the forthcoming *Atlas of Urban Expansion—The 2015 Edition*.[9] In the first publication, we modeled urban extent in 90 cities as a function of the city population, national per capita income, the availability of buildable land on the urban periphery, arable land per capita in the country as a whole, and the cost of transport. As expected in the classical models of the city—e.g. Alonso's *Location and Land Use*[10]—we found that the larger the city population, the greater its extent; the higher its per capita income, the greater its extent; the greater the amount of buildable land around it, the greater its extent; the greater the amount of arable land per capita in the country, the greater its extent; and the cheaper the cost of transport, the greater its extent. These variables were all significant at the 95% confidence level and together they explained more than 80 percent of the variation in urban extent in the 90 cities studied.

In the second publication, we found that urban extent—in a global sample of 120 cities selected from the universe of 3,646 cities that had 100,000 people or more in the year 2000—grew at a faster annual rate than the population of these cities. Cities in the sample expanded at an average annual rate of 3.6±0.4%; their population grew at an average rate of 1.6±0.3% per year; and these average rates were significantly different from one another at the 95% confidence level. The consumption of urban land per person increased at an annual rate of 2.1±0.4%; the average density of the built-up area of cities, its reciprocal, declined at the same average rate, 2.1±0.4% per year; and these average rates were significantly different from 0 at the 95% confidence level. We also found that average built-up area densities were significantly different among three world regions: Land-Rich Developed Countries (U.S., Canada and Australia), Europe and Japan, and the six remaining regions comprising the developing countries as a whole. Average built-up area densities in developing countries (173±28 persons per hectare circa 1990 and 135±21 p/ha circa 2000) were double those of Europe and Japan (83±19 persons per hectare circa 1990 and 66±15 p/ha circa 2000), while those in Europe and Japan were triple those of Land-Rich Developed Countries (27±4 persons per hectare circa 1990 and 22±4 p/ha circa 2000).

In that publication, we also studied urban expansion in a global representative group of 30 cities during the period 1800-2000, using historical maps of urban extent at 15-25 year intervals for earlier periods and satellite imagery for later periods. We found that 28 of these cities expanded at least 16-fold during the 20th century.[11] The results are discussed in greater detail in *Planet of Cities.*[12]

The expansion of Paris is shown in figure 3 below. In 1800, during the time of Napoleon, Paris has a population of half a million people and covered an area of some 11 km^2. By 2000, it had a population of some 10 million people and an area of some 2,000 km^2. In other

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9 Shlomo Angel et al., 2005. *The Dynamics of Global Urban Expansion,* Washington, D.C.: World Bank, Transport and Urban Development Department; Shlomo Angel et al., 2012. *Atlas of Urban Expansion,* Cambridge, MA: Lincoln Institute of Land Policy; Shlomo Angel et al., 2015. *Atlas of Urban Expansion – The 2015 Edition*, New York: New York University, Nairobi: UN Habitat and Cambridge MA: Lincoln Institute of Land Policy (forthcoming online publication).

10 William Alonso, 1964. *Location and Land Use,* Cambridge, MA: Harvard University Press.

11 Animation of the expansion of all 30 cities can be seen at https://www.youtube.com/playlist?list=PLzYZm159uzQNc7H5UCCXHx4c4TKdCeaNt.

12 Shlomo Angel, 2012. *Planet of Cities*, Cambridge MA: Lincoln Institute of Land Policy.

words, its population grew 20-fold while its area grew 180-fold. Average density in Paris thus declined 9-fold during this period—from 450 persons per hectare to 50 persons per hectare—at an average annual rate of 1.1%. In some cities in the group, an increase in density was observed in the 19th century and a decline in the 20th century. Similar rates of decline from peak density to that observed in Paris were observed in the other cities in the group as well.

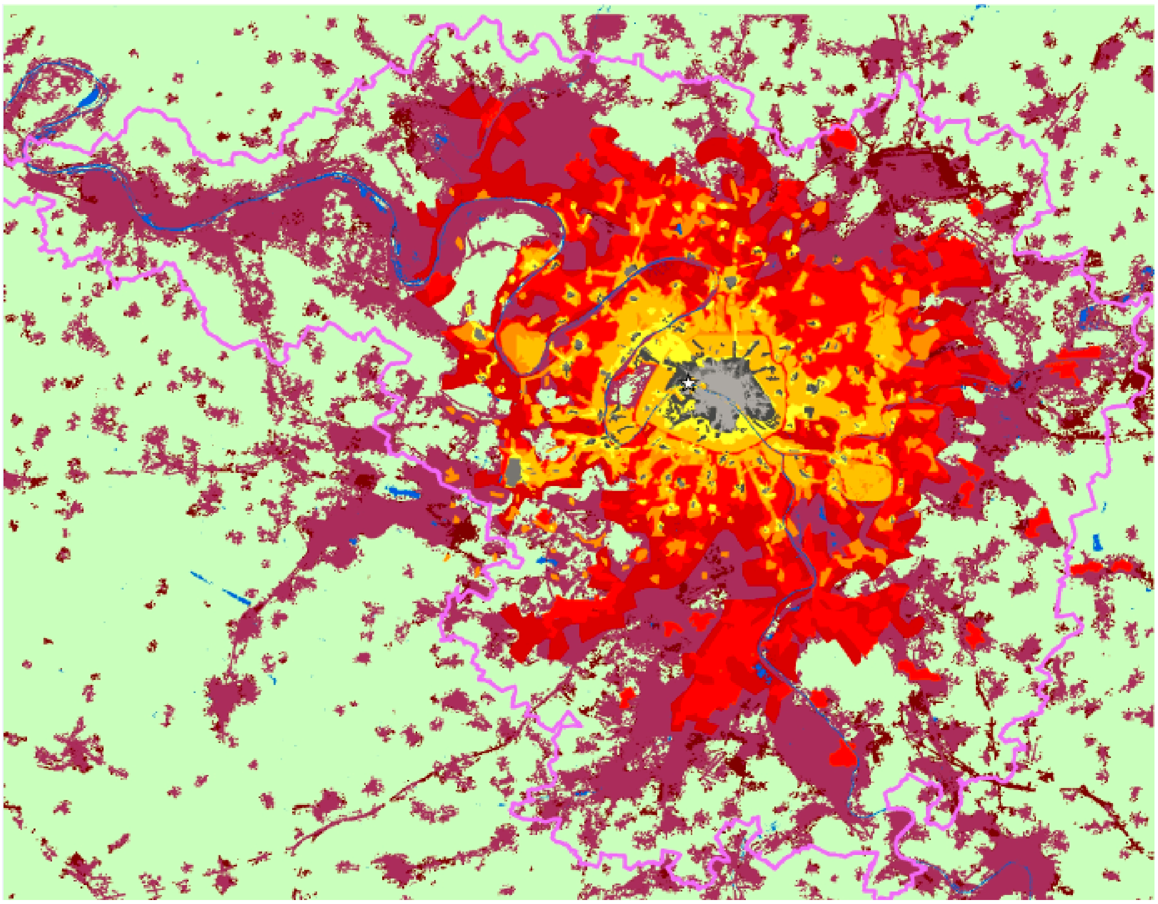

Figure 3: The expansion of Paris, France, from 11km^2 in 1800 (grey) to 2,000km^2 in 2000

The maps and metrics for a new global sample of 200 cities for three time periods—circa 1990, circa 2000 and circa 2014—will be available in the forthcoming *Atlas of Urban Expansion—The 2015 Edition* (Angel et al., NYU, UN Habitat and Lincoln Institute 2015), to be published online in the fall of 2015. The maps showing the change in urban extent in Accra, Ghana from 1991 to 2014, are shown in figure 4 below. Similar maps will be prepared for all the 200 cities in the global sample. Preliminary results for one-third of the cities in the new sample, results that still need to be checked, suggest that the average densities of the built-up areas of cities continued to decline—at a rate significantly different from 0 at the 95% confidence level—in the period 2000-2014 as well.

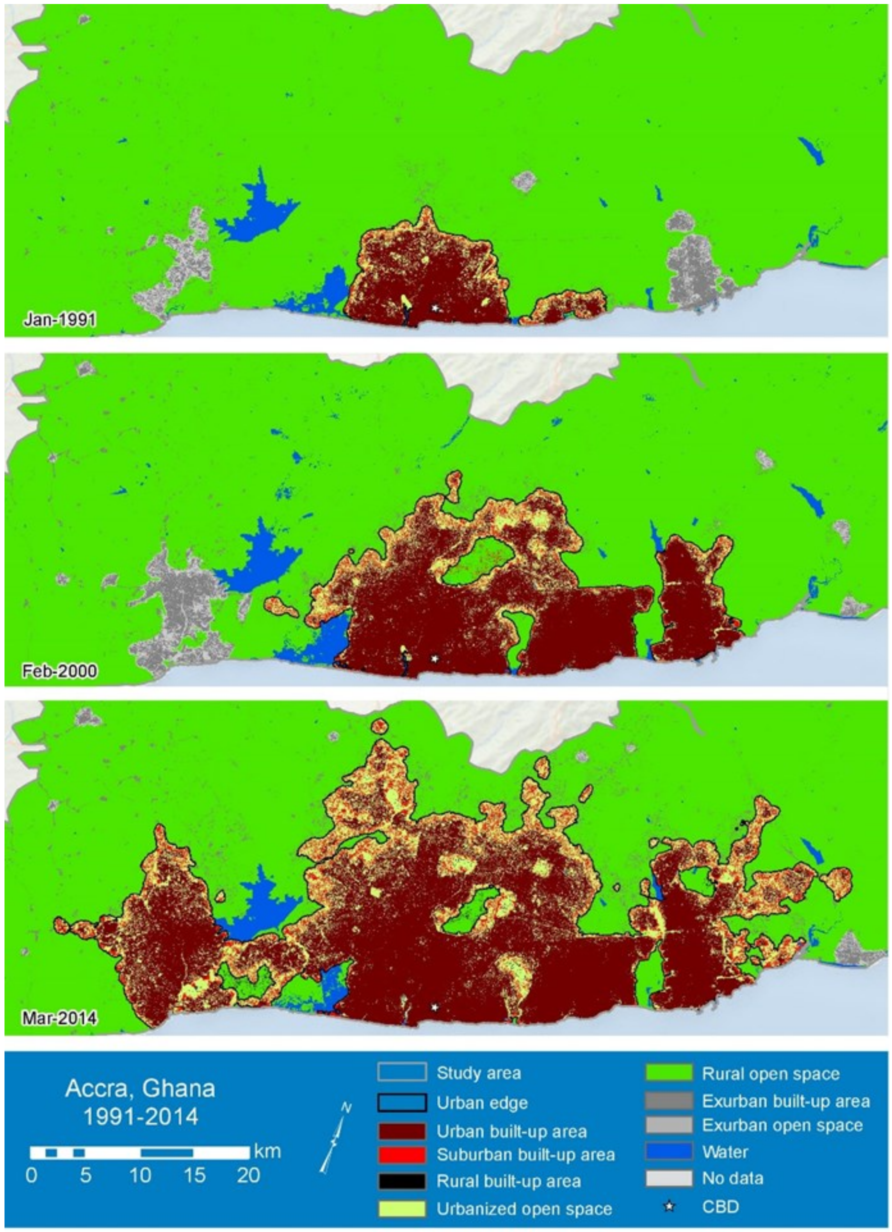

Figure 4: The expansion of Accra, Ghana, 1991-2014

Preliminary results for one-third of the cities in the sample of 200 cities, results that still need to be checked, suggest that the average densities of the built-up areas of cities—densities that were shown to decline between 1990 and 2000—continued to decline in the period 2000-2014, at a rate significantly different from zero at the 95 percent confidence level.

The expansion Accra, for example, during the 1990-2014 period was quite extraordinary (see figure 4). Preliminary results, yet to be confirmed, suggest that its population grew from 1.48 million in 1991 to 2.38 million in 2000, and to 4.14 million in

2014, at an average annual growth rate of 4.4%. Its built-up area grew from 10,300 hectares in 1991 to 32,900 hectares in 2000, and to 54,700 hectares in 2014, at an average annual growth rate of 7.7%, a rate almost double that of its population growth rate. As a result, the average built-up density in Accra declined from 145 persons per hectare in 1991 to 72 persons per hectares in 2000, increasing to 76 persons per hectare in 2014. On average, it declined to half its value during the 1991-2014 period, at an average annual rate of 2.8%. Similar calculations for all 200 cities in the global sample are now being prepared and should become available soon.

What can we say now about the prospects of the urban explosion in the coming decades? Between 2010 and 2050, the urban population in the developing countries is expected to double, from 2.6 billion to 5.2 billion. Economic development and cheap transportation are likely to increase land consumption per person or, alternatively, to lower average urban densities. If the consumption of land per capita increases at 1% per annum—the rate at which it increased in Paris, on average, during the last two centuries—the land area of cities in developing countries is likely to *triple*. If it increases at 2% per annum—the average rate of increase in our earlier sample of 120 cities between 1990 and 2000—the land area of cities in developing countries is likely to *more than quadruple*.

The prospects of urban expansion in Sub-Saharan Africa will be much more extreme. Between 2010 and 2050, the urban population in Sub-Saharan Africa is expected to *quadruple*, from 295 million to 1.15 billion. If densities remain the same, urban areas will increase 4-fold as well. If the consumption of land per capita increases at 1% per annum, the land area of cities in Sub-Saharan Africa is likely to increase almost *6-fold*. If it increases at 2% per annum, land area of cities in Sub-Saharan Africa is likely to increase *more than 8-fold*. These are indeed explosive increases in the expanse of cities. Lower, more modest, increases can be expected in developed countries: a 75% increase in area if land consumption increases at 1% per annum and a 160% increase if land consumption per capita increases at 2% per annum.

The mapping and measurement of urban extent and its key attributes in the global sample of 200 cities will make it possible for us to begin to answer the first question posed at the beginning of this paper: What is the physical extent of urban areas on our planet today, what are its key attributes, how are they changing over time, why, and why should it matter? The 'why' part of this question will be investigated in a series of multiple regression models that will use urban extent and its attributes as their dependent variables and city population, household income, transport cost, the availability of land for expansion, the regulatory environment, the preponderance of informal settlements and other data as independent variables. The 'why should it matter' part of this question should be clear from our earlier discussion. Policy makers at the local, national an international levels as well as academics, activists and interested citizens should be aware of the dimensions of the coming urban expansion, so that adequate lands can be prepared for that expansion, and so that it is orderly, efficient, equitable, and sustainable. Turning a blind eye to urban expansion will likely result in disorderly, inefficient, inequitable, and unsustainable expansion, while seeking to limit it forcefully in the name of rural land conservation, for example—and succeeding in the attempt—will likely result in choking the residential land supply and, in turn, in putting housing out of reach of the majority of households. These issues are investigated in the remaining phases of the monitoring effort.

Phase II: The Mapping and Measurement of Urban Layouts

We know very little about the peripheries of our cities, the vast areas where urban expansion is now taking place. Phase II of the monitoring effort—the mapping and measurement of urban layouts in the global sample of cities—seeks to fill this important gap in our understanding of cities. It seeks to answer the second question posed at the beginning of this chapter: How well laid out are recently built urban peripheries, how are layouts changing over time, why, and why should it matter?

Before seeking to outline the answer to this question, we need to understand the radical and irreversible transformations that are now taking place on the fringe of cities. Lands that may have been in cultivation for centuries are converted to urban use, never to convert back to rural use. The rural owners of the land may sell the land to urbanites—speculators, developers, or ordinary city folk—that may have much better information about its price, the laws governing it, and its potential use and value, and given this asymmetry of information, the land market on the urban periphery may be deeply flawed. The urban periphery, being far from the center of the city, may also be less well familiar to public officials and hence less regulated. Land documents may be incomplete or non-existent, while property rights and property lines may have been enshrined for generations through continuous use and may be quite resistant to abrupt change.

Ill understood and disorganized as it may be, land on the urban fringe is being transferred and put to urban use one way or another at a rapid rate, a rate commensurate with the pace of population growth and economic development in the city. And once land is transferred to urban use and to urban users, its character changes. It can now become part of the city in two quite different ways: It can become a marginalized part of the city, never making a full transformation from rural to urban use, retaining the old property lines and the old rural lanes. Or it can be properly integrated into the city with proper urban layouts involving new property lines, new street grids, and new arterial roads. The unfettered actions of the land market cannot and will not ensure that urban peripheries are properly laid out, and if they are not properly laid out they are likely to remain so for the foreseeable future. Strictly speaking, barring clearance and redevelopment—a highly unlikely outcome anywhere where people have a voice—rural or semi-rural layouts cannot be transformed into urban ones once they are fully occupied. In short, street layouts and property lines in built-up areas are, for all intents and purposes, irreversible.

After the Great London Fire of 1666, Sir Christopher Wren, the architect of London's St. Paul Cathedral, quickly presented King Charles II a plan for rebuilding the city with modern street grids, wide avenues with open vistas, and public squares (see figure 5). Others, notably John Evelyn and Robert Hooke, presented competing plans as well. But the King, fearful of an uprising, was reluctant to assume the power to confiscate the lands needed to implement the plans. In the resulting confusion, it was impossible to identify landowners for purposes of compensation. The city was quickly rebuilt along the old property lines. Invisible as they may be to the naked eye, old property lines exert an undeniable power over urban form.

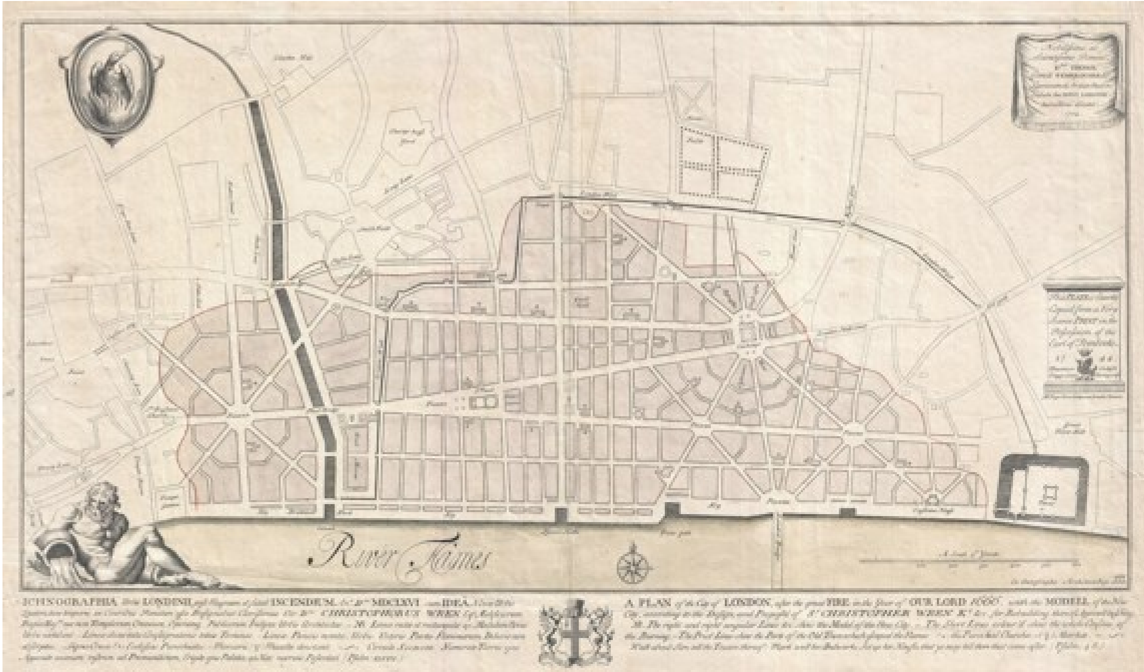

Figure 5: Sir Christopher Wren's plan, never realized, for rebuilding London after the Great Fire of 1666 (plan dated 1744)[13]

Modern-day suburban Bangkok, Thailand, and suburban Lima, Peru, offer two striking contrasts in their street layouts. The hands-off, laissez-faire approach to urban development that characterizes Bangkok illustrates how the absence of arterial roads creates large efficiency losses and stymies organized urban expansion. Figure 6 shows the pattern of narrow lanes in a large area of a northeastern inner suburb of Bangkok that was developed during the 1960s, 1970s, and early 1980s, leaving rural property lines largely intact. This example underscores one of the drawbacks of quick, laissez-faire, market-led urban expansion because it ignores the substantial land needs of public works: the arterial roads are spaced no less than 8 kilometers apart, and the local roads—while connecting each plot to the outside world—are not connected to each other to facilitate through traffic. Congestion is increased because longer intra-city trips are crowded into a small number of arterial roads, resulting in more air pollution and energy use and less labor productivity.

The absence of an arterial road grid in Bangkok makes it very difficult to extend the primary grid of key infrastructure services: water supply, sewerage, and storm drainage. The absence of an arterial road network also makes it much more difficult for the city to collect and treat its storm water and sewer water before pumping it out or recycling it. Indeed, Bangkok does not have a piped water system, a piped storm drainage system or a piped sewerage system. Finally, in the absence of any public pressure or appropriate and binding legislation, the newly developed areas outside Bangkok's traditional center have little public open space. In short, for Bangkok, one of the world's largest and fastest-growing

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13 1744 Wren Map of London, England, Accessed August 13, 2015. http://www.geographicus.com/P/AntiqueMap/London-wren-1744&Affiliate=notcot -

cities, the absence of adequate lands for public works has been devastating. It is expanding rapidly without an arterial road network, without a primary infrastructure network that can carry water, sewerage or storm water, without a system of dikes to manage its storm water, and without a hierarchy of public open spaces. The solutions to this self-inflicted environmental crisis require massive investments in public works, but in the absence of the rights-of-way for an arterial road network, a dike system, and the lands for a hierarchy of public parks and playgrounds protected from development, such investments are now exorbitant and quite possibly unaffordable. Necessary as they may be, the amount of destruction of private property that they could entail renders them next to impossible.

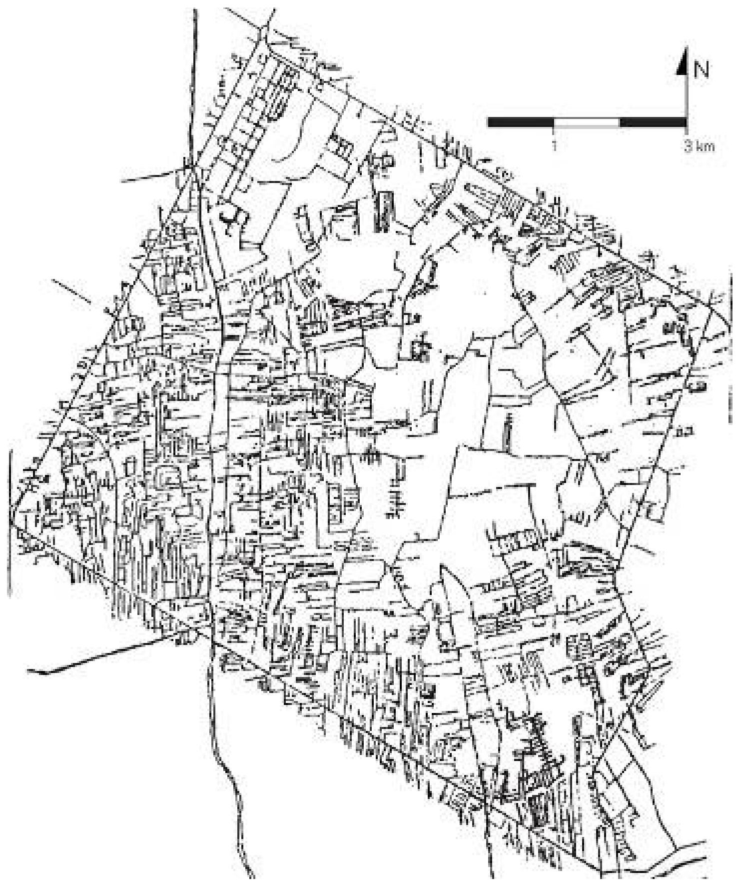

Figure 6: The Absence of Arterial Roads in a 60km^2 section of northwest Bangkok, Thailand, 1984

Planning and acquiring the land for public works requires organization. While Bangkok illustrates a state of anarchy and hardly any organization to speak of, the creation of Pampa de Comas, a large squatter settlement on public land on the desert outskirts of Lima, did require serious planning and coordination. Comas was formed by a series of organized invasions that were carefully thought out and far from spontaneous. People came together in the city, often organized by zealous priests, to plan and prepare for them. Each invading family occupied one building site that had been surveyed and selected in advance. The sites were relatively large, measuring 10-by-20 meters. There were 20 sites to a block and 10-

meter-wide roads between blocks. Some blocks were intentionally left open for markets, schools, and public open spaces. Comas is now a fully built urban neighborhood, indistinguishable from any other neighborhood in the city. Squatters were eventually awarded title documents, and the houses in the district are now part of Lima's formal housing market. Given its small blocks and wide streets, no less than 27 percent of the land area in Comas was devoted to local streets and an additional 3 percent to public open spaces (see figure 7).

Figure 7: The El Carmen squatter settlement, Comas district, Lima, Peru in 2009

The planning and the reservation of rights-of-way for street grids at the block level is essential for cities to operate efficiently and equitably. In his book, *La Grille y El Parque,* Adrian Gorelik[14] equates the 1898 street grid in Buenos Aires—the street grid shown in its 1904 plan as covering the entire territory of the Federal Capital—with the homogenization of its territory in the spirit of social reform by obliterating the differentiation between rich and poor, formal and informal, and by equalizing the distribution of public services, including streets and public open spaces. Indeed, it stands to reason that the Comas street grid and its open spaces accelerated its incorporation into metropolitan Lima as a district among equals. By making all plots similar to each other and facing a broad street, the Comas plan also reduced the difference in real estate values among the houses in the neighborhood and increased the value of real estate in the metropolitan area as a whole.

The lessons from Bangkok and Lima are quite clear: Urban peripheries can be said to be well laid out when they possess a number of key attributes: To be part of the metropolitan labor market, residential areas on the urban periphery need to be well connected to the

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14 Adrian Gorelik, 2001. *La Grilla y el Parque: Espacio Publico y Cultura Urbana en Buenos Aires,* Buenos Aires: Universidad Nacional de Quilmes.

metropolitan area, preferably by arterial roads that can carry public transport located within walking distance of homes. To facilitate the provision of infrastructure services, arterial roads and streets must to be laid out *before* plots revert from a rural to an urban use. New street layouts must not discriminate between rich and poor. An adequate share of the land needs to be dedicated to streets, and streets have to be wide enough. To serve low-income households, plot sizes in residential subdivisions must be small enough to be affordable. To make neighborhoods walkable, blocks must be small enough or the density of 4-way intersections must be high enough.

Focusing on urban peripheries built during the last two decades in a global sample of 200 cities, we measure these attributes in a randomly chosen set of 10-hectare locales in each urban periphery using high-resolution *Bing* and *Google Earth* satellite imagery. In parallel, we measure access to arterial roads—the density of arterial roads and the average beeline distance to an arterial road—in the expansion area as a whole. We report on the preliminary results from 20 cities below. In early 2016, we plan report on all 200 cities as well as on the change of urban layouts over time.

Phase I of the monitoring effort, described earlier, yields an important and invaluable input to phase II: Maps of the expansion areas of cities, areas built up between circa 1990 and circa 2000 and between circa 2000 and circa 2014. To our knowledge, no such maps have been available before, making it very difficult to say anything meaningful and precise about the emerging peripheries of cities. For purposes of analysis, in each city in the global sample we combined the two areas into one expansion area built between circa 1990 and circa 2014. In these expansion areas, we picked an initial set of 40 points, using a *Halton Sequence* to generate the points.[15]

The Halton Sequence generates a quasi-random number sequence that can be used to create a set of quasi-random coordinates of points the expansion area. The points are not truly random in the sense that, given the same origin coordinates—say, for example, 37.1°N and 95.7°E—the Halton Sequence will always generate the same sequence of coordinates for points for the area between 37.1°N and 37.2°N and between 95.7°E and 95.8°E. Using this sequence of points, we could find a unique set of points associated with the expansion area of a city that falls inside that area. Around each of these points, we drew a circle with an area of 10 hectares or 0.1km^2 and we focused our analysis on that circle, referred to as a *locale*. The extent of the sampling in a particular city's expansion area is not pre-determined. We start out with 40 locales in each city, but the decision of when to stop analyzing locales depends on results of a test designed to tell us whether we have captured the average expansion area value for a particular metric with a high degree of statistical confidence. Until this criterion is met, we continue the sequential sampling of locales within the expansion area. The expansion area of Addis Ababa, 1990-2014, and the set of locales there that have been analyzed during the pilot stage of this phase of the monitoring effort are shown in figure 8.

15 For an explanation, see, for example, https://en.wikipedia.org/wiki/Halton_sequence.

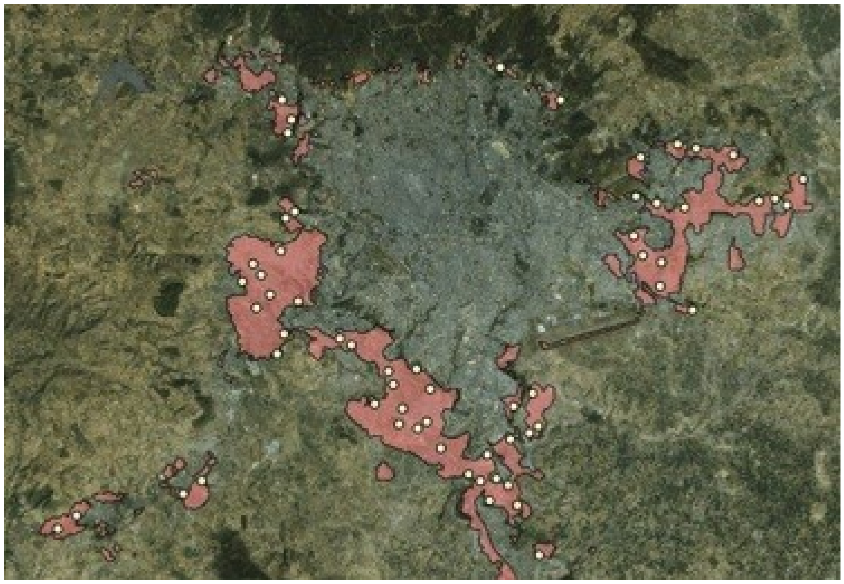

Figure 8: The expansion area of Addis Ababa, Ethiopia, 1990-2014, and the set of quasi-random 10-hectare locales used to analyze the quality of urban layouts there

Using high-resolution satellite images of each selected locale, trained analysts digitize street boundaries as well as the boundaries of residential and non-residential areas. Residential areas are then classified into four types, depending on the stage in their evolution: (1) *Atomistic Housing* where houses are built in succession, one after the other, without a prior subdivision of the land; (2) Informal Land Subdivisions, where land is subdivided into semi-regular plots and narrow lanes, typically ignoring land subdivision regulations; (3) Formal Land Subdivisions, where houses are built within regular street layouts; and (4) Housing Projects, where identical houses or apartment buildings are arranged in a regular, repetitive pattern on the site. In addition, wherever possible, analysts identify individual plots in land subdivisions and measure their widths and lengths. Finally, in addition to digitizing and labeling of land uses in locales, analysts digitize the medians of all blocks that intersect the locale, as well as the medians of all arterial roads—roads of 18-meter-width or more that are connected to other 18-meter-wide roads—inside and within one kilometer of the expansion area. Figure 9 shows a locales in the expansion area of Addis Ababa, characterized by a large percentage of the area in atomistic housing.

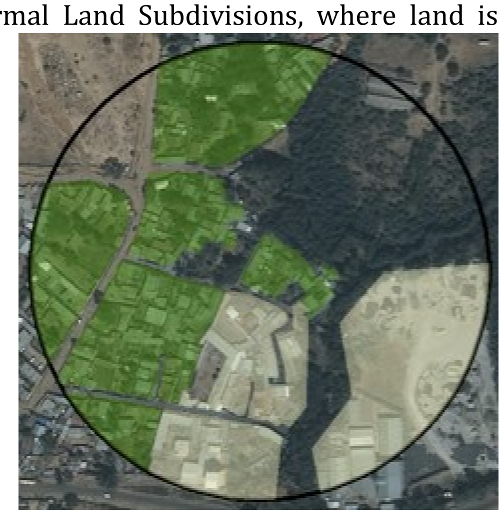

Figure 9: Atomistic housing in a 10-hectare locales in the expansion area of Addis Ababa

City, Country	Share of Built-up Area Occupied by Roads & Boulevards	Average Block Size (Hectares)	4-Way Intersection Density (No. per Km^2)	Density of Arterial Roads (Km Per Km^2)	Average Beeline distance to Arterial Road (meters)	Share of Area within Walking Distance (625m. Beeline) of Arterial Road
Accra, Ghana	18 ± 3%	3.9 ± 1.0	12 ± 8	0.09	2,915	14%
Addis Ababa, Ethiopia	25 ± 4%	3.5 ± 1.4	34 ± 11	0.66	618	69%
Ahmedabad, India	23 ± 4%	8.3 ± 2.7	15 ± 6	1.04	637	71%
Arusha, Tanzania	13 ± 3%	4.4 ± 0.9	15 ± 6	0.55	624	60%
Astrakhan, Russia	22 ± 4%	2.7 ± 0.7	27 ± 12	0.49	945	53%
Auckland, New Zealand	22 ± 4%	7.8 ± 2.9	6 ± 5	0.19	1,481	52%
Baghdad, Iraq	32 ± 6%	5.1 ± 1.2	18 ± 11	0.23	2,127	23%
Baku, Azerbaijan	15 ± 2%	5.4 ± 1.1	9 ± 5	0.27	1,468	35%
Bangkok, Thailand	19 ± 5%	5.3 ± 2.3	9 ± 9	0.01	8,990	4%
Belgrade, Serbia	14 ± 2%	7.7 ± 3.4	9 ± 8	0.17	1,279	37%
Berlin, Germany	18 ± 4%	8.1 ± 2.2	6 ± 4	0.19	1,693	29%
Bishan, China	20 ± 4%	14.5 ± 4.2	4 ± 6	0.29	1,397	54%
Bogota, Colombia	20 ± 7%	8.5 ± 2.7	28 ± 17	0.47	663	57%
Buenos Aires, Argentina	15 ± 2%	3.3 ± 0.9	42 ± 10	0.09	4,387	11%
Cabimas, Venezuela	22 ± 4%	7.6 ± 2.7	19 ± 9	0.02	1,568	27%
Caracas, Venezuela	19 ± 3%	8.1 ± 4.7	3 ± 4	0.11	1,787	25%
Curitiba. Brazil	17 ± 2%	5.9 ± 2.5	19 ± 11	0.07	2,811	16%
Haikou, China	21 ± 4%	3.6 ± 1.2	16 ± 13	1.11	473	77%
Johannesburg, South Africa	18 ± 3%	7.5 ± 3.1	17 ± 8	0.01	10,132	3%
Karachi, Pakistan	26 ± 5%	1.9 ± 0.8	72 ± 34	1.25	409	80%
Kayseri, Turkey	27 ± 4%	4.2 ± 2.6	48 ± 20	1.14	443	79%
Kolkata, India	8 ± 2%	8.0 ± 5.0	3 ± 3	0.11	2,939	24%
Lagos, Nigeria	16 ± 2%	4.4 ± 0.9	4 ± 3	0.15	1,954	26%
Luanda, Angola	15 ± 2%	2.4 ± 0.8	44 ± 18	0.23	1,740	27%
Mexico City, Mexico	23 ± 3%	2.8 ± 0.6	28 ± 11	0.02	11,546	3%
Montreal, Canada	17 ± 3%	6.6 ± 2.0	6 ± 6	0.04	2,850	14%
Mumbai, India	26 ± 7%	5.7 ± 2.2	12 ± 9	0.36	1,477	46%
Palmas, Brazil	35 ± 4%	3.1 ± 1.1	44 ± 19	0.72	465	74%
Paris, France	15 ± 2%	7.4 ± 2.2	6 ± 5	0.05	4,685	12%
Pingxiang, China	12 ± 3%	6.5 ± 2.6	28 ± 27	0.17	1,261	51%
Riyadh, Saudi Arabia	33 ± 4%	6.0 ± 2.5	4 ± 5	0.13	5,828	6%
Rovno, Ukraine	11 ± 2%	8.9 ± 2.3	9 ± 9	0.26	879	48%
Shenzhen, China	25 ± 4%	3.9 ± 1.8	16 ± 7	0.11	4,497	12%
Sialkot, Pakistan	16 ± 3%	4.7 ± 1.4	17 ± 11	0.68	685	59%
Springfield, MA, United States	22 ± 4%	13.0 ± 4.5	4 ± 6	0.00	4,759	3%
St. Petersburg, Russia	19 ± 3%	5.3 ± 1.5	11 ± 10	0.19	2,929	25%
Tokyo, Japan	22 ± 4%	3.5 ± 0.8	39 ± 14	0.29	1,021	42%
Valledupar, Colombia	26 ± 2%	2.3 ± 1.2	92 ± 23	0.15	638	52%
Average	20 ± 2%	6 ± 0.9	21 ± 6.	0.32 ± 0.11	2,553 ± 882	37% ± 8%

Table 2: Preliminary values for selected characteristics of urban layouts in a subset of 38 cities from the global sample of 200 cities, 2015.

The digitized results for 40 locales in the expansion area of each city in the global sample are processed in an automated Python Script in ArcGIS, resulting in a set of up to 18 metrics—some more useful than others—that characterize urban layouts in a given expansion area. Selected average metric results—including their 95% confidence limits[16]—for 40 locales in a subset of 38 selected cities from the global sample of 200 cities—for which preliminary data is already available—are presented, for illustrative purposes, in table 2, together with data on arterial roads in the expansion areas of these cities. It was not possible to include data on housing characteristics or on the share of roads in different road-width categories in the expansion areas of these cities at the time of writing, as these were still being tested for accuracy.

Table 2 reveals some important regularities in the urban layouts on the peripheries of cities in 2015. On average, the share of the built-up area devoted to streets and boulevards is 21±2%, with Kolkata as a low outlier at 8±2% and Palmas, Brazil, as a high outlier at 35±4%. Block sizes on the urban periphery of cities were found to be quite large, compared to say, blocks in Manhattan, New York, a highly walkable urban area. Blocks in Manhattan average 2.2 hectares in area, compared to the average of 6±1 for the 38 cities studied, with Valledupar, Colombia as a low outlier at 2.3±1.2% and Bishan, China, as a high outlier at 14.5±4.2. It is quite clear that in most of the urban peripheries in the cities studied, blocks are rather large, compromising their walkability. Table 2 also include a second measure of walkability—intersection density. Again, in Manhattan, average intersection density is 91/km^2. The average intersection density in the urban peripheries of the 38 cities studied was much lower, 21±6/km^2, with Caracas, Venezuela, as a low outlier at 3±4% and Valledupar, Colombia, as a high outlier at 92±23.

Table 2 also includes a number of measures on the availability of, and access to, arterial roads, the roads that can carry public transport and trunk infrastructure. An arterial road grid, with roads spaced one-kilometer apart, would have an arterial road density of 2km/km^2. All the 38 cities studied had lower arterial road densities, with an average of 0.3±0.1 km/km^2. The maximum density of arterial roads, 1.25 km/km^2, was found in Karachi, Pakistan. The minimum was found in Springfield, MA, United States, that had no arterial roads—roads of 18-meter width or more—in its expansion area at all. The average distance to an arterial road in this subset of 38 cities was 2,553±882 meters, clearly way beyond walking distance; the average share of the area in the urban peripheries of these cities that was within walking distance of an arterial road was 37±8%. These values confirm that most of the area of present-day urban peripheries is not accessible to arterial roads, and is therefore quite unlikely to be served by public transport in an efficient and equitable manner.

We look at one specific example: An image of a typical residential area in the expansion zone to the North of Kolkata, India, can be seen in the *Google Earth* image in figure 10. It is quite clear that most of housing is atomistic housing, built over land that was not subdivided into regular plots with street access to each plot before it was occupied. There are very few roads in the area, and only one wide paved road is shown on the right side of

[16] In subsequent analysis, we may experiment with eliminating one or two outliers locales before calculating average values for metrics in a given expansion area.

the image. We examined the new statistical findings for the expansion zone of Kolkata, including those shown in table 2 above, and they confirm these observations.

Figure 10: Unplanned atomistic residential development on the urban fringe of Kolkata, 2015

We can say with a 95% level of confidence that the share of the residential area occupied by atomistic housing in the expansion area of Kolkata is 92±7%. We can also say with a 95% level of confidence that the share of the built-up area devoted to roads and boulevards in the expansion area of Kolkata is 8±2%. Arterial roads in the expansion area of Kolkata are practically non-existent. Given the density of arterial roads, 0.11 km/km^2, we can estimate that, on average, arterial roads are spaced some 18 kilometers part. Finally, we can also say with a 95% level of confidence that the share of roads less than 4 meters in width in the expansion area of Kolkata is 67±13%. There is no question that these findings are a cause for worry. The absence of arterial roads and through streets, for one, means that the outlying areas of Kolkata are not efficiently connected to the rest of the city, compromising accessibility to jobs and reducing the efficiency and productivity of its metropolitan labor market. The absence of street layouts makes it very difficult to provide urban services in an efficient, equitable, and sustainable manner and clearly discriminates between rich and poor neighborhoods. Now that these areas are fully built-up, it will be very expensive, if not impossible, to provide them with adequate street networks, networks that should have been properly laid out ahead of the occupation of these areas.

To conclude this section, data on urban layouts in cities the world over is beginning to emerge, for the first time. A superficial examination of these data suggests that urban peripheries in cities the world over are not being developed in an efficient, equitable, and sustainable manner. That said, we need the full data set, soon to be completed, for all 200 cities in the sample to begin to understand the scope of the problem and to begin to chart effective paths for solving it, or at the very least ameliorating it in the coming years.

Phase III: The Land and Housing Survey in a Global Sample of Cities

The mapping and measurement of actual urban layouts in the expansion areas of the 200 cities in the global sample will provide us, for the first time, with an accurate picture of conditions on the ground in these cities at the present time. But it will not tell us much about why these conditions prevail, nor what are the consequences of these conditions for the people that have to confront them, the households that must find homes and the businesses and services that must locate in the new expansion areas of cities. Phase III of monitoring global urban expansion—*the Land and Housing Survey in a Global Sample of Cities*—seeks preliminary answers to these questions.

Urban layouts may be affected by a number of factors, among them the level of economic development in the city and its rate of change, the size of the population living in the city and its rate of change, the availability of buildable land on the urban periphery, the average size of rural plots there, rural land ownership patterns, the availability of ground water, and a number of additional factors. One of these additional factors is the regulatory environment or the policy environment governing land and housing development on the urban periphery. We may ask ourselves whether prevailing regulations and policies and their enforcement make a difference in the way urban peripheries are developed and, if we find out that they do, we may seek to change these regulations and policies so that the lead to better urban layouts. In an important sense, therefore, the regulatory and policy environment may have a critical effect on urban layouts and those, in turn, may have a critical effect on the affordability of land and housing. *The Land and Housing Survey in a Global Sample of Cities* is designed to explore these effects using data from a large enough sample of cities to construct statistical models that may shed light on these important effects.

The Land and Housing Survey includes two separate surveys. The first, *the Regulatory Survey*, seeks to obtain information on land ownership patterns on the urban fringe, land transactions, and respect for property rights; the practice of government land expropriation; land invasions and their handling by authorities; land-use planning and the presence of restrictions on the conversion of lands from rural to urban use; the responsibility for street layouts; the effectiveness of key land subdivision regulations; minimum plot size and minimum street width; height and density restrictions; and barriers to densification.

The second, *The Affordability Survey*, seeks to obtain information on the range of prices and rents as well as the key attributes of different types of residential plots and dwelling units in the city: building plots in formal and informal land subdivisions; land-and-house packages; apartments; and plots in squatter settlements. It also seeks information on the time of travel during rush hour by car, by two-wheelers, and by public transport—as well as the cost of travel by public transport—from four key locations on the urban periphery to the center of the city.

No results could be reported on this survey at the time of writing this chapter. The survey instruments have been finalized and translated into nine languages other than English— Arabic, Bahasa Indonesia, Chinese, French, Japanese, Korean, Russian, Portuguese and Spanish—and have been made available on a dedicated website. Two survey supervisors and 8 Regional Coordinators have been recruited, and 20 City-Based

Researchers have been contracted to complete the surveys in their cities. Initial results are expected early in the fall of 2016 and the survey should be completed by mid-2016, in time for Habitat III, The United Nations Conference on Housing and Sustainable Urban Development, to be held in the fall of 2016.

Phase IV: Mapping and Projecting Urban Extent in the Universe of Cities to 2045

Monitoring global urban expansion is aimed at understanding it better and at using our emerging understanding of its dimensions and attributes to inform local, national, and international actors that can make a difference in coming to terms it and doing something about it in the coming decades. That said, the initial focus on a sample of cities—while providing us with an overall knowledge of urban expansion as a global phenomenon—cannot inform individual cities of their prospects of expansion. Each city is, in a sense, unique and may therefore have unique expansion patterns that may be similar, but not necessary identical, to those of other cities. Assisting individual cities in making minimal preparations for their expansion—obtaining the rights-of-way for an arterial road grid and protecting open spaces in expansion areas, for example—requires the projections of both their populations and their urban extents some two-to-three decades in advance. Contemporary urban expansion plans, to the extent that they exist are usually rather short-sighted, typically with a 10-year planning horizon and very rarely a 20-year one. For expansion plans to have maximum effect, they need to be planned some 25-30 years in advance, long enough to take advantage of the vacant and inexpensive lands on the urban periphery, discouraging speculators from trying to second guess the location of the next road project, but not longer than a typical career arc of a municipal civil servant.

Phase IV of the global monitoring effort will focus on mapping and projecting urban extent in each of the 4,245 cities in the universe of cities to the year 2045. It will proceed in five stages:

- Given the coordinates of each city in the universe, we plan to map its urban extent and calculate its attributes circa 2000 and 2010 (and preferably in 1975 and 1990 as well) making use of newly available global urban land cover maps;
- Using population data for administrative districts containing these urban extents, we plan to calculate the population of each city in the universe circa 2000 and circa 2010 (and preferably in 1990 as well);
- Using a statistical model, we plan to project the population of each city to 2015, 2025, 2035, and 2045;
- Using a second statistical model, as well as the outputs of the first model and additional data, we plan to project the quantitative dimensions of urban land cover in each city to 2025, 2035, and 2045; and
- Using a third statistical model, as well as the outputs of the second model and additional data, we plan to map the projected urban extent to produce maps of estimated urban expansion for each city in 2025, 3025, and 2045.

The results of this phase of the monitoring program will be used to inform cities—and especially rapidly-growing ones—of their expansion prospects, as a basis for engaging them in a dialogue about these prospects, a dialogue that may lead them toward make some minimal preparations to ensure that their expansion is orderly, efficient, equitable and sustainable.

Work on this phase of the study has been initiated. We are in the process of assessing the accuracy of two recent global urban land cover maps by comparing them to the urban land cover maps in our global sample of 200 cities. The first one is *Global Land Cover 30* (www.globallandcover.com). This important project, launched by Chinese scientists in 2010 and now being completed, is based on freely available *Landsat* satellite imagery. It provides open and free access to a global land cover map with 10 land use classes—shown at 30-meter resolution—for two periods: circa 2000 and circa 2010. One of these land uses—Impervious Surfaces—allows us to obtain maps of the built-up areas of cities the world over, including all 4,245 cities in our universe of cities. Our initial tests suggest that this is a source of great promise, one that far exceeds the accuracy and level of detail of earlier global urban land cover maps.[17] A visual inspection of figure 11 suggests that this is indeed the case: While the map on the left lacks some detail and is for an earlier date, the two maps are quite similar to each other and cover approximately identical built-up areas.

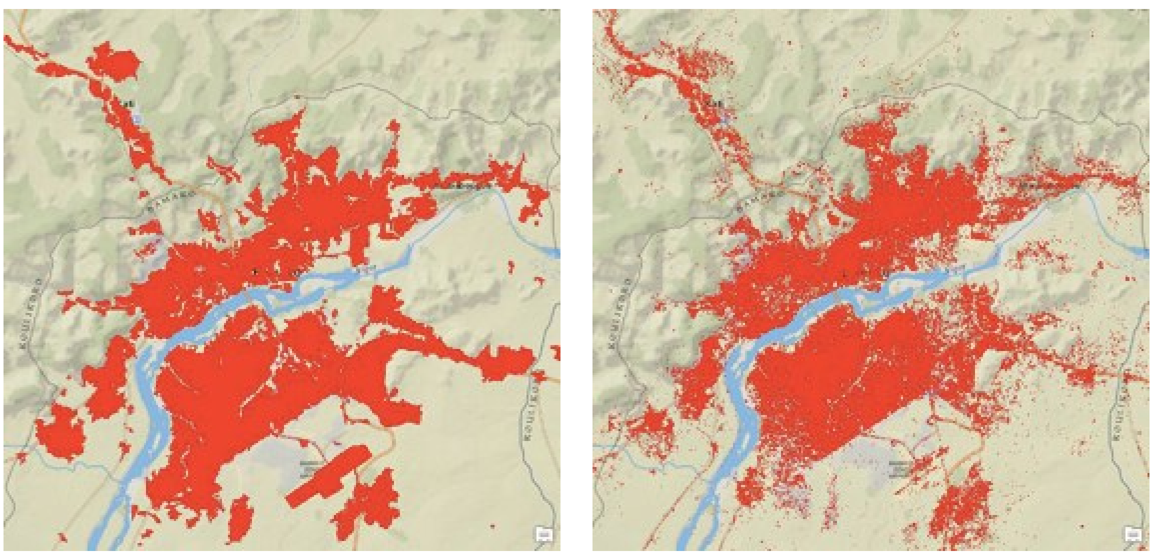

Figure 11: A comparison Global Land Cover 30 (left) and our own map (right) of the built-up area of Bamako, Mali, in 2010 and 2013 respectively

We have also began to test a second set of global urban land cover maps, also based on *Landsat* satellite imagery, prepared by the Joint Research Centre of the European Commission for the years 1975, 1990, 2000, and 2010. We have now begun to test its level of accuracy and its correspondence with our maps for the global sample of cities. This second global maps also shows great promise.

17 For a comparison of global urban land cover maps available in 2008, for example, see Potere, D., Schneider, A., Angel, S., and Civco, D.L., 2009. Mapping urban areas on a global scale: Which of the eight maps now available is more accurate? *International Journal of Remote Sensing* 30, 6531–6558.

This phase of the monitoring effort has only begun. Financial resources for its completion are not yet available and its results will not be ready for Habitat III, the United Nations Conference on Housing and Sustainable Urban Development, now scheduled for October 2016.

Conclusions and Implications

As noted earlier, monitoring global urban expansion is undertaken by a partnership between the NYU Urban Expansion Program, the United Nations Human Settlements Programme (UN Habitat), and the Lincoln Institute of Land Policy. Each institution will use the data to its own end and each institution will make the data available for public use on its own website. It stands to reason that each of these three institutions has different goals in mind for monitoring global urban expansion.

The NYU Urban Expansion Program, for one, is not monitoring global urban expansion for its own sake but with a pragmatic objective in mind. Its primary mission is to assist and accompany the municipalities of rapidly growing cities, enabling them to make room for their inevitable expansion in a set of four practical steps:

- Making realistic 30-year projections of land needs for urban expansion to 2045;
- Extending official city limits to encompass the projected expansion;
- Securing the rights-of-way for an arterial infrastructure grid in expansion areas; and
- Creating the institutional framework for protecting a hierarchy of open spaces there.

Monitoring global urban expansion at regular intervals—say, 5 to 10 years apart—aims at supporting this mission. Making room for urban expansion is critical in ensuring that residential land on the urban fringe remains affordable by all those in need as well as readily accessible by efficient and sustainable public transport. Making room is also critical in ensuring that new urban neighborhoods are laid out before they are occupied to ensure the orderly and efficient provision of infrastructure services. The NYU Urban Expansion Program is described in a recent article in *The Economist*, online at: http://www.economist.com/news/international/21604576-cities-are-bound-grow-they-need-planning-be-liveable-roads-redemption. A short video can be found at: http://urbanizationproject.org/blog/urban-expansion. A primer describing it can be found at: http://urbanizationproject.org/uploads/blog/UEPrimer2014.pdf. The intellectual foundation of the Program is a 10-year research project on urban expansion, culminating in the publication of two books, *Planet of Cities* and the *Atlas of Urban Expansion*.

Monitoring global urban expansion on a regular basis along the lines described in this paper will surely raise new questions, lead to new research and new actions programs, and be put to other uses in the years to come. We hope that our initial efforts at monitoring cities on a global scale will lay a more solid scientific foundation for the study of cities as well as for planning their future.

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