

The State of the Streets: New Findings from the *Atlas of Urban Expansion*—2016 Edition

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Abstract

Relatively little is known about the spatial organization of streets and roads in the world's cities, the differences that exist across cities, or the differences that have emerged within cities over time. We use evidence from the *Atlas of Urban Expansion—2016 Edition* to investigate these questions, focusing on measures of road capacity and road connectivity. We compare outcomes in cities' 1990 – 2014 expansion areas against outcomes in cities' pre-1990 areas to determine the direction of trends over time and whether the observed differences are statistically significant. The analysis is based on a 200-city sample that was carefully selected to represent the universe of 4,231 cities with populations of 100,000 or more in 2010. Road network measurements were taken using an intra-urban sampling framework based on a Halton sequence of quasi-random analysis sites. Information for network capacity and connectivity as well as complete maps of cities' arterial roads were created by the manual digitization of high resolution satellite imagery. We conclude that the composition of road networks is changing over time as new networks have narrower streets, fewer 4-way intersections, and fewer arterial roads. We explore the implications of these changes and how they may be addressed.

Keywords: Streets, intersection density, arterial roads, roads, urban layout, urban expansion

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The State of the Streets:
New Findings from the *Atlas of Urban Expansion—2016 Edition*

Introduction

This working paper presents new measurements of streets and roads from the *Atlas of Urban Expansion—2016 Edition*, measured over a 25-year period in a global sample of 200 cities. Urban planning has traditionally focused on streets and roads and it is only in recent decades that zoning and other considerations have eclipsed this core task. The results of the analysis of streets and roads show that in many cases planners and city officials may be neglecting the laying out of streets and roads, and that there is a compelling case for a reinvigorated focus on this key aspect of planning.

The *Atlas* revealed that the areas cities occupy have grown faster than their populations on average, and that as a result, population density in the average city, though not necessarily every city, has been declining (this is discussed in greater detail in a companion working paper, Blei et al 2018). Against a general trend of density decline, cities in most world regions have maintained the same share of their total built-up area in roads. Although that share is not that over time, we find that road space is being allocated to a denser network of narrower streets in cities' 1990 – 2014 expansion areas compared to their pre-1990 areas. We also find that arterial roads are scarcer and less accessible in the expansion areas of cities, (Angel et al 2016). Figure 1 illustrates the expansion areas of the Cairo, Egypt urban extent from 1992 to 2013, based on the analysis of Landsat satellite imagery from the *Atlas*.

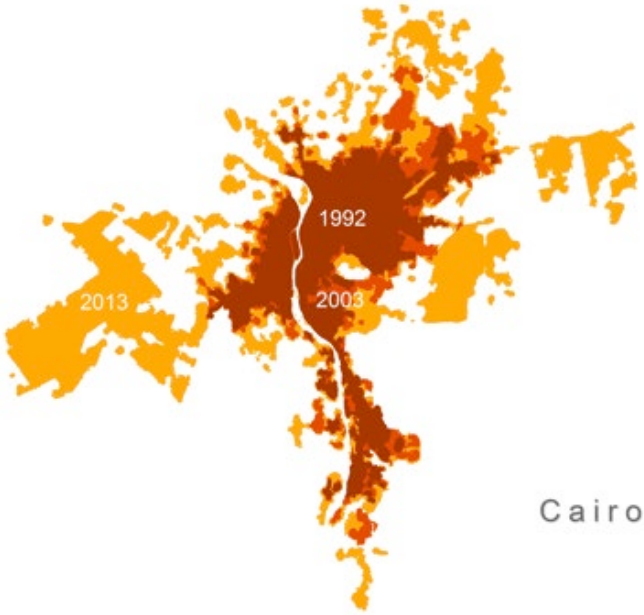

Figure 1: From 1992 to 2013, the population of Cairo, Egypt grew from 9.6 million to 15.7 million, a 1.6-fold increase. Because of increased land consumption per capita, the area of Cairo expanded even more, from 41,203 hectares to 136,416 hectares, a 3-fold increase.

The implications of these findings are somewhat distressing from the point of view of an urban planner or a city leader. The 2013 report *Streets as Public Spaces and Drivers of Urban Prosperity* identified three core functions of streets and roads – mobility, commerce and social interaction (UN Habitat 2013). Both mobility and commerce fundamentally come down to transportation: When an individual looks for a job or a firm looks for an employee or new customer, are they able to look throughout the whole metropolitan labor market, or are they limited to a fraction of the possible opportunities due to the difficulty of moving around (see, for example, Angel and Blei 2016)?

The results from the *Atlas* seem to indicate that the newly built areas of cities are in the latter category, with lower travel speeds and fewer corridors that are suitable for public transportation. People living on the new urban fringe may have diminished access to jobs (not to mention services and amenities) than those who came before them. Firms may have a more difficult time attracting workers and delivering goods and services. The city could become less equitable, less productive, and less sustainable.

The outcomes we observe today are actually an evaluation of the consequences of earlier planning actions (or inaction). The decisions that were made in the past are with us now, and most of the decisions that are made now about the routes and widths of streets and roads will also remain with us indefinitely. We find that the layout of a city is enduring and very difficult to change, though there are exceptions to this rule, notably Haussmann's transformation of Paris.

After the Great London Fire of 1666, for example, the famous architect Sir Christopher Wren quickly drew up plans to widen and straighten the narrow streets and crooked lanes of the devastated city (Figure 2). He saw in the burned landscape a tabula rasa, and he submitted his plans to King Charles II. The King supported the plans and envisioned a city of order and direction. Despite royal support for the plan, property owners asserted their rights and the city was quickly rebuilt along the same plot boundaries that have existed since medieval times (Wikipedia Contributions 2017).

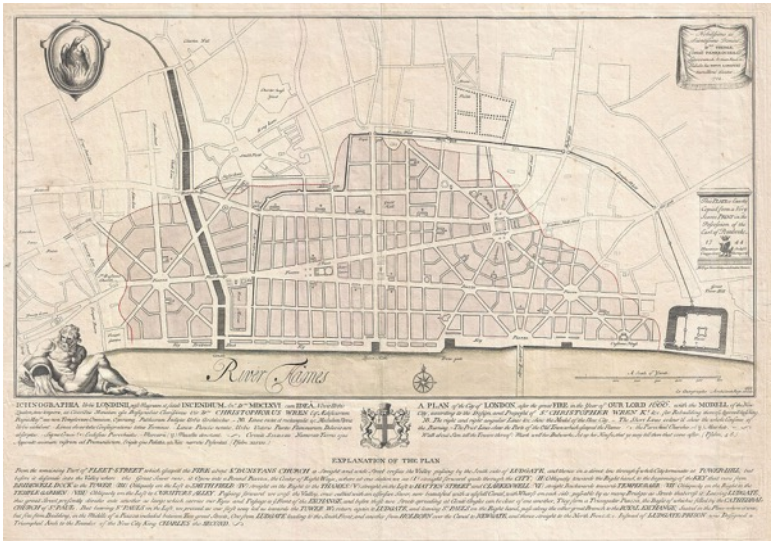

Figure 2: The plan of London of Sir Christopher Wren, 1666. Source: Wikipedia Commons

The planning decisions made today are happening in the context of historically rapid urbanization. It is often noted that 2.5 billion people will be moving to cities between now and 2050. Between 1990 and 2015, the world urban population increased from 2.3 billion to 3.9 billion – an increase of 1.6 billion, or approximately 70% (calculated from World Urbanization Prospects 2014). Over roughly the same time period, the land area of the average city increased by a factor of 2.1 (calculated from *Atlas of Urban Expansion—2016 Edition: Volume 1, Areas and Densities* Table 1). If that trend holds, a typical city should approximately triple in size between now and 2050. The global distribution of this growth is uneven, and 90% of the anticipated growth in cities will take place in developing countries, as illustrated in Figure 3. In many of those cities, there could be a 4-fold or greater increase in total area in the next 35 years (Angel 2012).

The layouts of cities must be planned if cities are to be orderly and productive, and planning must be done before much private sector development has occurred. Private sector actors will provide roads within individual developments, and informal development processes also lead to the setting aside of some land for streets and roads. However, neither the private formal sector nor the informal sector will provide for arterial roads, which are classic public goods that provide connectivity throughout the urban area. Nor will they provide for connectivity between developments, or necessarily emphasize the layouts and forms that optimize movement throughout the city. If the public sector is to have a meaningful impact on the layout of cities, land for arterial roads must be laid out and protected before private development occurs.

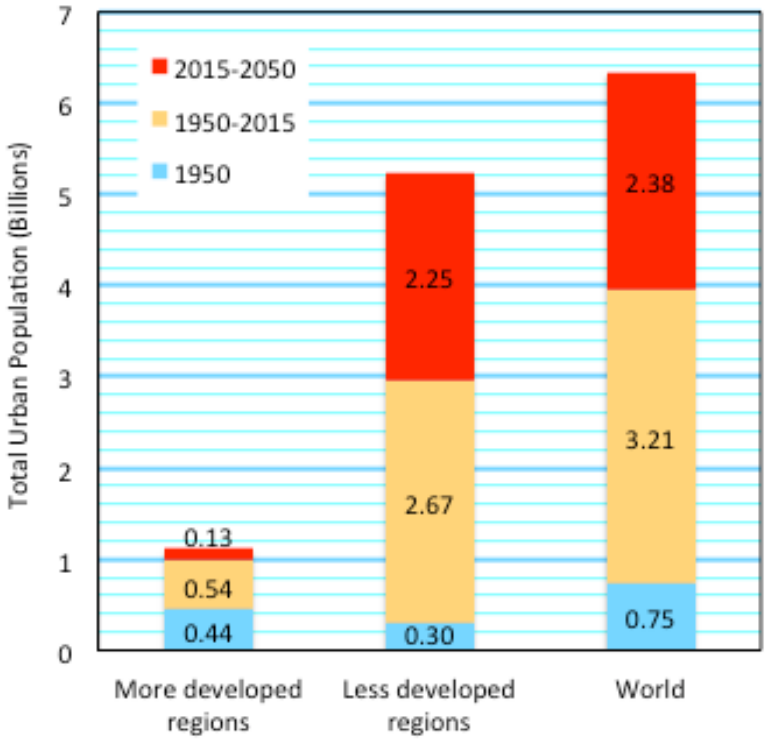

Figure 3: Between 2015 and 2050, 19 persons will be added to cities in less developed countries for every 1 person added to cities in more developed countries.

In the past, rapid urban expansion has strained the ability of municipalities to perform this task. In Latin America, for example, rapid urban growth with minimal planning led to the proliferation of informal settlements and slums (Rogler 1967). The cost of extending services to these areas has been quite high when compared to new and well-planned areas (Figure 4) (Abiko et al 2007, Fernandez 2011).



Figure 4: The cost of providing residential infrastructure in the Matinha favela in Rio was 6-9 times the cost of providing it in a new land subdivision (Abiko et al 2007).

This paper confirms empirically what planners and city leaders know from experience – that the same tendency of disorderly development that afflicted cities in Latin America in the 1960s and 1970s is afflicting the rapidly growing cities of today. Three case studies, of Kolkata, India; Chengdu, China; and Lagos, Nigeria illustrate the perils of failing to plan for adequate street capacity, street connectivity, and arterial roads. The paper concludes with a look at an ambitious project to address these issues in Ethiopia. The ultimate finding is a hopeful one: although cities have grown mightily in the past 25 years, and much of this growth has been unplanned, many cities will still triple or quadruple in size, and there is much good work that can be done.

The Measurement of Streets and Roads

The analysis of streets and roads in cities has proceeded without a broad empirical basis. Planners commonly measure the characteristics of street networks in an ad hoc way that facilitates specific projects, but the authors know of no other research that has measured the physical characteristics of streets in a representative sample of cities using a consistent methodology over several time periods. This is not to say that those characteristics have not been

measured – several excellent attempts have been made to quantify the physical characteristics of streets, and this paper draws heavily upon them. However, it is important to be able to measure the characteristics of the road networks that are being built today and compare them to the road networks of the past. Equally important is to be able to compare the road networks of different cities, and to study associated outcomes. The fundamental objective of this research is to take measurements in different cities and across different time periods, using the same consistent methodology.

Streets as Public Spaces and Drivers of Urban Prosperity, a pioneering UN Habitat report spearheaded by Gora Mboup, has spurred new research into the characteristics of streets (including providing the impetus for the research reported in this paper). That report built on the work Schmidt and Wells (2005). The authors of the report used satellite imagery to collect several indicators to assess street capacity and street connectivity in cities. They specifically looked at the share of land allocated to roads, street density, intersection density, and two measures of street connectivity focused on node analysis (UN Habitat 2013).

The *Atlas of Urban Expansion—2016 Edition* builds on *Streets as Public Spaces and Drivers of Urban Prosperity* in four ways – first, it offers more consistent and comparable results by limiting the analysis to the urban extent of a city. Second, it simplifies the data collection process by introducing a sampling methodology that allows for the investigation of many more cities at a much lower cost. Third, it factors street capacity into three additional measurements. Fourth, it offers results for streets and roads that were built in different time periods within the same city, allowing the authors to compare the streets and roads planned in an earlier period with those that were planned more recently.

The Atlas of Urban Expansion Methodology

The *Atlas of Urban Expansion—2016 Edition* was produced in collaboration with UN Habitat and the Lincoln Institute of Land Policy. The *Atlas* was designed to enable to scientific study of many of the characteristics of cities, particularly those that could be observed through remote sensing. It focused on the study of a stratified global sample of 200 cities, drawn from the universe of 4,231 cities having populations of 100,000 or more in 2010. (Figures 5 and 6) The universe was assembled using data from the UN Population Division and the Chinese Academy of Sciences. When assembling the universe, cities in urban agglomerations having multiple municipalities were merged. For instance, New York includes not only New York City, but also cities in New Jersey and Connecticut that are physically contiguous.

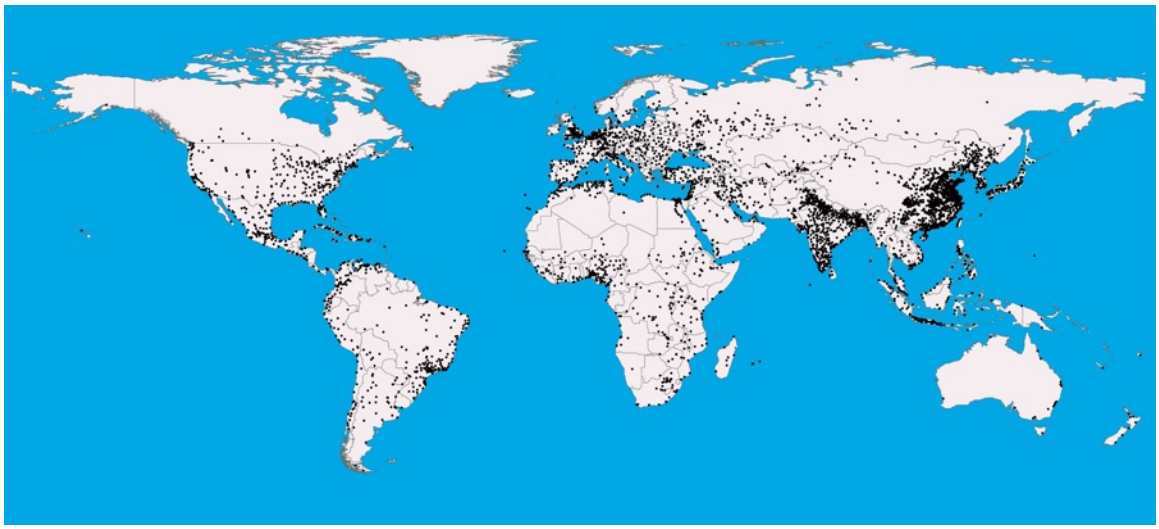

Figure 5: The universe of 4,231 cities having populations of 100,000 or more in 2010.



Figure 6: The stratified global sample of 200 cities.

The sample was stratified based on four "city size" categories, three "number of cities in country" categories, and eight world regions. Cities were randomly chosen based on these categories and each city has a statistical weight that allows results from that city to be extrapolated to the universe as a whole. Data from the sample can be used to report on all of the cities on earth with populations greater than 100,000 by applying those weights. Results will also be reported for each of the eight world regions that can be seen in Figure 7, when there are significant differences between them.

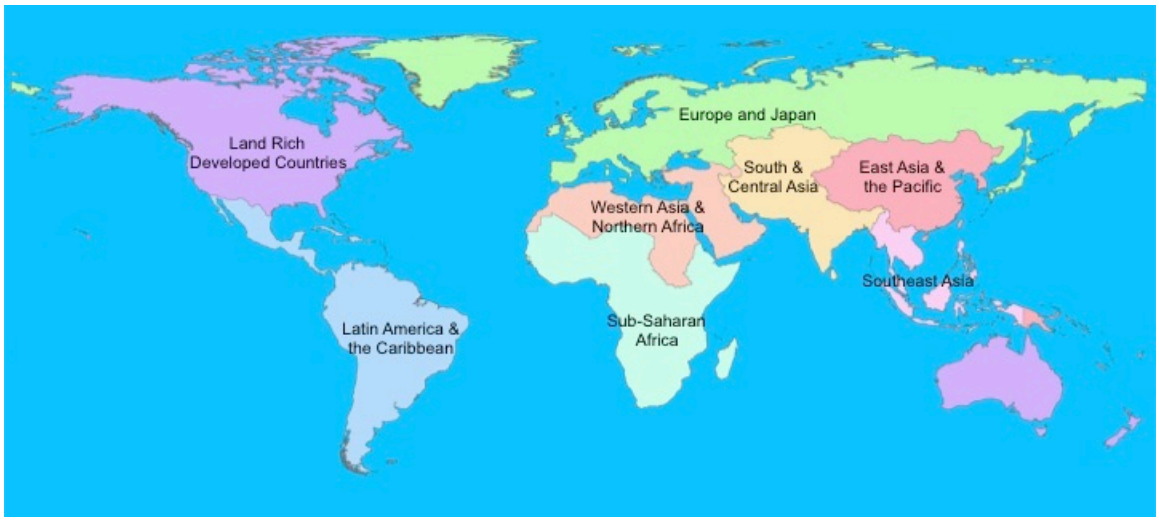

Figure 7: The eight world regions.

The *Atlas* is divided into two volumes. The first volume, *Areas and Densities*, focuses on the measurement of cities in three time periods using Landsat satellite imagery. The key output from this phase of the work is the measurement of the urban extent of the city in each of the three time periods – circa 1990, circa 2000, and circa 2014 – allowing for the detection of change in the area of the city over time (Figure 8). This definition of the urban area is based on the Roman concept of the *extremum tectorum*, or the "end of the rooftops" of the city, rather than on an administrative definition of the city. Census data was gathered for the administrative jurisdictions encompassing each urban extent, and this data was interpolated and apportioned to provide population estimates for the urban extent in each time period. This enabled the calculation of population density and the change in population density over time. Additional metrics were generated from the Areas and Densities data, including measures of the shape and compactness of the city and information on the composition of the areas of the city that were added over time – whether the city primarily grew through extension or leapfrog on the urban periphery, through infill of the existing urban extent, or through inclusion of surrounding settlements.

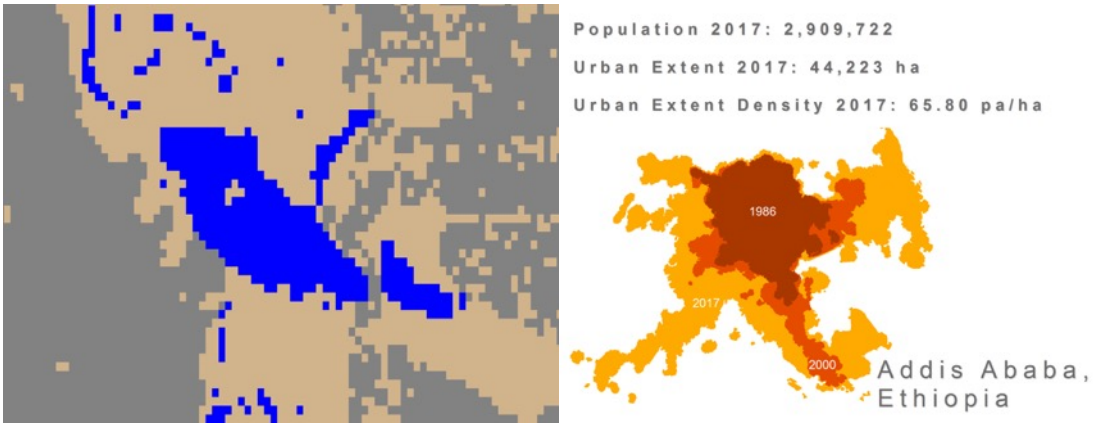

Figure 8: Processed LANDSAT imagery (left) and finalized urban extent of Addis Ababa, Ethiopia (right)

The information presented in this working paper is drawn mainly from the second volume of the *Atlas*, *Blocks and Roads*. *Blocks and Roads* reports on the measurement of the residential land uses and metrics stemming from the network of streets and roads. The study areas are defined using the urban extents identified in *Areas and Densities*. The extent of the city in 1990, which contains all of the growth that took place up to that year, is referred to as the pre-1990 urban extent. The 2015 urban extent includes all of the growth that took place up to that year. By erasing the pre-1990 urban extent from the 2015 urban extent, it is possible to identify only the areas that were developed between 1990 and 2015. This is known as the expansion area. This exercise allows us to speak about two areas in the city – the area that was built before 1990, and the area that was built from 1990 to 2015 (Figure 9).

These areas are quite large in most cases, with the average city adding approximately 42,000 hectares between the two periods. Existing techniques for measuring streets and roads rely on manual digitization techniques that would be much too labor intensive to deploy over such a large area in so many cities. To address this challenge, a new intra-urban sampling methodology was developed for use within the urban extent. This methodology relied on the placement of semi-random points throughout the urban extent. The location of each point is derived from a Halton sequence, which is a non-random series of numbers that behaves randomly for the purposes of statistical analysis (Figure 9).

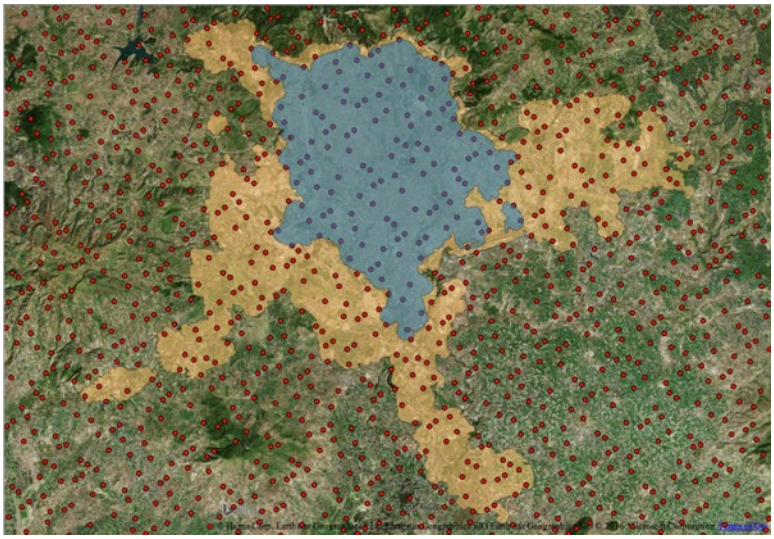

Figure 9: The area of Addis Ababa in 2017, divided into the pre-1990 area (blue) and the expansion area (orange), with Halton points (red dots).

Each Halton point was given a buffer of 178 meters, producing circles with an area of approximately 10 hectares. These circles were known as locales (Figure 10). Each locale has a sequential ID code based on the random Halton sequence. Sampling the locales sequentially based on this ID code yields a random distribution that provides good geographic dispersion with no clustering. Locales do occasionally overlap. In that case, the locale that is sampled second in the sequence is clipped to remove the area of overlap. In total, 13,157 locales were sampled in the pre-1990 area and 8,708 locales were sampled in the expansion area in the global sample of cities. On average, 109 locales were analyzed in each city – 66 in the pre-1990 area and 43 in the expansion area.



Figure 10: A typical locale in the pre-1990 area of Addis Ababa, with blocks, roads, and buildings visible.

The plan for the analysis required each city to receive 40 locales in the pre-1990 area and 40 locales in the expansion area. However, not all cities were large enough to accommodate 40 locales in both periods. In some cases, particularly in cities that were less than 10 square kilometers in area, the entire area of the city was digitized and the analysis was performed without sampling. At the end of the initial round of locale digitization, once each city had either been digitized in its entirety or had received 80 locales, there were enough resources remaining to digitize 2,200 additional locales. To allocate those additional locales among the different cities, an approach was used that attempted to quantify the statistical robustness of the results in each city for three key indicators – *Average share of built-up area occupied by roads; Share of Land in Residential – Informal;* and *Share of Land in Residential – Atomistic*. This relied on analyzing the variance among the locales that had been digitized and comparing it to the average variance in the sample of 200 cities. Cities that had high variance, comparatively, were prioritized to receive additional locales in order to ensure that a representative set of locales had been analyzed in that city. New locales were added in batches of ten to each of the ten cities with the highest variance. After each batch of ten, the data was re-processed and the cities were re-ranked. This continued until the remaining resources had been exhausted.

To gather the information, trained analysts manually digitized Bing satellite imagery within each locale. First, the boundaries of blocks were digitized, dividing the street space from the block space. Each block was then categorized into one of six land use types – (1) open space, (2) non-residential, (3) residential – atomistic, (4) residential – informal, (5) residential – formal, and (6) residential – housing project. A companion paper will address the results for residential subtypes. Figure 11 shows the division of a locale into land uses and street space.



Figure 11: A digitized locale showing land use divisions and street space.

Street space consists of everything within the locale that is not categorized into one of these six land uses. Specifically, street space is defined as areas within cities available for use by vehicles or pedestrians, whose primary purpose is to provide connectivity for travel (as opposed to parking). Spontaneous paths across open areas, paths within parks that were not available for through connectivity were excluded, and limited access roads such as expressways were not included in the calculation of street space. When defining the edges of a street, an effort was made to measure the true right-of-way, inclusive of sidewalks, bike lanes, and up to one lane of parking in each direction. Boulevards were included, with limitations on the width of the green spaces. If the green spaces were too wide, they were digitized separately as open space blocks. Street medians were traced down the centerline of all streets within the locale, as well as in a subset of streets beyond the locale boundary in order to create complete blocks. These medians were used to measure intersection density and average block size.

Analysts also drew a map of the existing arterial roads throughout the entire urban extent. Arterial roads were identified based on the connectivity they offered between distinct areas of the city, and their location relative to neighborhoods and town centers. Google Maps and Open Street Map categorizations were used for confirmation.

A standard street hierarchy includes arterial roads, connector roads, and local roads. The arterial roads provide connectivity throughout the metropolitan area. These roads make it possible to commute to jobs throughout the city, allowing for the formation of a metropolitan labor market. The local roads are the smallest roads and provide access to individual plots and parcels. The collector roads are mid-sized roads that carry traffic between the local roads and the arterial roads and provide connectivity within and between neighborhoods. The local and collector roads facilitate walking, biking, and lower-speed local traffic. Arterial roads were further sub-categorized into “Wide” arterial roads and “Narrow” arterial roads. Wide arterial roads were always at least 18 meters wide – enough for four lanes of traffic (Figure 12).

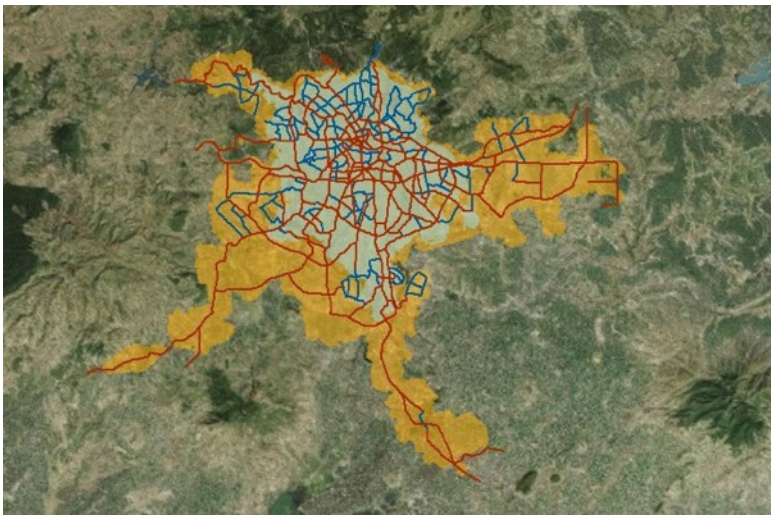

Figure 12: Wide (red) and narrow (blue) arterial roads in Addis Ababa.

In cities with few arterial roads, the collector and local roads were often marked in Open Street Map or Google Earth as arterial roads that could be used for travel throughout the metropolitan area. This is problematic, because those roads were not designed for this purpose and tend to have less connectivity and lower capacity (being narrower). Cities that only have collector and local roads will most likely have a lower average share of built-up area occupied by roads, resulting in congestion and other problems. Roads in this category were labeled as "Narrow" arterial roads, because their width was always less than 18 meters.

The measurements of the network of streets and roads can be broken down into capacity measures and connectivity measures. Capacity measures refer to the total amount of traffic that can be carried by the network at any given time. Connectivity measures attempt to assess the quantity of different route options available to a given user.

Three measurements of capacity will be reported: (1) the share of built-up area allocated to roads (Figure 13, showing a locale with streets in orange and the percent); (2) street density (Figure 14, showing street lines in a given area); and (3) the average street width.

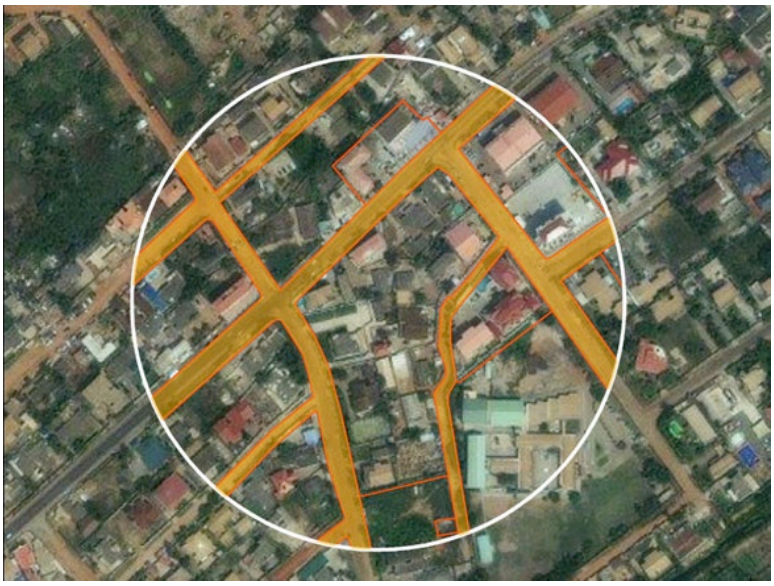

Figure 13: Street space (orange fill) and block space (red borders) in a locale in Accra, Ghana.

The *Atlas* reported on the average share of built-up area occupied by roads as the indicator of street capacity. This paper offers an additional insight: the average share of built-up area occupied by roads is, in fact, a composite indicator, the product of the average street width (weighted by segment length) and the street density (linear km of street per km2 of built-up area). Assuming a fixed average share of built-up area occupied by roads, street density and average street width will always move in opposite directions – an increase in street density implies a reduction in average street width, and vice versa.

Results will also be reported on two connectivity measures: 1) average block size (Figure 15) and 2) 4-way intersection density (Figure 14, again). Finally, results will be reported on arterial roads – 1) the density of arterial roads, and 2) share of the urban extent within walking distance of an arterial road.

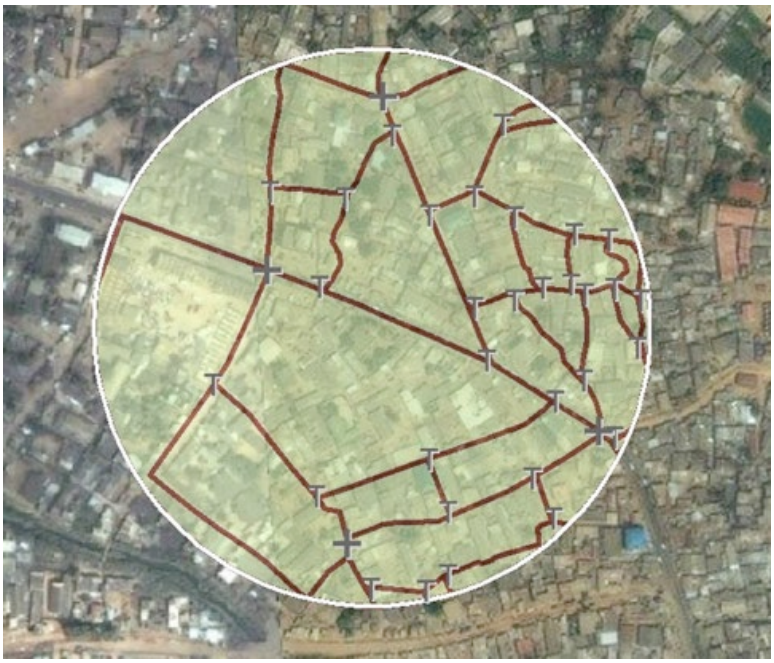

Figure 14: Street medians (brown) and intersections (4-way intersections are marked as X and 3-way are marked as T) in a typical locale.



Figure 15: Identifying all the blocks in a typical locale by digitizing the road medians around them, including blocks that are clipped by the circular boundary of the locale.

Findings

Road Capacity

The amount of road capacity a city will require is a function of the size of the city, the number of commuting trips, and the modes of transportation used during peak times. All else being equal, having a higher percentage of the land in streets or a higher median street width will mean that the road network is able to carry more traffic at higher speeds, regardless of mode. This logic has been codified in municipal regulations (a survey of which can be found in Ben-Joseph 1995) that prescribe minimum street widths based on the type of development that is taking place. UN Habitat takes a different tack, recommending that at least 30% of the land in cities be designated for streets, but without specifying a distribution of street widths (UN Habitat 2015). In Manhattan, for example, the share of land in streets is 36% (UN Habitat, 2013) and the minimum width for new streets is 12 feet (NYC DOT 2013). In theory, cities that are not dedicating adequate land to streets will suffer from commuting problems that will harm the functioning of the metropolitan labor market.

One way of understanding this is to simply think about the amount of land consumed by one car, moving at 60 km/hr. A common heuristic for safe following speed in traffic is the "3-second rule." In 3 seconds, a car traveling at 60 km/h will travel 16.6 meters. A standard travel lane is 3.5 meters wide (NSC 2005). A car moving at 60 km/h will need at least 58 m2 of street space in order to operate safely. If 100,000 people are commuting by car at the same time, the city will need 100,000 x 58 m2 of street space if the average travel speed is to be 60 km/h. If less street space is available, the average travel speed will have to be lower in order for the cars to operate safely (based on Bertaud 2011). This is a simplistic example, but the general principle holds – all modes of transportation consume a certain amount of street space at a given speed. If street space per capita is too low for a given mode, travel slows and commutes take longer.

For easy reference, Table 1 shows the acronyms in the graphs to follow.

Table 1: Acronyms and full names of each world region.

EAP	E&J	LAC	LRD	SCA	SEA	SSA	WANA
East Asia and the Pacific	Europe and Japan	Latin America and Caribbean	Land Rich Developed Countries	South and Central Asia	Southeast Asia	Sub-Saharan Africa	West Asia and North Africa

<u>Share of Built-up Area Occupied by Roads</u>

The *Atlas of Urban Expansion—2016 Edition* reveals that the average *share of the built-up area occupied by roads* did not change between the pre-1990 area and the expansion area in the universe of cities. In the pre-1990 area the value for all cities was 20.8% and it has now declined

to 20.7%. The difference is not statistically significant. Sub-Saharan Africa exhibited the only significant decrease, from 19.5% to 16.4%.

Western Asia and North Africa (which includes the oil-rich and car-dependent gulf states) has the highest share of land devoted to roads in both periods, with 25.1% in the pre-1990 area and 24.9% in the expansion area. Southeast Asia has the lowest share of land devoted to roads in the pre-1990 area, at 17.2%, and Sub-Saharan Africa has the lowest in the expansion area, at 15.9%.

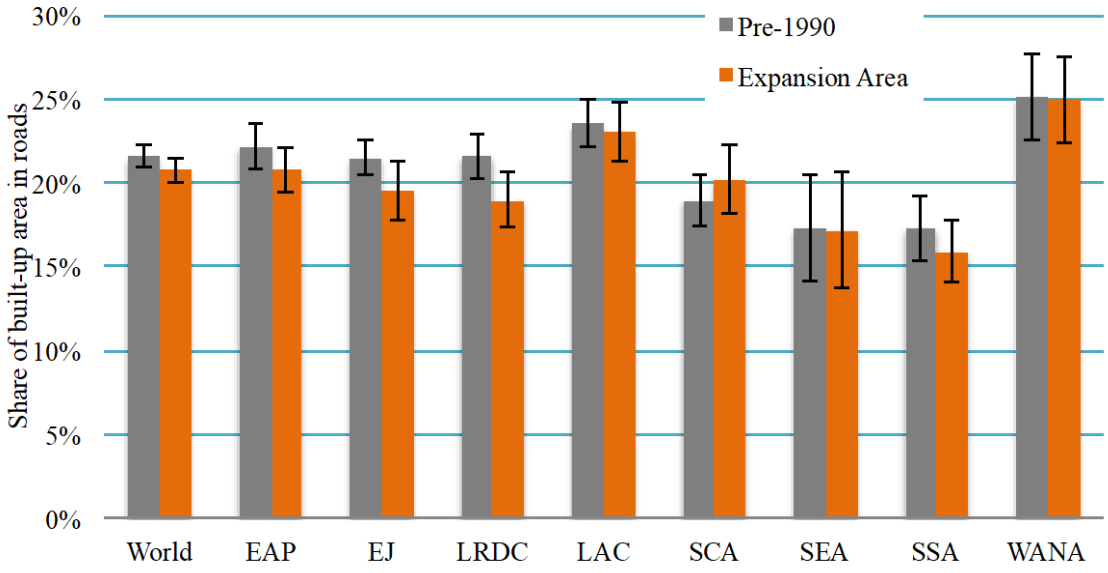

Figure 16: The share of land in streets has remained steady in most world regions, with a significant decrease seen in Sub-Saharan Africa alone.

Regression analysis finds that the share of built-up area occupied by roads is positively correlated with GDP, indicating that wealthier cities are likely to have more land devoted to roads.

Notably, two major cities in the 200 city sample in South and Central Asia have a very low share of the built up area in roads in the expansion area: Kolkata, India, has a share of 8.2%, and Dhaka, Bangladesh has a share of 11.2%. The city with the highest share is Palmas, Brazil, at 36.7%, and the next highest city is Riyadh, Saudi Arabia, at 34.6%. Full data on this metric can be found in Appendix A.

Average Street Width

Average street width is the mean distance between the two sides of a road right-of-way (including sidewalks and parking spaces that are within the right of way). It is the first street capacity factor. It is measured within a locale by taking a weighted average of length of each segment of a given width. The use of segment makes it possible to report on the share of total street length in streets of various widths. Four categories are reported on: less than 4 meters, 4-8 meters, 8-12 meters, 12-16 meters, and greater than 16 meters. Wider streets are able to carry more traffic and are also able to carry traffic at higher speeds.

Average street width decreased by 14% from 9.8 meters in pre-1990 period to 8.4 meters in the 1990-2015 period. The decrease in the overall average is driven by a reduction in roads of wider than 8 meters. The most common street width range is 4 to 8 meters. The share of roads less than 8 meters in width increased significantly, while the share of wider roads decreased significantly (Figure 16).

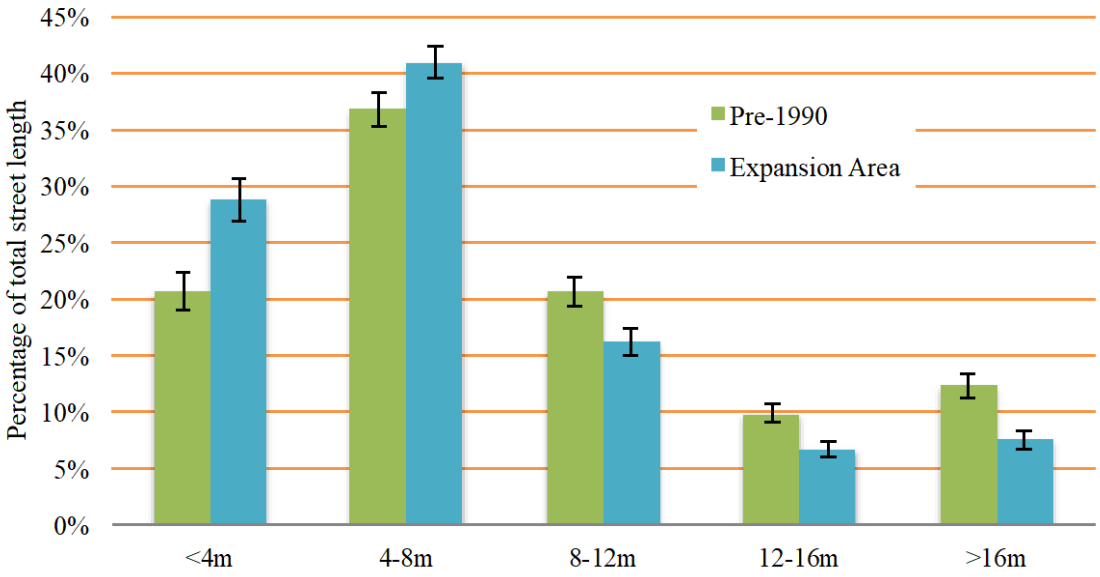

Figure 17: The share of streets of 8 meters or less has increased in the universe of cities, and the share of streets of greater than 8 meters has decreased.

Average street width decreased significantly in the regions East Asia and Pacific, Europe and Japan, Latin America and the Caribbean, and Sub-Saharan Africa. In Southeast Asia, South Central Asia, Land Rich Developed Countries, and Western Asia North Africa, there was no detectable change. The Land Rich Developed Countries region now has a significantly higher average street width than other regions.

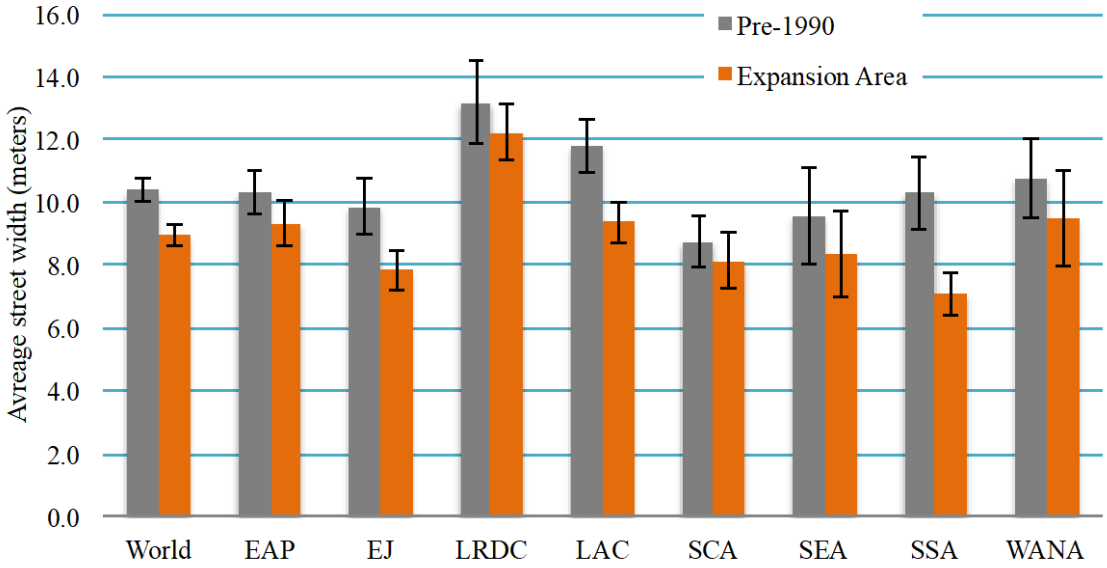

Figure 18: Average street width has decreased globally and in many world regions.

Regression analysis of street width, urban extent density, and GDP per capita provides some additional information about average street width. Street width is negatively correlated with density, meaning places that have lower urban extent density also have wider roads. Street width is positively correlated with GDP per capita, meaning places that have higher GDP per capita also have wider roads. Street area per person is also found to be independent of population density. In other words, cities that have low density and are wealthy can be expected to have wider roads than those that are high density and poor, but cities that are denser will not necessarily have more roads than those that are less dense. The relevant factor in determining street capacity is not density, but wealth.

The statistical relationship described above does not establish causality, but one possible hypothesis is that cities that are wealthier consume more land per capita, leading to lower population densities (first established in the original *Atlas of Urban Expansion* (Angel et al 2012), and explored in more detail in a companion working paper that is under development) and lower population densities lead to longer commuting distances, as jobs and homes are more spread out. All other things being equal, a city with half the population density will have double the area, and distances will be longer by a factor of the square root of 2. To keep commuting times reasonable, wealthy cities respond to this by building wider roads that can be safely used at higher speeds.

A different explanation could be that wider roads contribute to lower density, rather than resulting from lower density. Wider roads allow travel within cities at higher speeds, increasing the efficiency of the metropolitan labor market by reducing congestion costs and search costs and leading to more productivity and greater wealth. However, higher travel speeds increase the amount of land that is within a tolerable commute of employment centers. This reduces the competition for land and enables people to consume more of it, resulting in larger homes that are built at a greater distance from the city center. This requires additional exploration.

Street Density

Street density is the length of streets divided by area. It is the second street capacity factor. The product of street density and average street width is the share of built-up area in roads. If the share of built-up area in roads is fixed, street density cannot increase without a decrease in average street width. Street density is measured as the ratio of the sum of the lengths of all of the segments and the built-up area of the locale. It is then reported as linear kilometers of street per square kilometer.

Street density is a measurement of accessibility. Having a longer street network in a given area means that a greater share of that area will be in contact with a street. Higher street density may enable smaller plot sizes, for example. This can be distinguished from connectivity, which looks at the number of different potential route options in a street network based on the number and type of intersections. Simply measuring the length of roads in a given area does not give any information about how well those roads are connected, or if they are connected at all. However, street density does appear to be strongly correlated with intersection density for example, indicating that longer street networks also tend to have more connectivity.

Overall, street density increased 17%, from 21.6 km/km2 in the pre-1990 area to 25.0 km/km2 in the expansion area. Street density increased by at least 25% in 69 cities and by at least 50% in 26 cities out of the 200-city sample. It only declined by 25% or more in seven cities, four of which are secondary cities in China. It only declined by 25% or more in one major city, Ahmedabad, India.

Street density increased in every region except in the Land Rich Developed Countries, but the only statistically significant increases were in Latin American and the Caribbean and Sub-Saharan Africa. In Sub-Saharan Africa, street density increased by 39%, almost twice the increase seen in the next highest region, Latin America and the Caribbean (Figure 19).

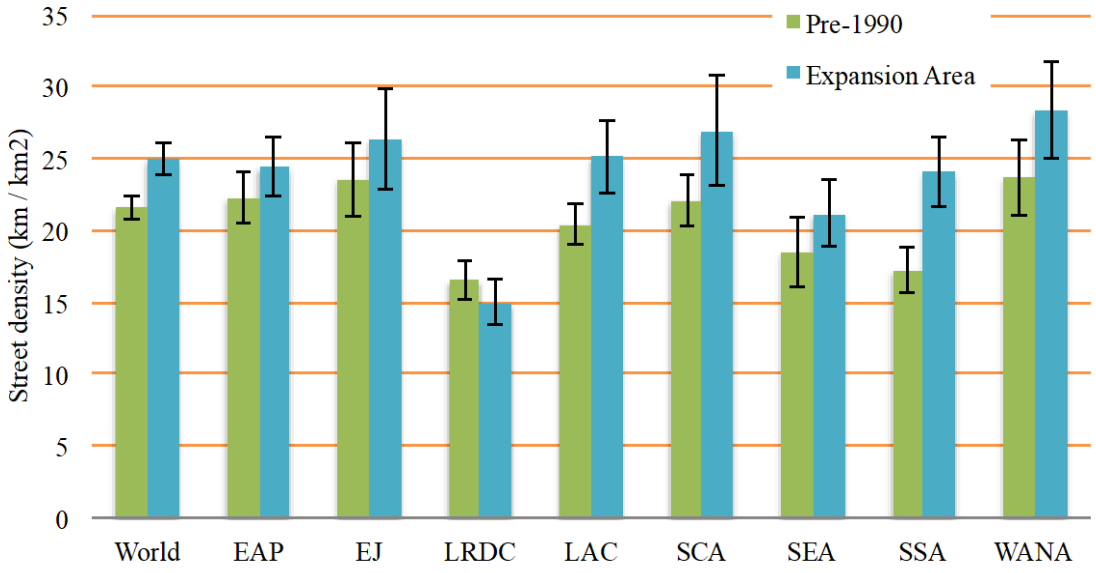

Figure 19: Street density has increased in all regions except LRDC and SEA.

Case Study: A Tale of Lanes and Alleys: Kolkata, India



Figure 20: A typical residential zone in the expansion area of Kolkata, India, having no clear road layout and no wide roads of any kind (Google Earth 2017).

Kolkata, India in 2014 had an urban extent of 96,868 hectares and a population of 15,123,555. Between 2000 and 2014, the city grew in area at a rate of 4.7% per year and population density declined at a rate of 3.7% per year. The city is occupying more land per person over time, and since 1990 the total area of the city has tripled.

In the area developed since 1990, only 9.2% of the land is dedicated to streets and roads – less than half the global average. To make matters worse, there is no evident street layout in many of these newly developed areas (Figure 20, for example). Rather, the dominant mode of residential development appears to be the conversion of existing agricultural plots into housing without land subdivision. Since 1991, efforts to reform this practice have been made and a number of orderly New Towns have been constructed (Sengupta 2008), but 80% of new residential construction is still either informal or completely atomistic according to the *Atlas.*

The effects of this lack of planning can be measured: The average road width in the expansion area is 4.4 meters, and 58% of roads are less than 4m wide. There are few connector roads and an almost complete lack of wide arterial roads, such that the average distance to a wide arterial road is 1.3km against a global average of 700 meters. The consequences of this practical failure to plan are predictable – severe traffic congestion accompanied by a breakdown in the effectiveness of public transportation (Halder 1997).

The result is greater travel times. In Kolkata, the average travel time to the CBD is 125 minutes, more than double the global average of 64 minutes[1]. Some of this can be explained by the spatial development pattern of the city. Lacking a framework of roads for expansion, the city has grown linearly along existing road and rail lines. This lengthens travel distances relative to a more circular pattern and is a direct consequence of the failure to provide sufficient infrastructure to accommodate growth.

A recent paper by Chakrabatty and Gupta (2015) highlighted the spiraling consequences of the inadequate street network in the city: Liberalization of the economy has made it much easier for residents to purchase private vehicles, greatly increasing demand for street space. In 1998, only 1.7% of households owned a car. This increased to 11% in 2008. Currently, cars cater to only 6% of rush hour passengers, but occupy 29% of the available road space. GDP per capita in India is increasing at a rate of roughly 6% per year (World Bank 2018) and it is likely that many more residents of Kolkata will be wealthy enough to purchase private vehicles in the coming years. If the city continues to expand in area, if private vehicle ownership continues to rise, and if the city fails to provide additional street capacity in newly developed areas, the inevitable geometric result will be total gridlock and the fragmentation of the metropolitan economy.

Road Connectivity

In an open plain, all land would be available for transportation and we would all travel as straight as the crow flies (Figure 21). Of course in cities, the majority of the land is occupied by other uses and the function of the street network is to allow us to move between these different areas. As discussed in the preceding section, the *capacity* of the street network is what determines how many of us can do so, and at what speeds and modes. The *connectivity* of the street network is what determines the efficiency with which we do so. Just as a higher capacity street network enables more users to move about the city more quickly, a more connected street network enables users to construct routes that more closely approximate the ideal of a straight line of travel.

[1] From unpublished research provided to the authors by Achilles Kallergis of the NYU Marron Institute of Urban Management.



Figure 21: Many route options and much capacity to accommodate vehicles and pedestrians, but no destinations in the Alvord Desert, Oregon (Pulliam 2008).

It is possible to have connectivity without adequate capacity, or vice versa. One can imagine a series of wide parallel roads separated by buildings, with no perpendicular roads – such a scenario could provide a very high level of street capacity, but it would have absolutely no connectivity and therefore no utility to any person interested in traveling on streets other than their own. One can also imagine a tightly woven grid of very narrow streets – almost too narrow to pass through. In this case, the lack of capacity reduces the usefulness of the network. In fact, it is the interaction of capacity and connectivity that actually determines how well the street network functions.

The *Atlas of Urban Expansion—2016 Edition* reported on connectivity by measuring the density of street intersections and on average block size. These indicators are also complimentary. Streets form the edges of blocks, and the corners of blocks are formed by street intersections. A higher intersection density in a given area will correspond to a lower average block size in that area, if street width is held constant. The street network and the intersections of the streets will define the boundaries of the space that is contained within blocks.

Intersection Density

Intersection density is the number of intersections per square kilometer. Intersection density is

measured using street medians, but the metric reported only represents intersections within the locale.

Two types of intersections are measured and reported in the *Atlas* – *three-way intersections*, meaning streets that form a T-junction, and *four-way intersections*, meaning streets that cross each other. When considering network efficiency, these two types of intersections can be thought of in terms of the number of choices that they offer a user. A three-way intersection offers two choices – turn right, or turn left. A four-way intersection offers three choices – turn right, turn left, or go straight. This seems simple, but the impact of the additional option can compound exponentially, such that a grid made up mainly of 4-way intersections offers a user a number of route options that is an order of magnitude greater than that which is offered by a network made up mainly of 3-way intersections.

In general, a network with more intersections for a given length of road will offer more possible routes between any two points, meaning a random user is more likely to find a route that approximates a straight line. This translates into shorter average travel distances and also into more network resilience, as users have more options to avoid traffic congestion, street repairs, parades, or other disruptions.

At least one study has also established higher intersection density as predictive of the rate of walking and cycling (Ewing and Cervero 2010). High intersection density is also associated in the same study with access to public transportation. The authors of the study hypothesize that this is because high intersection density indicates strong connectivity, which shortens access distances and offers more route options for potential users and also for transportation operators.

Results from the *Atlas* show that intersection density declined from 147 intersections per km2 in the pre-1990 area to 144 intersections per km2 in the expansion area. Some regions experienced statistically significant increases and decreases, but the net effect of these changes was not statistically significant at the global level (Figure 22).

The Land Rich Developed Countries region experienced the greatest decline in intersection density. Intersection density declined by 34.5%, from 101/km2 in the pre-1990 area to 66/km2 in the expansion area. Sub-Saharan Africa experienced the greatest increase in intersection density. Intersection density increased by 45.7%, from 105/km2 in the pre-1990 area to 151/km2 in the expansion area.

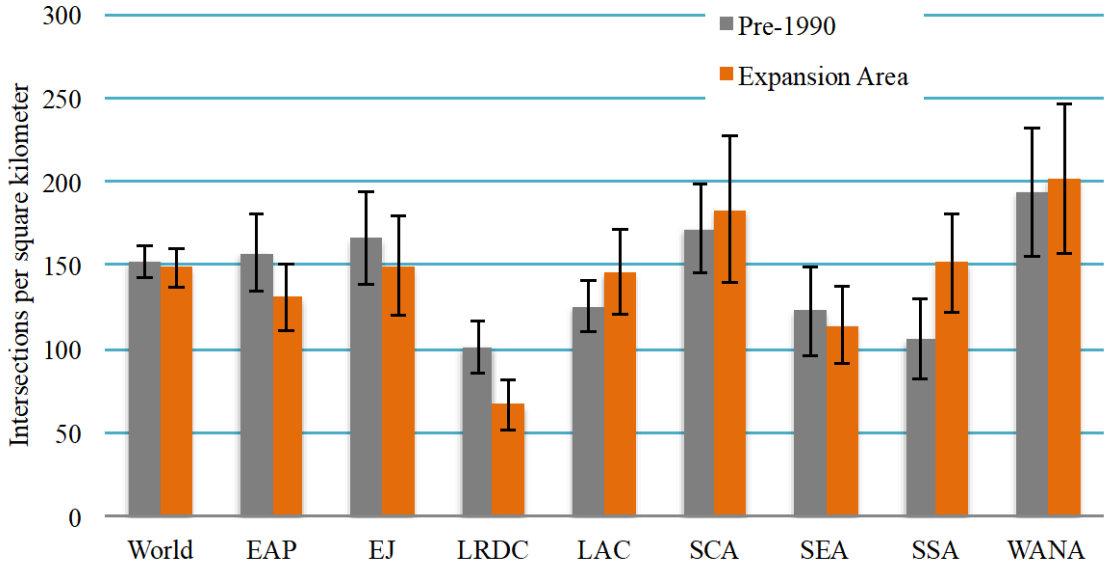

Figure 22: Intersection density declined slightly and insignificantly on a global level, but significant changes were seen in some regions.

Average Block Size

If the purpose of streets is to facilitate movement throughout the city, then the purpose of blocks is to furnish land for any activities that benefit from a fixed location. Blocks contain public and private buildings of all types, as well as urban amenities such as parks, parking lots, and public squares. It has been theorized that the size and shape of the blocks in a city has a noticeable impact on the types of activities that take place in that city. For instance, when the planners of New York's 1811 grid plan wrote, "A city is to be composed principally of the habitations of men and strait-sided and right-angled houses are the most cheap to build and the most convenient to live in," they were expressing a clear preference for right-angled blocks because of the impact of those blocks on the cost and utility of housing. Block length has also been implicated in conversations about walkability. A commonly expressed theory holds that short blocks are more walkable because they minimize travel distances, but this is more properly ascribed to the higher density of intersections that accompany shorter blocks (Sevtsuk et al 2016). This relationship between block size and intersection density means that average block size can, indeed, be taken as a rough proxy for connectivity, and perhaps a more intuitive one than the somewhat abstruse intersection density measures presented in the preceding section. In general, higher block size translates into lower intersection density and vice versa. This equates with longer travel distances and generally with less connectivity.

Block size is measured in hectares, and a block is defined as an area that is bounded on all sides by streets. In the *Atlas of Urban Expansion—2016 Edition,* the measurement of blocks is based on the street medians within locales, and street medians are digitized beyond the boundary of the locale in order to produce complete blocks. The average block size for a given locale represents all blocks that intersect that locale and the average block size for a city represents the weighted

average block size of all of the locales in that city. If an enclosing street median cannot be found for a block within 1km of the locale boundary, the area is not included in the calculation of average block size, so the *Atlas* methodology does include an upper bound for block size. Imagine a slice of a national forest or a field of corn that is included within the locale, for instance. It could not be considered to be part of a "block," and it would not be possible to find a road route that would enclose it within 1km.

Average block size has increased by 44% globally, from 3.6 hectares in the pre-1990 area to 5.2 hectares in the expansion area. Statistically significant increases were seen in every region except Sub-Saharan Africa, where no significant change was observed. The largest increase in absolute terms was in the Land Rich Developed Countries region, where average block size increased from 5 hectares to 7.6 hectares. The largest increase in percentage terms was in Western Asia and North Africa, where average block size increased 70% from 2.4 hectares to 4.1 hectares (Figure 23).

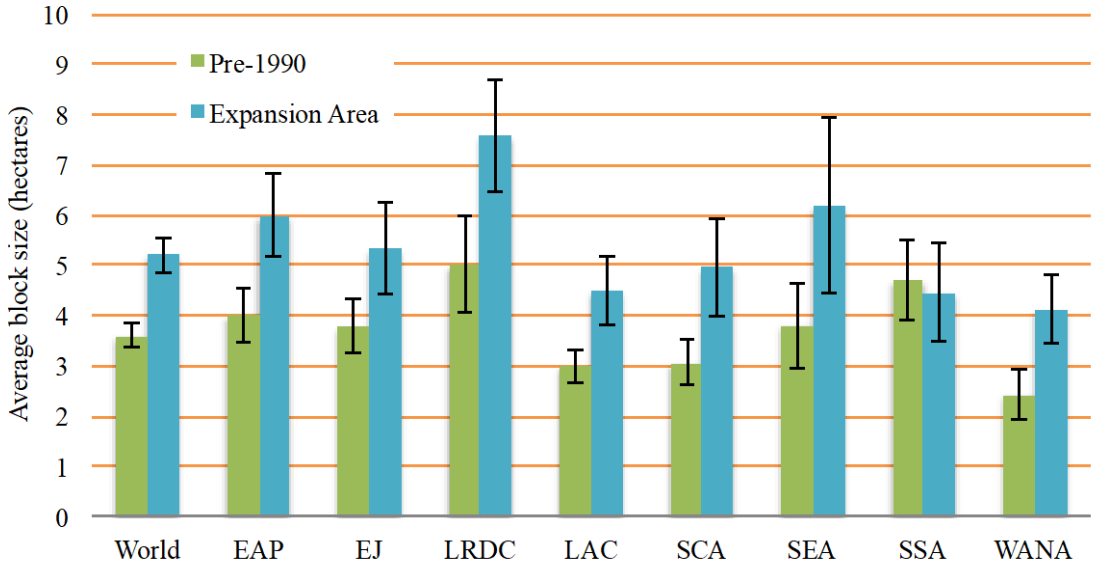

Figure 23: Average block size increased in all world regions except Sub-Saharan Africa.

The steep increase in block sizes and the lack of a major change in intersection density would appear to contradict an earlier statement about the relationship between intersection density and average block size. The explanation for this can be found by disaggregating intersection density into 3-way and 4-way intersections. Globally, in the pre-1990 area 15% of intersections were 4-way. In the expansion area, only 10% of intersections were 4-way (Figure 24). Over time, the share of 3-way intersections has been increasing, and larger blocks are resulting from the same number of intersections.

Share of 4-way Intersections

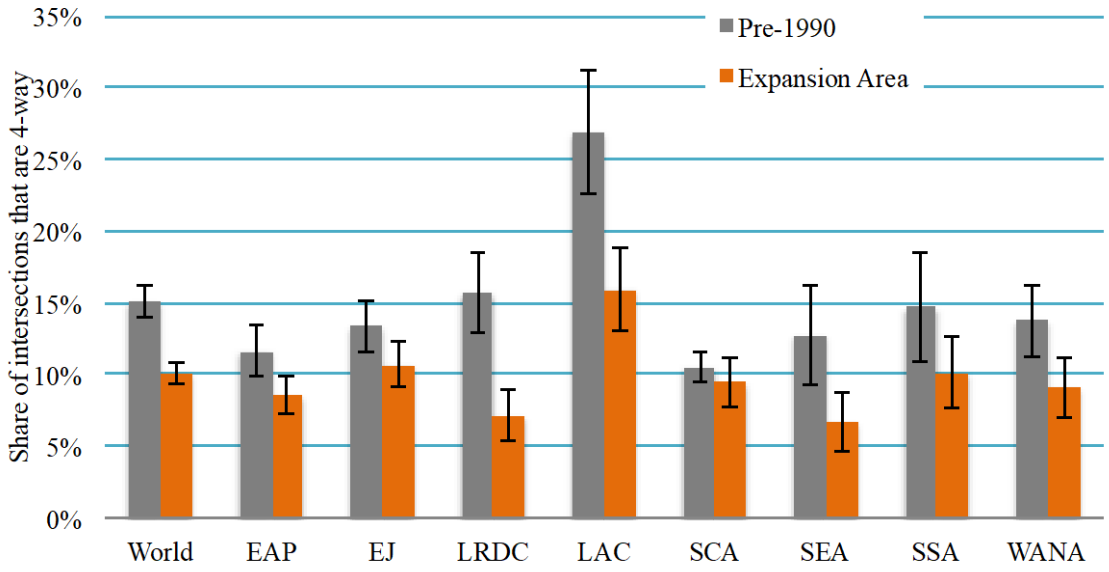

Figure 24: The share of 4-way intersections declined the most in places where average block size increased the most.

A quick comparison of Figure 23 and Figure 24 shows that the regions that experienced the greatest increase in block size were also those that experienced the greatest decline in the share of 4-way intersections. This is because 4-way intersections form blocks more efficiently than 3-way intersections, so a greater number of 3-way intersections is required to form the same number of blocks. As cities have shifted from having more 4-way to having more 3-way intersections, block size has increased, even if the total number of intersections has remained essentially the same. Combining the effects of a decrease in intersection density with a decrease in the share of 4-way intersections produces a much stronger effect, as can be seen in Figure 25, comparing the expansion areas of Bamako, Mali, and Victoria, Canada. Victoria, which has mainly 3-way intersections and low intersection density, has an average block size of 13.5 hectares – far above the global average. Bamako, which has many 4-way intersections and high intersection density, has an average block size of 1.4 hectares, about 1/3 of the global average.



Figure 25: The relationship between four-way intersections and block size: the expansion areas of Bamako, Mali on left (average block size 1.4 hectares, 20% 4-way intersections) and of Victoria, Canada on right (average block size 13.5 hectares, 3% 4-way intersections).

Case Study: Make Way for Private Cars – Poor Connectivity in Chengdu, China



Figure 26: (Left) OpenStreetMap capture of street layout in the expansion area of Chengdu, Sichuan, China, showing large blocks and many dead-end and 3-way intersections (OpenStreetMap 2018). (Right) A new apartment complex in Chengdu (killerturnip 2007).

Chengdu, China in 2009 had a total urban extent of 167,680 hectares and a population of 9,339,734. Chengdu has been expanding in area at a rate of 13% per year and has increased in area more than 5-fold from 2000 to 2009. At the same time, the population has nearly doubled and population density has been declining by 6.2% per year over the same period. The city is growing very rapidly and is also consuming much more land per person than in previous years.

In Chengdu, 21% of the land in the expansion area is used for streets and roads – almost exactly the global average. However, the intersection density in the city is 75/km2, which is roughly one-half of the global average. Out of those intersections, only 8% are 4-way intersections, and the rest are 3-way intersections. Average block size is 8 hectares, which is also significantly above the global average.

Observation of satellite imagery suggests that the growth of Chengdu has taken place mainly through major development projects on large plots of land. The homogenous nature of the residential stock in particular (with many exact copies of the same building appearing within a single large block) speaks to this hypothesis. In fact, the *Atlas* results show that 27% of new residential land in Chengdu is in these sorts of housing projects - more than quadruple the global average.

There is also a well-planned network of expressways in the expansion area of Chengdu, laid out in a radial and ring pattern. However, the city has failed to provide a network of wide arterial roads in the expansion area, and average distance to a wide arterial road is over 3km.

Local lanes and collector roads are provided within the large housing developments, but the developments themselves are not integrated to facilitate through-traffic. Many of the lanes are in fact long cul-de-sacs, and movement within a project usually requires traversing a cul-de-sac in order to reach one of a handful of collector roads, and then entering another cul-de-sac to arrive at your destination. Each project may have only one or two entrances and it is difficult or impossible to move between projects on the collector roads (Figure 26).

This lack of direct route options means that it is challenging to walk and to cycle in the expansion area of Chengdu, which was not always the case. According to China Daily, walking and cycling made up 70% of urban trips in 1997 but now make up only 4% of all trips. Most residents now rely on public transit or on private vehicles (China Daily 2017). Poor connectivity in the road network results in abnormally long travel distances that discourage the use of human-powered modes. At the same time, the number of vehicles in Chengdu has been increasing by 17% per year and now stands at 4.3 million. (Chen 2017) The current layout of the road network facilitates car travel with relatively minimal congestion, but concerns about pollution and lack of physical activity have led to a government initiative to create a parallel network of 17,000km of walking and cycling paths to compensate for this shortfall.

Arterial Roads

Urban economic theory tells us cities thrive because their concentration of people and firms leads to the formation of agglomeration economies that raise productivity. Firms are able to more easily access inputs because of their proximity to other firms, and they are also able to make better matches with individuals who are seeking jobs – a firm is more likely to find the right person to fill a given position, and a person is more likely to find the right position to fit their particular skill set. When congestion makes it more difficult for an individual to look for a job, or for a firm to move goods around the city, productivity goes down and workers – particularly those living further from the center, where housing is cheaper - are less likely to prosper (Glaeser 2011). A city with lower congestion costs and lower search costs will be more productive and also more equitable.

The arterial road network forms the backbone of the transportation network and is used by private individuals and firms as well as for public transportation. Streets are (arguably) a public good (Block 1983) and the laying out of arterial roads in particular is a core municipal function.



Figure 27: The BRT system of Curitiba, Brazil, running on the arterial road network (Mariordo 2006*)*

The arterial road network also has an important role to play in the reduction of greenhouse gas emissions, by increasing the utility and efficiency of public transportation. For public transportation to function, it must have a set of right of ways in which to run. These rights of ways must be large enough to accommodate mass transportation vehicles. More efficient operation can be achieved if the vehicles have a dedicated lane, but this requires enough space for at least two lanes of traffic in each direction – one for public transportation, and one for cars (Figure 27). The rights of ways must also be efficiently connected to one another, forming a system that can be easily navigated without detours or backtracking. As important, roads that are capable of carrying public transportation must be within walking distance of the majority of potential users and the majority of potential workplaces, or the public transportation system will struggle with the notorious "last mile" problem. All of these things require land throughout a city to be set aside for roads in a consistent and orderly fashion.

The *Atlas of Urban Expansion—2016 Edition* reports on three measures of arterial roads: the density of arterial roads, average beeline distance to an arterial road, and share of urban extent within walking distance of an arterial road. All three will be reported here, and a distinction will be made between wide arterial roads and narrow arterial roads, with the understanding that wide arterial roads are much more likely to have been planned for that use.

The *Atlas* does not report on the average width of an arterial road or the share of land in arterial roads, but a companion index has been estimated that calculates the share of land occupied by

wide and narrow arterial roads. This index is based on an estimate of the average width of a wide arterial road and the average width of a narrow arterial road.

Density of Arterial Roads

The metric *density of all arterial roads* measures the length of arterial roads per square kilometer of urban extent. A greater share of the urban extent will be adjacent to an arterial road if the arterial road density is higher. This is a measure of access. A decrease in the density of arterial roads indicates that access to arterial roads is also decreasing, in terms of direct plot access.

The density of all arterial roads decreased by 35%, from 2.0 km/km2 in the pre-1990 area to 1.3 km/km2 in the expansion area. This decrease was seen in every region, with the steepest declines occurring in Southeast Asia, Sub Saharan Africa, and East Asia Pacific. In Sub-Saharan Africa, the density of arterial roads declined from 1.6 km/km2 to .9 km/km2 (Figure 28).

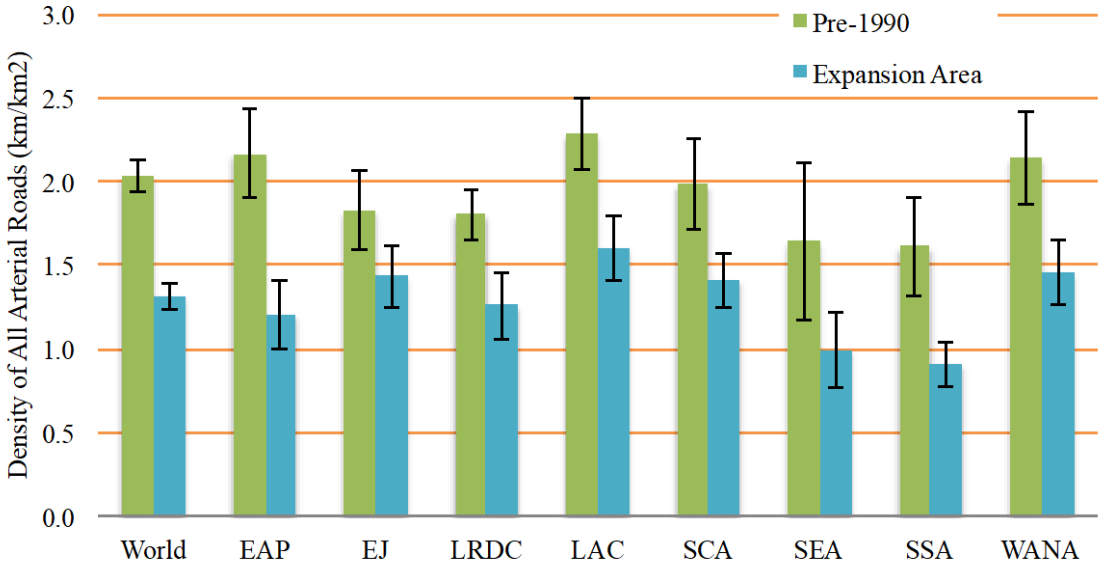

Figure 28: Density of all arterial roads decreased, with steep declines in several regions.

A closer examination reveals large differences in the change in density of wide arterial roads versus narrow arterial roads. The density of wide arterial roads declined from 1.3 km/km2 to 0.8 km/km2. The density of narrow arterial roads declined from 0.6 km/km2 to 0.5 km/km2. In other words, the density of wide arterial roads declined by 38%, but the density of narrow arterial roads declined by only 17%. The majority of the decline in density of arterial roads can be explained by a decline in the density of wide arterial roads.

This is a troubling finding, because wide arterial roads are most likely to be those that were planned in advance of development explicitly for service as arterials. Narrow arterial roads are usually secondary or tertiary roads (sometimes also unimproved rural or intercity roads) that were pressed into service as arterial roads, but were not specifically designed or laid out for that function. This has real implications for the utility of the arterial road network.

Share of Land Occupied by Arterial Roads

The *Atlas* does not gather systematic information about the typical width of arterial roads. However, analysts do use a cutoff of 18 meters to differentiate wide arterial roads from narrow arterial roads when digitizing, and this provides some basis for estimating possible arterial road widths. A review of a small subset of arterial roads found that wide arterials were 24 meters wide on average, and narrow arterials 12 meters wide on average.

Using this information along with the total road network length and the proportion of roads that are wide versus those that are narrow, the total area in wide and narrow arterials can be estimated. According to these estimates, the *share of land occupied by arterial roads* has declined from 4.2% in the pre-1990 area to 2.7% in the expansion area. The decline in the share of land in arterial roads was particularly large in East Asia and Pacific, falling by 46%, or 2.6 percentage points. Declines were seen in all regions (Figure 29). This can also be compared with the information in Figure 17. That figure shows the share of road length in roads of various widths. One of the categories, streets wider than 16 meters, should include nearly all of the arterial roads based on the criteria commonly used. That value declined from 12% in the pre-1990 area to 7% in the expansion area – almost exactly the same magnitude of decline as these estimates would indicate.

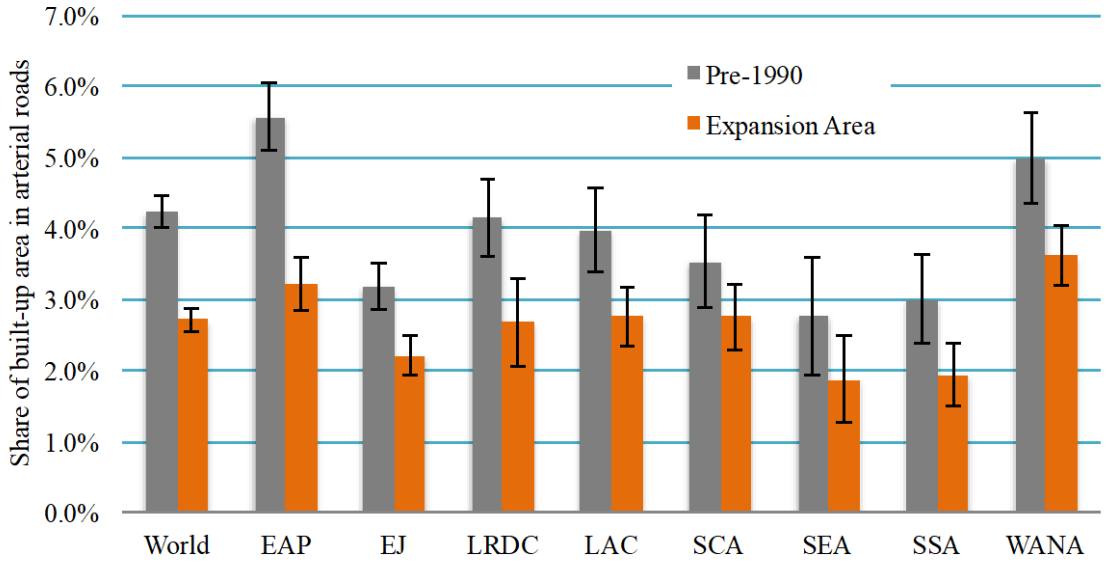

Figure 29: The estimated share of land in arterial roads has declined, with very steep declines seen in some regions.

The share of land in wide arterial roads has declined from 3.2% in the pre-1990 area to 1.9% in the expansion area. The share of land in narrow arterial roads is unchanged at 0.8%.

For comparison, a network of 30-meter wide arterial roads spaced 1km apart to form a 1km x 1km grid would take up approximately 6% of the land in a square kilometer. This would put the entire land area within 500 meters of a wide arterial road, or, in other words, within a 15-minute walk of a road that could carry public transportation and trunk infrastructure. A working example

of this sort of grid can be seen in Toronto, Canada, for example (Figure 30).

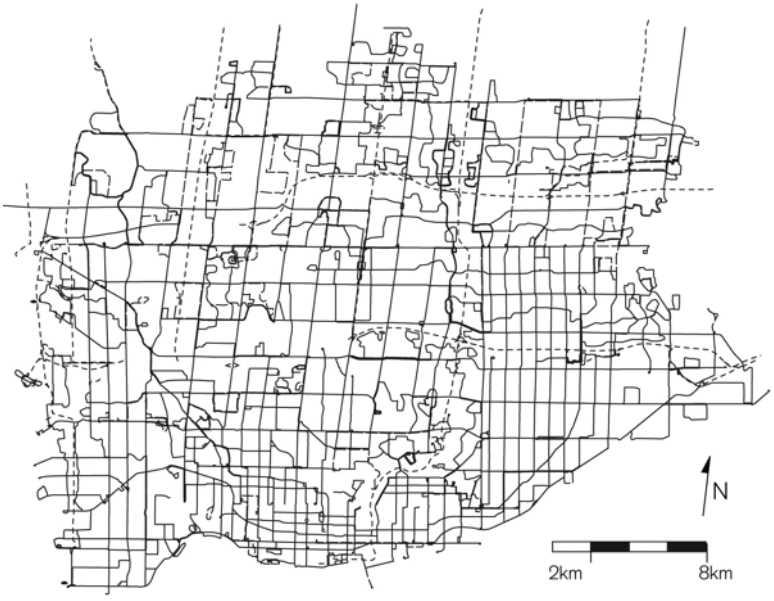

Figure 30: Toronto, Canada's bus and streetcar network, located largely on its arterial road grid, 2010.

Importantly, the image of Toronto does not show the actual road network, but a map of the bus and streetcar network. The implication is that decentralized labor markets, with jobs and housing located randomly throughout the metropolitan area, can only be efficiently served by public transit if the plan for the system is also decentralized. Such a public transit system will require a gridded network of rights-of-ways in order to operate.

Average Walking Distance to an Arterial Road

As important as the density of arterial roads and the share of land in arterial roads is the distance that a person must travel in order to reach an arterial road. However, data was not gathered on the street network throughout the city, only within selected locales. This makes it difficult to measure the actual distance between a random point and an arterial road.

Fortunately, it is possible to make an estimate of the actual distance by combining two measures - the *walkability ratio* and the *average beeline distance to an arterial road*.

Average beeline distance to an arterial road is collected citywide using a large number of points randomly placed throughout the urban extent. The distance from each point to the nearest arterial road is measured and the average of these measures becomes the average beeline distance to all arterial roads. The metric is expressed in meters.

The walkability metric is calculated on a locale basis, using the street medians information described earlier, along with a large number of random points. Walkability is the ratio of the beeline distance between any two points and the distance traveling on street medians between

those same two points. It is a measurement of the relationship between the beeline distance and the network distance.

By applying the walkability ratio as a correction to the beeline distance, we can take into account the fact that street networks do not always permit people to travel in a straight line between two locations. This also enables us to account for variations in the street networks of different cities. The metric produced by this calculation is called *average walking distance to all arterial roads*, and it can also be reported for wide and narrow arterial roads.

The average walking distance to all arterial roads increased by 90%, from 379 meters in the pre-1990 area to 721 meters in the expansion area. It increased significantly in all regions majority of world regions, with the largest increase in the East Asia and Pacific region, where it more than doubled (Figure 31). Data for the Land Rich Developed Countries region was highly variable, making it difficult to detect a change and leading to a large confidence interval.

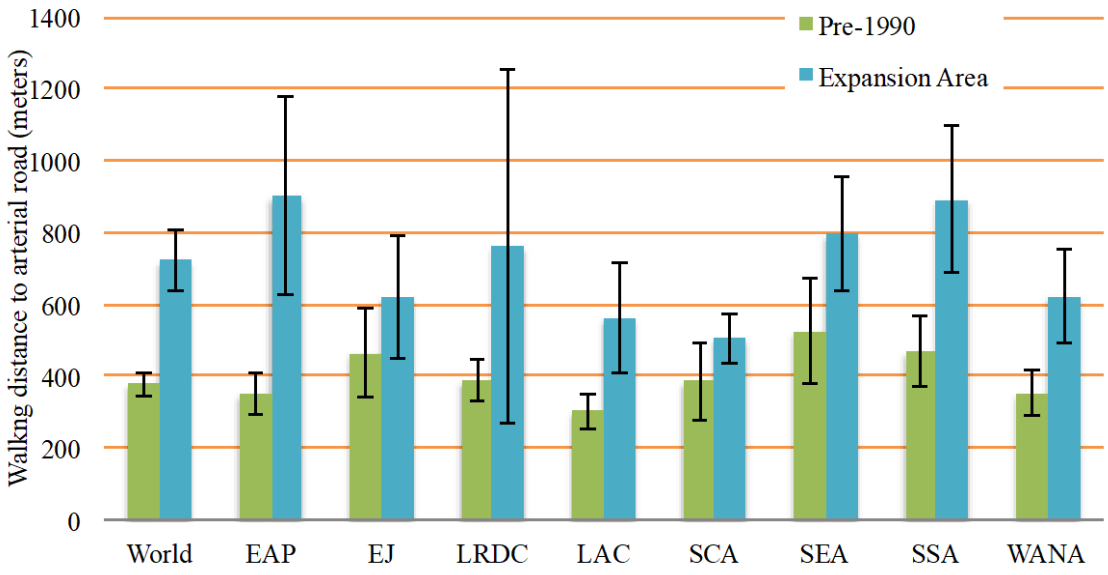

Figure 31: Average walking distance to an arterial road increased in a majority of world regions.

These results are quite different for wide arterial roads and narrow arterial roads. The average walking distance to a wide arterial road increased by 88%, from 634 meters in the pre-1990 area to 1197 meters in the expansion area. The average walking distance to a narrow arterial road increased by 24%, from 1723 meters in the pre-1990 area to 2137 meters in the expansion area.

It is important to consider the interaction between the walkability metric and the metric for beeline distance to arterial roads – not only are the arterial roads at a greater average distance from built-up areas, the routes that lead to those arterial roads have become less efficient, making it even more difficult to access arterial roads.

Share of Urban Extent within Walking Distance of an Arterial Road

The calculations made using walkability and the beeline distance to an arterial road do not take into account the actual locations of the urban extent, relative to the arterial roads because of the lack of a local street network map. An additional measure is therefore useful, which is the *share of the urban extent within walking distance of an arterial road*.

This is calculated by creating a "walking distance" buffer around each arterial road then measuring the share of the urban extent that falls within the buffer. Walking distance is defined as 625 meters, or roughly a 10-minute walk. This is based on research showing that the average person prefers to walk at about 1.4 meters per second (Levin and Norenzayan 1999), with time allowed for stop signs and traffic lights.

The share of the urban extent within walking distance of an arterial road decreased by 11%, from 93% in the pre-1990 area to 82% in the expansion area. It decreased in the majority of world regions. The biggest decline was in the Sub-Saharan Africa region, which fell by 16 percentage points, from 89% in the pre-1990 area to 73% in the expansion area (Figure 32).

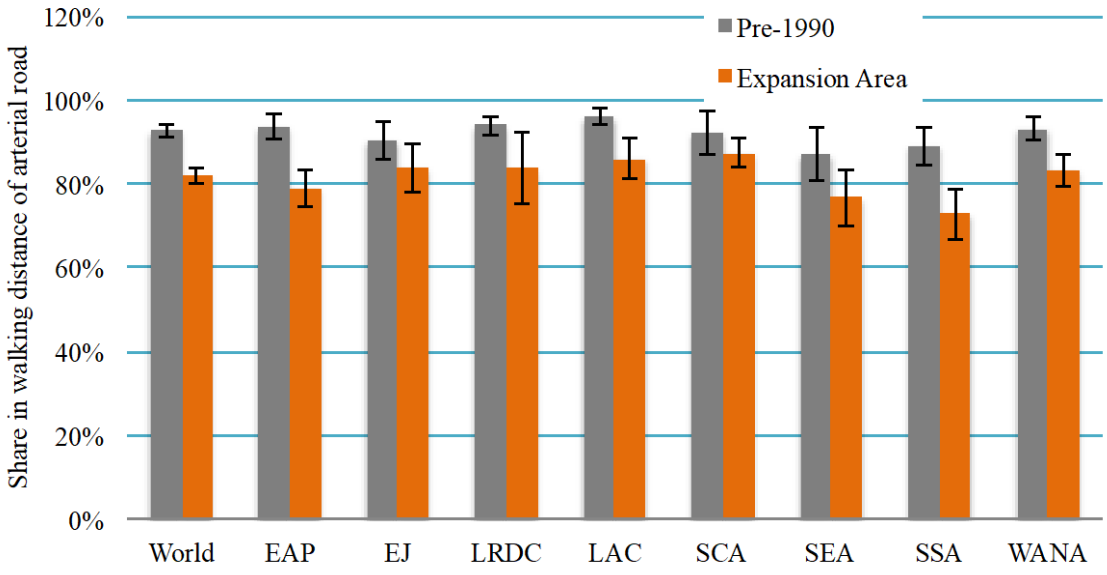

Figure 32: The average share of the urban extent within walking distance of an arterial road decreased in the majority of world regions.

The share of the urban area within walking distance of a wide arterial road declined from 83% in the pre-1990 area to 69% in the expansion area. For narrow arterial roads, the decline was from 54% to 50%.

It is important to note that the general results for narrow arterial roads (low density; a high distance to narrow arterial roads; and a low share of the area within walking distance of a narrow arterial) reflect the fact that these roads are not commonly used as arterial roads. When they are used as arterial roads, it is due to a lack of alternatives, as narrow roads are not suited to that use.

Wide arterial roads are capable of carrying public transit and trunk infrastructure, as illustrated by the example of Toronto. Wide arterials must also be planned before development occurs, requiring action on the part of municipalities to assemble and protect the land for the road right of way. The decline in access to these roads, particularly when coupled with declining overall street network efficiency, has real and serious implications for the use of public transit and greenhouse gas emissions.

As it becomes more difficult to reach roads that can carry public transportation, the popularity of public transit will continue decline, particularly in the newly built areas where these trends are emerging. Given a choice between walking a great distance to a public transit stop and using a private vehicle that allows door-to-door travel, it is likely that citizens in new areas will prefer the latter. This is especially true in a decentralized labor market, where the challenges of providing public transit are yet greater.

The use of private transportation may allow these citizens to access more jobs and more housing opportunities than if they used public transit, but the low density of arterial roads could mean that many of them end up stuck in traffic, with a lack of alternative routes and insufficient capacity for all users. Based on these results, cities would do well to plan ahead for urban expansion by laying out a relatively dense network of arterial roads.

Case Study: Stuck in Low Gear – Traffic in Lagos, Nigeria



Figure 33: Traffic in Lagos, Nigeria (Wikimedia Commons 2017)

Lagos, Nigeria in 2013 had a population of 11,008,357 and an urban extent area of 82,684 hectares. The urban extent has been growing at a rate of 2.6% per year and the city has more than doubled in size since 1984. The population is growing at a similar rate of around 2.4% per year.

Much of the residential development that has taken place has occurred on customary lands, and very little attention has been paid to the physical layout of the city as a whole. Of the residential areas developed since 1984, 91% were informal or atomistic in their layout, or both. The development pattern has tended to follow several existing corridors, creating spatial fragmentation. There are also choke points at several water bodies where a lack of infrastructure limits crossings.

Traffic in Lagos, Nigeria, has been called the worst in the world (Figure 33), in no small part due to an acute shortage of arterial roads in the expansion area of the city. In total, only 1.8% of the land in the expansion area is used for arterial roads. Earlier in this section it was noted that a 1km x 1km grid of 30-meter wide arterial roads would occupy 6% of the expansion area of the city. Because of this deficit, the average network distance to an arterial road is over 1.8 kilometers, and only 50% of the expansion area is within walking distance of a wide arterial road.

A common response to this shortage is to utilize local roads and collector roads in place of arterials, but the poor local road layout in Lagos makes this impossible. The city has reasonably adequate capacity - streets and roads take up 16% of the total land in the expansion area of Lagos, which is only slightly less than the global average of 20%. However, the distribution of street widths is heavily skewed toward smaller local roads, with only 3% of the total street length in streets of 16 meters in width or greater. 70% of streets are 8 meters wide or narrower. The connectivity of the network is also totally inadequate, with an intersection density of only 87 per square kilometer, against a global average of 144. Of those, only 4% of intersections are 4-way, against a global average of 10%.

The scarcity of wide arterial roads combined with the poorly connected network of small local roads means that road space per person is very low by global standards – only 7.1 square meters, versus a global average of 36 square meters per person. Any residents wishing to cross the city have to share the limited road space that is available, resulting in travel speeds that are extremely slow during peak periods. Average travel time to the CBD by public transport is 138 minutes, against a global average of 65 minutes[2].

The legendary traffic is Lagos has been reported by major news outlets (Taylor 2012, for example) and has also been studied academically. Traffic jams sometimes last as long as 12 hours, and total gridlock has even lasted overnight. A 15km journey takes an average of 3 hours and 55 minutes (Olofinji 2017), presumably during rush hour.

As in the previous two case studies, much of the blame for this is placed on rising vehicle ownership and an increasingly wealthy population. A more basic public sector failure is also to blame, however, as officials failed to plan for an adequate network of arterial roads before development occurred. Traffic can eventually be restricted and public transportation and mass transport can be encouraged, but about the fundamental failure there is little to be done – the land that needed to be set aside for arterial roads is now occupied by structures, and it is both politically and practically infeasible to move them in order to make space for a grid.

[2] From unpublished research provided to the authors by Achilles Kallergis of the NYU Marron Institute of Urban Management.

Conclusions

The *Atlas of Urban Expansion—2016 Edition* offers many indicators for assessing the state of the streets. Using the *Atlas* techniques, it is also possible to compare the quality of street networks that were built in an earlier period with those that were built more recently. This opens the door for real and empirically grounded critiques of the spatial planning that is taking place in cities today.

On average, street capacity has remained consistent, but streets are becoming narrower and street networks are becoming denser. Street networks now offer less connectivity, the share of 4-way intersections is declining and block size is increasing. Access to arterial roads has gone down and less land is being dedicated to that purpose. Neighborhood layouts measured at the locale level show that it is becoming more difficult to move around cities by car (due to narrower streets) and also as a pedestrian or cyclist (due to larger blocks and fewer 4-way intersections). The city as a whole is becoming more difficult to move through by private means (due to the lower density of arterial roads) as well as through public transit (due to the decrease in wide arterial roads).

Fortunately, there is much that can be done to reverse these trends. Simple commonsense planning standards can increase the 4-way intersection density and decrease block size in new developments by encouraging traditional gridded street patterns that emphasize connectivity. Basic preparation for urban growth can consist of securing land for future arterial roads and constructing more of those roads in order to increase the supply on the urban periphery. There are many more actions that could be suggested of course, but these two actions alone would significantly improve outcomes in a majority of cities.

The research presented in the paper bolsters the case for these types of active planning interventions in fast-growing cities around the world. The vast majority of those cities are in developing countries, however, and cities in those countries are often least equipped to intervene in the development processes.

Case Study: Making Room for Urban Expansion – Ethiopia and Colombia

The NYU Marron Institute of Urban Management has explored one strategy for supporting cities with rapid growth and limited capacity in creating more orderly urban layouts. NYU supports Urban Expansion Initiatives in Colombia and Ethiopia, and is exploring initiatives in other countries. These initiatives use a simple four-point program to help cities prepare for rapid urban growth:

1) Realistic Maps – Starting from data in the *Atlas of Urban Expansion—2016 Edition*, cities can estimate their future urban growth (Figure 34).

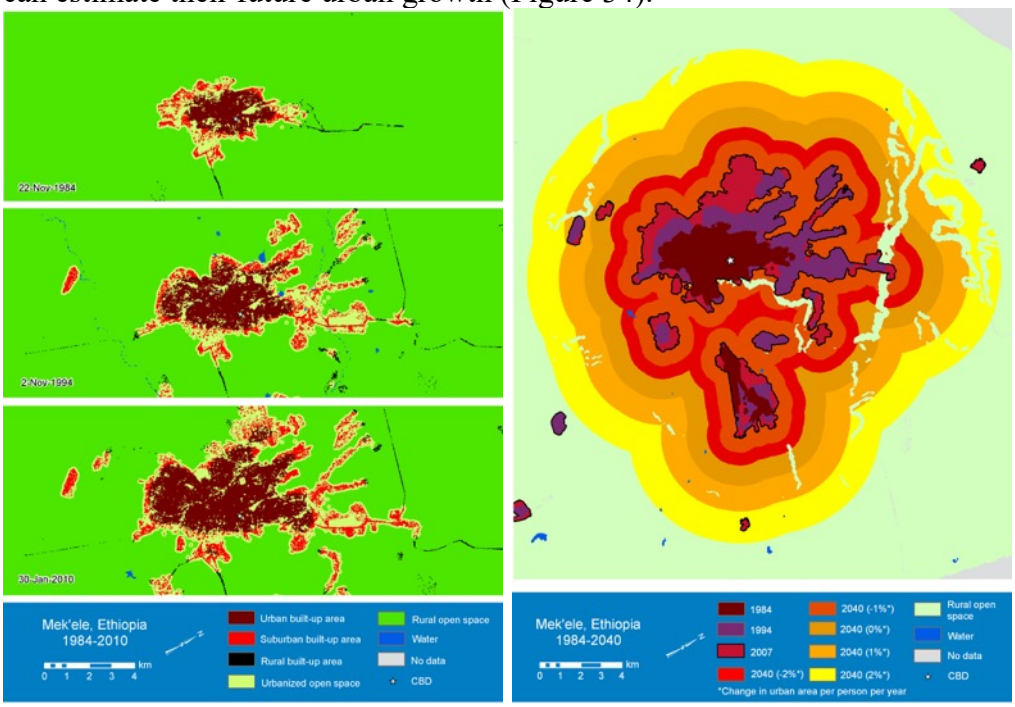

Figure 34: The *Atlas* analysis of Mekele, Ethiopia, was translated into growth projections under a number of scenarios for the next 30 years.

2) Expanded city boundaries – The planning jurisdiction must be expanded to include all of the area in the future urban extent (Figure 35).

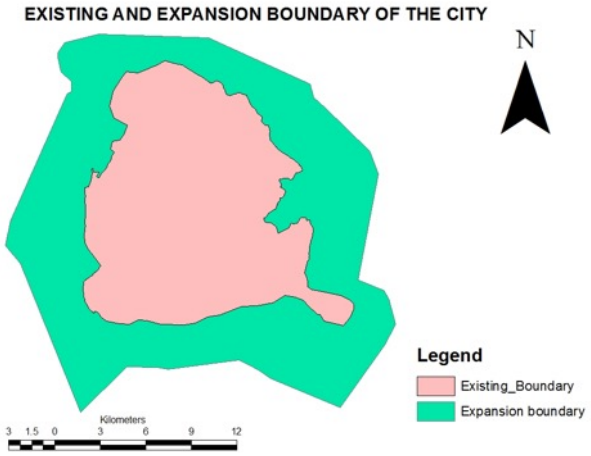

Figure 35: In response to the growth projections in Figure 34, Mekele worked to create an expanded planning boundary. This boundary was approved in 2014.

3) A grid of arterial roads – The backbone of future growth plans consists of the laying out of a grid of 30-meter wide arterial roads, spaced 1km apart. Land for these roads should be secured

before development occurs, and the roads can be constructed in line with the pace of development (Figure 36).



Figure 36: City officials then worked to plan a network of arterial roads that would service the 30-year expansion area.

4) A network of public open spaces – Cities should also take action to protect environmentally sensitive areas, and reserve them to create a network of public open spaces (Figure 37).

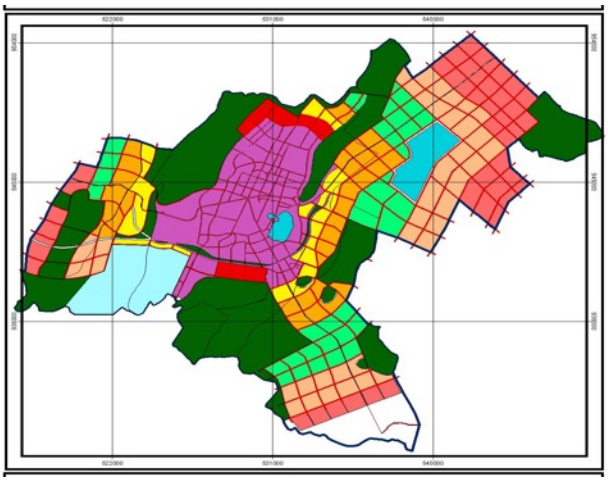

Figure 37: City officials then identified development phases and areas of environmental sensitivity that would be preserved from development (dark green).

These four actions can do much to address the challenge of rapid urban growth. NYU is currently working with 16 cities in Ethiopia and 109 cities in Colombia, in collaboration with the national government and other partners. In Ethiopia, cities have begun securing and constructing their future grid of arterial roads, and have also started to address another issue – the problem of neighborhood layouts.

Using ten macroblock patterns jointly developed with NYU, these cities are addressing the challenges of narrow streets, large blocks, and few 4-way intersections. Figure 38 shows a new local area development plan in Hawassa, Ethiopia, laid out using these new tools.

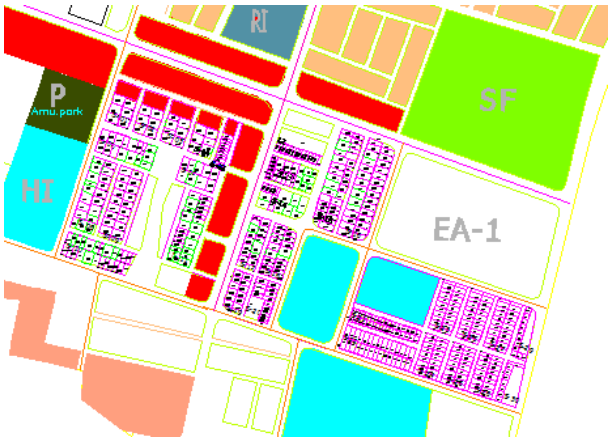

Figure 38: A new local development plan in Hawassa, Ethiopia, priorities 4-way intersections and small blocks, along with a robust secondary and primary road network.

These efforts have resulted in the protection of hundreds of kilometers of arterial road corridors and the development of thousands of new units of formal sector housing, at a minimal cost to the municipalities involved. Critically, the entire initiative has been locally led and largely locally funded, with only top-level involvement by international consultants and donors. The results can already be seen on the urban fringe of many Ethiopian cities, where new layouts are facilitating industrial development and the creation of new housing to accommodate the rapid urbanization that is taking place, without straining public coffers.

Final Remarks

The streets and roads data captured by the *Atlas of Urban Expansion—2016 Edition* shows cities that are becoming more fragmented and disconnected, with potentially longer and slower commutes and poor integration of new areas. This has implications for equity and productivity as well as environmental sustainability, as residents will have access to a lower share of jobs and firms will access to a lower share of workers in the metropolitan area, new residents in new areas will be disproportionately affected, and those who are able to participate in the metropolitan labor market will have trouble doing so with public transit and will be forced to rely on more polluting modes of transportation.

Efforts like those in Colombia and Ethiopia show that even countries with considerable obstacles can take proactive steps to address these challenges (Lamson-Hall et al 2018). These countries have embraced the lesson of the Great London Fire - that there is often only one opportunity to address the layout of streets and road, and it comes before development occurs. With 2.5 billion people moving to cities in the next 35 years, now is the time to act.

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Appendix A: Streets and Roads Data Tables

Tables showing streets and roads data for cities in the global sample are available for download at https://goo.gl/j3MkyX