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The Quality of Urban Layouts

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ABSTRACT

The research showcased in this paper seeks to explore and quantify the differences in urban layouts in a global sample of 200 cities. This important research allows for the comparison of the quality of urban layouts over time – specifically, between the areas of cities built before 1990 and the areas of cities built more recently. This comparison demonstrates that the quality of urban layouts has gone down significantly in the last 25 years – cities are now reserving less land for streets and roads, average block sizes are increasing, development is occurring further from arterial road networks, and informality is becoming more common. This paper outlines those findings for each of the five UN Regions and also analyzes differences between More Developed and Less Developed countries, as defined by the UN.

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The Quality of Urban Layouts

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MONITORING GLOBAL URBAN EXPANSION

This working paper showcases the methodology and selected findings of Phase II of the Monitoring Global Urban Expansion program. The analysis focuses on the five UN Regions and makes global comparisons as well. Two time periods are studied – the areas of cities developed before 1990 (the pre-1990 areas) and the areas of cities developed between 1990 – 2015 (the expansion areas).

The ultimate output of the Monitoring Global Urban Expansion program, Atlas of Urban Expansion—2016 Edition, is part of a long-term research project that includes a series of related publications and online resources that involve a number of partnerships and funding sources. The earlier phases of the research program leading to the creation of this new Atlas culminated in the publication of *The Dynamics of Global Urban Expansion* (Angel et al., 2005) and the *Atlas of Urban Expansion* (Angel et al., 2012). The World Bank supported the research work for the former publication and the Lincoln Institute of Land Policy supported research for the latter, as well as its publication. Research for both publications focused on the collection and analysis of satellite imagery and population data for a global sample of 120 cities in two time periods, 1990 and 2000. Research for the *Atlas of Urban Expansion* also included collecting, geo-referencing, and digitizing the historical maps of the built-up areas of cities at 20–25 year intervals for the period from 1800 to 2000 for a representative sub-group of 30 cities from the 120-city sample. The policy implications and the general lessons drawn from these data collection and analysis efforts were summarized in a policy focus report entitled *Making Room for a Planet of Cities* (Angel et al., 2011) and elaborated upon in the book, *Planet of Cities* (Angel, S., 2012).

The NYU Urban Expansion Program at the Marron Institute of Urban Management and the Stern School of Business at New York University, in partnership with the United Nations Human Settlements Programme (UN-Habitat) and the Lincoln Institute of Land Policy, initiated a multiphase research effort in 2014 to expand the monitoring of the quantitative and qualitative aspects of global urban expansion to more cities, more time periods, and more attributes. The monitoring program is now in advanced stages of completion of three interdependent phases. A number of new phases, requiring new partners and new sources of funding, are in earlier stages of development.

Phase I—the mapping and measurement of global urban expansion—focused on mapping and measuring urban extent, average built-up area density, fragmentation of the built-up area of the city by open spaces, and compactness of the geographical shapes of urban extents in the global sample of 200 cities in three time periods: circa 1990, circa 2000, and circa 2014. This phase required the classification and analysis of medium-resolution Landsat satellite imagery as well as the analysis of population data associated with the enumeration zones that contain the built-up areas of these cities. The key output of this phase is the Atlas of Urban Expansion—2016 Edition, Volume 1: Areas and Densities. This volume will be available as an open source of data for all interested parties worldwide in a website provisionally titled www.atlasofurbanexpansion.org, a PDF version, spreadsheets, and GIS files, all available for download. This phase will include a number of technical reports and publications focused on findings in peer-reviewed journals and other venues.

Phase II—the mapping and measurement of urban layouts—focused on the recently-built urban peripheries (areas built between 1990 and 2014) in the global sample of 200 cities; urban areas built before 1990 compared to areas built between 1990 and 2014 in cities in the global sample; and 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 subgroup of 30 cities from the global sample. This phase relied on digitizing and analyzing a random sample of 10-hectare locales using high-resolution Bing and Google Earth imagery. This analysis yielded information and metrics on different attributes of urban layouts that could be observed from space: the share of residential areas that were laid out informally, formally, or not at all; the share of the land that was laid out in rectangular grids; the share of the land in streets; the average width of streets; the average size of blocks; the density of 3-way and 4-way intersections; and the share of the built-up area within walking distance of arterial roads, among others. The key output of this phase is the Atlas of Urban Expansion—2016 Edition, Volume 2:

Blocks and Roads. This volume is available as an open source of data for all interested parties worldwide in a website titled www.atlasofurbanexpansion.org, a PDF version, spreadsheets, and GIS files, all available for download.

Monitoring Global Urban Expansion

Many if not most of the problems in cities can be avoided through foresight and planning – the securing of road grids in advance of development, the preparation of adequate urban lands for estimated population growth, and the development of mechanisms that allow for progressive normalization of informal housing are all important tools. But if mayors and policymakers are to invest resources in addressing these challenges, they must first be shown evidence that they have a problem. Phase II gathered evidence on the quality of urban development in the core of the city and on the periphery, allowing a comparison to be made between them.

Monitoring Global Urban Expansion focused on the study of the universe of 4,231 cities having more than 100,000 people in 2010. The UN Sample of 200 cities, shown in figure 1, was drawn from this universe to improve the study and monitoring of cities on a global scale. The sample allows for the gathering of detailed information about a number of cities, which can then be generalized to provide statistically accurate information about all of the cities on earth having populations greater than 100,000 in 2010. The sample has been tested for statistical veracity and has been found to be representative of the universe as a whole at the 95% confidence interval.[1]

Phase II was divided into three stages:

Phase IIa focused on the study of the 200 cities in the global sample, with an emphasis on the areas developed after 1990. To accomplish this task, the India Urban Expansion Observatory was established in Navi Mumbai, India, and staffed with 30 trained image analysts.

Phase IIb focused on the study of a selected sample of 30 cities for which historical maps were available from ~1800 to ~2000. 27 of these cities were in the UN Sample and

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[1] It is important to note that the sample was originally selected with a view to obtaining *global* averages and their change over time. This means that information on regional averages in this report are illustrative and may not have the statistical power to detect statistically significant differences between regional averages.

three were not. This study, though not globally representative, provided valuable insights into historical tendencies around urbanization and urban growth. The work was subcontracted to gvSIG Association and was conducted in Valencia, Spain, under the direction of Manuel Madrid.

Phase II c focused on the study of the remaining cities in the UN Sample – 173 cities for which historical maps were not available, but in which it was possible to identify the areas developed before 1990 and quantify their spatial characteristics. This work was also undertaken at the India Urban Expansion Observatory in Navi Mumbai, India.

The results of this study of urban layouts show that spatial planning has become stunningly deficient in recent years. The expansion zones in most cities are less planned and less connected to arterial roads than the pre-1990 areas. Indisputably, planners and officials are failing to prepare for urban expansion in a way that produces orderly and adequate land for housing with strong connections providing good access between newly built areas and older areas.

Figure 1: The UN Sample of 200 Cities.

To create the sample, the authors first gathered data from the UN Population Division, the Chinese Academy of Sciences, and www.citypopulation.de and used it to identify the universe of 4,231 cities having populations of 100,000 or more in 2010 (figure 2). These cities were stratified into 8 world regions, 3 country size categories, and 4 city size categories, encompassing 171 countries. The sample includes cities in 78 countries, containing 5% of the cities and 29% of the population of the universe of cities in 2010.

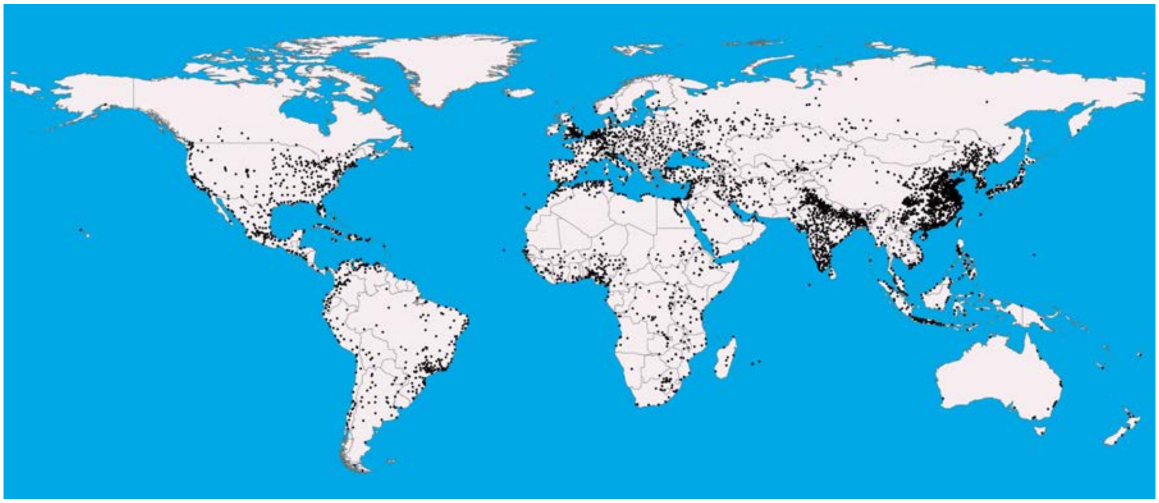

Figure 2: The universe of 4,231 cities having 100,000 people or more in 2010.

The sample has now been modified to correspond to the 5 UN world regions: Asia and the Pacific, which includes the countries of east, Southeast, South and Central Asia, along with the countries of the South Pacific, including Australia and New Zealand; Western Asia and North Africa, which includes the Arab countries, bot not Turkey and Israel; Europe and North America, which includes Turkey and Israel; Sub-Saharan Africa; and Latin America and the Caribbean. A map of the 5 UN Regions can be seen in figure 3.

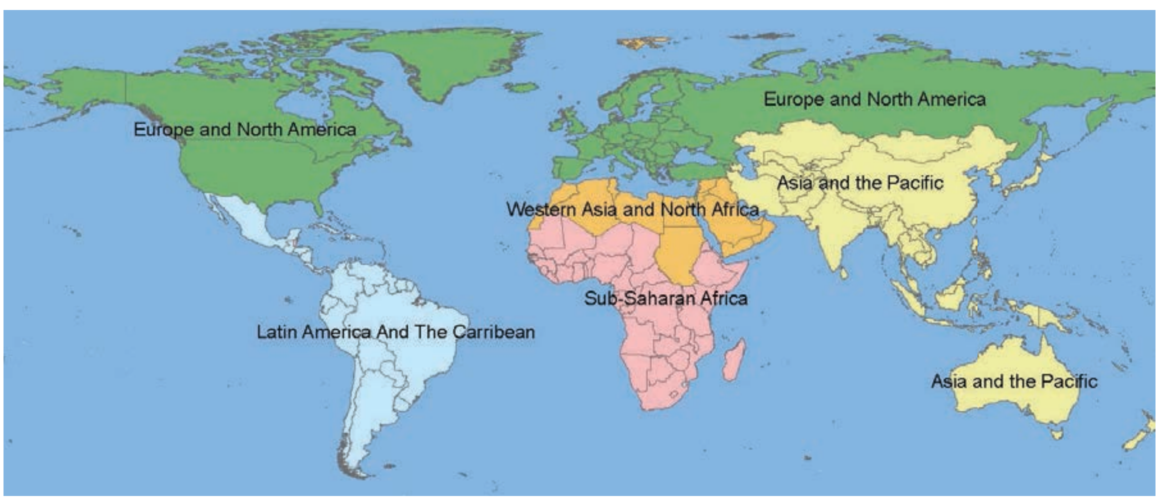

Figure 3: The five UN Regions: Europe and North America (green), Latin America and the Caribbean (blue), Sub-Saharan Africa (pink), Western Asia and North Africa (orange), and East Asia and Pacific (yellow).

The first and most critical step in measuring the characteristics of a city is to define the area of the city itself – in other words, how do we determine the unit that is being studied? National-level census data may provide the name of an urban area and a population figure, but such information rarely includes administrative boundaries. The boundaries that do exist frequently fail to include the entire built-up area of a city, and many cities include multiple municipal jurisdictions.

The governments of these municipalities are often organized as if each one is an island, but growth in cities often transcends or ignores jurisdictional boundaries, leading to a lack of clarity about what, exactly, should be considered "the city." This fragmentation can make it difficult to say much about the quantity of growth that is taking place on a metropolitan level. And yet, cities usually function as metropolitan units. It is quite common for people to live in one municipality, work and shop in another, and visit a third for entertainment or leisure. The proper definition of a city should encompass this phenomenon by including all of the appropriate municipal boundaries, based on built-up area.

As figure 4 shows, a wide variety of jurisdictional schemes can be identified, ranging from that of Beijing, China (whose jurisdiction is 3 times larger than the urban extent) to that of Buenos Aires, Argentina (where the jurisdiction of the Federal Capital is approximately one-eighth of total urban extent).

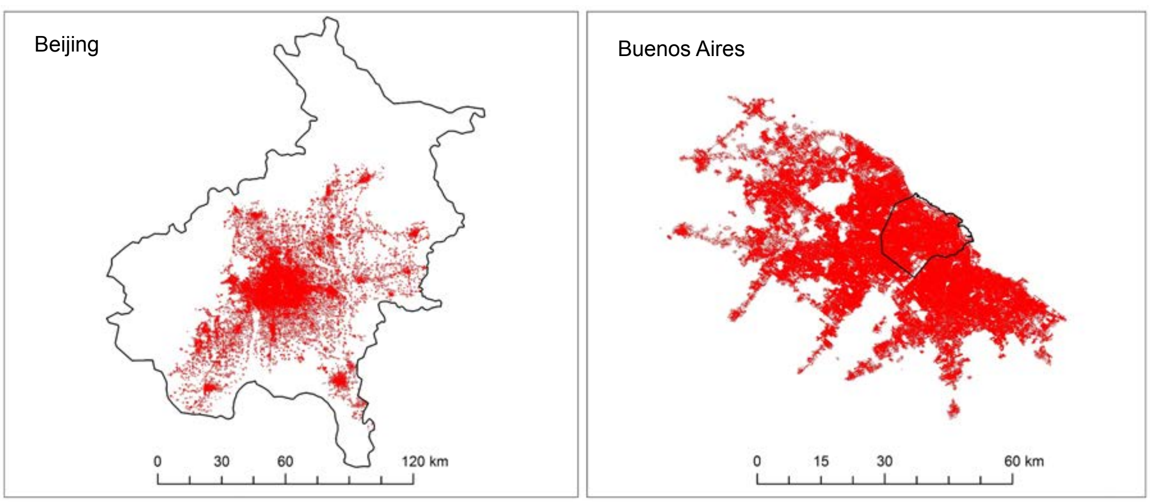

Figure 4: The municipal jurisdiction of the Beijing, China (left) and the Buenos Aires, Argentina, Federal Capital (right).

The methodology used by the NYU Urban Expansion Program addresses this issue by using the Roman concept of the *extrema tectorum* to define the area of the city – the furthest edge of the built-up area is used to define the boundary of the city. This allows researchers to focus on a consistent unit of analysis across different countries and regions – the city as a whole. Also, by focusing on the contiguous built-up area that makes up cities and metropolitan regions, this process highlights a great and growing need for effective metropolitan-scale collaboration among municipalities that can guide urban expansion.

The identification of the area of a city begins by associating its name and population (gathered from heterogeneous data sources including the UN Population Division, the Chinese Academy of Sciences, and www.citypopulation.de) with a specific coordinate centroid, typically the location of City Hall. The next step is identifying a set of population enumeration zones that most likely encompasses the entire area of the city (often done by checking *Google Maps* or a similar service). Freely available *Landsat* imagery is then classified to determine what is built-up within that study area. Built-up pixels that are found to be contiguous or, based on a clustering rule, nearly contiguous, are included in the urban extent of the city. If the original set of enumeration zones is found to be too small (with contiguous built-up pixels spilling past their boundaries) it is expanded and additional imagery is classified until the entire city fits within the set of enumeration zones comprising its study area. The delineation of the urban extent of the cities in the sample is mapped for three periods – ~1990, ~2000, and ~2015 (figure 5).

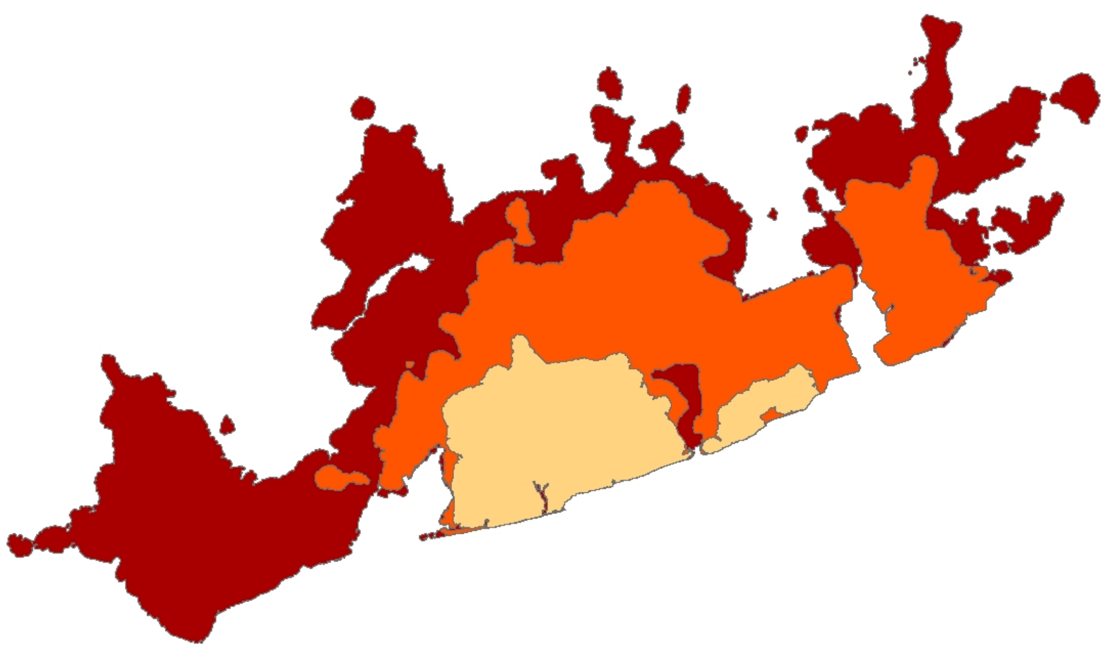

Figure 5: The urban extent of Accra, Ghana in ~1990 (tan), ~2000 (orange), and ~2015 (red).

The extents of all 200 cities have been measured in each of the three periods, making it possible to study the change over time in the urban extent of cities. Combined with the population data associated with the enumeration zones that encompass the urban extent of cities, it is also now possible to create comparable estimates of urban density for cities around the world (figure 6). In addition to this basic measurement, it is also possible to calculate metrics relating to fragmentation and compactness – qualitative attributes that can indicate the efficiency of the urban development that is taking place.

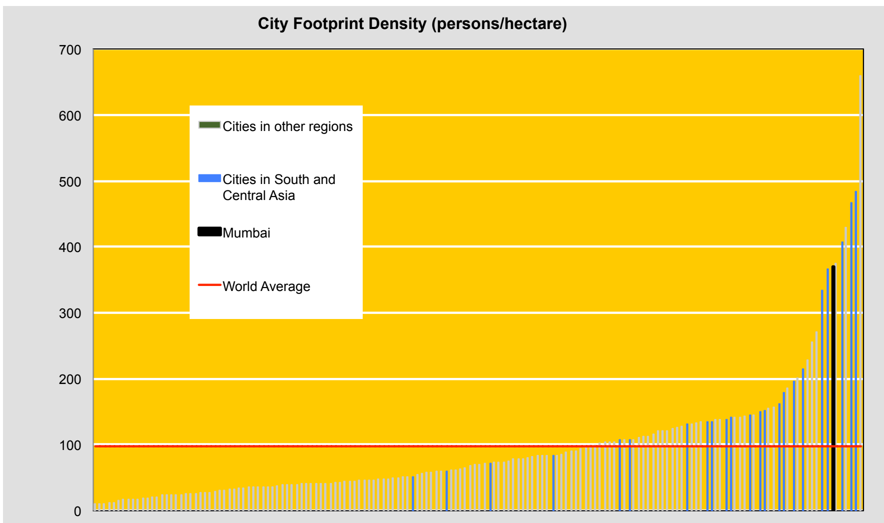

Figure 6: Global urban extent densities for the 200 cities of the global sample. Mumbai, India, for example, had a density of 370 person per hectare in 2015, against a world average of 106 persons per hectare.

The urban extents that are identified through the *Landsat* imagery analysis delineate the areas that were built up in ~1990, ~2000, and ~2015.

Another way to understand this is to think of them as zones of development – the ~1990 edge contains all of the development that occurred before ~1990, the ~2000 edge contains all of the development that occurred between ~1990 and ~2000, and so on. For the purposes of analysis, we combine the ~2000 and ~2015 edges into one zone, ~1990 - ~2015, which is known as the expansion zone. The expansion zone contains all development that has taken place in the past 25 years. This zone and the pre-1990 zone are used to study the qualitative characteristics of the city. By studying the characteristics of the pre-1990 zone and comparing them to the same characteristics in the expansion zone, it is possible to answer an important general question – how do the more recently built areas of cities compare to the older areas?

To answer this question in more detail, we developed a procedure for analyzing freely available *Bing* high-resolution satellite imagery of the pre-1990 zone and the expansion zone of each of the 200 cities. This procedure is partly based on the identification and sampling of small, 10-hectare areas known as locales. A bounding box is defined that encompasses the entire built-up area of the city and the XY coordinates of the bounding box. These coordinates are combined with a Halton Sequence of numbers, creating a set of points that are distributed quasi-randomly throughout the expansion zone (figure 7).

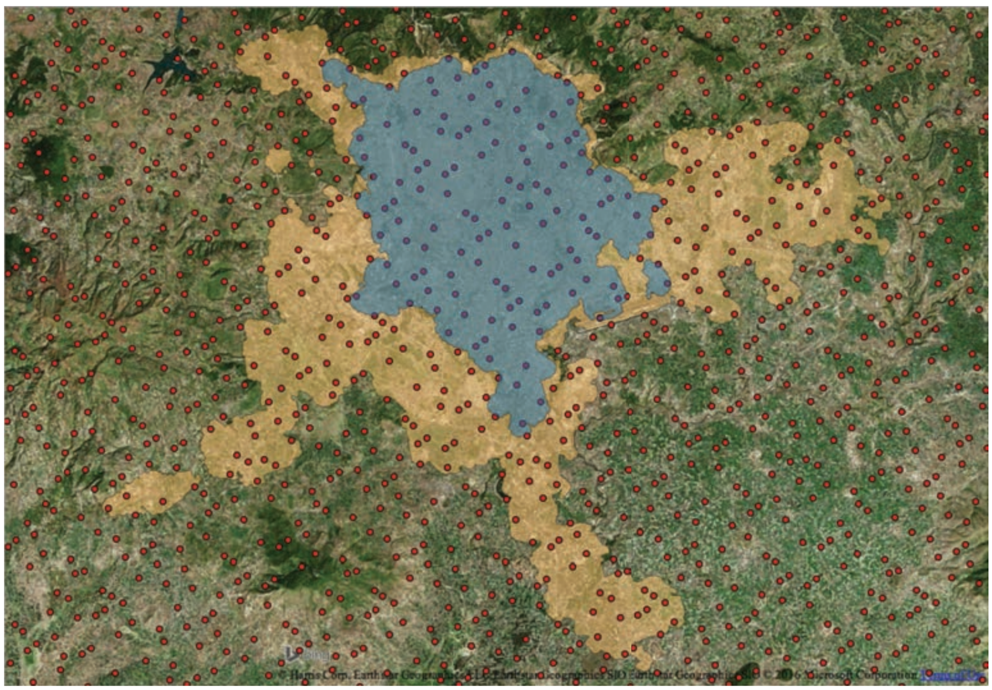

Figure 7: A grid of Halton Points covering the bounding box of Addis Ababa. Pre-1990 area is shown in blue and expansion zone is shown in orange.

The points that fall within the ~2015 urban extent are then buffered into 10-hectare locales and are sampled sequentially based on the order prescribed in the Halton Sequence, allowing us to study a large number of randomly distributed areas through the city. Each city in the sample was assigned at least 80 locales, though some cities were small enough that they were completely covered by using far fewer locales. Other cities were given additional locales in order to accommodate their large size and complexity.

In addition to the locale analysis, a map of the arterial roads was drawn for each city (figure 8).

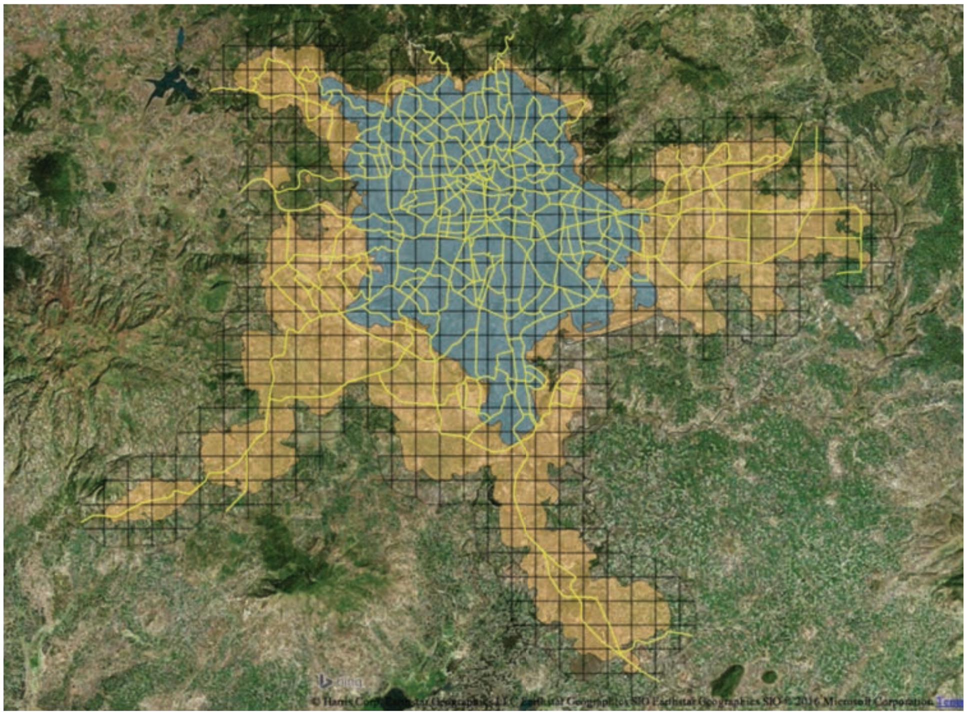

Figure 8: Arterial roads in Addis Ababa (yellow).

These roads are a critical component of a well-functioning urban area, allowing for the creation of an integrated metropolitan labor market, among other things. Arterial roads connect different areas of the city, creating a network that can carry trunk infrastructure and public transportation, reducing the cost of servicing new neighborhoods and increasing the likelihood that residents will choose greenhouse gas reducing transportation options.

Arterial roads are a classic public good, in that users cannot be effectively excluded from them. This can lead to a market failure, in which these roads are undersupplied. Unlike local roads, which are often planned by developers or quickly laid out as development occurs, the land for the rights-of-way of arterial roads must be projected, planned, and protected by public officials in advance of development. The presence or absence of these roads is an important indicator of the degree of planning that is taking place on the urban fringe.

Figure 9: A representative locale in the expansion zone of Addis Ababa, Ethiopia.

The features of each locale (figure 9, for example) in the cities of the UN Sample were digitized by trained analysts at the India Urban Expansion Observatory, a research facility jointly operated by NYU and the Mahatma Education Society, and located at the Pillai Architecture College in Mumbai, India. In total, 20,750 locales were digitized by the analysts, with roughly equal numbers in the expansion zone and in the pre-1990 area. In parallel, the gvSIG Association of Valencia, Spain digitized approximately 5,800 locales in five development zones in the selected sample of 30 historical cities. These 30 cities were divided into five zones, pre-1990; 1900-1930; 1930-1960; 1960-1990; and 1990-2015; with 40 locales digitized in each zone.

MEASURING KEY ATTRIBUTES OF URBAN LAYOUTS

The primary focus of the locale analysis was on the quality and orderliness of their block and road layouts, the quality of their visible infrastructure, the size of blocks and residential plots, and the density of street intersections. Orderliness or disorderliness that can be assessed from satellite imagery largely comes down to the way in which public space is used to organize the urban fabric (through road and block layouts), the level of infrastructure that is provided in a given area (indicative of formality or informality), and the form of dwellings, both through identification of plot boundaries and through a visual assessment of building types. Much of this work falls on the image analyst. With that in mind, detailed rules were developed to assist the analyst in classifying the imagery. These rules constitute the primary methodology used in Phase II b and Phase II c, and they are summarized here in order to improve the understanding of the selected results that follow.

Blocks and Roads

Classification of satellite imagery is fundamentally an exercise in pattern recognition. As with all pattern recognition, the first task in identifying the elements of a locale involves making a primary distinction between these elements. In our case, that distinction is between block space and road space. Road space consists of all land that is currently or potentially used by either pedestrians or vehicles to travel from one place to another. We seek to identify the *right-of-way* of streets and roads, containing both the area that is currently in use and any lands that are clearly reserved for future use. All of these areas constitute road space. Block space, in turn, consists of all other uses, including open space and off-street parking areas. Road space and block space add up to the entire area of a 10-hectare locale. In other words, all space that is not road space is block space, and all block space is assigned a land use. The division of a high-resolution satellite image of a locale in Accra, Ghana, into street space and block space is illustrated in figure 10.

Figure 10: The division of a high-resolution satellite image of a 10-hectare locale in Accra, Ghana, into road space (light brown) and block space (orange borders).

Block space is subdivided into units identified as *blocks*. Individual blocks are areas that are continuously bounded by roads or vacant open spaces (for instance, a block at the edge of a built-up area that borders on farmland). Any given block might contain several different land uses (say, apartment buildings on one end, single-family homes in the middle, and a school at the far end). Blocks and block space can be further subdivided into *plots,* individual parcels of land that would likely be identified as separate properties in a cadaster. Any given block is composed of either one large plot or a series of smaller plots. Much like the identification of rights-of-way, plot boundaries are identified through surface indicators, pattern recognition, and comparisons with nearby areas. The concept of the plot is very important in differentiating residential categories. A suburban plot in a formal residential area might contain several structures—a house, a garage, and a toolshed, for example. We were not interested in measuring the dimensions of these structures in this Atlas. Instead, our goal was to measure the use of the underlying land so as to get a sense of the shares of land in different uses. When land uses are determined, it is the land use of the *plot* as a whole that is determined and measured, not the land occupied by a specific building. The same principle holds true when assessing patterns to determine land use in a larger area: The key is to focus on the pattern of plot boundaries and not on building footprints.

Land Use Categories

Each city in the global sample has specific residential and non-residential typologies, along with unique characteristics of form and layout that deserve recognition and study in their own right. However, in order to study land use on a global scale, the land use categories must be simple enough and broad enough to be identified in any city in the world, encompassing (to the maximum extent possible) the whole range of land use types found in cities. Following a review of numerous land use classifications, we narrowed our classification to seven land uses that could be reliably identified in high-resolution satellite imagery, with a focus on four types of residential land use: (1) open space; (2) non-residential areas; (3) atomistic settlements; (4) informal land subdivisions; (5) formal land subdivisions; (6) housing projects; and (7) road space.

1. *Open Space* includes open countryside, forests, cultivated lands, parks, vacant lands that have not been subdivided, cleared land, and water bodies: seas, rivers, lakes, and canals;
2. *Non-Residential Areas* include all built-up areas, both public and private, that are not in residential use.
3. *Atomistic Settlements* are areas with irregular layouts that were clearly not subdivided or laid out before residential construction took place. This category includes squatter settlements that grew incrementally without an overall plan, homes built on irregular parcels of land, or homes built on rural plots that were not regularly subdivided before their conversion to urban use.
4. *Informal Land Subdivisions* are areas that have been subdivided for urban use, but that lack visible evidence of conformity to land subdivision regulations such as regular plot dimensions, paved roads, streetlights, or sidewalks. That said, structures in these informal land subdivisions, although different in size and form,

are typically laid out along straight or almost-straight roads, with regular intersections and standardized widths. Blocks are also regular or semi-regular in size and shape, when topography permits.

5. *Formal Land Subdivisions* are similar in layout to informal layouts, but exhibit a higher level of regularity, a higher level of provision of infrastructure, and better connections to existing roads. All roads must be paved for an area to be classified as a formal land subdivision. Sidewalks and streetlights are often visible as well.
6. *Housing Projects* range from large apartment tower projects to suburban tract housing. Housing projects share one feature: their structures must be essentially homogenous. These are projects in which all structures are built by a single developer using variations on the same plan.
7. *Road Space* contains the rights-of-way of lanes, streets and roads, both paved and unpaved, containing both the area that is currently in use and any lands that are clearly reserved for future use.

The four types of residential land use are illustrated with examples in figure 11. These types were chosen to reflect stages in the evolution of the housing sector, from a state of weaker planning skills and traditions, less regimented property-right and regulatory regimes, low availability of capital, and an absence of housing finance, to a state of stronger planning and regulatory regimes and a broader availability of capital. The housing sector is at its most basic in atomistic settlements, where the organization of the settlements is insufficient even to ensure consistent plot size or road width and where dwellings are located haphazardly and constructed over time. The housing sector is at its most complex when it is able to support large, planned housing projects, whether private or public, with access to capital, constructed from start to finish over a short period of time. The characterizations of these seven land use categories were used by analysts to determine the land uses within blocks in the 10-hectare locales, taking into account that a single block surrounded by roads or open spaces on all sides may contain more than one of six land uses.

Figure 11: Four types of residential land use identified in locales, using high-resolution satellite imagery: Atomistic settlements (top left), informal land subdivisions (top right), formal land subdivisions (bottom right), and housing projects (bottom left).

Plots, Blocks, and Intersections

The dimensions of residential plots in formal and informal land subdivisions are of interest because they may tell us, for example, whether large plot sizes in formal subdivisions are leading to high rates of land consumption per capita or whether small plot sizes in informal subdivisions reflect a discrepancy between minimum official plot sizes and those offered in the informal market. It is possible to measure plot sizes in land subdivisions using high-resolution satellite imagery when plots are relatively uniform. In these cases, it is possible to identify the boundaries between plots, to count the plots, and to determine their widths and depths. To measure plot dimensions in residential subdivisions, a block that had an array of plots of uniform size was identified and two lines were drawn along two of its edges. Each line was tagged with the number of plots along it, creating an estimate of typical plot depth and width in that area. This procedure is illustrated in figure 12. In this example, the length of the block (160 meters) is divided by 22 and its depth (40 meters) is divided by 2 to yield a typical plot size of 7.3-by-20 meters or 146m^2.

Figure 12: Arriving at a typical plot size in an informal subdivision in Guadelajara, Mexico, by measuring overall block length and depth and dividing each dimension by the number of plots along it.

The size of city blocks or, alternatively, the density of 4-way intersections compared to 3-way ones in typical city neighborhoods is of interest because neighborhoods with small blocks and with high 4-way intersection densities facilitate walking and bicycling, reducing the reliance on private automobiles and making the urban environment healthier and more convivial. It is indeed possible to measure the size of blocks and the density of both 3-way and 4-way intersections using high-resolution satellite imagery, and we did indeed measure them in all locales.

To measure block sizes and intersection density, the analysis of locales required the digitization of road medians (the lines along the middle of roads). This was done for all blocks in every locale, and included the digitization of medians along the entire perimeter of all blocks within the locale, including those clipped by the circular boundary of the locale. It is important to note that using this procedure implied that the area of blocks was calculated as the entire area enclosed by road medians, including the area of roads. The procedure for identifying and mapping blocks is illustrated in figure 13. The density of intersections was calculated by counting the intersections within the locale and dividing their total by the built-up area of the local, excluding areas identified as open space. The procedure for identifying and counting road intersections is illustrated in figure 14. In this example, there are 4 4-way intersections, 33 3-way intersections, and a total area of 9.3 hectares (or 0.093 km^2) in built-up areas. The 3-way intersection density in this locale is therefore 354 per km^2 and the 4-way intersection density is 43 per km^2.

Figure 13: 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.

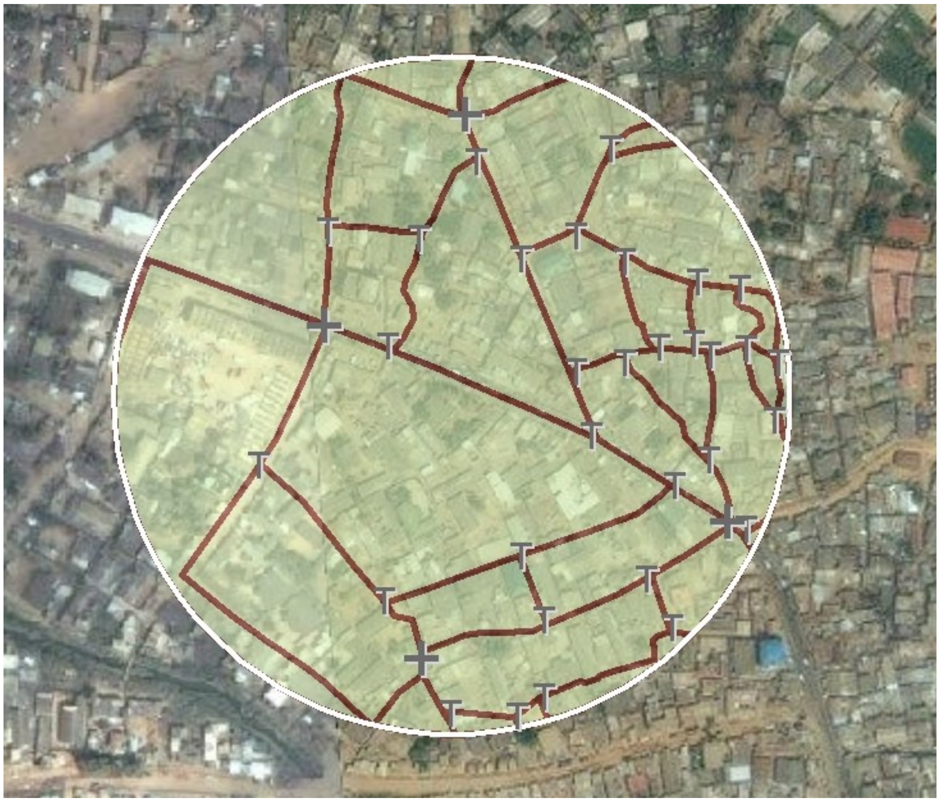

Figure 14: Identifying all the 3-way and 4-way road intersections in a typical locale by digitizing the road medians within the locale (4-way intersections are marked with a + and 3-way intersections are marked with a T).

Arterial Roads

Arterial roads in cities are of interest because they are essential for integrating urban labor markets—providing access, by all transport modes, from all residences to all workplaces in the city—and the more integrated their labor markets, the more productive they are. The road network in every country typically forms a three-tier hierarchy of primary, secondary, and tertiary roads. Central or state governments usually plan, acquire land, finance, construct, and maintain the primary intercity road network that connects the country together. Municipalities typically plan, acquire land, finance, construct, and maintain the secondary or arterial road network within their jurisdictions. In many cases, private developers of residential neighborhoods or of commercial, office, and industrial projects typically plan, acquire land, finance, and construct the tertiary roads that serve buildings within their projects. In many other cases, municipalities plan and build the tertiary road network as well. The network of arterial roads is a classic public good (i.e., users cannot be effectively excluded from using it). Since it is a public good, there is no market mechanism that can ensure that arterial roads are in adequate supply in appropriate locations. In other words, a shortage of arterial roads may be a form of market failure. This means that it is up to public authorities to supply arterial roads in adequate quantities, in the right locations throughout the city, preferably before development takes place. Whether or not this happens in practice can only be determined by observation and measurement.

We identified and digitized arterial roads throughout the urban extents of all cities in the sample. As noted earlier, in the largest cities in the sample we opted to sample locations selected at random and to identify and digitize arterial roads only in these sampled locations. The information obtained from digitizing arterial roads was then used to calculate the share of the built-up area within walking distance to arterial roads, the average beeline distance to an arterial road, and the density of arterial roads. All of these measures provide some insight, for the first time, on the availability of arterial roads in cities the world over, as well as on its change over time.

All roads that fall within the urban footprint (or its surrounding one-kilometer buffer) were considered as possible arterial roads. Likely candidate roads were identified in three data sources: Java Open Street Map, Google maps, and Bing maps, where roads are available as map layers. On any of these three road map layers, roads having through-connectivity are distinguished by width and color. Analysts examined each one-kilometer grid square in the urban extent to identify arterial roads. A candidate road was identified as an arterial road when it met two criteria:

1. It connected to other arterial roads, forming part of a network that extends throughout the city; and
2. It connected to the nearby minor roads. Limited access roads (freeways or expressways) were not considered arterial roads, even though they were connected to other arterial roads.

When an analyst identified a road as *arterial*, they differentiated it further into two categories: Wide and Narrow, where wide roads were those having rights-of-way of 18-meters or more. The network of wide and narrow arterial roads in the urban extent of

Addis Ababa, Ethiopia in 2014 is shown in figure 3.12. The same procedure was followed in identifying wide and narrow arterial roads in randomly selected 3-by-3-kilometer squares in the largest cities in the sample, as previously shown (figure 15).

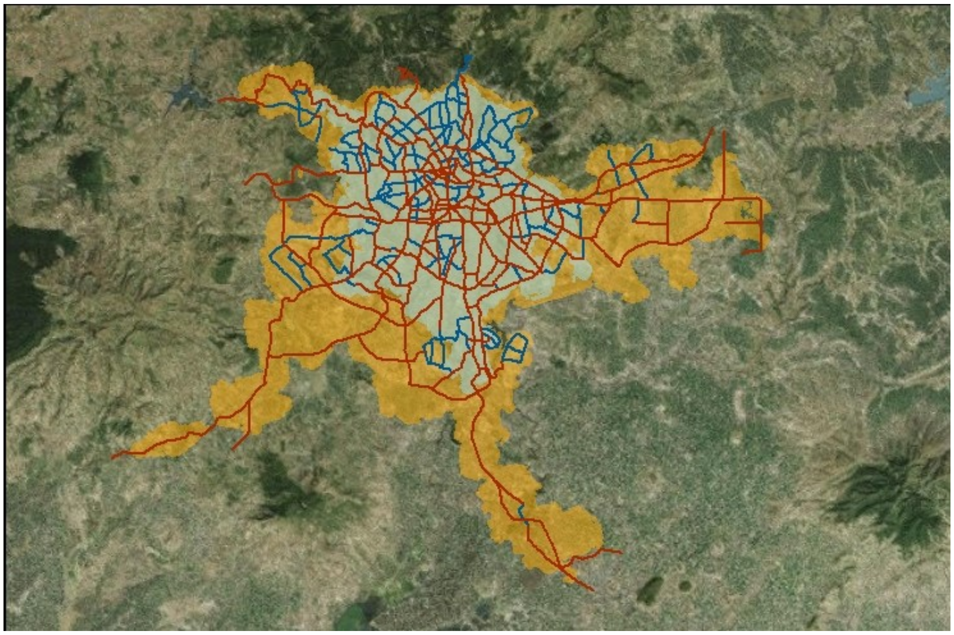

Figure 15: The network of arterial roads in the urban extent of Addis Ababa, Ethiopia in 2014, distinguishing wide arterial roads (brown) from narrow ones (blue).

Urban Layout Metrics

In each city in the global sample of 200 cities, we initially selected at random 40 locales for analysis in its pre-1990 area and 40 locales in its expansion area, a total of 80 locales per city or 16,000 locales for the global sample as a whole. Key layout features of these locales, observed in high-resolution satellite imagery, were then digitized, analyzed, and stored. The digital files associated with locales were processed in ArcGIS using a Python script that calculated the following metrics for each locale:

- **Land Use**
    - Share of land in open space (open space in locale/area of locale);
    - Share of built-up area in non-residential use (non-residential land in locale excluding roads/area of locale);
    - Share of the built-up area in residential use (all area in residential use in locale/built-up area of locale);

- Share of built-up area occupied by roads (area in roads/built-up area)
- Share of the residential area not laid out before development (area of atomistic settlements/residential area);
- Share of the residential area in informal land subdivisions (area in informal land subdivisions/residential area);
- Share of the residential area in formal land subdivisions (area in formal land subdivisions/residential area);
- Share of the residential area in housing projects (area in housing projects/residential area);
- Share of the residential areas laid out before development (area in both formal and informal land subdivisions/residential area);
- Share of locale that is gridded [visual assessment of the presence of orthogonal street grids in the locale and their assignment to three categories: *not gridded*, *partially gridded* (covering 10-90% of the locale area), and *gridded* (covering 90% or more of the locale area)].
- Average plot size in informal land subdivisions; and
- Average plot size in formal land subdivisions.

• **Roads**

- Share of roads less than 4-meters-wide (length of roads less than 4-meters-wide in locale/length of total road network in locale);
- Share of roads that are 4-to-8-meters-wide (length of roads 4-8-meters-wide in locale/length of total road network in locale);
- Share of roads that are 8-to-12-meters-wide (length of roads 8-12-meters-wide in locale/length of total road network in locale);
- Share of roads that are more than 16-meters-wide (length of roads more than 16-meters-wide in locale/length of total road network in locale); and

    - Average road width in locale.
- **Block Layout**
    - Average block size (hectares);
    - The density of 3-way intersections (number per square kilometer of locale area);
    - The density of 4-way intersections (number per square kilometer of locale area);
    - Share of intersections that are 4-way (ratio of 4-way intersections to total number of intersections in locale);
    - The Walkability Ratio (The average ratio of the beeline distance and the street travel distance for 40 pairs of sample points within the locale that are more than 200-meters apart);

In addition to calculating metrics for individual locales, a number of metrics were calculated for the arterial road network identified in each city:

- **Arterial Roads**
    - The average density of all arterial roads (linear kilometers of arterial roads/square kilometers of urban extent);
    - The average density of wide (18m+) arterial roads (linear kilometers of wide arterial roads/square kilometers of urban extent);
    - Average beeline distance to all arterial roads (meters);
    - Average beeline distance to wide arterial roads (meters);
    - Share of the urban extent within walking distance (625m) of all arterial roads; and
    - Share of urban extent within walking distance (625m) of wide arterial roads.

Data for each locale is stored in four files: (1) Locale boundary file; (2) Blocks file; (3) Plot measurement file; and (4) Street medians file. Arterial roads data is stored in two additional files: (5) Arterials master file; and (6) Arterials study area file. All of the data is stored in shapefile format and can be downloaded on a city-by-city basis or in batches at www.atlasofurbanexpansion.org. In addition, selected metrics are available for download in table format, both as csv files and as excel spreadsheets.

Selected Findings: Blocks and Roads

Housing projects, formally subdivided areas, and informally subdivided areas that can be thought of as having been *laid out*, or planned for urban use before the land was occupied make up 69% of residential neighborhoods in the pre-1990 area. In the expansion area, developed from 1990 - 2015, 57% of residential neighborhoods were laid out before the land was occupied.

By region, declines were seen in Sub-Saharan Africa, Western Asia and North Africa, and Asia and the Pacific. Asia and the Pacific had the steepest decline, with the share of residential areas planned before occupation falling from 70% - slightly above the global average – to 49%, eight percentage points below the global average (figure 16). Planning improved in Europe and North America as well as in Latin America and the Caribbean, where the share of residential areas planned before occupation is now approximately 80%.

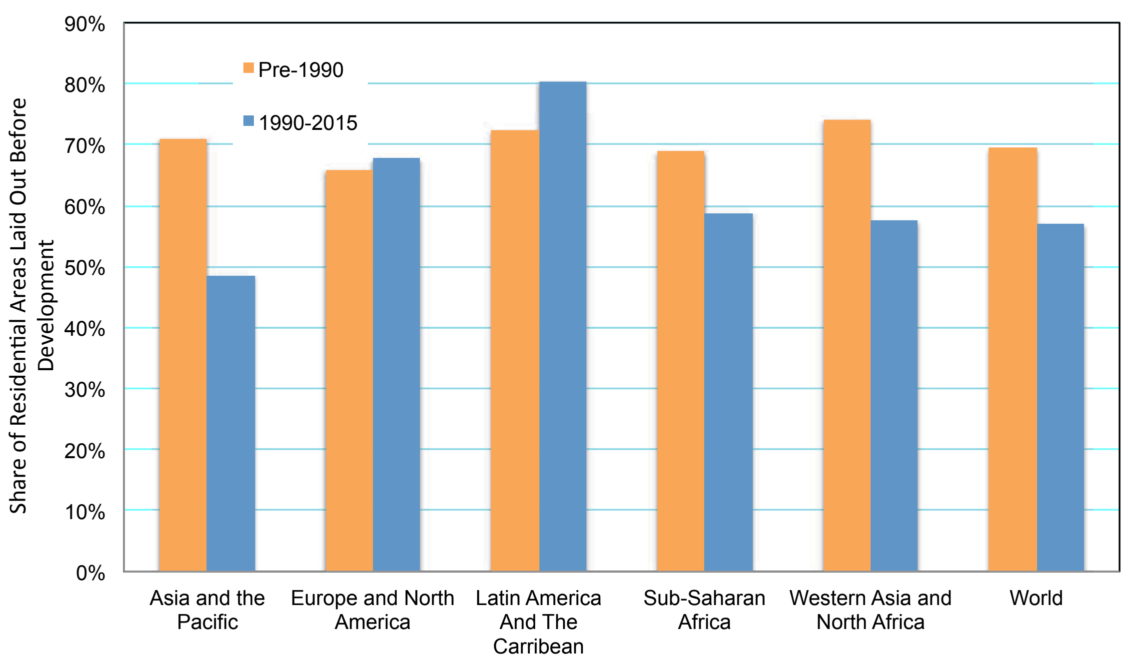

Figure 16: The share of residential area laid out before development fell in three of the five UN Regions and also declined globally.

In addition to a general decline in the amount of planning, there has been a specific increase in the incidence of informality. Informally subdivided housing is built on land that has been organized for urban development, but appears to lack the full compliment of services. It is identified by recognizing that the development has a pattern, with regularly sized blocks and plots and orderly local roads, but lacks street paving, sidewalks, and street lighting. From these clues we can infer that such areas were planned by informal developers and most likely are not in compliance with local land subdivision regulations. These areas are distinct from atomistic settlements (such as those seen in Figure 12 above), in which no planning took place whatsoever.

Worldwide, 17% of residential neighborhoods in the pre-1990 zone were informal, versus 27% in the expansion zone (figure 17). Increases in informality were particularly high in Latin America and the Caribbean, Western Asia and North Africa, and in Sub-Saharan Africa. In Latin America, the share of residential areas that were informally subdivided rose from 14% in the pre-1990 area to 47% in the expansion zone. In Western Asia and North Africa, the increase was similarly stunning – from 7% to 49%. Finally, informality in Sub-Saharan Africa increased from 21% to 51%. A decline was only seen in one region. In Europe and North America, the share fell from 24% to 21%.

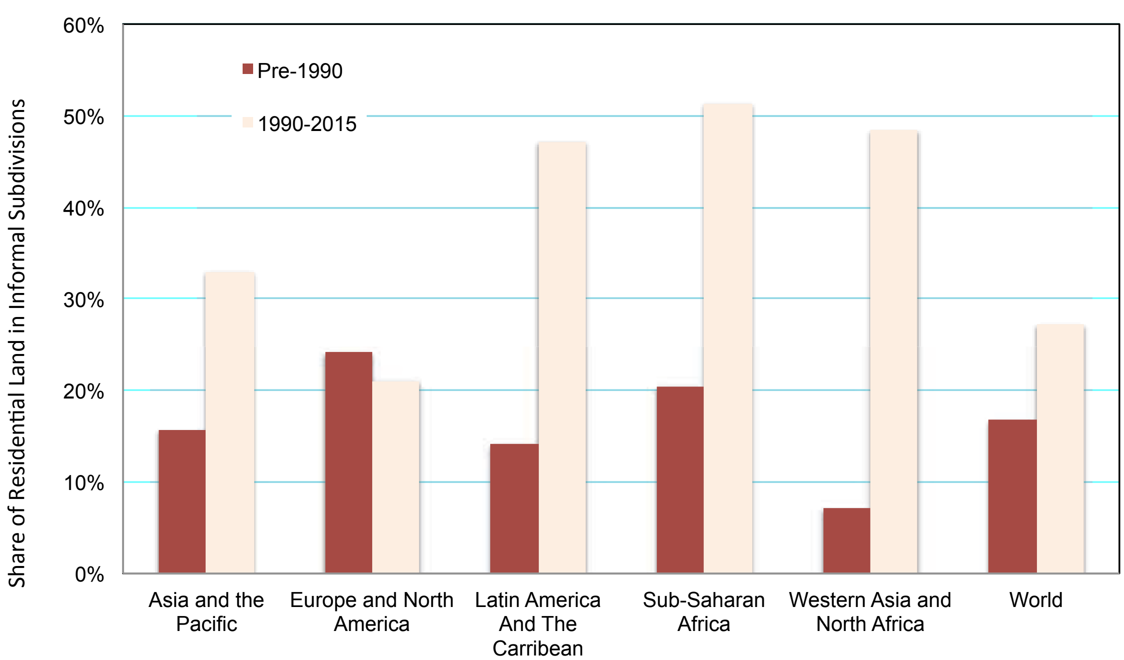

Figure 17: Informality increased in all of the regions except Europe and North America.

It is quite possible that the high levels of informality in most regions are not due to any particular shock in the last two decades, but are rather symptomatic of a more generalized failure to keep up with urban expansion. Worldwide, it is common for informally developed neighborhoods to transition over time to a formal status, with informal housing being built as needed, services being installed more gradually, and titles in some form coming later. This regularization is, in fact, much more common than the demolition of non-compliant structures and zones, something that a companion study on regulatory regimes found to be almost non-existent[2]. This can be seen in the neighborhood of Comas, in Lima, Peru – a former squatter settlement that has, over time, been normalized and is now a desirable neighborhoods (figure 18).

Figure 18: The former squatter settlement of Comas, in Lima, Peru. Inset: A home in this neighborhood recently sold for $180,000.

A similar trend can be observed in the historical sample of 30 cities (figure 19). In this sample, the share of residential areas having informal layouts is significantly higher in places that were more recently built and are closer to the urban periphery. Again, a reasonable hypothesis (absent any evidence for a change in the planning and regulatory systems) would state that planners in these cities are failing to keep up with the pace of

[2] For more information on the study of regulatory regimes, contact plamsonh@stern.nyu.edu.

development, and have adopted a pragmatic policy of regularizing informal settlements after they have been built.

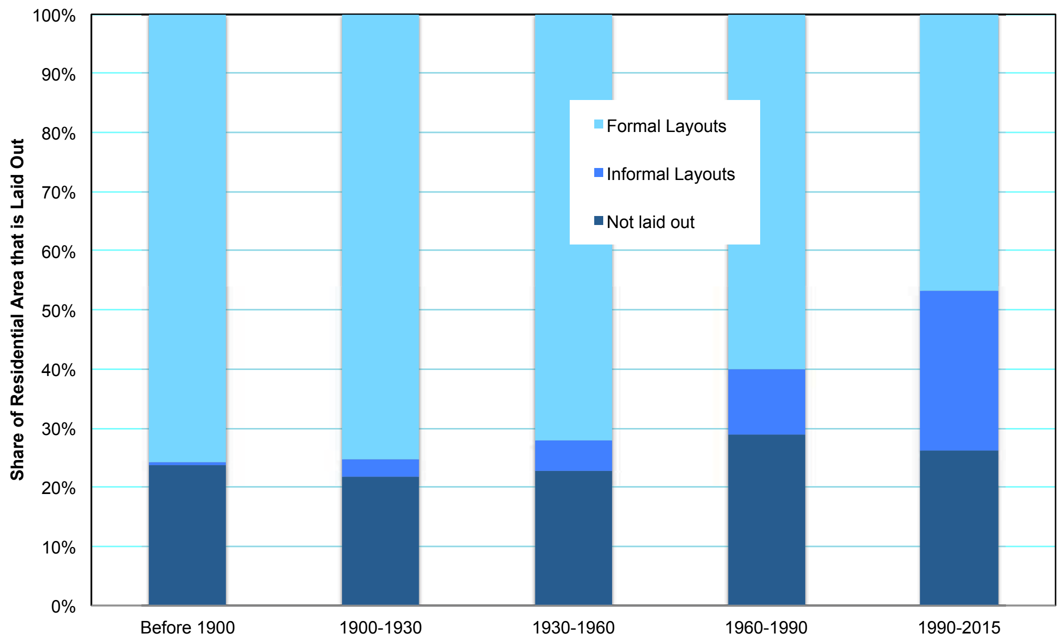

Figure 19: The share of land in informal layouts increased over time in the sample of 30 historical cities.

The share of land in streets has declined slightly, from 21% in the pre-1990 area to 20.6% in the expansion zone (though the decline is not statistically significant). In fact, most world regions saw no change (figure 20). However, the general pattern of stability is disrupted in Latin America, which saw an increase in the share of land in roads from 20% in the pre-1990 area to 25% in the expansion zone. In Sub-Saharan Africa, by contrast, the share declined from 23% in the pre-1990 area to 16% in the expansion zone. The decline in Sub-Saharan Africa was the only significant decrease reported worldwide.

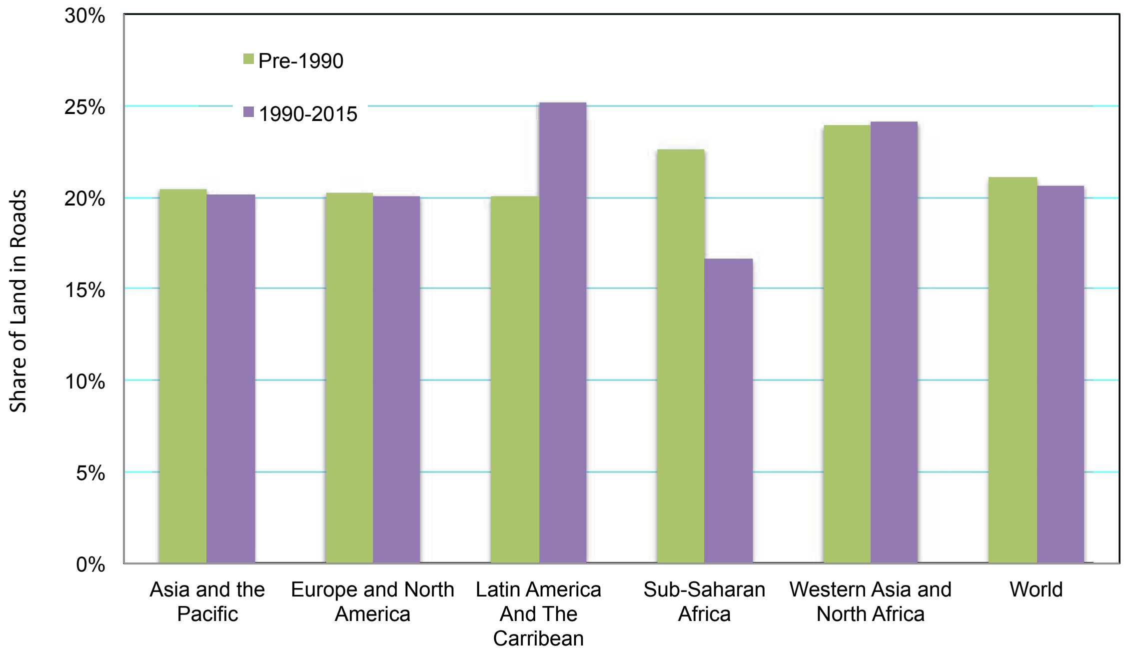

Figure 20: The share of land in roads has increased in Latin America and the Caribbean and declined in Sub-Saharan Africa.

Many of the roads that are being built are less than 4-meters in width. As figure 21 shows, the share of roads that are less than 4-meters wide increased from 19% in the pre-1990 zone to 29% in the expansion zone, globally. Increases in the share of roads less than 4-meters wide can be seen in Sub-Saharan Africa, where the share nearly doubled from 17% to 32%; Europe and North America, where the share increased from 20% to 26%; and in Asia and the Pacific, where the share increased from 18% to 34%. The only region showing a decline in the share of these narrow roads was Latin America and the Caribbean, where it fell from 24% to 17%.

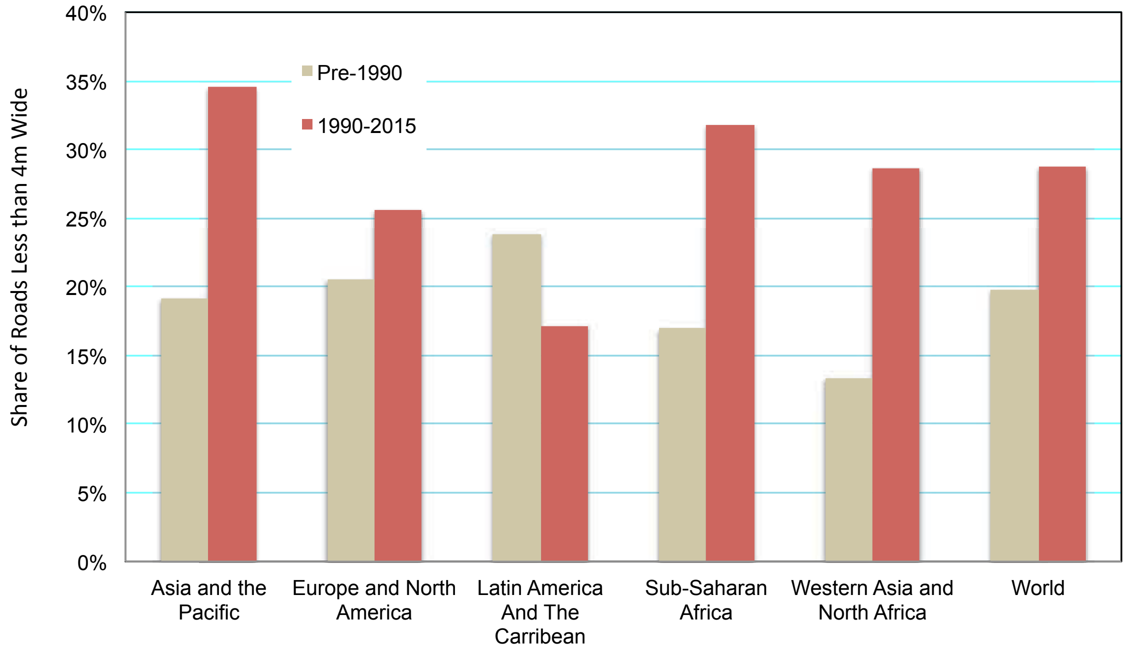

Figure 21: The share of roads less than 4m wide increased in all world regions except Latin America and the Caribbean.

If the road networks are to provide connectivity as well as capacity, they must not merely be built, but must also be properly laid out. One measure of layout, the density of 4-way intersections, is an important indicator of both walkability and drivability. A higher density of 4-way intersections means that multiple routes are available between two points, making it easier to avoid traffic bottlenecks and congestion as well as reducing overall travel times. The density of these intersections (the number of intersections per square kilometer) has fallen from 23.3 intersections per square kilometer in the pre-1990 area to 19.4 intersections per square kilometer in the expansion zone (figure 22). This means that the road networks in more recently developed areas offer fewer opportunities to avoid congestion, fewer route options, and reduced walkability. Newly developed areas of cities are therefore harder to navigate, impeding their integration with the older parts of the city.

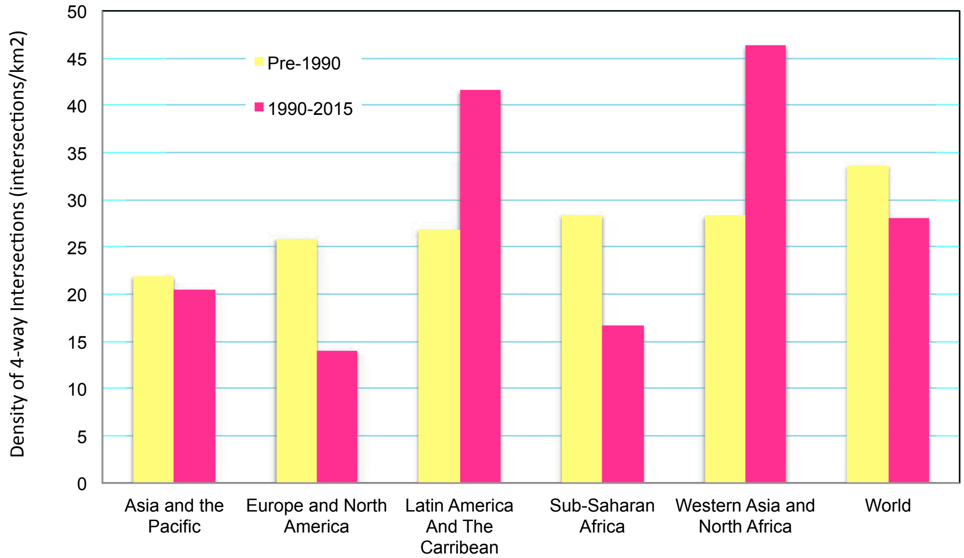

Figure 22: The density of 4-way intersections fell worldwide and in most regions, but increased in Western Asia and North Africa and in Latin America and the Caribbean.

The problem is particularly acute in Europe and North America, where the density of 4-way intersections fell from 26 per km2 to 14 per km2. This may reflect the stylistic choices of large suburban developers. These choices increase the isolation of new neighborhoods, at the expense of walkability. This can be seen in a representative locale showing Phoenix, Arizona, figure 23.

Figure 23: In this locale in Phoenix, Arizona, 4-way intersections are uncommon, harming walkability and increasing travel distances.

Problems can also be seen in Sub-Saharan Africa, where the density of 4-way intersections has fallen from 28 per km2 in the pre-1990 area to 16 per km2 in the expansion zone.

The low 4-way intersection density is implicitly related to another disturbing phenomenon – the increase in the size of a typical block. Neighborhoods having small blocks tend to be more walkable for the simple reason that people are generally able to find a more direct route to their destination, versus having to circumnavigate large blocks. The size of a typical block rose from 3.8 hectares in the pre-1990 area to 5.2 hectares in the expansion zone. Particularly sharp changes were observed in Asia and the Pacific and in Europe and North America – two regions that have embraced curvilinear suburban design - where the increases were from 3.5 hectares to 6.1hectares and from 3.4 hectares to 6 hectares, respectively (figure 24). This trend toward large blocks with limited intersections significantly compromises walking and biking, making cities less pedestrian friendly and less bicycle friendly. In New York, for comparison, a typical block is 2.2 hectares and is very walkable (figure 25).

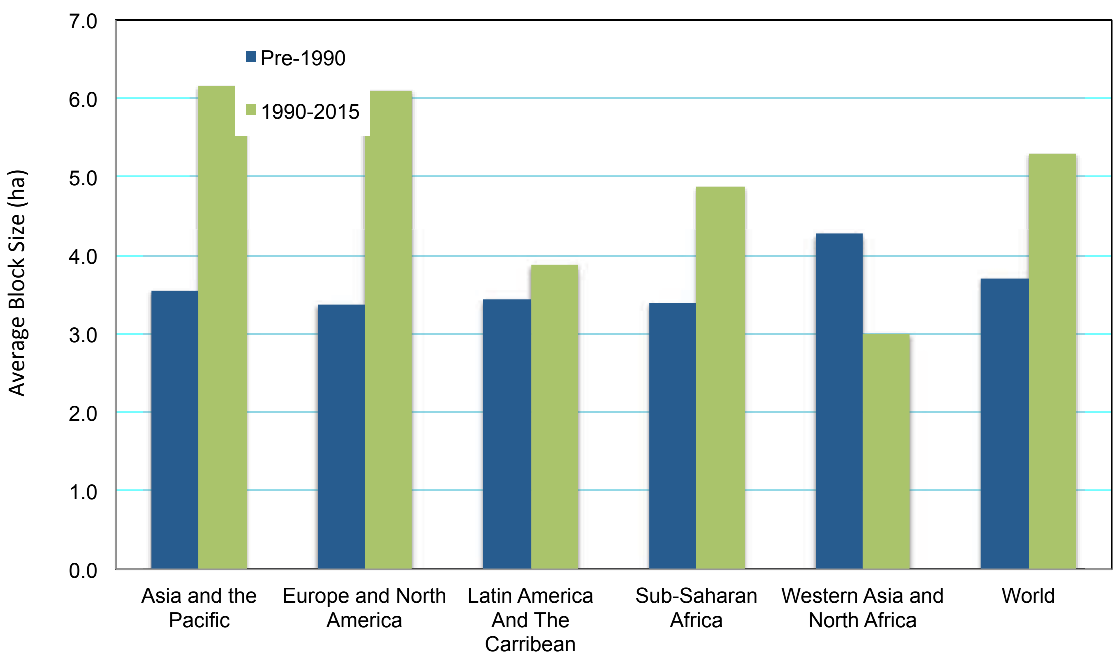

Figure 24: The size of an average block has increased in all world regions except Western Asia and North Africa.

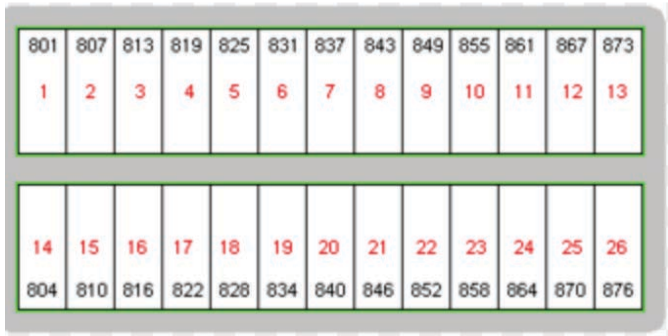

Figure 25: A typical Manhattan block is 2.2 hectares.

A simple way to achieve consistently low block-size and high density of 4-way intersections is to lay out the expansion areas of cities using a grid plan – both local roads and larger arterial roads can be laid out in this way, ensuring an efficient spatial layout.

This method of urban planning has been successfully used for thousands of years, perhaps beginning with the city of Hat-hetep Senusret in ancient Egypt some 4,000 years ago. It is common in both developed and developing countries in present-day cities. In figure 26, grids can be seen in Bamako, Mali, and in Chicago, Illinois, for example.

Figure 26: Gridded layouts in the expansion areas of Chicago, Illinois (left) and Bamako, Mali (right).

Regrettably, this age-old system of planning has fallen out of favor. Only 3.4% of locales in the expansion zones of the cities in the global sample were found to contain road networks that were gridded or partially gridded, compared to 7.7% in the pre-1990 area (figure 27). In the historical sample of 30 cities, 28% of areas built before 1900 were found to be gridded, falling to just 9% in the area developed between 1960 and 1990 (figure 28).

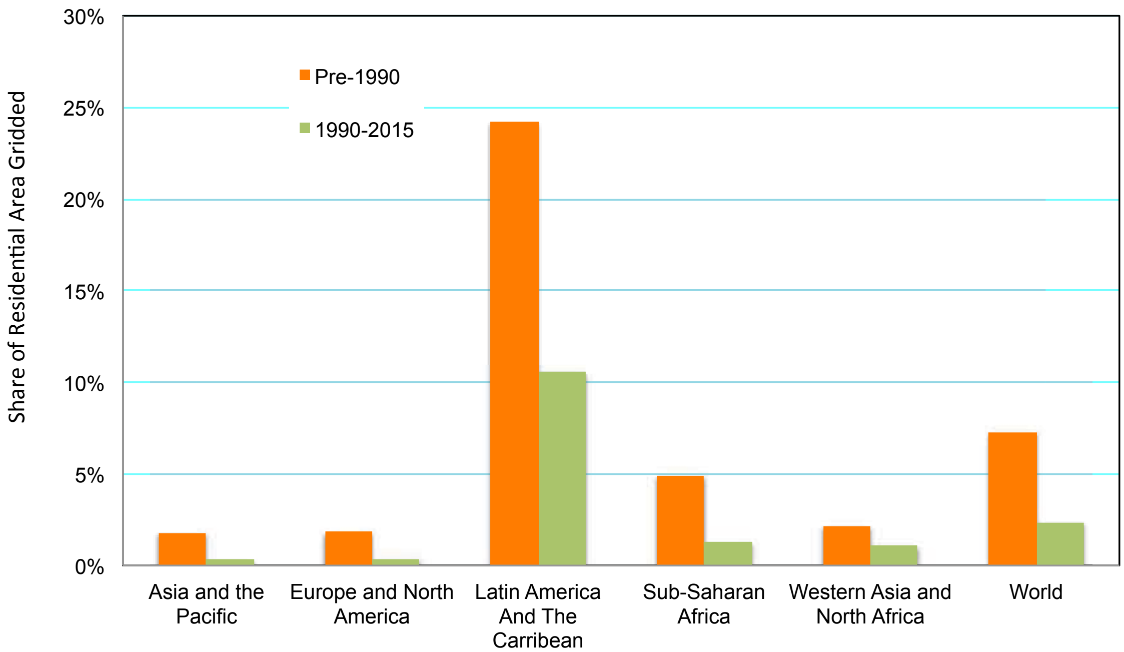

Figure 27: The share of locales containing gridded layouts has declined to the point of vanishing in all regions except Latin America and the Caribbean.

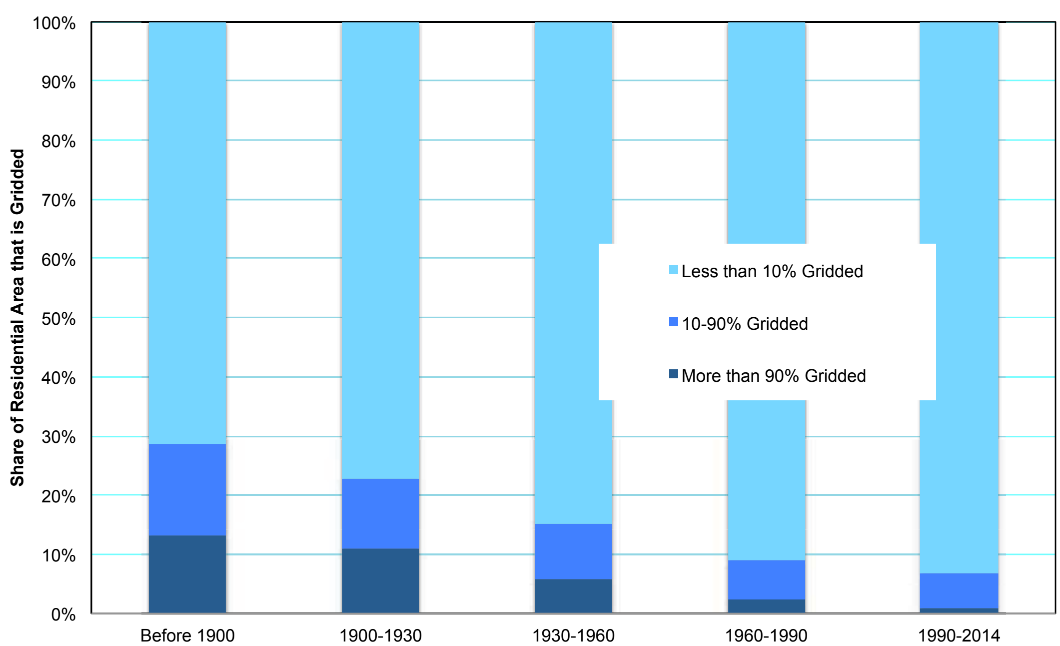

Figure 28: In the sample of 30 historical cities, the share of locales that are either partially or totally gridded has fallen over time.

A notable exception to this trend away from grids can be found in Latin America and the Caribbean, where the historic *Leyes de los reinos de indios* required that cities be laid out in plain, rectilinear grids.[3] The form has persisted, such that almost one-quarter of locales in the pre-1990 area had clear grid plans, and 10% of those in the expansion area had such plans. This share, though still quite low, is five times greater than the next highest region.

Selected Findings: Arterial Roads

The mapping of arterial roads provides perhaps the greatest opportunity to assess the quality of urban planning in a given city. These are the roads that ensure connectivity between different areas of the city, and they are the backbone of the transportation networks that lead to the creation of large labor markets and their ensuing agglomeration economies. Equally important, the proper deployment of these roads can reduce the cost of providing infrastructure services. Finally, as discussed earlier, these roads are a classic public good and must be laid out by the public sector in advance of the occupation of the land by development.

The work of measuring arterial roads is comprehensive and city-wide, with the task organized through the division of the city into a series of one-kilometer-by-one-kilometer grid squares. A one-kilometer buffer is added to the periphery of the city when creating the grid squares, so that roads that are adjacent to the urban area are also included (figure 29). Each square is methodically checked for the presence of arterial roads and the roads that are found are classified as either wide—meaning greater than 18meters in width—or narrow. Wide arterial roads are those that are best equipped to carry trunk infrastructure and public transportation. Narrow arterial roads are more likely to be local roads that are serving a connectivity function, rather than roads that were designed explicitly for the purpose of being arterials.

3 Brillembourg, Carlos M., 2016. "Latin American Architecture." *Encyclopedia Brittanica Online* , 2016 Edition. Online at: https://www.britannica.com/art/Latin-American-architecture#ref996087.

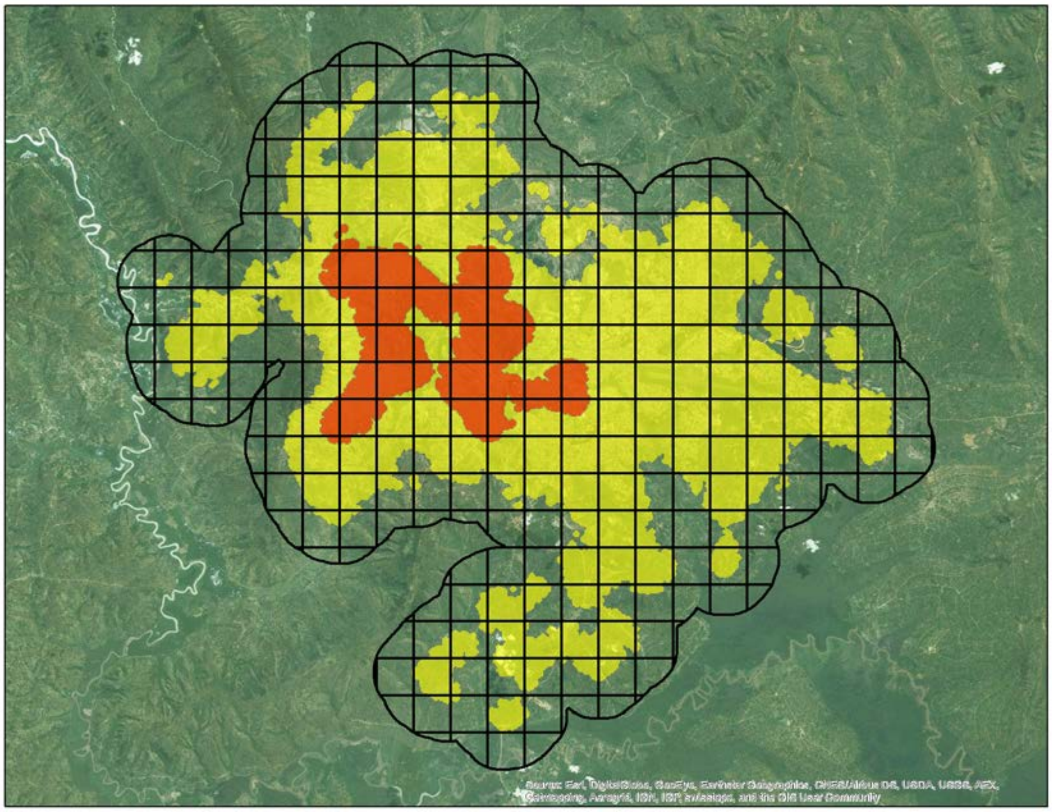

Figure 29: The grid used to identify arterial roads in Kigali, Rwanda, with the pre-1990 area in red and the expansion zone in yellow.

In a small number of very large cities, a sampling methodology was developed that relied on Halton Points, with a one-kilometer square around each Halton Point, buffered to an additional distance of one kilometer on each side of the square. This produced an area of three square kilometers. A random sample of these areas was studied and the results were generalized to describe the arterial road network in the sampled cities. The application of this method in Hangzhou, China, can be seen in Figure 30.

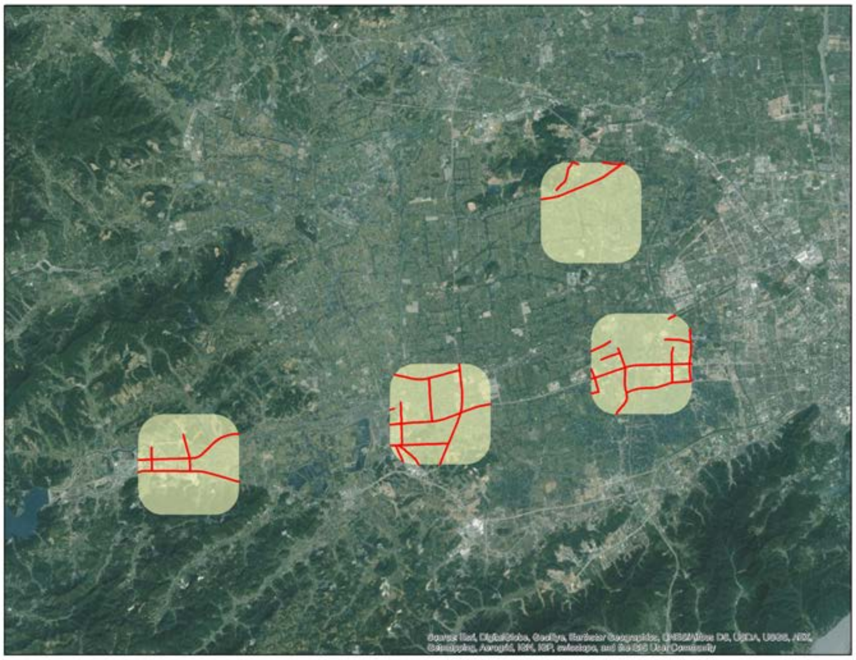

Figure 30: Representative arterial road samples in Hangzhou, China

The digitization and analysis of these arterial road maps show that the share of land within walking distance (625m) of any arterial road has fallen from 92% in the pre-1990 area to 82% in the expansion zone. Access to *wide* arterial roads has fallen from 83% to 69% (figure 31). In other words, about one-third of the expansion area in a typical city does not have easy access to an arterial road that can carry public transportation.

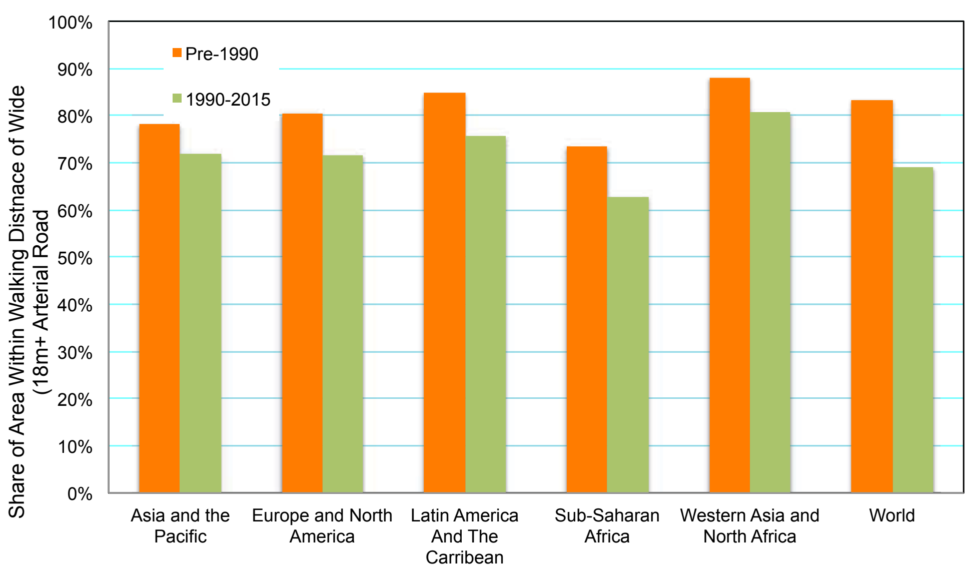

Figure 31: The share of the area within walking distance (625m) of a wide (18m+) arterial road has fallen in all world regions and worldwide.

The share of area within walking distance of a wide arterial road has fallen in all regions. The average decline in most regions was on the order of 10%. In Sub-Saharan Africa, the share fell from 72% to 62%, meaning approximately 40% of newly developed areas are not within walking distance of an arterial road.

In Sub-Saharan Africa, the decline is paralleled by a larger than average increase in the beeline distance to an arterial road (figure 32). The beeline distance to an arterial road nearly doubled, from 305-meters in the pre-1990 area to 530-meters in the expansion zone, compared to a global average increase from 220-meters to 410-meters. This beeline distance does not take into account the need to navigate neighborhood streets, which could greatly increase the walking time. Neighborhoods at such a remove from arterial roads are most likely quite isolated from the urban labor market, and residents may face difficulties in finding employment and in commuting.

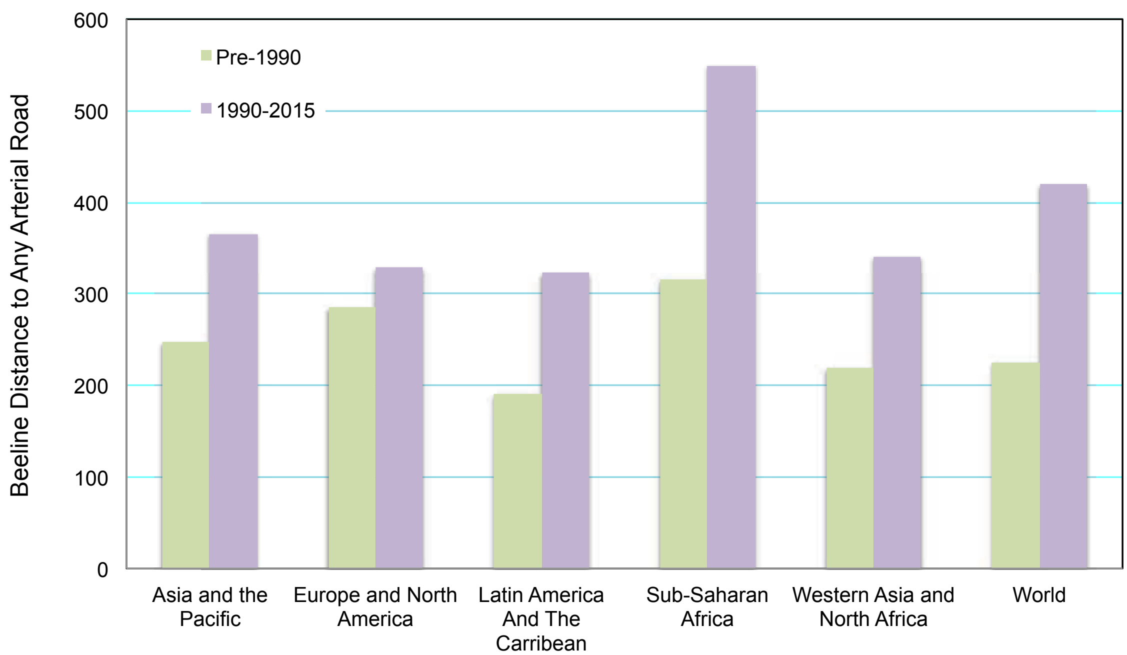

Figure 32: The beeline distance to an arterial road increased in all world regions, with a particularly large increase in Sub-Saharan Africa.

The share of area within walking distance of wide arterial roads has also declined over time in the selected sample of 30 historical cities (figure 33). In general, the selected sample reports lower access to arterial roads than the UN Sample of 200 cities. In the final period for example, 50% of areas in the selected sample of 30 cities were within walking distance of a wide arterial road, compared to 69% in the UN Sample. However, the 30 historical cities do serve to illustrate the general trend of worsening access to arterial roads.

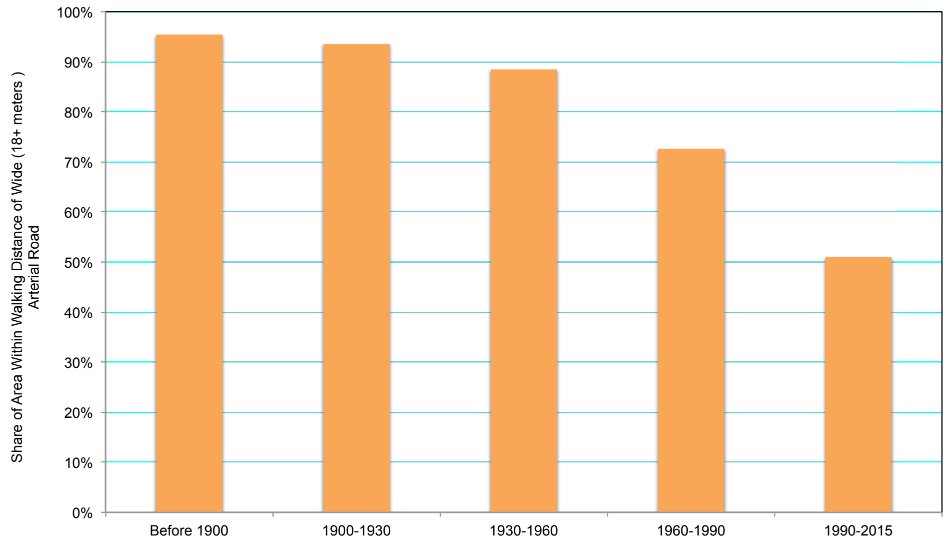

Figure 33: The share of area within walking distance (625m) of a wide (18m+) arterial road in the historical sample of 30 cities.

Improving the confidence in the metric averages

The metrics that we calculated exhibited a high degree of variation across locales within a city. This intra-city variability poses a challenge for making correct inferences. More specifically, in order to detect statistically significant differences in the mean value of a metric across cities, precise estimates of the mean value of a metric within a city are needed. Although the sample average for a given metric—say, the average share of the built-up area in roads—might differ in two cities, the number of locales in each city might not be large enough to reject the null hypothesis that the two means are equal to each other. We can improve the precision of our estimates by adding locale observations to each city, but additional locales entail additional costs, in terms of both time and money.

Given the time and cost associated with extracting data from each locale, the study leading to the production of this volume of the Atlas operated with a budget allowing for the analysis of approximately 20,000 locales in the 200 cities in the global sample. All in all, some 30 analysts worked for an average of 90 days each to digitize and analyze these locales. We initially allocated 80 locales to each city in the sample, 40 in the pre-1990 area of the city and 40 in its expansion area. Then, rather than equally dividing the remaining 4,000 locales evenly among all cities, these locales were allocated using a rule to improve the overall precision of our subsequent estimates of city averages. This rule was based on the understanding that some cities are more complex than others and feature more variability in key metrics of interest. Adding locales to these cities may therefore be especially useful in improving the precision of our estimates.

We chose to focus on three principle metrics, or 'variables of interest', that are of key importance in assessing the quality of urban layouts: (1) the share of the built-up area in roads; (2) the share of residential land in atomistic settlements; and (3) the share of residential land in informal land subdivisions. Each sampled locale provides values for each one of these three metrics. For each city, given a set of sampled locales, we can calculate the sample average and sample standard deviation of each variable of interest. The method chosen to add locales to particular cities uses the information on the averages and standard deviations for these three metrics to improve the statistical power to detect differences between hypothesized means in the cities in the global sample. The procedure we followed involved the following steps:

- Initially, allocate 80 locales to each city;
- Calculate the statistical power associated with one-sided hypothesis tests for each of the variables of interest in all the cities in the sample;
- Create a power index for each city, which is the average statistical power associated with the tests for the three variables of interest;
- Sort cities on the basis of the power index from lowest to highest;
- Select the 20 cities with the lowest rankings on the power index;
- Add 10 new locales to each of these 20 cities, then calculate new metrics and new power indices;
- Rank cities again, using this new information;
- Repeat the process until all 4,000 new locales have been allocated.

It should be noted that in some cities, the expansion area is sufficiently small that it might be completely covered with locales, either before the initial 80 locales are randomly chosen or before the termination of the procedure for adding locales. As soon as it becomes impossible to add another locale that does not overlap with the existing locales, no more locales are added to a given city. As noted earlier, all in all, 20,795 locales were digitized and analyzed, a maximum of 270 locales in Cairo, Egypt and a minimum of 25 locales in Zhijin, China. Unfortunately, the addition of locales at this scale does not yet ensure that the average values reported are significantly different from each other.

Conclusion

The study of the areas of cities through Phase II allowed for the making of comparisons within cities and between cities and regions over time. The more detailed analysis provided by the in-depth study of the 30 historical cities provided fundamental information about the historical quality of urban development. More research is required, but, in general, this direction of inquiry provides information that was not previously available on a topic that is of great interest and importance to professional planners and to city officials, as well as to the billions of people who are already living in cities and who will be moving to cities in the decades to come.

Overall, the quality of urban planning in the world's cities and its effect on the ground is worsening over time. As cities expanded between 1990 and 2015, informality increased, orderly residential planning decreased, neighborhoods became less walkable, less land was allocated to streets and roads, roads became narrower on average, and access to arterial roads worsened. Planners and developers moved away from time-tested methods such as the laying out of road grids, perhaps gravitating toward large-block curvilinear suburban development plans that increase isolation and segregation.

If these results are representative of the trajectory of future growth, then it is clear that the cities of the future are at risk of being less productive, less inclusive, and less sustainable than the cities of the past. It is easy to envision cities of enclaves, with the wealthy and middle class living in privately planned communities, surrounded by walls, and the poor and working class living in underserved and chaotic informal developments, with few connections between them. The benefits of urbanization would be squandered as cities failed to develop integrated labor markets and prosperity failed to spread. To put it another way, this research could be interpreted as a call for the reinvigorating of basic spatial planning, at a massive scale, appropriate to the challenge of rapid urbanization.

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