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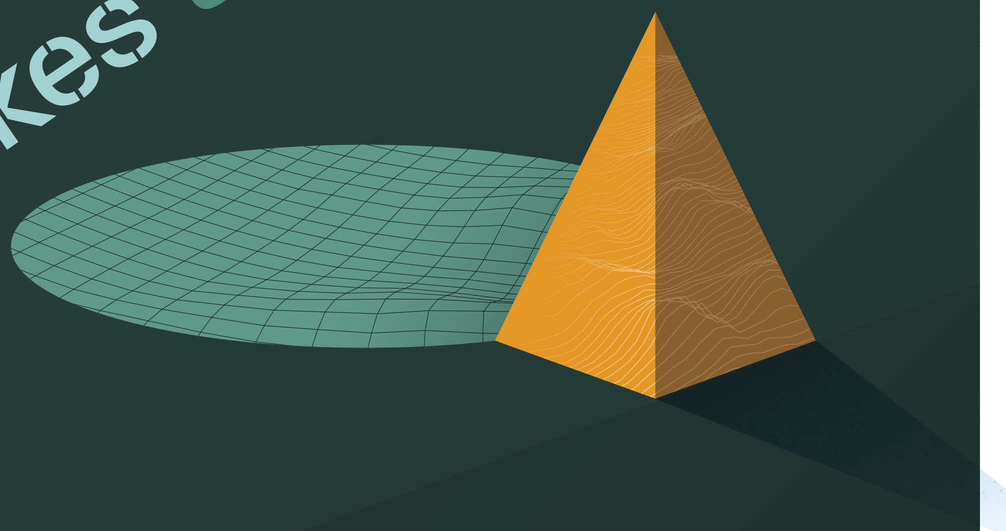
Pancakes to Pyramids



City Form to Promote Sustainable Growth

Somik Lall, Mathilde Lebrand,
Hogeun Park, Daniel Sturm
and Anthony Venables

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Foreword

What drives the shape of cities, and what actions can policy makers take to guide their growth?

The authors of *Pancakes to Pyramids* set out to find out. I am pleased to say that they have succeeded in increasing our understanding of the economic variables that drive urban expansion, while challenging conventional wisdom about sprawl. Most importantly, they have opened up a field of inquiry that will be central to the World Bank's mission of poverty reduction and sustainable and inclusive development in the years ahead as leaders strive to create green, resilient, and inclusive cities that attract people and businesses.

As low- and middle-income countries urbanize in the decades ahead, this report provides new evidence for city leaders interested in managing spatial growth. It also provides a theoretical model to test assumptions about compactness and public transport that will be crucial to rein in commuting time, fuel use, and greenhouse gas emissions.

Drawing on ground-breaking data covering almost 10,000 cities between 1990 through 2015, this report shows a dynamic two-way relationship between a city's economy and the height of its buildings. The extent to which firms benefit from concentrating their workers in one place is one of the factors that determines how compact a city is likely to be. Other factors include the total size of a city, the ease with which people can move around the city, and the ability of developers to build tall—an ability that may encounter regulatory, technical, or financial constraints.

Building tall is not a matter of creating a distinctive skyline with notable skyscrapers. Much more than a vanity project, enabling the construction of taller buildings—say, 5 to 10 stories high—is a matter of livability; vertical layering creates enough floor space to accommodate growing populations without packing people into smaller and smaller spaces. It's the difference between crowding versus livable density, slums and sweatshops versus more humane housing and office conditions.

The Covid-19 pandemic has highlighted the life-and-death implications of crowded neighborhoods that are ill equipped to curb the spread of disease. As countries slowly extricate themselves from the pandemic, planning for a better urban future requires understanding the forces that have shaped the cities we inhabit today.

My hope is that this report helps to start a conversation about urban growth and policy choices at all country income levels, to afford people everywhere the opportunity to live in decent housing, apply for competitive jobs, access affordable services, and thrive.

Juergen Voegele
Vice President
Sustainable Development Practice Group
World Bank

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Acknowledgments

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The report draws on three background papers:

> ***The Evolution of City Form:*** Evidence from Satellite Data. World Bank Policy Research Working Paper 9618. Somik Lall, Mathilde Lebrand, and Maria Edisa Soppelsa.
>
> ***Exploring the Urban Model:*** Employment, Housing, and Infrastructure. Daniel M. Sturm, Kohei Takeda, and Anthony J. Venables.
>
> ***Applying the Quantitative Urban Model to Cities in Developing Countries.*** Daniel M. Sturm, Kohei Takeda, and Anthony J. Venables.

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Abbreviations

AMM	Alonso-Muth-Mills model
BRT	Bus rapid transit
CBD	Central business district
CEPAC	Certificate of Potential Additional Construction
CCFLA	Cities Climate Finance Leadership Alliance
CIESIN	Center for International Earth Science Information Network
DLR	German Aerospace Center
DP	Displaced person
EAP	East Asia and Pacific
FAR	Floor-area ratio
FUA	Functional urban area
GHS-BUILT	Global Human Settlement Built-up Area Grid (dataset)
GHS-UCDB	Global Human Settlement Urban Center Database (dataset)
GDP	Gross domestic product
GGMCF	Global Gridded Model of Carbon Footprints (dataset)
GHG	Greenhouse gas
GLTN	Global Land Tool Network
GPR	Gross plot ratio
GUF	Global Urban Footprint (dataset)
JRC	European Commission Joint Research Centre
KRIHS	Korea Research Institute for Human Settlements
LVC	Land value capture
MENA	Middle East and North Africa
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
N-sector	Non-tradable sector
OECD	Organisation for Economic Co-operation and Development
PPP	Public–private partnership
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
TDR	Transferable development rights
T-sector	Tradable sector
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-Habitat	United Nations Human Settlement Programme
WSF-3D	World Settlement Footprint 3D (dataset)
WUP	World Urbanization Prospects

Why this report?

Policy makers have often misjudged the potency of market forces. Many policy makers perceive cities as constructs of the state—to be managed and manipulated to serve some social objective. In reality, cities and towns, just like firms and farms, are creatures of the market.

WORLD DEVELOPMENT REPORT 2009: RESHAPING ECONOMIC GEOGRAPHY

Towns and cities are economic and social microcosms in which large numbers of people and firms interact. These interactions largely shape how a city looks, how it functions, and how it grows. But how exactly does this many-sided relationship work? What are the specific drivers of urban economic and spatial development?

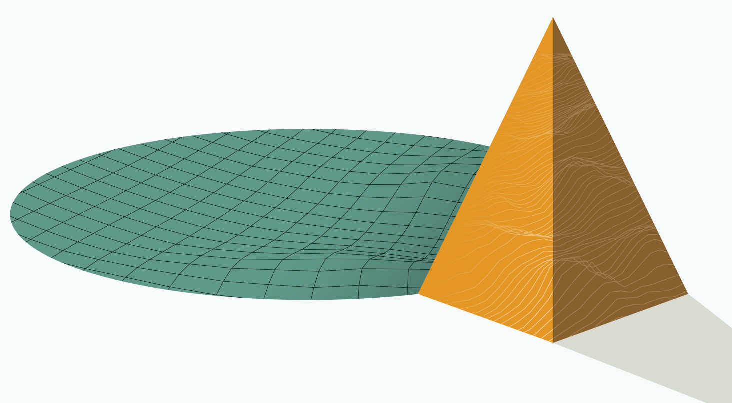
Pancakes to Pyramids brings us closer to answering these questions, beginning with an idealized contrast between two patterns of urban spatial growth. Pancakes are cities that grow outward and remain relatively low-built. Pyramids are cities that grow partly outward, but also partly inward and upward, filling vacant parcels and adding height to central districts to increase economic and residential densities. Both types of density can help cities overcome the challenges that come with population growth, and most urgently, evolving from a pancake into a pyramid, creating a platform with more options for controlling greenhouse gas emissions.

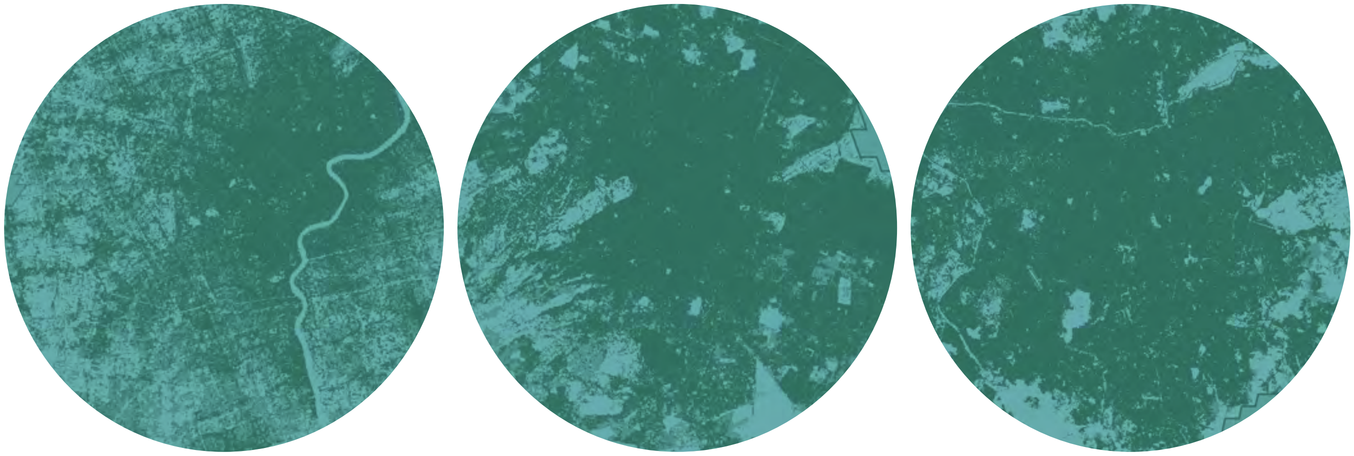
The report draws on new evidence, econometric analysis, and predictive modeling to relate the economic growth of cities to their past spatial evolution—and to the possibility and conditions for future pyramidal growth. Urban spatial expansion is examined across 9,500 cities worldwide, making novel use of satellite imaging data from the Global Human Settlement Urban Centre Database (GHS-UCDB). Econometric analysis is used to distinguish multiple drivers of urban spatial growth. Based on this analysis, a canonical economic model—the new urban model—is described and then applied to counterfactual experiments that predict how cities may evolve under different plans and policy scenarios.

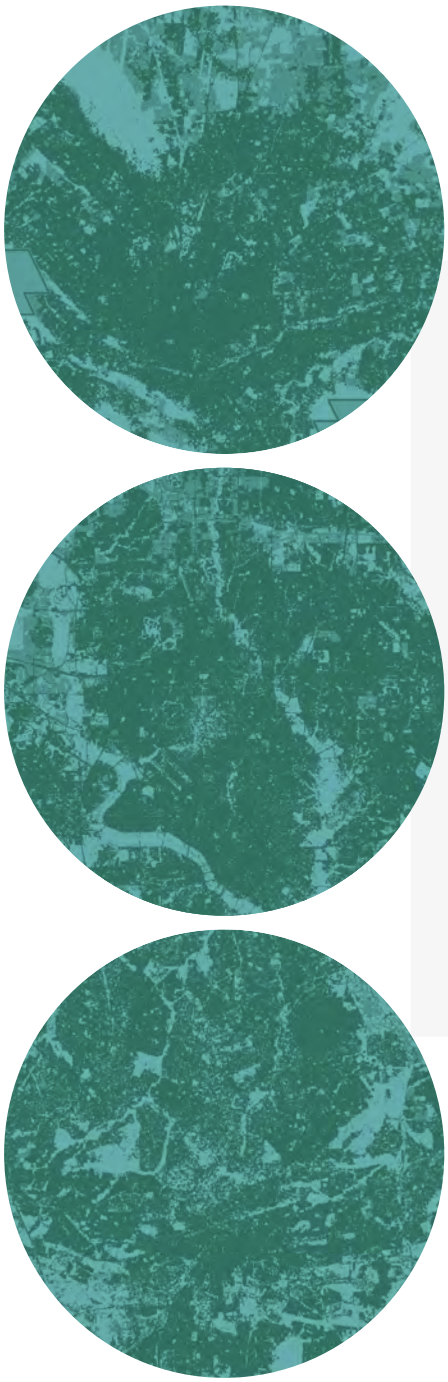
The stakes of these spatial evolutionary processes for today's rapidly growing lower income cities are high. In South Asia, Sub-Saharan Africa, and elsewhere, wherever urban horizontal expansion is not managed well, cities will become unlivable (Ellis and Roberts 2016; Lall et al. 2017). The harmful effects of uncontrolled pancake expansion are overwhelmingly likely to appear in cities that get big while remaining poor. But they can also occur in cities that grow at higher income levels, if the spatial expansion of these cities is unplanned—or if their planners make poorly founded assumptions about how cities grow.

How can today's low- and lower-middle-income cities plan for growth and development tomorrow? What should leaders do now to put these cities on a livable, sustainable path, averting a future of sprawl and smog? *Pancakes to Pyramids* describes how economic and spatial development processes go hand in hand. The dynamics of urban spatial evolution can be complex, but their relation to economic growth and development is increasingly well understood.

City leaders who understand these dynamics are best able to anticipate future needs—choosing the right urban plans, policies, and investments, in the near term, that will create enabling conditions for the city's sustainable growth at later development stages.







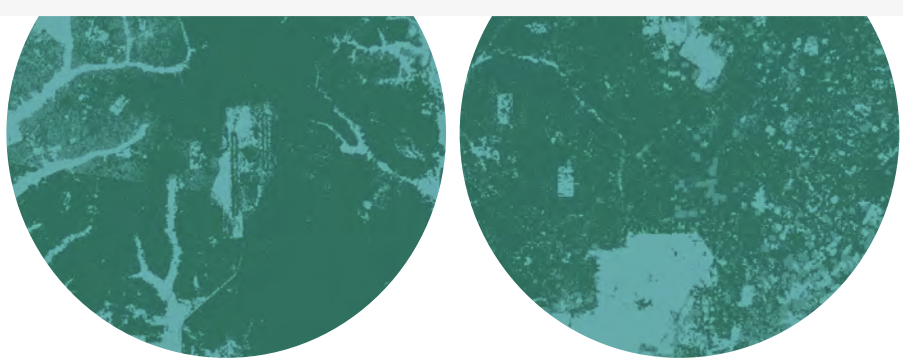
Overview

There is no logic that can be superimposed on the city; people make it, and it is to them, not buildings, that we must fit our plans.

Jane Jacobs 1958

Spatial expansion of cities requires land, but the final product of urbanization is floor space.

Alain Bertaud 2018



Overview

Today more than half the world's population (55 percent) resides in urban areas. Three decades hence, this share will likely surpass two-thirds (68 percent by 2050 in a recent projection; United Nations 2018c). Such rapid growth in cities creates new opportunities—but it is also putting new pressures on cities and countries. Much of the new urbanization will take place in Sub-Saharan African and South Asian countries with low incomes and weak institutional and fiscal capabilities. By one estimate of the Organisation for Economic Co-operation and Development, growth and development globally will require infrastructure investments of $6.3 trillion a year over 2016–30 (OECD 2017).

How will city leaders and national governments keep up with urbanization, enabling cities to adapt and thrive—sustainably—as their populations continue to grow rapidly? Recent approaches to this question in urban development policy have tended to focus on urban density as key to livability and efficient resource use, inspiring plans that seek to recreate features of downtown districts in rich countries. While Pancakes to Pyramids also looks at density, it does so differently, reframing the question as an empirical one about how cities evolve. The most useful guidance for planners starts not with emulating efficient cities, but with understanding processes that affect all cities due to urban spatial evolution.

What drives changes in a city's shape, in the pattern of its spatial expansion, and in its related distribution of housing and of economic activity? Which economic and institutional forces do most to determine the evolution of urban form and function? How do these various drivers interact? Combining new data with new analysis, Pancakes to Pyramids advances policy makers' insight into these questions—and helps city and country decision makers seek evidence-based, actionable answers to the challenges facing cities now.

The main report consists of four chapters:

- ***Chapter 1*** describes new global evidence—derived from satellite data—for rates and patterns of urban spatial development since 1990. It examines spatial development across 9,500 cities worldwide, using satellite imagery from the Global Human Settlement–Urban Centre Database 2015 (GHS-UCDB). Developed by the European Commission's Joint Research Centre (JRC), the GHS-UCDB estimates city incomes and populations for 1990, 2000, and 2015. To analyze what has changed in a geographical space and to reliably measure how cities have evolved, it uses the urban extent corresponding to the most recent data, those from 2015. A novel feature is the report's definition of cities using the "Degree of Urbanization" approach: a new, consistent basis for international comparisons of urban growth developed by the European Commission and endorsed in March 2020 by the United Nations Statistical Commission. The methodology is explained in chapter 1 and annex 2 of the main report, as well as in Lall, Lebrand, and Soppelsa (2021).

- ***Chapter 2*** combines this global evidence with economic data and econometric analysis to identify the drivers of recent urban spatial growth along three margins: horizontal spread (outward extension), infill development (inward additions in the gaps left between earlier structures), and vertical layering (upward construction). The end product of this growth is floor space, the amount and distribution of which are central to understanding how a city becomes livable and sustainable.

- ***Chapter 3*** provides an analytical framework—based on the analysis in chapter 2—to explain why one city grows differently from another. An important contribution of chapter 3 is to incorporate the vertical structure of cities, a nascent field in urban economics. Most previous urban economics literature on city structure has focused on horizontal development (Ahlfeldt and Barr 2020).

- *Chapter 4* guides leaders in using the analytical framework to assess and quantify the likely impacts of particular plans and policies on urban spatial growth. For example, city leaders can use the framework and its underlying predictive model to better project the impacts of investments such as transport infrastructure and of changes to zoning laws, building codes, and land use regulations on the city's productivity and its future physical form and human geography.

The report thus draws on recent advances in two areas—satellite imagery and urban economics—to give leaders new tools for investigating the combined effects of economic drivers and policy choices on a city's development path. Governing the drivers of urban spatial form and function are complex institutional and decision-making processes that combine with fundamental economic forces to affect the size and shape of a city's built-up area, the heights of its structures, the contours of its skyline, the distribution of its population densities, and its floor space per person. By illuminating how economic productivity shapes location decisions by households and firms over time, and how the quantity and spatial distribution of urban floor space respond to these changes in demand, *Pancakes to Pyramids* can help decision makers identify the planning and regulatory approaches most likely to promote prosperity and sustainability. As countries and cities grapple with the challenges brought about by Covid-19, the fundamental forces shaping urbanization are likely to be central for a resilient recovery (box 1).

Box 1 Will the Covid-19 pandemic reshape urbanization?

There is much current discussion about how the Covid-19 pandemic will affect the future shape of cities. Although it is impossible to say with certainty what the lasting impacts of Covid-19 will be on urbanization, a number of reasons suggest that the long-run impact may not be very large. Historically, outbreaks of the plague often killed large shares of the urban population, but the terrible death tolls did little to stop the continuous march toward urbanization.

Four reasons suggest why the impact of Covid-19 on modern cities might be largely temporary. First, only a relatively small share of jobs can be done from home. Dingel and Neiman (2020) estimate that about 37 percent of jobs in the United States can be done from home, and a substantially lower share, estimated at less than 10 percent, in less developed countries (Gottlieb et al. 2021). Second, although many jobs can in principle be performed from home, face-to-face interactions in an office are likely to offer substantial productivity benefits, as argued by Storper and Venables (2004).

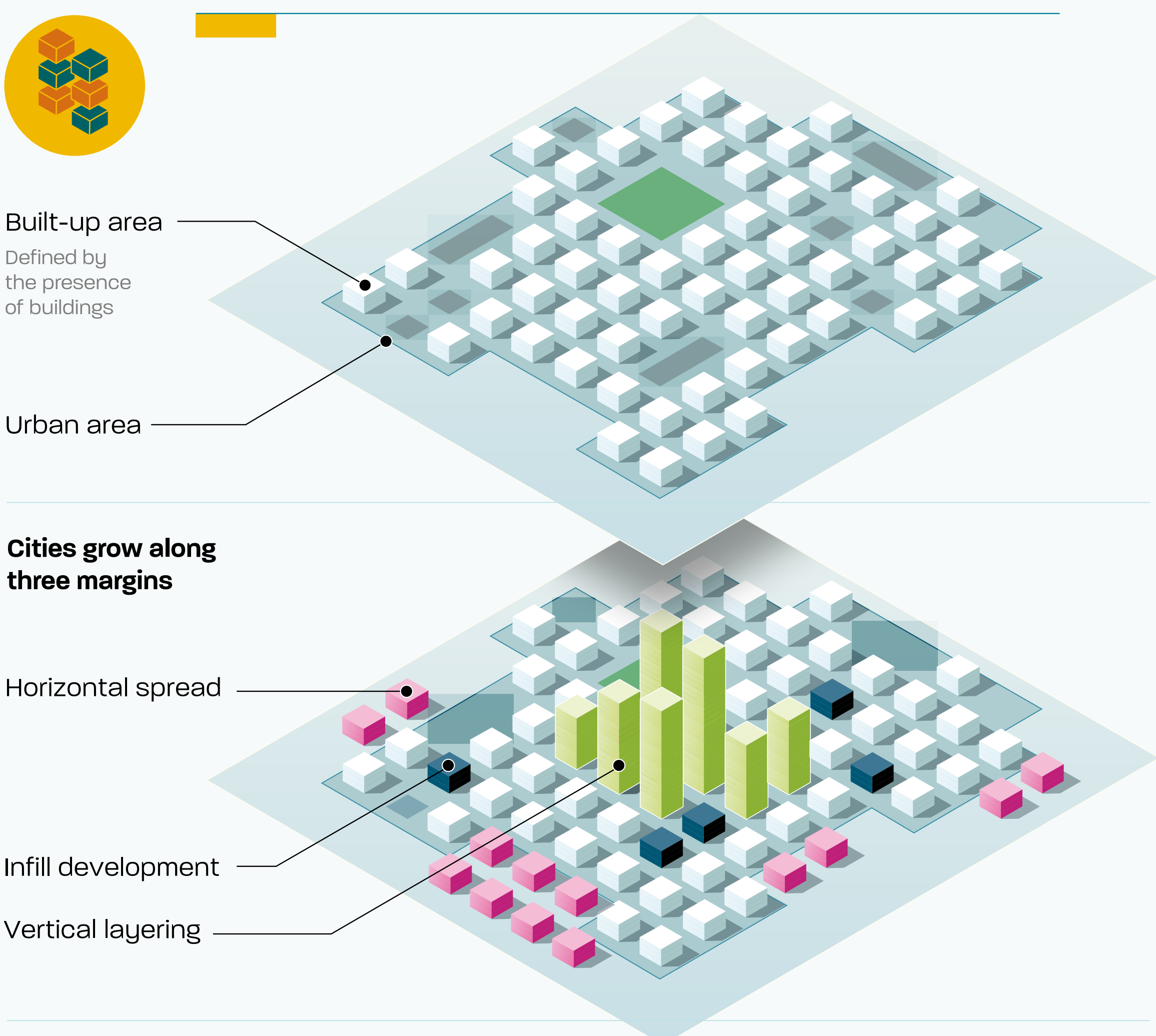
Third, cities are places not just to work but also to consume. To consume urban amenities such as restaurants, theaters, or museums requires travel, which advantages central locations in cities. The analysis in this report shows that such consumption access can generate concentrations of service sector jobs in central locations, even without agglomeration forces in the production of tradable goods (chapter 3). Fourth, in a world of hybrid working—with some days in the office and some at home—long commutes from the fringes of cities to well-paying jobs in urban centers could actually become more attractive rather than less.

Pancakes to pyramids: Physical manifestations of city development

Cities are economic and social microcosms in which thousands—or millions—of people and firms interact. These interactions shape a city's growth along three margins (figure 1):

- Horizontal spread—extending beyond the city's previously built-up area.
- Infill development—closing gaps between existing structures.
- Vertical layering—raising the skyline of the existing built-up area.

Figure 1 The growth of a city along three margins—horizontal spread, infill development, and vertical layering



Source: Authors' depiction.

As cities grow in productivity and in population, they add floor space by expanding outward, inward, upward, or—more usually—along all three margins to varying degrees. The report uses the terms pancakes and pyramids as shorthand for two broadly different tendencies in the physical manifestation of city growth:

- ***Cities with low productivity and income levels generally grow as pancakes***—flat and spreading slowly.[1] Low economic demand for land and floor space keeps land prices low and structures close to the ground, especially at the urban edge. Given slow expansion, growth in population density is often accommodated by crowding, starkly visible in the slums of developing country cities.

- ***Cities with higher productivity may evolve from pancakes into pyramids***—their horizontal expansion persists, yet it is accompanied by infill development and vertical layering. A rising demand for floor space in economically productive cities (especially near downtown centers), combined with a related rise in housing investment and consumption, leads developers to fill vacant or underused land at and within the city edge with new structures. These pockets of close-in land become dense with office and residential space. The same demand for floor space drives expansion not just horizontally in two dimensions, but also in the third—the vertical. Structures are built taller on average, and at the urban core, they are built much taller, forming sharply peaked skylines.

While pancake expansion and pyramidal expansion are physical manifestations of city development, the drivers of that development are largely economic and institutional. What decides whether a pancake city evolves into a pyramid?

Much of the answer—though not all—lies in economic growth, productivity, and trade. A pancake city's chance for pyramidal expansion hinges on its success at nurturing highly productive economic activities that benefit from urban scale and agglomeration potential. These activities are likely to be in tradable sectors: concentrating in cities, firms produce goods and services to supply to buyers outside the city and possibly internationally.[2]

The other piece of the answer is found in laws, institutions, and capacity. Pyramids are more likely to evolve in countries and municipalities where property rights are clear, land values are transparent, land use and zoning are compatible with local preferences, and the enabling environment encourages durable investment in infrastructure—especially early investment, informed by forward-thinking urban plans.

A canonical framework developed for this report (Sturm, Takeda, and Venables 2021a) outlines the key institutional and economic drivers:

- ***Economic structure***—the extent to which tradable sector firms can benefit from agglomeration economies.

- ***Population size***—the ability of larger cities to have higher productivity, because agglomeration economies reflect scale along with density. Large urban populations also create opportunities for scale economies in providing network infrastructure and local public goods.

1 Pancakes typically range from 4 to 10 inches in diameter and are 1/3 inch thick (https://en.wikipedia.org/wiki/Pancake). They don't hold well if they are made any larger. Also known traditionally in the United States as griddle cakes, pancakes are found under different monikers around the world: injira (Ethiopia), lahoh (Somalia and Yemen), crepe (Belgium, France), blini (Russia), dosa (India), panekuk (Indonesia), tiganites (Greece).

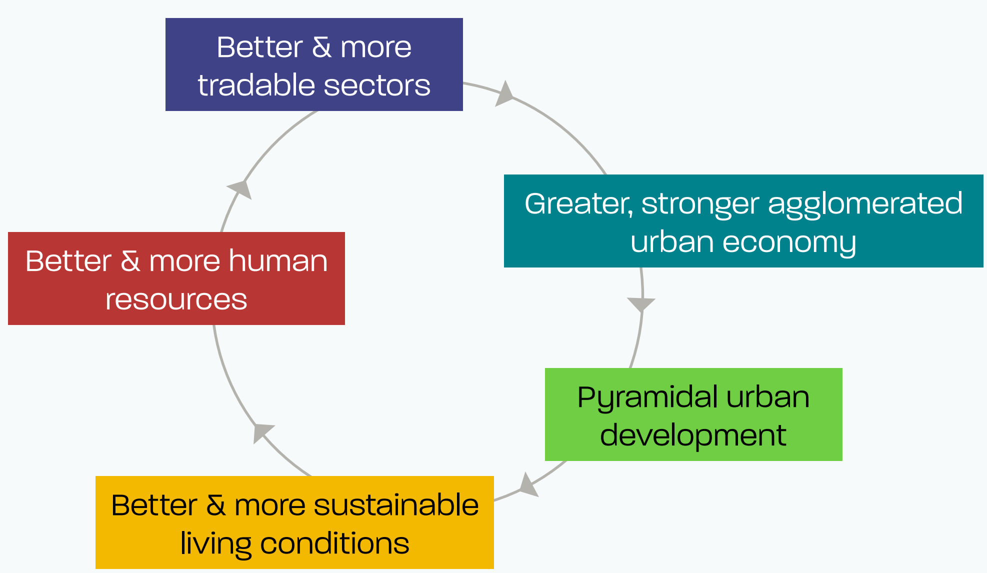
2 A tradable sector supplies goods and services that are exported to other regions or countries. These include manufacturing and various services, from business, legal, and financial services to media and education.

- ***Ability of developers to build tall***—an ability that may encounter regulatory, technical, or financial constraints. It requires:
    - Institutions, governance, and urban plans and policies. A city's shape reflects the institutional structure of the land market, building and land use regulations, taxes, and the investment in and placement of public assets—in particular, the transportation network. These factors—grounded in law, governance, and policy—are explored in some of the experiments conducted for this report.
    - Building technologies—innovations that make increases in building height less costly.
- ***Transport and mobility***—the ease with which people can move around the city, including but not limited to public transport investments (such as metro rail systems).

While pyramidal development with peaked skylines may be the outcome of strong agglomeration forces and complementary institutions, steepening a city's skyline should not be the focus of policy, nor the key metric by which urban success is judged. Improving living standards and sustainability should be.

Urban economic development and spatial transformation form a virtuous cycle that enhances livability and promotes sustainability. Pyramidal growth is preferable to pancake growth because pyramidal growth keeps this virtuous cycle going (figure 2).

Figure 2 The virtuous cycle of urban economic development and spatial transformation



Source: Authors' depiction.

Sustainable densities

Density can help cities become productive, livable, and sustainable, though it does not inherently make them so. Population density alone does not guarantee that a city will realize its potential for economic efficiency and productivity. And not all densely settled neighborhoods provide residents with decent housing and amenities—or with affordable transport options to connect workers to job opportunities.

Urban plans and policies thus do not just seek high residential density, or a large number of residents per unit of land area. Rather, planners seek density of a particular kind: that which promotes productivity and livability, along with sustainability. Higher densities contribute to productivity if they make it easier for households—as consumers and as workers—to connect with firms that serve and employ them. Higher densities also contribute to livability when they enhance sociability and access to amenities. Finally, higher densities promote sustainability if they enable urban residents to use resources less intensively, especially by reducing carbon emissions.

Residential density in cities can take two forms. One less livable form of density is *crowding*—people are packed into small amounts of floor space per person. The other, more livable form is *vertical layering*, as defined above—elevating a city's skyline with upper stories that amply accommodate large numbers of residents and firms, while leaving room among buildings for green space. The contrast appears in figure 3, which juxtaposes Dharavi, a slum neighborhood of Mumbai, with midtown Manhattan, New York. Both have similar density—around 60,000 people per km²—but midtown Manhattan has about 8 times more floor space per person than Dharavi.

Figure 3 Two forms of urban residential density: Crowding in Dharavi, tall buildings in Manhattan

Dharavi, Mumbai
Average household income
Approximately $ 812
62,000 people per km²
Total floor space 96,000 m²

Midtown East, New York
Median household income
$ 137,130
58,000 people per km²
Total floor space 760,000 m²

Source: Upper image from A. Savin (https://w.wiki/p3), distributed under a copyleft license; lower image from Google, "Streetview," digital images, Google Maps (http://maps.google.com), photograph of 18 Sutton Place South, New York, taken May 2019. Total floor space was calculated by authors based on WSF-3D data.

Note: The total floor space numbers refer to the floor space built on the inset square section of 90,000 m² (300 m x 300 m).

Each form of residential density—crowding and vertical layering—comes at a cost:

- Crowding is common where cities are growing at low incomes, as most are now doing in Africa and South Asia. In the average Sub-Saharan African city, 60 percent of the population lives in slums—a much larger share than the 34 percent average in cities around the world (Lall, Henderson, and Venables 2017; United Nations 2015)—and the lack of residential floor space takes a severe toll on livability.
- Vertical layering, while creating more floor space per unit of land area and thus allowing more livable densities, is more expensive than single-story construction. Because building tall requires better technology, it depends on larger capital investments by land developers, who require an expectation of high returns. Such expectations depend on prior public investments in transport infrastructure and public services, as well as on the economic outlook and business environment.

The trade-off for crowded cities and reduced floor space is thus its cost in quality of life. The trade-off for vertical layering and increased floor space is the quantity of private and public capital that is needed to build tall, and that will not be present unless the city's productivity and institutional capacity are sufficient to create an enabling business environment. Only cities that attract and nurture highly productive firms—firms that benefit from agglomeration economies—are able to attract the private capital needed for vertical layering and pyramidal growth.

Pyramid cities, if managed well, can provide not only the residential density but also the financial means and the political will to support sustainable urban development. The economic density and productivity of pyramids can generate enough capital for expensive public and private investments in shifts to low carbon technology. Although the built environment of cities today often favors a preference for car ownership, it does not need to: providing lower-emission transport options can shape mobility preferences (Mattauch, Hepburn, and Stern 2018; Weinberger and Goetzke 2010). Furthermore, the dense social and economic interactions that occur in cities can amplify an emergent cultural preference for sustainability, supporting and complementing institutional transitions to less carbon-intensive development (Nyborg et al. 2016).

While rising productivity and incomes are thus the necessary foundations of pyramids—thriving, livable cities that achieve density through vertical layering and increased floor space—the benefits of pyramidal growth extend to an enhanced potential for city life that respects planetary boundaries. Dense connections among people, in cities that abound in both economic and social capital, can accelerate a "social tipping" toward sustainability values and commitments, as neighbors and peers mutually reinforce each other's awareness of climate change and the need to step up both privately and publicly. Vertical layering and infill development, like retrofitting, can make cities more energy efficient and reduce overall resource consumption. And, over time, the freedom of pyramidal cities to preserve green space even as densities rise, and to promote walking and biking as primary urban travel modalities, will reduce total greenhouse gas emissions while adding to livability. Where economic density and population density allow, investing in public space, sidewalks, and bicycle lanes (as opposed to car roads and parking lots or structures) is a comparatively efficient use of public funds, at a time when municipal revenues are under severe pressure from the economic impacts of the Covid-19 crisis and its aftermath.

Five stylized facts

If agglomeration dynamics are not present, cities normally will not evolve from pancakes into pyramids, because their lower incomes and productivity will keep them flat. The best-laid urban plans, the most thoughtful zoning and height regulations, even costly investments in mass transit: none of these will create livable, sustainable densities without well-functioning markets, economic growth, and increasing demand for floor space near the urban core. To this extent, economy is destiny.

Yet economic density, rising productivity, and rising incomes are not sufficient. Without appropriate and early infrastructure investments, enabled by institutional capacity and leadership, poor pancake cities can grow richer and yet remain pancakes. Moreover, even cities that become pyramids will never entirely escape the economic drivers of horizontal spread. Rich cities continue to grow out at the edges. How far a city shifts toward pyramidal expansion as it becomes richer is a relative question: the answer is dictated by circumstances, some historical or accidental, others a result of planning and coordination.

From this report's new empirical and analytic work on the drivers of urban spatial evolution, five stylized facts emerge:

1. *The growth of urban built-up area worldwide is not as large as conventional wisdom suggests.*
2. *In developing country cities, spatial expansion is happening mostly through horizontal spread.*
3. *Increasing incomes are the one indispensable driver of vertical layering, because building tall is capital intensive.*
4. *Dysfunctional urban land markets, along with zoning and restrictive building regulations, are factors that can militate against taller structures, economic density, and pyramidal growth.*
5. *Improved transport technology enables economic concentration in urban cores, supports cities' economic and spatial growth, and increases the demand for livable residential floor space.*

STYLIZED FACT 1 *The growth of urban built-up area worldwide is not as large as conventional wisdom suggests*

Over the quarter century between 1990 and 2015, the urban built-up area worldwide grew by 30 percent—or 66,000 km^2, the size of the island nation of Sri Lanka—through both horizontal spread and infill. In developing countries, total urban built-up area increased by 34 percent.[3] Significant, to be sure. But not quite the explosive and rapacious expansion estimated in many recent studies. For example, the *Atlas of Urban Expansion* (Angel et al. 2016) argued that in this period the total area of cities in less developed countries grew by a factor of 3.5. The authors added that if this (overstated) rate were to continue through 2050, the total territory occupied by cities globally would be large enough to cover all of India.

Globally, between 1990 and 2015, an outsized share of total urban built-up area growth was concentrated in high-income and upper-middle-income countries. In 1990, cities in high-income countries accounted for 48 percent of global urban built-up area. These same rich country cities then contributed 29.5 percent of the world's growth in built-up area. More striking is the rapid expansion of urban built-up area in upper-middle-income countries: these countries contained one-third of the world's urban built-up area in 1990, but they contributed 44 percent of its expansion between 1990 and 2015.

3 Forecasts by Jones et al. (forthcoming), prepared for the European Commission using the Degree of Urbanization approach, predict that total urban land area will grow 29 percent between 2015 and 2050—in line with the spatial growth rates we measure here for 1990–2015.

STYLIZED FACT 2 *In developing country cities, spatial expansion is happening mostly through horizontal spread*

Built-up area can grow at a city's extensive margins as the city expands outward through what this report calls horizontal spread. But built-up area can also expand inside the margins through what economists call "intensive margin development"—here termed infill development.

While most cities grow through a combination of horizontal spread and infill, the relative prominence of each type of expansion changes with successive stages of economic development. It also reflects changes in construction technologies, preferences, and local government priorities. Cities in poorer countries tend to expand more horizontally than cities in rich countries—an indication that rich country cities increase their total urban floor space through vertical layering, as well as along the other two margins.

In low-income and lower-middle-income countries, 90 percent of urban built-up area expansion occurs as horizontal spread. Nevertheless, there is a silver lining: in high-income and upper-middle-income country cities, a larger share of new built-up area is provided through infill development. For example, a city in a high-income country that increases its built-up area by 100 m^2 will add about 35 m^2 through infill development and 65 m^2 through horizontal spread. But a similar city in a low-income country will add about 90 m^2 through horizontal spread and only 10 m^2 from infill. These findings are consistent with our intuition that agglomeration economies, incomes, and supply capabilities all improve with a country's transition to upper-middle-income status.

STYLIZED FACT 3 *Increasing incomes are the one indispensable driver of vertical layering, because building tall is capital intensive*

A city that grows in population, but not productivity and incomes, will not generate enough economic demand for new floor space for its spatial expansion to keep pace with population growth. For example, if population grows by 100 percent but incomes stay constant, the city's total floor space increases by 60 percent. This 60 percent increase is too small to allow a newly doubled population the same amount of floor space per person as before: each inhabitant's residential and work space will shrink, eventually making the city less livable. Our econometric results show that:

- If a city's population doubles but incomes stay constant, the city's floor space per person declines by 40 percent.
- If per capita income doubles but population stays constant, the city's total floor space per person increases by 29 percent.

Increasing incomes are a uniquely necessary condition for a rise in floor space per person through vertical layering and pyramidal growth: the reason is that building tall is capital intensive. Whether developers are putting up high-rise office buildings or substituting formal apartment blocks for informal slum dwellings, the needed investment is one that can be made only with adequate incomes, capital wealth, and financial institutions. Even if the levelized lifetime costs of different building types proved similar—an unlikely assumption—meeting the upfront capital costs of load-bearing structures would still be more feasible in cities with higher incomes and productivity.

Higher incomes further enable vertical layering by reducing the marginal cost of building tall, as opposed to building single-story structures, in cities with sufficient market demand for land and floor space. In a productive urban agglomeration, land is the scarcest of resources, and it becomes still more valuable as it is connected to infrastructure. Any structure built with substantial materials needs sound foundations and installed water, sewerage, and electricity. If the fixed costs of initial investments in land, foundations, and infrastructure account for a large share of a building's overall cost, then adding stories will reduce the unit cost of floor space: building upper stories multiplies floor space by a larger factor than it increases overall costs.

Vertical layering and infill development slow horizontal spread, but they do not stop it. Even as richer and more productive cities add floor space by reaching upward, they continue to expand outward. Workers are more likely in rich cities than in poor cities to live in a less residentially dense suburb while commuting to an economically dense center. Pyramid cities thus require economic growth, not only to supply the capital needed for vertical layering, but also to fund local coffers and make the large public transport investments that support concentrated hubs of economic activity and longer residence–workplace commutes.

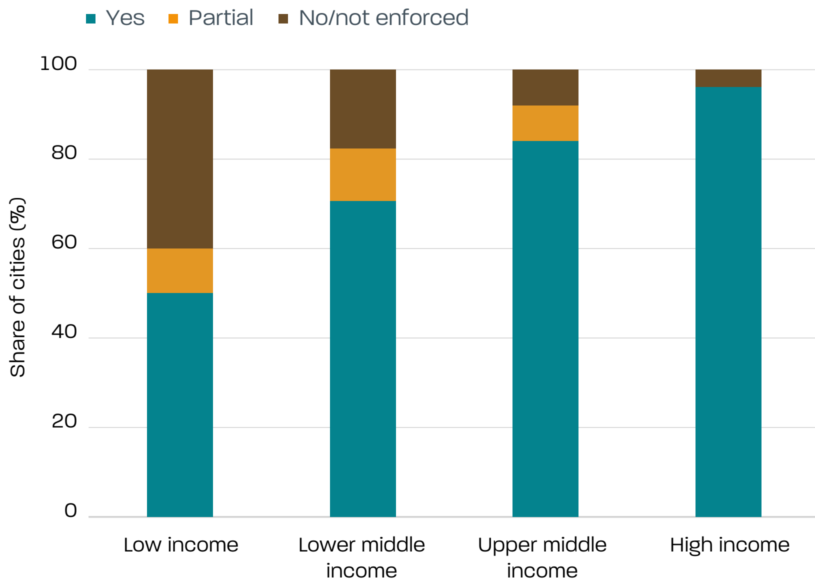
STYLIZED FACT 4 ***Dysfunctional urban land markets, along with zoning and restrictive building regulations, are factors that can militate against taller structures, economic density, and pyramidal growth***

While low incomes may constrain the ability to develop urban land, they are not the only such constraint: a city's spatial evolution can also reflect numerous impediments related to policies and weak institutions. Formal institutions for titling and for property transfer tend to function more smoothly and predictably in countries with higher levels of human capital and government effectiveness (La Porta et al. 1999; Glaeser et al. 2004). In developing country cities, a lack of legal clarity in land tenure often deters investors from sinking capital into formal structures and contributes to the persistence of slum areas. Many of these cities struggle with overlapping and sometimes conflicting property rights systems—formal, customary, and informal—that together pose barriers to urban land access, to plot consolidation, and to evolution in land use. Developers cannot readily buy downtown land, whether to convert it from low-density habitation to higher-density apartments or to build new commercial structures in economically dense clusters. Formal land transactions are long, costly, and complicated (World Bank 2015c). These land market constraints reduce the collateral value of structures and give developers little incentive to build tall, while they also tempt all parties to do business informally (Lall, Henderson, and Venables 2017).

Land management is essential, especially for emerging and lower income cities: their potential for future pyramidal growth hinges largely on their ability to plan for productive economic agglomerations at early development stages, both at the city's edge and in areas of new expansion. Building regulations, such as floor-area restrictions, can be economically counterproductive by limiting density (residential and commercial) and by lengthening commutes. Zoning restrictions can be damaging if they lock in patterns of land use that become inefficient as a city develops. Appropriate zoning, however, can reduce negative externalities that affect households and can encourage commercial concentrations that promote positive spillovers and externalities among firms.

In developing-country cities, current urban plans and planning institutions are often ineffective—neither coordinating market-driven investment in structures nor managing the spatial form of cities for efficiency, livability, and sustainability (figure 4). One challenge is the inappropriate adoption of building codes and planning models through inheritance from former colonial regimes or importation from richer countries (Goodfellow 2013). Another challenge is that plans lack credible accounts of finance, market dynamics, and distributional impacts. Take minimum lot sizes: though they may be intended as pro-poor land use regulations, in practice they limit households' investment choices. In Brazil, they appear associated with slum formation (Lall, Wang, and Da Mata 2007). Still other challenges arise from capacity and resource constraints.

Figure 4 Weak zoning and land use plans in cities of low- and lower-middle-income countries



Source: Authors' analysis, based on Regulatory Survey data by Angel et al. (2016) retrieved from http://atlasofurbanexpansion.org/.

STYLIZED FACT 5 *Improved transport technology enables economic concentration in urban cores, supports cities' economic and spatial growth, and boosts demand for livable residential floor space*

Many developing country cities today struggle with the high road congestion and commuting costs—in time and money—that result from poor transport infrastructure and limited public transit options. Such congestion impedes the separation of residence from workplace, limiting cities' spatial expansion along with their economic growth and productivity. According to the 2019 Tom-tom Index, the most extreme urban congestion occurs largely in developing countries: those countries represented on the list of the world's 10 most congested cities, including Colōmbia, India, Peru, and the Philippines. Transportation in such cities is often informal and chaotic. Few have been able to afford large mass transit interventions.

Past transport technologies have shaped cities' economic and spatial growth. For example, in London in the 19th century, the revolution in steam railways slashed travel times and allowed the first large-scale separation of workplace from residence—promoting economic density in the center and supporting the city's spatial expansion (Heblich, Redding, and Sturm 2020). Later, the mass production of cars dramatically reshaped urban density and living space. Future investments in transport policies and infrastructure will similarly affect a city's ability to grow, lower its pollution levels, and reduce its carbon footprint.

Which transport technologies are best? The answer depends on circumstances. Underground rail (metro or subway) construction is capital intensive, and its success will reflect a city's ability to achieve economic and population density. Recently, bus rapid transit (BRT) systems have rapidly gained prominence as an alternative to subways in developing country cities—yet BRT systems have also encountered challenges. While early transport infrastructure investments can be critical for a city's potential evolution into a dense pyramid, the identification of appropriate modalities and the planning of networks requires extensive and evidence-based study of a city's particular geographic, economic, and social contexts.

Policy implications

Governing both the economic and the institutional drivers of urban spatial form are policies and decision-making processes, which combine with fundamental forces to affect a city's pattern of spatial development—and, in particular, its potential to evolve from earlier pancake growth to later pyramidal growth. Urban plans and policies influence the pace of new construction to meet demand, the height of the resulting structures, the contours of the city's skyline, the clustering of its firms into hubs of productive activity, the pattern of its residential densities, the distance from residences to workplaces, and the extent to which commutes are costly, time consuming, and carbon-intensive. The city's livability and sustainability reflect the effects of policy on land transfer, on the ease of formal development, on patterns of formal and informal settlement, on pollution, on transportation modalities, on the availability of amenities, and on floor space per person.

From the five stylized facts that emerge from this report's analysis, four main policy implications can be drawn—implications that especially concern leaders in developing countries with emerging cities:

First, setting the stage for pyramidal growth requires planning for expansion along all margins—not only the vertical layering and infill development that will be enabled by future productivity, but also the horizontal spread that will occur at the city's edge and that requires urban planning to be strengthened and land to be laid out for development. City leaders need to plan for spatial development along all three margins. The analysis in this report shows that economic drivers induce cities with lower incomes—at earlier stages of economic development—to develop physically as pancakes. As incomes grow, cities start growing horizontally, building low and extending outward. Only at later stages, with higher incomes and productivity, can they hope to evolve into pyramids. The spatial development of cities is thus closely tied to their economic transformation: a city's shape tends to track its per capita GDP, from low- to lower-middle- to upper-middle-income. To enable these transformations, there is urgent need to coordinate land management with infrastructure, natural resources, and hazard risk to reflect market need and societal preferences.

An important consideration is that urban development decisions are long-lived. Because the economic system reorganizes itself around infrastructure and urban plans, and because so much of current growth is in cities, this inertia can extend over centuries. A delay in greening city investments may therefore prove extremely costly if it locks in technologies that turn out to no longer be appropriate (because of their excessive carbon, land, or water intensity) or settlement patterns that prove vulnerable to changing climatic conditions.

Second, city shape is driven by economic fundamentals. The forces that raise pyramids with peaked skylines, signaling high demand for floor space in the central business district, are those of economic agglomeration. They are the same forces that drive tradables production and productive job creation. The hope of "leapfrogging" urban spatial development stages—turning pancakes into economically dense pyramids despite weak demand for downtown space, and in the context of factor markets that are currently inefficient or sluggish—is likely quixotic.

Third, allow for redevelopment in the future. As cities develop economically, their management and financing capabilities improve. Regulations need to be adaptable to changing demand and supply conditions, anticipating the emergence of new uses for scarce urban land. When Seoul changed its density regulations to increase development potential and density inside its greenbelt, the change spurred a sharp rise in redevelopment and revitalized the city (figure 5). Also important here is to conserve irreplaceable cultural and natural amenities—these have not only intangible permanent value, but also a unique potential to create economic value and attract investment at later stages of urban development and neighborhood regeneration (box 2).

Fourth, Infrastructure matters. A principal factor in setting a city's growth path is its plan for networked infrastructure, including roads and transit arteries between the center and periphery. Some capital investments are best to plan for—or even finance and execute—in the earlier spatial development stages, when cities stand to benefit disproportionately over the life of the investment. If a smaller, low-income city spreads quickly into a larger pancake with no effective plan, its opportunities to reap future returns from large infrastructure investments may fade.

Figure 5 Flexible rules enabled Seoul's infill redevelopment

Sejong-Ro, 1962

Sejong-Ro, 2015

Source: Left image from Korea Research Institute for Human Settlements (KRIHS); right image from Seoul Research Data Service, http://data.si.re.kr/seoulphoto.

These policy implications point to three recommendations for city leaders and decision makers.

1. ***Strengthen institutional foundations.*** Although lower-income, less productive cities cannot be molded into pyramids today, decision makers can set the stage for future transformative growth by establishing the right institutional environment. Because economic and physical evolution go hand in hand, cities need integrated legal and regulatory reforms and frameworks that will enable both economic and spatial development. Especially important are steps to strengthen land markets and urban planning institutions.

2. ***Evaluate infrastructure investments.*** To support the market forces that drive urban economic agglomeration, productive job creation, and income growth, governments can give priority to policies and investments that coordinate infrastructure investment with land management under forward-looking plans. In addition, governments can provide public goods and amenities that directly enhance livability. The new urban model used in this report and its annexes (Sturm et al. 2021a) offers city leaders economic intelligence, helping them to assess the likely impacts of large infrastructure investments as well as regulatory approaches. The new urban model also allows leaders to pinpoint challenges and risks that call for careful assessment and management.

Box 2 Cultural and natural amenities are important over the course of a city's growth and development

Cultural and natural amenities make cities vibrant and attractive places, enhancing their quality of life (UNESCO 2016; Tweed and Sutherland 2007). As developing countries face rapid urbanization, they must not assume that growth comes at the cost of these unique assets (World Bank 2012). Far from an inevitable trade-off, cultural and natural amenities make cities and regions competitive and innovative (Alberti and Giusti 2012). Cultural and natural assets also matter for sustainability in urban development, according to the new Habitat III urban agenda (UN 2016).

Caring for cultural and natural amenities thus needs to be complementary to cities' economic development, with a central place in urban plans. Here infill development and redevelopment are especially relevant. To balance cultural and natural conservation with urban economic development, instruments include (World Bank 2012):

- *Heritage investment.* In Ireland, Dublin's Talent Hub leverages cultural assets to promote knowledge industries. By undertaking major urban regeneration and historic preservation projects in central Dublin over the past 30 years, the government helped the city attract young and creative classes, boosting the local economy.
- *Public–private partnerships (PPPs).* In developing countries, the public sector by itself is likely to lack both the capacity and the funds for urban regeneration projects that preserve cultural and natural assets. Moreover, such projects generally depend on private sector stakeholders—among others—to identify economically viable new uses for existing areas and structures. In Istanbul, Turkey, the Akaretler Row Houses regeneration project used PPPs to engage multiple stakeholders in its strategic plan, formed by government agencies working with private developers.
- *Financing through taxation coupled to incentives.* Emerging cities often lack the infrastructure and public services needed for urban regeneration. The Akaretler Row Houses project used land value capture (LVC) to recover the cost of urban redevelopment in Istanbul. Through LVC, the municipality collected locally generated tax revenue from project areas to fund infrastructure improvements—creating a positive feedback loop. The project succeeded in maintaining sites' cultural values while promoting local businesses and creating employment.

3. ***Mobilize finance for durable urban investment.*** By a conservative estimate, worldwide urban infrastructure financing needs amount to $4.1–4.5 trillion annually (CCFLA 2015). Climate mitigation costs are likely to add another $0.4–1.0 trillion annually—and adaptation costs add a further $120 billion annually, which could become much greater if the average global temperature increases by more than 2°C above preindustrial levels. Pyramidal growth requires intensive investments in both structures and infrastructure. The main difficulty for city leaders is the lumpiness of investment, as the initial capital layout for any large investment—in transport, water provision, solid waste management, or sewage removal and treatment—is likely to far exceed the budget of any city government. Leaders must therefore identify financing solutions that enable the city to anticipate and meet its future needs. City leaders should clarify regulatory frameworks for municipal borrowing, public–private partnerships (PPPs), and land value capture transactions, and they should streamline intergovernmental fiscal and institutional frameworks. In addition, leaders should keep in mind that while cheap financing can raise money for investment, repaying it requires predictable revenue. For this purpose, strong economic fundamentals based on agglomeration economies will be vitally important.

Photo: iStock, Akaretler Row, Istanbul, Turkey

Photo: World Bank/Flickr, Bogotá, Colombia

I

How are cities accommodating families and firms—and how fast is global built-up area expanding?

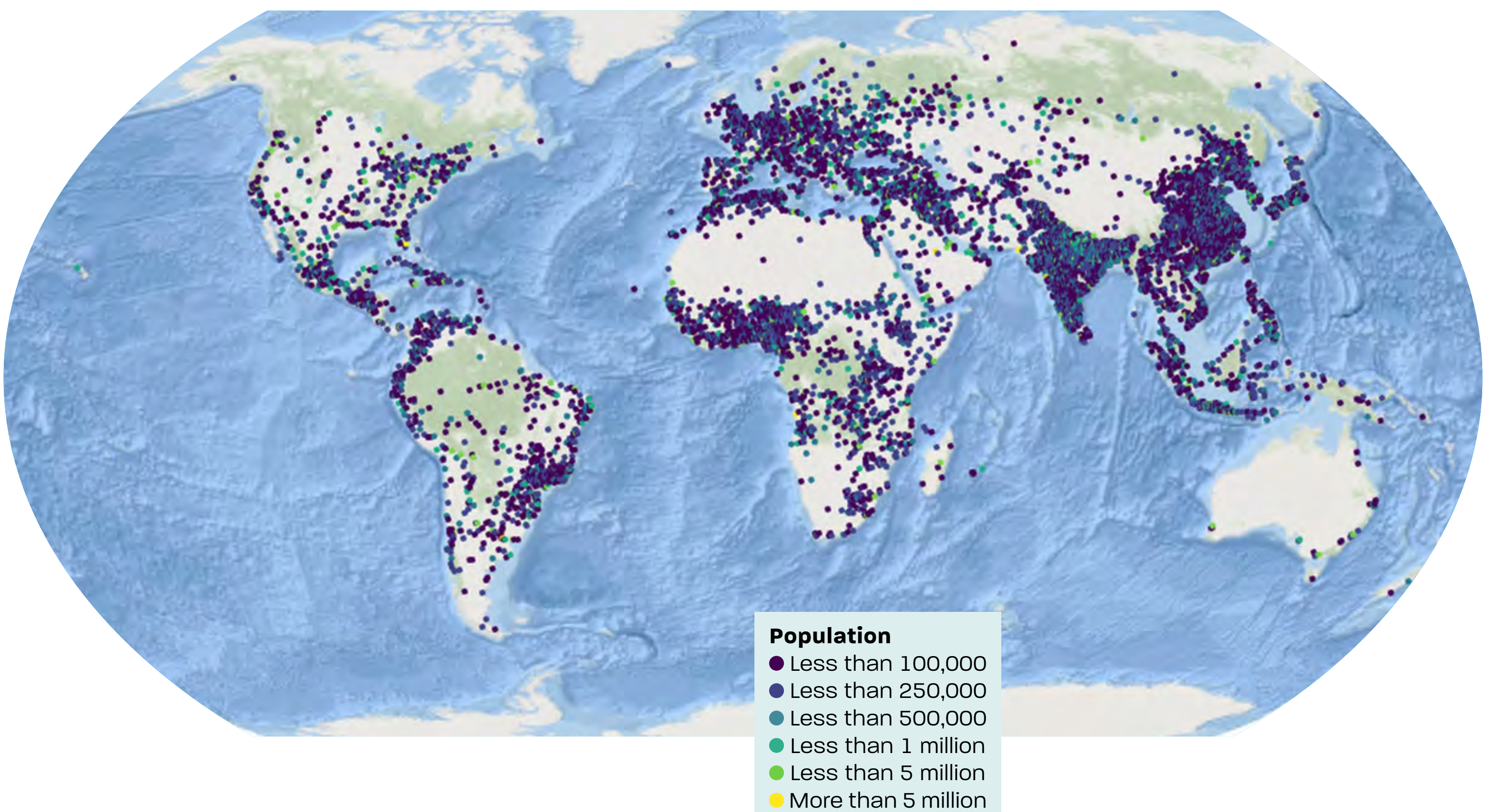
How are cities accommodating families and firms—and how fast is global built-up area expanding?

Chapter 1 provides empirical evidence on the pace and patterns of urban spatial development, drawing on new observational data for city growth worldwide since 1990 (figure 1.1, box 1.1, box 1.2). From these data, new facts emerge on:

- The extent to which growing cities expand their built-up area and their height.
- The implications of this spatial evolution for the amount of floor space available (box 1.3).
- The drivers of changing residential densities over time—both the ratio of population to built-up area, and the ratio of population to floor space.

Beginning with data showing that global urban built-up area has been expanding more slowly than is sometimes claimed, chapter 1 continues with an account of how various income groups, regions, and countries have contributed to this global expansion of cities.

Figure 1.1 Coverage of cities studied in this report



Source: GHS–Urban Centre Database.

Box 1.1 What is a city?

To overcome the vagaries in how countries define towns and cities, this report uses a recently devised methodology—the Degree of Urbanization—which allows for international comparisons of urban growth. Endorsed by the UN Statistical Commission for this purpose, the Degree of Urbanization was developed by the European Commission in collaboration with five international organizations. A strength of this measure is that it can be consistently applied to identify cities and settlements globally (Dijkstra et al. 2020). In contrast, other global urban mapping exercises have limited city samples (for example, Angel et al. 2011). Because the Degree of Urbanization measure is based not only on built-up areas but also on population density, it may be better suited to capture rapidly transitioning areas in developing country cities. Other exercises often fail to identify these transitional areas because, despite a huge population influx, the areas' built environments may remain limited (with relatively low shares of impervious surface).

The report defines an urban center as "a population of at least 50,000 inhabitants in contiguous dense grid cells with population densities greater than 1,500 inhabitants per square kilometer" (Florczyk et al., 2019). Box table 1 reports the distribution of cities across world regions and city sizes.

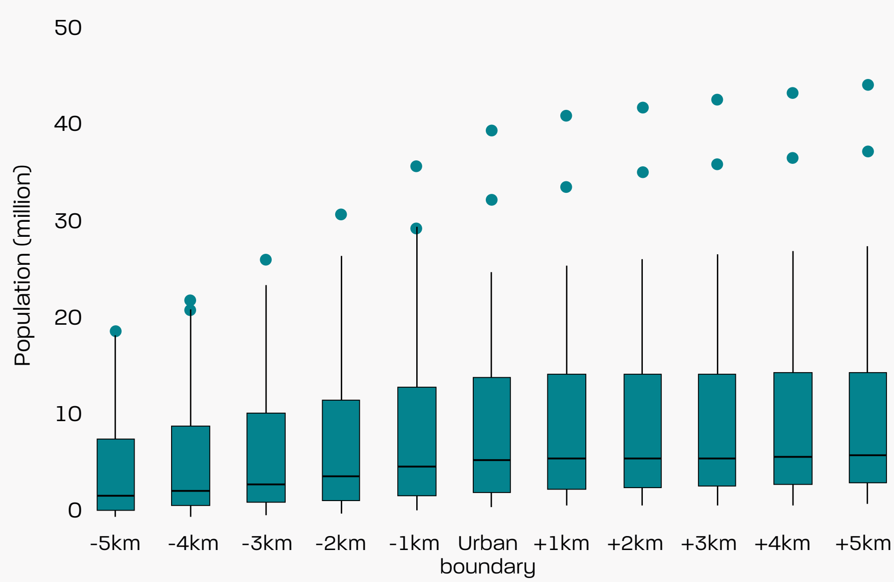
Does the density threshold of 1,500 people per square km underestimate

Box table 1 Distribution of cities analyzed in this report, by city population and region

Region	**Less than 70,000**	**70,000–100,000**	**100,000–200,000**	**200,000–500,000**	**500,000–1 million**	**1 million–10 million**	**More than 10 million**
East Asia & Pacific	612	609	819	476	131	116	11
Europe & Central Asia	345	297	324	225	77	56	2
Latin America & Caribbean	267	228	255	158	60	51	3
Middle East & North Africa	221	137	199	113	43	40	2
North America	77	86	92	60	22	33	2
South Asia	312	362	588	390	122	84	7
Sub-Saharan Africa	300	290	439	217	55	52	1

Source: Authors' analysis, based on GHS–Urban Centre Database.

Box figure 1 Population estimates with additional buffered urban areas are similar to the population within the urban centers boundary



Source: Authors' analysis, based on GHS–Urban Centre Database.

the size of cities? No—this density threshold is robust. Because the arbitrary selection of the density threshold (1,500 people per square km) could introduce bias in estimating the size of cities, two additional correction methods were used to supplement the density threshold and reduce bias: adding pixels with built-up coverage over 50 percent to urban centers, and gap-filling based on neighboring pixels (Dijkstra et al. 2020).

Based on these combined methods, the cities defined by Degree of Urbanization are well aligned (91.9 percent) with nationally defined cities having more than 300,000 population globally (Dijkstra et al. 2020). In a further sensitivity test of different urban boundary sizes, the 50 fastest-growing cities from 1990 to 2015 were selected to assess population variations across different sizes of urban areas. Multiple ring buffers (from –5 km to +5 km from the edge of the urban boundary) were added to the urban boundary.

As shown in box figure 1, except for two outliers—Guangzhou, China and Jakarta, Indonesia—the median values of population estimates with additional buffered urban areas are similar to the population within the urban boundary. For instance, the additional 5 km buffer increases Mexico City's urban area by 74 percent (1,556 square km) while increasing its population by only 3.3 percent, and it increases Los Angeles's urban area by 57 percent (3,205 square km) while increasing its population by only 4.6 percent.

This report also uses data from the German Aerospace Center (DLR) on cities' height based on its World Settlement Footprint 3D product (WSF-3D; see box 1.2). Height data are available for 400 cities—and the sample is chosen to be representative of the Global Human Settlement Layer database, which covers all cities in the world. The data on city heights add to our understanding of complexity and layering in city development. Though these data are not the final word, they are a good step toward understanding urban spatial evolution. Annex 2 provides details on the data and measurement.

Source: Authors.

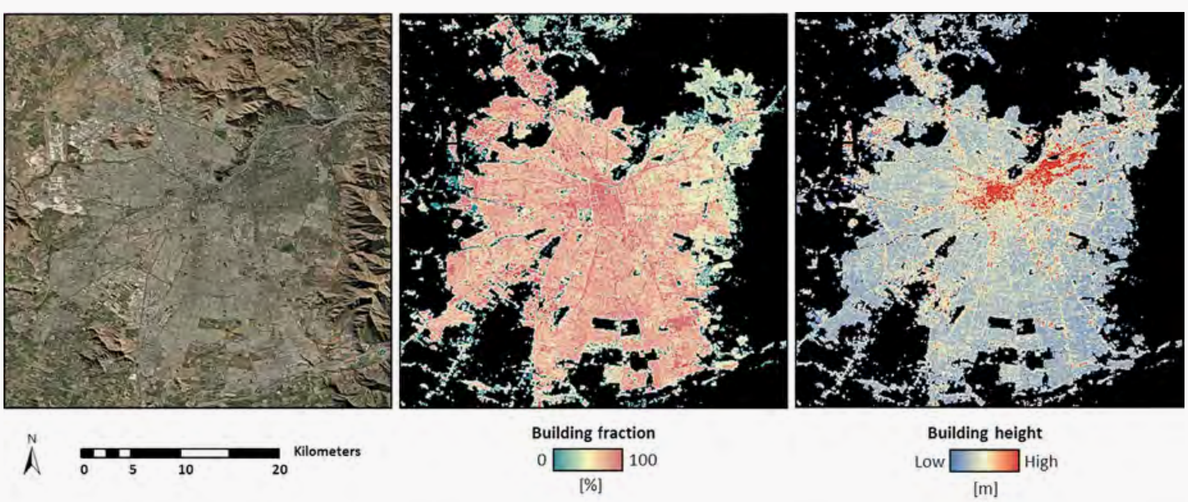
Box 1.2 Height data on cities everywhere: The World Settlement Footprint 3D (WSF-3D)

The World Settlement Footprint 3D (WSF 3D), developed by the German Aerospace Center (DLR), is a three-dimensional model of the built environment worldwide. The WSF 3D estimates building area, height, and density at an aggregated 90 m spatial resolution. It uses extensive machine learning to jointly analyze data of four kinds:

- 12 m digital elevation and radar intensity data from the German TanDEM-X satellite mission.
- 10 m multispectral Sentinel-2 imagery.
- The human settlement mask of the World Settlement Footprint 2015 (WSF 2015).
- Where available, vector data for building location—for example, data from the Open Street Map initiative.

The WSF 2015 and WSF 3D methodologies are described in detail in Marconcini et al. (2020) and Esch et al. (2020, 2021).

For the present study, the 30 m ALOS World 3D elevation model (AW3D30) was used as the standard input to estimate built-up height, because German data distribution regulations (SatDSiG) still require a specific clearance for the use of TanDEM-X height information.



Source: WSF-3D data of "Building Fraction" and "Building Height" derived for the city of Santiago, Chile.

Box 1.3 Seeking livable urban densities around the world: From population density to per capita floor space

A novel feature of *Pancakes to Pyramids* is its use of global data on building heights. These data are produced by German Aerospace Center (DLR), using their World Settlement Footprint 3D product (WSF-3D; see box 1.2).

Why seek to measure and understand cities' height profiles? Because these profiles indicate vertical layering. And layering is key to providing floor space together with urban density—the combination that reshapes pancakes as pyramids, enabling cities to be not only dense with people, but also thriving, livable, and sustainable.

Without accurate estimates of height data, we could not confidently compare floor space across cities. Nor could we track its distribution within the geography of a single city. Following convention, this report defines urban *population density* as the ratio of population to horizontal built-up area—not floor space (which can also be added vertically). But we use this conventional measure of population density advisedly, because density as measured by built-up area does not in itself make cities livable. To get at livability, we add a measure of *per capita floor space.*

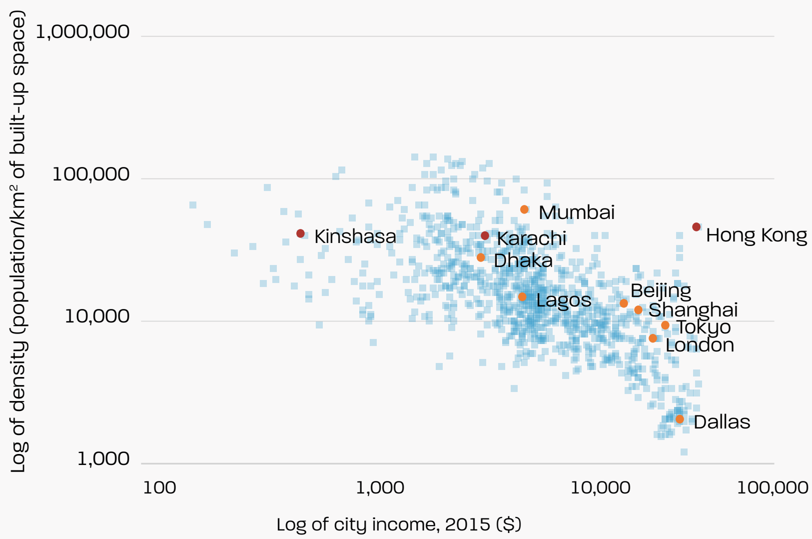
To appreciate the practical difference between measuring a city's population density—relative to built-up area—and its per capita floor space, compare box figures 1 and 2. Each figure plots population per square kilometer on the vertical axis, per capita income on the horizontal axis. But in box figure 1, the unit of urban area used for the vertical axis is built-up area. In box figure 2, it is floor space.

Both figures reveal similar general patterns: cities in richer countries tend to be less dense relative to built-up area, and also to allow more per capita floor space. But in box figure 1, Hong Kong seems at first glance to be an exception to this pattern. Its ratio of population to built-up area resembles that of Kinshasa or Karachi.

The reason for this seeming anomaly in box figure 1 is that Hong Kong's total built-up area is limited by its island geography, pushing its population density—defined as the ratio of people to built-up area—extremely high. More than most high-income cities, Hong Kong has had to build upward and inward rather than outward. And yet, as box figure 2 shows, Hong Kong's per capita floor space is in line with that of a high-income city such as London or Tokyo.

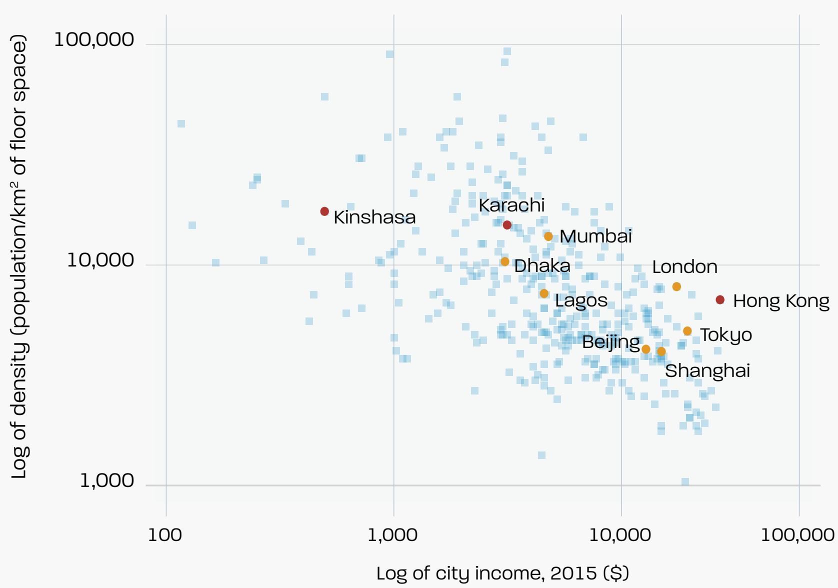
Kinshasa and Karachi lack as much per capita floor space as Hong Kong because their population densities (relative to built-up area) are achieved through crowding—not vertical layering. If it is critical to avoid confusing the economic geography of crowded pancakes like Kinshasa and Karachi with that of an efficient pyramid like Hong Kong, measuring cities' floor space–adjusted density makes more sense. And that can be done only by measuring height.

Box figure 1 Urban population density, 2015



Source: Authors' analysis, based on GHS–Urban Centre Database.

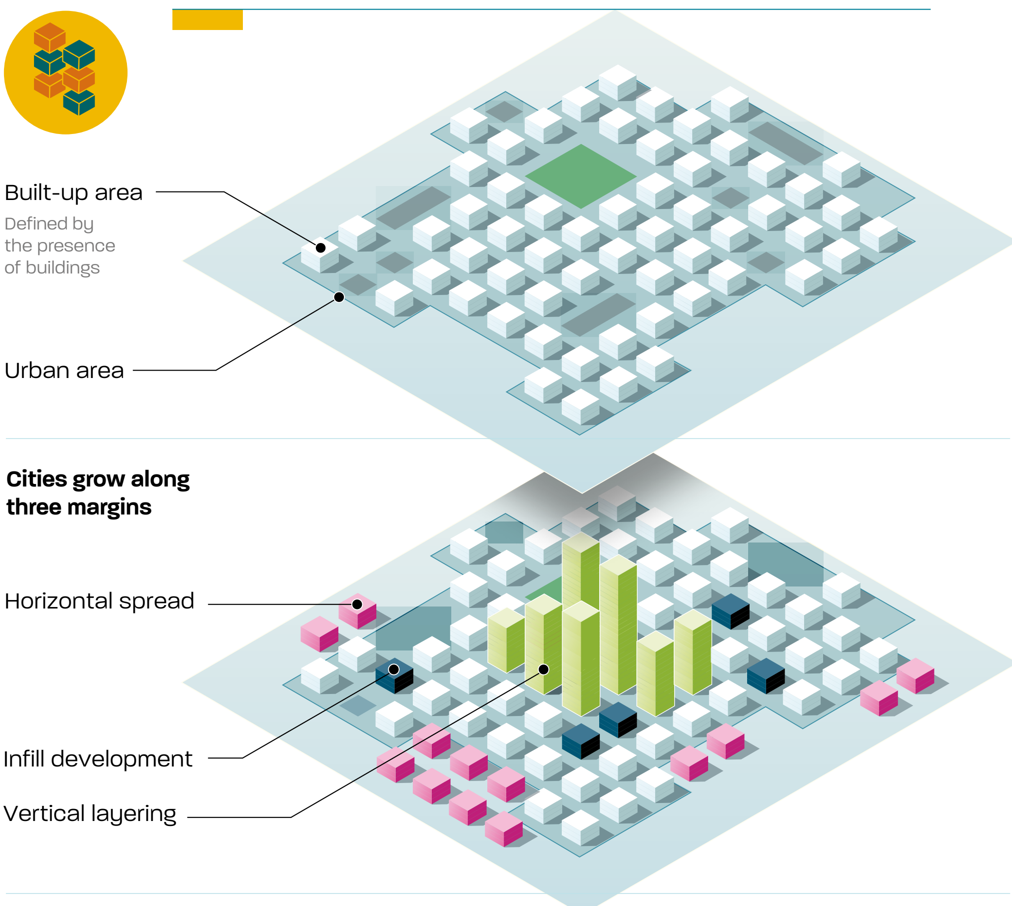
Box figure 2 Floor space–adjusted density, 2015



Source: Authors' analysis, based on WSF-3D data.

Motivating this and the following chapters is a basic contrast between two idealized physical city types resulting from opposed patterns of spatial growth: some cities are *pancakes*, and others are *pyramids*. Generally, cities at low productivity and income levels grow as pancakes: flat and expanding slowly, chiefly through *horizontal spread* (figure 1.2). Low market demand for land and floor space keeps land prices in pancake cities low and keeps structures close to the ground, especially at the city's edge. The slow rate of spatial growth may lead the city to accommodate population growth through crowding—a process starkly visible in the slums of developing country cities.

Figure 1.2 The growth of a city along three margins—horizontal spread, infill development, and vertical layering



Source: Authors' depiction.

In contrast to cities at low levels of productivity, which have no choice but to grow as pancakes, cities that attain higher productivity may evolve from pancakes into pyramids. Their pancake expansion goes on, yet it is accompanied by growth along two other margins: *infill development*, or the filling of vacant and underused land at and within the city edge, and *vertical layering*, or the building of taller structures around centers of economic activity (see figure 1.2). As pancakes turn into pyramids, their skylines grow more sharply peaked—and they accommodate population growth, not by crowding, but by adding total floor space throughout the city and providing ample floor space per person (box 1.4).

While pancake expansion and pyramidal expansion are physical manifestations of city development, the drivers of that development are largely economic and institutional. Later chapters in this report identify and explain these drivers, indicating how they can be used to model and predict the effects of plans and policies on urban spatial growth, density, productivity, livability, and sustainability. The sections in this chapter set the scene by describing key patterns that emerge from the global satellite data.

Box 1.4 The benefits—and costs—of urban density

Economists and planners working on issues of city development often showcase urban population density—that is, a high number of residents per land area unit—and focus on pursuing its advantages. Two compelling cases for urban population density appear in Edward Glaeser's *Triumph of the City* and Serge Salat's *Cities and Forms.* A recent survey of empirical work by Gabriel Ahlfedt and Elisabetta Pietrostefani shows that urban population density is associated with many benefits: doubling urban density is associated with premiums in wages (4 percent), patent activity (19 percent), consumption variety value (12 percent), the preservation of green spaces (23 percent), and the use of non-car transport modes (7 percent), as well as with reductions in average vehicle mileage (–8.5 percent), energy consumption (–7 percent), pollution concentration (–8 percent), crime (–8.5 percent), and unit costs of providing local public services (–14.4 percent) (Ahlfeldt and Pietrostefani 2019).

In developing countries, from India and Vietnam to Brazil and Colombia, larger cities with denser populations mostly have better living standards than smaller and less densely populated ones (Glaeser and Xiong 2017). This is true of certain amenities in rich countries, too. Across lower and higher income countries, both the share of people with access to the Internet and the share with bank accounts are highest in cities and decline at lower densities.

Yet urban population density—considered in itself as the ratio of population to built-up area, without reference to floor space consumption or other measures of livability—can also have large drawbacks. We have seen that a city with a growing population but stagnant incomes will become increasingly crowded, as floor space fails to keep up with population growth. And even as more people compete for the same floor space, land and housing prices go up. Other things, too, become more expensive: with rising population and residential density come rapidly rising urban transport costs. And then there is traffic congestion. Unlike the benefits of density, these costs or "demons of density" (Glaeser 2011) have received comparatively little empirical research attention.

Examining the costs of population density, Duranton and Puga (2020) showed that a typical elasticity of the price of housing at the center of a city with respect to city population is about 0.1. Measuring the elasticity of house prices with respect to density—accomplished simply by conditioning out the city's total land area—results in a figure of 0.3. With housing constituting a third of household expenditure in large cities, the cost of living in a city that is 10 percent denser is about 1 percent higher. But these costs appear to become manageable if cities both expand horizontally and add floor space (Duranton and Puga 2020).

Developing country cities are where the demons of density are most apparent. The relatively flat and crowded centers of these cities often afford only tiny amounts of floor space per person. The dynamics of richer cities are different: vertical layering adds floor space on buildings' upper stories, even as continuing horizontal spread also adds to the average floor space available for each resident.

The lesson is that population density (the ratio of population to built-up area) is not an end in itself—certainly it is not a sufficient measure of either livability or sustainability. Cities should also afford decent quantities of per capita floor space, as well as amenities, efficient transit systems, and controls on harmful externalities of urban growth.

The spread of urban built-up area is slower than has been thought

How are cities evolving in space—horizontally and vertically—around the world? The satellite data show that between 1990 and 2015 the world's total urban built-up area increased by 66,000 square km, or the size of Sri Lanka. Urban built-up area increased from 226,768 square km to 294,550, a growth of 30 percent.

In developing countries, urban built-up area increased over 1990–2015 from 117,977 square km to 166,231. That is a 34 percent rate of built-up expansion, an annual growth of 1.36 percent. This growth is significant, to be sure, but not quite the explosive and rapacious spread estimated by many recent studies. For example, the *Atlas of Urban Expansion* argued that during this period the area occupied by cities in less developed countries increased by a factor of 3.5—and that if this rate were to continue, the total amount of land taken over by urban land use would be equivalent to the entire country of India by 2050 (Angel et al. 2016).

Others have predicted recently that developing countries' urban population will have doubled between 2000 and 2030 and built-up area will have tripled. Urban land cover in Sub-Saharan Africa is expanding at the fastest rate—more than 12-fold, it is said, between 2000 and 2050 (Angel et al. 2016). Again, urban land areas have been projected to expand by 0.6–1.3 million square km between 2015 and 2050, an increase of between 78 and 171 percent over the urban footprint in 2015 (Seto et al. 2014).

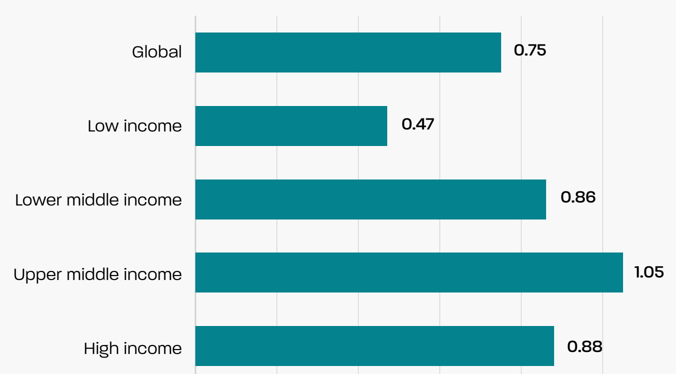
This report employs urban built-up area estimates from satellite imagery at high spatial resolutions to examine urban spatial development (see box 1.1). These granular data suggest that horizontal expansion in growing cities is considerably slower than population increase—a finding with considerable bearing on Sustainable Development Goal 11, "Make cities inclusive, safe, resilient and sustainable" (box 1.5).

Box 1.5 Sustainable Development Goal 11 and urban built-up area expansion

Sustainable Development Goal (SDG) indicator 11.3.1—the sustainable urbanization rate—is defined as the ratio of the land consumption rate to the population growth rate. The SDG tracker reports that data are unavailable for this indicator.[1] Between 1990 and 2015, the global urban population increased by 35 percent, and the developing country urban population increased by 36 percent. In low-income countries, the urban population grew by as much as 72 percent.[2] If we measure the land consumption rate as total built-up area growth, the sustainable urbanization rate can be benchmarked as follows (box figure 1):

- Global: 0.75.[2]
- Low-income countries: 0.47
- Lower-middle-income countries: 0.86
- Upper-middle-incomes countries: 1.05
- High-income countries: 0.88

Box figure 1 Sustainable urbanization rate: Ratio of urban land consumption growth rate to urban population growth rate



Source: Authors' analysis, based on GHS–Urban Centre Database.

Note: Box figure 1 shows that the relative growth of city built-up area—while inherent in early urban development stages—is far slower in low- and lower-middle-income countries than was recently thought.

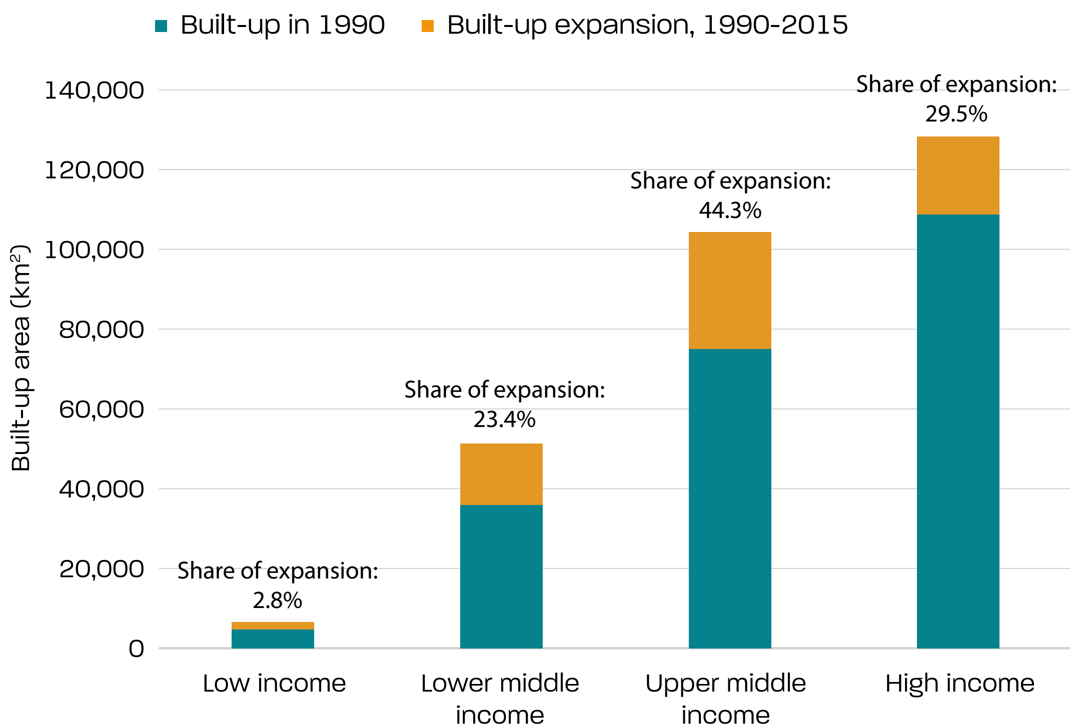
1. https://sdg-tracker.org/.
2. Using the urban centers thresholds described in this report. Total urban population increased from 2.2 billion to 3.1 billion from 1990 to 2015; developing countries' urban population increased from 1.7 billion to 2.5 billion.
3. Urban built-up area increase of 33 percent alongside population growth of 72 percent.

These findings cast doubt on an often repeated account of unfettered urban spatial expansion. They should not come as a surprise, however. Land area is built up mainly for residential, commercial, and industrial structures. The demand for these structures tends to rise only with economic development, and when supported by a conducive policy environment.

Who is contributing the most to urban built-up expansion?

Globally, the expansion of urban built-up area over 1990–2015 was disproportionately concentrated in high-income and upper-middle-income countries. As figure 1.3 shows, in 1990, cities in high-income countries accounted for 48 percent of global urban built-up area (108,726 square km). The same rich country cities contributed 29.5 percent of the world's growth in built-up area between 1990 and 2015.

Figure 1.3 Urban built-up area expansion by national per capita income level, 1990–2015



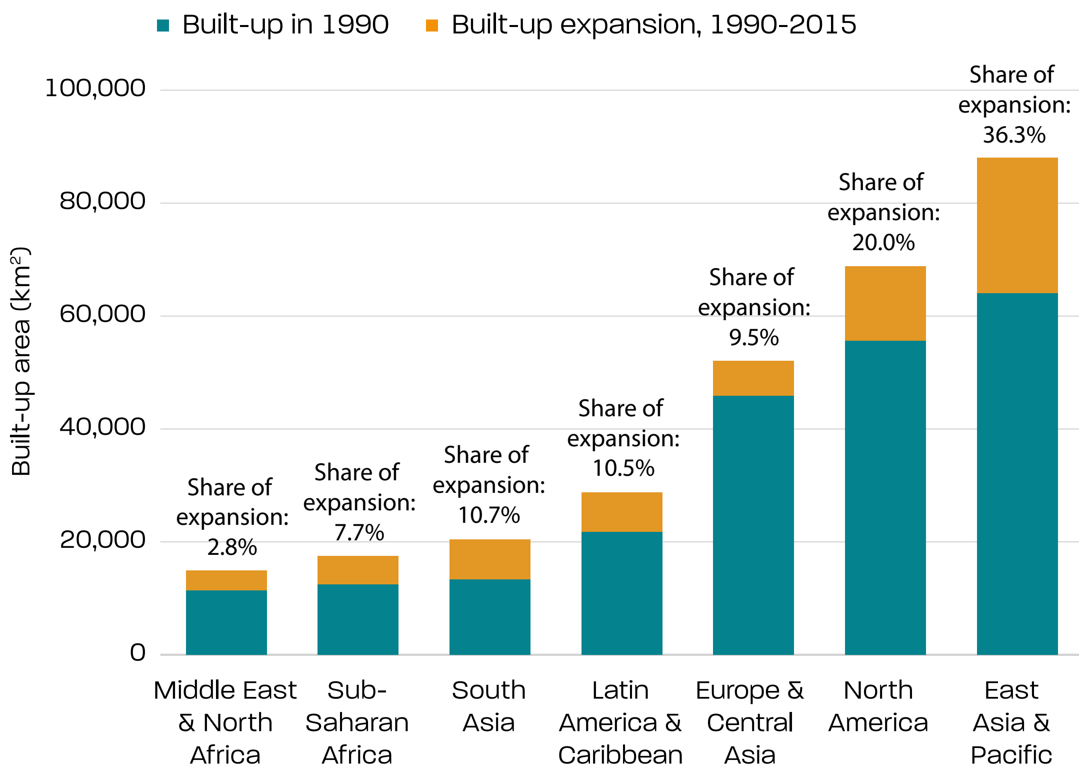
Source: Authors' analysis, based on GHS–Urban Centre Database.

Even more striking in figure 1.3 is the rapid expansion of urban built-up area in upper-middle-income countries. Containing one-third of the world's urban built-up area in 1990, these countries contributed 44 percent to its expansion between 1990 and 2015: their rate of urban built-up expansion was about 1.5 times as high as that of high-income countries.

As is also shown in figure 1.3, lower-middle-income countries contributed 23 percent to urban built-up area expansion over 1990–2015, while low-income countries contributed just 2.8 percent. Nevertheless, the 2.8 percent contribution represents a 32 percent rate of expansion from the low initial amount of urban built-up area in low-income countries.

The distribution of urban built-up area expansion across regions appears in figure 1.4. Over 1990–2015, East Asia and the Pacific (EAP) made a much higher total contribution to urban expansion than any other region. The smallest total contributions were those of Middle East and North Africa (MENA) and Sub-Saharan Africa (SSA). Urban built-up area in EAP grew seven times more than in MENA—and 1.7 times more than in cities in North America.

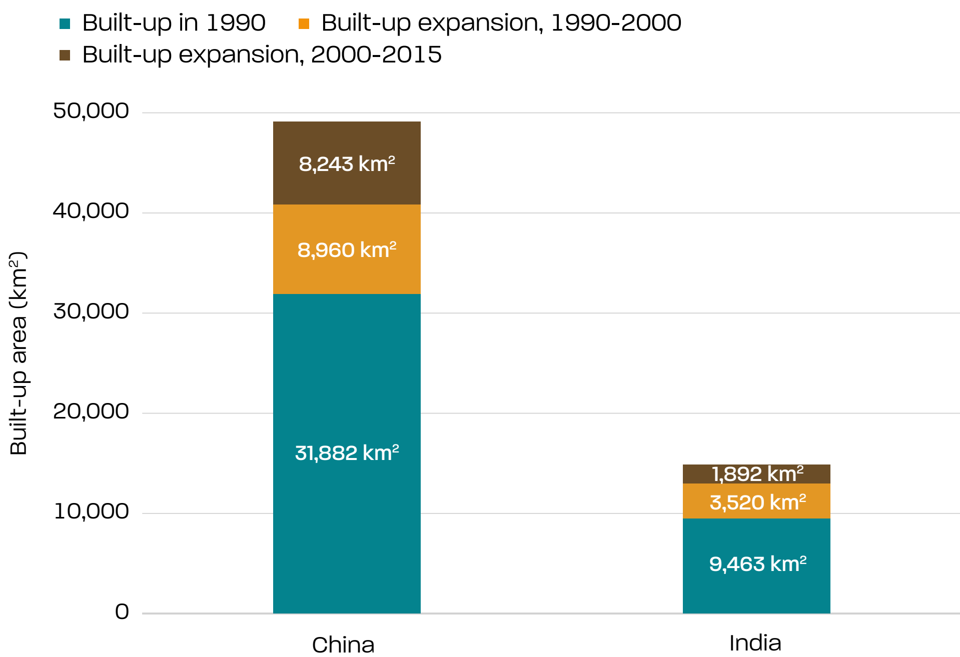
Figure 1.4 Urban built-up area expansion by region, 1990–2015



Source: Authors' analysis, based on GHS–Urban Centre Database.

Two countries, China and India, led globally in expanding urban built-up area over 1990–2015. China alone contributed 60 percent of all urban built-up area expansion by upper-middle-income countries during this period. In absolute terms, China added more than 17,000 square km of such area (figure 1.5). India's urban built-up expansion was also impressive: starting from 9,463 square km in 1990, it had added 5,421 square km by 2015, contributing 8.2 percent of the world's total urban built-up area expansion. While smaller in absolute terms than China's urban expansion, India's was more nearly comparable in its rate of growth: urban built-up area expanded by 45 percent in India over 1990–2015. People and firms in India have been pushed to the outskirts of large metropolitan areas by rising economic demand for cities—following India's economic liberalization in the early 1990—in combination with urban land use regulations and density caps affecting metropolitan cores (World Bank 2013b; Ellis and Roberts 2016).

Figure 1.5 Urban built-up area expansion in China and India, 1990–2015



Source: Authors' analysis, based on GHS–Urban Centre Database.

Photo: Li Yang/Unsplash

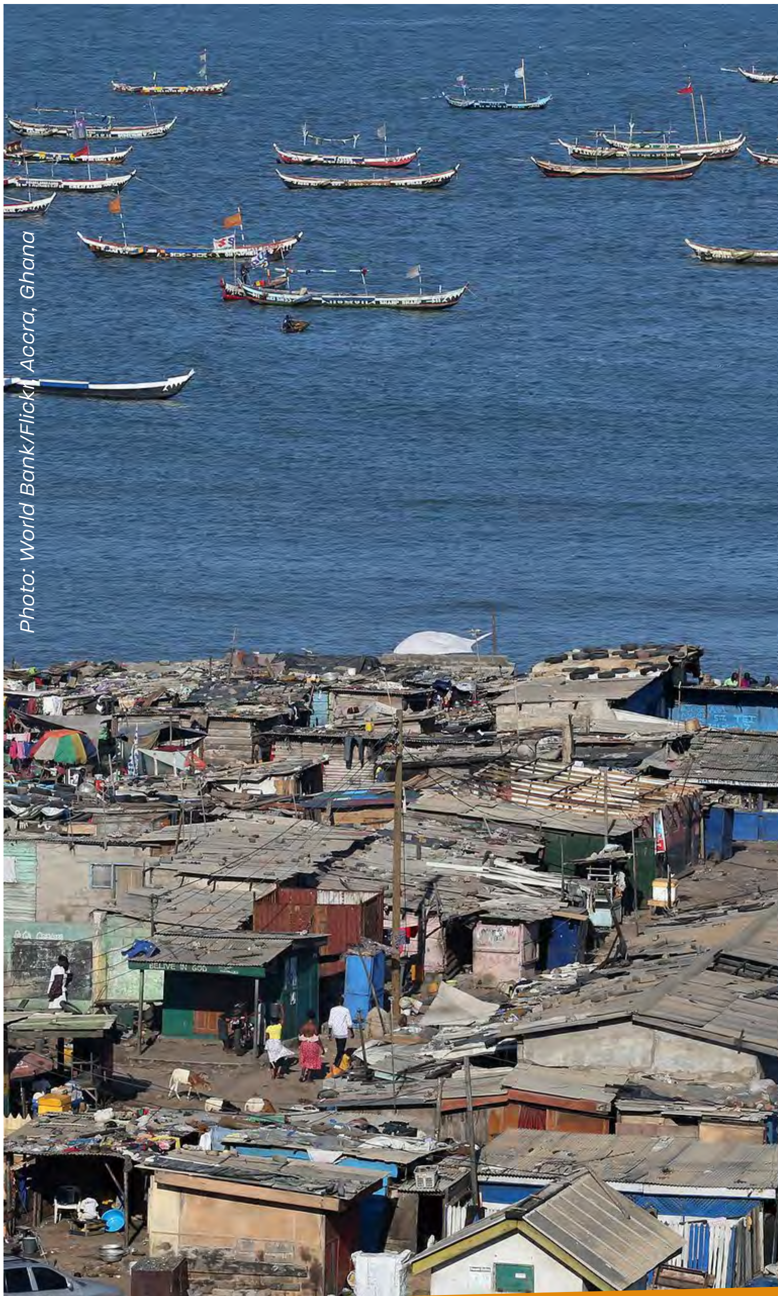


Photo: World Bank/Flickr, Accra, Ghana

Photo: Eart/Unsplash, Paris, France

SPOTLIGHT 1

Stages of urban economic development can be seen in cities' average building heights—and in their skylines

Richer cities are taller. This simple, intuitive truth about the impact of economic development on building height can be broadly confirmed by comparing six cities at different income levels and urban structures. The two poorer cities—Accra (low income) and Lagos (lower middle income)—are built very low on average, with few buildings taller than 10 m, and almost none above 20 m (figures S1.1 and S1.2). These poorer cities also lack central clusters of higher structures to make their hubs visually identifiable. In contrast, the two richer cities—Mexico City (upper middle income) and Paris (high income)—are built at far greater average heights, with cores towering over surrounding areas (figures S1.3 and S1.4).

Figure S1.1 Average building height in Accra (low income)

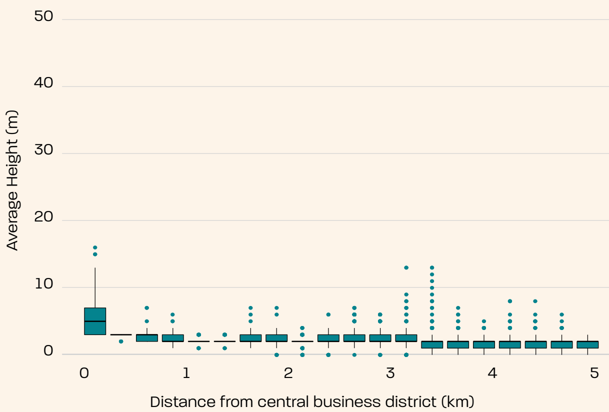


Figure S1.2 Average building height in Lagos (lower middle income)

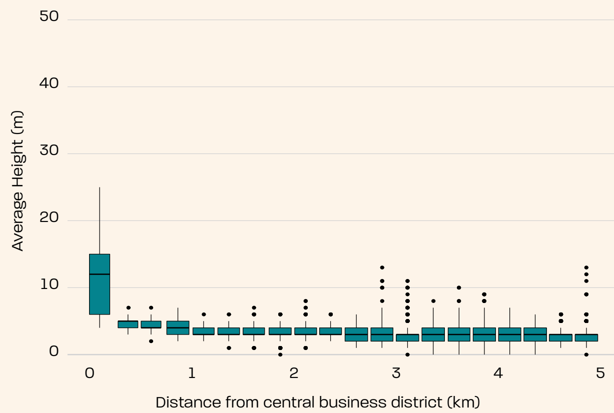


Figure S1.3 Average building height in Mexico City (upper middle income)

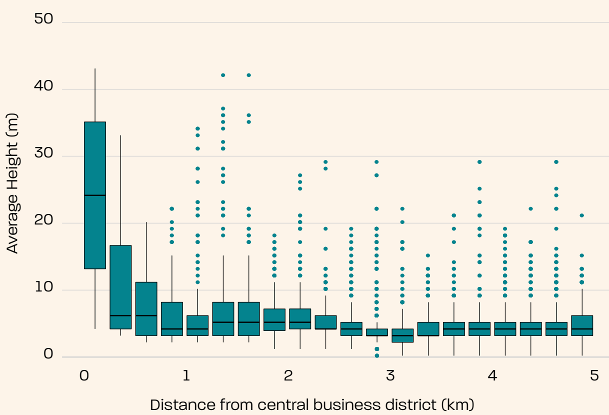
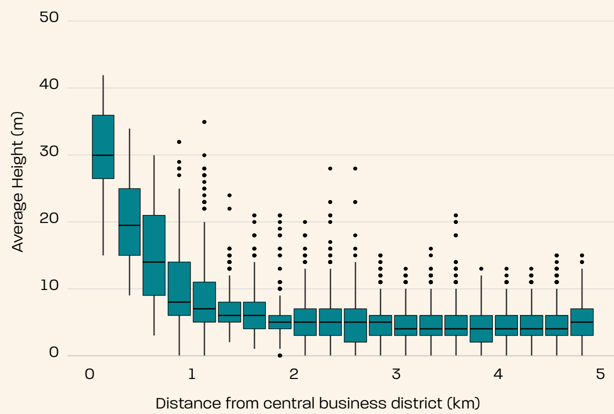


Figure S1.4 Average building height in Paris (high income)

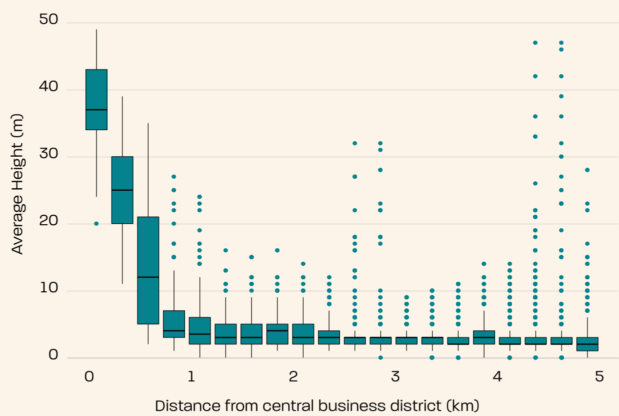


Source: Authors' construction, based on WSF-3D data.

The four cities at different income levels in figures S1.1–S1.4 suggest a general pattern: a pyramidal height distribution sloping down from the city center. While the degree of concentration differs across cities' income and structure, the central area tends to be taller than other areas. Yet this general tendency does not mean that all city centers benefit from economic concentration. In low-income cities with high residential concentrations and lower building height, the more central neighborhoods are likely to feel more crowded—compared with surrounding areas.

Are cities in land-rich countries, such as the United States and Australia, too sprawling to display pyramidal growth? No: the data show that, to some extent, even hugely expansive high-income cities are pyramid cities. In Houston (figure S1.5) and Sydney (figure S1.6), building heights are highest at the center, declining continuously with distance.

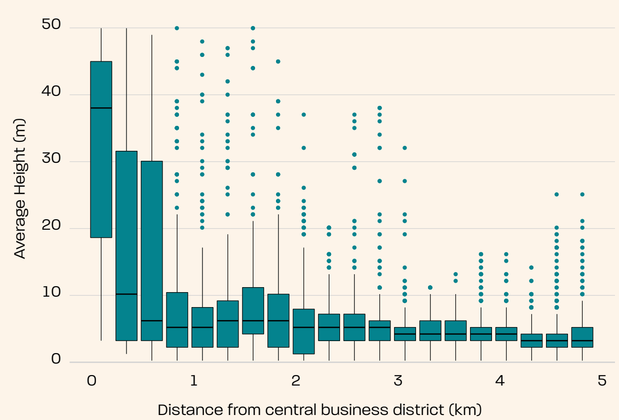
Figure S1.5 Average building height in Houston (high income)



Source: Authors' construction, based on WSF-3D data.

Source: Houston, Texas. March 14, 2018. Image ©2018 Planet Labs, Inc. cc-by-sa 4.0.

Figure S1.6 Average building height in Sydney (high income)



Source: Authors' construction, based on WSF-3D data.

This report also documents a less familiar, perhaps less obvious, fact: richer cities' skylines peak more sharply. In cities in upper-middle- and high-income countries, building heights decline more steeply from the inner urban core (table S1.1). Cities in these higher income countries have more centrally concentrated floor area than those in lower income countries—and the richer city centers stand out more visibly from less central neighborhoods.

Table S1.1 Average building height moving away from the central business district

Average distance (km)	Average building height (m)					
	Accra	*Lagos*	*Mexico City*	*Paris*	*Houston*	*Sydney*
0–1	2.93	4.70	8.74	14.87	13.83	15.51
1–3	2.12	3.26	5.61	5.67	3.69	6.38
3–5	1.82	3.04	4.42	4.59	3.00	3.88

Source: Authors' analysis, based on WSF-3D data..

The pyramidal height distribution patterns seen in satellite data on Houston (see figure S1.5) and Sydney (see figure S1.6) show that even these sprawling cities conform to the general pattern associating higher productivity and income with higher urban structures and steeper skylines. Yet on a closer look, Houston and Sydney may complicate this general picture with their many outlying clusters of taller buildings. These outliers likely reflect edge-city development enabled by networks of infrastructure that encourage agglomerations of tradable sectors along main arteries. What is clear is that, as a general rule, building height is associated with economic activity.

Photo: World Bank/Flickr, Bogotá, Colombia

II

What has driven urban spatial evolution since 1990? The answers are complicated—but incomes are key

What has driven urban spatial evolution since 1990? The answers are complicated—but incomes are key

The econometric analysis in chapter 2 aims to isolate and measure the drivers of urban spatial evolution in its main dimensions, using data on economic and population growth (1990–2015). The analysis yields useful insights into the complex etiology of cities' spatial form. It also informs the analytic framework and predictive application of the new urban model in chapter 3.

How cities grow

How does a city adjust to accommodate increasing numbers of people—other than by simply becoming crowded and congested? Basically, it can accommodate its growing population by expansion along three margins. These margins are:

- ***Horizontal spread.*** At or near the city edge, the city can add land area through extensive growth.
- ***Infill development.*** Inside the city edge, the city can add built cover by filling in green or "brown" land with structures—or (less frequently) it can replace old structures with new ones.
- ***Vertical layering.*** The city can increase its floor-area ratio—available floor space per unit of land area—by building taller structures, thus fitting more total floor space onto the same amount of land.

Each of these three margins reflects a specific combination of demand signals. Generally, if productivity and incomes are sufficient to generate demand for more built-up area, then supply will respond to that demand, driving the city to expand and increase its total floor space. The extent to which this happens in practice will change—as the population grows, and as productivity and incomes rise through successive stages of a city's economic development.

Residential densification, or a rise in population density—defined as a rise in population relative to built-up area—is derived from population growth combined with the three margins: horizontal spread, infill development, and vertical layering. Critically, an increase in population density need not cause a decline in floor space per person. Both may coincide, as when developing country cities accommodate growing populations in crowded neighborhoods and slums (because only limited income is available for housing investment and consumption). But this is not inevitable: as a productive city grows richer, with people and firms generating greater demand for land, housing, and centrally located office space, it can add to its population density while still expanding (or only slightly shrinking) its floor space per person.

How income and population growth drive overall urban built-up expansion

Both a city's population size and its income level drive expansion in its built-up area—but of these two drivers, population is by far the stronger. Specifically:

- ***The elasticity of built-up area to population is 0.35.*** If the city's population increases by 10 percent —while incomes remain constant—its built-up area increases by 3.5 percent. This 3.5 percent figure represents a striking response to population growth.
- ***The elasticity of built-up area to income is 0.1.*** If the city's average annual income (per capita GDP) increases by 10 percent—while population remains constant—its built-up area increases by 1 percent. Rising incomes thus drive expansion, but they do so far more slowly than rising population.

Box 2.1 Econometric issues in estimating the drivers of built-up area expansion

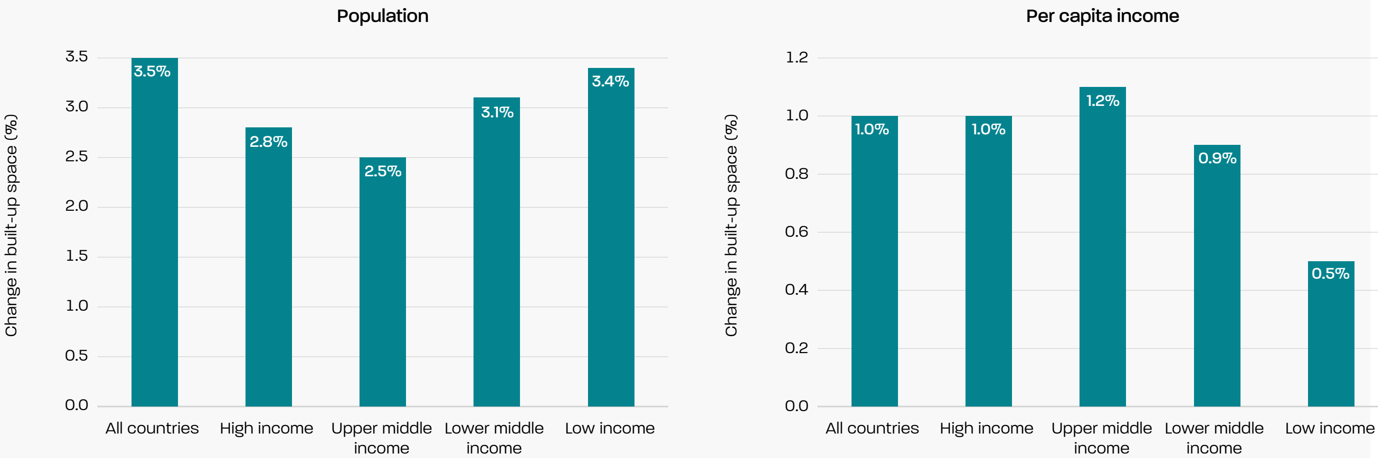
At least two econometric issues arise when estimating the impacts of growing populations and rising incomes on urban built-up area. First is endogeneity: unobserved factors may simultaneously affect both the dependent variable (built-up surface) and the explanatory variables (city population size and annual per capita income). Second is the omission of variables: certain unobserved factors, such as geographic and weather amenities, may independently affect built-up area or even be among its key predictors. In each case, a simple ordinary least squares (OLS) estimator will be biased. The panel regression analysis is based on the following specification:

For city c, at time t,

$$\ln BU_{c,t} = \alpha + \gamma^{bu} \ln Income_{c,t} + \beta^{bu} \ln Pop_{c,t} + FE + \epsilon_{c,t}$$

where BUc,t is built-up area for city c, at time t, and FE city and year fixed-effects. Box figure 1 shows the results for the previous specification for all countries first and then for cities per income group.

Box figure 1 How is a 10 percent increase in population and income associated with built-up expansion?



Source: Econometric analysis by report team; details in Lall, Lebrand, and Soppelsa (2021).

The figure shows the results of the specification using city and year fixed effects, for all countries and by income group. More specifications are reported in Lall, Lebrand, and Soppelsa (2021). A first specification reports the results of the between estimator, which includes year fixed effects and city controls. Year fixed effects control for aggregate changes that have affected all cities at each period. The built-up area of the city in 1975 is added as a control for unobserved variables such as geographic characteristics that are a main determinant of city growth over time. A second specification reports the results for the between and within estimator, adding both year and city fixed effects. The panel data allow for city fixed effects to control for the large heterogeneity of unobserved city characteristics.

Two additional specifications report the results using an instrument strategy for both population and income to correct potential endogeneity issues. The first instrument is the lag of population and income. However, it reduces the sample of observations by a third. The second instrument used for income is the country per capita GDP.

Another specification uses nighttime lights as a proxy for income. A final specification uses functional urban areas (FUAs) to measure urban boundaries. Our preferred specification is given by the between and within estimator, which is reported in the figure. Income and population elasticities can be inferred from the regression results. Estimates are similar when using instrumental variables, nighttime lights, and FUAs. The exception is when we use FUAs for land-rich countries (Australia, Canada, New Zealand, and the United States)—the elasticity of built-up area to population is 0.21, and the elasticity of built-up area to income is 0.38.

In box 2.1, a figure provides income and population elasticities of built-up area expansion using a panel of observations from the Global Human Settlement Urban Centre Database (GHS-UCDB) for 1990, 2000, and 2015.[1] City income and population estimates are also from the GHS-UCDB (similar estimates are obtained when using country income).

Cities grow differently at different stages of economic development. Box figure 1 in box 2.1 reports the results of the elasticities of built-up area to population and incomes at various stages of economic development (as defined by World Bank classifications). These estimates are based on the between and within estimator for city built-up area.

As box figure 1 in box 2.1 shows, as a city's population increases by 10 percent, its built-up area increases by 3.5 percent when keeping income constant and controlling for unobserved city and year characteristics. This number is far lower than previous estimates reported in the literature (Angel et al. 2016). It shows that cities have not expanded their built-up area as much as their population growth may have seemed to suggest. The figure also shows that as a city's per capita income increases by 10 percent, its built-up area increases by 1 percent when keeping population constant and controlling for unobserved city and year characteristics. Higher income increases the demand for residential and commercial space and is associated with a city's growing ability to build higher and acquire more efficient public services, such as subways (metro rail systems).

In poorer countries, population growth is associated with faster built-up area expansion than in richer countries. As the urban population increases by 10 percent, a city's built-up area increases by 3.4 percent in low-income countries. The corresponding figure is 3.1 percent for lower-middle-income countries, 2.5 percent for upper-middle-income countries, and 2.8 percent for high-income countries.[2] In contrast, rising incomes are associated with slower built-up expansion in poorer countries than in richer ones. As income increases by 10 percent, the city's built-up area increases by 0.5 percent in low-income countries, 0.9 percent in lower-middle-income countries, 1.1 percent in upper-middle-income countries, and 1 percent in high-income countries. These results are consistent across cities of different sizes. However, the income elasticity of built-up area is smaller for cities with more than 500,000 persons: for these cities, as income increases by 10 percent, the city's built-up area increases by 0.7 percent.[3]

Cities in poorer countries thus expand more horizontally than cities in richer countries—a finding that suggests richer countries are increasing their total urban floor space through vertical layering, as well as along the other two margins (horizontal expansion and infill development; box 2.2).

1 While built-up area for all cities with more than 50,000 inhabitants globally is available for four years—1975, 1990, 2000, and 2015—the 1975 data are dropped due to measurement concerns. The various Landsat missions used in the GHS-UCDB—Landsat 1–3 for 1975, Landsat 4–5 for 1990, Landsat 7 for 2000, and Landsat 8 for 2015—were designed for compatibility (in spectral bands and wavelength, for example). Still, the 1975 built-up layer may underestimate built-up area, as Landsat 1–3's spatial resolution (60 meters) is coarser than that of Landsat 4–8 (30 meters). Details are in annex 2.

2 There is no contradiction in the fact that the estimated coefficients per income group are all lower than the estimated coefficient when including all cities.

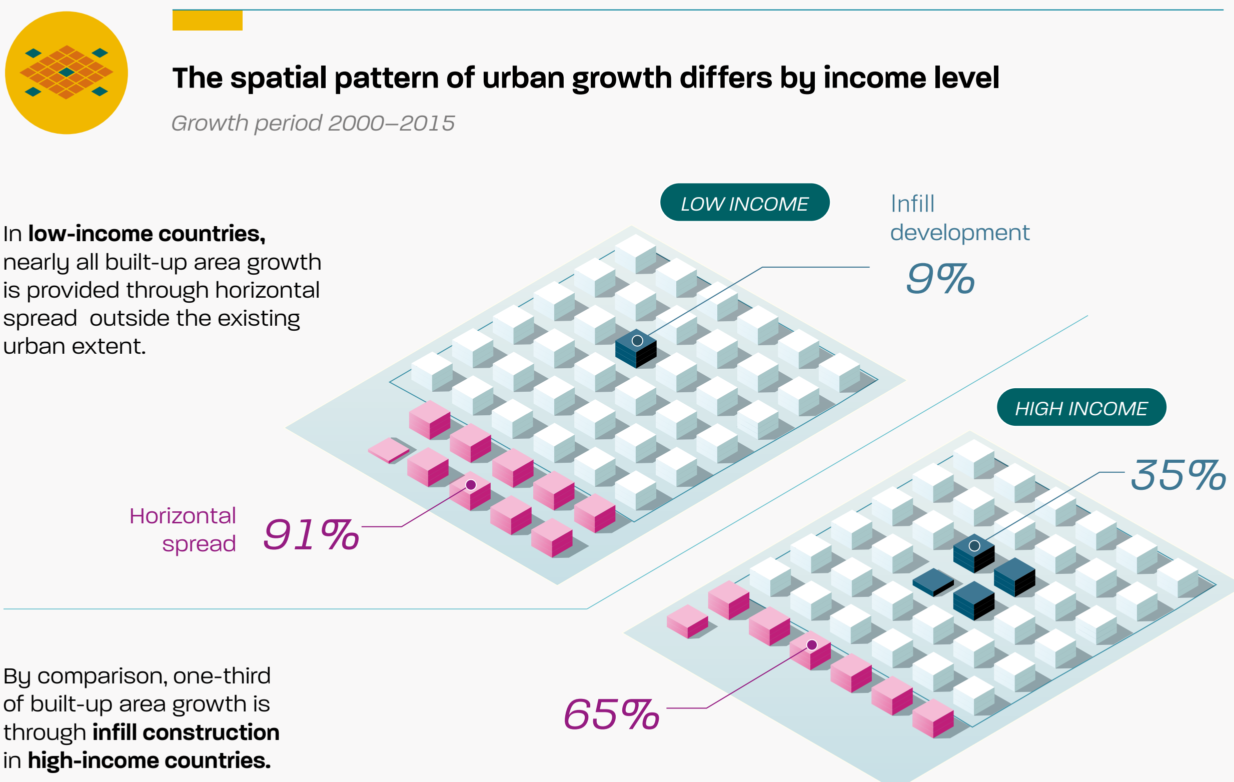
3 The corresponding increase in built-up area for smaller cities is 0.1 percent (associated with a 10 percent increase in incomes).

Box 2.2 Two concurrent processes: Horizontal spread and infill development

Built-up area can grow at a city's extensive margins, as the city expands outward through what this report calls horizontal spread. But built-up area can also expand within the city's boundaries through what economists call intensive margin development—here termed infill development. While most cities grow through a combination of horizontal spread and infill development, the proportions of each are likely to change at different stages of economic development—and with changes in construction technologies, preferences, and local political choices.

Horizontal spread dominates the growth of built-up area—and its share was even greater in 2000–2015 than in the previous decade. In low-income countries, 90 percent of built-up area is provided through horizontal spread. Nevertheless, there is a silver lining: in high-income and upper-middle-income country cities, a larger share of new built-up area is provided through infill development. For example, a city in a high-income country that increases its built-up area by 100 square m will add about 35 square m through infill development and 65 square m through horizontal spread. However, a similar city in a low-income country will add about 90 square m through horizontal spread, with only 10 square m from infill. These findings are consistent with the underlying intuition that agglomeration economies, incomes, and supply capabilities all improve with a country's transition to upper-middle-income status.

Box figure 1 The contribution of horizontal spread and infill development to total additions to built-up area, 2000–15



Source: Authors' analysis, based on GHS-BUILT data.

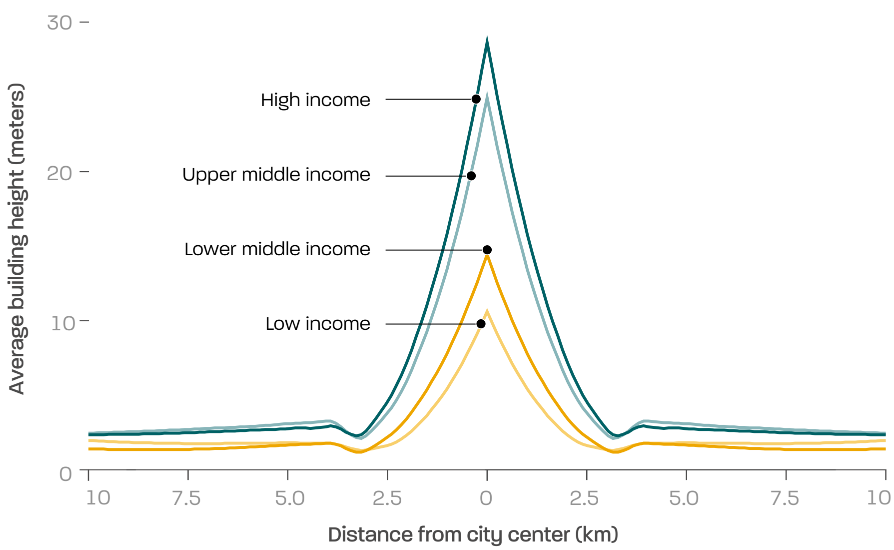
Note: These estimates of infill development are likely to be biased downward—the satellite imagery cannot identify changes in land use and the intensity of land development in places that have already been built up.

How income and population growth drive vertical layering

Cities can add floor space through vertical layering as well as horizontal spread and infill—by building upward, as well as by expanding outward. Vertical layering plays a key role in adding downtown floor space, which alleviates crowdedness in urban centers and enables cities to achieve livable population densities.

To isolate and measure the effects of income and population growth on vertical layering, we use a subsample of almost 400 cities—representative of the larger Global Human Settlement Layer sample—to examine how heights vary with economic development. These data were described in box 1.2. A visual inspection of the data shows that richer cities are physically higher and more structurally compact near the center: they are more pyramid shaped, with peaked skylines and a higher concentration of downtown floor area for residents and businesses (figure 2.1).

Figure 2.1 Richer cities are more pyramid shaped, with peaked skylines



Source: Authors' analysis, based on WSF-3D data..

Note: The graph reports the smoothed line of average pixel heights per city. Each pixel contains information on both its average height and the calculated distance to the highest pixel of the city. First, in each city, pixel heights are averaged for each interval of distance to the highest point. Second the lowess function is used to report the smoothing lines of average heights for cities per income group. The figure above reports the lowess smooth of average height per distance to the highest city point per income group.

The patterns displayed in figure 2.1 reflect economic processes. Highly productive agglomeration economies drive rising demand for commercial floor space and for housing, both of which are normal goods (demand increases with income). Higher income cities meet part of this demand through developers who increase building height in response to rising land prices, especially downtown: pyramids form through infill development, utilizing all available land area near the center.

Richer cities thus have taller structures, with more concentrated commercial and residential space near the center, than poorer ones—yet rich cities also tend to expand more. Even as richer cities add floor space by building upward, they still expand outward: their workers are more likely than workers in poor cities to live in a less residentially dense suburb while commuting to an economically dense center.

While low-income cities are built much closer to the ground, they are also less outwardly expansive. Low economic demand for suburban residential space keeps people in poor cities crowded together. Most workers in poor cities have lower incomes and few transit options, so they cannot afford the time or expense of a long commute and must live near their jobs. Crowding into the urban core, they increase its population density—importantly defined here as the ratio of population to built-up area, rather than floor space—to levels that are unlikely to be seen at later stages if the city becomes richer.

Box 2.3 provides the technical specifications of the drivers of building heights. The independent effect of population growth on the average height of urban structures is somewhat larger than that of income growth (figure 2.2):

- The elasticity of height to population is 0.25. If the city's population increases by 10 percent (while incomes remain constant), its average building height increases by 2.5 percent.
- The elasticity of height to income is 0.185. If the city's income increases by 10 percent (while population remains constant), its average building height increases by 1.9 percent.

Box 2.3 Technical specifications of city height estimates

This chapter provides results from econometric analysis to assess the income and population elasticities of city height.[1] Height is measured as the average height of the city's buildings within 5 km of the highest point in the city.[2] A similar analysis is conducted using the average over the whole urban extent as defined by GHS-UCDB, or using quantiles over the whole distribution.

Using the cross-section data for almost 400 cities, the following specification is estimated for all cities:

$$\ln \text{Average Height}_c = \alpha + \gamma^{height} \ln \text{Income}_{c,2000} + \beta^{height} \ln \text{Population}_{c,2000} + Region\ Dummies + \epsilon_c$$

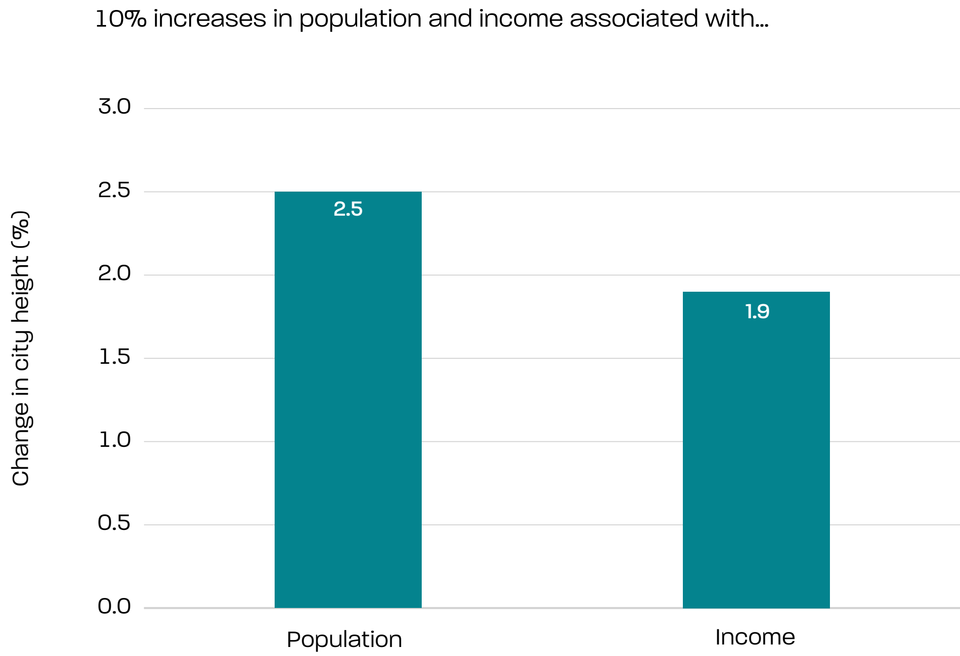
with the average height of buildings within 5 km of the highest point in city c. Several specifications are estimated with region dummies as additional controls and replacing city income with its equivalent at the country level.[3]

1 The subsample of 400 cities was built to be as representative as possible at the global level of the Global Human Settlement Layer sample of cities. As a first check, the same regression is run using both the universe and the subsample. The within estimator of the income and population elasticities of built-up area was obtained for each sample and was shown to be very similar. See Lall, Lebrand, and Soppelsa (2021) for details.

2 Given that most surface is expected to be built around the highest point of the city, the measured height per pixel in this 5 km radius will correspond to both the average over the buildings and the average for the total area of the pixel. DLR data provide height averages over the area of the pixel.

3 Population and income from 2000 are used for two reasons. First, height data have been collected between 2007 and 2011, with the year of collection reported in the data. Second, adding some lag in the explanatory variable can be thought of as an instrumental strategy to deal with the endogeneity issues associated with the initial specification.

Figure 2.2 How income and population are associated with cities' vertical structure



Note: The figure shows the population and income elasticities of average height results from the regression reported in Lall et al. (2021). Data on average height have been collected between 2006 and 2011 and correspond to only one point in time for each of the 397 cities. Several specifications, OLS, with nighttime lights and region dummies, are tested in the paper by Lall et al. (2021). The figure reports the results of the OLS estimation.

Combined with the elasticities of built-up area to income and population described above, these elasticities of height to income and population fully capture the association between each driver and total floor area growth across cities. Notably, however, the elasticity of height to population is lower than that of built-up area to population—while the elasticity of height to income exceeds that of built-up area to income.

Why are rising incomes a stronger driver of vertical layering than of horizontal spread? Intuitively, these findings suggest that households—which can afford higher rents as their incomes rise—prefer to pay more for housing closer to job centers. Living near the center reduces commuting time, and it allows access to downtown amenities.

Richer cities also tend to produce more tradable services—which rely more heavily than non-tradables on knowledge workers, and which gain the most from agglomeration effects and from higher densities of local economic activity. These incentives boost the demand for downtown floor space and thus for higher commercial buildings in urban centers. On the supply side, higher land prices and the density of demand create incentives for developers to supply more floor space in a given land unit area. The need for higher structures also improves capabilities in the construction sector, which requires advanced engineering technologies to build upward, as well as in the real estate sector (Ahlfeldt and Barr 2020).

Across geographic regions, cities display a large heterogeneity in their patterns of vertical expansion (Lall, Lebrand, and Soppelsa 2021). Compared with cities in the East Asia and Pacific region, cities in Latin America and the Caribbean have shorter buildings. But the widest divergences from global averages are seen in South Asia and in Sub-Saharan Africa. Cities in these regions have the lowest buildings (controlling for income and population).

Vertical layering, in addition to horizontal spread, is essential for cities to increase their floor space and remain livable as their populations grow. Duranton and Puga (2020) make back-of-the-envelope calculations of the floor space that Latin American cities will need over the next 20 years. Assuming that 2 percent income growth will increase the demand for housing by 1.5 percent per year (with housing prices constant)—and assuming 1.5 percent annual population growth—housing demand will rise by 3 percent per year. If that rate holds for the next 20 years, the result will be a cumulative 80 percent increase in demand, or a near doubling in the amount of floor space needed to accommodate firms and families. Achieving this doubling of total floor space through horizontal spread alone is unlikely—and undesirable.

How cities supply floor space by building upward and expanding outward

Floor space is critical for cities to accommodate families and firms. It can be added through horizontal spread, vertical layering, or infill development. This section uses the previous horizontal and vertical growth estimates to measure the elasticities of floor space to income and population, both individually and in combination (specifications appear in box 2.4).

Figure 2.3 shows these elasticities and confirms that as cities grow in population, in incomes, or in both, they add floor space by building both upward and outward. The effects on height and built-up area are:

- The elasticity of height to the combination of population and income is 0.44. If the city's population and income both increase by 10 percent, its average building height increases by 4.4 percent.
- The elasticity of built-up area to the combination of population and income is 0.45. If the city's population and income both increase by 10 percent, its built-up area increases by 4.5 percent.

Box 2.4 Technical specifications of floor space estimates

Income and population elasticities of total floor space are defined as the following:[1]

$$\text{Income Elasticities of Floor Space} = \frac{\partial Floor\ Space / Floor\ space}{\partial Income / Income} = \gamma^{bu} + \gamma^{height}$$

$$\text{Population Elasticities of Floor Space} = \frac{\partial Floor\ Space / Floor\ space}{\partial Population / Population} = \beta^{bu} + \beta^{height}$$

The elasticities of per capita floor space to income and to population are then expressed as:[2]

$$\text{Income Elasticities of Floor Space per Capita} = \gamma^{bu} + \gamma^{height}$$

$$\text{Population Elasticities of Floor Space per Capita} = \beta^{bu} + \beta^{height} - 1$$

1. These expressions are derived using the log properties.

$$ln(TFA) = ln(Built - up * Height/3) = ln(Built - up) + ln(Height) + constant$$

$$\Rightarrow dln(TFA) = dln(Built - up) + dln(Height)$$

The elasticities for total floor area with respect to income or population are then derived.

$$\epsilon_{TFA,inc} = \epsilon_{built-up,inc} + \epsilon_{height,inc}$$

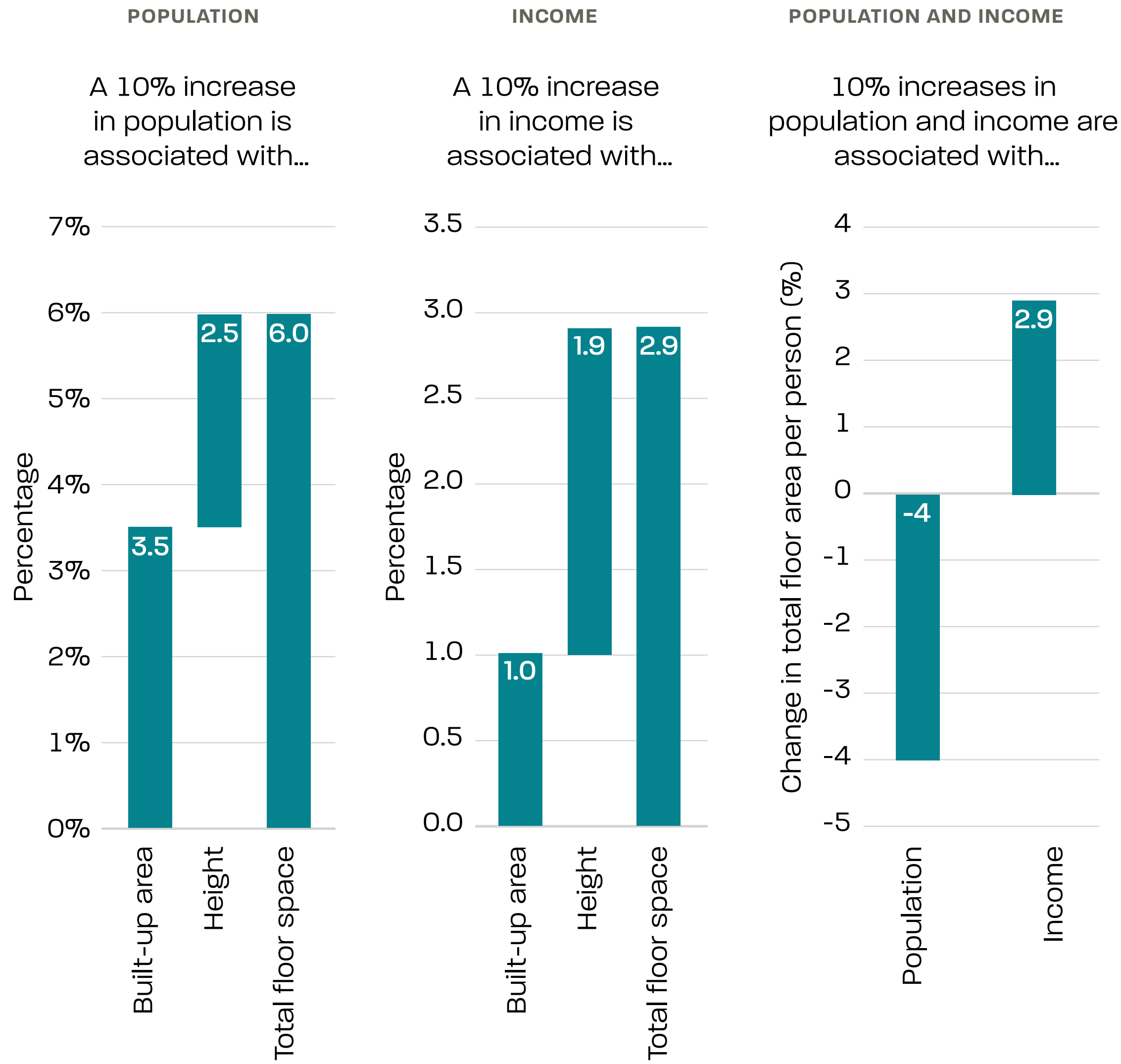
$$\epsilon_{TFA,pop} = \epsilon_{built-up,pop} + \epsilon_{height,pop}$$

2. The elasticities for total floor area per person with respect to income or population are then derived.

$$\epsilon_{TFA\ percap,inc} = \epsilon_{built-up,inc} + \epsilon_{height,inc}$$

$$\epsilon_{TFA\ per\ cap,pop} = \epsilon_{built-up,pop} + \epsilon_{height,pop} - 1$$

Figure 2.3 The elasticities of a city's built-up area, average building height, and total floor space to its population and income



Source: Authors' analysis, based on GHS–Urban Centre Database and WSF-3D data.

Note: Because population is kept constant, the income elasticities for total floor space and total floor space per person (per capita floor space) are the same (0.29).

These estimates have profound implications for a growing city's supply of floor space, and also for its tendency to sprawl outward—especially in the absence of rising productivity and incomes. If incomes do not grow but remain constant, a 10 percent increase in the urban population increases total floor space by only 6 percent. Furthermore, the 6 percent increase in total floor space is achieved more through horizontal spread (built-up area expansion) than through vertical layering (upward construction).

- ***The elasticity of total floor space to population is 0.60.*** If the city's population increases by 10 percent (holding income constant), its total floor space increases by 6 percent through a combination of built-up area expansion (3.5 percent) and vertical layering (2.5 percent).

The 6 percent increase in total floor space, as a result of increasing the city's population by 10 percent, falls short of the 10 percent increase in the number of people needing space. This is suggestive evidence that floor space does not increase in proportion to population and that residents of larger cities consume substantially less floor space per person.

Cities with rising productivity and incomes fare better. If a city's income increases by 10 percent, holding population constant, total floor space—and thus per capita floor space—increases by almost 3 percent.

- ***Elasticity of total floor space to income: 0.29.*** If the city's income increases by 10 percent (holding population constant), its total floor space increases by 2.9 percent through a combination of built-up area expansion (1 percent) and vertical layering (1.9 percent).

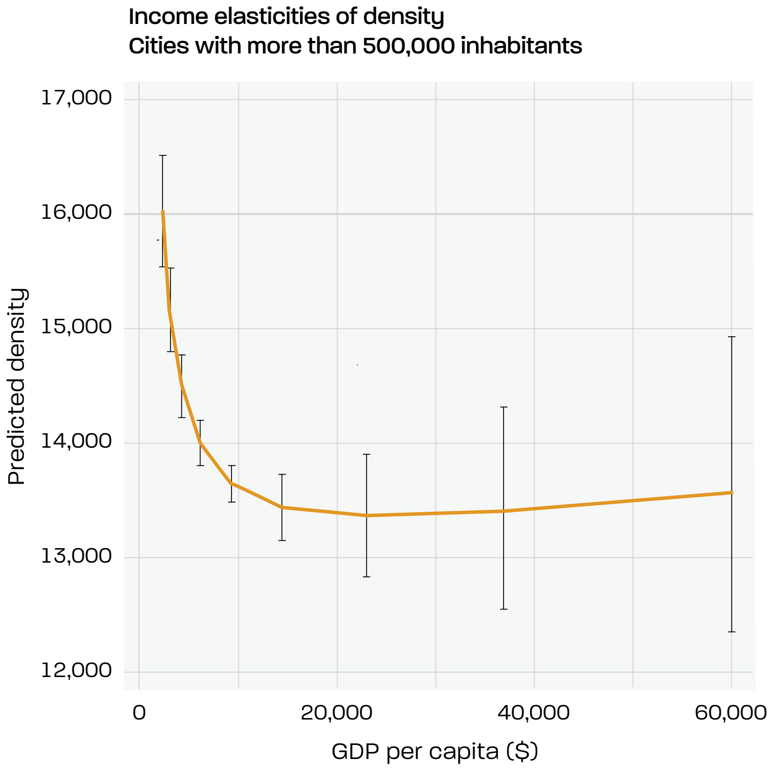
Because the floor space available per person rises with income—though not proportionally so—the city becomes more livable. An intuitively plausible explanation for the income gains not reflected in added floor space is that some are dissipated in higher housing prices. Also, rising incomes are likely to increase demand for housing services, which include the quality and variety (not just the quantity) of floor space. But unless per capita income increases by at least 14 percent, if population increases by 10 percent then floor space per person will fall.

One of the key stylized facts is that increasing incomes are the one indispensable driver of vertical layering, because building tall is capital intensive. This is true for office blocks, and also for the move from informal to formal settlement. It therefore requires income levels, capital wealth, and financial institutions that enable these investments to be made. Even if the levelized lifetime costs of different building types were similar, meeting the upfront capital costs of load-bearing structures would still be more feasible in cities with higher incomes and productivity.

How population density responds to income growth

Finally, how do cities' population densities—defined as their ratios of population to built-up area—change in response to income growth? And how do these densities evolve over time? To answer these questions, a panel regression (along the lines of equation 1) was estimated with density measures for cities around the world. (One modification to the estimation was the introduction of a quadratic term to pick out potential nonlinearities in the response of population densities to incomes.) Annex 1 provides these estimates. As shown previously, as cities become richer, their demand for floor space rises and their supply of built-up area increases in response, even with population held constant. So as cities expand in built-up area, they become less densely populated. The income elasticity of density is −0.10 using the between and within estimator; introducing instruments for incomes increases it to −0.15.

Figure 2.4 Predicted density over built-up area



Source: Authors' analysis, based on GHS–Urban Centre Database.
Note: Density is measured with respect to built-up area, not floor area.

Figure 2.4 shows the predicted densities at various income levels. As cities become richer, they expand in response to a higher demand for floor space, making themselves less densely populated. However, a nonlinear specification for cities larger than 500,000 inhabitants reveals that population density stops declining and more or less stabilizes when cities reach $20,000 per capita GDP: if anything, density after that point begins a gradual increase.

As the populations of large cities keep growing, some of these cities will add more space through vertical layering—adding both to livability and to economic agglomeration gains.

SPOTLIGHT 2

Disruptive technologies and the future of cities: A policy and analytic agenda

Cities across the globe are entering a realm of rapid disruption brought about by a wave of transformational technological progress. The new informational, transactional, and operational technologies—popularly termed *Industry 4.0*—are likely to change the shape of cities and could well require a rethinking of how we define density.

The most profound disruptions are likely to come from operational technologies that combine data with automation. Examples include hyperloop, robotics, machine learning, 3-D printing, autonomous vehicles, artificial intelligence, and off-grid energy systems. The fundamental driver is the falling cost of routine functions. These disruptors are at the frontier of innovation and are likely to fundamentally reshape notions of density and economic geography.

The city of the future is also likely to have a different economic base. The future of work will be one based more on the:

- ***Gig economy***—based on flexible, temporary, or freelance jobs, often involving connecting with clients or customers through an online platform.
- ***Sharing economy***—involving short-term peer-to-peer transactions, often through some type of online platform that connects buyers and sellers.

With such technology come changes in connectivity and proximity. These types of work have a different infrastructure base. For example, they may not need networked services but will instead be on micro-grids and will be more home-based.

To help city leaders make more informed choices in anticipating and planning for the future spatial organization of cities, a forward-looking policy and analytic program are urgently needed to addresses the following issues:

What lessons from classic urban economics and economic geography get overturned, and which hold up well under rapid technological change? Will new digital technologies lead to a rethinking of common economic wisdom, perhaps in the way that the new trade theory provides a new perspective on globalization?

How are the impacts of the current technological/digital revolution on cities different from the impacts of other general technology revolutions? New digital innovations have spread faster around the globe, but that does not mean that the benefits in each country will be universally shared. Just as in previous episodes, there will be winners and losers. Yet, the new digital technologies, because of their rapidly falling costs and the extensive scope of their applications, could yield higher returns more quickly and for more people around the world.

What time frames should we be thinking of? The fast pace of digital technological innovation clashes with the long time scales inherent in urban development. Technologies tend to be outdated within five years. Major infrastructure and zoning choices, in contrast, are policy decisions with consequences through generations.

Are there important interactions with other major global trends? Digital technologies and urbanization are not the only mega trends shaping economic development. Climate change (and environmental degradation more generally), demographic trends, the possible reversal of globalization, or a gradual shift in global economic and political power could co-determine how cities will fare. Do possible interactions affect how we should view digital technology change in cities?

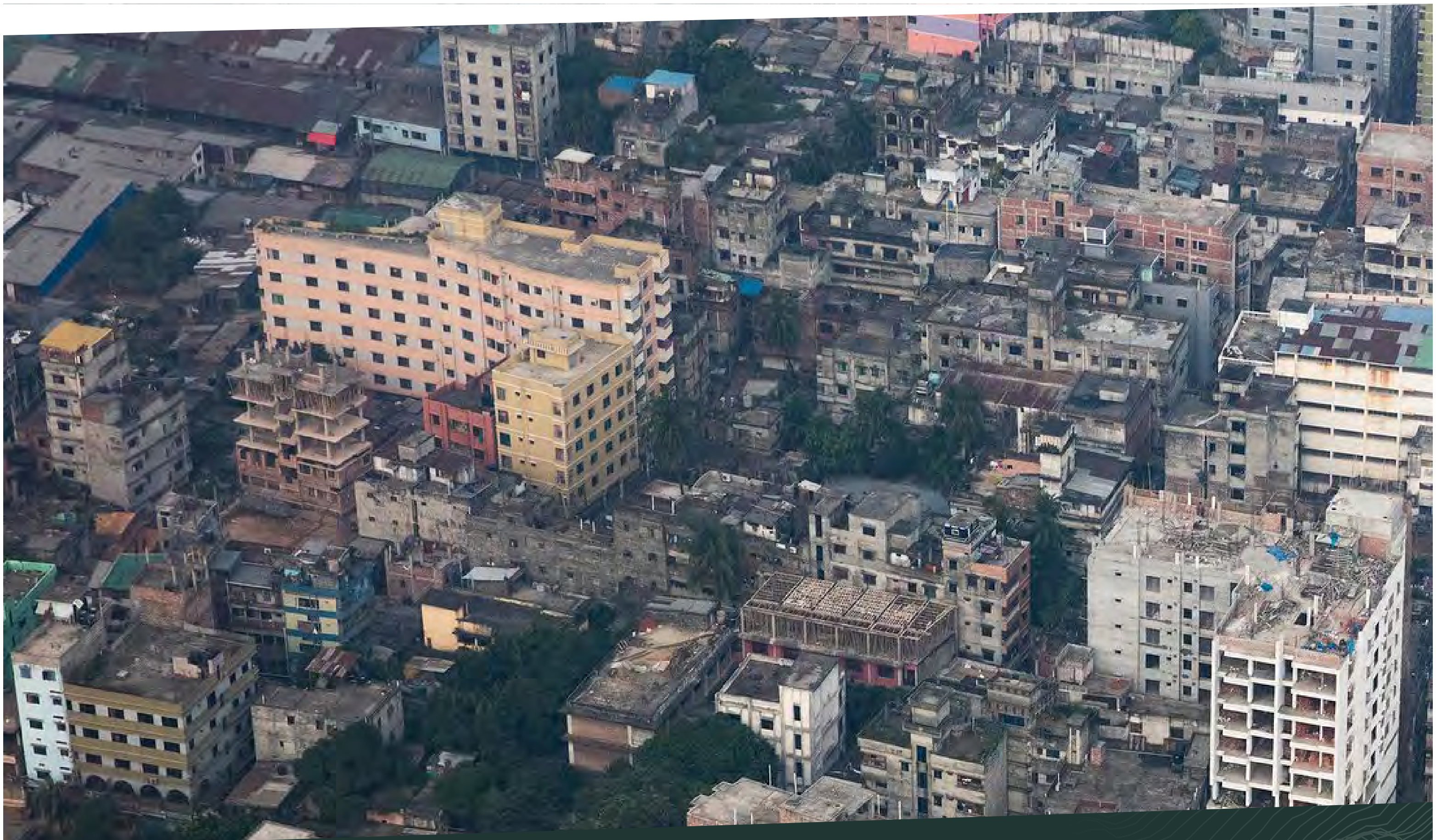


Photo: World Bank/Flickr, Dhaka, Bangladesh

III What drives one city to grow differently from another?

What drives one city to grow differently from another?

Chapters 1 and 2 of this report have examined the three main margins of urban spatial expansion observed around the world from 1990–2015: horizontal spread, vertical layering, and infill development. To clarify what drives each of these margins, chapter 3 now digs more deeply into the determinants of a city's spatial form, applying a structural urban model derived from what urban economists know as the *new urban model* (box 3.1). The resulting analytic framework can provide insight into the likely productivity and density effects of various policies and policy changes, including large investments such as transit systems and other infrastructure.

Using a structural urban model to clarify cities' spatial development

This section presents a version of the new urban model that is tailored to help policy analysts estimate the aggregate quantitative impacts of economic policies—and compare the impacts of alternative policies using counterfactual simulations. Such a framework is especially useful when large spillovers, linkages, and general equilibrium effects may be important but are hard to discern using reduced form approaches. The framework can also help decision makers predict the gains and distributional impacts from future investments and policy changes.

Box 3.1 What is the new urban model, and how can its analytic framework help city leaders?

The structural approach to urban economics that informs *Pancakes to Pyramids* is based on a new urban model, which builds on the earlier urban tradition of the Alonso-Muth-Mills (AMM) model (Alonso 1964, Mills 1972, Muth 1969), and does so in a way that is both more general and can capture heterogeneity of cities. The new urban model can be applied to help city leaders understand how economic productivity and various aspects of urban form mutually interact.

The AMM model generally assumed that all employment takes place in the city center and that all workers commute to this central district (or point). There is an implicit assumption that agglomeration forces create this central clustering, but firm productivity is taken to be fixed. This basic model yields important insights, particularly about the determination of land rents and the varying density of settlement at different distances from the center. Policy applications of the model to particular cities, such as those of Bertaud and Brueckner (2005) and Brueckner and Sridhar (2012), showed how central area height restrictions could encourage urban sprawl and reduce real incomes in the city.

The new urban model—first developed by Ahfeldt et al. (2015) who build on earlier work by Lucas and Rossi-Hansberg (2002) and Fujita and Ogawa (1982)—differs in two main respects. First, agglomeration forces are made explicit, and worker productivity is assumed to depend on the scale and density of economic activity in the city, in line with the findings of empirical research on agglomeration. Second, firms, as well as households, choose where to locate in the city, responding to costs of commuting, wages and floor space prices in different parts of the city. These changes give a better description of the city as some employment may be dispersed, and some residences will be in or close to the center. They also give a much richer set of responses to investment and policy changes. For example, height restrictions may change the location of firms as well as households, this in turn changing the form of clusters of employment and hence of productivity.

The new urban model also fills out further aspects of the city in greater detail. There is rich modeling of construction technologies, infill within the city boundary as well as extensive growth at the city margin, and multi-sector approaches with different economic activities having different locational priorities. Dynamic aspects of the model make it possible to look at the process of development and redevelopment of a growing city.

Importantly, new sources of data provide information on building height (lidar), on traffic and commuting flows on the city's transport network (mobile phone data), and hence on the possibility of linking people's places of work, home, and recreation. These developments enable the new urban model to be calibrated to particular cities, and to serve as a tool for policy analysis.

Informing the structural urban model are several basic intuitions about the decisions that face firms, workers, developers, and landowners:

- ***Firms must choose their locations.*** Production can, in principle, occur anywhere in the city, but in practice a firm's choice will reflect characteristics such as productivity, access to labor, and the supply of commercial floor space.
- ***Workers must choose where to reside and where to work across all locations in a city.*** Both choices will depend on how attractive locations are as places to live in and to work in, as well as on the cost of commuting between residence and workplace.
- ***Developers create housing and commercial space using the capital and land available in each location.*** Demand for floor space will determine the profitability of their investments.
- ***Landowners determine land use.*** Their decisions reflect tradeoffs between estimated returns on residential or commercial use, along with any regulatory land use restrictions.

All these individual decisions are related through general equilibrium market clearing conditions, which equate the demand and supply for each factor in each location and pin down prices, wages, and rents.

Because all employers need access to workers, urban firms on average tend to favor central locations. Neighborhoods near the center are closer to a larger share of the city's total land area than are areas near the urban edge. Furthermore, edge areas may not be favored by radial transport networks.

For many firms, however, access to workers is not the only consideration—and firms in some sectors have other overriding reasons to be located away from the center. To better understand firms' location decisions, this report's structural urban model broadly distinguishes two production sectors: *tradables* and *non-tradables* (box 3.2). The two sectors have different priorities in choosing urban locations:

- ***Many non-tradables producers prefer to be near the final consumer, so they are less centralized than tradables producers.*** Non-tradables firms will be somewhat dispersed throughout the city. In contrast, tradables firms—those that trade externally—are less constrained by a need to be near local consumers and so may be more centralized.
- ***Firms in certain specific sectors are especially likely to benefit from agglomeration economies, so they will cluster together.*** Business services, finance, and many creative sectors tend to cluster and are likely to locate in a central business district (CBD).
- ***Employers require floor space to operate, and their varying demands for space—and for specific building types to supply it—are a further crucial factor in firms' location decisions.*** Office-based employers can build tall, enabling high density in the CBD. In contrast, most manufacturing firms require more space per employee, sometimes in structures that are necessarily low-built: such manufacturers are more likely to occupy the city edge.

Just as important as firms' choices about where to locate are workers' choices about where to live—along with the related decisions of developers and landowners about where to provide residential floor space. The decisions by developers and owners that produce this stock reflect both demand and supply factors:

- *Housing floor space demand* comes from households that seek greater access to jobs, services, and amenities—and that act on a variety of innate preferences for particular locations, needs for floor space, and degrees of affordability. These choices are shaped substantially by available and accessible transport modes and mobility technology.

- *Housing supply* is shaped by the availability and price of land and by available construction techniques. Multi-story apartment blocks will be built where land is expensive. One- and two-story housing will be built farther from the center, where land is cheaper. Construction types vary widely in durability and capital cost, and informal settlements arise because of people's inability to afford the capital cost of durable structures—along with institutional barriers to efficient land use. Importantly, decisions about durable structures must largely reflect expectations about future demand and how the city is likely to grow (Henderson, Regan, and Venables 2020).

Overarching the spatial distribution of firms and residents are three further factors:

- ***Natural geography.*** Geographic features influence a city's transport options and accessibility. For this report, the most stylized model ignores geographic differences and assumes that every city is on a "featureless plain." But in applying the framework to real cities, geography matters. This includes elevation, coastal location, and local amenities, including parks and open spaces.
- ***Institutions, governance, and urban plans and policies.*** A city's shape reflects the institutional structure of the land market, building and land use regulations, taxes, and the investment in and placement of public assets—in particular the transportation network. These factors—grounded in law, governance, and policy—are explored in some of the experiments conducted for this report.
- ***Population size.*** The model employed here reflects city size through a variable for urban growth.

All of the aspects described above interact: the places where people work and live (and commute from), the choices made by firms about location, production, and hiring, and the construction decisions of land developers. A key mechanism that coordinates these choices is the land market and the price—or rental rate—of land in different neighborhoods. The structural urban model used here captures these interactions in a consistent manner.

Later sections of this chapter apply this model to a particular city—Dhaka. General insights are obtained by using the model to analyze the interactions of firms, people, and other elements in a hypothetical city located on a "featureless plain." This illustrative hypothetical city will be monocentric, with rotational symmetry and a perfectly circular boundary.

Key variables for this hypothetical city are illustrated in figure 3.1. Plotted against the horizontal axis of each panel (a, b, c, and d) is distance from the city center: as we look from left to right, we are thus traveling along a radial slice of the city, from the CBD to a point beyond the city edge.

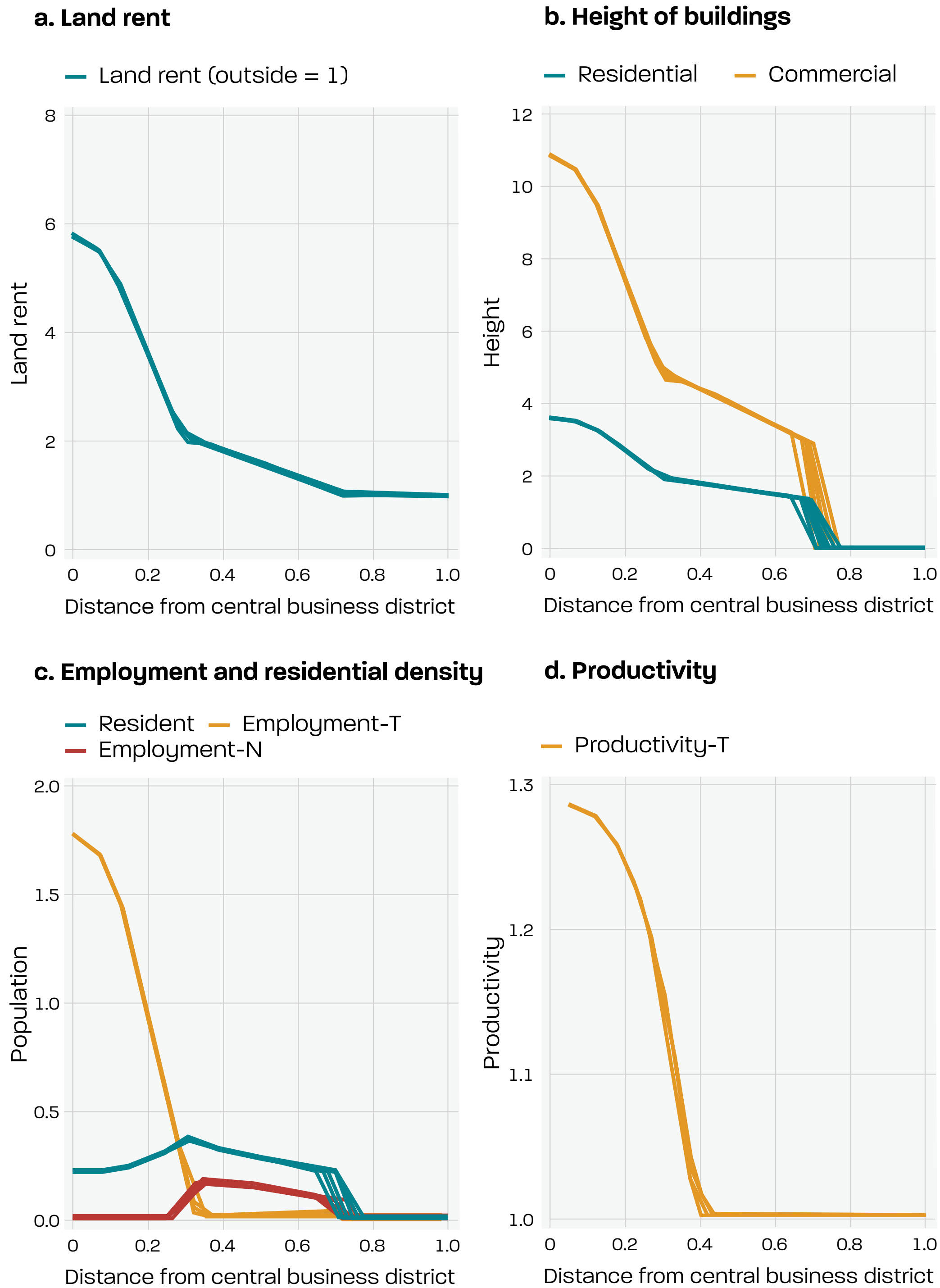
Box 3.2 Tradables and non-tradables in the urban economy

What does a city produce—what goods and services do its firms hire people to provide? The larger share of its labor force is probably employed in non-tradables: activities that supply goods and services to the local urban population. Such non-tradables include personal services, retail, hospitality, construction, building maintenance, transport, and public services.

A smaller share of workers are likely to be employed in tradables, or goods and services that are exported to other regions or countries (as well as being consumed locally). Tradables include manufacturing and varied services, from business, legal, and financial services to media and education.

A city must export something in exchange for any food, fuel, or other goods and services that are not locally produced. But the size of its tradables sector varies with many factors. The more the city's imports can be financed by funds transferred from outside the city (government transfers, resource rents, or development aid), the smaller its tradables sector will be (Gollin, Jedwab, Vollrath 2016).

Figure 3.1 Some patterns predicted by the model for a hypothetical city—built on a "featureless plain"



Source: Authors' analysis.

Note: The model is simulated on a two-dimensional plain and for now considers a fixed city population. The figure reports a one-dimensional slice from center to edge. The city edge is slightly jagged, because discrete finite size cells are used in simulation. Units used for all four charts, whether for distance or for other variables, are abstracted model units—they are not directly interpretable as kilometers, people, or dollars. But because each model unit is consistent wherever it appears, the charts allow comparisons across cases.

Plotted against the vertical axis of figure 3.1a is land rent, which is costly at the center and declines with distance, until reaching the level of land rent outside the city—this point defining the edge of the city. On the vertical axis of figure 3.1b is building height, which responds to rent: as developers seek to economize on land area relative to other factors, they build taller structures in the center with more stories than at the edge. Note that the model example for figure 3.1 allows residential and commercial structures to use different technologies, so figure 3.1b reflects how commercial firms—to the extent that they are office-based—will consistently build taller than residential developers.

Patterns of employment and residential density appear in figure 3.1c. Plotted against the vertical axis are three distinct aspects of density, defined as people per unit of land area: the density of workers in the tradables sector (T-sector), the density of workers in the non-tradables sector (N-sector), and the density of residents. Readers will note that the plotted heights measure density, not the numbers of people working or living at each distance from the center since a belt far from the CBD is far larger in area than a belt of the same width closer in.

Why is T-sector density so strikingly skewed toward the center, in contrast to the other two densities shown in figure 3.1c? Because, in the model used for figure 3.1, firms in the tradables sector benefit from agglomeration economies (box 3.3). Accordingly, firms in this sector cluster in the center: a preference that does much to drive the high land rents in figure 3.1a, and building heights in figure 3.1b. In contrast, the N-sector in figure 3.1c is highly dispersed, spreading outward through residential areas at increasing distances from the center. Finally, residential density is highest at some distance from the CBD: workers want access to the cluster of central employment, but commercial development prices most of them out of the innermost core—the downtown CBD itself.

The presence of agglomeration economies in the model used for figure 3.1—along with developers' ability to build tall in the CBD, and the consequent clustering of T-sector firms near the center—gives the city the benefit of high productivity. As indicated in figure 3.1d, productivity is highest for the firms nearest the core: that is what justifies the high rents they are willing to pay.

Box 3.3 Agglomeration economies

Firms and workers in some types of economic activity have higher productivity when they are located in a large and dense cluster of economic activity. Numerous factors create this effect. In a cluster, firms have lots of suppliers and customers nearby, not only saving on transport costs but also allowing knowledge transfer and the use of just-in-time technologies. The cluster may be large enough for highly specialized firms to develop, with very high productivity in a particular activity—an example of Adam Smith's scale and specialization. Pools of highly skilled labor may develop, with skills being passed from worker to worker—or generation to generation in some cases. These agglomeration economies may operate across a wide range of activities, or in particular sectors such as financial services, high-technology clusters, and film and media centers.

A good deal of research has quantified these effects. This suggests that, in high-income countries, the agglomeration scale elasticity is around 3–5 percent, implying that a city with a population of 8 million has productivity 15 percent higher than one with 250,000 people. In upper-middle-income countries the effect has been estimated to be several times larger again. Less research on this subject has been done in low-income countries, but such as there is suggests a much weaker effect, perhaps because the sectors in which agglomeration economies are most powerful are largely absent from low-income cities (see Grover, Lall, and Maloney 2021 for a review of evidence and further discussion).

What determines the shape of the city?

Underlying the benchmark city of figure 3.1 are the economic, technical, and policy relationships that factor into a city's economic and spatial development. Four of these factors are especially important:

- Agglomeration economies, or the extent to which the city's economic structure enables T-sector firms to benefit from urban agglomerations.
- Construction costs, reflecting constraints—whether financial, technological, or regulatory—on developers' ability to build tall.
- The city's total population size.
- Transport and commuting costs, affecting the ease with which people can move around the city.

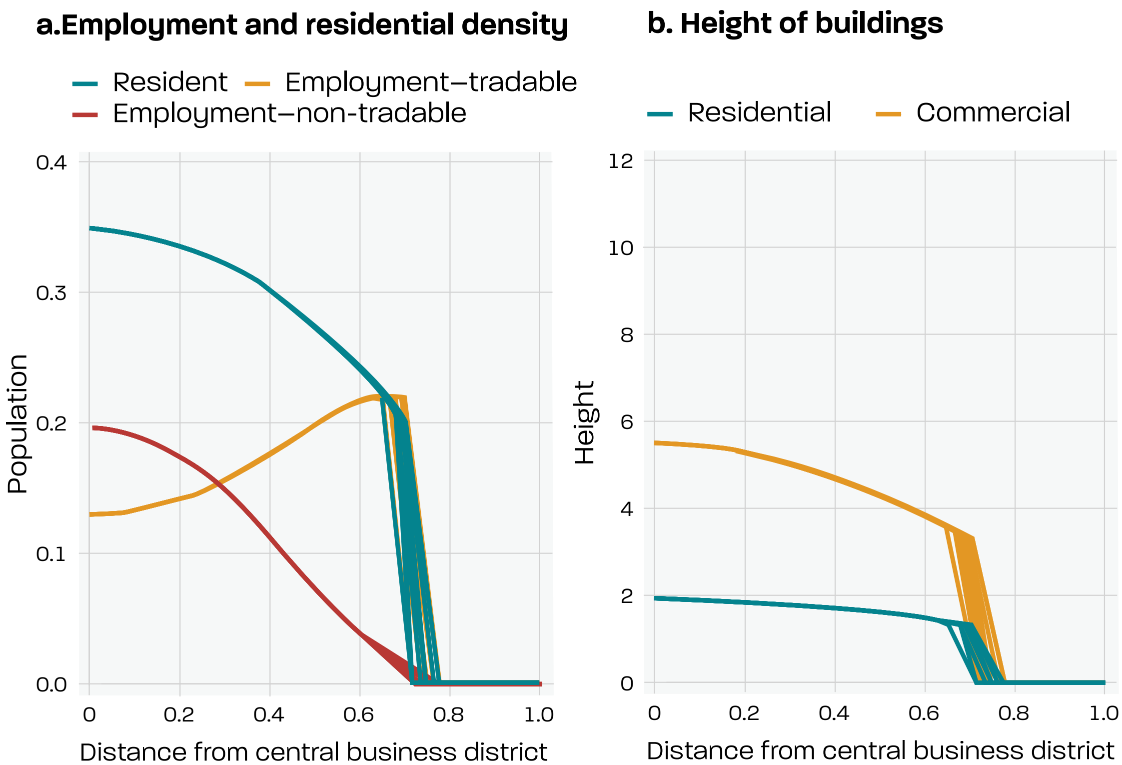
Cities vary in each of these dimensions, along with others—and each is critical to determining a city's shape, as well as its prosperity.

The absence—or presence—of agglomeration economies as a key determinant of city shape

Agglomeration economies are a key driver of the centripetal forces and density of the CBD in the benchmark city. But many cities lack the types of productive sectors that are able to benefit from agglomeration economies. What is the shape of such cities?

Figure 3.2 describes a city, the same as the benchmark in all respects except that the T-sector does not benefit from agglomeration economies, having instead constant returns to scale. The differences are striking. In figure 3.2—compared with figure 3.1c—the employment structure of the city is inverted, with tradable (T-sector) employment density highest at the city edge, and non-tradable (N-sector) employment density highest in the center. Residential density is also now higher in the center than anywhere else in the city. The reason is that non-tradables firms—including retail and personal services—gain from easy access to large numbers of customers, while residents gain from easy access to these firms both as employees and customers. When the T-sector has no incentive to cluster, the densities of N-sector employment and of residents can drive each other ever higher near the center without heavy competition from the T-sector. Land rent in the city center is much lower, this implying less tall buildings (figure 3.2b).

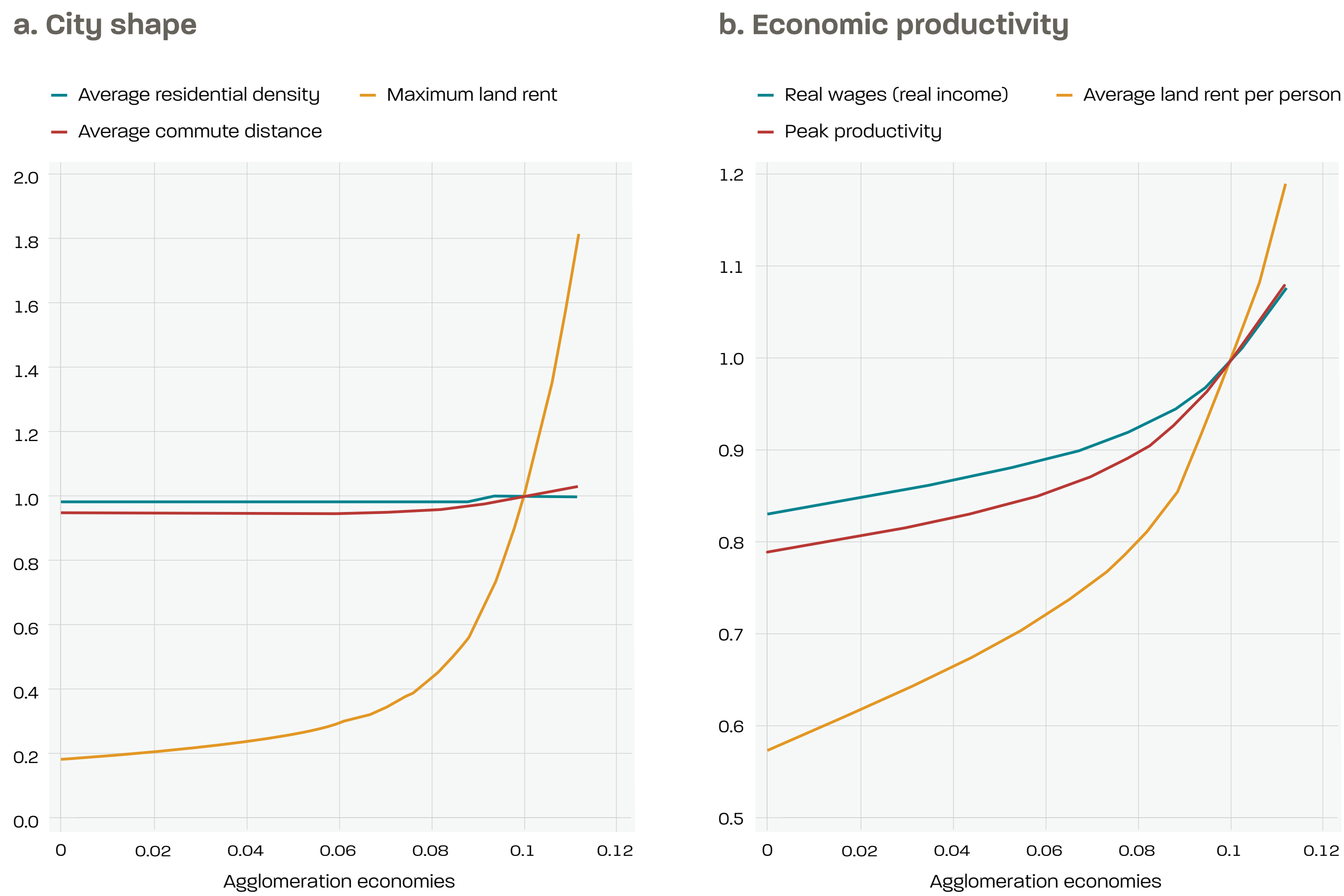
Figure 3.2 Spatial distribution of residents and employment (tradables and non-tradables sectors) and heights of buildings in a city lacking agglomeration economies



Source: Authors' analysis.

The scale and further implications of these agglomeration effects appear in figure 3.3. On the horizontal axis is a measure of agglomeration economies, ranging from 0 (the city described in figure 3.2) through 0.1 (the benchmark city of figure 3.1) to a higher value. All variables measured on the vertical axis are expressed relative to the benchmark city (all take value 1 at point 0.1).

Figure 3.3 Effects of agglomeration economies on other city characteristics in the new urban model



Source: Authors' analysis.

The city shape captured in figure 3.3a gives average residential density, maximum land rent, and average commute distance. Maximum land rent—a reflection of demand for space in the CBD—increases sharply with agglomeration economies, varying ninefold across the range provided. Average residential density and commute distance increase slightly: while the locational patterns of residence and employment vary substantially, there is little change in the overall land area of the city.

Figure 3.3b gives real income measures. Peak productivity is more than 30 percentage points higher with agglomeration economies than without. This is largely a direct consequence of switching on these economies—but it is amplified by the fact that, the larger these scale economies are, the more firms and employment cluster. The additional income generated by higher productivity is divided between worker households and landowners. We measure the worker household benefit by average utility (the average wage net of commuting costs and housing costs).[1] The figure indicates that the benefits of agglomeration-driven productivity go disproportionately to land rents (which more than double across the range of the figure)

1 The same amount of floor space costs different amounts at different places in the city. The utility measure deflates nominal wages by a location-specific price index to control for this variation.

relative to worker household utility, which increases by around 25 percent.

The message of figure 3.3 is that the shape of the city varies greatly with its economic function. Some T-sectors have strong agglomeration economies, others do not. Still others may be prone to agglomeration economies but also be very land-intensive—car factories are built sprawling, not tall—so clusters develop on the city edge, while the center attracts N-sector activities.

Construction costs as a constraint on floor space growth and building height

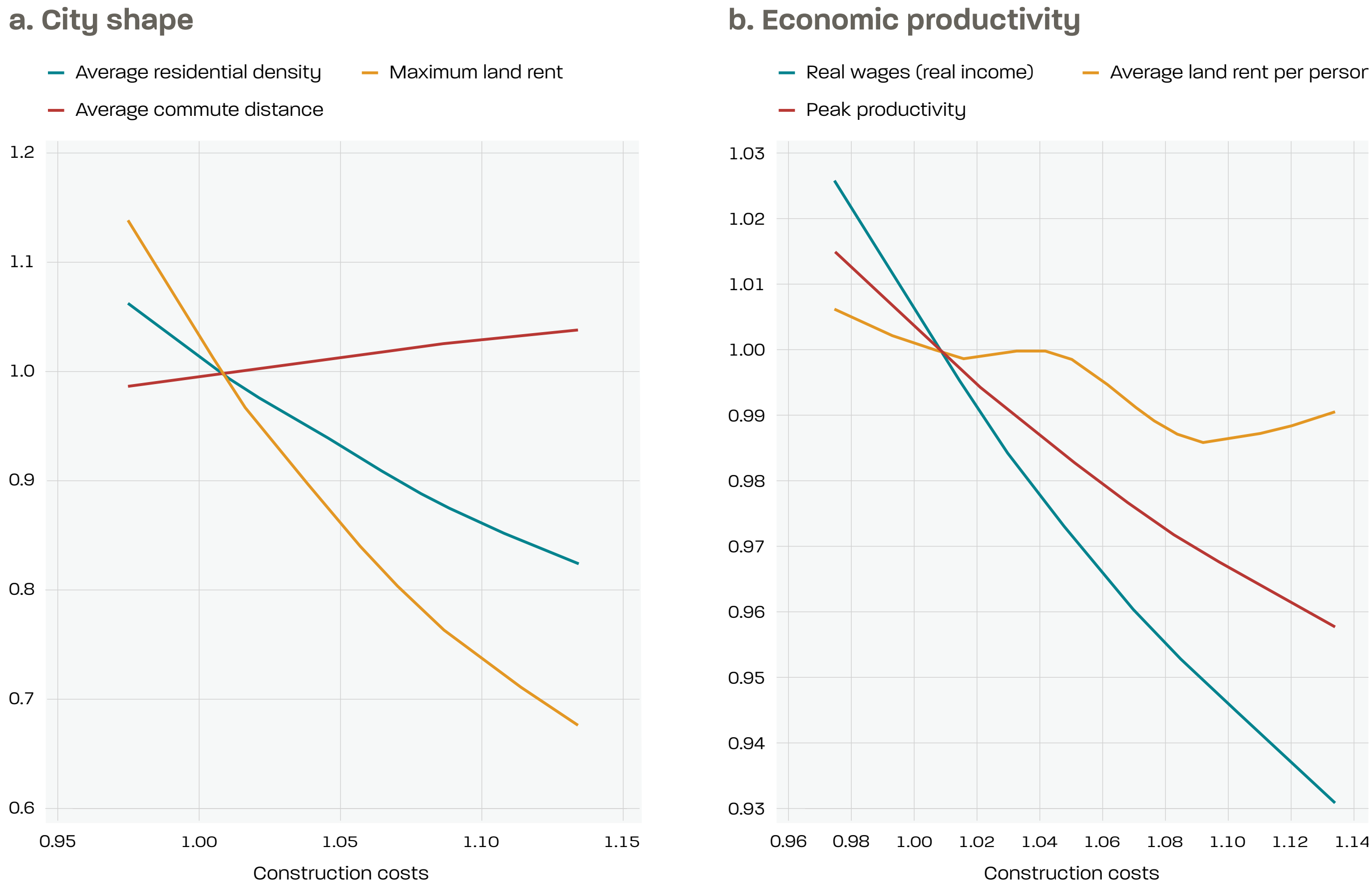
Land is the city's scarcest factor. Development and construction technology transform land into floor space. Numerous constraints affect this transformation, each with effects on the city's shape and growth.

Building technology varies, from the mud floors and iron roofs of informal settlements to the steel and glass of modern high-rise districts. Costs vary—especially the capital costs of building durable, load-bearing, and tall structures. The capital intensity of these structures means that they are relatively more expensive in capital scarce countries than in capital abundant ones: as incomes rise, building types evolve. The associated capital requirements appear in the data (Dasgupta, Lall, and Lozano-Gracia 2014) and can be captured in modeling. Henderson, Regan, and Venables (2020) model the evolution of slum and formal settlements theoretically and in an application to Nairobi, incorporating the loss of amenities due to high slum density (see also Bird and Venables 2019). Whereas formal structures can deliver density with height, informal ones can deliver it through crowding (little floor space per person, little green space per house).

Building and development choices are also shaped by institutional and regulatory factors. A lack of clarity in land tenure creates a bias against sinking capital into formal structures—a factor in the perpetuation of slum areas. Building regulations, such as floor area restrictions, often restrict the density of both commercial and residential development: such restrictions lengthen commutes and weaken agglomeration spillovers between firms. Zoning can be done in ways that are damaging, locking in land-use patterns that become inappropriate as a city develops. But zoning can also yield benefits by reducing negative externalities that affect households—and also, possibly, by encouraging a concentration of commercial activities that promotes positive spillovers and externalities between firms.

To see the implications of these factors for the shape of the city, figure 3.4 varies a parameter of the model that captures construction costs and the obstacles to building tall. The horizontal axis is the construction cost parameter, relative to its value in the benchmark. Increasing this parameter by 10 percent implies that at a given land rent, buildings will be about one-third as tall as in the benchmark case. Associated with this, the city sprawls, with lower density and longer commutes.

Figure 3.4 Effects of construction costs on other city characteristics in the new urban model



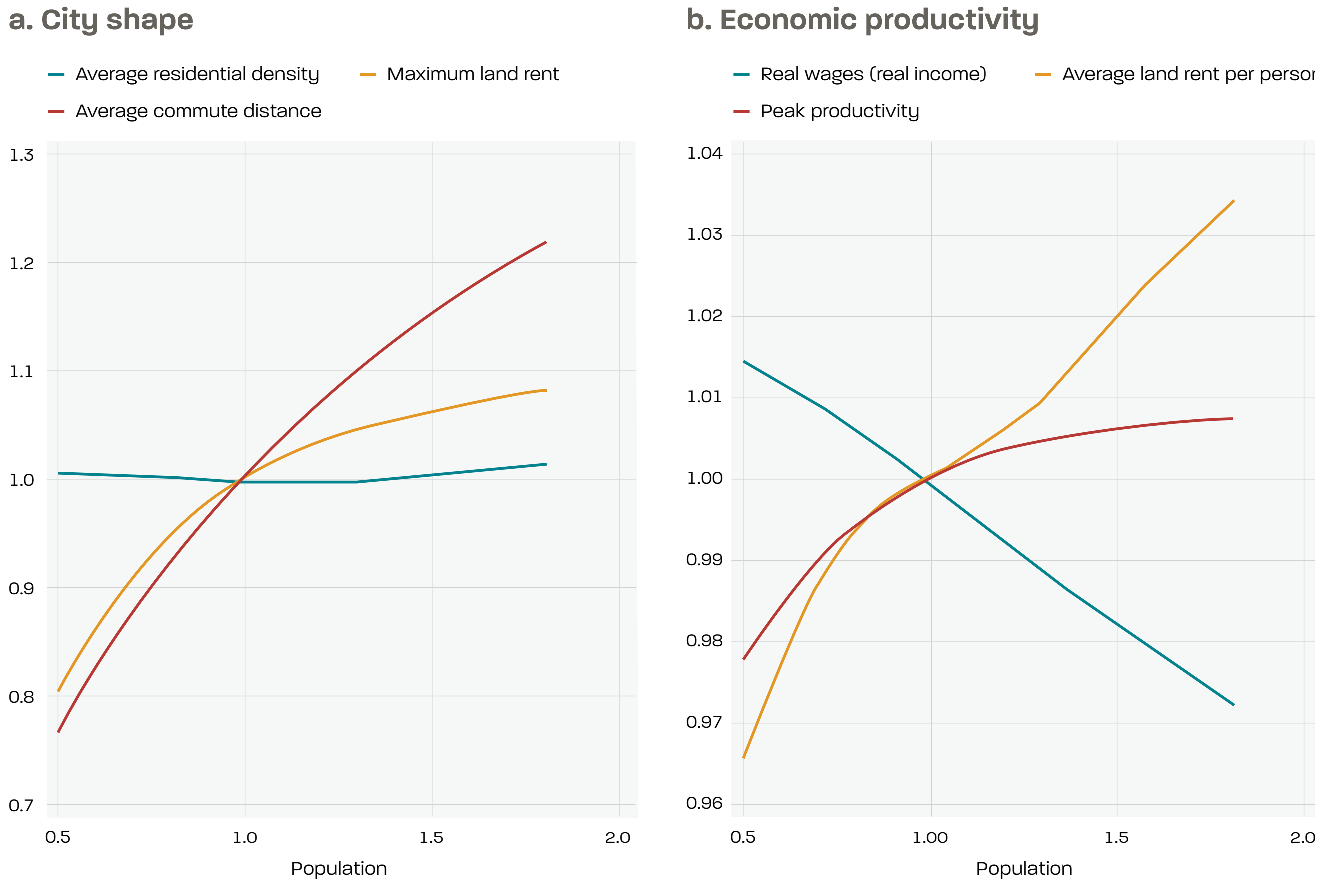
Source: Authors' analysis.
Note: Population size is fixed.

Income effects are shown in figure 3.4b. As the central cluster becomes less dense, productivity is about 3 percent lower, reducing worker household utility by 5 percent. Average land rents per capita also fall, but by less—lower rents in the central area are offset by somewhat higher rents in outlying areas.

City population size as a driver of downtown rent, building height, and employment density

Large cities tend more than small ones to form pyramids. Varying the model city's population size can quantify this generalization. In figure 3.5, the horizontal axis is population relative to the benchmark city: a nearly fourfold variation in city population size is indicated in the figure (50–180 percent of the benchmark).

Figure 3.5 Effects of city population size on other city characteristics in the new urban model



Source: Authors' analysis.

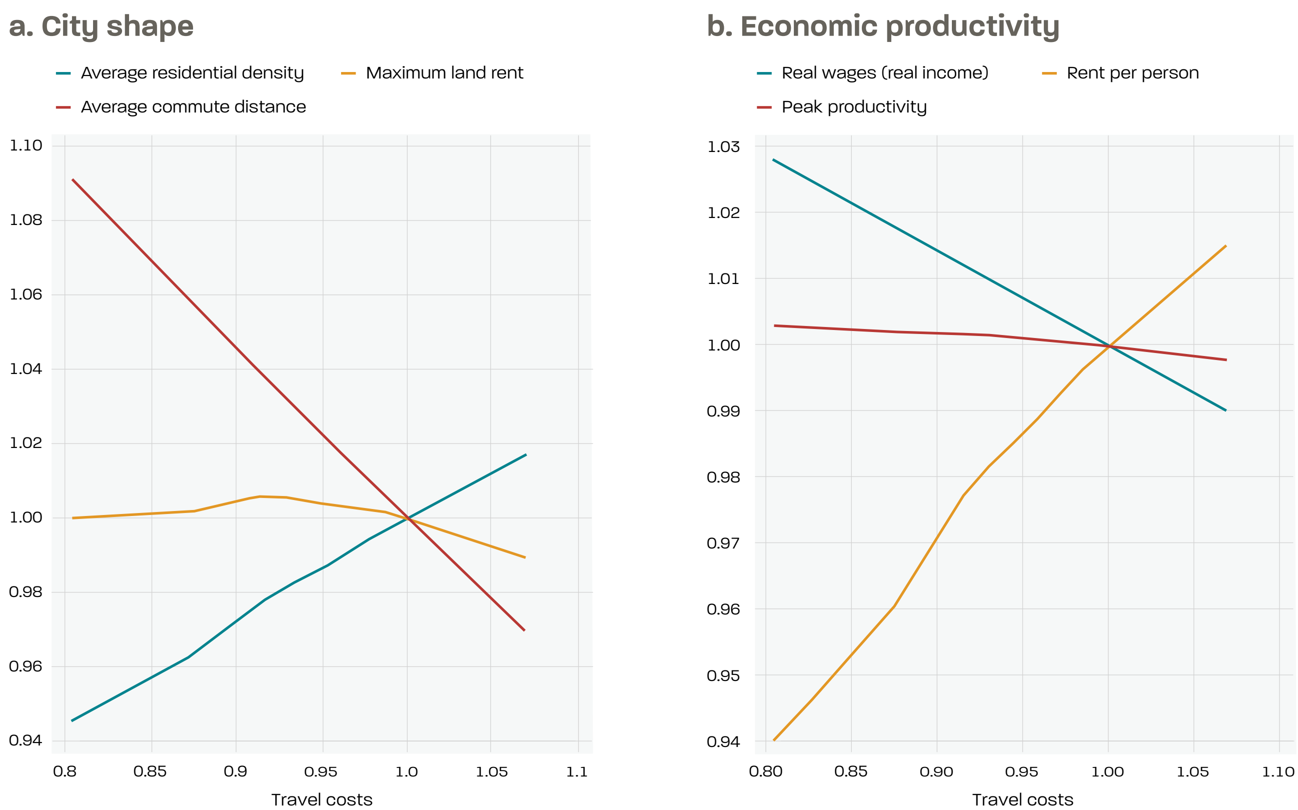
Figure 3.5a indicates that, as expected, cities with larger populations have higher rent in the center—a sign of taller central buildings and higher employment density. Yet residential density varies little, indicating that the city's built-up area grows almost in proportion to its population size. Along with this horizontal spread, average commute distance rises sharply (by more than 50 percent). Figure 3.5b shows the productivity and wage effects of population size variations. From left to right, a rise in population results in somewhat higher productivity: agglomeration economies reflect scale as well as density. Yet this rise in productivity is small relative to the nearly fourfold increase in population size as the additional employment in the city spreads over a larger land area.

As the city grows more rapidly in population size than in productivity, worker household utility (real income) bears the penalty of higher commuting costs and higher average rent per person—even though nominal wages may remain broadly in line with productivity. From left to right in figure 3.5b, as the population grows, average rent per person rises by 6 percent, while real wages fall by 4 percent. Any productivity gains that firms may be realizing in this city—which is likely to be increasingly crowded—are either dissipated in commuting costs or transferred to landowners.

Commuting costs as drivers of rents, job locations, and residential densities across the city

Reducing commuting costs has the dual effect of enabling both employment concentration and residential dispersion: forces that appear to pull in opposite directions. What is the net effect on the city's expansion, distribution of densities, and income and productivity levels? Figure 3.6 shows the effects of varying commuting costs, relative to the benchmark case. Thus, a value of 0.9 on the horizontal axis indicates that all the travel costs in the city are cut by 10 percent from their benchmark values.

Figure 3.6 Effects of commuting costs on other city characteristics in the new urban model (fixed population)



Source: Authors' analysis.

Figure 3.6a captures both the employment concentration and the residential dispersion that result from lowering commuting costs. From right to left, as the city grows in area relative to its population (a spread that is implied by the decline in commuting costs), residential density declines. But because the average commute grows longer in about the same proportion as the decline in density, the concentration of jobs around the CBD (reflected in the maximum value of land rent) does not vary much. A slightly greater employment density near the center has a small positive effect on maximum productivity, shown in figure 3.6b. Worker household utility (real income) now receives a double benefit from the commuting cost reduction—a user benefit, or direct effect from the improvement, plus wider benefits that result from the city's additional productivity. Average land rents per person fall substantially, however: as lower commuting costs increase the city's physical size, the effective supply of land for development increases.

Because reduced commuting costs imply an increase in worker household utility, a further predictable effect of lower commuting costs is migration: drawn by higher urban wages, migrants add to the city's population. This in-migration response can be captured in the model by supposing that there is a supply curve of labor to the city. If the elasticity of this supply curve is set, for illustrative purposes, at 2, then the 3 percent increase in real wages illustrated in figure 3.6b will lead to a 6 percent increase in city population. When combined, the insights from figures 3.5 and 3.6 predict dual effects from transport improvement: the combination of travel costs and induced in-migration leads to lower residential density, longer commutes, and a higher concentration of employment in the center.[2]

Transport improvements, however, generally are not citywide—instead, they entail developing particular road or rail networks that benefit some locations more than others. Most cities have some sort of hub and spoke transport network, with arteries radiating out from the center to outlying districts and beyond the city. What is the effect of adding such a radial transport network to the benchmark city? In a dramatic experiment in the model, six new roads lead radially out from the CBD, on which journeys are 50 percent faster (shorter distance) than elsewhere.[3] Adding this network creates powerful centripetal effects: the new roads advantage the central area, along with other locations along the new travel corridors. At the center, employment density and maximum rent nearly double, as the road system enables residents to move away from the CBD and downtown land becomes available for businesses and jobs—with consequent agglomeration benefits.

The real income effects of the radial road network are substantial, comprising three components. The first and smallest component is the network's direct user benefit—the value of time and cost savings, holding firm and household locations unchanged. This direct benefit accounts for a 3 percent increase in worker household utility. In addition, productivity gains arising from the city's new spatial pattern lead to wider, indirect benefits that boost real wages: these indirect benefits add a further 4 percent to worker household utility. And if all these effects are accompanied by in-migration, real wages rise still further. All told, the combined impact of direct and indirect benefits, including effects from in-migration, increases worker household utility by 9 percent compared with the city that lacks the radial road network.

2 The maximum rent schedule of figure 3.5a becomes U-shaped, increasing at low travel costs as greater population leads to a denser central area.

3 Travel choices are then made efficiently, on the shortest path between each node pair in the city.

The key messages from this experiment are two:

- Transport networks are key to creating hubs of economic activity in city centers.
- Transport networks' direct income benefits (reductions in travel time and cost) may only account for a small part of their total benefits, which also include indirect benefits driven by agglomeration economies and increased firm productivity (the combined effect of firm and worker relocation).

The modeling approaches outlined here can be used to forecast the possible effects of transport policies on city growth and development. Because these effects are highly sensitive to place and context (box 3.4), scenarios require the detailed calibration that we describe in the next section (see also Sturm, Takeda, and Venables 2021b).

Projecting the effects of policy on cities' spatial growth: The new urban model in action

Whereas the previous section provided general insights into urban growth for a hypothetical city, the new urban model can also be applied to real cities.

Modeling the evolution of a city such as Bogotá, Dhaka, or Mexico City enables city leaders to consider granular predictions about the direct and indirect impacts of potential policy interventions. Unlike reduced form methods—which can estimate only a part of these policy impacts—structural urban models estimate the broader impacts and understand the mechanisms behind them. They offer economic intelligence on the effects of policy packages as opposed to standalone efforts, and on the advisability of complementary policies to manage the downside risks of specific investments.

Structural urban models can thus be pragmatic tools. One practical use of the new urban model is to look at the wide-ranging effects of urban land use policies in combination with transit systems and other large improvements. Most transportation investments are expensive, especially in developing cities, and have broad efficiency and distributional implications. Recent modeling studies have predicted the impacts of such investments—along with complementary policies—in Bogotá (box 3.5) and Mexico City (box 3.6).

The new urban model can be used to understand the trade-offs and unintended consequences of local land use rules and initiatives, which are likely to have complicated impacts throughout a city. For example, one model allows for both formal and informal construction, enabling policy makers to quantify the costs of formalizing slums (Henderson, Regan, and Venables 2020). Another model allows planners to characterize optimal zoning across residential and commercial use, taking into account the fact that households and firms do not fully internalize the consequences for others of their location choices (Allen, Arkolakis, and Li 2016). In Bird and Venables (2019), a similar model is applied to evaluate the impact of tenure reform in Kampala, while also accounting for various types of municipal housing policy: public housing projects, slum upgrading programs, and land change.

Gechter and Tsivanidis (2020) quantify the impacts of redeveloping Mumbai's 58 textile mills during the 2000s—finding that while the amount of formal housing in the city center increased, poor residents of nearby slums were also displaced as housing prices rose across the area. Anticipating such effects would allow for complementary and compensating policies to manage these downside risks.

Box 3.4 How transport innovations have shaped cities

Historically, the main effect of transport technology—steam engines, subways, cars, and so on—has been to enable urban expansion and increase the living space consumed by households (Glaeser 2020). The transport innovations that most affected cities' spatial evolution in the 19th century were large public transit systems, such as street cars and subways. By contrast, the innovation that most affected cities in the 20th century was mass-produced cars.

In the 19th century, while streetcars and subways initially enabled urban sprawl, they also induced urban economic density through agglomeration. Enabling residences to exist farther from workplaces supported spatial expansion but also attracted jobs to city centers (see Heblich, Redding, and Sturm [2020] on the example of London from 1801 to 1921).

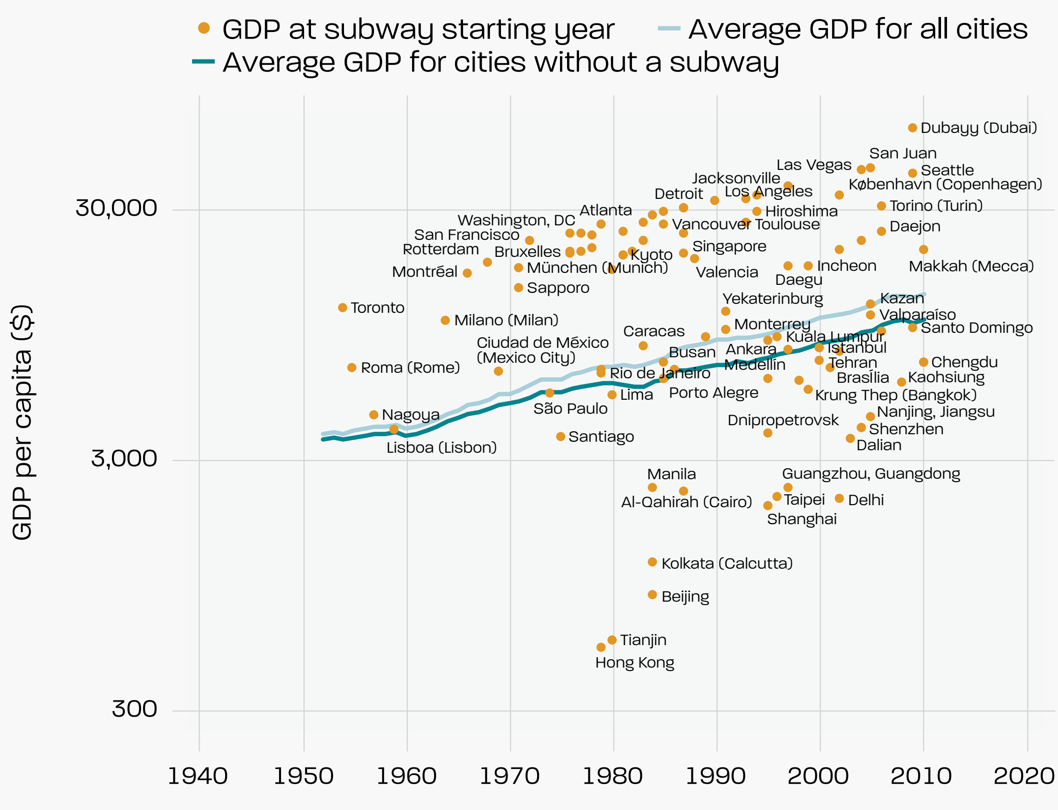
In the 20th century, the mass production of cars dramatically affected both density and living space. In the United States especially, cars reduced transport costs and strongly drove the horizontal spread of built-up area—making urban sprawl, with its associated externalities, a central challenge for city planners today (Burchfield et al. 2006).

Generally, subways lead residential locations to disperse centrifugally—but they do so less than highways have been shown to do (Gonzales-Navarro and Turner 2018). Subways are thus less conducive to sprawl. According to analyses done for this report, cities at given population and income levels are more residentially dense when they have subways.

Subway construction, however, is capital intensive. Furthermore, the success of subway investments depends on a city's density. These requirements partly explain why not all cities have subways. Among cities that do, a majority began providing subway services only after they reached $5,000 per capita GDP or higher (box figure 1).

Today, in the poorest countries, car ownership remains very low, and many workers still walk to work or to access services. As incomes rise, ownership of private vehicles is likely to follow, pushing cities outward and widening the spatial separation of residences from workplaces. But new transportation trends—such as autonomous vehicles—and broader technological changes (notably increased telecommuting) will also affect city shapes (Glaeser 2020).

Box figure 1 Most cities provide subway services only after reaching at least $5,000 per capita GDP



Source: Authors' calculations using data from Gonzalez-Navarro and Turner (2018).

Other questions remain open for which a structural model is useful to capture all following impacts and unintended consequences. For example, while building higher in the city center might seem a good idea, it also attracts more people to the city center and generates additional negative externalities that are not internalized by the households or firms moving there. Spotlight 3 discusses this question in the trade-off of urban form and greenhouse gas emissions. Another important question relates to unintended gentrification and spatial inequalities that could accompany policies that enhance the overall economic efficiency of the city. The main normative question here is, "How do we compensate and protect the welfare of the poor and vulnerable communities as regulations are changed to improve aggregate efficiency in resource allocation?" If efficiency enhancement is the main objective of reforms, the outcome would be Pareto optimal if, in principle, there would be net gains after displaced people are compensated. In practice, however, it is not clear that mechanisms exist to compensate those who are worse off following changes in housing and land markets.

The absence of compensating mechanisms means that the displacement of poor households or other vulnerable groups reduces their living standards. Although the model presented here can highlight potential displacement and gentrification following efficiency-enhancing policies, further work is needed to understand how to design and implement complementary compensatory policies.

Box 3.5 Density-enhancing land value capture schemes can amplify the economic benefits from Bogotá's Transmilenio bus rapid transit system

Quantitative models in the spirit of the new urban model can identify policies to complement expensive infrastructure and maximize returns on investments. One such analysis recently examined the bus rapid transit (BRT) system in Bogotá, Colombia (Tsivanidis 2019).

Using a model that allowed for multiple skill groups of workers with non-homothetic preferences over various transport modes, Tsivanidis quantified the BRT system's impact on aggregate performance not only through reduced time losses from travel, but also through improved allocation between workers and places of employment and residence. After accounting for reallocation and general equilibrium effects, the analysis suggested that welfare gains were 20–40 percent larger than otherwise estimated.

The quantitative model generated other striking findings. For example, it showed that Bogotá's feeder bus system (which partly solves the last-mile problem of getting residents between poor, dense peripheral neighborhoods and the BRT) improves welfare more than any single trunk line. Also, Tsivanidis ran a counterfactual exercise suggesting that if the government had adopted a land value capture scheme—increasing zoning densities near BRT stations, and auctioning building permits to developers—welfare gains could have been 18 percent higher. Further, government revenues could cover between 8 and 40 percent of the systems' construction costs.

Using the new urban model to estimate the impacts of reduced travel times and increased housing supply in metropolitan Dhaka

This section illustrates how the new urban model can be used to analyze and model various impacts on a real urban agglomeration:

Box 3.6 Transit infrastructure lowers informality rates in Mexico City

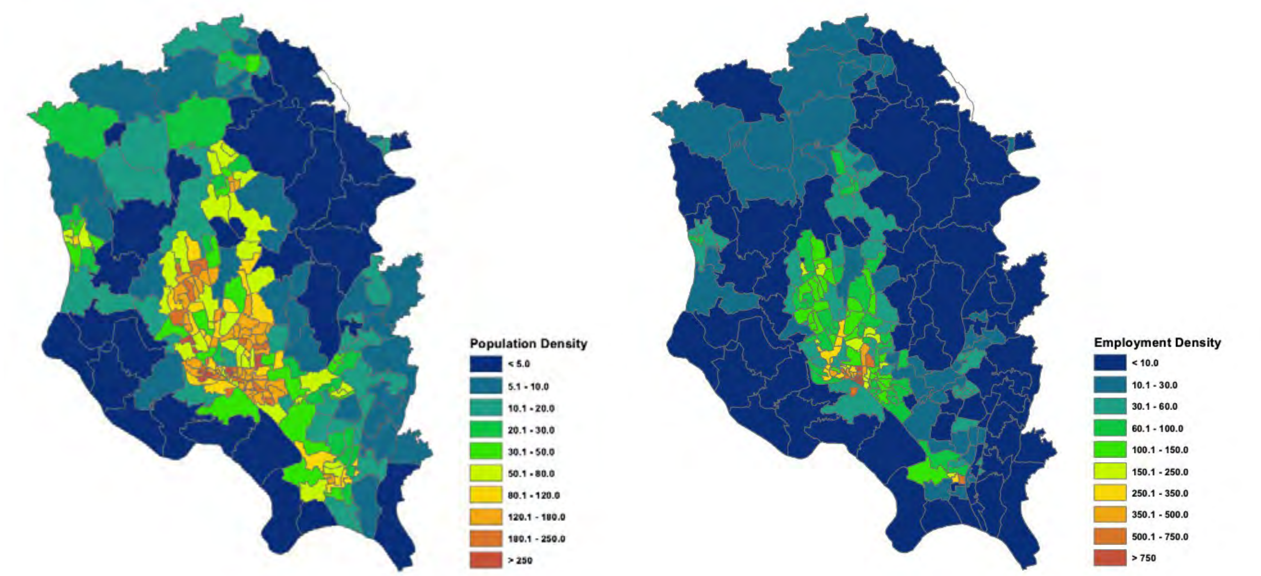
Informality presents policy challenges for most policy makers in developing cities. Can transit infrastructure increase allocative efficiency by reducing informality? A new study explores this question by analyzing the effects of metro system construction in Mexico City (Zarate 2020).

Assuming that high urban transit costs may prevent workers from commuting and thus limit their access to formal employment, and finding that informality declines by 4 percentage points in areas near the new metro stations, Zarate uses a model to estimate the efficiency gains that result. He determines that workers' reallocation to the formal sector explains approximately 17–25 percent of the total gains from the metro system—and that for every dollar spent on its construction, average real income increases by 20 percent relative to a perfectly efficient economy.

the city of Dhaka, Bangladesh. One of the major cities of South Asia, Dhaka is home to a dynamic ready-made garments industry that connects the city's economy with global value chains. Having experienced rapid population growth since the partition of India in 1947, Dhaka continues to attract new residents at a rapid pace. Today the metropolitan area covers about 1,465 square km—comparable to the Greater London Authority. We first outline the steps involved in applying the model to Dhaka, and then the results of policy experiments, including transport improvements and lower-cost building technologies.

Application of the model involves several steps. First is obtaining basic data, including counts of employment at workplaces (from the 2013 employment census, capturing both formal and informal employment) and residential population (from the 2010 population census)—both of these across the 266 wards of Dhaka's metropolitan area. Figure 3.7 shows the enormous variation in population and employment density across those wards. Central parts of Dhaka have vastly higher employment densities and much higher population densities. Employment at workplace density is just under 3 workers per hectare at the 5th percentile, while it is 485 workers per hectare at the 95th percentile, and the median is 41 workers per hectare. Similarly, population density is just over 3 people per hectare at the 5th percentile, while it is 232 people per hectare at the 95th percentile, and the median is 53 people per hectare.

Figure 3.7 Population and employment density in Dhaka



Source: Sturm, Takeda, and Venables 2021b.

Second is establishing information on the key relationships in the model. Travel times between and within wards can be obtained from city sources, but a full description of commuting flows is less easy to obtain. Kreindler and Miyauchi (2020) use mobile phone data from Dhaka to estimate the flows. They estimate that the elasticity of commuting flows with respect to travel time is −2.5: that is, a 1 percent increase in travel times reduces commuting flow by 2.5 percent on average. Kreindler and Miyauchi also report a decomposition of this overall effect into the separate contributions of commuting costs and of preference heterogeneity.

A further relationship is that between house prices and the amount of floor space supplied in various neighborhoods of the city—the elasticity of housing supply. As is the case in most developing country cities, there is no systematic data on the price of a square meter of residential or commercial floor space in different parts of Dhaka. To overcome this problem, we use newly available data from the German Aerospace Centre (DLR), in which satellite pictures allow measurements of built-up area and building height for cities around the world. Using these data, we compare the heights predicted by the model to the heights observed in the data for different values of housing supply elasticity in the model.

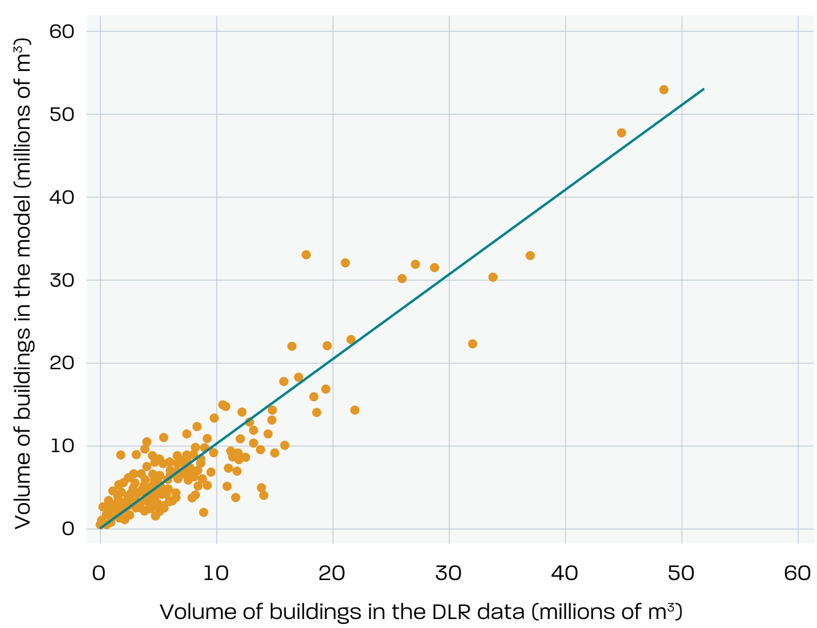
Figure 3.8a shows the variation in the height of buildings across the wards of Dhaka in the DLR data and the heights predicted by the model for the best fit value of housing supply elasticity. While the correlation between the DLR height data and the model-predicted heights is not perfect, the two are clearly strongly correlated (the correlation coefficient is 0.49) and lie close to the 45 degree line.[4] Figure 3.8b compares the volume of buildings in the data and the model, where we feed the observed built-up area into the model as data. Comparing the model-predicted heights to the observed heights in the data, the best fit value of the housing supply elasticity is 1.45: that is, a 10 percent increase in the price of a square meter of floor space in a location triggers a 14.5 percent increase in the supply of floor space. This value for the housing supply elasticity is slightly below the average housing supply elasticity estimated by Saiz (2010) across different metropolitan areas of the United States. Two reasons may lie behind this difference: one is the higher costs of building tall structures in Dhaka compared with US cities, while the other is more stringent regulatory constraints in Dhaka.

4 The DLR height data come with their own measurement error, which is—on a percentage basis—likely to be especially pronounced in lower-density peripheral locations of Dhaka. In these areas, the time lag between the census and height data probably also leads to further substantial measurement error. We take these errors into account when we estimate land prices in each location of Dhaka, as discussed in Sturm, Takeda, and Venables (2021b).

Figure 3.8 Height of buildings and volume of floor space in the model and the data for Dhaka

a. Height of buildings

b. Volume of floor space



Source: Sturm, Takeda, and Venables 2021b.

Another relationship is the agglomeration parameter—the elasticity of productivity with respect to employment density. An extensive literature has used different strategies to estimate the strength of this agglomeration force in cities. Relying on this literature we set this elasticity to 0.05, which is close to the average value of this parameter reported in the meta study of Melo, Graham, and Noland (2009). Increasing the density of employment in a ward by 10 percent therefore increase productivity in this location by 0.5 percent.

Using the basic data and these key relationships, the model can be calibrated to the observed distribution of employment and population that was illustrated in figure 3.7. The model then provides estimates of other key variables that are not directly observed. Intuitively, the model-estimated wages ensure that workers decide to commute so that the inflows of commuters to a destination match the observed employment at workplaces. Land rents are such that the observed built structures and population densities are consistent. And spatial variations in productivity are consistent with the observed pattern of employment.

Figure 3.9 shows the distribution of land prices estimated by the model. The land price is the maximum price that the construction sector can bid for land in a particular location, given its production technology and the demand for floor space in that location. The land prices predicted by the model vary by a factor of roughly 18 between the 5th and 95th percentile of the land price distribution—a range similar to the variation of land prices in cities where we have good measures of the value of land in different locations of the city.

Figure 3.10 combines the estimated variation in wages and floor space prices across the wards of Dhaka to estimate productivity in different locations of the city. Intuitively, the model predicts that firms in locations with high floor space prices and wages must have higher levels of productivity, as they otherwise would not be able to break even in a competitive market. The model predicts considerable variation in productivity across different locations, with locations at the 95th percentile having roughly 51 percent higher productivity than locations at the 5th percentile.

Figure 3.9 Estimated land rent in Dhaka

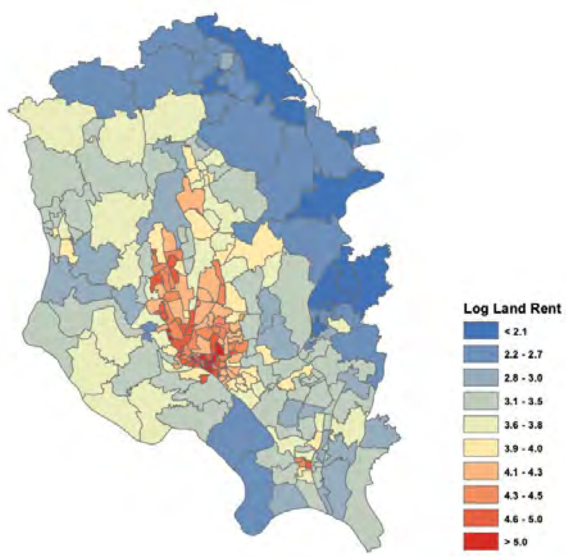
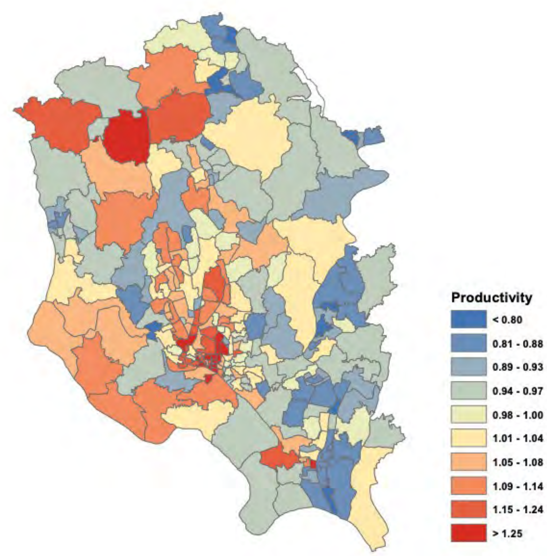


Figure 3.10 Estimated productivity in Dhaka

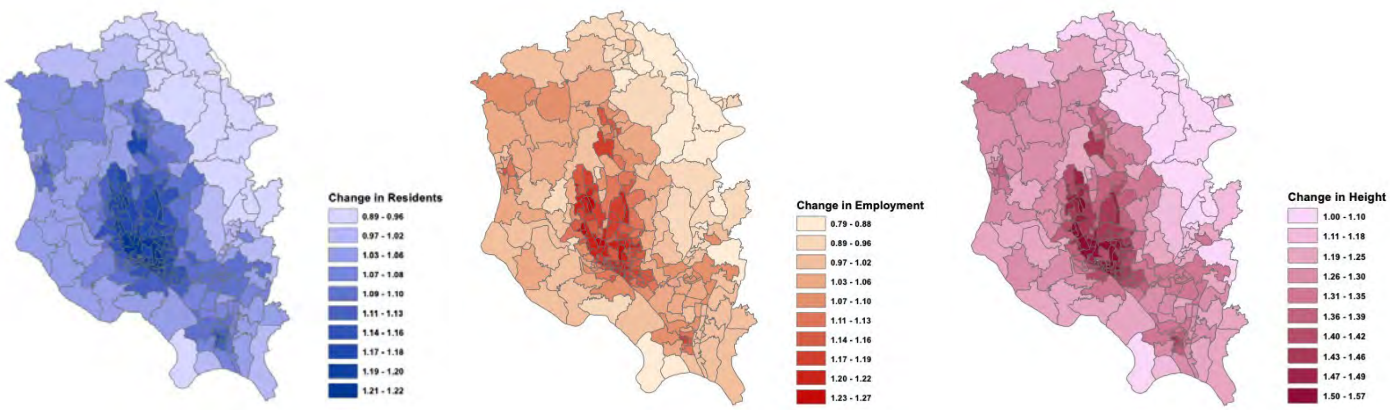


Source: Sturm, Takeda, and Venables 2021b.

Having estimated the key parameters of the model and fitted it to Dhaka, we use it to evaluate the impact of two policy interventions: a change in the density of development and the building of a north–south road through the city. The results presented here are for a variant of the model in which all employment is assumed to be in the tradables sector (T-sector), and the costs of construction for commercial and residential buildings are the same.

Figure 3.11 examines the impact of a 25 percent increase in the housing supply elasticity. To achieve this change would require either an improvement of the technology of the construction sector or a relaxation of planning constraints. Our model estimates that such a change would increase worker welfare by 5.4 percent, while the income of landowners would fall by nearly 3 percent and the total population of the city would expand by 11 percent.

Figure 3.11 Estimated impact of a 25 percent increase in the housing supply elasticity in Dhaka



Source: Sturm, Takeda, and Venables 2021b.

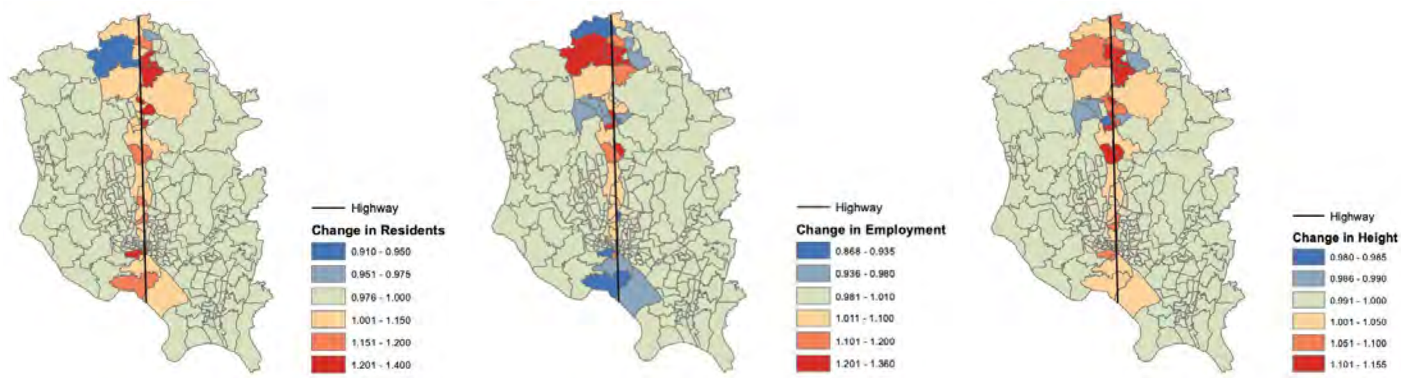
Figure 3.11 shows that while we assume that the housing supply elasticity changes by the same amount in all wards of Dhaka, the impact of this change is highly uneven. The heights of buildings in the very center of Dhaka increase by over 50 percent, while building heights in the periphery of Dhaka are essentially unchanged. This asymmetry is also mirrored by employment and population density, which both increase in Dhaka's central areas—while both decline in its peripheral wards, even as the city grows in population by 11 percent. Intuitively, relaxing the housing constraint allows employment to further agglomerate in the highly productive city center, and residents follow this trend to be close to the concentration of jobs.

A further striking insight from this counterfactual is that while the average height of buildings in Dhaka increases by nearly 30 percent, the average commuting time actually increases marginally by just under 1 percent. This at first sight counterintuitive result is driven by two opposing developments. Those living in the high-density core of the city experience a fall in average commuting times. However, the remaining residents in the peripheral wards experience a reduction in local jobs and are more likely to commute to the dense urban center as a result. These results show how important it is to take general equilibrium forces into account when assessing the impact of urban interventions.

Figure 3.12 examines the impact of constructing a new north–south road through Dhaka that would cut travel times on this route by 25 percent relative to current travel times. As the figure illustrates, the road acts as a magnet for economic activity in Dhaka with increases in both employment, population, and building heights along the road. The road would increase aggregate worker welfare by just under 0.5 percent, while the income of landowners would increase by approximately 1 percent. This illustrates that improvements in commuting speeds not only benefit commuters, but are also capitalized into land prices. These increases in land values are highly unequal, with landowners close to the new road benefiting while land values in other parts of Dhaka decline marginally.

Transport improvements—either across the city or in particular places—are just a few of the policy changes that can be explored in the model. Other experiments include the general equilibrium impacts of much more targeted interventions, such as an increase in permitted building heights in particular locations of a city or improvements in travel speeds on particular travel corridors. In each of these cases the model illuminates the general equilibrium linkages that need to be taken into account in evaluating urban policies.

Figure 3.12 Estimated impact of a new north–south radial road in Dhaka



Source: Sturm, Takeda, and Venables 2021b.

The starting point of this report is that cities are about interaction, and that effective policy requires that the interactions are understood and that their implications are factored into decision making. The modeling approach outlined here is a tool for deepening this understanding and for seeing the fuller consequences of planned or likely changes in aspects of the city. As with all modeling exercises, many important features of the city and the urban system are omitted. For example, the data allow us to infer the productivity that a place offers to firms and the amenity that it offers to households, but is the amenity due to access to jobs; proximity to a park, a train station, or a school; or the social capital of the neighborhood? The research literature provides results on some of these causal channels, but others will remain hard or impossible to quantify. In other dimensions, too, such as dynamics and the full costs of adjusting to change, progress will be made, but uncertainties will remain. Furthermore, adding detail to a model does not necessarily add insight. The new urban model should be viewed as one part of a toolkit for evaluating urban development and policy change, while being far from encompassing all the consequences of such changes.

SPOTLIGHT 3

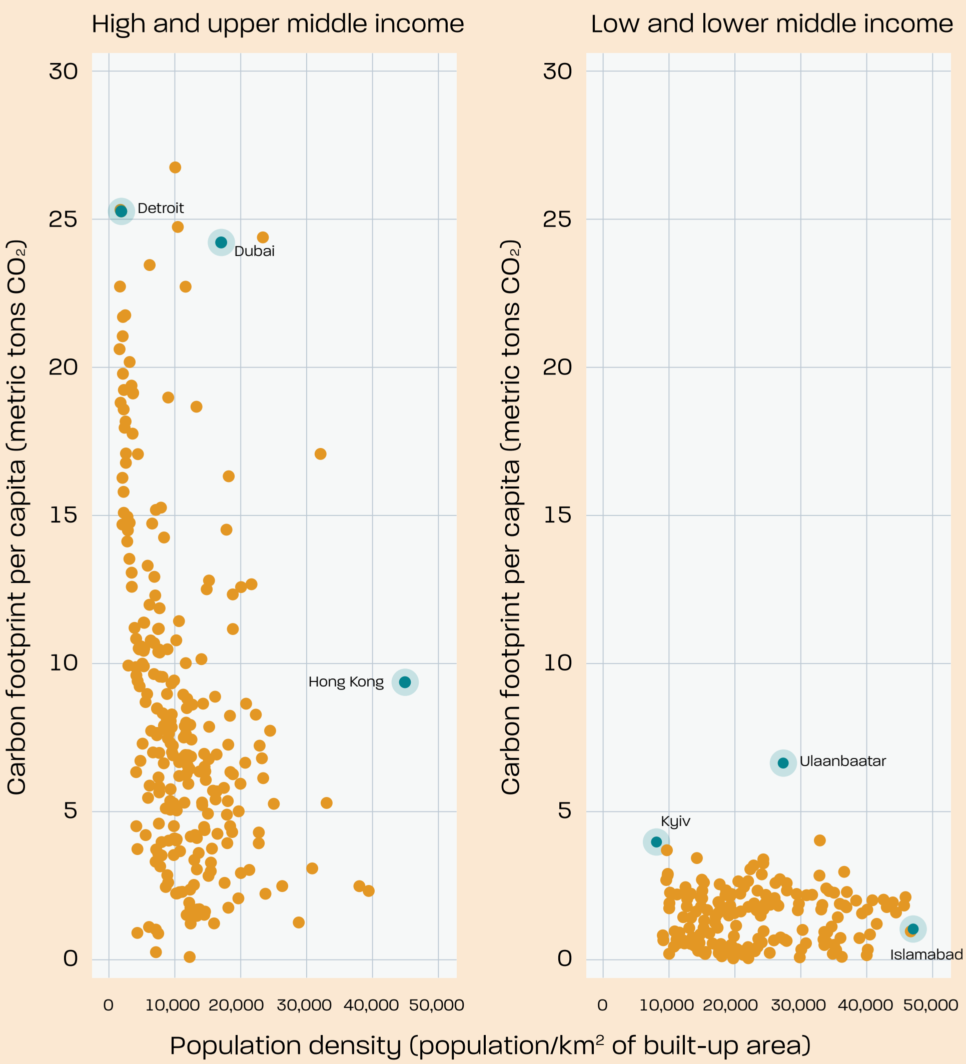
Urban form and greenhouse gas emissions

This report provides new evidence on the three dimensions along which a city grows as well as an analytic framework to examine the institutional and economic forces that shape how a city is built.

The analytic framework developed in chapter 3 can provide city-specific insights on the implications of density-enhancing policies and transportation investments on greenhouse gas (GHG) emissions. The policy counterfactuals—changes in density by increasing housing supply and the changes in transport speeds—as described in the chapter, show that implications of these improvements are not straightforward. For example, increasing the density of a location makes a place more attractive and brings in commuters from distant areas. Manhattan has a lot of skyscrapers so a lot of people can live close to work, but because it's such a great place people commute into Manhattan from distant places. They wouldn't do that if Manhattan had a bunch of bungalows. Careful city-specific analytics can help untangle the granular implications of policy efforts.

The jury is still out on the impact of urban form on greenhouse gas emissions. For example, Xu et al. (2019) [correct capitalization] show that population density and the overall physical compactness of urban land patches have opposing influences on energy-related per capita GHG emissions across EU member countries. High population density, mixed-use urban development with a lower degree of physical compactness is advisable in terms of reducing energy footprints and mitigating GHG emissions. Ma, Liu, and Chai (2015) find that compact urban development leads to low-carbon travel behavior. The evidence on the links between urban density and greenhouse gas emissions also varies across countries at different stages of development, like the relationships of building heights and built-up expansion examined in chapter 2.

Figure S3.1 While GHG emissions per capita decline with urban density in high- and upper-middle-income countries, low- and lower-middle-income cities buck the trend



Source: Authors' analysis, based on GHS–Urban Centre Database and Global Gridded Model of Carbon Footprints (GGMCF) retrieved from Moran et al. (2018).

Figure S3.1 shows that while GHG emissions per person decline with urban densities for high- and upper-middle-income countries, the association does not seem to hold for low- and lower-middle-income countries. Another insight here is that cities in low- and lower-middle-income countries are already far denser than cities in high- and upper-middle-income countries. As chapters 1 and 2 showed, cities in low- and lower-middle-income countries are likely to see greater urban expansion and reduction in densities as they develop.

Finally, research is needed to understand the relative contribution to GHG emissions of urban structures and industrial emissions that are co-located in cities. These include power plants, steel plants, and cement plants. Such a decomposition is part of future work being done at the World Bank.

Photo: Nik Shuliahin/Unsplash, Kentucky, U.S.

Photo: South Korea/Flickr

IV From pancakes to pyramids: *What city leaders need to know*

From pancakes to pyramids: *What city leaders need to know*

Pyramids are generally better than pancakes at meeting three key urban planning objectives: driving prosperity, ensuring livability, and respecting planetary boundaries. Compared with a pancake city, a pyramid city will drive more growth in urban productivity and incomes because it is more economically dense and efficient—its inward and vertical expansion reduce the distances between firms, jobs, and workers. A pyramid is also better at achieving livable urban population densities, accompanied not by crawling traffic and crowded slums, but by efficient transport connections and decent formal housing. And while a sprawling pancake is likely to impose steep burdens on the climate through unmanaged vehicle emissions, a pyramid allows leaders to plan for the city's future population growth and spatial expansion in ways that will limit or reduce its carbon footprint.

But not every pancake can become a pyramid. When a city with low productivity and low incomes adds to its population, it cannot accommodate this growth through a costly vertical layering of built-up area. Instead, such a poor and economically inefficient city can absorb newcomers only by crowding them into low-built quarters and by spreading outward where land is cheapest. Such a city will remain a pancake—and it will continue to expand in two dimensions, rather than three, as long as its economy remains sluggish and its average resident household remains poor.

As chapters 1, 2, and 3 have shown, pyramidal expansion flows from economic transformation. Only agglomeration economies, based on specialization and tradables production, can be counted on to set a city's productivity and incomes on an upward path. And only a city that is economically on the rise will generate increasing economic demand for floor space—the prerequisite for land developers to invest in multistory construction around business districts and elevate the urban skyline.

How can city leaders and decision makers act to shift urban expansion to a pyramidal trajectory? First, they should never aspire to transform pancakes into pyramids where urban economic productivity is low, where demand for floor space is weak, or where inefficient land markets impede formal investment and redevelopment. Plans that try to force a neighborhood's vertical expansion through legal and regulatory incentives alone—without sufficient market demand for floor space, or without functioning factor markets and adequate private investment—will yield only ghost districts, their tall structures disused or underused. Such plans run afoul of basic principles of economic geography.

Second, once leaders recognize why mandated pyramidal growth plans cannot work independently of the economic drivers of urban spatial evolution, they should investigate the more realistic options that remain. While these options differ from city to city, they can appear more readily through the new urban model described in chapter 3 (data requirements are summarized in box 4.1). Leaders can use this model to assess the likely impacts of particular plans and policies on future urban spatial growth—given a range of alternative scenarios for economic transformation and rising productivity—along with the predicted effects of these scenarios on firm and household location decisions over time. The new urban model can thus clarify how the city's future physical form and human geography might respond to public investments—notably in transport infrastructure—and to changes in zoning laws, building codes, and land use regulations. All of these policy choices will affect the quantity and spatial distribution of urban floor space, including patterns of residential density, as developers respond to changes in demand.

After determining which urban plans, regulations, and investments are best aligned to promote future urban prosperity and sustainability, city leaders must put their strategies into practice through coordinated action on three fronts—economic, spatial, and financial. Chapter 4 analyzes these closely linked challenges under the three section headings that follow:

- ***Planning for economic growth and productivity.*** Leaders must provide an institutional environment that not only enables economic agglomerations for increased productivity and incomes, but also ensures demand-responsive urban planning regimes and allows for the future provision of floor space to meet rising demand. Land must be formally transferable and thus accessible to development: ownership must be legally clear, and land market transactions efficient. Land use and building height regulations, where used, must be appropriate and not needlessly restrictive. In the absence of a predictably functioning and fluid land market, developers cannot confidently expect high returns—and will never make the high capital investments needed for vertical layering, which would define the city's evolution from a pancake to a pyramid.
- ***Infrastructure planning for economic density, livability, and sustainability.*** In evaluating infrastructure investments, leaders should focus on supporting the market forces that will drive urban economic agglomeration and productive job creation within an environmentally responsible vision for longer-term spatial expansion. The central challenge is to coordinate investments with land management, aligning connective infrastructure plans with land use regulations to shrink economic distances between areas of potentially high economic productivity and high residential density. Also vital are public goods and amenities that will directly result in a more livable and sustainably dense city. The new urban model can provide leaders with valuable economic intelligence to assess the likely impacts of infrastructure investments and regulation—and can point out risks that demand careful management.
- ***Durable financing for capital investment costs and recurring expenses.*** The vital link between economic growth policies and infrastructure plans, durable financing is essential to pyramidal development. Investing in urban infrastructure is a capital intensive proposition in the short, medium, and long terms. To build and maintain a high quality and affordable transport system—or any other urban public service or facility—means mobilizing revenue to cover both the initial investment and later operating costs. Accordingly, leaders must identify financing solutions for the city to anticipate and meet its future needs. City governments should clarify

Box 4.1 Data requirements for the new urban model

The basic data needed to compute the new urban model—as described in chapter 3—are the following:

- A *GIS shapefile* that partitions the city into a set of locations.
- *Population data* (or data on the economically active population) for each location in the city.
- *Employment data* (if possible, by sector) for each location in the city.
- *Travel times* between all pairs of locations in the city.

Note that in defining the city by area, it is important to include enough of the hinterland that everyone working in the city can be plausibly assumed to live within the city perimeter.

In a developing country, two additional data types are likely to be valuable:

- *Mobile phone data* to estimate commuting flows and, if needed, employment and population in each location of the city.
- *Satellite data on built-up area and building heights* to estimate the housing supply elasticity and floor space prices.

Further data that could be used to inform or check model parameters include *household surveys* reporting household expenditure shares, *firm surveys* reporting firm input shares, *commuting surveys*, and *real estate price data.*

Source: World Bank.

regulatory frameworks that pertain to municipal borrowing, public–private partnerships (PPPs), and land value capture transactions. Also helpful is to streamline intergovernmental fiscal and institutional frameworks. While cheap financing can raise money for investment, repaying the principal requires a solid funding base—and that will require strong economic fundamentals based on urban agglomeration economies.

Alongside this chapter's specific practical guidance, city leaders ought also to keep in mind some broader lessons from *Pancakes to Pyramids*. One is that every city, regardless of its productivity and income, must plan for spatial development along all three margins: not just inward and upward, but outward. While poorer cities tend to develop as pancakes for fundamental economic reasons, it is also normal for richer ones—including pyramids—to continue their horizontal expansion. No city that keeps increasing its population will stop extending outward altogether, unless it is inhibited from doing so (and such inhibitions can be costly to the city's economy and to urban residents). So sustainability initiatives should not obstruct horizontal spread but should plan for it. Meanwhile, urban regulations and policy interventions, including investment, are necessary to create a favorable environment for infill construction and vertical layering.

Another general lesson is that urban economic and spatial transformation form a virtuous cycle: if rising productivity and incomes in urban agglomerations can drive vertical layering and livability through the addition of floor space, this pyramidal expansion and increasing residential density can then feed back into the economic density that drives agglomeration forces. Furthermore, this economic and spatial virtuous cycle can spin off many options for sustainable urban development—from the revenues that finance low-carbon transit infrastructure, to the shifting preferences that lead to greener commutes and less carbon-intensive consumption in rich cities.

A final key point is that while urban pancakes and pyramids are spatially opposed, the fundamental drivers of urban development—and of the well-being of urban residents—are not spatial. Instead, they are economic and institutional. A rise in average population densities across a city and the rise of a peaked downtown skyline may reflect strong agglomeration forces and complementary institutions. Nevertheless, achieving pyramidal growth should not be the focus of urban policy or the key metric by which success is judged. Improving a city's livability and sustainability must be.

Policy making for economic growth and productivity—strengthening institutional foundations

While low-income and low-productivity cities cannot be transformed into pyramids today, decision makers can set the stage for future transformative growth by establishing the right institutional environment. Because economic and physical transformation go hand in hand, cities need integrated legal and regulatory reforms and frameworks that will enable both economic and spatial development. Especially important are steps to strengthen land markets and urban planning institutions. Low- and lower-middle-income countries are expected to dominate demographic urbanization in the coming decades (box 4.2)—and these, in general, are the countries with the weakest urban institutions and planning capacities today.

City leaders and planners will need adaptable strategies. Plans and regulations should allow the best use of land—but they must also allow changes in land use, and in users, as demand evolves further. Three key considerations will be how to:

- Reform land markets and clarify land and property rights.
- Strengthen urban land use planning.
- Manage land valuation and prices.

Box 4.2 Urbanization in low-income and lower-middle-income countries: How will it drive global demand for urban floor space in the coming decades?

The United Nations projects that 2.3 billion people will be added to urban areas between 2020 and 2050, with 90 percent of this increase taking place in Asia and Africa (UNDESA 2018). Urban population growth will be concentrated in a few countries. China, India, and Nigeria will account for 35 percent of the projected growth. These are significant numbers, to be sure—but proactive planning can help developing country cities prepare for such growth.

It is useful to place these projections in perspective. An additional 2.3 billion people over 30 years translates into 42 percent growth, or 1.4 percent annually. Low-income countries will experience 65 percent growth (2.15 percent annually), and lower-middle-income countries 107 percent growth (3.57 percent annually)—considerably higher than richer parts of the world.

If the past foretells the future, the estimates in chapter 2 can help us understand how population growth will affect global demand for floor space in cities of low- and lower-middle-income countries globally. A conservative estimate, with no productivity growth, would suggest that between 2020 and 2050 these cities' built-up area will need to expand by 64 percent (low-income cities) and 36 percent (lower-middle-income cities). An optimistic estimate, with higher productivity and doubled incomes, would generate an additional 10 percentage points in demand for built-up area in each city category. Rising populations and incomes would also increase the demand for vertical layering.

Reform land markets and clarify land and property rights

Land market inefficiencies appear widely in cities in the developing world, for reasons that range from unclear ownership rights to inefficient land allocation mechanisms and development regulations. And wherever land markets do not function well, urban land tends to be underutilized. Prices for central locations are likely to be too high. Land in those locations may go unused, or it may be underdeveloped with low floor space or low built-up area. To enable these cities' future transformation into dense and livable urban areas, the first prerequisite is to improve access to land.

Facilitating developers and households' access to buildable land requires unambiguous and tradable land and property rights. Informal land markets are just not good enough for cities in developing countries, especially those experiencing rapid economic and population growth. Urban land is a vital economic asset, and asset transactions are viable only where purchasers can rely on enduring documentation of ownership. A formal market both offers purchasers the state's protection and—because transactions are readily observable and recorded—generates the public good of accurate valuation.

The first requirement of an effective and enforceable land and property registration system is tenure security. Such security enables land transactions to proceed unhindered by insecure land tenure arrangements—arrangements that limit trade, in practice, to parties who live locally or inside small circles of trust. Globally, an estimated 70 percent of all land lacks formal title.[1] Alternative forms of tenure security include certificates of occupancy and usufruct rights, along with other forms of partial tenure that protect the rights to use and exploit land. Some forms of tenure security, though not equivalent to formal titles,

1 https://www.worldbank.org/en/news/feature/2017/03/24/why-secure-land-rights-matter.

enable land transactions or permit access to credit—giving assurance to households to invest in improving their housing conditions without fear of uncompensated eviction (GLTN n.d.).

Perceptions of weak or nonexistent land tenure security are widespread. According to a recent global study on perceptions of property rights by Prindex (2019), one-fifth of persons globally expressed fears of being forced out of their homes against their will in the coming five years. And because this study was conducted prior to the Covid-19 outbreak, it likely underestimates current perceptions of tenure insecurity. Countries that have invested in strengthening their land administration systems—for example, Rwanda and Singapore—have only a limited share of the population (less than 10 percent) reporting such perceptions. But this figure rises up to about half the population in other countries that have not invested sufficiently in land registration, such as Burkina Faso and the Philippines (Prindex 2019).

Without secure property rights or perceived tenure security, households will not invest in improving their shelter beyond minimal repairs. Similarly, governments will rarely invest in improving access to infrastructure and services for settlements that lack formal property rights. Such settlements often do not even appear in official city maps. Without private investment in shelter or public investment in infrastructure, slums and informal settlements remain unlivable (box 4.3).

Besides clear land and property rights, a government's ability to assemble privately owned land for urban expansion or redevelopment also requires a coherent policy and regulatory framework for land assembly: one such framework is *land readjustment* (Rabé 2010). The most commonly used tool for expanding urban boundaries on the periphery of cities, land readjustment is also used for infill development. The government pools privately owned parcels in an area and prepares a land use plan, designating spaces for public

Box 4.3 Urban slums—a lagging indicator of inefficient land markets

Land market inefficiencies often arise from a lack of formal title and from perceived tenure insecurity. Such inefficiencies inhibit cities' formal development, making housing unaffordable within cities and contributing to exurban sprawl. In addition, these market failures restrict central population densities and thus price out poor residents from adequately located land. Poor people who need to live within reach of job opportunities, yet who lack access to public transportation infrastructure, often find themselves with no option but to settle on marginal land, which may be at risk of flooding and landslides. Such settlements tend to become crowded and unlivable slums.

Nearly a billion people globally live in these slums (including squatter and other informal settlements). Their land tenure is insecure, their housing is substandard, and their infrastructure connections are typically poor, lacking water, sanitation, or stormwater drainage.[1] Not surprisingly, such places correlate with Covid-19 hotspots (Lall and Wahba 2021).

The good news is that many low- and lower-middle-income countries are taking steps to clarify land rights and thus make land markets more efficient. Botswana took the bold step of regularizing customary lands in 2008, partly because the Land Boards faced challenges to administering tribal land (Malope and Phirinyane 2016). Namibia recognizes traditional leaders as part of the formal land system; they are designated by the president, and their details are published in the government gazette (United Nations 2015). And Zambia passed a new planning bill in 2015, extending planning controls across state and customary land and designating all local authorities as planning authorities (Wesseling 2016).

Some countries and cities are also developing hybrid regimes to make formal and customary land rights administration more compatible. For example, in Nigerian states with largely Muslim populations, the emir's representatives subdivide and allocate land with the help of volunteer professionals from government: an example is the city of Rigasa, in the extreme west of Kaduna (Igabi, Local Government Area, Nigeria; Lloyd-Jones et al. 2014).

1 https://unstats.un.org/sdgs/report/2019/goal-11/ (last accessed February 20, 2021).

infrastructure and services such as roads and open spaces. It then implements the plan, providing trunk infrastructure, and distributes lots to landowners, proportional to the original parcels but smaller (for example, 50–60 percent). Because the new lot is serviced, it is worth more than the landowner's original parcel. The government retains selected, strategic land parcels, which it auctions or sells at market rate to recover the cost of infrastructure and service delivery (Lozano-Gracia et al. 2013).

Land readjustment is useful for urban regeneration where land ownership is divided among many private parties because such readjustment avoids the need for the government to buy land outright. Yet it presupposes strong local institutions and a sound legislative framework. Land readjustment has been used in Germany, Japan, and the Republic of Korea to assemble and plan privately owned land on the peri-urban fringe and develop it with infrastructure and services. In Japan, 40 percent of the total annual supply of urban building plots from 1977 to 2000 was secured through land readjustment. In the Republic of Korea, 95 percent of urban land delivery between 1962 and 1981 occurred in the same manner (Povey and Lloyd-Jones 2000).

Land readjustment has proved a successful instrument for urban redevelopment—notably in Bangkok in the 1970s and 1980s, when rapid economic growth drove up urban land prices. Many slums were in accessible urban areas, which now became desirable to developers. To accommodate commercial development without displacing residents, the government brokered seven land-sharing deals with slum dwellers. Existing development was to be densified, enabling the verticalization of low-rise or low-density residential uses and the opening of some of the land for new development. The seven deals—struck in cases where land rights had long been disputed between landowners and 10,000 slum dwellers—allowed the building of high rises for existing residents, while releasing other portions of the land for lucrative real estate development. In all seven cases, the slum dwellers paid for part of the construction through a loan program. Generally, land sharing can work both for squatter households, which gain the right to remain on the site (though in new, multifamily, medium- to high-rise housing), and landowners, who recover and benefit from part of their land (Rabé 2010).

Another use of land readjustment was in Mumbai, where the World Bank supported the India Mumbai Urban Transport Project: a vertical resettlement program for about 100,000 residents who formerly lived in urban slums and shantytowns along aging roads and railway tracks. Through consultations with local displaced persons (DPs), the Maharashtra State, Indian Railway Authorities, and nongovernmental organizations, the project resettled DPs into apartment buildings close to their current locations in an effort to preserve their social fabric. As an incentive to apartment builders, tradable development rights— described in the next subsection below—enabled builders to acquire subsidized floor area ratios (FARs) for constructing additional commercial space.[2]

An alternative to land readjustment is state expropriation of private land. Through powers of eminent domain, governments can seize land to pursue a public purpose—such as the provision of public infrastructure—while following a due process, which includes compensation for the previous owners at the market or replacement value of the land expropriated. In instances where governments control public land, an up-to-date inventory of landholdings and a market-based allocative system (auctions, sealed bids, or market valuations) can ensure that land is allocated to its most efficient use, and affordable housing subsidies can be granted to eligible residents.

2 https://www.worldbank.org/en/country/india/brief/mumbai-urban-transport-project.

Strengthen urban land use planning

Two government instruments are vital for enhancing urban connectivity, productivity, and livability:

- ***Land use planning***—the distribution of land uses across space together with transportation and mobility infrastructure.
- ***Zoning regulations***—the rules that govern population density, building heights, and floor space.

What leaders do not always recognize is that both these instruments have fundamental economic effects, and that their design will influence the market drivers of urban economic development—for good or for ill.

Economically, land use planning and zoning regulations are critical because their absence will generate negative externalities and coordination failures. Unregulated markets are unlikely to yield the most economically efficient quantity or density distribution of urban built-up area, and they are unlikely to provide a city with its economically ideal form. The reason is that, while firm productivity and job generation through density are positive externalities accruing freely to all, the investments needed to make higher population densities economically efficient—such as roads, buildings, and network utilities—are not fully internalized by firms and households. These market and coordination failures lead to suboptimal investment and, ultimately, weaker productivity gains, slower job creation, and lower wages.

In addition to land use planning and zoning regulations, a supplementary instrument considered in this subsection is *transferable development rights.* Described below, such rights can introduce dynamism into land markets and enable efficient development and density distributions in line with market demands.

Land use planning. Well-functioning cities will provide public services, such as policing and health care, along with physical infrastructure—roads, drainage, street lighting, electricity, water, sewerage, and waste disposal—in ways that benefit from complementarities and economies of scale. Moreover, all these services and infrastructure elements must be provided at once: addressing just one or two of them is of little value if the others remain unresolved. Land use planning can help prevent these failures through foresight and strong implementation.

That said, not all land use planning approaches lead to viable results. The preparation of a master plan is too often a static exercise, taking so much time that when the plan is adopted, conditions have changed and the plan is no longer enforceable. Or the process may be a supply-driven exercise based on rigid planning and engineering norms, such as the strict separation of land uses, the adoption of road hierarchies, and low built-up densities: norms inherited from colonial regimes or imported from other countries. These cases reflect a disconnection between the planning process and the land uses that firms and households require—and, perhaps, a disconnection from the city's socioeconomic and cultural reality.

The more viable land use planning processes are those that are more responsive to demand. Cities including Seoul and Singapore have adopted demand-responsive planning through the integration of land use and transport infrastructure, and through the adoption of high FAR densities and mixed-use development. For instance, the FAR for commercial developments in downtown Singapore (called the Gross Plot Ratio, or GPR) ranges around 10–15, which allows for efficient land development and urbanization.[3] In contrast, cities such as Mumbai and São Paulo have traditionally had low FARs, around 1.5–2.5—a figure that is too low and does not allow for optimal land development.[4]

3 In fact, the Urban Redevelopment Authority (URA) of Singapore provides a map with the detailed land use and development control information at the parcel level for the city at: https://www.ura.gov.sg/maps/?service=mp.

4 São Paulo allows for the FAR to increase to 4 in certain specially designated areas for urban operations with the additional development rights—called certificates of potential additional construction or CEPACs—described in the subsection on "Tradable development rights" (World Bank 2013; Smolka 2018).

Cities including Curitiba and Tokyo have also promoted transit-oriented development approaches that create higher densities and mixed uses around public transportation nodes, resulting in a dynamic, dense, and livable built environment.

To be both viable and strong, urban land use planning institutions must have a unique power of enforcement. Empowered public authorities are essential to enforce private property rights. Because building the city depends on private rights over land and structures, planning enforcement is fundamental to successful urbanization. For land registers and mortgage collateral to perform their core functions—supporting a land parcel market, providing finance for investment in structures—they need well-functioning on-the-ground enforcement.

Zoning regulations. Zoning regulations similarly require public enforcement. For the purpose of increasing market efficiency, zoning regulations have two functions: coordination and information.

- ***Coordination***—or the alignment of firms to a common, publicly set standard—lowers development costs by providing standardized designs.
- ***Information*** is provided by standards that govern structural features observable only during construction, such as foundations. Such standards enable property transactions by assuring later purchasers that they have sufficient information about what they are buying.

By supporting property valuation, both the standardization and the information functions of zoning regulations enhance structures' collateral value.

Transferable development rights. In some instances, a property's location and land value would warrant higher density development, but the property is legally protected through preservation—either as a historic building or as an open space that provides a valuable amenity. Landowners can be compensated for such government restrictions on their development rights through a transfer to them of transferable development rights (TDRs). Owners can sell permissible TDRs to developers in areas designated for additional densification potential.[5]

In the United States, New York City used TDRs to preserve its historic Grand Central Station and its High Line (which was transformed into a linear park), and Boston has used TDRs to preserve historic neighborhoods such as Back Bay, while cities have also used TDRs to control urban sprawl and preserve agricultural lands at the peri-urban fringe (Waldek 2018). In Brazil, São Paulo has pioneered related market-based tools, such as the auctioning of additional development rights (CEPACs, or certificates of potential additional construction) beyond the maximum FAR in the designated densification zones called "urban operations." The sale proceeds are used to finance infrastructure upgrades in the area. São Paulo city also has an instrument called Outorga Onerosa, which allows property owners to build as much as 20 percent extra onto their development by paying a fee into a general fund for infrastructure improvement in the city. The city's rationale for introducing such instruments is to decouple land ownership from the development rights and to monetize the latter for revenue generation, offsetting infrastructure improvement costs (Smolka 2018).

5 Djankov et al. (2020) make an important distinction between possessory and transferable rights in the context of urban spatial structure. While weak possession rights reduce the incentives to build better housing or own more land, limited ability to transfer property makes it difficult to match workplace with home location and enable redevelopment of urban land. When possessory rights are limited, residents must either invest in self-protection or risk losing their property, and both the costs and the risk scale up with investment: thus, residents invest less, they consume lower quality housing, and urban density levels are higher. When transfer rights are limited, people are stuck in place even when economic circumstances change.

Manage land valuation and prices

The key to economically efficient urban land use is the land market. Because a land parcel's initial use may become less efficient over time, efficiency requires land to shift among various uses and thus among various owners: such shifts are central to a city's expansion and infill development. Although land use generally should be as free of restrictive regulation as possible, public intervention is sometimes required to offset market failures (Henderson and Wang 2007; World Bank 2013). For example, while land markets allocate land between urban and rural uses, governments may create incentives to conserve farmland and green space. Similarly, while markets allocate land among various urban uses, governments need to legislate and regulate to prevent neighborhoods from being underserved and to prevent disruptive land use.

The market's efficient allocation of land use requires not only legal mechanisms for land transfer—including clear titling and tenure arrangements, discussed in the subsection above—but also ways for market actors to price land parcels in accordance with their fair value. In developed countries, markets determine land values and prices through an examination of property attributes and market data from similar transactions. Governments manage existing data on land prices to provide up-to-date and reliable information for professional appraisers as well as the general public.

In developing countries, by contrast, market actors face many challenges in valuing and pricing land. One common obstacle to land valuation and pricing in developing countries is a lack of basic institutions. If land registries exist, they are likely to be archaic, lacking the dynamic functionality that allows them to be searched or updated quickly. For example, Kenya's valuation and rating system has not been updated since colonial times, and property rolls are outdated: Mombasa's was last updated in 1992, Nairobi's in 1981 (World Bank 2016a). Some cities in Ethiopia do not even have such rolls (World Bank 2015a). In Malawi, only ratable areas are listed and valued for tax purposes, even though some nonratable areas have become indistinguishable from ratable areas. As a result, Lilongwe City Council's property valuation roll is estimated to list about 45 percent of the properties in the city, and Blantyre's lists about a third (World Bank 2016b). In Ghana, property valuations have not changed in the past 15–20 years (World Bank 2015b).

Many developing countries thus lack the capacity to systematically record and manage information on land transactions—and where transaction data exist, they may not reflect the true price of land, whether because of widespread informality in land transfers (to save on duties) or because of heavy public subsidies on housing and land use. With no credible system to discover and disseminate land values, the risk of land undervaluation is substantial, as buyers may attempt to defraud existing landowners. But even honest buyers can face challenges in determining a fair offer: too often, developing country cities lack ancillary data to indicate a parcel's income generation potential and its development input costs.

Public initiatives to improve land valuation systems can promote economic development. During the 1970s, the Republic of Korea brought transparency to land valuations and made information on land values widely accessible by encouraging the development of a cadre of property appraisers. In previous land acquisitions, local government officials had assessed market values and asset replacement costs. In 1972, the government introduced the Basic Land Prices system, which mandated the assessment of land and buildings by certified private appraisers. Estimated property values from two appraisers were averaged for a final value. If the two appraisals differed by more than 10 percent, a third private appraiser was selected, and a new average calculated (World Bank 2013).

City leaders in several developing countries are now making similar efforts to improve land valuation systems. Between 2008 and 2010, the city of Bogota updated its cadastral database, revaluing the 2.1 million properties it contains and generating a new revenue stream of $171 million annually (Ruiz and Vallejo 2010). To complete the cadastral update, the government introduced information technology, consulted with stakeholders, and began estimating property values using spatially detailed information from GIS systems (Uribe 2010). Because no property transaction information was available, a team of expert appraisers collected price data using a combination of approaches to yield an appraised value. But to keep property taxes progressive—and to avoid resistance from property owners—the city imposed a cap on property tax increases. (Such caps exist in developed countries for various reasons, not all of them dictated by economic efficiency or by the public good: in the United States, tax assessors' calculated property values are assumed to reflect around two-thirds of market value.)

The dearth of publicly available data on land and property prices in developing countries prevents analysis that is critical for appraisals, not only by market actors seeking to value land, but by governments seeking to tax real property and sales of land. The result is to deprive cities of public revenues that could be raised through local financing mechanisms involving real estate and infrastructure. The integral role of land valuation in local public revenue generation—whether through taxation or through the sale or lease of public land—is discussed in a separate section below.

Infrastructure planning for economic density, livability, and sustainability—scaling up and evaluating investments

Linked to the functioning of a city's land markets is its demand for physical structures, infrastructure, housing, and amenities—and some parts of this demand are especially tricky to meet, because they need to be anticipated early. To set the stage for future economic growth and pyramidal development, city leaders in developing countries not only need to plan for the present: they need to plan far ahead.

The emergence of thriving, livable, sustainable cities depends in large part on physical structure and infrastructure investments, which come with particular challenges. One is *path dependence.* Another is *interdependence.* These challenges imply a need for thorough *coordination* among infrastructure investments, land use plans, and zoning regulations. And whichever viable options are chosen, they must begin with *early infrastructure investment* to set cities on a path toward density and productivity.

Understand path dependence

To attain pyramidal growth, urban development needs to follow a path that makes financing as feasible as possible. It is critical for leaders to recognize that not all paths are equally affordable, and that cities are less likely to reach the goal if they set out in the wrong direction. New housing, infrastructure, and industrial premises will vary widely in cost according to how they are sequenced. All three will be least expensive and most feasible if they are made in the following order:

1. ***Infrastructure,*** planned to set high expectations for future economic development stages.

2. ***Housing,*** enabled by connective infrastructure, a functioning land market, and demand-responsive land use regulation.

3. ***Industrial premises,*** attracted by efficient connections inside and outside the urban

area, by agglomeration economies, and by a reliable labor supply in a prosperous and livable city.

Why invest in infrastructure first? Because sewerage, drainage, electricity, clean water, and internet connectivity are cheaper if they are provided all at once—at full scale—than if they are added individually to houses and factories in a piecemeal fashion over time (Collier 2016). Furthermore, urban structures share a "putty clay" quality: once constructed, they are difficult to modify and can stay in place for more than 150 years (Hallegatte 2009).

Account for the interdependence of infrastructure and physical structures

Another challenge is the interdependence of public infrastructure investments with private investments in physical structures. For firms, the productivity of premises depends on proximity to infrastructure, workers, and customers—a proximity defined not just by physical distance but by transportation options. For households, the utility of housing depends on firms' investments in accessible jobs—an accessibility that also reflects transport network planning. However, for the city that must finance transportation infrastructure and decide on public transit investments, a rapid transit system is more viable where both economic and population densities are higher.

Alongside this interdependence of public transport investment choices and firm and household location decisions, any additional social returns to infrastructure—such as sustainability—will also reflect the proximity of dense residential neighborhoods to hubs of economic activity where firms are located. In addition, much of a structure's financial value is determined by complementarities with other structures in the neighborhood or city. Yet path dependence makes these complementarities a matter of prediction as well as observation: investors need to anticipate what other structures will be built nearby. Finally, these predictions are self-fulfilling. As expectations affect investments, so investments affect expectations. The first structures built in a neighborhood or city will dictate the options for further investments in the vicinity. This circularity makes the challenges of path dependence and interdependence are all the more pressing.

Coordinate infrastructure investments, land use plans, and zoning regulations

For all the reasons discussed above, effective coordination is vital to the success of developing cities at nurturing economic agglomerations and making the urban environment livable and sustainable. To manage

Box 4.4 Using the new urban model to scrutinize received assumptions about the economic consequences of urban policies and investments

Given a typical developing city's large need for urban infrastructure and limited financing capacity, city leaders must carefully examine the likely impacts of policies and investments. Efforts need to be directed where they can have the greatest positive impact, and unintended consequences must be anticipated and prevented.

The new urban model outlined in chapter 3 of this report can help leaders compare the implications of various options for a city's productivity, livability, and sustainability. This economic intelligence can augment other sources of planning intelligence (such as the CAPSUS and CALTHORPE models, among many others)—especially in scrutinizing received assumptions about the consequences of various urban policies and interventions.

For example, will greenbelt policies increase economic efficiency and aggregate welfare? Or will they constrain economic growth and ultimately impede a city's pyramidal transformation? Again: will land market reforms help poor people? If so, under what conditions? It is plausible that increased aggregate urban efficiency may come at the cost of poorer residents' displacement to less efficient neighborhoods (for example, with poorer access to jobs and amenities). So, if the city does not already provide mechanisms to compensate these residents, critical complementary policies may be called for to protect them.

the twin challenges of urban path dependence and interdependence, city leaders must seek synergies among infrastructure investments, land use plans, and zoning regulations. A government's ability to make early, coordinated public investments will directly influence later decisions by firms weighing their own private investments in the urban economy. Only efficient infrastructure and service provision will generate economic density and improve livability, job market matching, and productivity.

Especially important is to avoid coordination failures in which single-sector interventions hinder urban economic density. Inefficient structures can set back productivity growth and spatial transformation for decades. The new urban model can help leaders review options that, though in use elsewhere, could warrant skepticism—or could require complementary policies to be implemented efficiently (box 4.4).

Make infrastructure investments as early as possible—while coordinating them with urban plans

Infrastructure will guide the course of a city's development. Besides determining where structures with various uses can be located, it is also a signal to investors about the future functions of areas around the city. Infrastructure is thus a coordinating device—an irreversible, and therefore credible, commitment that is highly visible and so shapes private investors' expectations and decisions.

If infrastructure is postponed until after population settlement, the investment will prove far more costly, and it may also encounter political obstacles. Services that must be placed underground are less expensive to install at scale on clear sites, rather than retrofitted beneath (or over or around) existing structures on previously developed land. Furthermore, belated infrastructure initiatives pose a prospect of disruption to private homes and can face public resistance. In Sierra Leone, Freetown grew rapidly during a period when the government was unable to make investments—the civil war decade of 1991–2002. Now that all urban spaces are settled, local opposition to road construction is perpetuating a severe lack of road infrastructure.

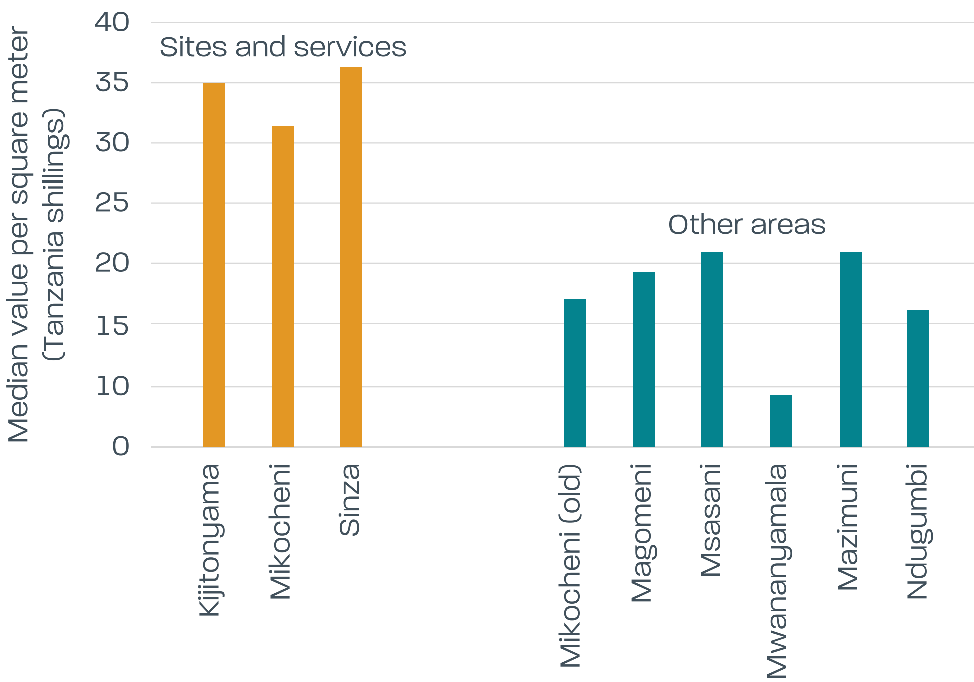
Sites and services projects: Lessons from World Bank experiments with early infrastructure investment. During the 1970s and 1980s, the World Bank used what it called "sites and services" projects to install infrastructure ahead of urban settlement growth. Undertaken in many cases to prevent slum formation—or to set up durable foundations for upgrading slums to formal neighborhoods—the projects covered more than 20 urban neighborhoods in Brazil, El Salvador, Jamaica, Peru, Senegal, Tanzania, Thailand, and Zambia, including tens of thousands of households. Some sites and services projects made new investments in undeveloped land, while others focused on upgrading existing slums. Both project types comprised infrastructure investment in roads, electricity, water, and public buildings such as schools, clinics, and community centers. High costs led to the projects' discontinuance during the late 1980s, despite anecdotal evidence of beneficial long-term impacts.

A recent research study examines the longer-term benefits of these sites and services projects and is expected to find them financially efficient, while also identifying a possible distinction between the benefits of the earlier infrastructure investments represented by new development projects and the later interventions entailed by slum upgrades (Michaels et al. forthcoming). The costs and benefits that researchers examined are of two sorts: effects on land values in certain areas, and physical effects on the urban landscape. The researchers believe that, in the long run, the sites and services projects tended to increase property values and to raise a city's tax base. Moreover, the new construction projects likely realized higher long-term benefits than the slum upgrades did.

In Dar es Salaam, for example, sites with new development projects have higher land values than land elsewhere in the city—including rich neighborhoods—partly because the sites and services areas have a higher average ratio of building footprint to plot area (figure 4.1).

The study shows further that plots are now larger where investments were made ahead of settlement: an example is Sinza, the area of Dar es Salaam in the upper left of figure 4.2. The same plots have higher land values per square meter than projects in upgraded slum areas, such as Manzese in the bottom right of figure 4.2—a part of Dar es Salaam where roads are disorganized, plots are small and irregular, and land is not even valued for tax collections (the tax benefit would not justify the assessment cost). Although drawn in the 1970s, the sites and services plans for Dar es Salaam closely match the shape of the city's road network today. This durability confirms that investment in infrastructure determines a city's future course, while leading to higher land values that are taxable and can finance future investments.

Figure 4.1 Land values of new development projects are higher than values in other neighborhoods of Dar es Salaam, including rich ones



Source: Michaels et al. forthcoming.

Another recent study examined sites and services projects in India (Owens, Gulyani, and Rizvi 2018). The study found that these projects resulted in the creation of well-planned, well-serviced neighborhoods that are both mixed-income and mixed-use. In Chennai and Mumbai, the success of the sites and services projects hinged on four key features (Gulyani 2016):

- ***Tiny plots compared with standard plots of the time.*** The smallest sites and services project plot was 33 m^2 in Chennai, 21 m^2 in Mumbai. In contrast, other housing developments in these cities had minimum plot sizes of about 150–200 m^2. The smaller plots were far more affordable and allowed lower-income households to enter the housing market.

Figure 4.2 Differential impacts of new development projects and upgrading projects in Dar es Salaam

Source: Michaels et al. forthcoming.

Note: The upper left of the photograph shows Sinza, a new development project. The bottom right shows Manzese, an upgrading project.

- ***Spatially efficient site planning norms.*** These site plans lowered the unit costs of developed plots while further increasing urban density. For example, only 34 percent of land was allocated to streets and open spaces, compared with the 50–60 percent often seen in other developments in India at the time. Even so, average road density in these neighborhoods exceeds that of the parent city as a whole. Smart planning thus lowered the cost of infrastructure provision and individual housing plots while creating compact, walkable, livable neighborhoods.
- ***Varied plot sizes, affordable to different income groups.*** In Chennai, the plot sizes ranged from 33 to 223 m^2, in Mumbai from 21 to100 m^2. Today these are true mixed-income neighborhoods, with lower-income families occupying smaller plots and middle- and high-income families occupying larger ones.
- ***Design for mixed use.*** The sites and services projects in India included commercial areas (shops), amenities (schools, clinics), and locations for light industrial production. All these types of businesses, services, and amenities exist in the neighborhoods today. Mixed use has resulted in vibrant streets.

This evidence from Chennai, Mumbai, and Dar es Salaam suggests that sites and services projects are potent instruments for managing urban expansion and creating affordable housing. City governments can use the sites and services approach and planning norms to shape future urban growth—moving beyond "putting stakes in the ground," and using early infrastructure investment to earmark future neighborhoods. Governments and the private sector can create more affordable housing by scaling up delivery of small housing plots, on which families can build incrementally.

The need to ensure basic services for all. Whether urban expansion (horizontal spread) or redevelopment (infill) is planned, city leaders must ensure that infrastructure and basic services are provided for all residents. In particular, access to potable water and safe sanitation is essential to limit the incidence of waterborne diseases and enable a healthy population. Also critical are transportation options to connect residents to jobs around the city. All these investments are expensive—but they are most expensive when they require retrofitting previously settled, yet underserviced, neighborhoods. They are less expensive in undeveloped areas where the government has previously secured its rights-of-way and does not need to disrupt residents' lives.

Durable financing for capital investment costs and recurring expenses—mobilizing urban revenue sources

Achieving economic density will require cities in developing countries to make huge infrastructure investments (box 4.5). How can city leaders bridge this financing chasm? What revenues can they tap?

In most developing countries, urban public finance to date has relied on intergovernmental fiscal transfer systems, which account for about 60 percent of all subnational expenditures in developing and emerging economies (Shah 2006). In Uganda, the share of local government revenues coming from central government grants reaches as much as 91 percent (Farvacque-Vitkovic and Kopanyi 2014). Such fiscal transfers are mostly untransparent and unpredictable. In addition, they involve a complex political economy that may not favor cities and is typically biased toward rural areas and smaller settlements.

A better financing approach is to *tax the value of land and property* for initial infrastructure investments, for the recurring cost of infrastructure (operation and maintenance), and for the provision of public goods and services. Other financing options include private sector investment in service delivery through *public–private partnerships* (PPPs), and *borrowing on capital markets* for creditworthy cities.

Tax the value of urban land and property

Urban land values can offer a durable basis for urban infrastructure financing. In cities in developing countries, municipal own-source revenues—especially from property taxes—are a generally underdeveloped financing source. In Mumbai, for example, property taxes constitute just 12 percent of total local government revenues (Farvacque-Vitkovic and Kopanyi 2014). A common reason for low or nonexistent land and property taxes is the absence of clear land ownership and tenure rights: as discussed above, city leaders should make it a top priority to strengthen titling institutions, with a cadaster system that creates incentives for citizens to keep property and tenure information up to date. Without clear land records and land rights, land and property taxes cannot be relied on as a source of municipal revenue.

Land and property taxes are especially fruitful when cities experience rapid economic growth: steeply rising productivity and incomes lead to steeply rising land prices, which will yield substantial revenue if the right valuation and taxation enforcement mechanisms are in place (box 4.6). This process is circular, however.

While potentially generating increased revenues, rapid urban economic growth also creates new infrastructure needs and thus calls for greater investment resources. Infrastructure financing in France, Japan, and the United States was based most heavily on land values during periods of rapid urban growth, when urban investment made rapid leaps in scale.

Consider public–private partnerships (PPPs) for service delivery

A city's ability to attract private investment in infrastructure and service delivery will hinge on its ability to develop a robust regulatory framework for public–private partnerships (PPPs). From the city's perspective, the ability to design PPPs and enforce contracts will be critical. From the investor's perspective, a key requirement will be the availability of adequate information, with credit enhancement mechanisms to attract investment.

Borrow on capital markets—if the city's creditworthiness allows

The bar for borrowing on capital markets is even higher than that for securing private investment through PPPs. Among the 500 largest World Bank client cities in developing and emerging economies, only 90 (18 percent) are deemed creditworthy on domestic and international credit markets—and just 32 (6 percent) have ever issued a municipal bond.[6] The reasons for this general lack of creditworthiness are manifold: the lack of buoyant municipal revenues, the lack of expenditure rationalization, the presence of debt and contingent liabilities, the lack of asset management strategies, and the lack of a national framework governing creditworthiness are among the many contributing factors.

6 World Bank City Creditworthiness database.

Box 4.5 The global urban infrastructure financing gap: A challenge for developing country cities

The gap in urban infrastructure is huge. Today, 156 million urban inhabitants live without access to improved water sources and 700 million without improved sanitation.[1] In particular, slums and informal settlements often lack individual access to water and sanitation, and the use of public facilities exposes them to contagion risk. Poor residents of informal settlements often resort to purchasing water from informal vendors at much higher unit rates—often five times as much as what other households pay when purchasing water from the municipal system (Klein 2012). Underinvestment in public transportation and the lack of affordability means that poor people often have no means of getting to work except walking. For instance, 48 percent of the population in Nairobi walks to work (World Bank 2016a), which means that in a one-hour commute, they can barely access 14 percent of the jobs in the city (Avner and Lall 2016).

Urban infrastructure financing shortfalls in developing countries and emerging economies are not rigorously or coherently estimated. For the cost of reaching the Sustainable Development Goals globally, the Global Infrastructure Outlook estimates the total annual infrastructure financing gap at $3.7 trillion (Global Infrastructure Hub 2017). In contrast, the State of the City Climate Finance Report estimates the global annual gap at $4.1–4.5 trillion—rising to $4.5–5.4 trillion if one were to include a 9–27 percent premium to enhance the resilience of the infrastructure (United Nations 2015). Given that such global figures include both developed and developing countries and both urban and rural space, the annual gap in urban infrastructure financing for developing countries may be roughly guessed to reach at least $1.5–2 trillion. That conservative figure dwarfs all the official development assistance that is available globally every year.

While much of the infrastructure deficit will be in developing countries, existing infrastructure in the developed world suffers in many countries from deferred maintenance, and thus requires important capital investment. The United States alone is estimated to need nearly $0.5 trillion of infrastructure investment a year between today and 2040, and Europe another $0.6 trillion a year (Global Infrastructure Hub 2020).

1 https://www.unwater.org/water-facts/urbanization/.

Fix the fundamentals—fiscal, economic, and institutional—to mobilize urban finance

To mobilize finance, municipal governments and utilities need to demonstrate the ability and commitment to pay for that finance with funding.[7] And funding, in a municipal environment, comprises either local (own-source) revenues, generated from taxes and service charges, or fiscal transfers, including aid grants. The greater the volume of private finance, the greater the need for funding. Financing more means funding better.

Fixing the fiscal fundamentals of municipalities, utilities, and other public services is thus a core part of mobilizing finance for urban development. New investments in high-quality and affordable transport systems depend on fiscal as well as financial sustainability, not only for the initial capital investment, but also to fund ongoing operations and maintenance.[8]

When connective infrastructure investments succeed, they help cities improve their economic fundamentals: efficient connections foster agglomeration economies, which increase local revenue potential.

Whatever a city's economic development stage, and whatever its productivity and income level, sound municipal finance can exist only where property rights are clear and urban land markets function efficiently. For developing country cities, effective titling and tenure reforms to clarify land rights can underpin an effective municipal asset management strategy by supporting an up-to-date land and property cadaster at the base of a tax system. Only when cities can thus secure funding, and can use funding to obtain financing, can they empower themselves to achieve their full potential—as dense, efficient economic agglomerations that are livable for people and sustainable for the world.

7 White and Wahba (2019) make an important point that financing and funding are two different things. Finance is raising money for investment. Funding is the payment for the investment, including the financing cost, over the long term. Finance thus does not obviate the need for funding. Indeed, because finance comes at a price (interest or return on equity), it aggravates the funding need.

8 Urban transport financing needs to be based on an appropriate mix of complementary financing instruments (Ardila-Gomez and Ortegon-Sanchez 2016). Several solutions exist to enable cities to better capture the value created through integrated land use and transport planning (Salat and Ollivier 2017; Ollivier et al. 2021).

Box 4.6 Taxing land and property values to finance urban infrastructure

Taxes on land values can fund infrastructure for dense urban development. They can also make land use more efficient: taxes based on market valuations give property owners an incentive to develop land to its most profitable use commensurate with its market value.

When valuable downtown locations with higher land prices are taxed in accordance with their value, they will attract greater investment in residential and commercial structures, making the city center more residentially and economically dense. As a result, land values will rise further. Yet the resulting rise in taxes is nondistortionary, because appreciation in land values constitutes an economic rent for a scarce resource—not a return on any economic activity by the owner (there is no economic behavior to be distorted).

Higher revenues from land and real estate can be realized in three ways:

- Increased valuation of land and properties after infrastructure is planned, bringing assessed values closer to market values and thus deepening the tax base.
- Improved compliance, causing more property owners to pay land and property taxes and thus broadening the tax base.
- Monetization of underused public land.

Creating a land and real estate tax system to support urban development and densification will be a challenge for most developing country cities. Strong institutions are essential to define property rights clearly, to ensure standardized and objective methods of land valuation, and to support and oversee land management, land sales, and tax collection. In addition, planners considering sole reliance on property taxes as an option should be aware that property values respond only slowly to annual changes in economic activity.

Annex 1

Income elasticity of population density

The evolution of built-up area has implications for population density. We estimate income and population elasticities of density measured as population over built-up area. Using the Global Human Settlement Layer panel data, different specifications are estimated including nonlinear effects for the largest cities based on the following regression:

$$\ln Density_{c,t} = \alpha + \beta_1 \ln Inc_{c,t} + \beta_2 \ln Inc_{c,t}^2 + \beta_3 \ln Pop_{c,t} + \beta_4 \ln Pop_{c,t}^2 + \lambda_t + \gamma_c + \epsilon_{c,t}$$

As shown previously, as cities become richer, their demand for floor space rises and their supply of built-up area increases in response, even with population held constant. So as cities expand in built-up area, they become less densely populated. The income elasticity of density is –0.10 using the between and within estimator; introducing instruments for incomes increases it to –0.15. Table A1.1 provides estimates of the income elasticity of density using various specifications.

Table A1.1 Determinants of naïve population density (population over built-up area)

Dependent variable: **Population density over built-up area**	**Between + within estimator**	**Between + within estimator with lag**	**Between + within estimator with IV for income**	**For cities > 500,000 only**	**Nonlinear specification for cities > 500,000**
Ln Income	–0.105*** (0.00484)		–0.149*** (0.00439)	–0.0762*** (0.0103)	–0.397*** (0.0946)
Ln Population	0.649*** (0.0177)		0.627*** (0.00856)	0.784*** (0.0277)	–0.446 (0.380)
Ln lagged Income		–0.181*** (0.00650)			
Ln lagged population		0.478*** (0.0347)			
Square Ln Income					0.0197*** (0.00584)
Square Ln Population					0.0432** (0.0132)
Constant	3.270*** (0.218)	5.699*** (0.424)	3.860*** (0.119)	-0.615 (0.402)	9.400*** (2.768)
FE	City + Year	City + Year	City + Year	City + Year	City + Year
Controls	No	No	No	No	No
R-squared	0.415	0.328		0.466	0.477
N. of obs	28352	18856	27460	2495	2495

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Note: Standard errors in parentheses.

Annex 2 Data and methodological details

This report examines spatial development across 9,500 cities worldwide by synthesizing Global Human Settlement Urban Center Database 2015 (GHS-UCDB) and World Settlement Footprint 3D product (WSF-3D) retrieved satellite imagery. To apply a consistent measure of cities, this report uses a new methodology endorsed by the UN statistical commission—the Degree of Urbanization—that allows for international comparisons of urban growth across time and countries.

The GHS-UCDB is a combined dataset based on the Global Human Settlement Built-Up grid (GHS-BUILT), a new global definition of cities, and socioeconomic characteristics such as income and population. By combining such data, the GHS-UCDB are comparable across time and countries. Due to the nature of remote sensing-derived information; however, there are concerns about measurement errors. Here, we explore comparative advantages and potential uncertainties in using GHS-BUILT and Degree of Urbanization, and illustrate how we address several concerns data and measurement concerns.

Global Human Settlement Built-Up grid (GHS-BUILT)

Comparative advantages of GHS-BUILT

GHS-BUILT is a satellite imagery-derived dataset to measure built-up area. The dataset constructed a series of built-up layers across four different periods (1975, 1990, 2000, and 2015). Each year of the dataset is based on the different collections of Landsat satellite imagery. A total of 33,202 scenes were implemented to produce the multitemporal layers of built-up (Florczyk et al., 2019).

GHS-BUILT applies consistent measurement for detecting the built-up layer, globally. A building extraction algorithm was applied to global imagery to extract full information of built-up areas rather than sampled areas in selected regions. This consistent measurement allows us to explore the presence of built-up without consideration of the geographical coverage constraints. Since cities in developing countries often grow extensively within a relatively short period, it is critical to capture a full picture of built-up.

Higher spatial resolution compared to other global urban mapping products. The GHS-BUILT constructed the built-up layers of 30 m spatial resolution. While there are different global urban mapping products such as Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Type (MCD12Q1) and Global Land Cover (Globcover), the spatial resolutions of those products are 500 m and 300 m, respectively. This coarse resolution may lead to omission and commission errors. The recent development of the global land cover product—Copernicus Global Land Service offers a 100 m resolution built-up layer; however, this has limited temporal coverage (2015-2019). Another Landsat satellite-based built-up layer, GlobeLand30 (30 m spatial resolution), is also only available after 2000.

GHS-BUILT is accurate across diverse urban landscapes. Diverse approaches were applied to test the accuracies of GHS-BUILT. Yang et al. (2019) test the accuracy of different urban land products, including GlobeLand30, Global Urban Footprint (GUF), and GHS-BUILT, across different urban settings. The overall accuracy levels are 0.87, 0.81, and 0.89, respectively. Given the limited temporal resolution of GlobeLand30 and GUF and their lower accuracy, GHS-BUILT is a suitable product for this report. Extensive sampling and validation done by Liu et al. (2018) reported moderate accuracies in 1990, 2000, and 2014 as 0.72, 0.72, and 0.71, respectively. Leyk et al. (2018) also confirmed the higher accuracy of GHS-BUILT in rural-to-urban transition areas.

Concern with GHS-BUILT

Multiple Landsat missions and different satellite sensors may deliver inconsistent results. The Landsat imagery used for GHS-BUILT varies across periods. The 1975 layer is based on 7,597 scenes from the Landsat 1-3 Multispectral Scanner. The 1990 layer used 7,375 scenes from the Landsat 4-5 Thematic Mapper-TM. The 2000 layer used 8,788 scenes from the Landsat 7 Enhanced Thematic Mapper+. The 2014 layer used 9,442 scenes from the Landsat 8 Operational Land Imager (Florczyk et al., 2019). Since the series of Landsat satellites were designed to maintain compatibility across different Landsat missions, spectral bands' wavelength and resolution should be similar (Corbane et al., 2019). In theory, GHS-BUILT was not affected by different Landsat missions. However, due to the coarse resolution of Landsat 1-2 Multispectral Scanner (60 m) compared to others (30 m), the 1975 layer potentially underestimates the built-up areas. To alleviate measurement concern, we dropped the 1975 layer for the analysis.

Under- and over-estimation of built-up areas. While GHS-BUILT has higher accuracy compared to other global products, one might still have concerns of under- and over-estimation of built-up areas. Based on the extensive validation based on 40 million individual building polygons from 277 different cities, Corbane et al. (2019) reported the reliable accuracies across different regions (Oceania: 0.82, Africa: 0.79, Europe: 0.78, Asia: 0.76, and America: 0.77). While the field of remote sensing keeps evolving with the new sensor developments such as GHS-BUILT S2 based on Sentinel-2 satellite (10 m spatial resolution), at this point, the GHS-BUILT is the only product fitted to the analytical goals of the report in terms of spatio-temporal scales.

Degree of Urbanization

The Degree of Urbanization is a method for delineating cities, urban, and rural areas endorsed by the UN Statistical Commission in March 2020 (Dijkstra et al., 2020). An urban center is classified based on the condition of contiguous grid cells (1 km^2) that have at least 50 percent built-up and 1,500 inhabitants, and the total urban center population should have more than 50,000 persons.

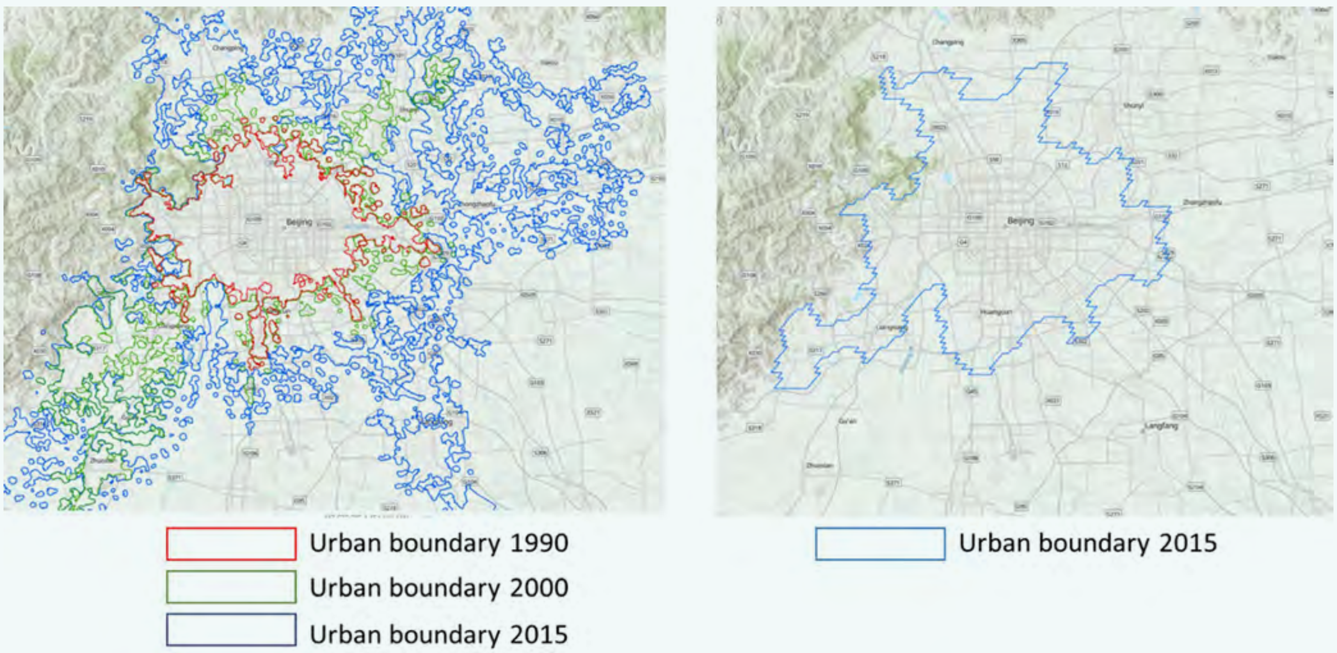
Comparative advantages of Degree of Urbanization

Consistent measurement for defining urban areas, globally. A major strength of this method is that it can be applied globally to identify cities and settlements (Dijkstra et al., 2020). GHS-UCDB provides data on more than 9,500 cities around the world. This method can better capture the cities in developing countries because the method is not only based on the built-up areas but also population density. In the case of cities in developing countries, a relatively low share of impervious areas often hampers identification of cities despite the cities having experienced a massive population influx.

Measurement with consistent geographical boundary. The GHS-UCDB is developed based on the urban areas of 2015. Since the database uses a constant geographical boundary across multiple years (i.e., 1975, 1990, 2000, and 2015), the data maintain compatibility across multiple periods, unlike other urban mapping products that use different geographical boundaries for urban areas by period by period. This is a fundamental difference compared with the urban mapping work done by Angel et al. (2016). Since the urban boundary (see Beijing below as an example) defined by

Angel et al. has changed over time, this may underestimate built-up areas in 1990 and overestimate built-up areas in 2000 and 2015. The omitted built-up areas at the outskirt of the cities in 1990 could be automatically included in 2000 and 2015. For example, the built-up area outside of Beijing's 1990 urban boundary cannot be identified as built-up area. In Angel's calculation, the annual built-up growth in Beijing is 5.2 percent (from 668 km^2 in 1988 to 2,654 km^2 in 2013); by contrast, we calculate annual growth of 0.42 percent (from 1,246 km^2 in 1990 to 1,382 km^2 in 2015; figure A2.1). As mentioned above, having a consistent measurement of urban boundaries enables us to maintain compatibility across multiple periods.

Figure A2.1 Different urban boundaries in Beijing, China



Source: Authors' depiction, based on Angel et al. (2016) for left image and GHS–Urban Centre Database for right image.

Urban area does not only consist of impervious areas. Many global urban mapping products estimate the urban area only based on the spectral characteristics of each pixel. That is, urban areas often were classified based on their physical status, whether the pixels are impervious areas (i.e., built-up) or not. However, the urban area includes not only built-up areas but also other amenities. By combining the population density parameter and the gap-filling method, the Degree of Urbanization enables classifying impervious areas and other amenities into urban areas.

Concerns in use of Degree of Urbanization and GHS–UCDB

Arbitrary density threshold. To examine the density thresholds, three additional robustness checks were carried out: adding pixels having built-up coverage over 50 percent added to urban centers, gap-filling based on neighboring pixels, and excluding pixels having less than 3 percent of built-up (Dijkstra et al., 2020). Based on these combined methods, the cities defined by Degree of Urbanization are well aligned (91.9 percent), with nationally defined cities with more than 300,000 population globally (ibid.). The UN World Urbanization Prospects (WUP) 2018 also reported similar numbers of cities with at least 300,000 inhabitants across the world (table A2.1). While the numbers of cities in South Asia and North America exhibit relatively large gaps between WUP and GHS-UCDB, the other five regions are similar across four different periods (Dijkstra et al. 2020).

Table A2.1 Comparison between GHS-UCDB and World Urbanization Prospects

	1990	2000	2015
Degree of Urbanization	1,167	1,410	1,768
World Urbanization Prospects	976	1,276	1,772

Source: Based on figure 15 in Dijkstra et al. (2020).

As another set of robustness checks, we consider Functional Urban Area (FUA) boundaries defined on the urban centers and neighboring areas belonging to commuting zones. This is particularly important for understanding the spatial development of cities in land-rich countries that have relatively large urban extents and low population density. Since the FUA boundary contains neighboring areas, it is considerably larger compared with the GHS-UCDB. The FUAs of high-, upper-middle-, lower-middle-, and low-income countries are 6.1, 3.6, 2.5, and 2 times larger than the areas of GHS-UCDB, respectively.

Table A2.2 Built-up area comparison between GHS-UCDB and FUA

	Income group	1990	2000	2015	Annual growth rate (%)
GHS-UCDB	High-income	108,726	122,023	128,237	0.66
	Upper-middle-income	74,982	92,021	104,289	1.32
	Lower-middle-income	35,969	46,330	51,462	1.43
	Low-income	4,716	6,009	6,596	1.34
FUA	High-income	168,115	200,791	226,130	1.19
	Upper-middle-income	98,904	125,034	152,056	1.72
	Lower-middle-income	41,916	54,733	63,164	1.64
	Low-income	5,018	6,473	7,366	1.54

However, the total built-up area difference between GHS-UCDB and FUA is relatively small (table A2.2). While total area of FUA is 4 times larger than total area of GHS-UCDB, the amount of built-up area in FUA is only 1.5 times larger than in GHS-UCDB. That is, the GHS-UCDB does not miss a significant portion of urban built-up areas. The difference mostly comes from high-income and land-rich countries. For example, the United States itself accounts for 31 percent (49,075 km^2) of the total built-up area difference (158,132 km^2). Additionally, the annual built-up growth rate differences between GHS-UCDB and FUA are small except for high-income countries. In the case of the United States, the annual built-up growth rate jumps from 0.85 percent using GHS-UCDB to 1.55 percent by FUA. Therefore, other than a few exceptions—high-income land-rich countries including the United States, Canada, and Australia—the GHS-UCDB adequately captures urban built-up areas (table A2.3).

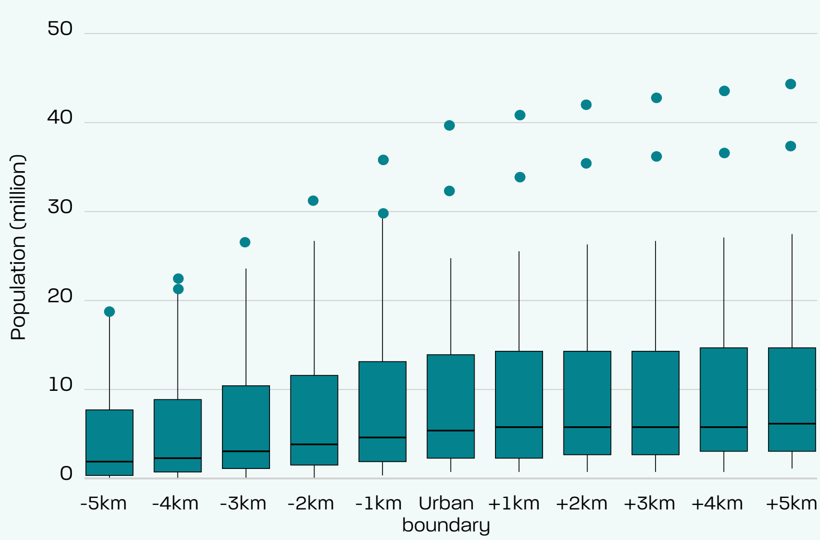
Table A2.3 Built-up area comparison in high-income land-rich countries

	Country	Square kilometers 1990	Square kilometers 2000	Square kilometers 2015	Annual growth rate (%)
GHS-UCDB	United States	48,353	56,508	60,030	0.87
	Canada	4,291	4,833	5,313	0.85
	Australia	3,701	3,945	4,095	0.40
FUA	United States	76,254	97,001	112,456	1.55
	Canada	5,917	6,974	8,208	1.31
	Australia	5,139	5,703	6,271	0.80

Missing people due to the underestimated extent of cities. Mainly, for rapidly growing cities, one may be concerned if urban centers, defined by the degree of urbanization, are able to capture the proper population of the region. To assess this concern of missing population, we develop a sensitivity test for the top 50 (spatially) growing cities from 1990 to 2015. Multiple ring buffers (from negative 5 km to positive 5 km away from the edge of the urban boundary) were added to the urban boundary in order to assess the population variations across different sizes of urban areas. The gridded population dataset retrieved from WorldPop (2018) was overlaid to the urban boundary layers to calculate the population.

As shown in figure A2.2, except for two outliers—Guangzhou, China and Jakarta, Indonesia—the median values of population estimates with additional buffered urban areas are similar to the population within the urban boundary. For instance, the additional 5 km buffer increases Mexico City's urban area by 74 percent (1,556 km²) while increasing its population by only 3.3 percent, and it increases Los Angeles' urban area by 57 percent (3,205 km²) while increasing its population by only 4.6 percent.

Figure A2.2 Estimated population within the urban area in the top 50 growing cities, 1990 and 2015



Source: Authors' analysis.

World Settlement Footprint (WSF) 3D

While the recent development in the field of remote sensing enables capturing global urbanization extensively, the 3D structure (building height) of the city is rarely incorporated. Lidar and active remote sensing techniques are often employed to represent three-dimensional urbanization; however, most of those studies are restricted to sampled areas due to the high cost of data acquisition. For the global level studies, Mahtta et al. (2019) explored vertical and horizontal urbanization by combining NASA's QuickSCAT SeaWinds and Global Human Settlement Layer (GHSL). However, SeaWinds is not designed to measure urban dynamics, so the sensor cannot properly capture the complex building structures in cities. A recent study done by Jedwab et al. (2021) used a global building database (Council on Tall Buildings and Urban Habitat) to measure cities' vertical height. Unfortunately, these data also cannot fully represent the cities' vertical heights due to their nature: self-reported data in selected cities and restricted samples of buildings (i.e., height above 80 m).

To better understand the spatial structure of cities with a constant measurement, this report used newly developed global 3D built environment data. The World Settlement Footprint 3D (WSF 3D) is developed by the German Aerospace Center (DLR) to derive a worldwide 3D model of the built environment in a fine resolution (90 m x 90 m) based on the data collected by TanDEM-X satellites. By synthesizing TanDEM-X and the 30 m ALOS World 3D elevation model (AW3D30) with the 12 m spatial resolution of Digital Terrain Model and multi-spectral Sentinel-2 Imagery, DLR successfully develops a global building height database with a vertical resolution of 1 m (figures A2.3, A2.4).

Figure A2.3 Schematic process of WSF 3D development

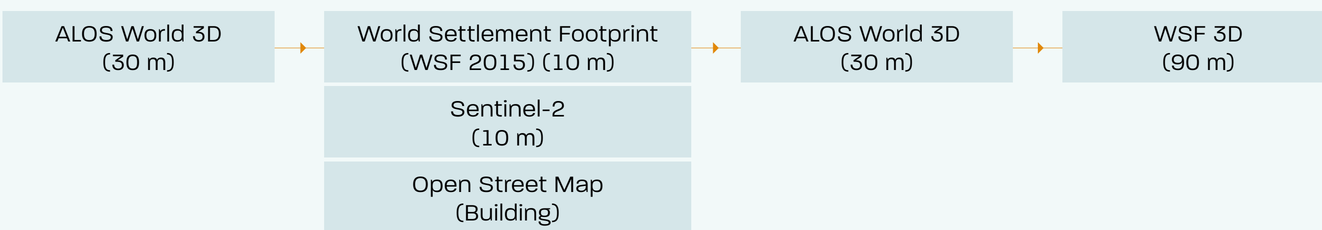
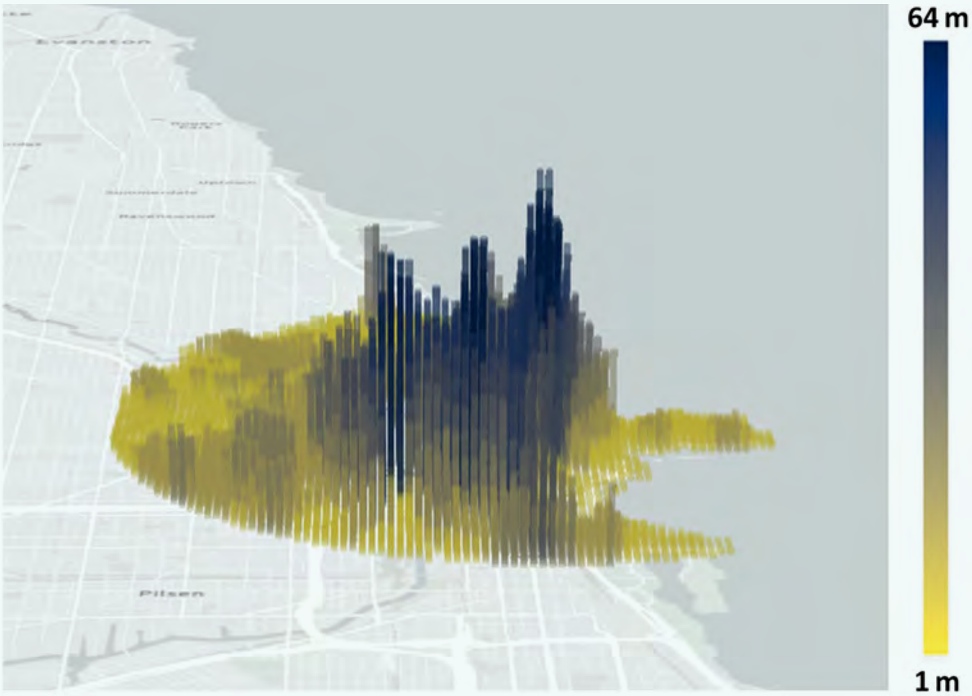


Figure A2.4 Average building height in Chicago, Illinois



Source: Author's construction, retrieved from WSF-3D data.

In this report, we collected WSF-3D data for approximately 400 cities around the world. The data represent diverse geographical areas that enable us to explore different spatial structures of cities across regions (table A2.4).

Table A2.4 Selected cities for WSF-3D data

Regions	*Number of cities*
Europe & Central Asia	57
Middle East & North Africa	31
South Asia	66
East Asia & Pacific	124
Latin America & Caribbean	38
Sub-Saharan Africa	45
North America	12

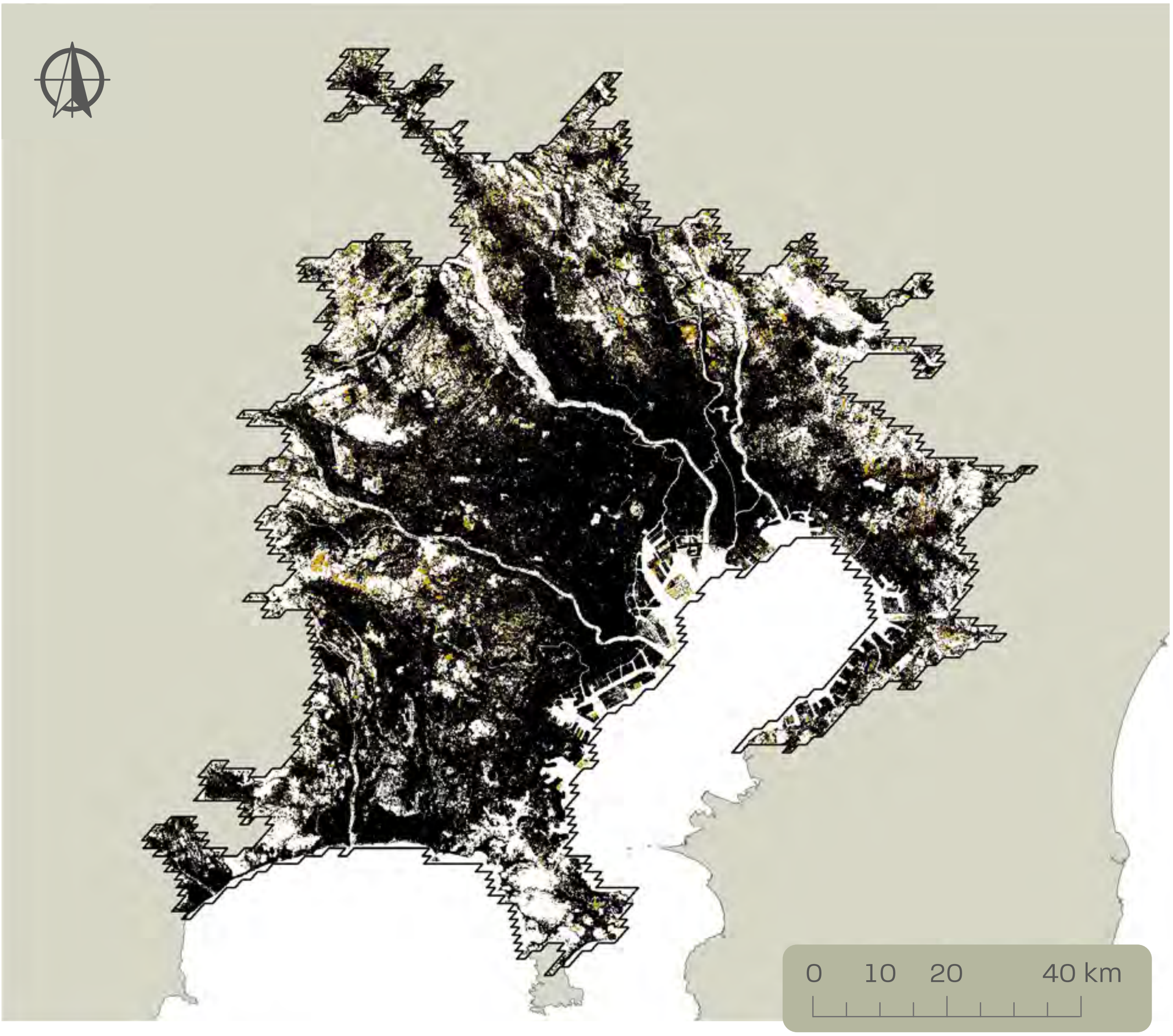
Annex 3 Spatial development of the five largest cities in each region of the world

No.	Region	City	Country	Urban areas (km²)	Built-up expansion 1990-2015 (km²)	Built-up expansion (% per year)	Population growth (% per year)
1	East Asia & Pacific	Tokyo	Japan	5,318	385	0.44	0.75
2		Guangzhou	China	6,622	1,342	2.65	2.54
3		Osaka	Japan	3,158	123	0.24	0.09
4		Shanghai	China	3,318	905	2.25	3.41
5		Jakarta	Indonesia	5,009	418	1.00	2.30
6	Europe & Central Asia	London	United Kingdom	1,864	65	0.21	1.03
7		Moscow	Russia	1,882	164	0.58	1.29
8		Paris	France	1,638	84	0.30	0.50
9		Dortmund	Germany	1,315	71	0.37	−0.23
10		Istanbul	Turkey	1,340	129	0.79	2.30
11	Latin America & Caribbean	São Paulo	Brazil	2,005	146	0.44	1.04
12		Buenos Aires	Argentina	1,967	223	0.72	1.19
13		Mexico City	Mexico	2,114	510	2.00	0.59
14		Rio de Janeiro	Brazil	1,367	81	0.43	0.89
15		Monterrey	Mexico	667	161	1.86	1.05
16	Middle East & North Africa	Tehran	Iran	1,382	102	0.65	2.09
17		Cairo	Egypt	1,585	119	0.83	1.77
18		Riyadh	Saudi Arabia	1,016	136	0.96	3.05
19		Baghdad	Iraq	787	72	0.72	1.64
20		Kuwait City	Kuwait	476	22	0.29	2.56
21	North America	Los Angeles	United States of America	5,633	643	0.60	0.89
22		New York		5,384	481	0.56	0.26
23		Chicago		3,830	414	0.64	0.21
24		Dallas		3,699	788	1.44	1.77
25		Houston		3,418	804	1.58	2.10
26	South Asia	Kolkata	India	2,817	113	0.39	0.92
27		Delhi (New Delhi)	India	2,474	443	1.82	2.25
28		Dhaka	Bangladesh	3,248	195	1.02	3.48
29		Hyderabad	India	874	168	2.48	1.65
30		Mumbai	India	1,077	32	0.36	1.25
31	Sub-Saharan Africa	Johannesburg	South Africa	1,638	126	0.61	3.07
32		Lagos	Nigeria	1,196	165	0.91	2.60
33		Accra	Ghana	846	84	0.74	3.33
34		Cape Town	South Africa	697	42	0.46	2.75
35		Durban	South Africa	745	61	0.82	1.25

East Asia & Pacific

Tokyo, Japan

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.44%

Total built-up expansion (1990–2015)

385 km²

Annual population growth

0.75%

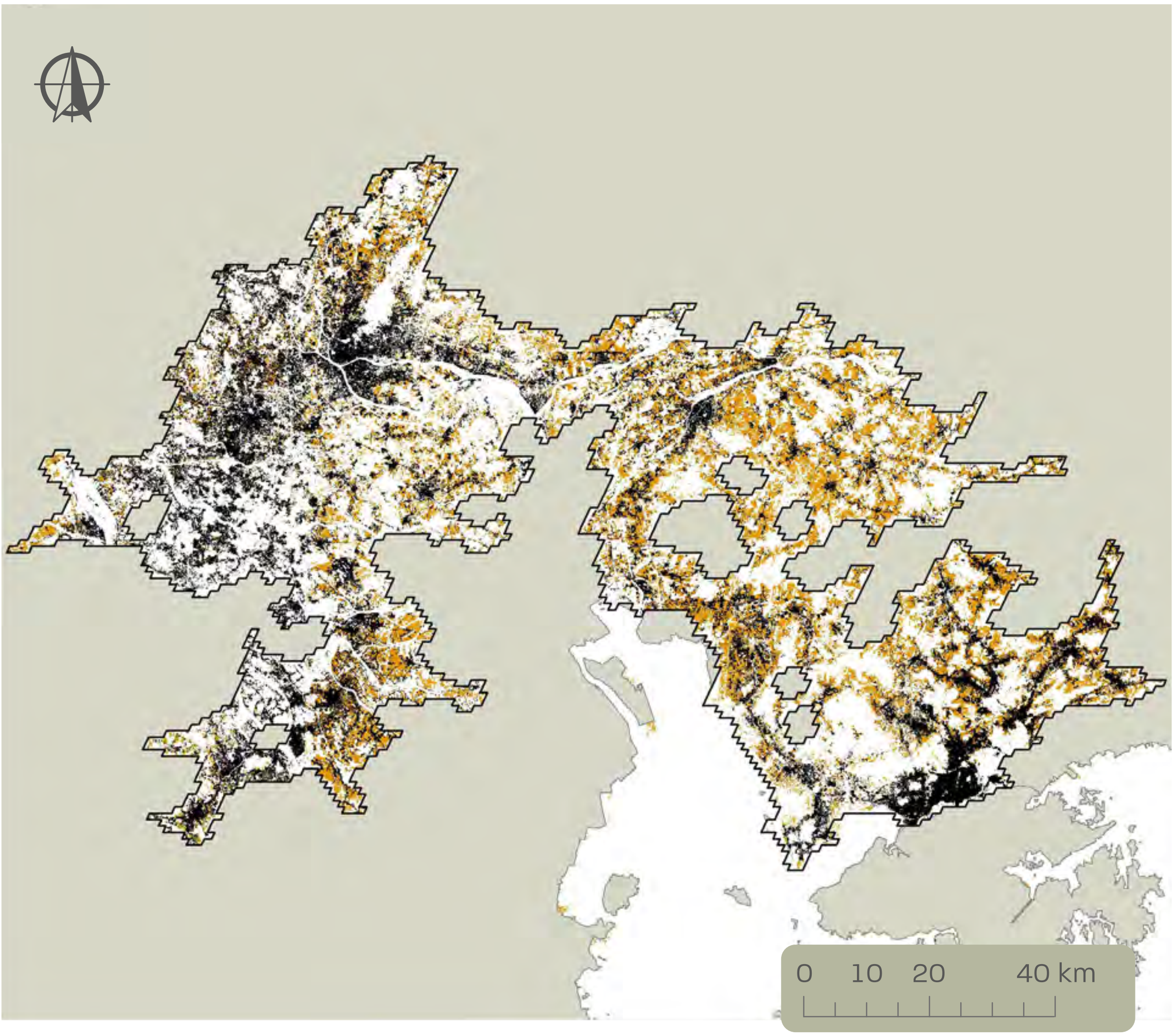
Built-up area per person (2015)

108 m²

East Asia & Pacific

Guangzhou, China

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

2.65%

Total built-up expansion (1990–2015)

1,342 km²

Annual population growth

2.54%

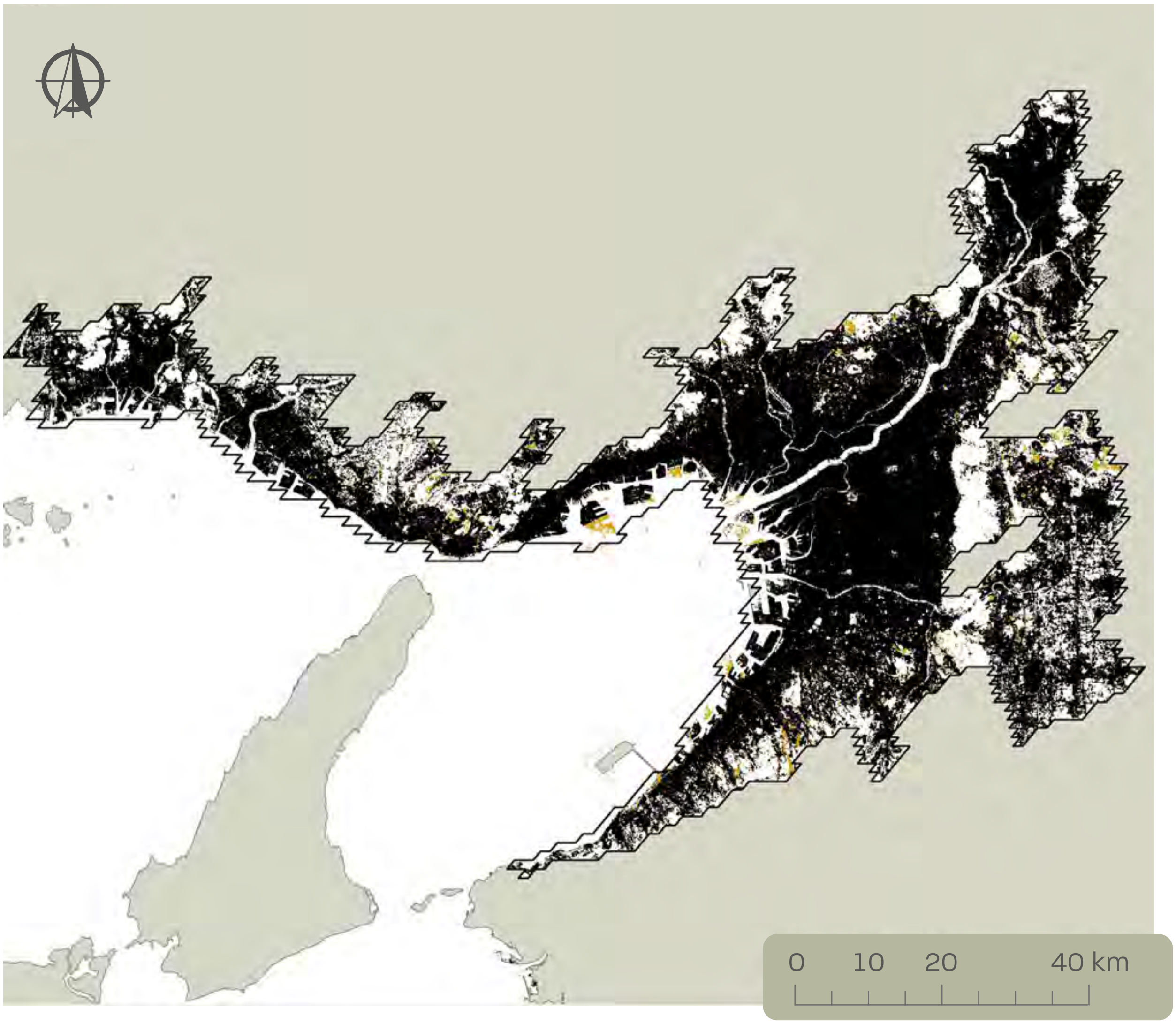
Built-up area per person (2015)

61 m²

East Asia & Pacific

Osaka, Japan

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.24%

Total built-up expansion (1990–2015)

123 km^2

Annual population growth

0.09%

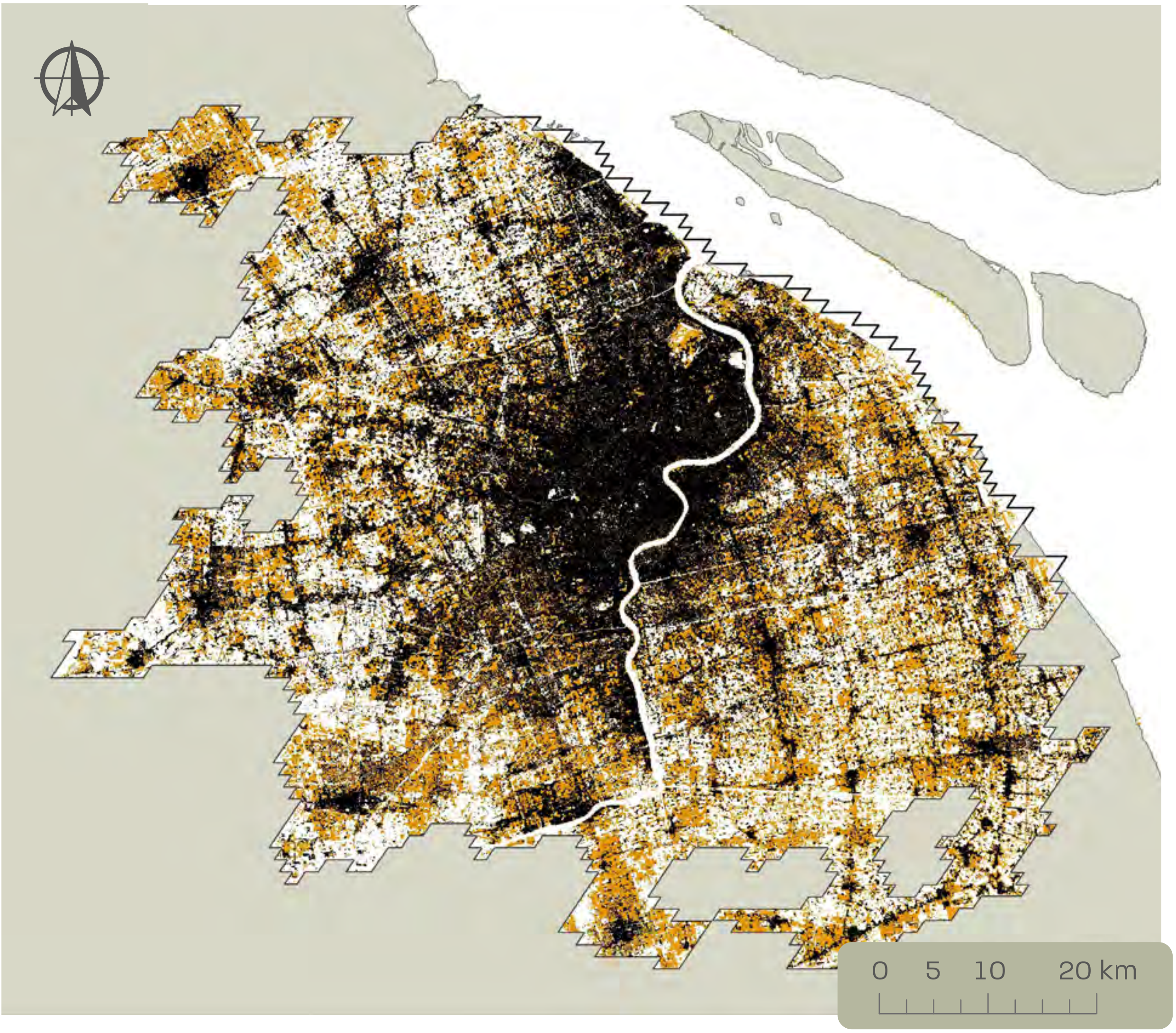
Built-up area per person (2015)

133 m^2

East Asia & Pacific

Shanghai, China

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

2.25%

Total built-up expansion (1990–2015)

905 km²

Annual population growth

3.41%

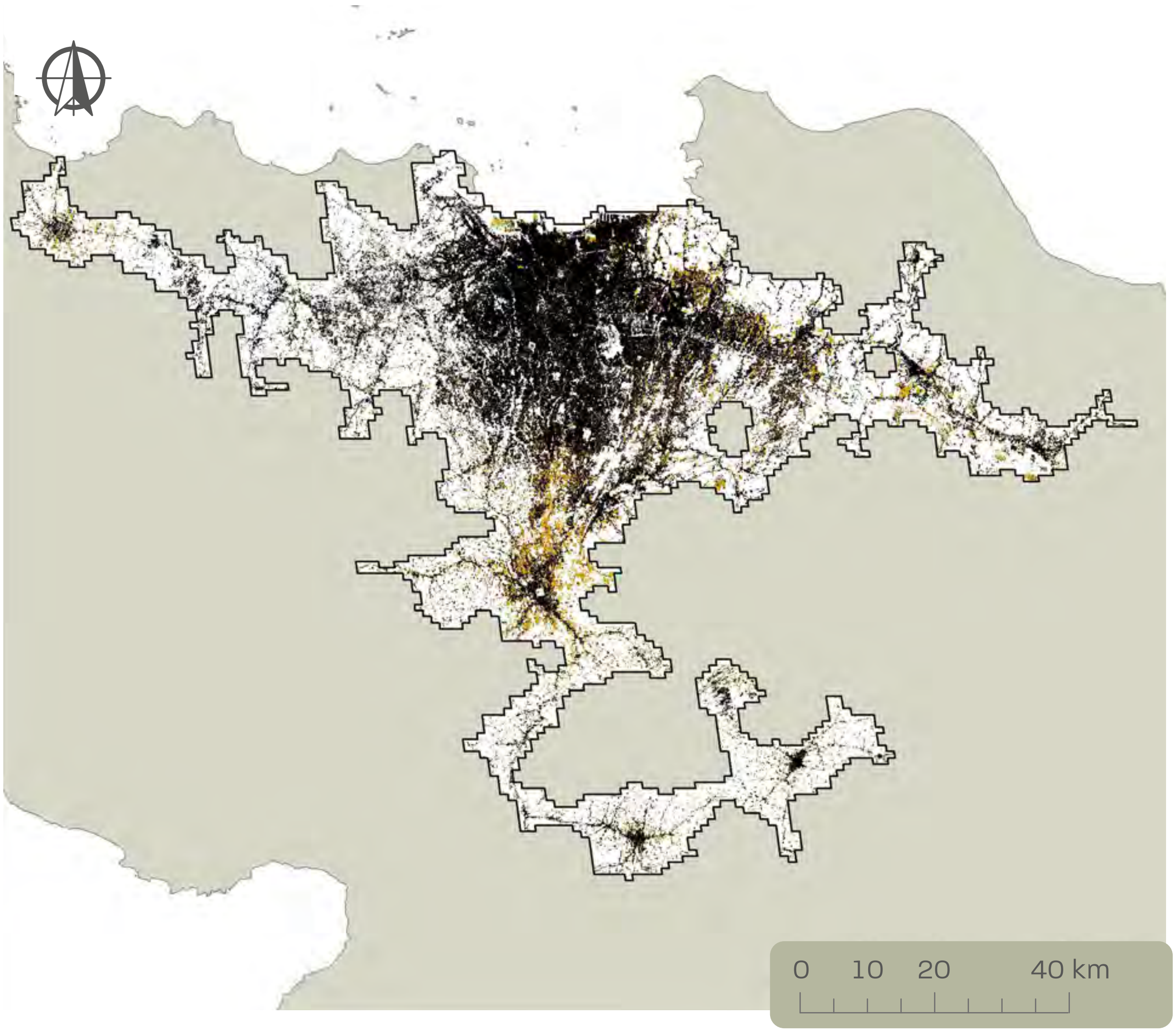
Built-up area per person (2015)

64 m²

East Asia & Pacific

Jakarta, Indonesia

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.00%

Total built-up expansion (1990–2015)

418 km^2

Annual population growth

2.30%

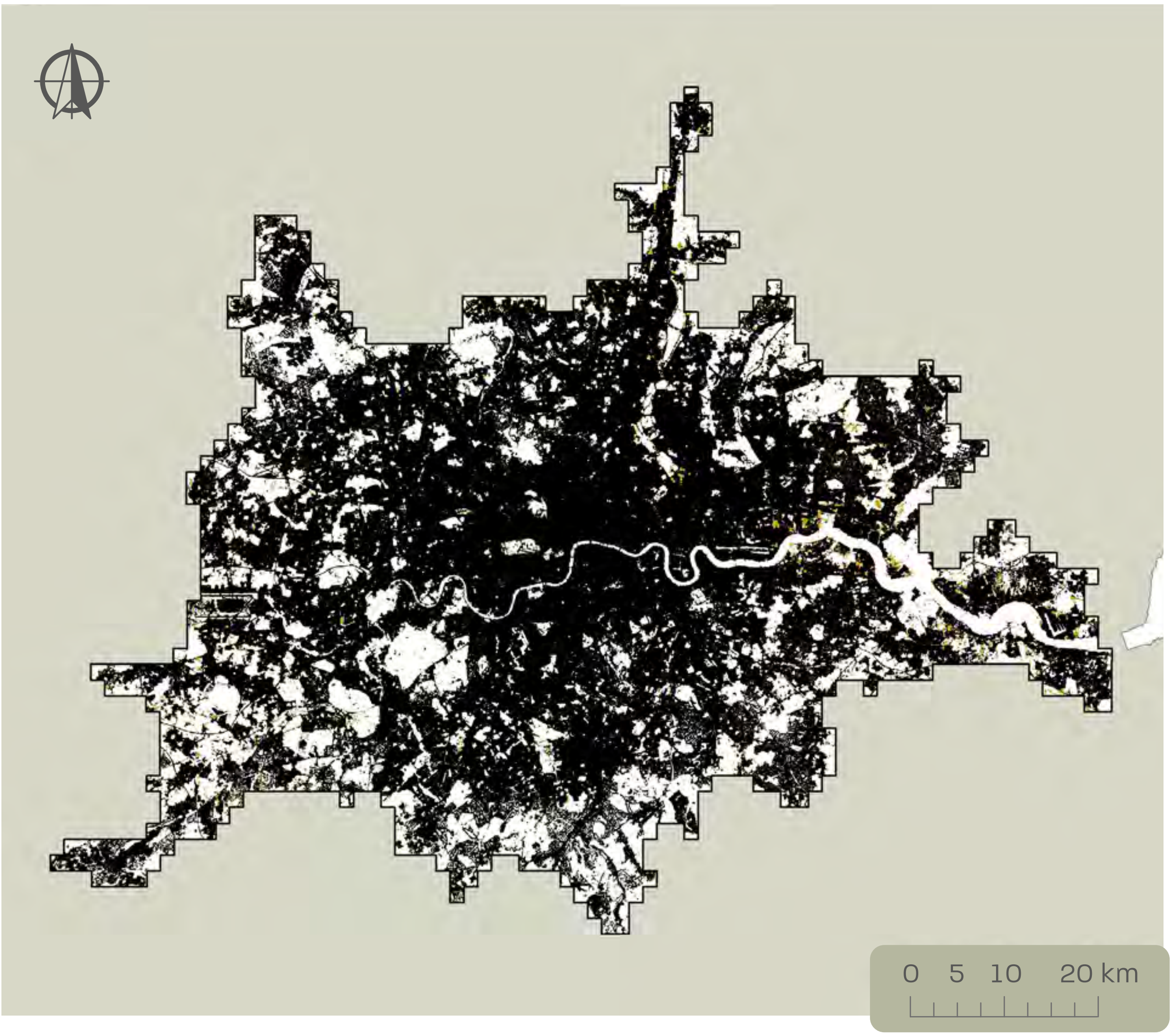
Built-up area per person (2015)

49 m^2

Europe & Central Asia

London, United Kingdom

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.21%

Total built-up expansion (1990–2015)

65 km²

Annual population growth

1.03%

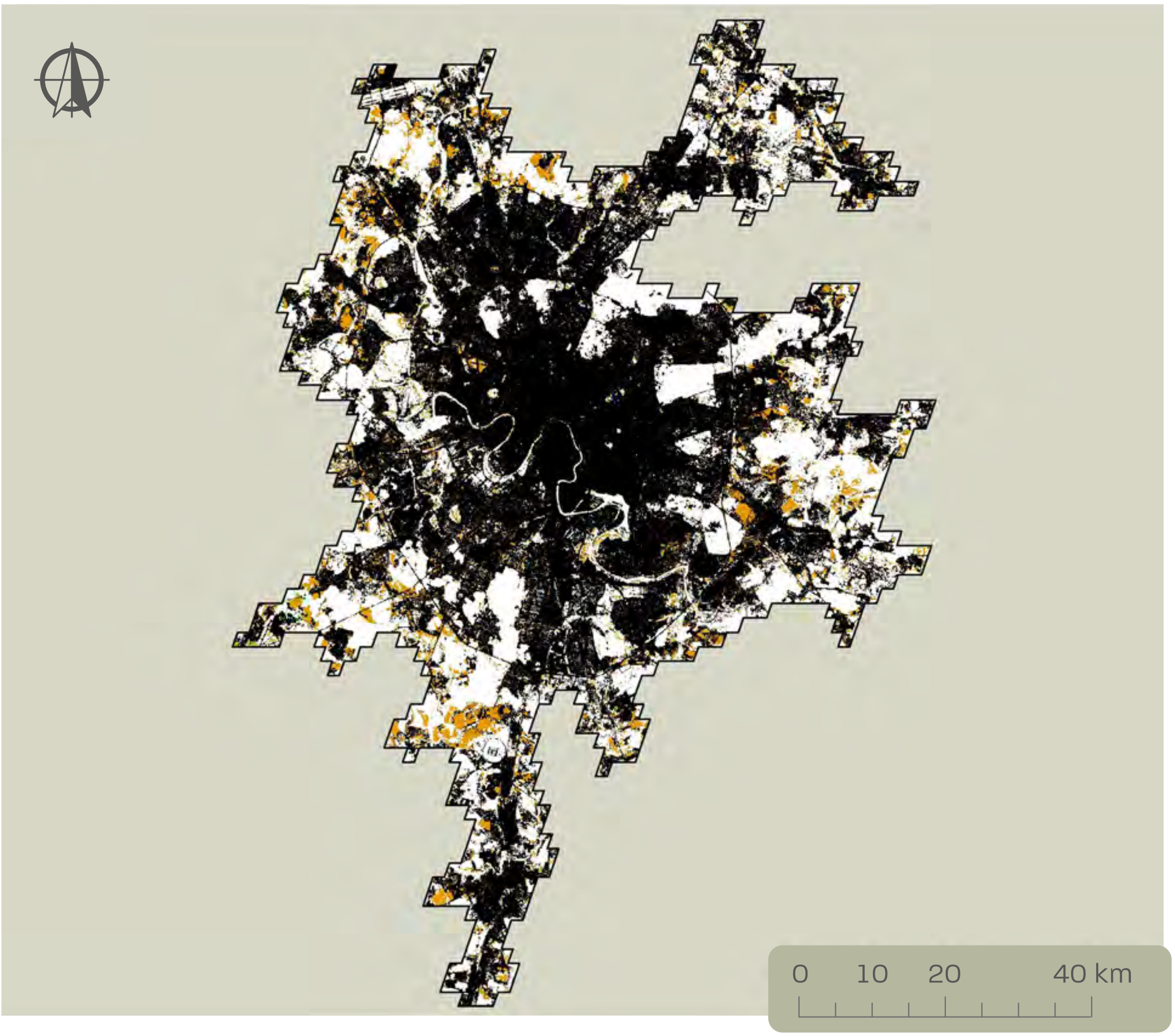
Built-up area per person (2015)

131 m²

Europe & Central Asia

Moscow, Russia

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.58%

Total built-up expansion (1990–2015)

164 km^2

Annual population growth

1.29%

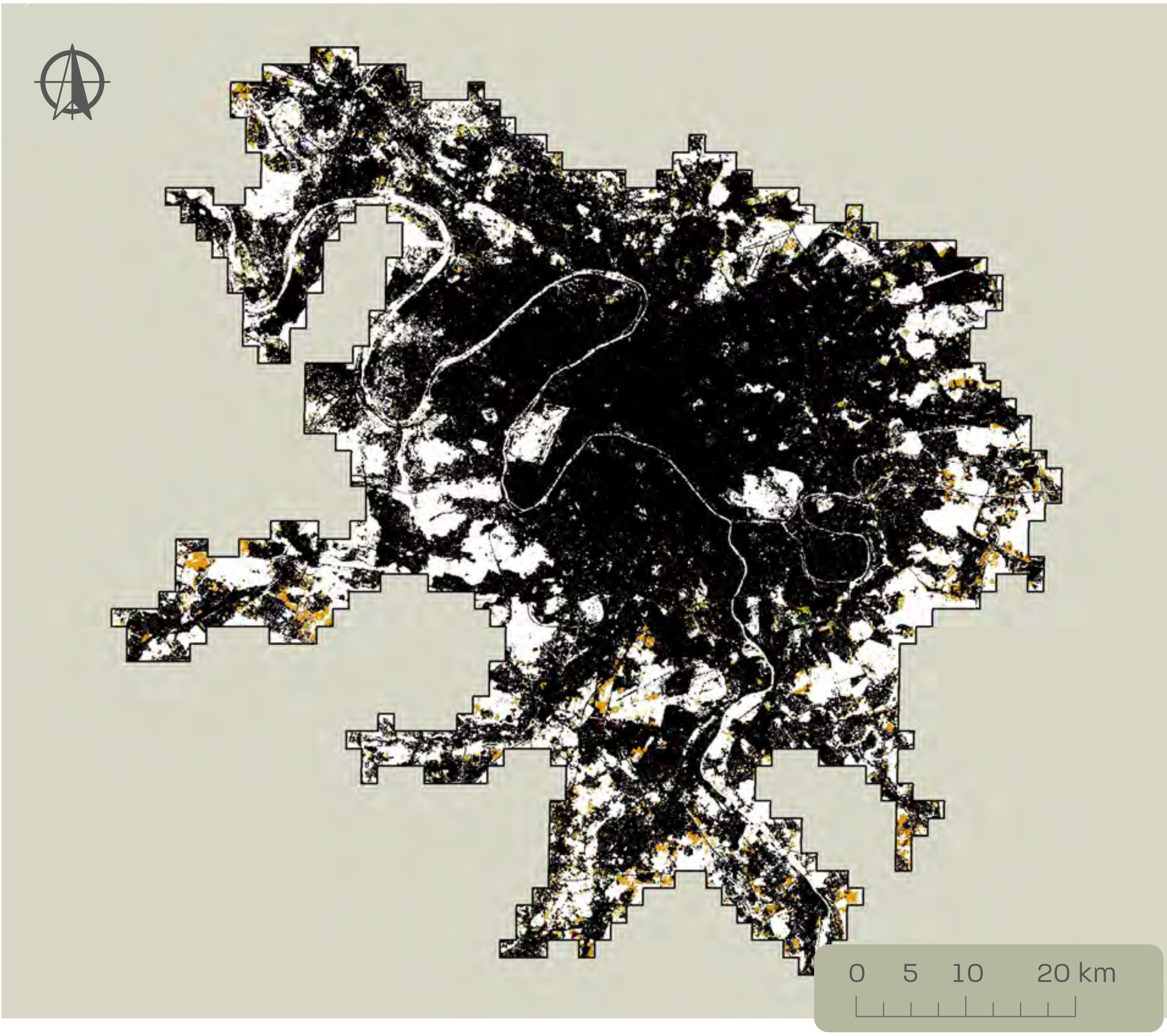
Built-up area per person (2015)

82 m^2

Europe & Central Asia

Paris, France

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.30%

Total built-up expansion (1990–2015)

84 km²

Annual population growth

0.50%

Built-up area per person (2015)

117 m²

Europe & Central Asia

Dortmund, Germany

● Built-up in 1990 ● Built-up in 2015

Annual built-up expansion

0.37%

Total built-up expansion (1990–2015)

71 km^2

Annual population growth

–0.23%

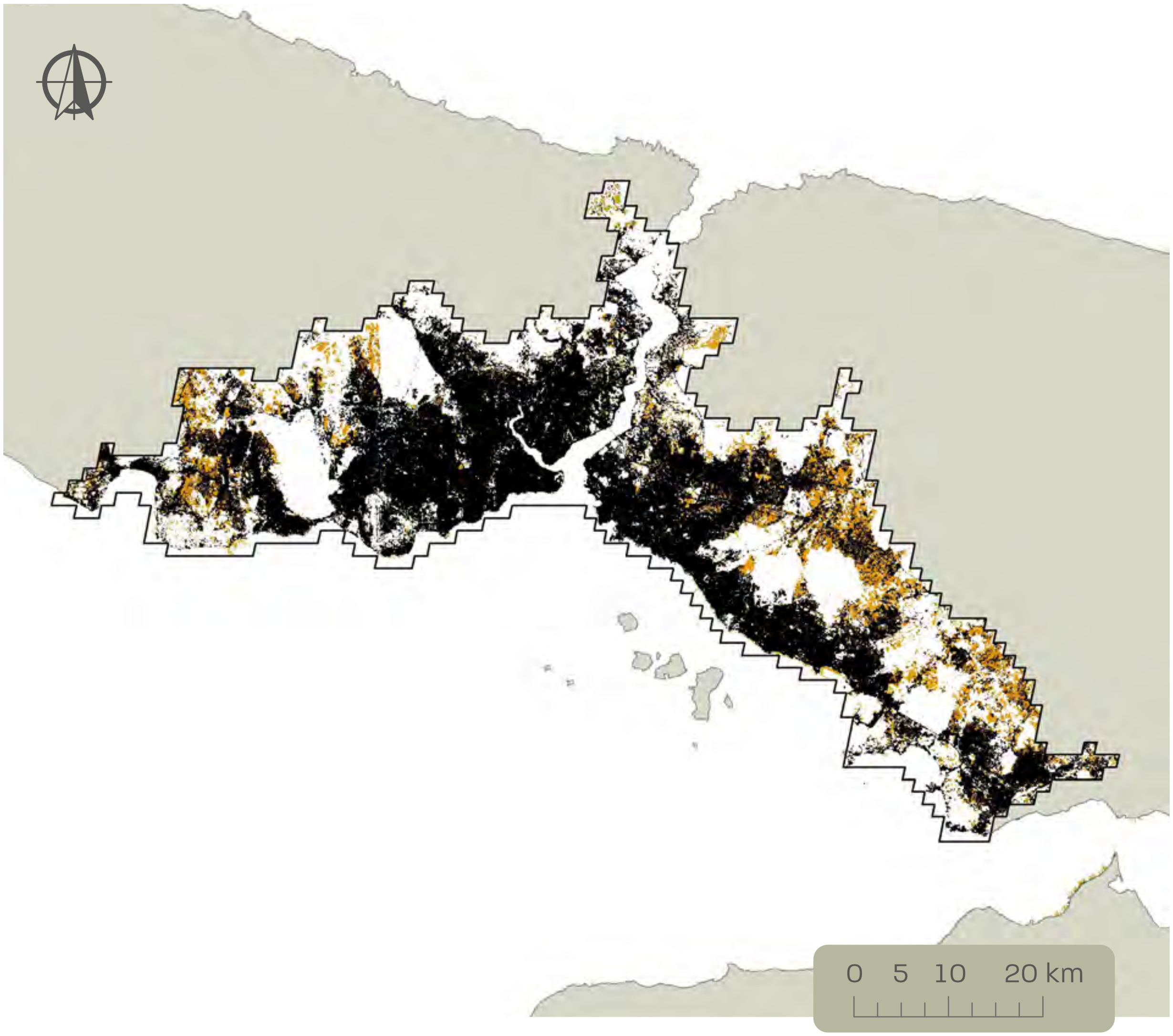
Built-up area per person (2015)

224 m^2

Europe & Central Asia

Istanbul, Turkey

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.79%

Total built-up expansion (1990–2015)

129 km^2

Annual population growth

2.30%

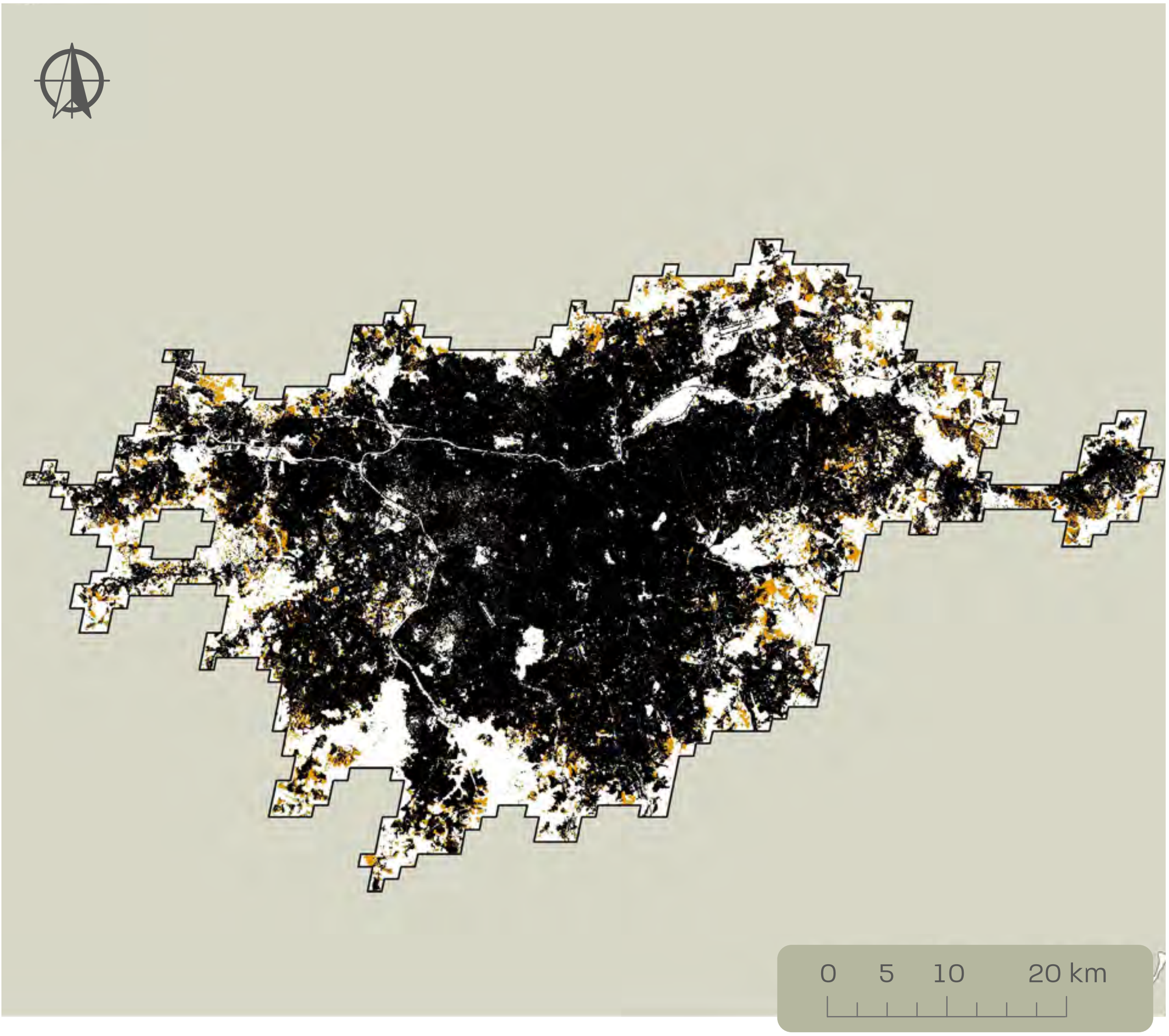
Built-up area per person (2015)

47 m^2

Latin America & Caribbean

São Paulo, Brazil

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.44%

Total built-up expansion (1990–2015)

146 km²

Annual population growth

1.04%

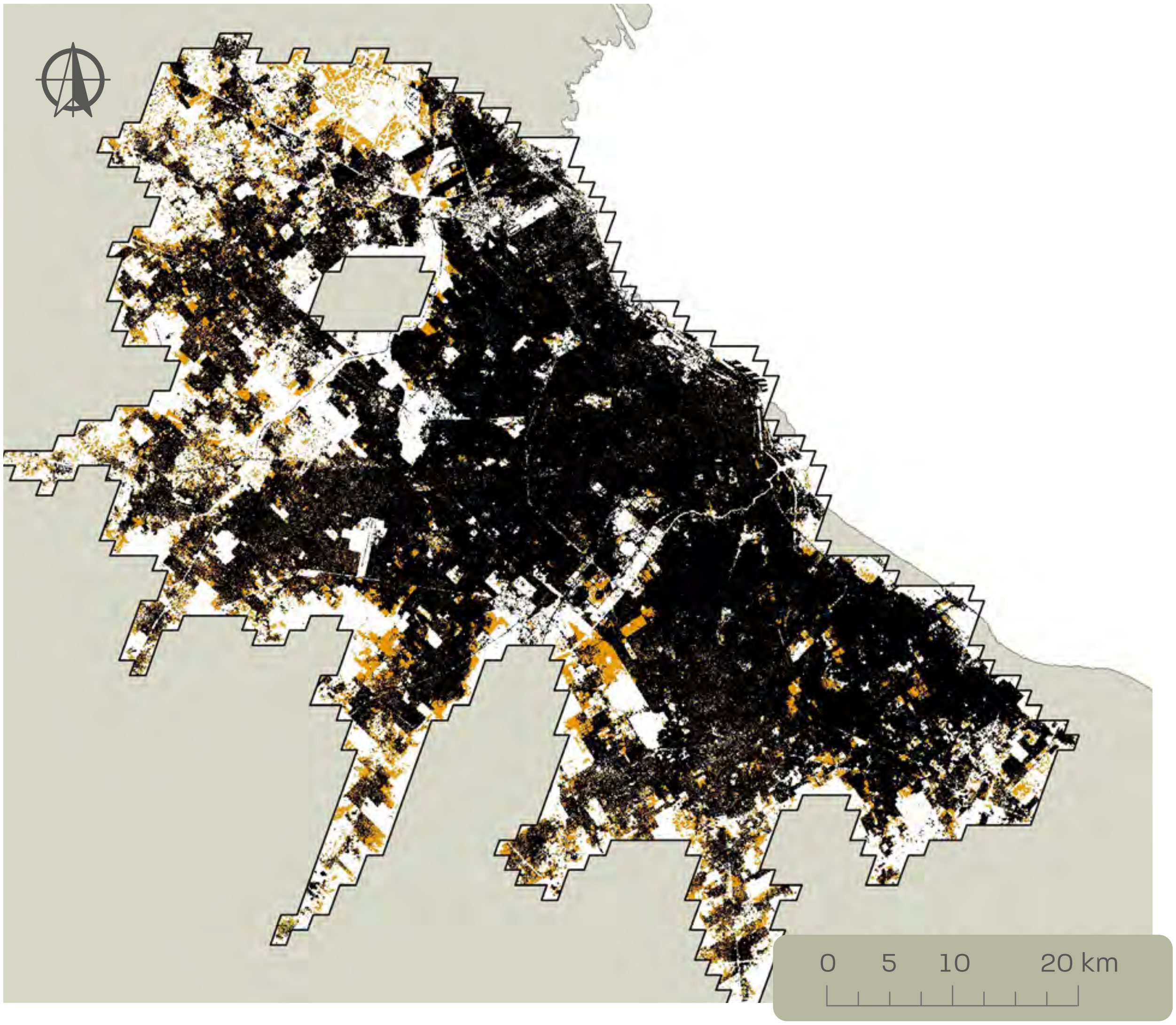
Built-up area per person (2015)

71 m²

Latin America & Caribbean

Buenos Aires, Argentina

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.72%

Total built-up expansion (1990–2015)

223 km²

Annual population growth

1.19%

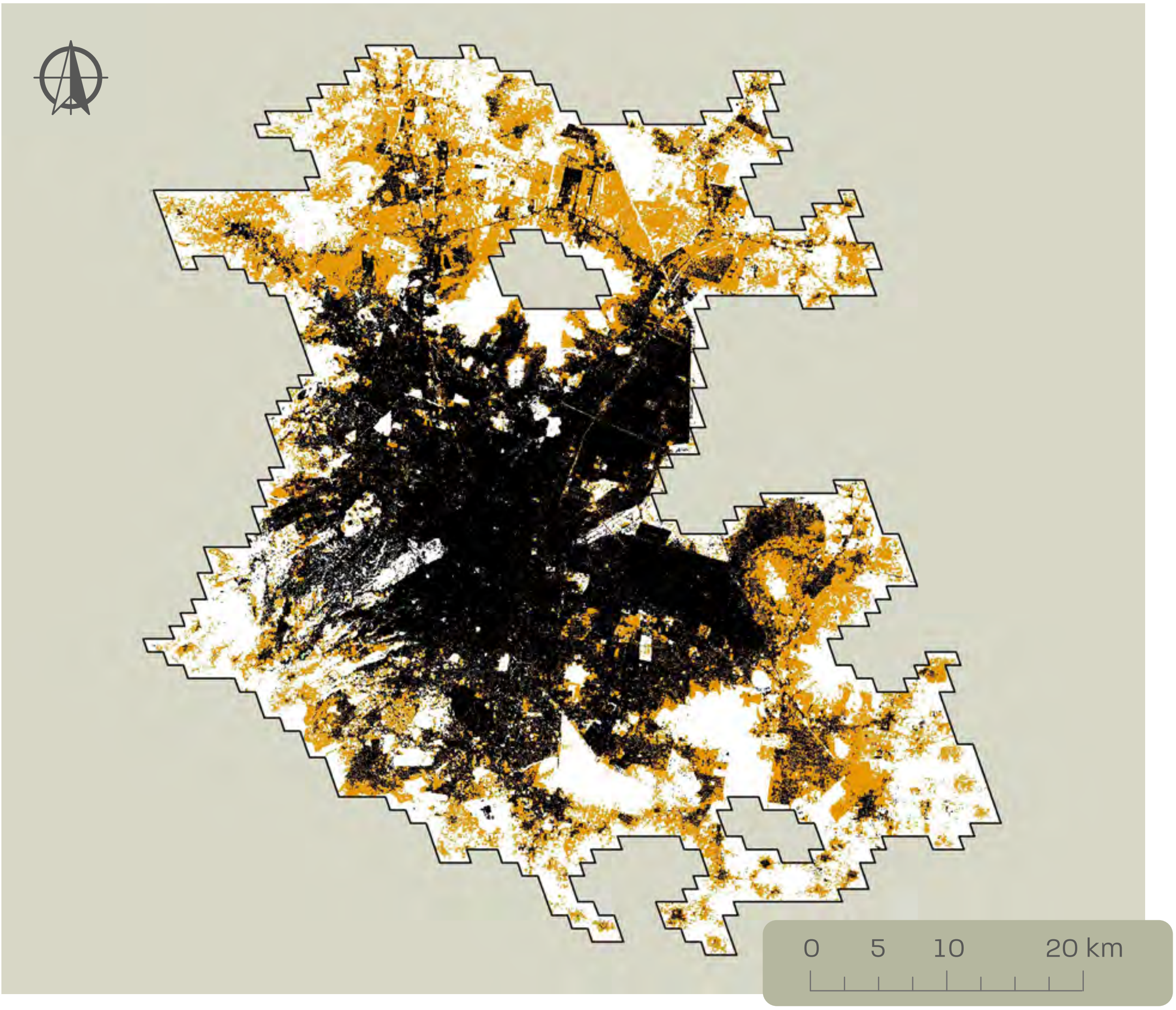
Built-up area per person (2015)

95 m²

Latin America & Caribbean

Mexico City, Mexico

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

2.00%

Total built-up expansion (1990–2015)

510 km^2

Annual population growth

0.59%

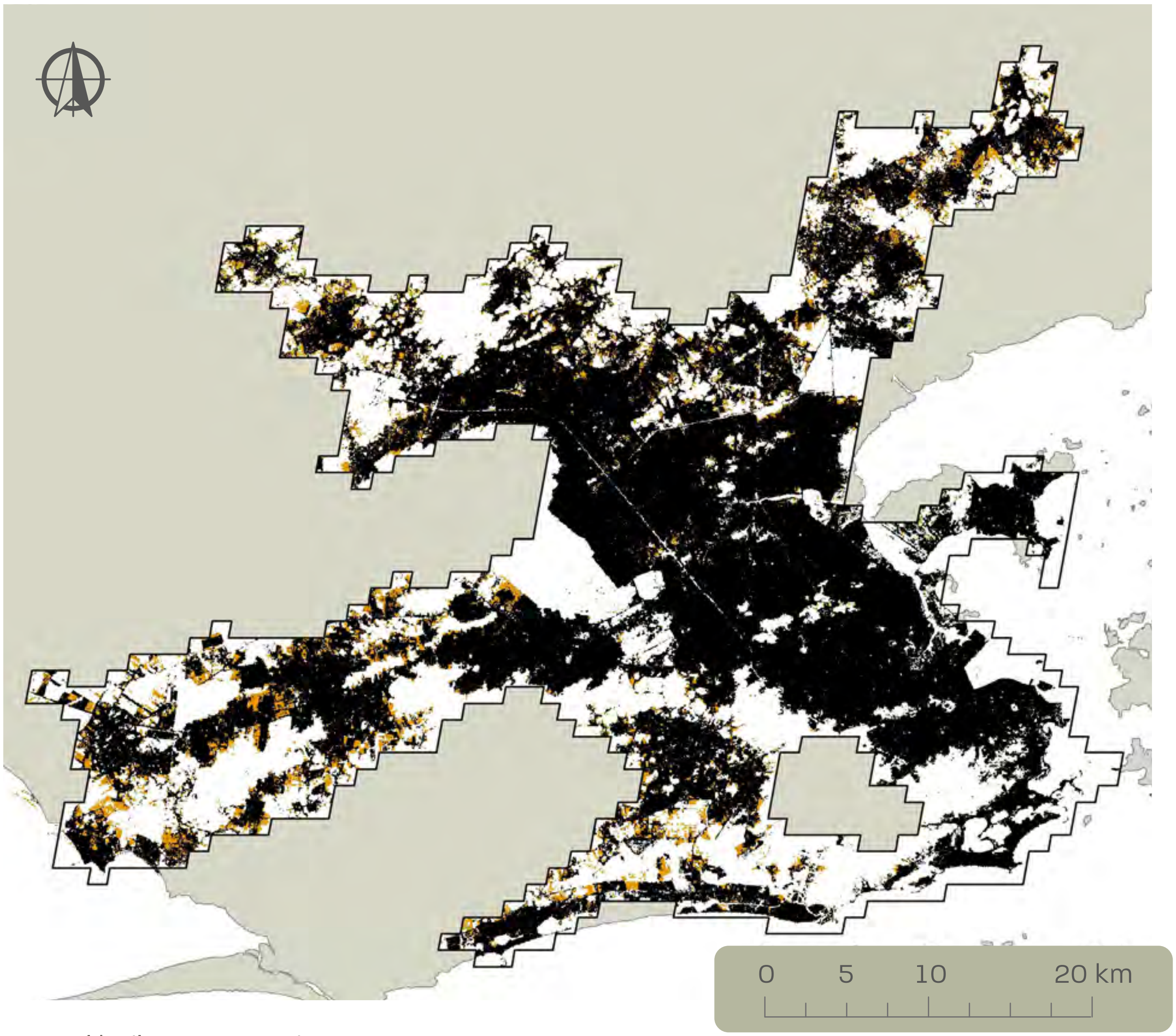
Built-up area per person (2015)

55 m^2

Latin America & Caribbean

Rio de Janeiro, Brazil

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.43%

Total built-up expansion (1990–2015)

81 km²

Annual population growth

0.89%

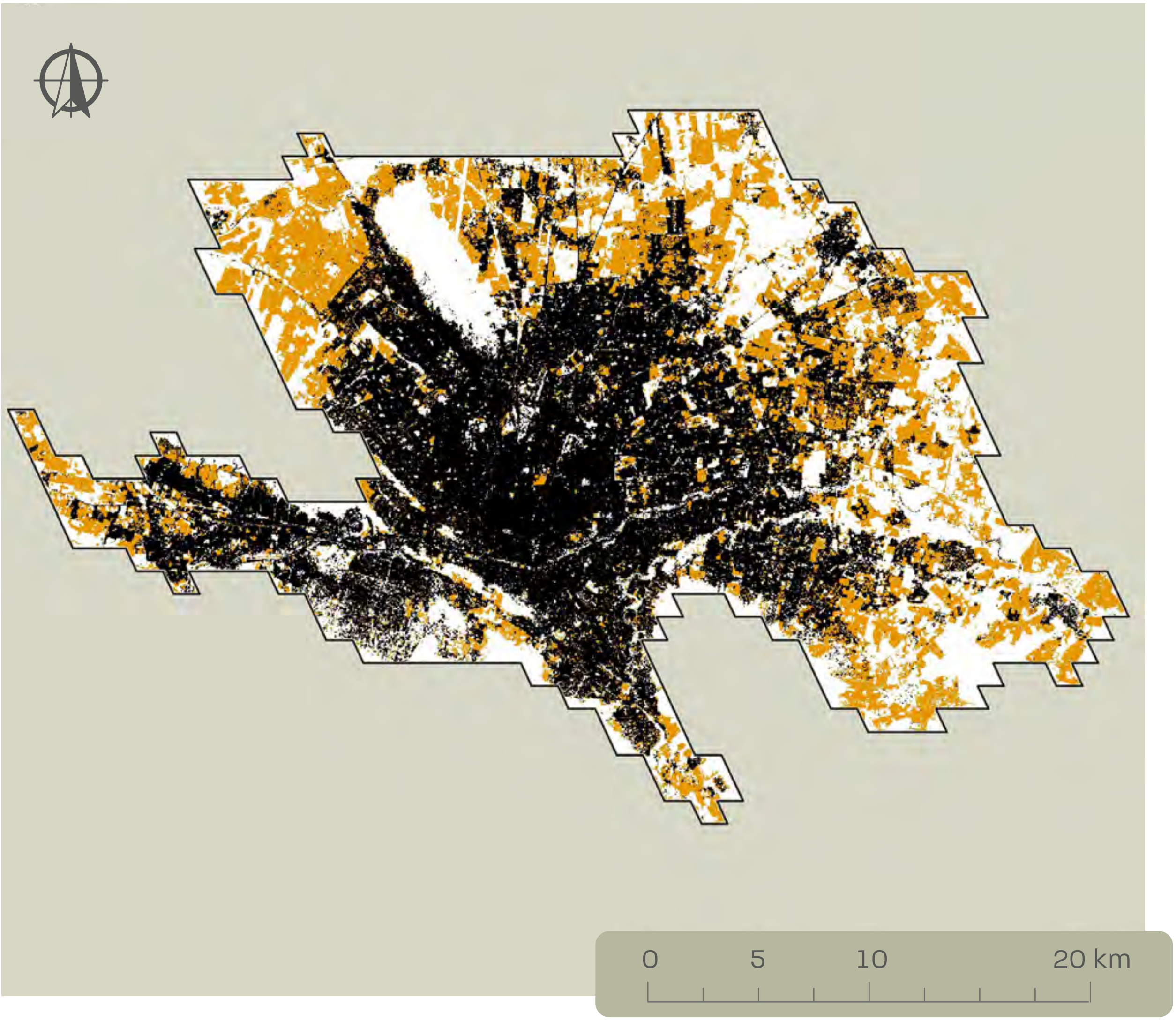
Built-up area per person (2015)

79 m²

Latin America & Caribbean

Monterrey, Mexico

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.86%

Total built-up expansion (1990–2015)

161 km²

Annual population growth

1.05%

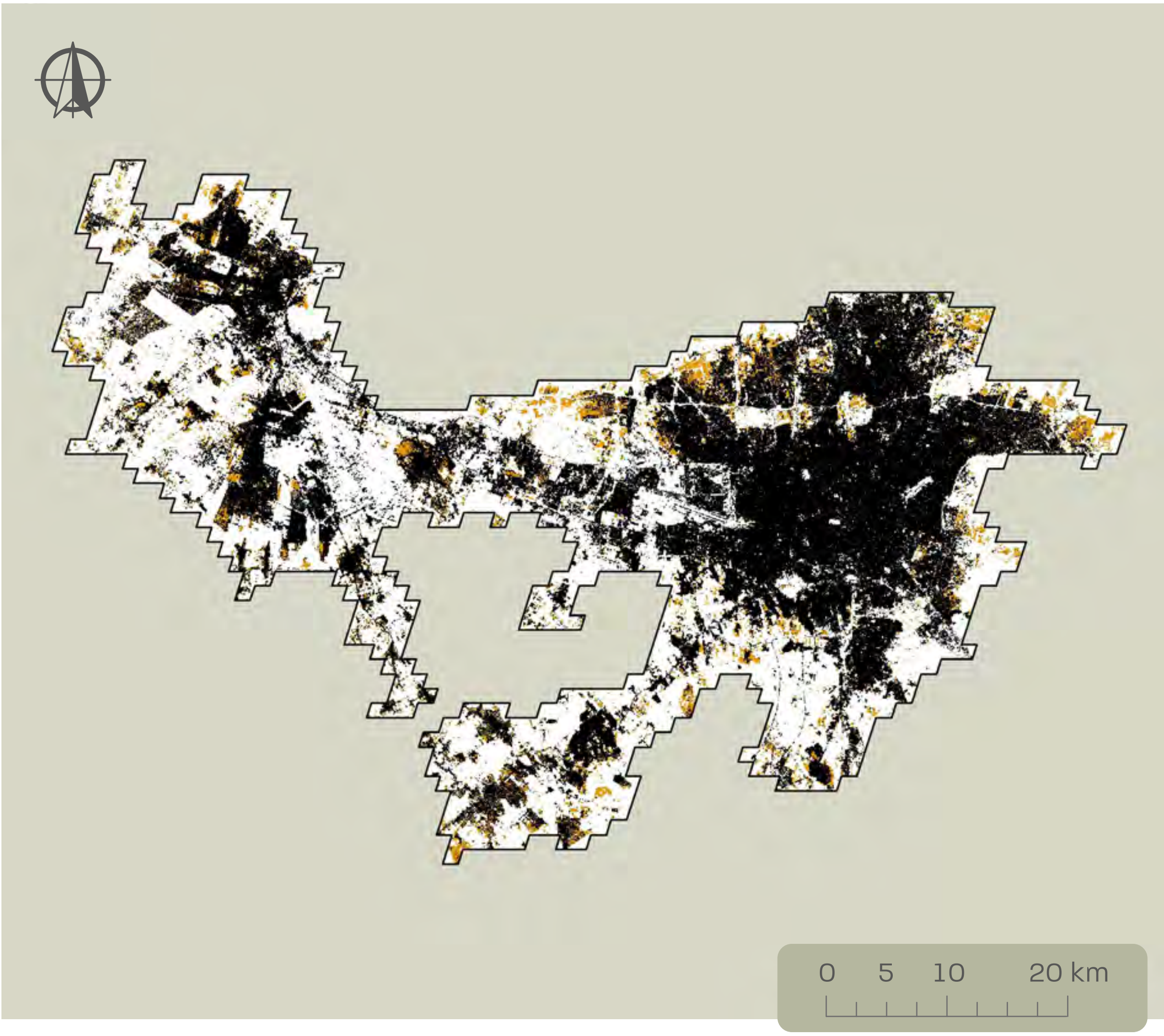
Built-up area per person (2015)

102 m²

Middle East & North Africa

Tehran, Iran

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.65%

Total built-up expansion (1990–2015)

102 km^2

Annual population growth

2.09%

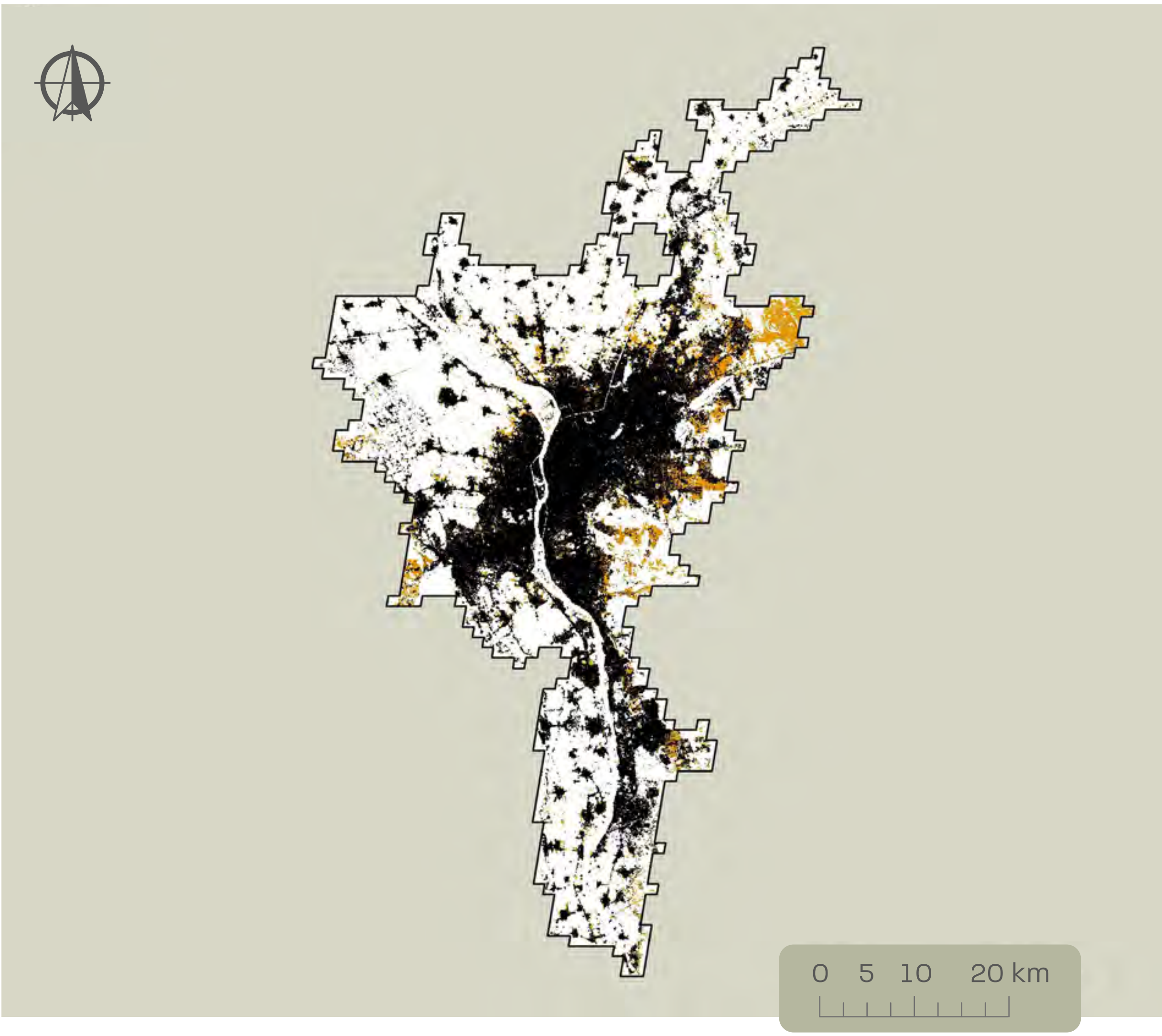
Built-up area per person (2015)

52 m^2

Middle East & North Africa

Cairo, Egypt

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.83%

Total built-up expansion (1990–2015)

119 km²

Annual population growth

1.77%

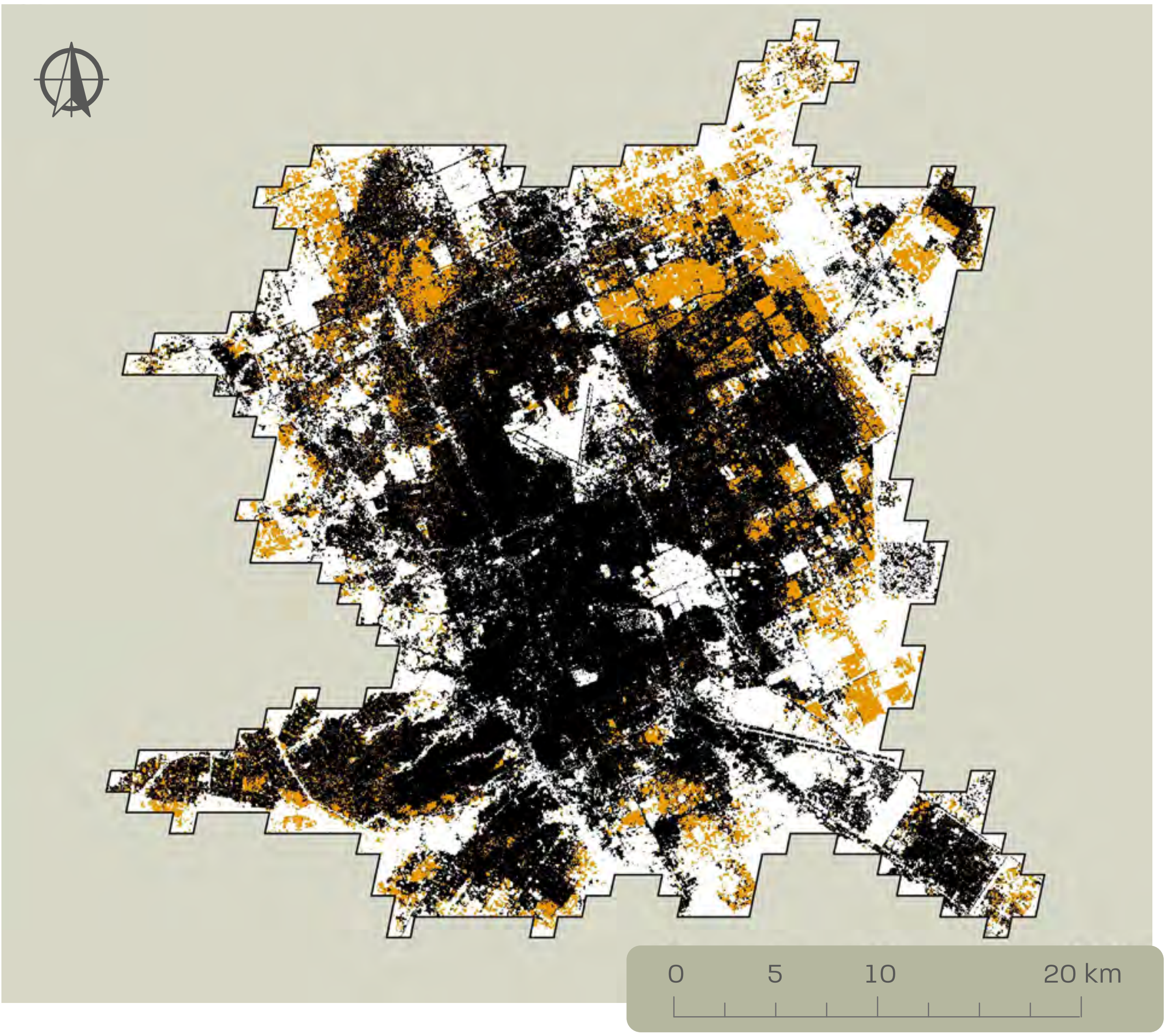
Built-up area per person (2015)

30 m²

Middle East & North Africa

Riyadh, Saudi Arabia

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.96%

Total built-up expansion (1990–2015)

136 km^2

Annual population growth

3.05%

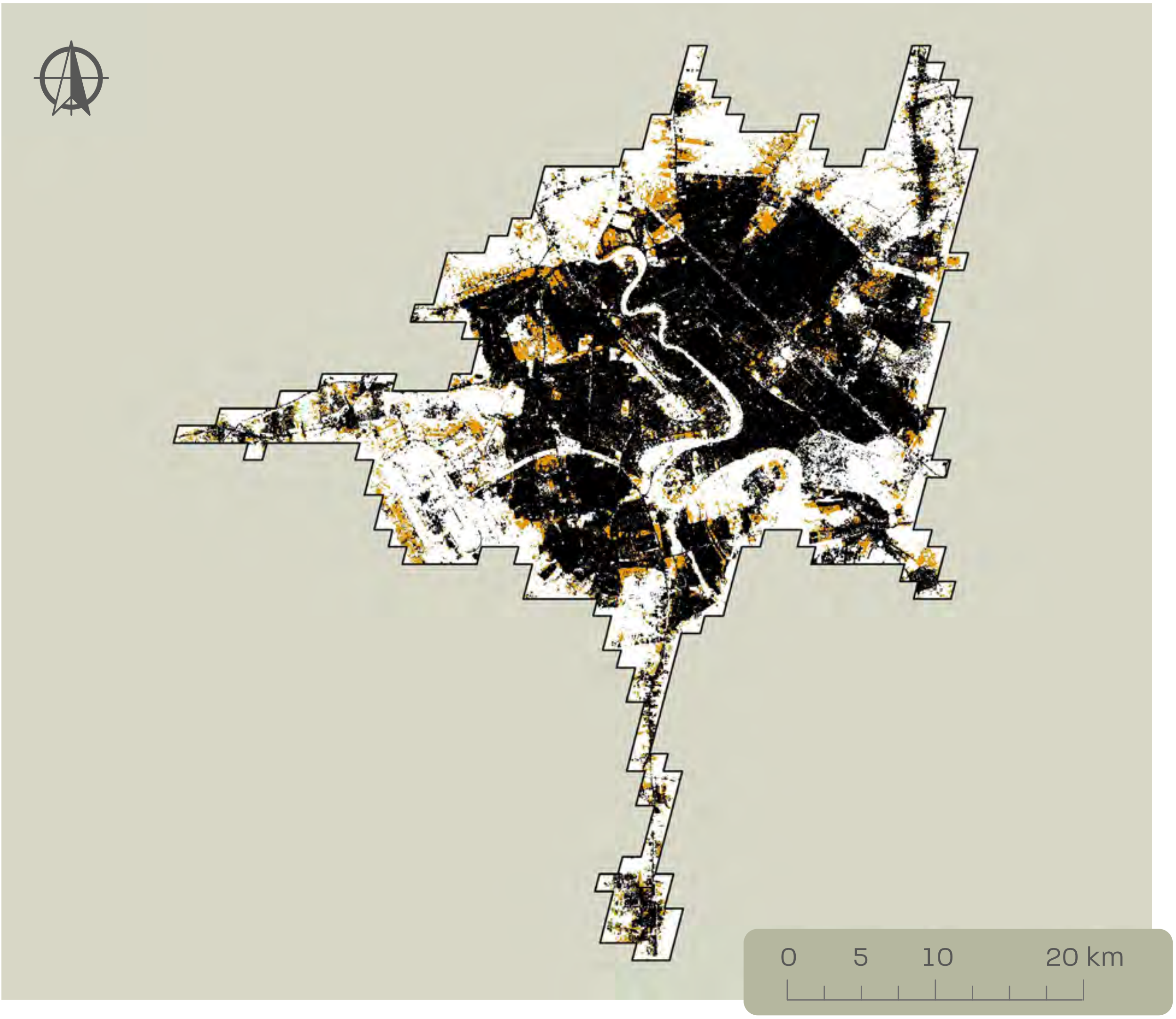
Built-up area per person (2015)

106 m^2

Middle East & North Africa

Baghdad, Iraq

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.72%

Total built-up expansion (1990–2015)

72 km²

Annual population growth

1.64%

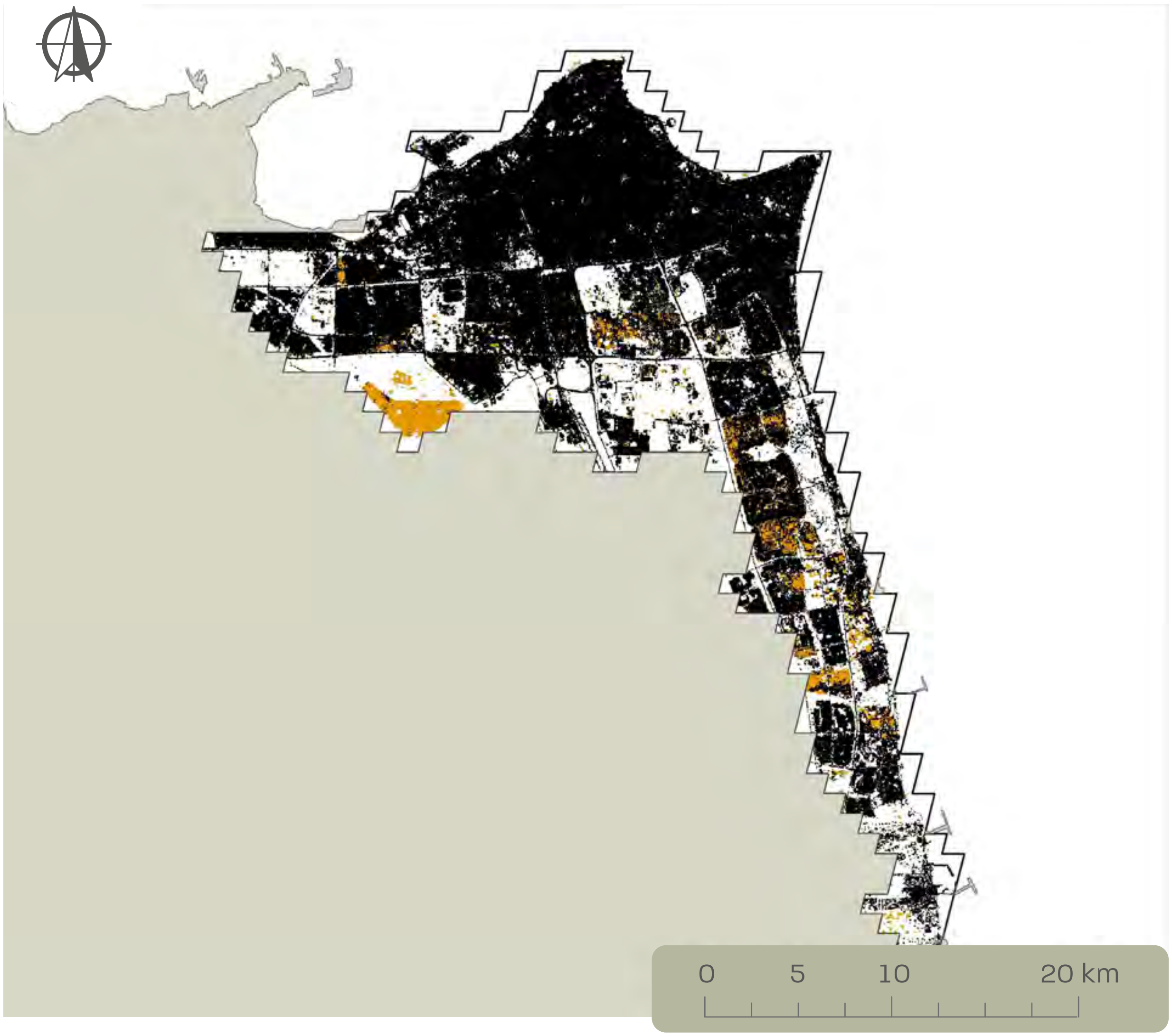
Built-up area per person (2015)

76 m²

Middle East & North Africa

Kuwait City, Kuwait

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.29%

Total built-up expansion (1990–2015)

22 km²

Annual population growth

2.56%

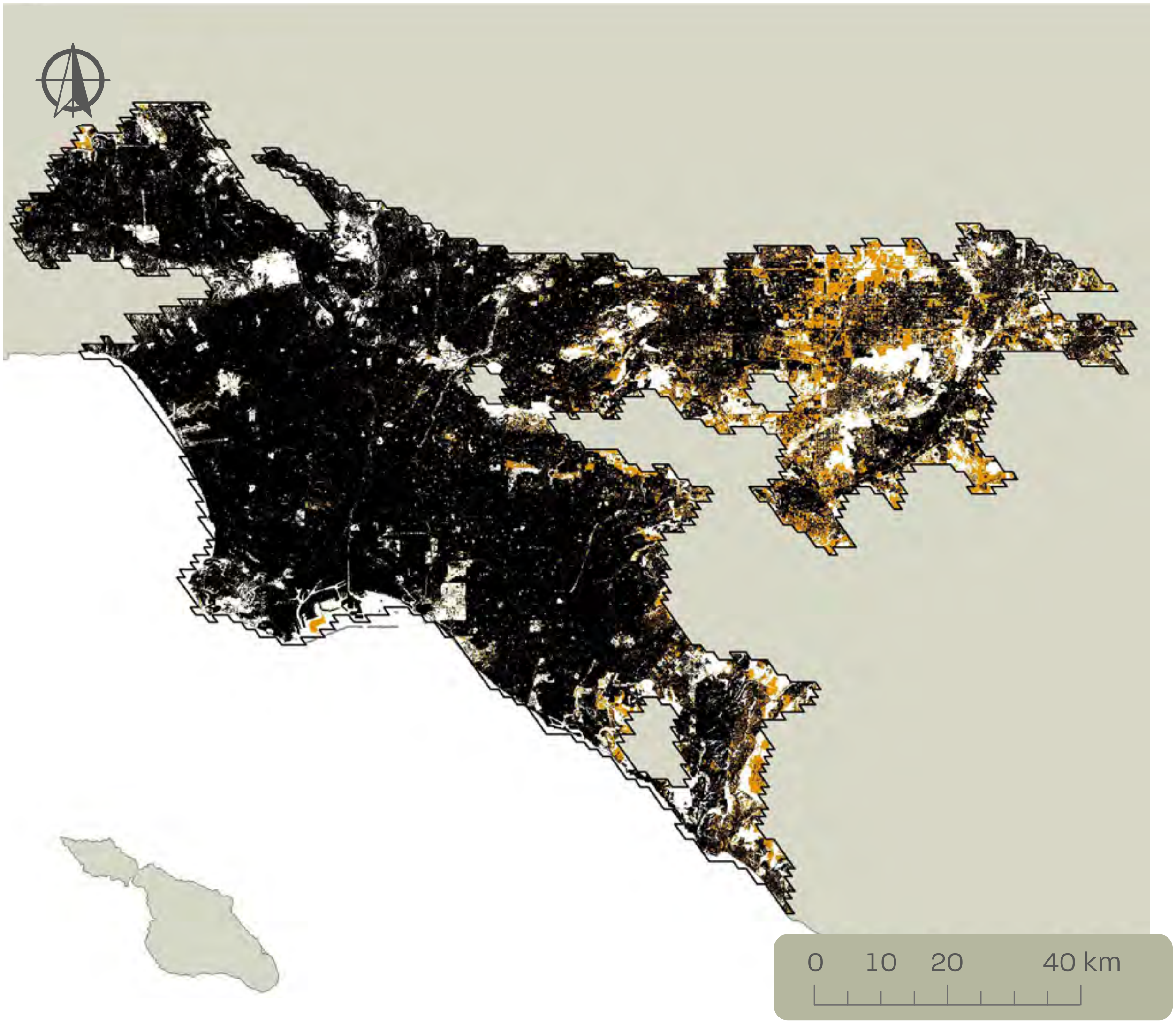
Built-up area per person (2015)

96 m²

North America

Los Angeles, California

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.60%

Total built-up expansion (1990–2015)

643 km^2

Annual population growth

0.89%

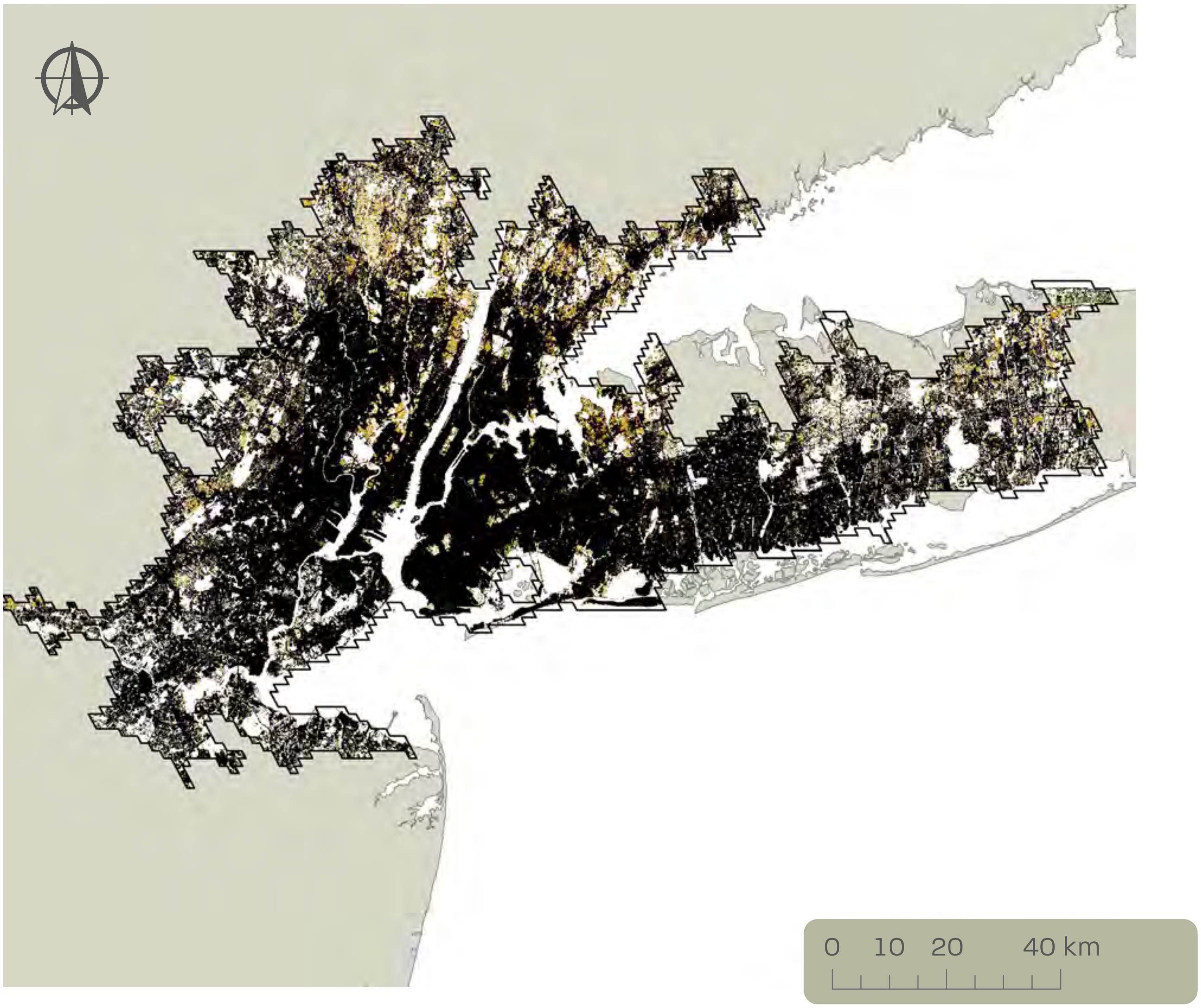
Built-up area per person (2015)

315 m^2

North America

New York, New York

Built-up in 1990 Built-up in 2015



Annual built-up expansion

0.56%

Total built-up expansion (1990–2015)

481 km^2

Annual population growth

0.26%

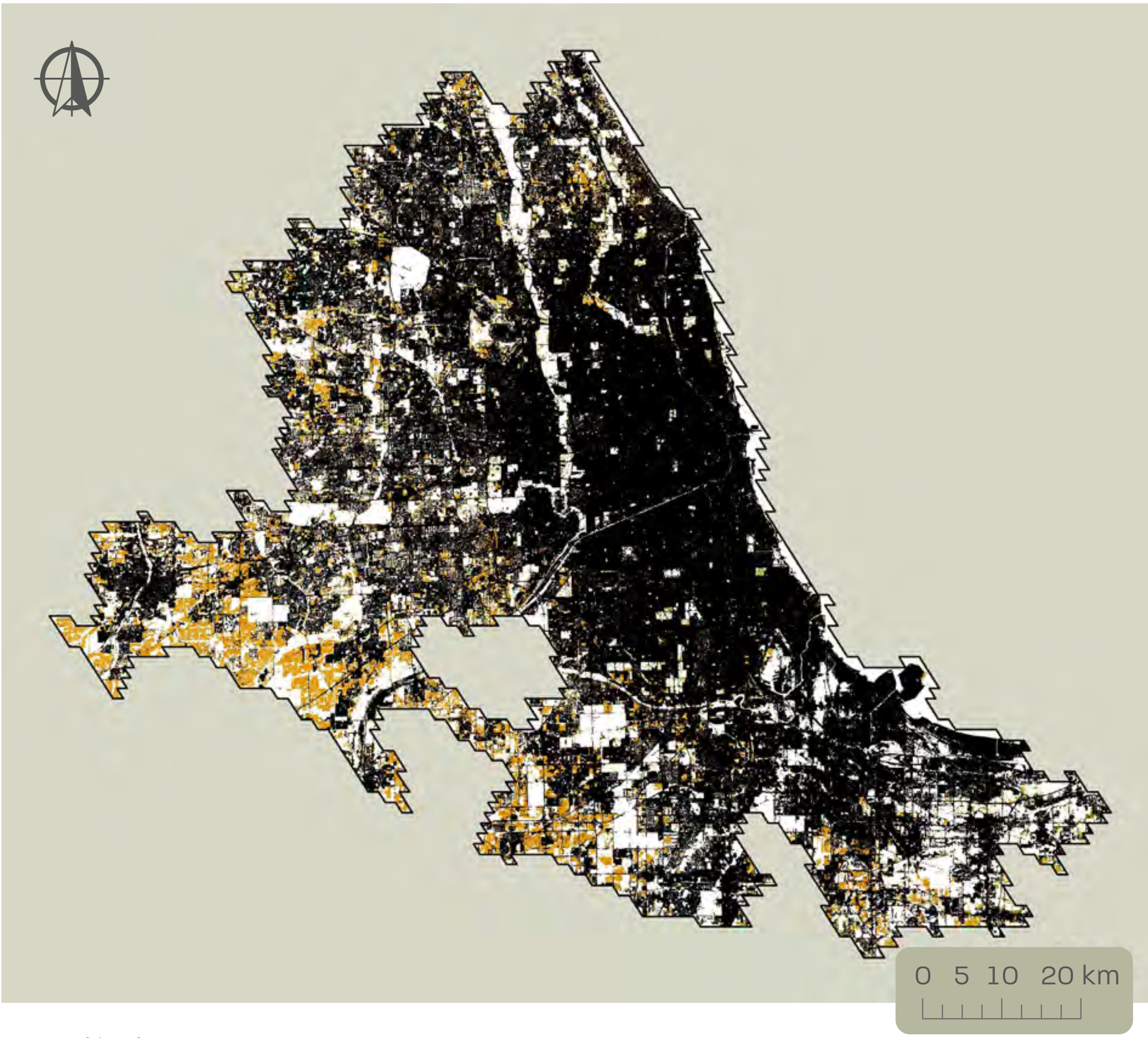
Built-up area per person (2015)

220 m^2

North America

Chicago, Illinois

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.64%

Total built-up expansion (1990–2015)

414 km^2

Annual population growth

0.21%

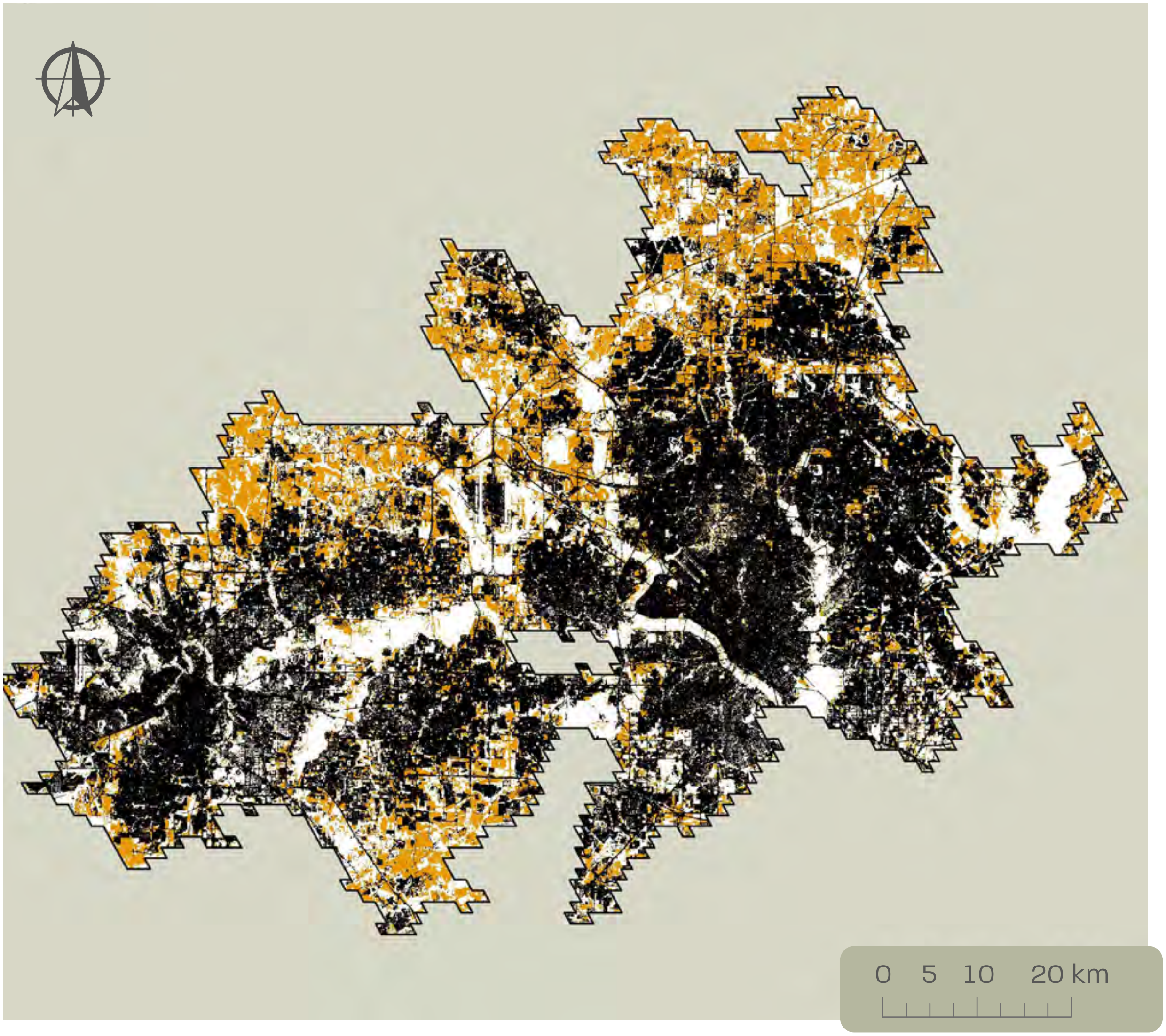
Built-up area per person (2015)

396 m^2

North America

Dallas, Texas

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.44%

Total built-up expansion (1990–2015)

788 km^2

Annual population growth

1.77%

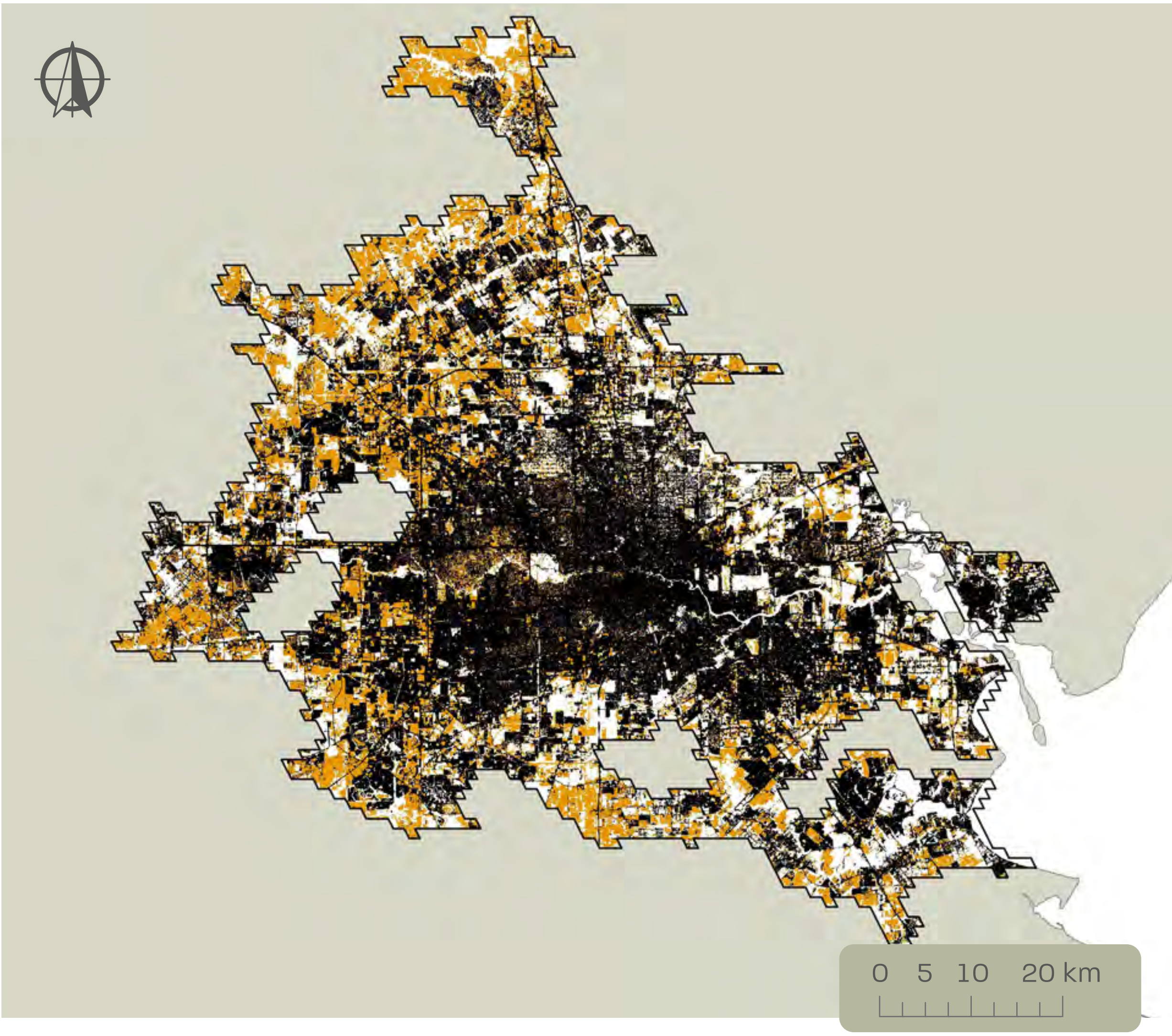
Built-up area per person (2015)

459 m^2

North America

Houston, Texas

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.58%

Total built-up expansion (1990–-2015)

804 km²

Annual population growth

2.10%

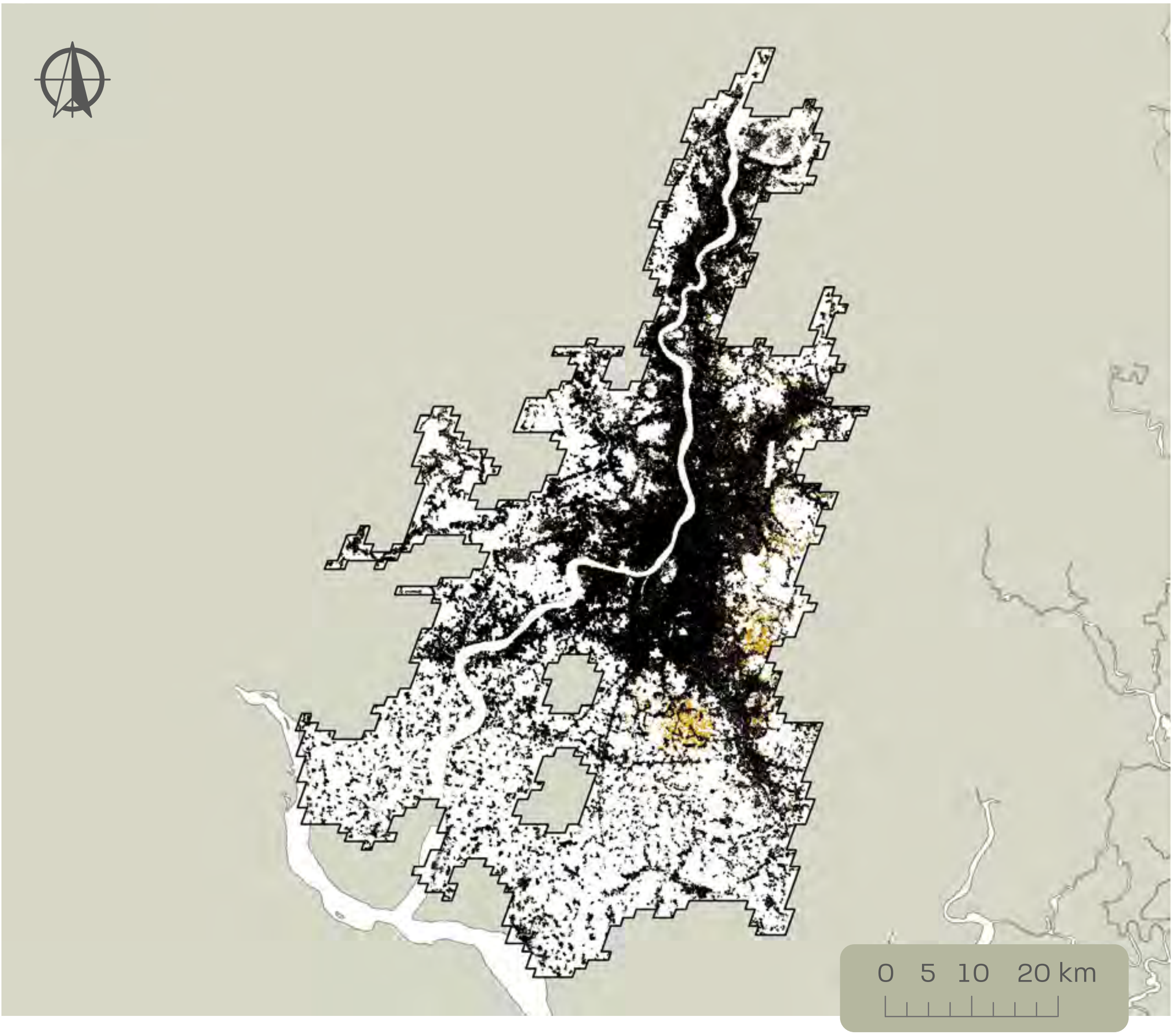
Built-up area per person (2015)

437 m²

South Asia

Kolkata, India

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.39%

Total built-up expansion (1990–-2015)

113 km²

Annual population growth

0.92%

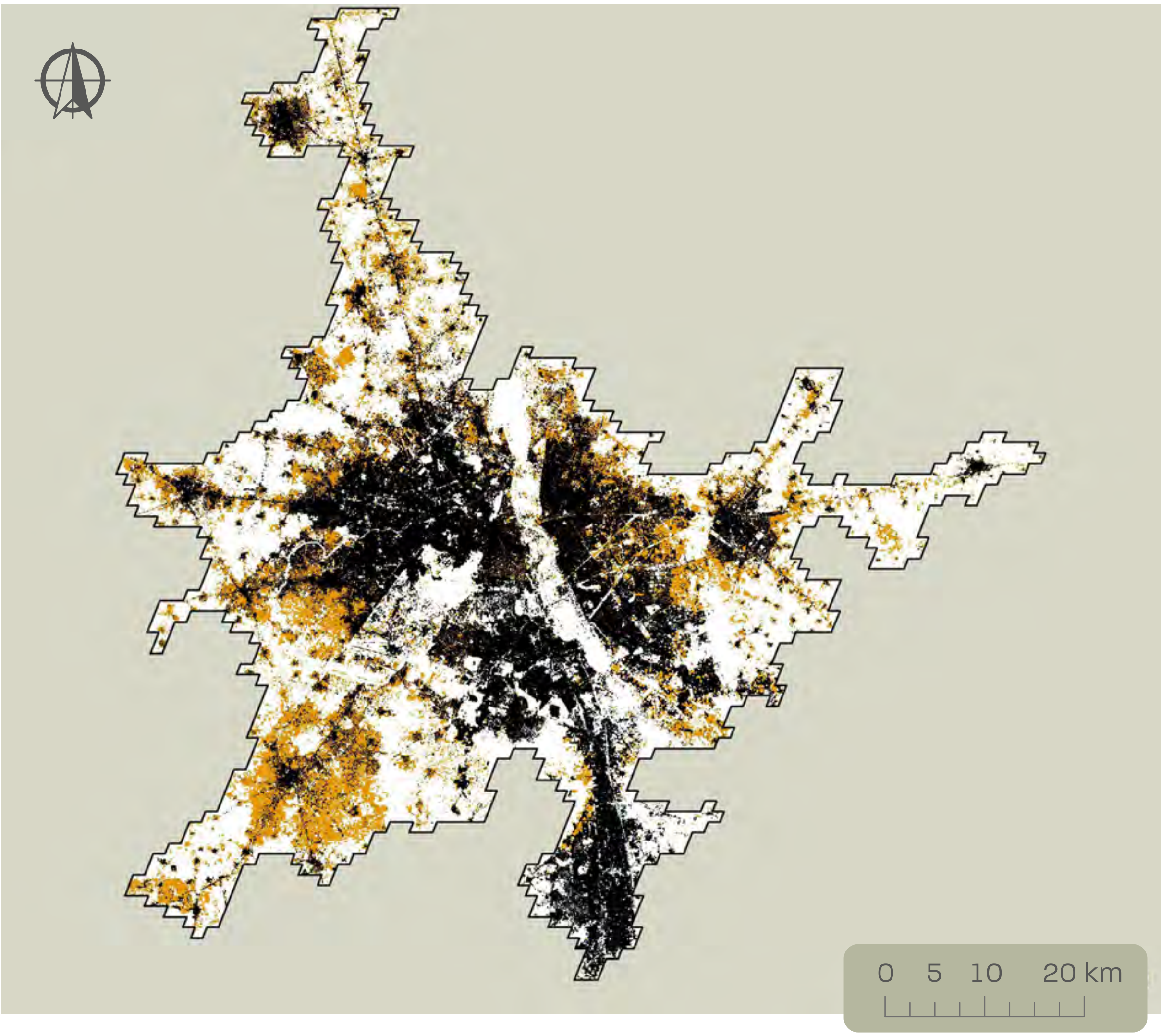
Built-up area per person (2015)

54 m²

South Asia

New Delhi, India

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.82%

Total built-up expansion (1990–2015)

443 km^2

Annual population growth

2.25%

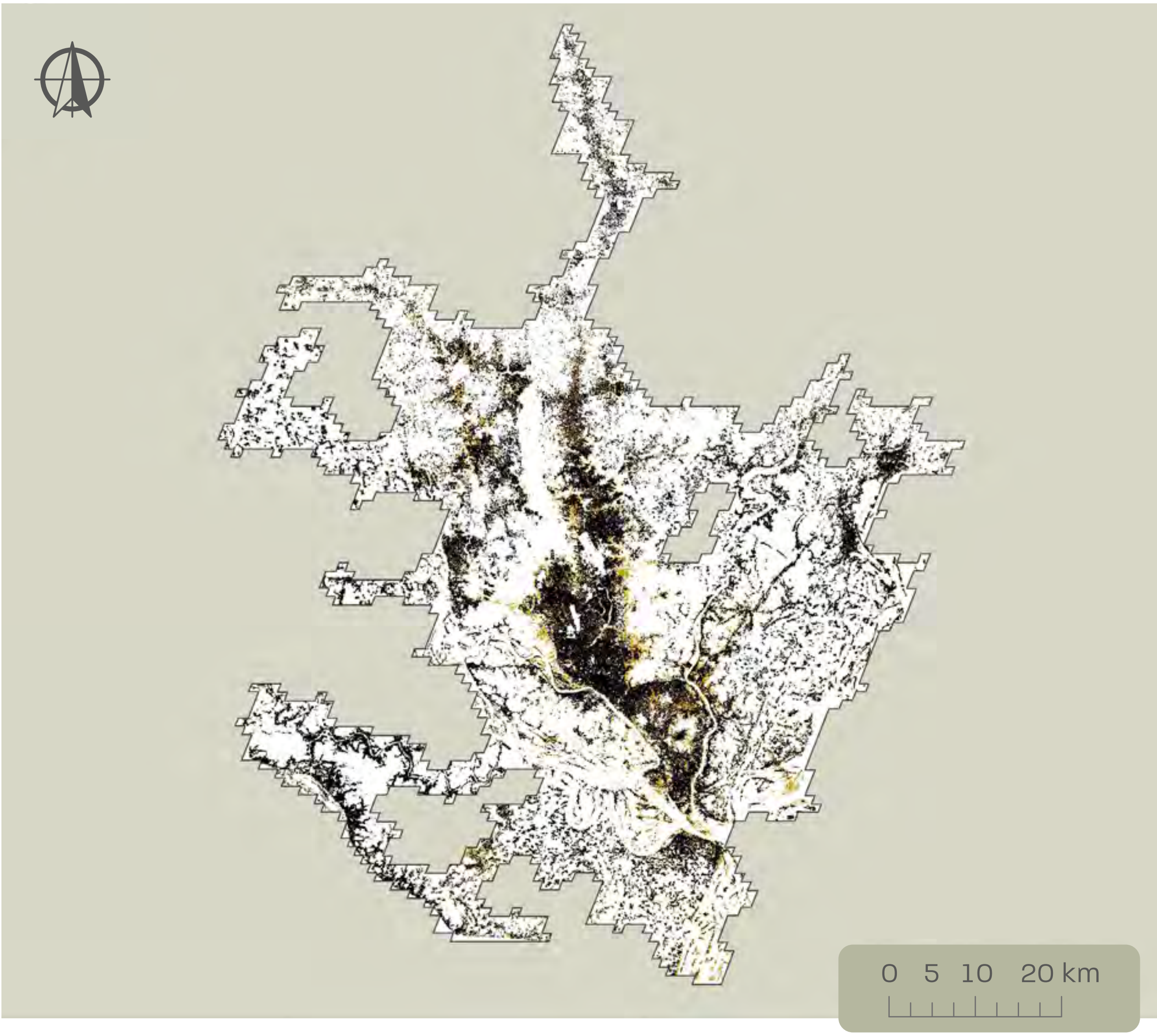
Built-up area per person (2015)

40 m^2

South Asia

Dhaka, Bangladesh

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

1.02%

Total built-up expansion (1990–2015)

195 km^2

Annual population growth

3.48%

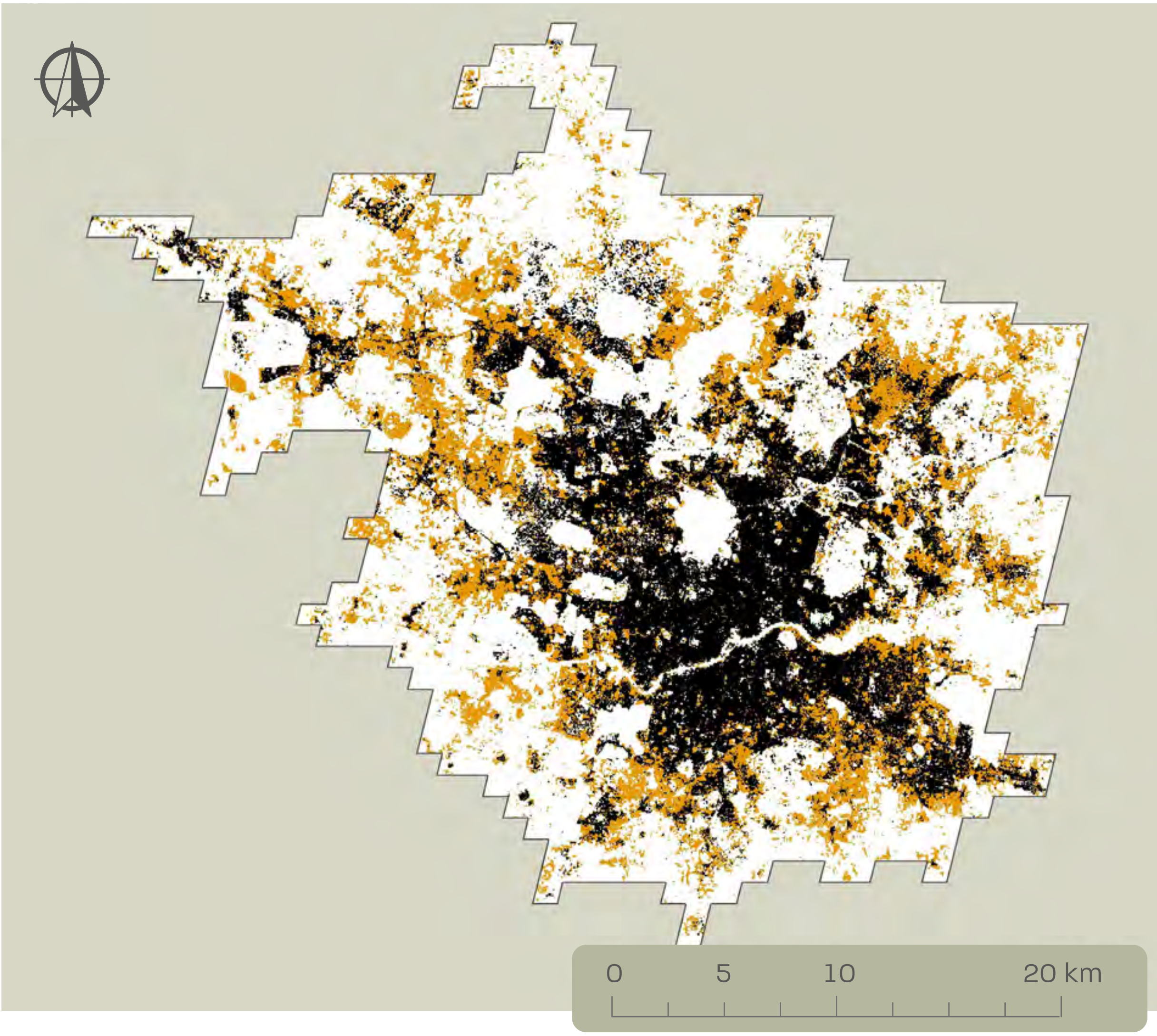
Built-up area per person (2015)

33 m^2

South Asia

Hyderabad, India

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

2.48%

Total built-up expansion (1990–2015)

168 km²

Annual population growth

1.65%

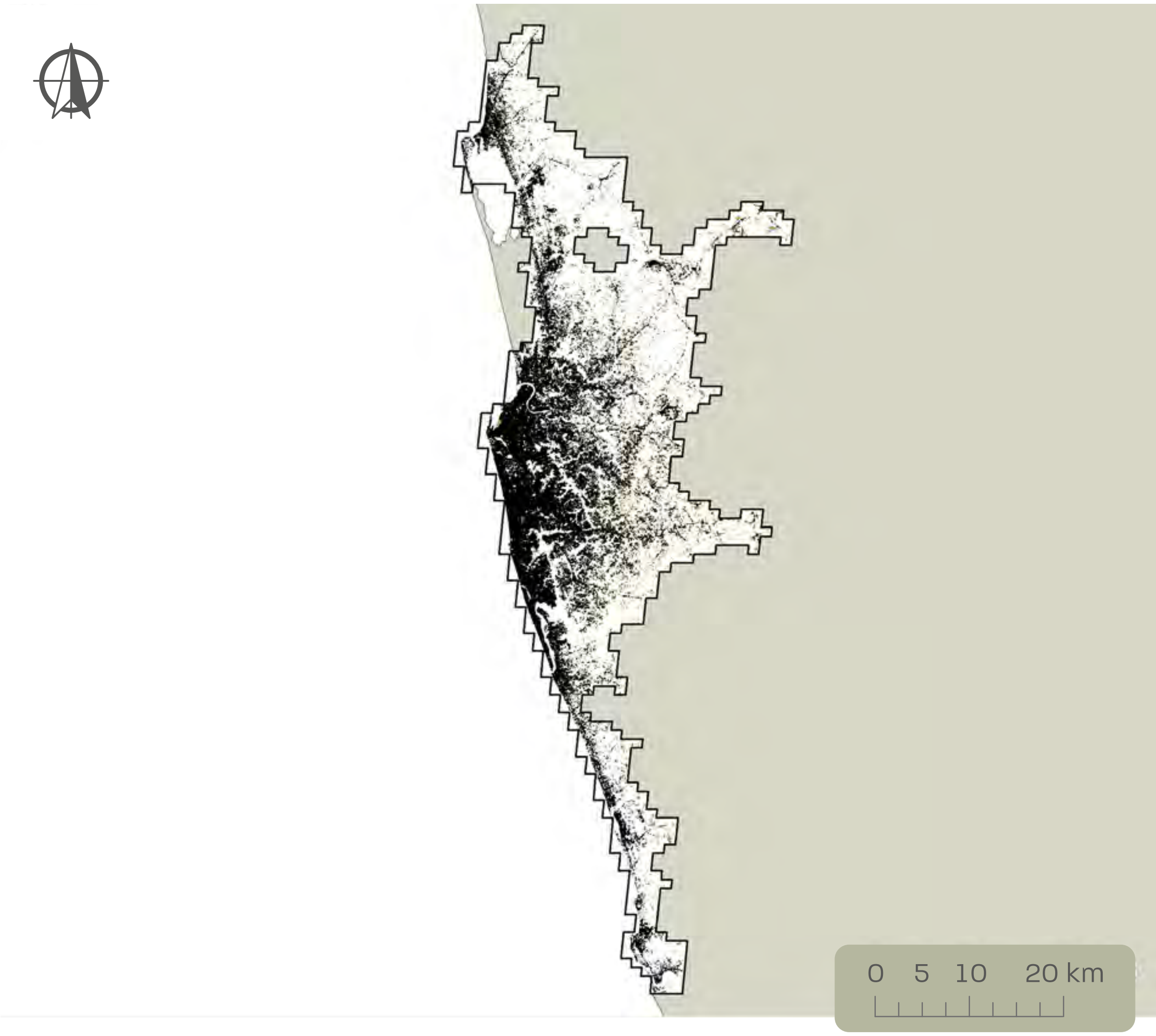
Built-up area per person (2015)

45 m²

South Asia

Colombo, Sri Lanka

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.36%

Total built-up expansion (1990–2015)

32 km²

Annual population growth

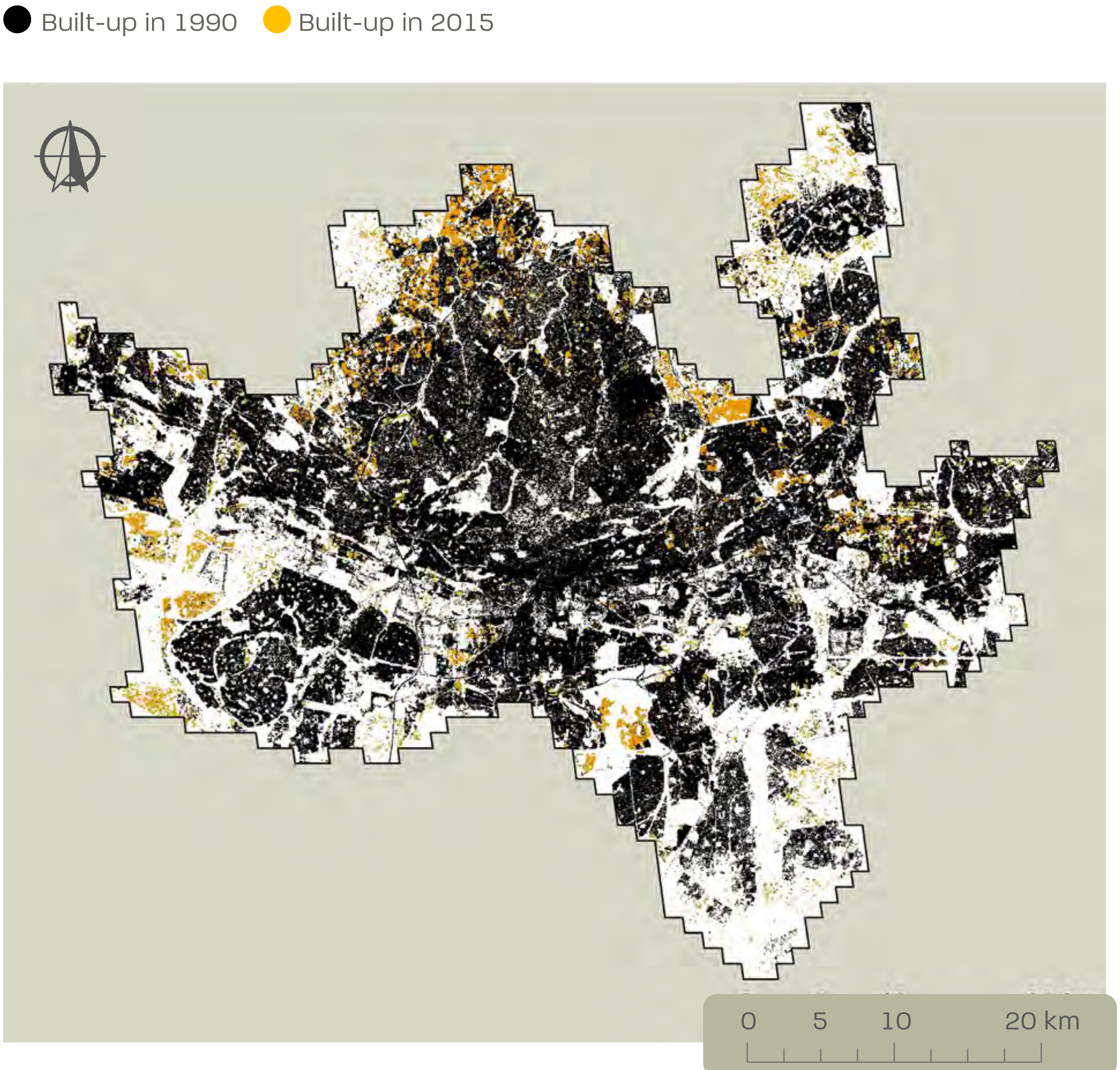
1.25%

Built-up area per person (2015)

17 m²

Sub-Saharan Africa

Johannesburg, South Africa



Annual built-up expansion

0.61%

Total built-up expansion (1990–2015)

126 km^2

Annual population growth

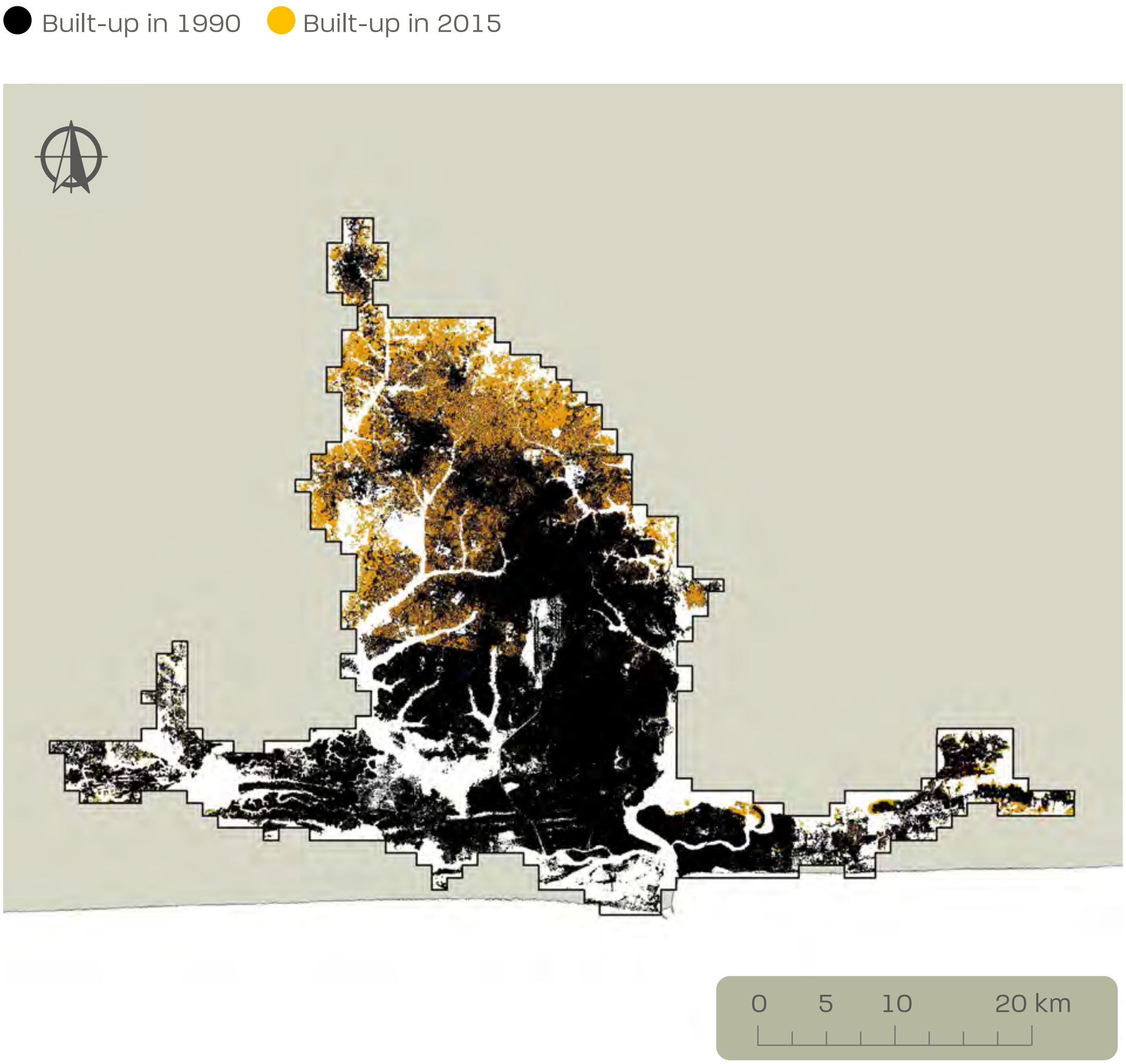
3.07%

Built-up area per person (2015)

133 m^2

Sub-Saharan Africa

Lagos, Nigeria



Annual built-up expansion
0.91%

Total built-up expansion (1990–2015)
165 km²

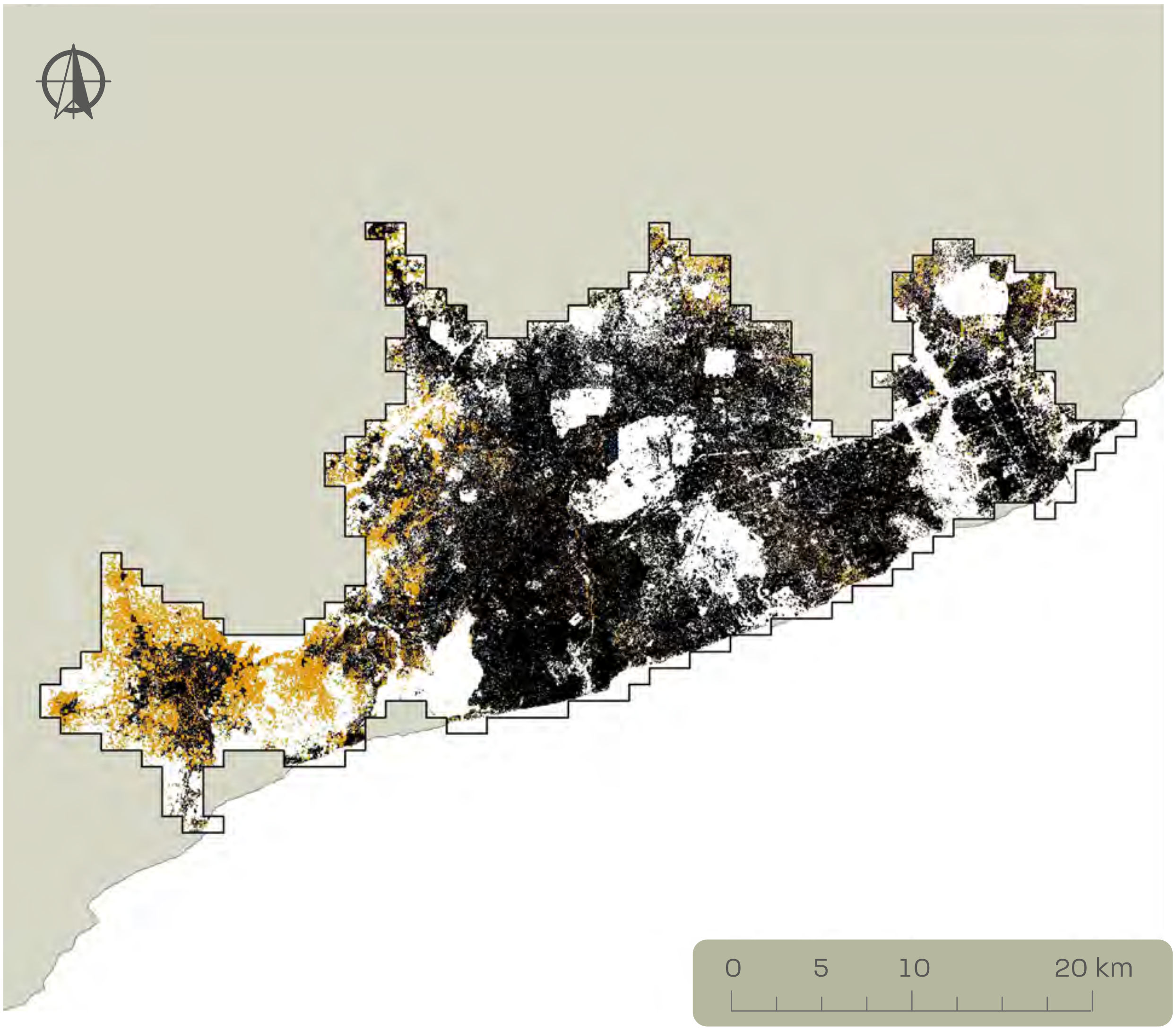
Annual population growth
2.60%

Built-up area per person (2015)
67 m²

Sub-Saharan Africa

Accra, Ghana

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.74%

Total built-up expansion (1990–2015)

84 km²

Annual population growth

3.33%

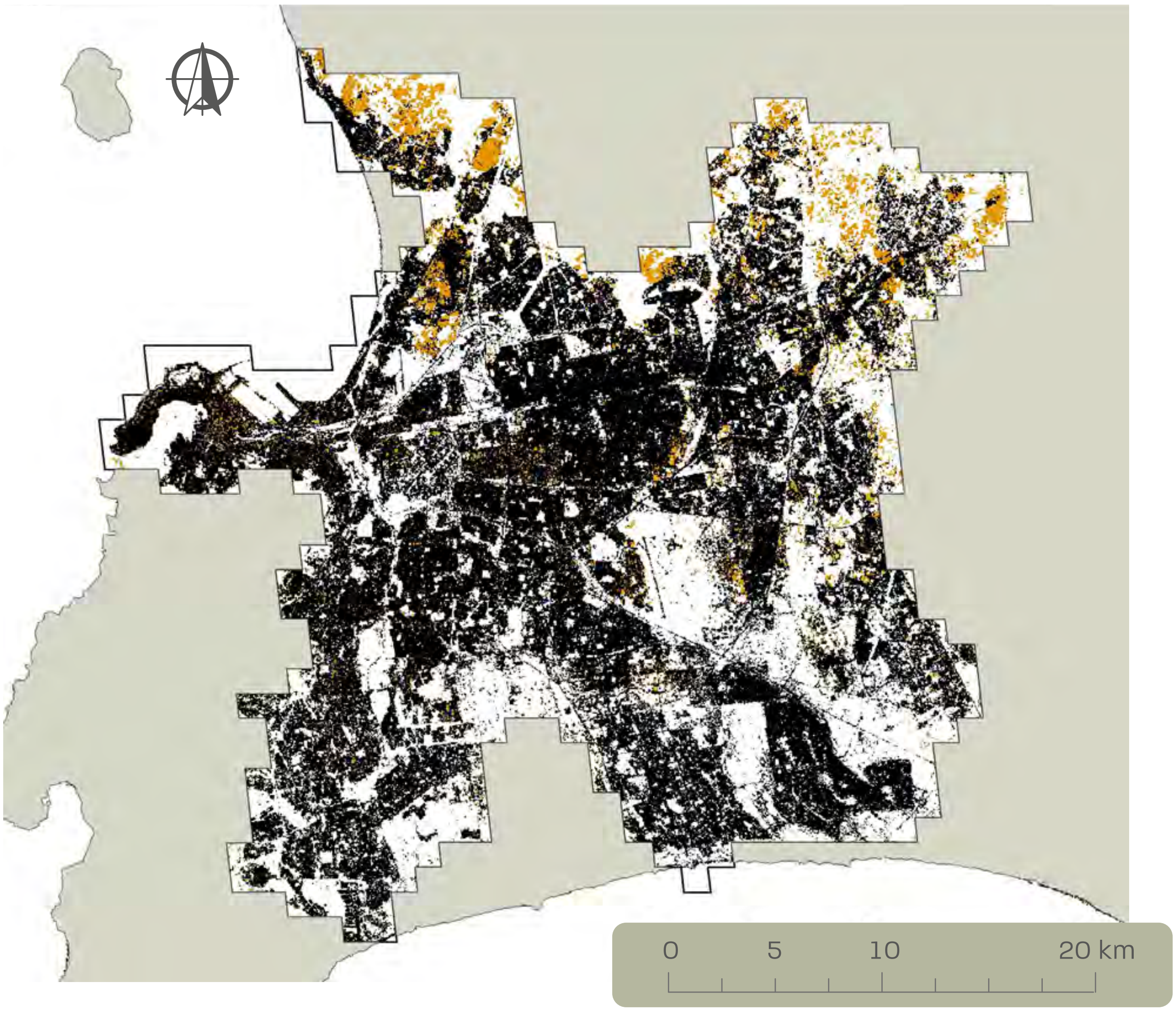
Built-up area per person (2015)

106 m²

Sub-Saharan Africa

Cape Town, South Africa

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.82%

Total built-up expansion (1990-2015)

42 km^2

Annual population growth

2.75%

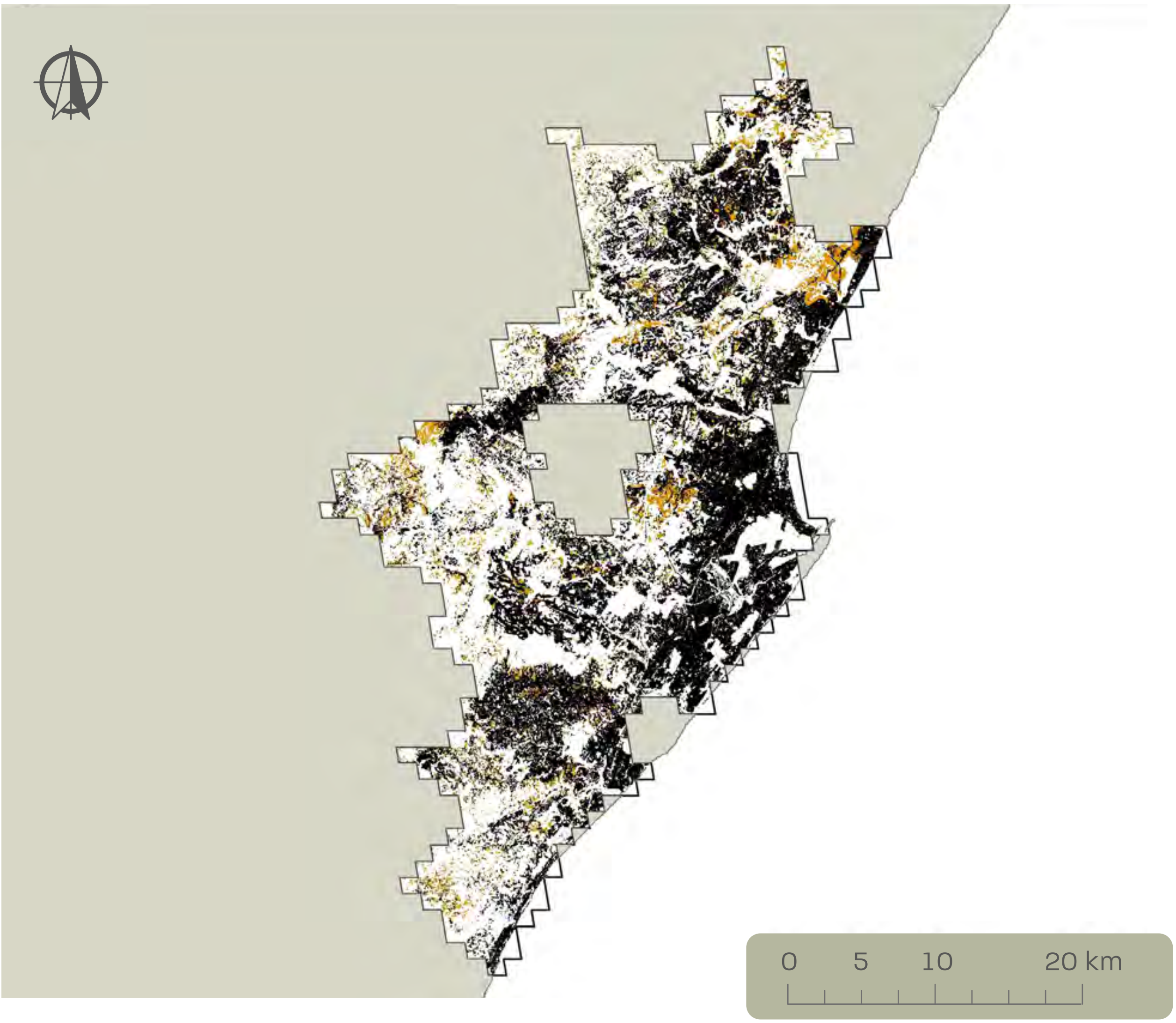
Built-up area per person (2015)

111 m^2

Sub-Saharan Africa

Durban, South Africa

● Built-up in 1990 ● Built-up in 2015



Annual built-up expansion

0.82%

Total built-up expansion (1990–2015)

61 km^2

Annual population growth

1.25%

Built-up area per person (2015)

115 m^2

Works cited

Ahlfeldt, G. M., and J. Barr. 2020. "The Economics of Skyscrapers: A Synthesis." CEPR Discussion Paper DP14987, Center for Economic and Policy Research, Washington, DC. https://ssrn.com/abstract=3650100.

Ahlfeldt, G. M., and E. Pietrostefani. 2019. "The Economic Effects of Density: A Synthesis." International Trade and Regional Economics Discussion Paper 13440, Centre for Economic Policy Research, London School of Economics and Political Science.

Ahlfeldt, G. M., S. J. Redding, D. M. Sturm, and N. Wolf. 2015. "The Economics of Density: Evidence from the Berlin Wall." *Econometrica* 83: 2127–2189.

Alberti, F. G., and J. D. Giusti. 2012. "Cultural Heritage, Tourism and Regional Competitiveness: The Motor Valley Cluster." *City, Culture and Society* 3 (4): 261–273.

Allen, T., C. Arkolakis, and X. Li. 2016. "Optimal City Structure." 2016 Meeting Paper 301, Society for Economic Dynamics.

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

Angel, S. 2011. *Making Room for a Planet of Cities*. Washington, DC: World Bank.

Angel, S., J. Parent, D. L. Civco, A. Blei, and D. Potere. 2011. "The Dimensions of Global Urban Expansion: Estimates and Projections for All Countries, 2000–2050." *Progress in Planning* 75 (2): 53–107.

Angel, S., A. M. Blei, J. Parent, P. Lamson-Hall, N. G. Sánchez, D. L. Civco, R. Q. Lei, and K. Thom. 2016. *Atlas of Urban Expansion—2016 Edition*. New York: NYU Urban Expansion Program at New York University, UN-Habitat, and the Lincoln Institute of Land Policy.

Ardila-Gomez, A., and A. Ortegon-Sanchez. 2016. *Sustainable Urban Transport Financing from the Sidewalk to the Subway: Capital, Operations, and Maintenance Financing*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/23521.

Avner, P., and S. Lall. 2016. "Matchmaking in Nairobi: The Role of Land Use." Policy Research Working Paper 7904, World Bank, Washington, DC.

Bertaud, A. 2018. *Order Without Design: How Markets Shape Cities*. Cambridge, MA: MIT Press.

Bertaud, A., and J. K. Brueckner. 2005. "Analyzing Building-height Restrictions: Predicted Impacts and Welfare Costs." *Regional Science and Urban Economics* 35 (2): 109–125.

Bird, J., and A. Venables. 2019. "Growing a Developing City: A Computable Spatial General Equilibrium Model Applied to Dhaka." Policy Research Working Paper 8762, World Bank, Washington, DC.

Brueckner, J., and K. Sridhar. 2012. "Measuring Welfare Gains from Relaxation of Land-use Restrictions: The Case of India's Building-height Limits." *Regional Science and Urban Economics* 42 (6): 1061–1067.

Bryan, G., E. Glaeser, and N. Tsivanidis. 2019. "Cities in the Developing World." *Annual Review of Economics* 12: 273–297.

Burchfield, M., H. G. Overman, D. Puga, and M. A. Turner. 2006. "Causes of Sprawl: A Portrait from Space." *The Quarterly Journal of Economics* 121 (2): 587–633.

Byamugisha, F. 2013. *Securing Africa's Land for Shared Prosperity*. Washington, DC: World Bank.

CCFLA (Cities Climate Finance Leadership Alliance). 2015. *The State of City Climate Finance 2015*. New York: CCFLA.

CIESIN (Center for International Earth Science Information Network). 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4GH9FVG.

Collier, P., and A. J. Venables. 2016. "Urban Infrastructure for Development." *Oxford Review of Economic Policy* 32 (3): 391–409.

Corbane, C., M. Pesaresi, T. Kemper, P. Politis, A. J. Florczyk, V. Syrris, and P. Soille. 2019. "Automated Global Delineation of Human Settlements from 40 Years of Landsat Satellite Data Archives." *Big Earth Data* 3 (2): 140–169.

Dasgupta, B., S. V. Lall, and N. Lozano-Gracia. 2014. "Urbanization and Household Investment." Policy Research Working Paper 7170, World Bank, Washington, DC.

Dijkstra, L., A. J. Florczyk, S. Freire, T. Kemper, M. Melchiorri, M. Pesaresi, and M. Schiavina. 2020. "Applying the Degree of Urbanisation to the Globe:

A New Harmonised Definition Reveals a Different Picture of Global Urbanisation." *Journal of Urban Economics* 103312.

Dingel, J., and B. Neiman. 2020. "How Many Jobs Can Be Done at Home?" *Journal of Public Economics* 189 (September).

Djankov, S., E. L. Glaeser, V. Perotti, and A. Shleifer. 2020. "Measuring Property Rights Institutions." Working Paper 27839, National Bureau of Economic Research, Cambridge, MA.

Duranton, G., and D. Puga. 2015. "Urban Land Use." In *Handbook of Regional and Urban Economics*, edited by G. Duranton, J. V. Henderson, and W. C. Strange, 467–560. Amsterdam: Elsevier.

Duranton, G., and D. Puga. 2018. "Urban Growth and Its Aggregate Implications." Working Paper 26591, National Bureau of Economic Research, Cambridge, MA.

Duranton, G., and D. Puga. 2020. "The Economics of Urban Density." *Journal of Economic Perspectives* 34 (3): 3–26.

Ellis, P., and M. Roberts. 2016. *Leveraging Urbanization in South Asia: Managing Spatial Transformation for Prosperity and Livability*. Washington, DC: World Bank.

Esch, T., J. Zeidler, D. Palacios-Lopez, M. Marconcini, A. Roth, M. Mönks, B. Leutner, E. Brzoska, A. Metz-Marconcini, F. Bachofer, S. Loekken, and S. Dech. 2020. "Towards a Large-scale 3D Modelling of the Built Environment: Joint Analysis of TanDEM-X, Sentinel-2 and Open Street Map Data." *Remote Sensing* 12 (2391).

Farvacque-Vitkovic, C., and M. Kopanyi. 2014. *Municipal Finance Handbook: A Handbook for Local Governments*. Washington, DC: World Bank.

Florczyk, A., M. Melchiorri, C. Corbane, M. Schiavina, M. Pesaresi, P. Panagiotis, F. Sabo, S. M. C. Freire, D. Ehrlich, T. Kemper, P. Tommasi, D. Airaghi, and L. Zanchetta. 2019. "Description of the GHS Urban Centre Database 2015." Brussels: Publication Office of the European Union.

Florczyk, A., C. Corbane, D. Ehrlich, S. Freire, T. Kemper, L. Maffenini, and F. Sabo. 2019. "GHSL Data Package 2019." European Commission Joint Research Center, 29788.

Fujita, M., and H. Ogawa. 1982. "Multiple Equilibria and Structural Transition of Non-monocentric Urban Configurations." *Regional Science and Urban Economics* 12 (2): 161–196.

Gechter, M., and N. Tsivanidis. 2020. "Spatial Spillovers from Urban Renewal: Evidence from the Mumbai Mills Redevelopment." Working Paper. http://www.personal.psu.edu/mdg5396/MumbaiMills.pdf.

Glaeser, E. 2011. *Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*. Penguin Books.

Glaeser, E. 2020. "Infrastructure and Urban Form." Working Paper 28287, National Bureau of Economic Research, Cambridge, MA.

Glaeser, E., R. La Porta, F. Lopez-de-Silanes, and A. Shleifer. 2004. "Do Institutions Cause Growth?" *Journal of Economic Growth* 9: 271–303.

Glaeser, E., and W. Xiong. 2017. "Urban Productivity in the Developing World." Working Paper 23279, National Bureau of Economic Research, Cambridge, MA.

GLTN (Global Land Tool Network). n.d. "Access to Land and Tenure Security." https://gltn.net/access-to-land-and-tenure-security/.

Global Infrastructure Hub. 2017. *Global Infrastructure Outlook 2017*. Oxford, UK: Oxford Economics.

Global Infrastructure Hub. 2020. *Global Infrastructure Outlook 2020*. Oxford, UK: Oxford Economics.

Grover, A., S. Lall, and W. Maloney. 2021. *Place, Productivity, and Prosperity: Revisiting Spacially-targeted Policies for Regional Development.* Washington, DC: World Bank.

Gollin, D., R. Jedwab, and D. Vollrath. 2016. "Urbanization with and without Industrialization." *Journal of Economic Growth* 21 (1): 35–70.

Gonzalez-Navarro, M., and M. A. Turner. 2018. "Subways and Urban Growth: Evidence from Earth." *Journal of Urban Economics* 108 (C): 85–106.

Goodfellow, T. 2013. "Planning and Development Regulation amid Rapid Urban Growth: Explaining Divergent Trajectories in Africa." *Geoforum* 48: 83–93.

Gottlieb, C., J. Grobovšek, M. Poschke, and F. Saltiel. 2021. "Working from Home in Developing Countries." *European Economic Review* 133, 103679.

Gulyani, S. 2016. "Success When We Deemed It Failure? Revisiting Sites and Services 20 Years Later." World Bank *Sustainable Cities* blog, June 23. https://blogs.worldbank.org/sustainablecities/

success-when-we-deemed-it-failure-revisiting-sites-and-services-20-years-later.

Hallegatte, S. 2009. "Strategies to Adapt to an Uncertain Climate Change." *Global Environmental Change* 19 (2): 240–247.

Heblich, S., S. J. Redding, and D. M. Sturm. 2020. "The Making of the Modern Metropolis: Evidence from London." *The Quarterly Journal of Economics* 135 (4): 2059–2133.

Henderson, J. V., T. Regan, and A. J. Venables. 2020. "Building the City: From Slums to a Modern Metropolis." LSE Research Online Documents on Economics 105054, London School of Economics and Political Science, LSE Library.

Henderson, J. V., and H. G. Wang. 2007. "Urbanization and City Growth: The Role of Institutions." *Regional Science and Urban Economics* 37 (3): 283–313.

Ingram, G., Z. Liu, and K. Brandt. 2013. "Metropolitan Infrastructure and Capital Finance." In *Financing Metropolitan Governments in Developing Countries*. Lincoln Institute of Land Policy.

Jones, B., D. Balk, H. Engin, S. Leyk, and M. Montgomery. Forthcoming. *Projecting Global Population Grids to 2100.* Luxembourg: Publications Office of the European Union.

Klein, M. 2012. "Infrastructure Policy: Basic Design Options." Policy Research Working Paper 6274, World Bank, Washington, DC.

Kreindler, G., and Y. Miyauchi. 2020. "Measuring Commuting and Economic Activity inside Cities with Cell Phone Records." Working Paper. https://economics.mit.edu/files/14088.

La Porta, R., F. Lopez-de-Silanes, A. Shleifer, and R. Vishny. 1999. "The Quality of Government." *Journal of Law, Economics, and Organization* 15 (1): 222–79.

Lall, S., J. V. Henderson, and A. J. Venables. 2017. *Africa's Cities: Opening Doors to the World*. Washington, DC: World Bank.

Lall, S., M. Lebrand, and M. Soppelsa. 2021. "The Evolution of City Form: Evidence from Satellite Data." Policy Research Working Paper 9618, World Bank, Washington, DC.

Lall, S., H. Selod, and Z. Shalizi. 2006. "Rural–Urban Migration in Developing Countries: A Survey of Theoretical Predictions and Empirical Findings." Policy Research Working Paper 3915, World Bank, Washington, DC.

Lall, S., and S. Wahba. 2020. "Cities, Crowding, and the Coronavirus: Predicting Contagion Risk Hotspots." *Sustainable Cities* (blog), April 23, 2020. https://blogs.worldbank.org/sustainablecities/cities-crowding-and-coronavirus-predicting-contagion-risk-hotspots.

Lall, S. V., and S. Wahba. 2021. "Crowded Cities." *Sustainability* (forthcoming).

Lall, S., H. G. Wang, and D. Da Mata. 2007. "Do Urban Land Regulations Influence Slum Formation? Evidence from Brazilian Cities." Brazilian Association of Graduate Programs in Economics.

Leyk, S., J. H. Uhl, D. Balk, and B. Jones. 2018. "Assessing the Accuracy of Multi-temporal Built-up Land Layers across Rural-urban Trajectories in the United States." *Remote Sensing of Environment* 204: 898–917.

Liu, X., G. Hu, Y. Chen, X. Li, X. Xu, S. Li, and S. Wang. 2018. "High-resolution Multi-temporal Mapping of Global Urban Land Using Landsat Images Based on the Google Earth Engine Platform." *Remote Sensing of Environment* 209: 227–239.

Lloyd-Jones, T., M. Theis, S. Adenekan, S. Gusah, and M. Mutter. 2014. "The Informal Housing Development Process in Nigeria: The Case of Kaduna." London: MLC Press.

Lozano-Gracia, N., C. Young, S. V. Lall, and T. Vishwanath. 2013. "Leveraging Land to Enable Urban Transformation. Lessons from Global Experience." Policy Research Working Paper 6312, World Bank, Washington, DC.

Lucas, R. E., and E. Rossi-Hansberg. 2002. "On the Internal Structure of Cities." *Econometrica* 70 (4): 1445–1476.

Ma, J., Z. Liu, and Y. Chai. 2015. "The Impact of Urban Form on CO_2 Emission from Work and Non-work Trips: The Case of Beijing, China." *Habitat International* 47: 1–10.

Mahtta, R., A. Mahendra, and K. C. Seto. 2019. "Building up or Spreading out? Typologies of Urban Growth across 478 Cities of 1 Million+." *Environmental Research Letters* 14 (12): 124077.

Malope, P., and M. Phirinyane. 2016. "Enhancing Property Rights through Land Tenure Regularization in Botswana." Paper prepared for presentation at the 2016 World Bank Conference on Land and Poverty, Washington, DC, March 14–18.

Marconcini, M., A. Metz-Marconcini, S. Üreyen, D. Palacios-Lopez, W. Hanke, F. Bachofer, J. Zeidler, T. Esch, N. Gorelick, A. Kakarla, and E. Strano. 2020. "Outlining Where Humans Live: The World Settlements Footprint 2015." *Scientific Data* 7 (242).

Mattauch, L., C. Hepburn, and N. Stern. 2018. "Making Carbon Pricing Work for Citizens." *Nature Climate Change* 8: 669–677.

Melo, P., D. Graham, and R. Noland 2009. "A Meta-analysis of Estimates of Urban Agglomeration Economies." *Regional Science and Urban Economics* 39 (3): 332–342.

Michaels, G., D. Nigmatulina, F. Rauch, T. Regan, N. Baruah, and A. Dahlstrand. Forthcoming. "Planning Ahead for Better Neighborhoods: Long Run Evidence from Tanzania." *Journal of Political Economy* (forthcoming).

Mills, E. S. 1972. *Studies in the Structure of the Urban Economy*. Baltimore, MD: Johns Hopkins Press.

Moran, D., K. Kanemoto, M. Jiborn, R. Wood, J. Többen, and K. C. Seto. 2018. "Carbon Footprints of 13,000 Cities." *Environmental Research Letters* 13 (6): 064041.

Muth, R. F. 1969. *Cities and Housing: The Spatial Pattern of Urban Residential Land Use*. Chicago, IL: University of Chicago Press.

Navarro, I. A., and G. K. Turnbull. 2014. "Property Rights and Urban Development: Initial Title Quality Matters Even When It No Longer Matters." *The Journal of Real Estate Finance and Economics* 49 (1): 1–22.

Nyborg, K., J. M. Anderies, A. Dannenberg, T. Lindahl, C. Schill, M. Schlüter, W. N. Adger, K. J. Arrow, S. Barrett, S. Carpenter, F. S. Chapin III, A.-S. Crépin, G. Daily, P. Ehrlich, C. Folke, W. Jager, N. Kautsky, S. A. Levin, O. J. Madsen, S. Polasky, M. Scheffer, B. Walker, E. U. Weber, J. Wilen, A. Xepapadeas, and A. de Zeeuw. 2016. "Social Norms as Solutions." *Science* 354 (6308): 42–43.

OECD (Organisation for Economic Co-operation and Development). 2017. "Technical Note on Estimates of Infrastructure Investment Needs." Background paper, *Investing in Climate, Investing in Growth*, OECD Publishing, Paris.

Ollivier, G., A. Ghate, K. Bankim, and P. Mehta. 2021. *Transit-Oriented Development Implementation Resources and Tools, 2nd Edition*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/34870.

Owens, K. E., S. Gulyani, and A. Rizvi. 2018. "Success When We Deemed It Failure? Revisiting Sites and Services Projects in Mumbai and Chennai 20 Years Later." *World Development* 106: 260–272.

Prindex. 2019. "Press Release: Almost 1 Billion People Worldwide Expect to Lose Their Homes against Their Will, Prindex Global Study Reveals." Press Release, March 26. https://www.prindex.net/news-and-stories/press-release-almost-1-billion-people-worldwide-expect-lose-their-homes-against-their-will-prindex-global-study-reveals/.

Povey, M., and T. Lloyd-Jones. 2000. "Mixed Use Development: Mechanisms for Sustaining the Livelihoods and Social Capital of the Urban Poor in Core Areas." Paper presented at the 17th Inter-Schools Conference on Sustainable Cities: Sustainable Development, Oxford Brookes University, Oxford, UK, April.

Pulido, D., G. Darido, R. Munoz-Raskin, and J. Moody. 2018. *The Urban Rail Development Handbook*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/30392.

Rabé, P. E. 2010 "Land Sharing in Phnom Penh and Bangkok: Lessons from Four Decades of Innovative Slum Redevelopment Projects in Two Southeast Asian 'Boom Towns.'" Paper presented at the "Places We Live: Slums and Urban Poverty in the Developing World" policy workshop, World Bank, Washington, DC, April 30.

Ruiz, F., and G. Vallejo. 2010. "Using Land Registration as a Tool to Generate Municipal Revenue: Lessons from Bogota." Annual Conference on Land Policy and Administration, World Bank, Washington, DC, April 26–27.

Ryberg-Webster, S., and K. L. Kinahan. 2014. "Historic Preservation and Urban Revitalization in the Twenty-first Century." *Journal of Planning Literature* 29 (2): 119–139.

Saiz, A. 2010. "The Geographic Determinants of Housing Supply." *Quarterly Journal of Economics* 125 (3): 1253–1296.

Salat, S. 2013. *Cities and Forms: On Sustainable Urbanism*. Urban Morphology Institute.

Salat, S., and G. Ollivier. 2017. *Transforming the Urban Space through Transit-Oriented Development: The 3V Approach*. Washington, DC: World Bank https://openknowledge.worldbank.org/handle/10986/26405.

Seto K. C., S. Dhakal, A. Bigio, H. Blanco, G. C. Delgado, D. Dewar, L. Huang, A. Inaba, A. Kansal, S. Lwasa, J. E. McMahon, D. B. Müller, J. Murakami, H. Nagendra, and A. Ramaswa. 2014. “Human Settlements, Infrastructure and Spatial Planning.” In *Climate Change 2014: Mitigation of Climate Change, Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York: Cambridge University Press.

Shah, A. 2006. “A Practitioner’s Guide to Local Government Fiscal Transfer.” Policy Research Working Paper 4039, World Bank, Washington, DC.

Smolka, M. 2018. “Assessing the Monetary Relevance of Land Value Capture: The Case for Charges for Additional Building Rights in São Paulo, Brazil.” International Conference on Municipal Fiscal Health, Lincoln Institute of Land Policy, Detroit, MI, May 2018. https://www.lincolninst.edu/sites/default/files/research_-_martim_smolka.pdf.

Storper, M., and A. J. Venables. 2004. “Buzz: Face-to-face Contact and the Urban Economy.” *Journal of Economic Geography* 4 (4): 351–370.

Sturm, D., K. Takeda, and A. J. Venables. 2021a. “The Urban Model: Jobs, Housing, Infrastructure, and Policy.” Forthcoming.

Sturm, D., K. Takeda, and A. J. Venables. 2021b. “How Useful Are Quantitative Urban Models for Cities in Developing Countries? Evidence from Dhaka.” Forthcoming.

Toulmin, C. 2005. *Securing Land and Property Rights in Sub-Saharan Africa: The Role of Local Institutions*. Geneva: World Economic Forum.

Tsivanidis, N. 2019. “Evaluating the Impact of Urban Transit Infrastructure: Evidence from Bogotá’s TransMilenio.” University of California, Berkeley. https://static1.squarespace.com/static/55bb98e2e4b0ba843f39599e/t/5d039b14655edc0001d608a9/1560517406526/TsivanidisTransMilenio_6.2019.pdf.

Turnbull, G. K. 2005. “The Investment Incentive Effects of Land Use Regulations.” *The Journal of Real Estate Finance and Economics* 31 (4): 357–395.

Tweed, C., and M. Sutherland. 2007. “Built Cultural Heritage and Sustainable Urban Development.” *Landscape and Urban Planning* 83 (1): 62–69.

United Nations. 2015. *The State of City Climate Finance 2015*. New York: United Nations.

United Nations. 2018. *World Urbanization Prospects: The 2018 Revision*. New York: United Nations.

UNDESA (United Nations Department of Economic and Social Affairs). 2018. *2018 Revision of World Urbanization Prospects*. New York: UNDESA.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2016. *Culture for Sustainable Urban Development*. Paris: UNESCO.

UN-Habitat (United Nations Human Settlements Programme). 2008. *Mozambique Urban Sector Profile*. Nairobi: UN-Habitat.

Uribe, M. C. 2010. “Land Information Updating, a De Facto Tax Reform: Bringing Up to Date the Cadastral Database of Bogota.” In *Innovations in Land Rights Recognition, Administration and Governance*, edited by K. Deininger. Washington, DC: World Bank.

Walkdek, S. 2018. “Inside the Secret Life of New York’s Grand Central Terminal.” *Architectural Digest*, August 14. https://www.architecturaldigest.com/story/grand-central-terminal-history.

Weinberger, R., and F. Goetzke. 2010. “Unpacking Preference: How Previous Experience Affects Auto Ownership in the United States.” *Urban Studies* 47 (10): 2111–2128.

Wesseling, T. 2016. *New Approaches to Physical Planning in Zambia*. Royal HaskoningDHV.

White, R., and S. Wahba. 2019. “Addressing Constraints to Private Financing of Urban (Climate) Infrastructure in Developing Countries.” *International Journal of Urban Sustainable Development* 11 (3): 245–256.

World Bank. 2012. *The Economics of Uniqueness: Investing in Historic City Cores and Cultural Heritage Assets for Sustainable Development*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/12286.

World Bank. 2013a. *Urbanization beyond Municipal Boundaries: Nurturing Metropolitan Economies and Connecting Peri-Urban Areas in India. Directions in Development*. Washington, DC: World Bank.

World Bank. 2013b. *Planning, Connecting, and Financing Cities Now: Priorities for City Leaders*. Washington, DC: World Bank.

World Bank. 2014. *Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization*. Washington, DC: World Bank.

World Bank. 2015a. *Ethiopia Urbanization Review: Urban Institutions for a Middle-Income Ethiopia*. Washington, DC: World Bank.

World Bank. 2015b. *Ghana Urbanization Review Overview: Rising through Cities in Ghana*. Washington, DC: World Bank.

World Bank. 2015c. *Stocktaking of the Housing Sector in Sub-Saharan Africa: Challenges and Opportunities*. World Bank, Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/23358.

World Bank. 2016a. *Kenya Urbanization Review*. Washington, DC: World Bank.

World Bank. 2016b. *Malawi Urbanization Review: Strengthening Rural-Urban Linkages*. Washington, DC: World Bank.

World Bank. 2016c. *Regenerating Urban Land: A Practitioner's Guide to Leveraging Private Investment*. Urban Development. Washington, DC: World Bank.

World Bank. 2020. *Public–Private Partnerships in Land Administration: Analytical and Operational Frameworks*. Washington, DC: World Bank.

World Bank and Development Research Center of the State Council, People's Republic of China. 2014. *Urban China: Toward Efficient, Inclusive, and Sustainable Urbanization.* Washington, DC: World Bank.

WorldPop and CIESIN (Center for International Earth Science Information Network). 2018. *Global High Resolution Population Denominators Project*. School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur; and Columbia University. https://dx.doi.org/10.5258/SOTON/WP00647.

Wu, W. 2013. "Public Private Partnership for Urban Infrastructure Financing and Management." Background paper for the World Bank Urbanization Project, World Bank, Washington, DC.

Xu, C., D. Haase, M. Su, and Z. Yang. 2019. "The Impact of Urban Compactness on Energy-related Greenhouse Gas Emissions across EU Member States: Population Density vs. Physical Compactness." *Applied Energy* 254.

Yang, F., Z. Wang, X. Yang, Y. Liu, B. Liu, J. Wang, and J. Kang. 2019. "Using Multi-Sensor Satellite Images and Auxiliary Data in Updating and Assessing the Accuracies of Urban Land Products in Different Landscape Patterns." *Remote Sensing* 11 (22): 2664.

Zarate, R. D.. 2020. "Spatial Misallocation, Informality and Transit Improvements: Evidence from Mexico City." Unpublished working paper.

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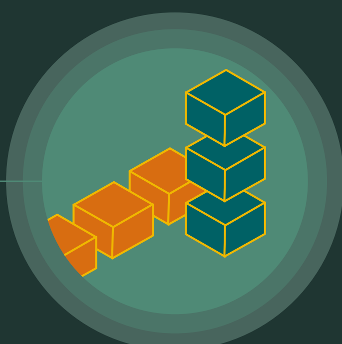
I

How are cities accommodating families and firms—and how fast is global built-up area expanding?

II

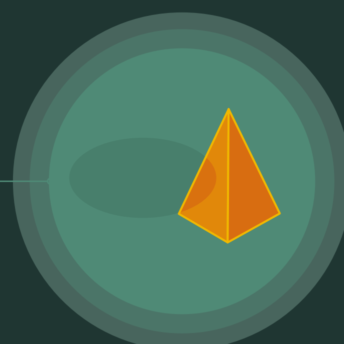
What has driven urban spatial evolution since 1990? The answers are complicated—but incomes are key

III



What drives one city to grow differently from another?

IV



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