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CITY SHAPES AND CLIMATE CHANGE IN AFRICA

SEPTEMBER 2023, NO.40

SAHEL AND WEST AFRICA Club Secretariat

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WEST AFRICAN PAPERS

The West African Papers series explores African socio-economic, political and security dynamics from a regional and multidisciplinary perspective. It seeks to stimulate discussion and gather information to better anticipate the changes that will shape future policies. The series is designed for a wide audience of specialists, development practitioners, decision makers and the informed public. Papers are available in English and/or French, and summaries are available in both languages.

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Abstract:
Africa is undergoing an unprecedented urban and climate transition; yet, given the right conditions, compact urban forms can encourage greater sustainability, resilience and liveability in the coming decades. Using novel techniques and newly available data, this report fills in existing data gaps by producing measures of compactness for 5 625 urban agglomerations, along with other urban form attributes. Even though urbanisation is often unplanned and uncoordinated, a promising trend has emerged: very large cities (of over 4 million inhabitants) are more compact, discounting the population effect, on average, than larger (1 million to 4 million inhabitants) and intermediate cities (50 000 to 1 million inhabitants). Moreover, less compact agglomerations tend to have smaller buildings, flat, low skylines, less complete centres (reflecting a less optimal use of space) and polycentric patterns (i.e. multiple centres, rather than a single, monocentric city). This report analyses the consequences of less compact agglomerations for sustainability and liveability. The disadvantages include higher energy demand, less accessibility to services and opportunities, less walkable urban landscapes and greater car dependency, in addition to higher outdoor air pollution. It also considers the potential trade-offs with resilience; for example, compactness can lead to a loss of green space and an increase of urban heat island effects. The report offers opportunities in the coming years to single out potential areas of action for resilience, as well as for monitoring and evaluating progress.

Key words: Compactness, Africa, cities, sustainability, spatial data

JEL classification: Q24, Q47, Q54, Q56, Q58, R58

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THE SAHEL AND WEST AFRICA CLUB

The Sahel and West Africa Club (SWAC) is an independent international platform. Its Secretariat is hosted at the Organisation for Economic Co-operation and Development (OECD). Its mission is to promote regional policies that will improve the economic and social well-being of the people in the Sahel and West Africa. SWAC produces and maps data, drafts analyses and facilitates strategic dialogue in order to help policies better anticipate the transformations in the region and their territorial impact. It also promotes regional co-operation and more contextualised policies as a tool for sustainable development and stability. Its current areas of work are food dynamics, cities, environment and security.

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THE ‘FOUNDATION’ OF DATA

An additional 950 million people will live in African urban agglomerations by 2050, from a base population of 567 million in 2015 (OECD/SWAC, 2020[1]). These new urban residents must undergo this transition at a time of unparalleled climate stress. Africa is and will remain a minor contributor of global emissions, even with rapid urbanisation. Despite this, the continent must do far more than others to adapt. Developed countries, however, in the Glasgow Climate Pact, have promised to accelerate financial and technological support to ensure a just and inclusive low-carbon transition for low-income countries.

African urbanisation can boost resilience but may exacerbate residents’ vulnerability to climate. Urbanisation is not the problem, but it may be too spontaneous and moving at a rate too rapid for infrastructure to keep up with. The result is an augmentation of informal settlements, inadequate transport systems, extremely high living costs relative to incomes, pervasive congestion, disappearing green spaces and rising outdoor air pollution, especially in larger cities (Gnacadja, 2022[2]; Anderson, Patiño Quinchía and Prieto-Curiel, 2022[3]; Stucki, 2015[4]). The Climate Change Vulnerability Index ranks cities in sub-Saharan Africa as “extremely at risk”, not only because of the expected effects of climate change, but because of the poor urban infrastructure and services (Maplecroft, 2022[5]; Gnacadja, 2022[2]). At times, urbanisation is encroaching on irreplaceable ecosystems and destroying biodiversity. Urbanisation without guidance can lead to avoidable deaths from floods (e.g. in KwaZulu-Natal province in South Africa in May 2022) and from landslides (as seen in Yaoundé, Cameroon, in November 2022). It runs the risk of locking in infrastructure vulnerable to climate change, as well as high energy demand from transport and buildings, since infrastructure can be costly to change once it is in place and lasts for decades (OECD, 2017[6]).

By 2050, Africa is projected to contribute only 4% of cumulative global energy-related CO_2 emissions, regardless of the scenario (IEA, 2022[7]). Nevertheless, there is now widespread recognition that cities are an essential factor in achieving national governments’ mitigation and adaptation commitments under the 2015 Paris Climate Agreement (UNFCCC, 2015[8]). Ultimately, African urban agglomerations will bolster or undermine national efforts to meet climate goals, which partially depends on how they urbanise. Many West African countries’ self-determined adaptation and mitigation commitments, known as Nationally Determined Contributions (NDCs), do not include the contribution of cities (Anderson, Rhein and Acosta, 2022[9]). Responding to climate change requires local actions that reflect and respond to local conditions.

Despite these challenges, urbanisation can advance not only the climate agenda but economic prosperity. African urban agglomerations drastically improve the quality of life for residents today. Urban residents frequently possess greater educational attainment, higher wages and better provision of infrastructure than their rural counterparts (OECD/UN and ECA/AfDB, 2022[10]). But with today’s climate policies, the increase in global average temperatures is likely to hit 2°C around 2050, which would reduce African GDP by around 8% in 2050 relative to a baseline without any climate action, involving an expected loss of nearly 15% in GDP in West Africa in 2050 (IEA, 2022[7]). Urgent action on climate is needed in African urban areas to reduce the severity of these economic effects (IEA, 2022[7]).

Cities – especially the larger ones – can, and should, promote compact urban forms (with sufficient resources, policies and regulations) to encourage greater sustainability, resilience and liveability. Compactness, morphologically speaking, can reduce travel distances, improve accessibility to urban amenities and services through greater connectivity, encourage mixed land use, reduce energy use from vehicles – all of which lower emissions as well as pollution (Ahlfeldt et al., 2018[11]; OECD, 2018[12]). Compact urban development can avoid the expansion of settlements into vulnerable areas (e.g. those that are susceptible to floods and landslides) and can limit the loss of critical ecosystem services (e.g. in settlements on floodplains), enhancing resilience.

Compactness and higher density allow more people to live within an urban area, bringing them closer together and reducing travel distances and energy use from buildings and infrastructure systems, along with emissions (OECD, 2019[13]). From an economic perspective, compactness increases the advantages of economies of scale, as well as the efficiency of infrastructure in such sectors as transportation, health and energy.

Compactness can help cities become resilient, sustainable and liveable, but it does not inherently make them so. Not all densely settled neighbourhoods provide residents with decent housing and amenities; overcrowding is a risk (OECD and European Commission, 2020[14]). Likewise, greater compactness can lead to a loss of green spaces, which can increase a propensity to heatwaves and risk loss of biodiversity (Anderson, Patiño Quinchía and Prieto-Curiel, 2022[3]). Cities should thus also carefully monitor where and how land is being converted, to maximise its benefits and minimise drawbacks.

Yet, the nature of compactness in African urban agglomerations today is largely unknown beyond platitudes or a handful of one-off exercises in large metropolises. Mounting evidence reveals the diverse reality of Africa's urban transition (OECD/SWAC, 2020[1]), but what this means on the ground has not been explored, partly because of the quality of existing data (Box 1). We aim to remedy this by producing a new set of comparable indicators for African urban agglomerations, which will be updated regularly. Google AI Africa recently released the Open Buildings dataset, mapping building footprints across the African continent, which were not available before 2021 (Wojciech et al., 2021[15]). Combining this with the mapping of urban agglomeration boundaries by Africapolis has made it possible to calculate multiple indicators for 5 625 urban agglomerations across the continent (OECD/SWAC, 2020[16]).

- The first section demonstrates that even though urbanisation is less planned, a promising trend has emerged: very large cities (over 4 million inhabitants) are more compact, on average, than larger (1 million to 4 million inhabitants) and intermediate cities (50 000 to 1 million inhabitants).

- The second section analyses the characteristics associated with less compact urban forms, which include smaller buildings, flat, low skylines, less full centres (reflecting an inefficient use of space) and polycentric patterns (i.e. multiple centres rather than a monocentric city).

- The final section investigates the consequences of less compact agglomerations for sustainability: higher energy demand, less accessibility on foot to services and opportunities, leading to greater car dependency, in addition to higher outdoor air pollution. Likewise, it explores trade-offs, namely, compactness at the expense of green space and the exacerbation of urban heat island (UHI) effects.

The story of compactness in African urban agglomerations is more complex than is often supposed – as are its implications for sustainability and resilience. As Africa undergoes unprecedented urbanisation and climate change, these transitions coincide with the unparalleled availability of open-source data. This offers an opportunity for actors to guide these phenomena. All these indicators will be available online on OECD/SWAC's Mapping Territorial Transformations in Africa platform (MAPTA)[1] and will be regularly updated.

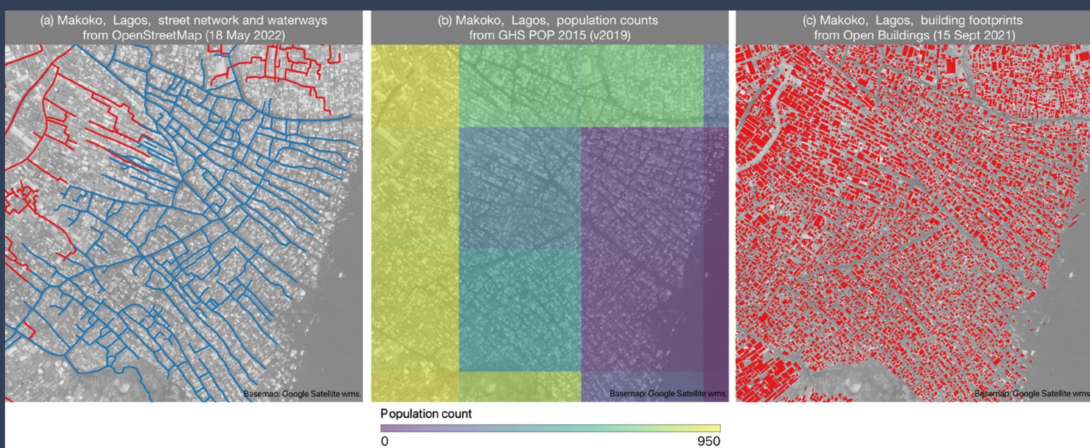
Box 1.

About the underlying data: Harnessing the power of building footprints

Measuring compactness in African urban agglomerations, or other features of the urban form, is challenging due to the limited and poor quality of the data available. Often analyses use population density data (measuring inhabitants per square kilometre), which may or may not be geospatially located reliably in Africa, especially in the case of small cities. Often, population density datasets model the population distribution in Africa since the reported data are often irregular or non-existent. Yet, measuring urban form based on modelled data does not provide any insight into whether the features of urban form truly reflect the reality on the ground or are simply a by-product of the models applied to the data. For example, the Global Human Settlement Layer (GHSL) estimates that no inhabitants live in parts of Makoko, an informal settlement off the coast of Lagos (Nigeria) (purple region in Map 1, middle panel) even though the satellite image underneath shows individuals living in the area (Melchiorri, Ehrlich and Kemper, 2021[17]). Other studies rely on street network data (for example, from OpenStreetMap), but these miss many settlements in low- and middle-income countries or fail to capture the full extent of the urban area, as in the case of Makoko, Nigeria (Map 1, left panel). Using either of these datasets to capture urban morphology can potentially convey an inaccurate picture.

Map 1.

Makoko (Nigeria), fully captured by building footprints and only partially captured by population density and street network data



Note: Left: street network and waterways from OpenStreetMap. Right: population counts from GHSL project.

Source: (Open Street Map, 2022[18]; Melchiorri, Ehrlich and Kemper, 2021[17]; Wojciech et al., 2021[15])

Google AI Africa released the Open Buildings dataset in 2021. This dataset maps building footprints on the entire African continent (excluding some areas, for political reasons) and was not available before 2021 (Wojciech et al., 2021[15]). The dataset includes, for each mapped building, its footprint boundary, the co-ordinates of the geometric centre and a confidence score (i.e. how sure the algorithm is that it is a building). The information on building location and footprint size is useful to characterise the constructed building density of the urban layout in each area.

The power of the novel dataset is that parts of the continent that are not captured by other sources – for example, the population density or street network data – can be seen in the building footprint data, especially for small agglomerations. Makoko, for instance, is visible using building data (Map 1, right panel).

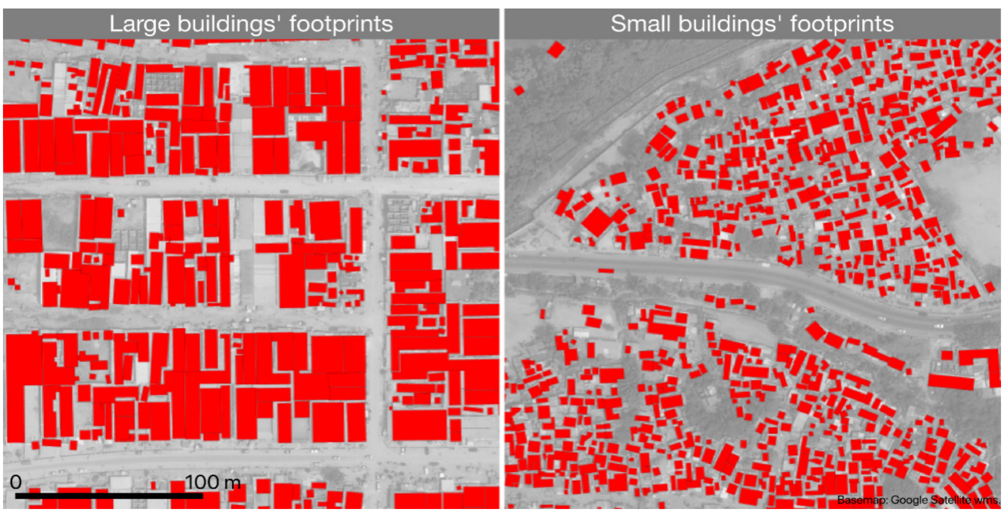
The building data, combined with the Africapolis 2015 dataset,[2] makes it possible to calculate indicators on urban form that better reflect what is happening within cities, including small (10 000 to 50 000) and intermediate cities (50 000 to 1 million). Defining urban areas is challenging and administrative boundaries do not fully reflect the extent of urban development. Africapolis maps the boundaries for any agglomeration of at least 10 000 individuals and where buildings are less than 200 metres apart. The same definition is applied to all urban areas in the continent, enabling comparability across borders. Despite some missing areas in the Open Buildings dataset, more than 183 million buildings can still be identified in the 5 625 urban agglomerations.

The compactness indicators – along with other features of urban form – were constructed based on the distribution, distance and location of buildings within a city. As these indicators do not depend directly on the size of the city, they can be used to compare without bias cities of very different sizes, i.e. a city of thousands of people as opposed to one with millions of inhabitants.[3]

What the underlying data looks like: Buildings in African urban agglomerations

Buildings have varying footprints, from only a few square metres to huge structures of hundreds of square metres (Map 2). For each of the buildings, the co-ordinates of the buildings' centre and footprint are used to create novel indicators related to compactness.

Map 2.
Abidjan (Côte d'Ivoire): Close-up of large and small building footprints in the Open Buildings dataset



Note: Large and small building footprints in Abidjan. Both images are plotted to the same scale.

Source: Data based on (Wojciech et al., 2021[15]), overlaid on Google Satellite Image.

COMPACTNESS OF AFRICAN CITIES

Larger urban agglomerations (of 1 million to 4 million) tend to be less compact than intermediate ones (50 000 to 1 million inhabitants); likewise, intermediate are less compact than small (10 000 to 50 000), but this trend reverses: **very large cities (above 4 million inhabitants) are more compact** than large or intermediate ones (after discounting for city size). Very large cities are likely to suffer greater penalties from inefficient use of space and have greater access to resources and better institutional capacity to guide urban development.

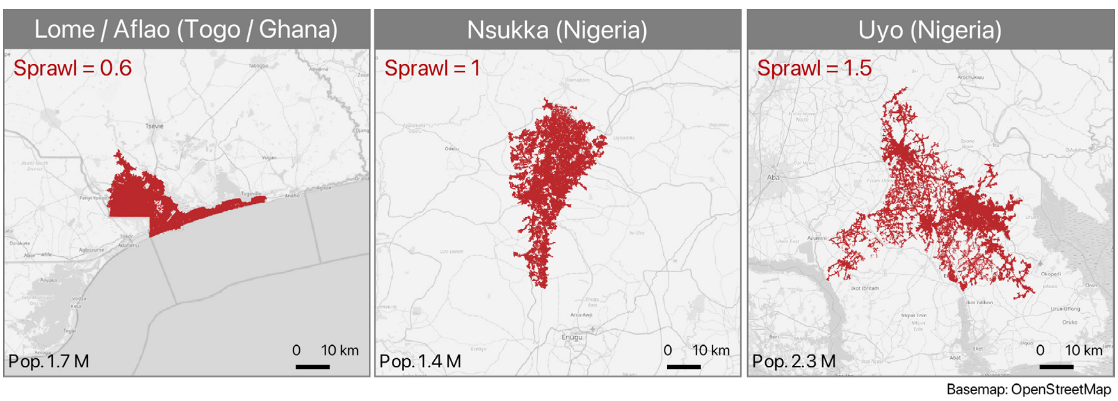
Measuring compactness

Two indicators were developed to capture compactness – sprawl and elongation – since unidimensional approaches "are [often] too simplistic to describe such a complex phenomenon. Multidimensional approaches are much better suited to capture its different aspects and manifestations" (OECD, 2018$_{[12]}$). These two measures encapsulate the morphological nature of compactness, using interbuilding distances, instead of features such as mixed land-use or high densities (in terms of people) (Box 1).

- **Sprawl** measures the space between buildings (which is weighted to be comparable between cities). Higher values (above 1) signal more "empty" space or greater sprawl between buildings, while lower values (below 1) mean less distance between buildings and more compression.

Lomé (Togo) is at one end of the spectrum (at 0.6 on the sprawl index), so interbuilding distances are shorter, while Uyo (Nigeria) is at the other (1.5), with far more sprawl and greater distances between buildings, i.e. less compact. Notably, Lomé has a larger number of buildings, approximately 0.9 million, with a total building footprint of 45 km^2 distributed over 353 km^2. Meanwhile, Nsukka and Uyo (both in Nigeria) have less than half the number of buildings, 392 000 and 333 000, respectively, but lower building footprints (Uyo 32 km^2 and Nsukka approximately 26 km^2), which are distributed over larger urban areas: 886 km^2 and 699 km^2, respectively (Map 3).

Map 3.
Examples of sprawl in agglomerations of similar sizes



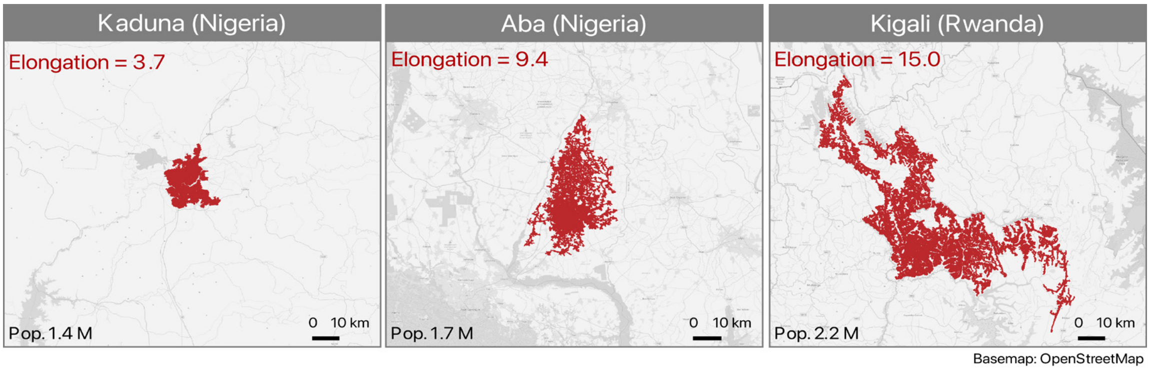
Note: Sprawl index for Lomé (Togo), Nsukka (Nigeria) and Uyo (Nigeria). The three maps are plotted with the same scale and correspond to cities with similar population, but the urban form of the cities is critically different.

Source: Authors' calculations.

- **Elongation** measures the extent to which the shape of the city departs from being a circle (weighted to be comparable between cities). A circle is the least elongated urban form possible (value of 1), but a more elliptical shape increases distances in the city, while the most elongated shape is a line (which will involve increasingly higher values).

Kaduna (Nigeria) has a circular form (value of elongation is 3.7). In Aba (Nigeria), the elongation is 9.4, so it has a more elliptical shape. Kigali (Rwanda) resembles almost a line (with an elongation of 15) (Map 4).

Map 4.
Examples of elongation in cities of similar size

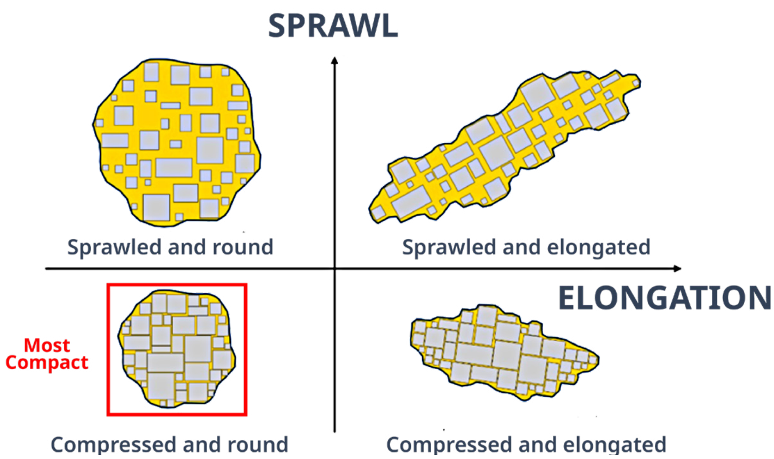


Note: Elongation of Kaduna (Nigeria), Aba (Nigeria) and Kigali (Rwanda). The three cities have a similar population and the maps are plotted to the same scale.

Source: Authors' calculations.

A compact city is rounder, with the least sprawl feasible (given terrain and needs – e.g. open spaces and streets). A stylised version is shown in the bottom-left quadrant in Figure 1. Cities can take many other forms, but the least compact have greater sprawl and more elongation, with increasing distances between buildings.

Figure 1.
How sprawl and elongation relate to compactness



Note: The y axis visualises a configuration of buildings for sprawl, while the x axis visualises a configuration of buildings for elongation.

Source: Authors' diagram.

Very large cities are more compact

According to the observed values of both metrics, very large cities (above 4 million) are rounder (with less elongation) and more compressed (with less sprawl) than large cities (between 1 million and 4 million) and intermediate cities (50 000 to 1 million) (Table 1). Both indicators – sprawl and elongation – increase with city size up to large cities (1 million to 4 million), and then this trend reverses. This means that very large cities fill in space between buildings and start to become more circular, reducing distances.

Table 1.

Very large cities tend to be more compact

Average values of sprawl and elongation index by city size in the 5 625 urban agglomerations in Africa

	Sprawl	Elongation
Less than 50k	0.89	6.73
50k to 1m	0.94	6.85
1m to 4m	0.98	7.25
+4m	0.93	6.34

Note: Smaller sprawl values mean shorter distances between buildings, i.e. more compressed, while smaller elongation values signify that the shape of an agglomeration is more circular and therefore more compact.

Source: Author's calculations. All data available at: https://mapping-africa-transformations.org/climate-urbanform/.

The compactness of very large cities may stem from more robust policy packages (e.g. transit-oriented development) as well as better institutional capacities and resources. Accra (Ghana), Abidjan (Côte d'Ivoire), Lagos (Nigeria), Johannesburg (South Africa), Kisumu (Kenya), Dar es Salaam (Tanzania) and Nairobi (Kenya) (cities above 4 million) have, or are in the process of introducing, transit-oriented development strategies, which aim to create accessible compact cities through mixed-use development and public transport. Johannesburg, for example, has been in the implementation phase for over a decade (since 2012) and will continue until 2040. As part of the strategy, the City of Johannesburg implemented bus rapid transit construction, six parks, three new clinics, a new library, Campus Square Sky Walk, part of the Great Walk Bridge, in addition to non-motorised transport infrastructure – all of which enables the city to contain its sprawl, increasing compactness.[4]

Likewise, Lagos developed the Lagos Strategic Transport Master Plan, which recognises the multiple modes needed to create an efficient transport system for its residents. The city had already introduced bus rapid transit, which led to a massive drop in private vehicle use (while reducing expansion) and is now embarking on the Lagos rail transport system, notably the 13-kilometre rail line, which is expected to shift the land-use patterns along the corridor.[5] Similarly, local governments in Africa often have exceptionally low local fiscal capacity and rely heavily on transfers from national governments, which can be unreliable and unpredictable. Larger cities, however, especially those over 4 million, have more to guide urban development towards compactness. Kampala (Uganda), a city of slightly less than 4 million, raised its own-source revenues by over 100% in four years, through a variety of concurrent administrative reforms, by boosting internal staff, digitising databases and reforming taxes, e.g. instituting online payments and streamlining tax brackets, all of which provided more resources to guide urban development.

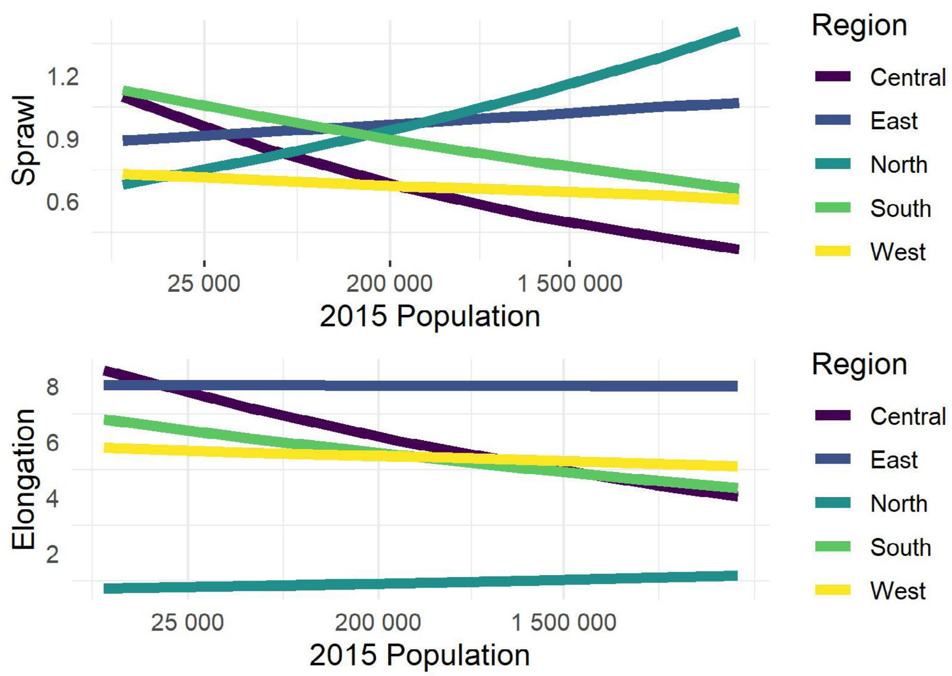
Regional trends

Trends in compactness and city size vary across regions. Larger agglomerations increase compactness in the regions of West, Central and South Africa, as discussed above. By contrast, larger cities tend to be less compact in North and East Africa, which may be due in part to topography and historical dependency.

In West Africa, larger cities tend to become more compact than smaller cities, by reducing the space between buildings (i.e. less outward sprawl), while city shape becomes slightly more circular across city sizes (Figure 2). The South and Central regions display even more dramatic changes with city size: a city that is five times larger has almost 10% and 20% less sprawl, respectively. Likewise, cities in these regions become substantially more circular over time. In contrast, cities in North and East Africa become significantly less compact, i.e., with greater space between buildings (more sprawl out), as demonstrated in Figure 2. A city that is five times larger in North Africa will have 20% more space between buildings, while in East Africa it will have 10% more space between buildings. City shapes remain relatively constant in these regions: North African cities are quite circular and East African agglomerations more elliptical.

Figure 2.

How compactness changes with city size across regions in Africa



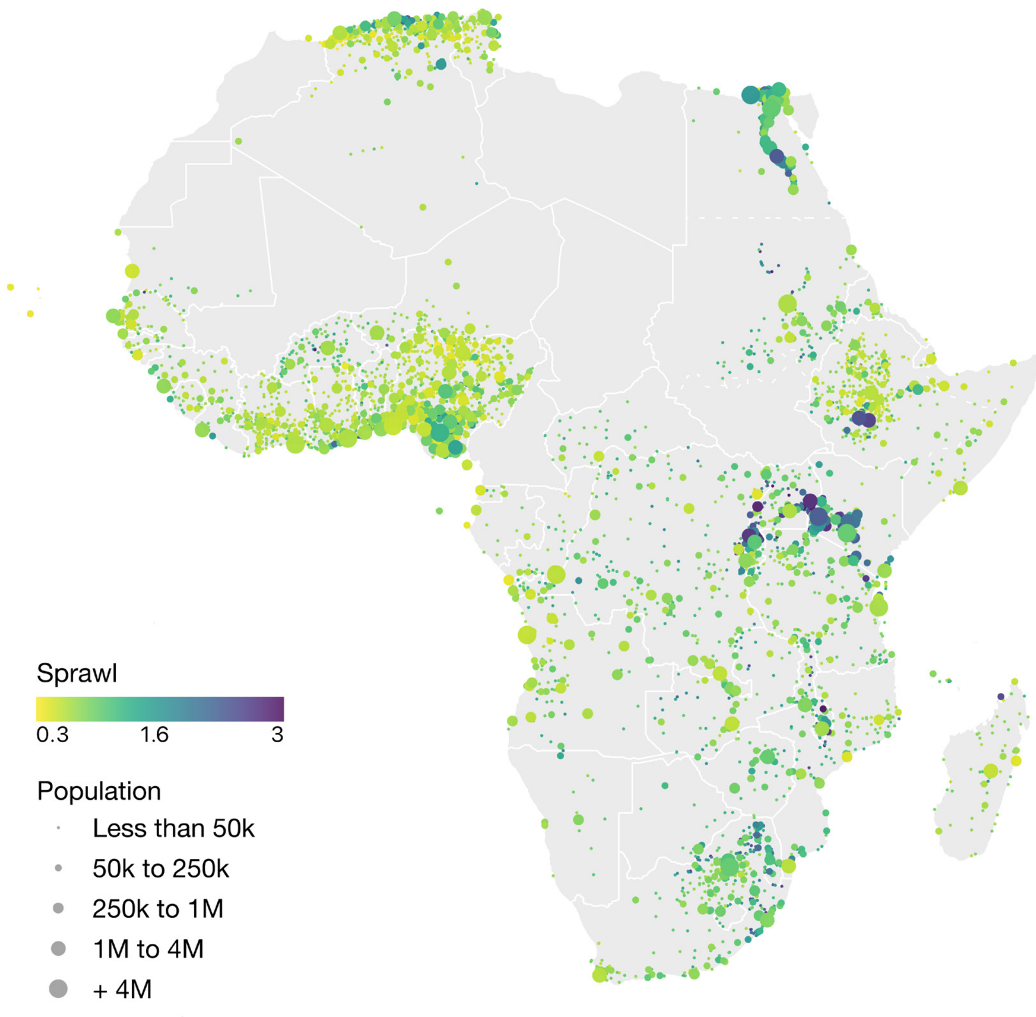
Note: Sprawl and elongation are two indexes calculated using interbuilding distances. Higher sprawl and elongation mean that an agglomeration is less compact. The plots above are the predicted results of a scaling effects model. West Africa includes Benin, Burkina Faso, Cape Verde, The Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo. Central Africa includes Angola, Burundi, Cameroon, Central African Republic, Chad, Democratic Republic of the Congo, Republic of the Congo, Equatorial Guinea, Gabon, Rwanda, and São Tomé and Príncipe. South Africa includes Botswana, Eswatini, Lesotho, Namibia and South Africa. North Africa includes Morocco, Algeria, Tunisia, Libya, Egypt, Sudan and Western Sahara. East Africa includes Tanzania, Kenya, Uganda, Rwanda, Burundi, Democratic Republic of Congo, Sudan, South Sudan, Djibouti, Eritrea, Ethiopia, Somalia, Mozambique, Madagascar, Malawi, Zambia, Zimbabwe, Comoros, Mauritius and Seychelles.

Source: Authors' calculations.

Map 5 visualises the "sprawl" indicator in 5 625 urban agglomerations, for a closer look at these regional trends. Reflecting the trends outlined above, Rwanda, Kenya and Uganda in East Africa have the highest levels of sprawl (the bluish, green and yellow dots) and thus more space between buildings. The physical terrain partially explains why agglomerations in East Africa develop in these patterns, since the mountainous territory makes some distances between buildings unavoidable. The urban footprint adjusts to the usable land, resulting in organic shapes. For instance, if the elevation differences inside a city increase by 136 m, the elongation is higher by one unit.

Map 5.

Sprawl in 5 625 African agglomerations



Note: Values of sprawl across cities in Africa. Higher sprawl means more empty space between buildings.

Source: Authors' calculations

Sprawl is also quite high in Egypt. The average for a city of less than 50 000 is 0.81, with intermediate cities (of 50 000 to 1 million) at 1.2 on average, while larger cities increase to 1.4 (above 1 million). As of 2015, 93% of the population lived in cities – 84 million people (OECD/SWAC, 2020[16]). Every year, the population of the Nile River Delta increases by 2.4 million people and grows by approximately 40 inhabitants/km² (OECD/SWAC, 2020[16]). The Egyptian urban system has historically been dominated by two capitals, Cairo and Alexandria, but several other cities have emerged since the 1950s in the Nile River Delta, such as Tanta, El-Mahalla El-Kubra, Zagazig and Asyut. Part of this development originated during the Nasser regime (1954-70), which followed a Soviet model and moved core industries – aluminium, sugar and textiles – into secondary cities (OECD/SWAC, 2020[16]). As the population quadrupled, this led to the development of large, dense agglomerations in the Nile Valley shaped by agricultural morphologies (OECD/SWAC, 2020[16]). Agricultural plots were laid out in strips along irrigation canals fed by the waters of the Nile, which laid the foundation for future cities. The historical legacy of coastal development can also help explain the high levels of sprawl. In general, the sprawl in coastal cities is 5% more than in cities inland, probably as a result of the coastline forcing less compact development (Map 5).

Sprawl in border cities is 15% higher than in non-border cities, due to the difficulties of co-ordination. The average sprawl within 20km of a border is 1.02, compared to around 0.89 in non-border cities. Likewise, border cities, for example, are 14% more elongated than cities inside a country (Map 5).

There is feedback between sprawl and elongation. Cities that are more fragmented tend to be more elongated, but it is possible to have elongated city shapes with varying levels of fragmentation, or space, between buildings. Kigali (Rwanda) and Hawassa (Ethiopia) have similar levels of elongation, of 15 and 14, respectively. However, Kigali has almost twice the level of sprawl, with a figure of 2.6 compared to 1.0 in Hawassa. Kigali has more space between buildings, probably because of the mountainous terrain. Similarly, Kigali and Abuja have almost the same levels of sprawl, approximately 1, but Kigali is three times more elongated (15 compared to 5).

ATTRIBUTES OF LESS COMPACT AGGLOMERATIONS

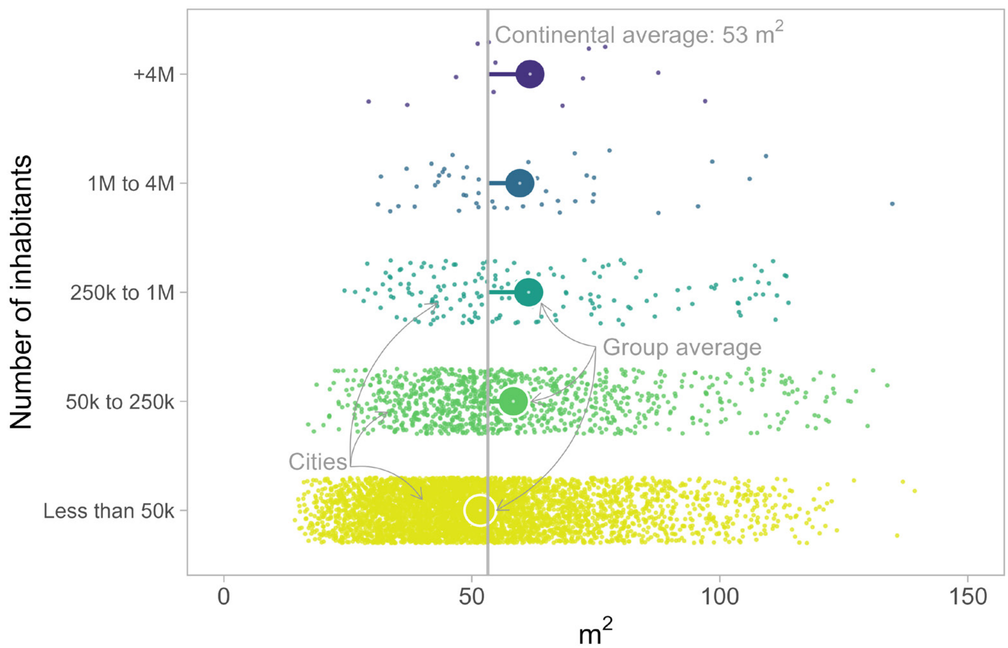
The analysis shows that less compact urban agglomerations (in terms of sprawl and elongation) share several characteristics. Less compact agglomerations tend to: (1) have smaller buildings; (2) have relatively flat and low skylines (i.e. building heights throughout the urban fabric); (3) have less full centres (signalling potential for infill); and (4) be more polycentric. These attributes reflect the nature of informal settlements (with pockets of small buildings throughout the urban fabric).

Abundance of small buildings

Less compact agglomerations have smaller buildings, according to the models used here (after controlling for other factors like population or topography), and very large agglomerations tend to have some of the largest buildings in terms of footprint and height. Small buildings are pervasive, however, even in large and very large agglomerations. On average, 31% of the total building footprint in Africa appears to be made up of building footprints smaller than 50 m^2. Small cities (between 10 000 to 50 000 people) have the smallest buildings (on average, 51.7 m^2), but the size is not substantially bigger in larger cities (Figure 3). Building footprints in cities of over 4 million people are only 61.7 m^2 on average (essentially a square with sides of 7.8 metres).

Figure 3.

Small building footprints, on average, across city sizes in Africa



Note: Every circle represents an African urban agglomeration. The vertical dark grey line shows the continental average (53m^2). The coloured, larger circles represent group averages.

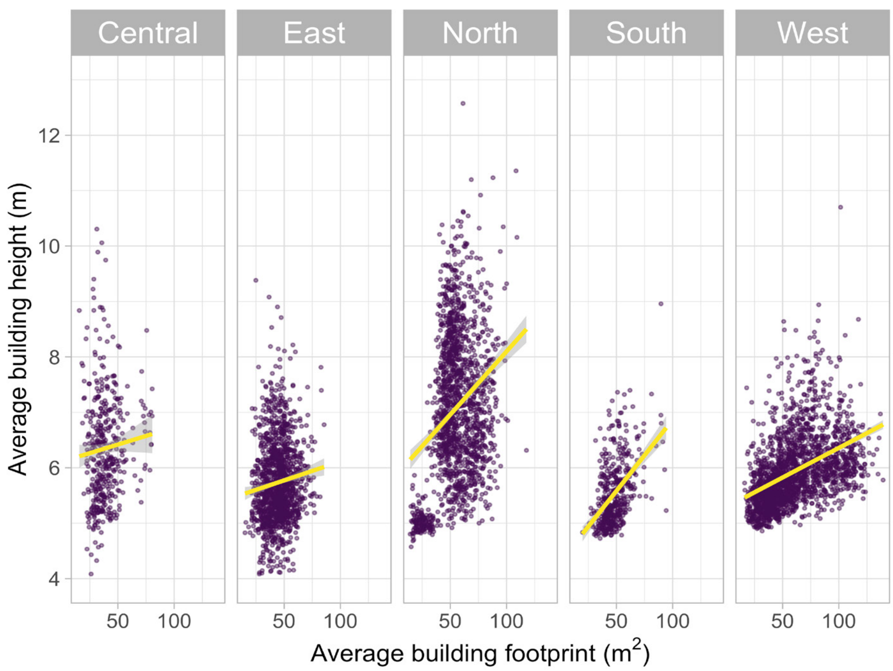
Source: (Wojciech et al., 2021[15]; OECD/SWAC, 2020[16]).

Importantly, the prevalence of such buildings does not necessarily translate into low densities, in terms of population. Some informal settlements in Nairobi can house as many as 1 500 people per hectare or more, comparable to the density of the island of Manhattan in New York City (OECD/SWAC, 2020[1]). But small buildings and high densities are often symptomatic of overcrowding. Approximately 40% to 60% of households already live in overcrowded conditions across West Africa (Chipeta et al., 2022[19]).

In almost half of urban agglomerations, the average **height** of buildings is only one or two storeys, less than 6 m (a storey is typically between 2.5 m and 3 m in height) (Esch et al., 2020[20]).[6] There is a positive correlation between average footprints and heights in each agglomeration by region (Figure 4). Bigger building footprints tend to be associated with higher buildings. In some regions, this relationship is not as strong, which may mean that large building footprints are occupied by warehouses, manufacturing plants and factories, which tend not to be very high. Figure 4 also shows that the same building footprint can be associated with a range of heights. For example, average building footprints of 50 m^2 are associated with anywhere from 5 m to 12 m in height, from two to five storeys. "Small footprints" might thus set certain limits in height, both structurally and practically, but may still be multi-storey developments. There is scope for vertical growth, not only for new buildings, but for adding floors to existing structures.

Figure 4.

Building footprints and heights across African regions



Note: Each purple dot represents the average building footprint in square metres and the average building height in metres. Each panel represents a different region.

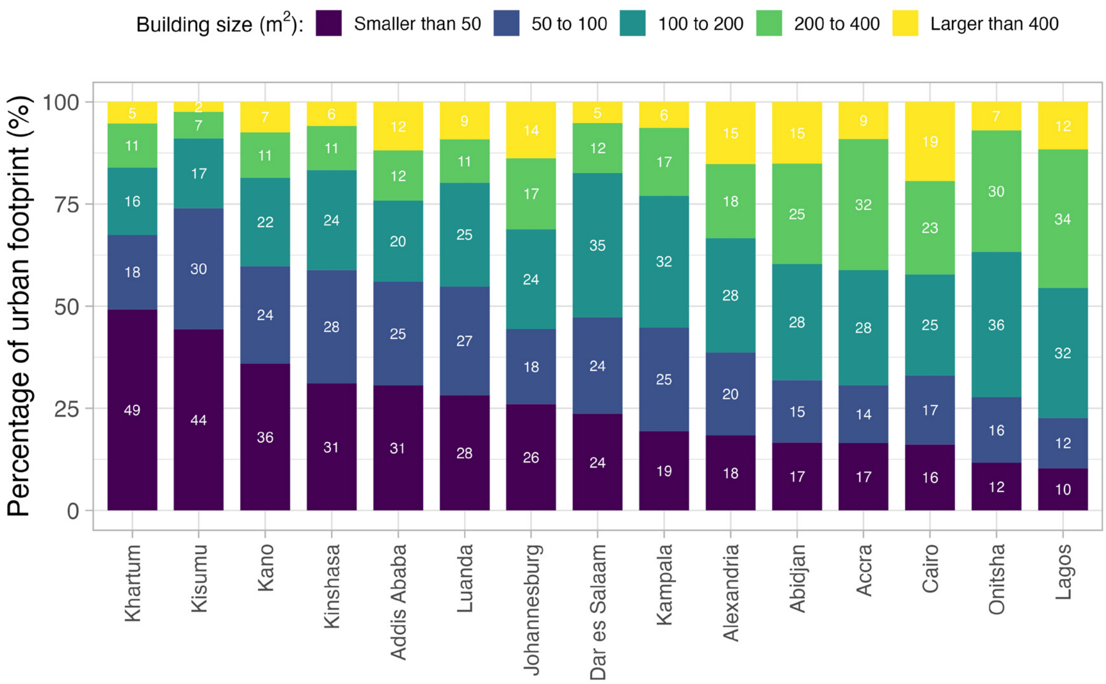
Source: Average height data are taken from (Esch et al., 2020[20]) and mean building footprint from authors' calculations based on Open Buildings database (Wojciech et al., 2021[15]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

Larger cities have more big buildings

Larger cities have a greater relative abundance of bigger buildings – in terms of footprint and height – which contributes to the greater compactness in very large cities (as noted in the previous section). For example, in four Nigerian cities – Benin, Ibadan, Port Harcourt and Lagos – more than 75% of the total building footprint is from buildings bigger than 100 m^2 (almost double the continental average) (Figure 5). The same applies to Kisumu (Kenya), where large buildings contribute greatly to the surface of the city (Figure 5).

Figure 5.

Percentage of urban footprint occupied by large buildings in the 15 most populous cities in Africa



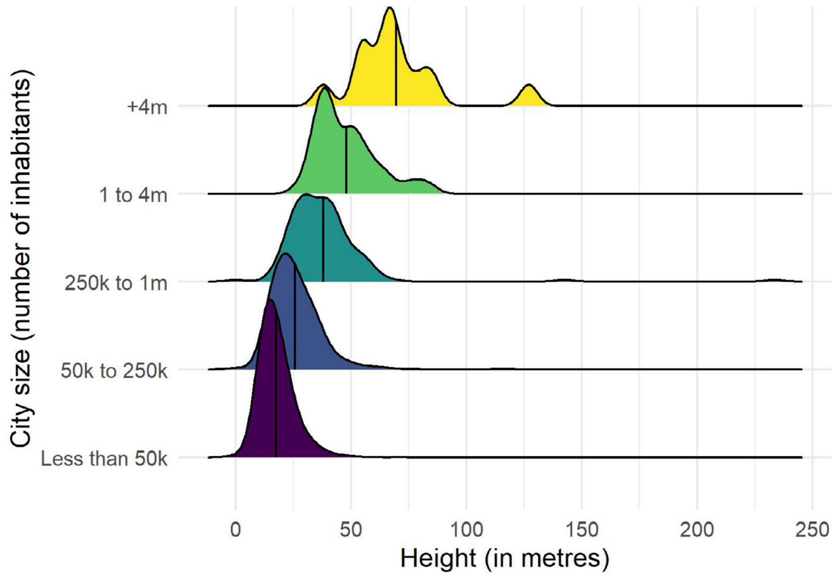
Note: Composition of the footprint of the 15 most populous cities in Africa depending on the size of their buildings. In Khartoum (Sudan), for example, 49% of the buildings are smaller than 50 m^2 and 84% smaller than 200 m^2. However, only 10% of the buildings in Lagos are smaller than 50 m^2 and 54% are smaller than 200 m^2.

Source: Authors' calculations based on Open Buildings database (Wojciech et al., 2021[15]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

Likewise, larger cities also have higher maximum building heights (Figure 6). The maximum height in cities of over 4 million residents in Africa is close to 70 m, on average, to 50 m in large cities from 1 million to 4 million, 38 m (on average, in cities from 250 000 to 1 million), 36 m (on average in cities of 50 000 to 250 000) and 18 m (on average, in cities of less than 50 000). As cities become larger, building heights evolve.

Figure 6.

Larger cities have the tallest buildings



Note: Maximum height in metres observed in all urban agglomerations classified by city size.

Source: Data provided by (Esch et al., 2020[20]).

Although the proportion of "small" buildings is low, there are still many small buildings, even in cities like Lagos (Nigeria). In total, the Open Buildings data from Google AI Africa suggests that Lagos has more than 1.1 million buildings of less than 50 m^2. Equally, Lagos has the same number of small buildings and population in Lagos than in 672 small cities in Africa combined. Therefore, it should not be assumed that because Lagos is a large city, it has fewer small buildings.

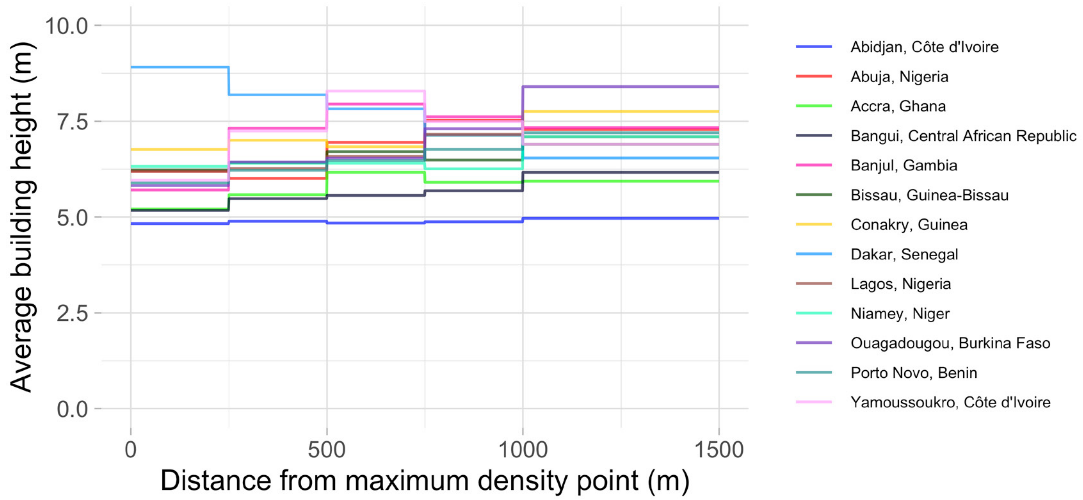
Low, flat skylines across the urban fabric

Even larger cities with a greater abundance of bigger buildings have skylines that tend to be low and flat across the urban fabric. By contrast, in compact cities, the highest buildings tend to be in the centre of the city, steadily declining outward, and are typically characterised by a sloping, "pyramidal" height distribution (Lall et al., 2021[21]). Even so, cities that become pyramids will never entirely escape the economic drivers of horizontal sprawl. Flat cities, also called "pancakes" (Lall et al., 2021[21]) run the risk of packing people into limited floor space per person, while higher buildings can accommodate large numbers of residents and firms, avoiding overcrowding, while leaving room among buildings for green space.

African cities show no relevant difference in average building size, in terms of height or area, within the first kilometre from the centre, as would be expected. Intermediate and large cities show a gradual decrease in building size, not the steep decline seen in cities of high- and middle-income countries.

Many cities are flat throughout the entire urban fabric, with only one or two storeys – for example, Abidjan (Côte d'Ivoire), Accra (Ghana), Conakry (Guinea) – except for Dakar (Senegal), with three storeys on average and a slight decrease in height (Figure 7). The maximum density point is used as the starting basis and the average height of buildings is measured in concentric circles outwards. Similar trends are observed throughout cities in other low-income and lower middle-income cities in the rest of the world (Lall et al., 2021[21]). The average height in central business districts (CBDs) in low-income cities is around 10 m, gradually increasing with income to almost 30 m (Lall et al., 2021[21]).

Figure 7.
Average building heights up to 1 500 metres from a city's maximum density point



Note: Average building height estimated from satellite imagery by the German Aerospace Centre (DLR).

Source: Calculated by DLR using buffers from the maximum density points identified in this study.

Box 2.
How flat is an agglomeration?

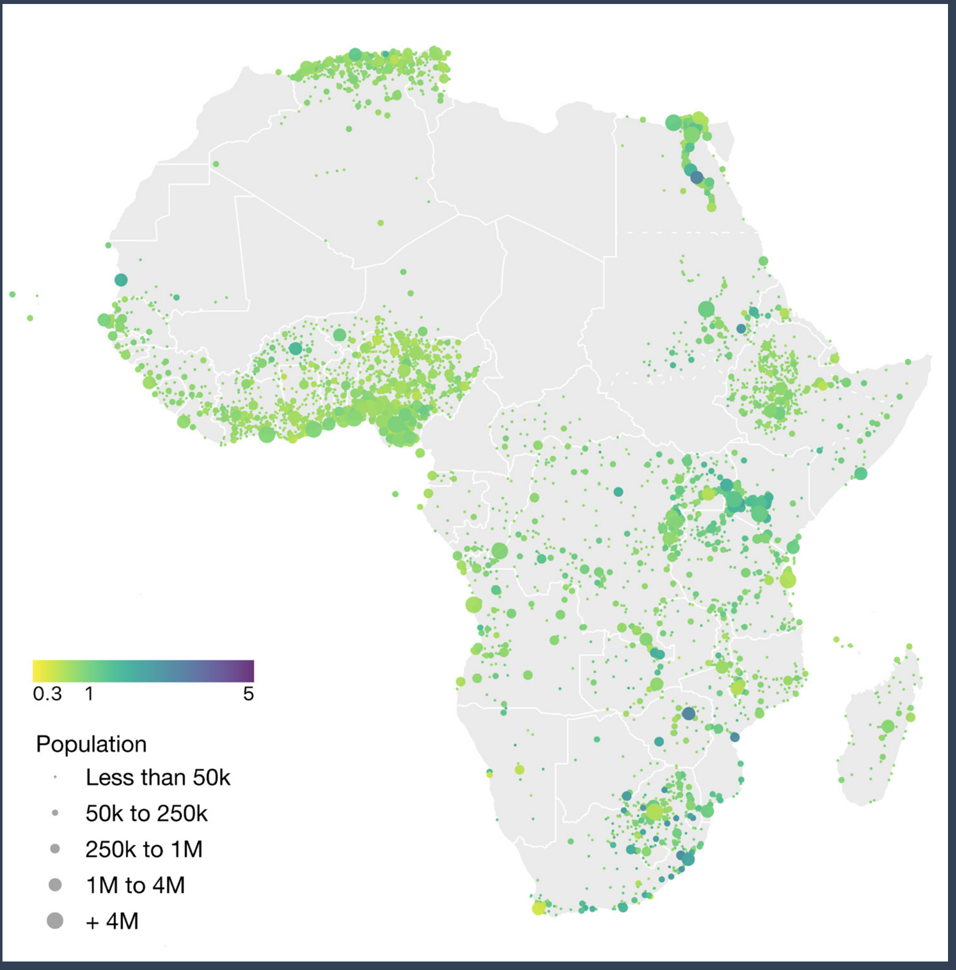
Analysing the heights and areas of buildings throughout the urban fabric can be cumbersome. This study developed an indicator to signal how flat a city is. The average size of the buildings (in terms of footprint) within 1 kilometre of a city centre (defined as the maximum density point) is divided by the average size of buildings outside this 1 km circle.

A value of less than 1 means that the buildings in the maximum density point are smaller, equal to 1 signifies the same size, and greater than 1 means the buildings around the maximum density point are larger than the rest of the city (Map 6).

Of the urban agglomerations, 1 734 have values of less than 1, with 1 984 urban agglomerations equal to 1 and 1 825 fall between 1 and 2, while 82 are greater than 2. For these latter groups, the buildings are larger in the centre than in the rest of the city, indicating a slight pyramid, as suggested above.

Map 6.

From pancake to pyramid



Note: Ratio between the average building size within 1 km of the densest point in the city and the rest of the city. Larger values correspond to cities where the densest point has bigger buildings.

Source: Authors' calculations based on Open Buildings database (Wojciech et al., 2021[15]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

Obstacles to bigger buildings

Building larger, higher buildings can encourage compactness (especially when combined with high densities and mixed land use). Higher does not necessarily mean skyscrapers, but multi-storey development instead of only one or two storeys, or even adding floors on to existing buildings.

Building sizes and heights are a response to resource availability and demand and evolve over time, as can be seen in the greater abundance of bigger buildings in larger cities. Low-rise houses with a small footprint are typically the most affordable option, because they minimise both land and home costs. Building tall is more expensive, since it requires technology and capital investment, with an expectation of high returns. Such expectations depend on prior public investments in transport infrastructure – e.g. buses, sidewalks – and public services, as well as on the economic outlook and business environment. Therefore, larger cities (which tend to have more resources and demand) have larger and taller buildings.

Cycle: Unaffordable housing, small buildings, less compact agglomerations

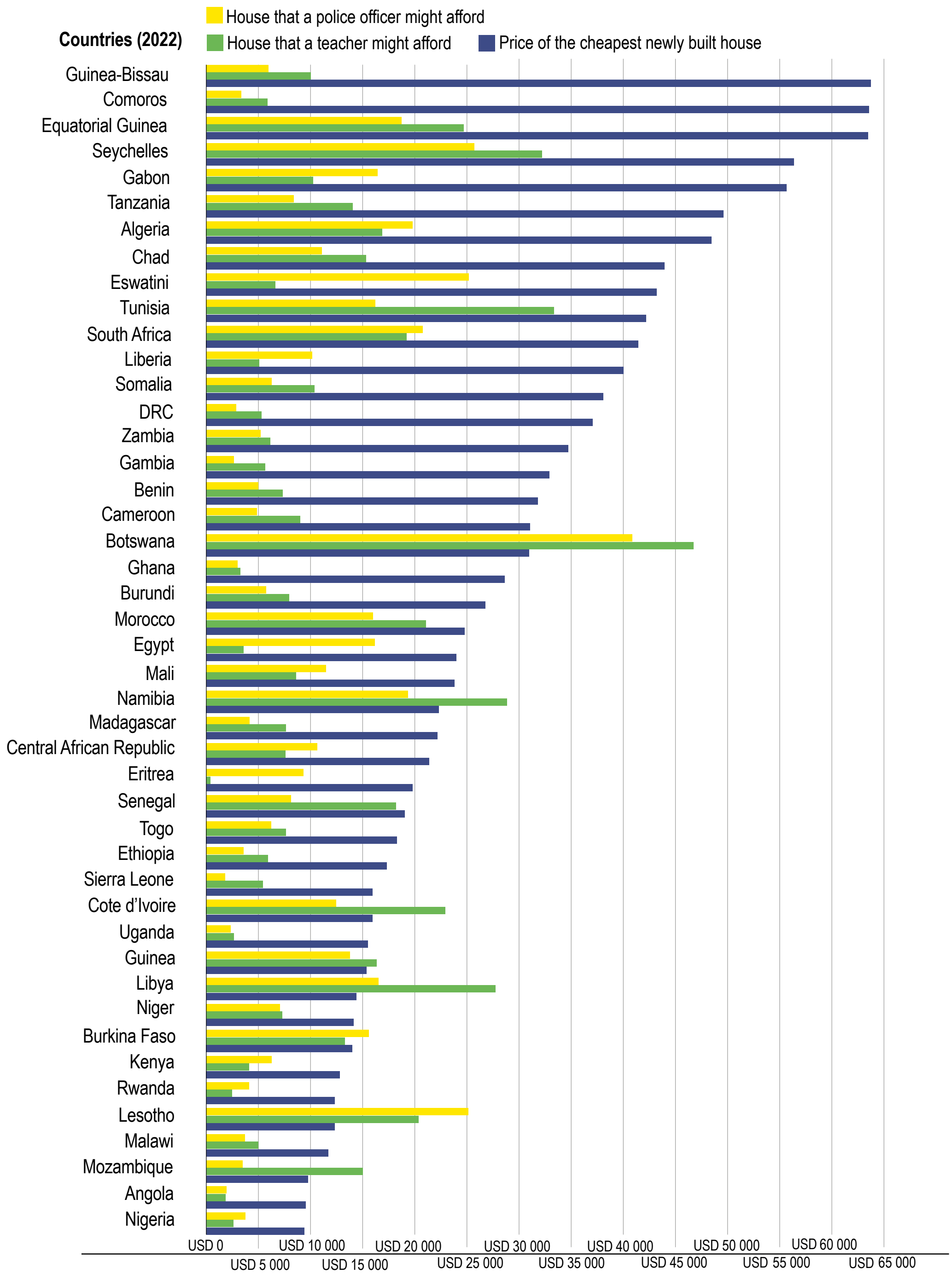
Small buildings, in terms of footprint and height, may indicate that residents have kept their smaller homes, as villages morph into cities or even conurbations with demographic rates rising (in situ urbanisation), rather than rebuilding.

Small buildings may also indicate rapid urbanisation, a mismatch between the housing stock available, its affordability and the size of the population. Almost 78% of residential areas developed between 1990 and 2014 in sub-Saharan Africa (i.e. regions that lie south of the Sahara) are informal (Angel, Parent and Civco, 2010[22]). In other words, the formal housing market is not delivering affordable accommodation for most people. The search for affordable housing has been shown to accelerate urban growth in other parts of the world, leading to greater energy demand for transport, if infrastructure is not provided.

The cheapest newly built house in the formal sector in Africa as of 2022 costs between USD 10 000 and USD 65 000, depending on the country, according to Centre for Affordable Housing Finance in Africa. This is well beyond what most people are able to pay (Centre for Affordable Housing Finance in Africa, 2022[23]). Even workers in the formal sector, e.g. teachers and police officers, have difficulty paying such prices (Figure 8).

Figure 8.

Affordability of housing for teachers and police officers across Africa



Note: The Centre for Affordable Housing Finance in Africa calculated the typical salary of an urban police officer and an urban teacher in Africa's 54 countries, and then calculated the housing price that each could afford with a mortgage, given current rates and terms in the country. The graph below compares (a) the price a police officer or teacher could potentially afford with (b) the price of the cheapest newly built house – all converted into USD. The price of the cheapest newly built house is only affordable to a teacher in eight of the 54 countries. For a police officer, the cheapest newly built house is probably unaffordable in all but five countries. A two-income household might be able to afford one – but even then, if the two income earners are teachers or police officers, several countries would remain unaffordable.

Source: Taken from Centre for Affordable Housing Finance in Africa (2022[23]).

This lack of affordability of newly built formal housing, even for those who are formally employed, reflects outdated and inhibiting regulatory standards for newly built homes. Minimum lot size requirements and building height requirements, for example, have an important impact on urban development patterns and limit the availability of housing and development of more compact and sustainable urban environments, as well as the affordability of housing.

- Some of these overly restricted lot size requirements are inherited from the colonial era (Visagie and Turok, 2020[24]). For example, in Nairobi, the legal plot size is 250 m^2, between the size of a tennis and a basketball court (Visagie and Turok, 2020[24]). In Dar es Salaam, 300 m^2 is a minimum lot size for residential development in low-density residential development. Similarly, in Ghana, the planning guidelines specify that in an area designated for low-density residential development (e.g. housing density of 10 to 15 dwellings per hectare), the predominant development should be detached houses on plot sizes of not less than 500 m^2, the size of a basketball court.

- Restrictive height limits can also limit compactness and the availability of affordable housing and impede the development of sustainable and walkable urban environments. African cities could promote a better balance between the benefits and the drawbacks of building height restrictions in developing urban planning policies. Many cities have building height restrictions. In Addis Ababa (Ethiopia), it is 22 m in most areas of the city, with a maximum of 32 m, leading to a predominantly low-rise urban form; in Nairobi (Kenya) 67 m, a maximum of 80 m; in Lagos (Nigeria) 30 m, in some areas a maximum of 50 m; in Dar es Salaam (Tanzania) it is 30 m in most areas, with a maximum of 60 m; in Accra (Ghana), 60 m and 80 m. However, restrictions can serve important purposes – preserving historic areas, protecting views and ensuring safety.

Such policies, which promote minimum lot sizes and height restrictions, tend to push low-income residents into the informal sector, blocking efforts to upgrade existing buildings and discouraging investment.

"Sprawl is partially driven by lower land prices around the urban periphery, but it means that urban residents need to travel longer distances, [often] at greater personal and environmental expense," (Moreno Monroy et al., 2020[25]). When land and construction costs close to the centre are too high, people will seek housing on the periphery, where they can minimise the land cost. This can lead to less compact urban forms and construction in potentially vulnerable areas or in areas with critical ecosystem services. This may make housing more affordable, but comes with disadvantages, such as expensive transport costs and long commutes. If the housing is built at a low density (say, because of high minimum lot sizes or high minimum floor area rules), or if the newly built areas are not serviced with infrastructure, it can be challenging to provide public transport, leading to greater dependence on cars, in addition to higher energy demand. All this can lead to increasing emissions and pollution from transport and buildings.

Supply-side challenges to bigger buildings: Vertical growth

Acquiring a loan for construction is quite difficult, particularly for large projects – which is why the continent is scattered with partially constructed, unfinished buildings. In Senegal, for example, around 40% of developers say access to cash is their biggest obstacle, compared with 14% in the rest of the world (The Economist, 2021[26]). Developers will sometimes start construction for a multi-storey building in the hope that prospective tenants will put in a deposit on a partially finished building. If this does not pan out, the developer ends up in financial trouble (Devermont and Salmon, 2021[27]).

Bigger building projects may stall for other reasons. Many developers are caught short by the fluctuating price of materials, which was exacerbated by the COVID-19 pandemic. The unabated rise in the cost of materials in Nigeria, for example, is expected to further slow planned developments in 2023 and increase housing prices.

In the past two years, prices of essential building materials, including cement, reinforcement, paint, sanitary fittings, sand, roofing, tiles and granite, rose by over 50% (Gbonegun, 2023[28]). Weak property rights can be a factor for unfinished buildings (Devermont and Salmon, 2021[27]). People choose to build because the land does not have a solid legal foundation or because the laws on who owns the land are lax (The Economist, 2021[26]).

The rising price of materials affects the affordability of housing, exacerbating the movement of people towards the periphery. In Nigeria, the price of rentals is rising in the city centres of Lagos, Abuja, Ogun, Ibadan, Port Harcourt, Anambra, Abia and Kano, with homeowners and property managers raising rents by over 75% over the past two years (Gbonegun, 2023[28]).

More compact agglomerations, more full

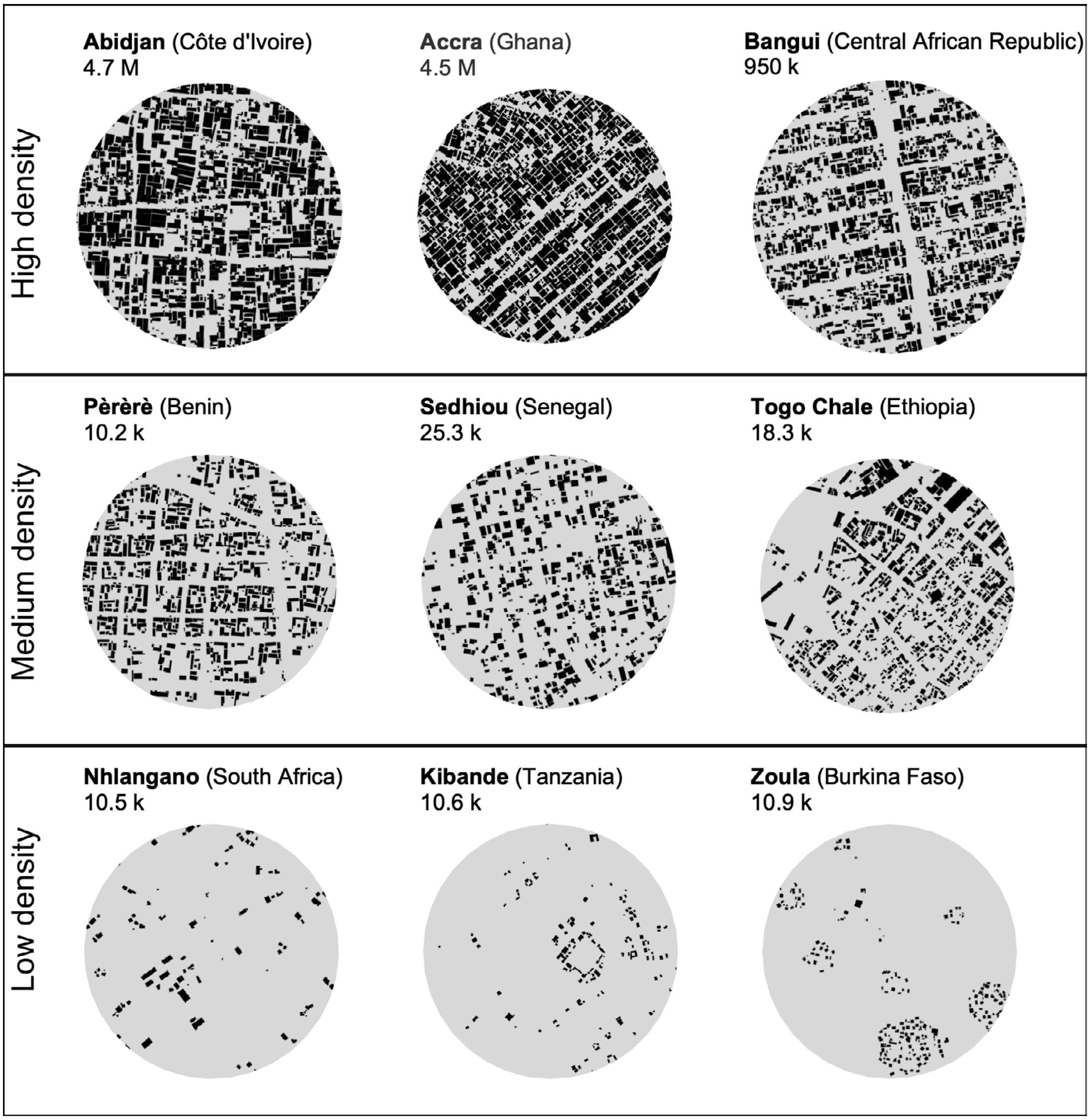
This report shows that more compact agglomerations tend to have greater fullness in city "centres". CBDs, i.e. city centre(s), can facilitate sustainability by promoting higher densities in the centre, which lowers the costs of infrastructure provision such as public transport, lowers buildings' energy use, and improves the liveability of cities. Agglomerations with less constructed centres have the potential for infill, curbing horizontal sprawl and increasing compactness if such issues as affordability and supply of buildings can be addressed.

Identifying the CBD(s) of nearly 6 000 urban agglomerations is arduous and difficult to compare. We thus identified the most built-up point in cities and evaluated what percentage of its area is constructed in the 250 metres and 1 kilometre around this point.[7] These percentages provide an indication of the fragmentation of the built environment – i.e. if there is potential for infill – or if it is built up at the expense of other facets of resilience, such as green spaces (which reduce the impact of heatwaves). Moreover, it is comparable across agglomerations (this is referred to as "fullness", for simplicity's sake). These values will never be 100%, because of other types of man-made infrastructure, such as roads, as well as natural (e.g. green and blue) spaces.

In Abidjan (Côte d'Ivoire), Accra (Ghana) and Bangui (Central Africa Republic), more than 60% of the city centre is occupied by buildings within the 250 metres around the maximum density point (Figure 9). In Abidjan, Accra and Bangui, 27%, 25% and 40% of the space, respectively, is not occupied by buildings. Pèrèrè (Benin), Sedhiou (Senegal) and Togo Chale (Ethiopia) have 49%, 48% and 30% built, respectively. The three agglomerations in the bottom row have less than 10% constructed. The cities in the middle and bottom rows show potential for infill.

Figure 9.

Visualising the fullness in the most built-up areas in agglomerations



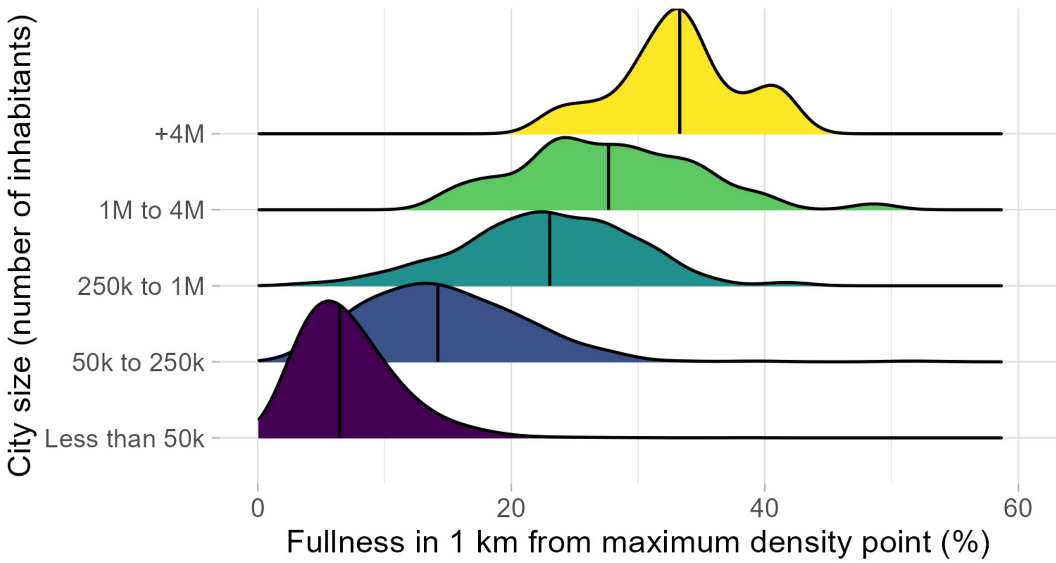
Note: Building footprints at the maximum density points in Abidjan (Côte d'Ivoire), Accra (Ghana) and Bangui (Central Africa Republic), where more than 60% of the surface has been built in the 250 m around the maximum density point, respectively.

Source: Modified after Prieto-Curiel, Patiño and Anderson (2023[29]).

City size is strongly related to the fullness at its maximum density point (Figure 10). In small cities, only 7% is occupied by buildings in the 1 kilometre surrounding the maximum density point. For small intermediate cities (50 000 to 250 000) and larger intermediate cities (250 000 to 1 million), approximately 15% and 23% is built up, respectively, while 28% is built up in large (1 million to 4 million) and 33% in very large (above 4 million). For those that have a relatively small proportion of built-up area, of less than 10%, the potential for infill in the existing agglomeration can act as a substitute for some of the horizontal expansion on the urban periphery, contingent on affordable housing being available.

Figure 10.

City size and the built-up area of the maximum density point



Note: Distribution of the area covered by buildings in 1 km around the maximum density point, grouped by city size.

Source: Authors' calculations based on Open Buildings database (Wojciech et al., 2021[15]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

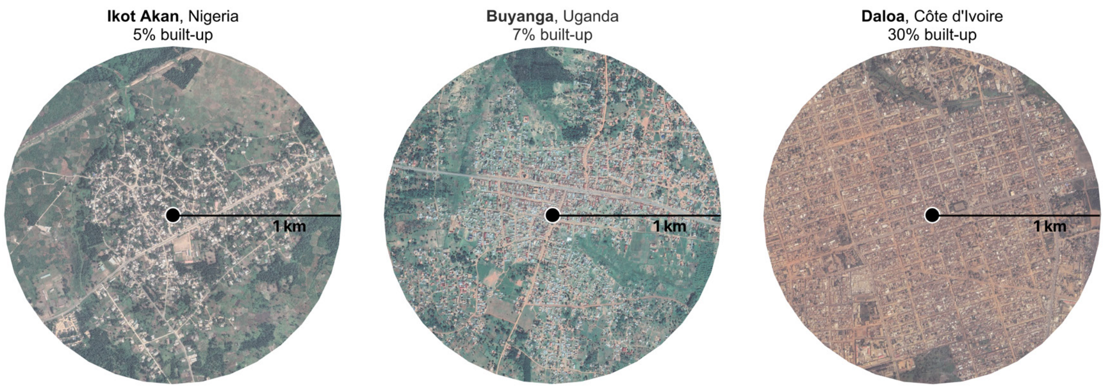
Although the fullness is higher in larger cities, that is generally because they have more buildings and not necessarily because the buildings are higher. In general, the footprints of buildings within the 1 km around maximum density points are 10-16% larger, on average, than buildings' footprints at 1 km from the centre. In Central Africa, the area occupied by buildings within 1 km of the densest point increases 3.3 times if the city has 10 times the population, but a building's footprint only increases 1% near the centre. In North Africa, the area occupied by buildings within 1 km of the densest point increases 2.6 times if the city has 10 times the population, but the building footprint only increases 6% near its centre. In West Africa, on average, the area occupied by buildings within 1 km of the city centre is 3 times larger in cities with 10 times the population, but the average size of buildings decreases by 1.7% near the centre. Therefore, although the area occupied by buildings may increase in some cities near the densest point, it is mostly due to the high number of buildings, rather than the fact that they are larger.

Infill vs. loss of green space in dense centres: Managing trade-offs

Map 7 gives a series of satellite views of the maximum density points in intermediate cities (100 000 to 250 000) with low (with less than 4.5% of the area built up), medium (6.4% to 9.6%) and high levels of fullness (28.7%).[8] These cut-off points were determined based on the distribution of the data. In the next three decades, these cities are likely to experience major transitions, given the need to accommodate increasing numbers of people, so the pressing question is whether there is potential for infill.

In Ikot Akan (Nigeria), in the left-hand image, and Buyanga (Uganda), centre, infill remains a possibility. However, it runs the risk of taking up green space, as seen in Daloa (Côte d'Ivoire), the right-hand image. Green spaces boost both resilience (by reducing the impact of heatwaves) and sustainabilility (by absorbing pollution). To avoid losing green space while accommodating growing numbers of people with unnecessary urban expansion, cities could preserve green spaces by acquiring them and converting them into parklands. This, however, requires resources for maintenance and monitoring (Anderson, Patiño Quinchía and Prieto-Curiel, 2022[3]) and also, as noted above, requires encouraging the construction of multi-storey buildings by improving access to finance and property rights. In addition, these images reveal that even cities of very similar size may look dramatically different at their most built-up points.

Map 7.
Bird's-eye view of fullness metric in intermediate cities



Note: Satellite views as available in the Google Satellite web map service on 21 January 2023.

Source: Google Satellite Image web map service in QGIS.

Quality of life in a 'full centre': Infrastructure in Kano and Ibadan

To give one example comparing two Nigerian cities, approximately 40% of Ibadan's (308 000 people) and 36% of Kano's (388 000 people) centre is occupied by buildings in the 1 km around the maximum density point, which reduces the costs of public infrastructure, from transport to electricity. However, simply having many buildings does not necessarily mean that this infrastructure makes cities liveable (San Emeterio and Moriconi-Ebrard, 2022[30]).

In Ibadan, San Emeterio & Moriconi-Ebrard (2022[30]) note the decaying city centre – i.e., dilapidated housing, the lack of sewers, few sidewalks, inadequate roads and no public lighting. It has only 83.9 intersections per km^2, less than half what Kano has, with 202 intersections per km^2 – i.e., Ibadan is less walkable than Kano because of longer distances between intersections (Open Street Map, 2022[18]). The lack of lighting restricts commercial life to daylight hours, which inhibits business activity and growth. The condition of the centre can be attributed to a lack of public investment and of the resources for maintenance (San Emeterio and Moriconi-Ebrard, 2022[30]). In contrast, Kano may not look more attractive, but "many houses have been renovated, rebuilt in solid form, raised, equipped with terraces and modern frames" (San Emeterio and Moriconi-Ebrard, 2022[30]), who note "the more frequent presence of public lighting, which facilitates night travel and therefore a real urban life after sunset". Kano, however, benefits from public investments and resources, partly because it is classified as a UNESCO World Heritage Site. In Kano, private investment in renovation of housing stock appear to go hand-in-hand with public sector investment. These examples suggest the importance of public investment and that inherently, a "full city centre" does not guarantee well-being or that a city will be accessible or sustainable.

Why are some centres less full?

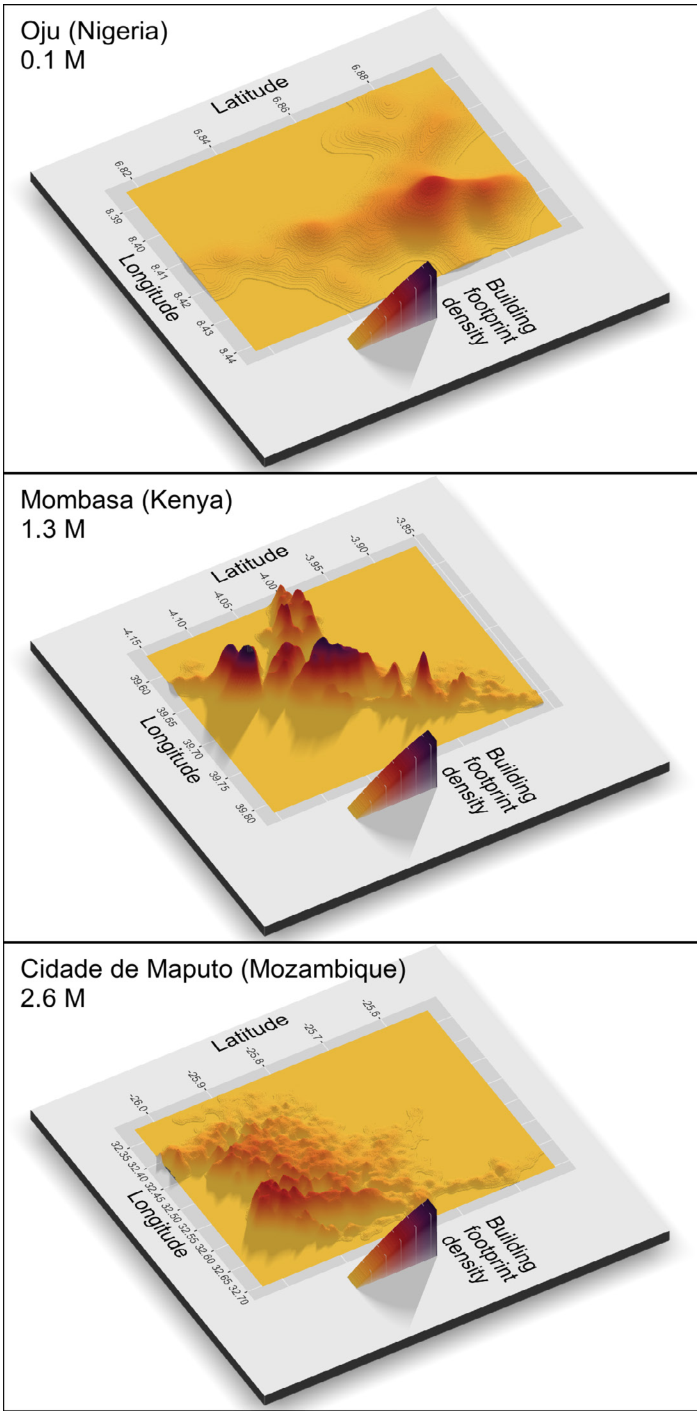
Part of the fullness of agglomerations' centres (i.e., the area buildings occupy around the 1 km surrounding the maximum density point) relates to city size. Fewer people means less demand for space in the centre. However, this does not explain all the variation, since, as seen above, cities of similar size have very different levels of fullness. Agglomerations will need to explore such dynamics closely in the local context. Issues of building size, including functioning land markets, regulations, affordability, financing and supply-side challenges, may also be at play. Another relevant concern is single-use zoning for government-regulated land, which is inflexible and limits opportunities for mixed-use developments by separating residential, commercial and industrial uses (as in Ghana, Lesotho, Malawi, Mauritius, Namibia, Tanzania and Zambia). Land speculation and natural terrain may also play a role. Some areas may be less full because of differences in elevation, critical ecosystem services (watersheds) or protected green or blue spaces. These should all be investigated before infill for these areas is considered.

Polycentricism and compactness: The trade-offs

Polycentric agglomerations tend to be less compact. As a city's population grows, its structure evolves, morphologically and functionally (Derudder et al., 2021[31]). For many cities in Europe, China and Latin America, this involves a transformation from monocentric (with a single centre) to polycentric (multiple centres). In a monocentric city, most activity is concentrated in a central area, while in a polycentric structure, activities are more evenly distributed across the urban fabric. Polycentric urban forms have the potential to reduce average commuting times and costs, reducing emissions as well as outdoor air pollution (Did et al., 2022[32]). In Africa, large and very large cities tend to be polycentric, while small and intermediate ones may sprawl out but are nevertheless monocentric. Historical legacy also influences morphology. Cities in former British colonies tend to be more polycentric, with more sprawl, than those in former French colonies. In the older, colonial sections, cities have less intense land use and a more irregular layout and more leapfrog development at the margin (Baruah, Henderson and Peng, 2021[33]).

In Figure 11, morphological polycentricity is measured in terms of the distribution of buildings through the urban fabric (Derudder et al., 2021[31]; Yang et al., 2021[34]).[9] A value of 1 is monocentric, with higher values indicating the presence of more centres. For example, Oju, a small city in Nigeria, is monocentric, as shown by the single peak, while Mombasa (Kenya) and Cidade de Maputo (Mozambique) are increasingly polycentric (Figure 11).

Figure 11.
3D Visualisation of the building footprint density in cities



Note: The density of the buildings in Oju (Nigeria) has a polycentricity index of 1, Mombasa (Kenya), a polycentricity index of 8 and Cidade de Maputo (Mozambique) a polycentricity index of 5. The index is based on an underlying kernel density estimation of the intensity of the number of buildings and constructed surface per unit area (see Appendix C for more details on the index). A city with a polycentricity index of 1 is monocentric (meaning that it functions around a single centre, identified as the location in the city with the highest density) (Prieto-Curiel, Patino and Anderson, 2023[29]). If the city has two distant centres of equal size, the index has a value of 3; and if it has three distant and centres of equal size, the index has a value of 6 (which fall between the cities in Mombasa and Maputo.

Source: Authors' calculations.

African urban agglomerations exhibit similar trends as the rest of the world. On average, small cities tend to be monocentric, while intermediate, large and very large cities start to develop more centres (Table 2).

Table 2.

Increase in polycentrism across city sizes

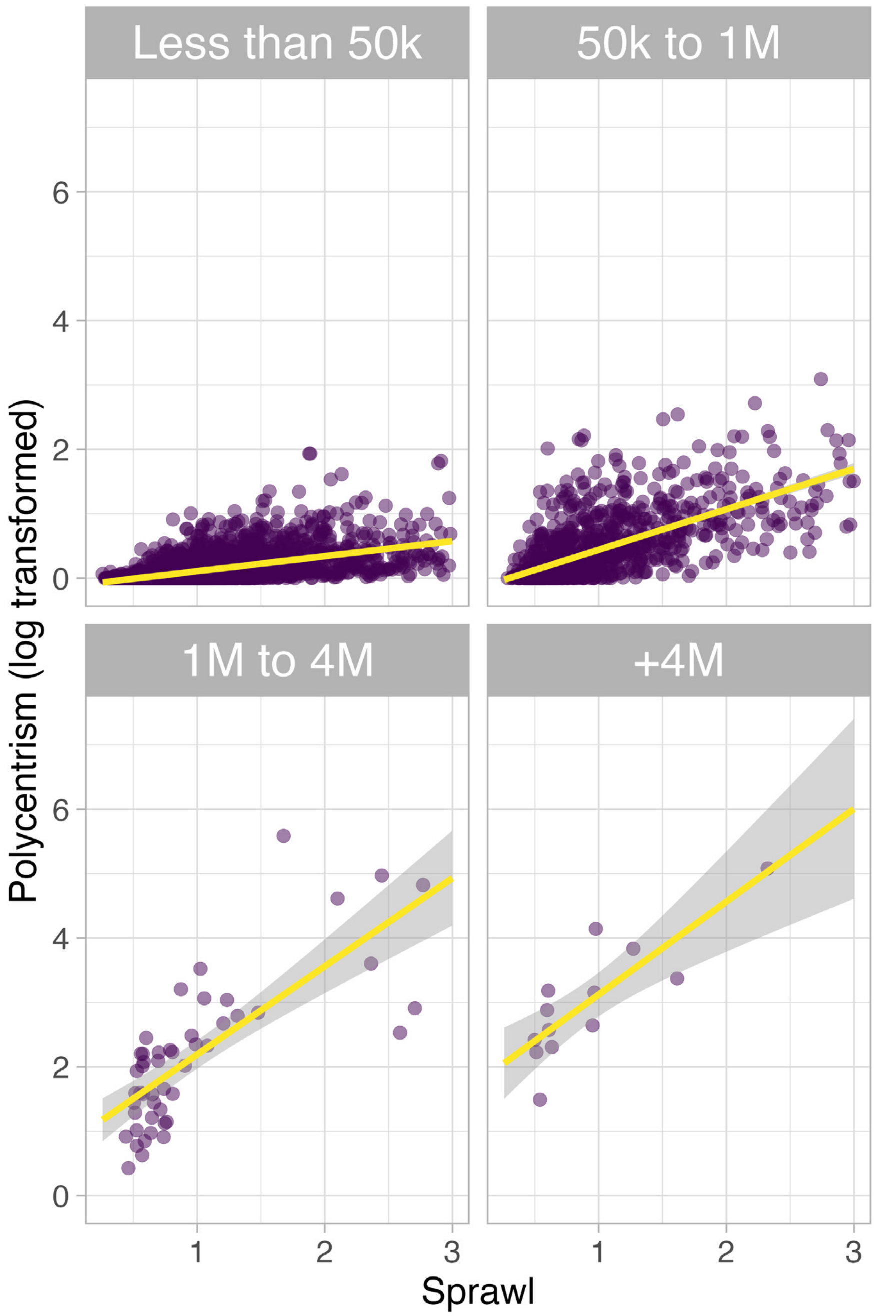
	Polycentrism Index	Interpretation
Less than 50k	1.1	Monocentric
50 000 to 1 million	1.8	Fairly monocentric
1 million to 4 million	21.5	Polycentric
Over 4 million	32.8	Polycentric

Note: The index is based on an underlying kernel density estimation of the intensity of the number of buildings and constructed surface per unit area (see Appendix C for more details on the index). A city with a polycentricity index of 1 is a monocentric city (meaning that it functions around a single centre, identified as the location in the city with the highest density). If the city has two distant and equal-sized centres the index has a value of 3. If the city has three distant and equal-sized centres, the index has a value of 6 (which fall between the cities in Mombasa and Maputo (Figure 11).

Source: Authors' calculations based on Open Buildings database (Sirko, W. et al., 2021[39]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

The relationship between city size, compactness and polycentrism is more complex. Figure 12 shows that in small agglomerations (of less than 50 000) and intermediate ones (50 000 to 1 million), monocentric agglomeration and extensive sprawl is commonplace. This can lead to greater dependency on cars and longer commutes to access services and opportunities (Figure 12). It is less common to have a monocentric agglomeration with extensive sprawl (large or very large), but the sprawl of these agglomerations is often associated with more centres, as seen in Figure 12. Since large and very large agglomerations start to involve more sprawl, polycentricism adds to the liveability of cities, with multiple centres of activity. This suggests that as cities become bigger, they become better at using space.

Figure 12.
The relationship between polycentricism and sprawl by city size



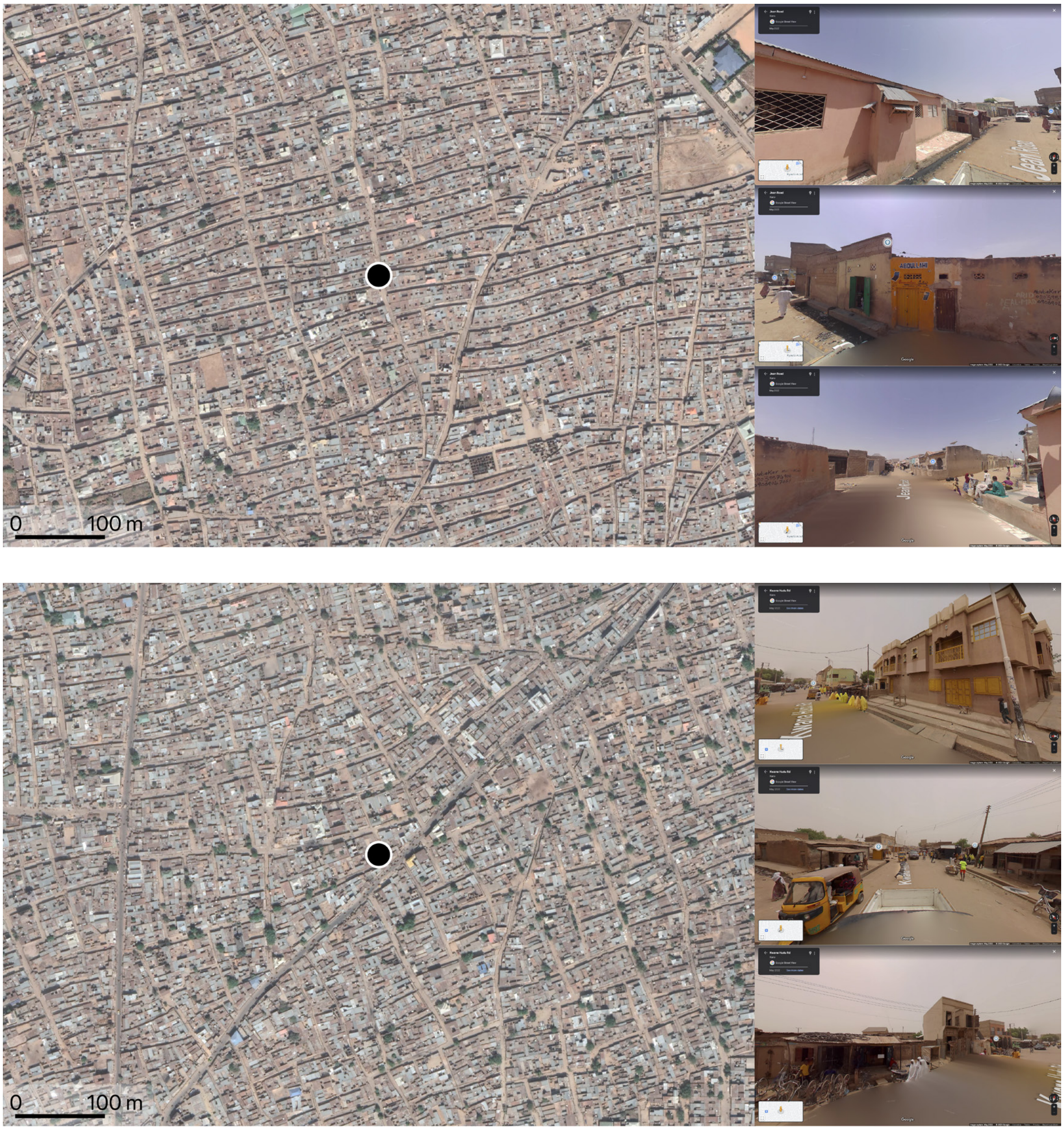
Note: The index is based on an underlying kernel density estimation of the intensity of the number of buildings and constructed surface per unit area (see Appendix C for further details on the index). A city with a polycentricity index of 1 is a monocentric city (meaning that it functions around a single centre, identified as the location in the city with the highest density). If the city has two distant centres of equal size, the index has a value of 3. If the city has three distant and equal-sized centres, the index has a value of 6 (which fall between the cities in Mombasa and Maputo (Figure 11). Here the polycentrism index is converted using logarithmic transformation to observe the relationship with sprawl across city sizes (in the transformed scale, a monocentric city has a value of 0, a city with two centres of equal size has a value of 1.1, and a city with three equal-sized centres has a value of 1.8).

Source: Authors' calculations based on Open Buildings database (Sirko, W. et al., 2021[39]) and Africapolis boundaries (OECD/SWAC, 2020[16]).

To see what these centres look like, Map 8 picks two centres in Kano (Nigeria) and Map 9 does the same for Mombasa (Kenya). On the left is a bird's-eye image of the "centre" and on the right-hand-side, the Google Street images of the surrounding area. The morphological centres clearly identify packed clusters of buildings with some of the characteristics of informal settlements (unpaved streets, organic layouts). Most of the buildings identified are low-rises of one or two storeys. The street view captures cafes, restaurants, hospitals, churches, or schools, suggesting that they may be quite functional areas, in terms of daily life.

Map.8

Kano (Nigeria): Morphological centres



Source: Google satellite view, accessed 24 January 2023.

Map.9

Mombasa (Kenya) : Morphological centres

Source: Google satellite image WMS in QGIS and Google Street View.

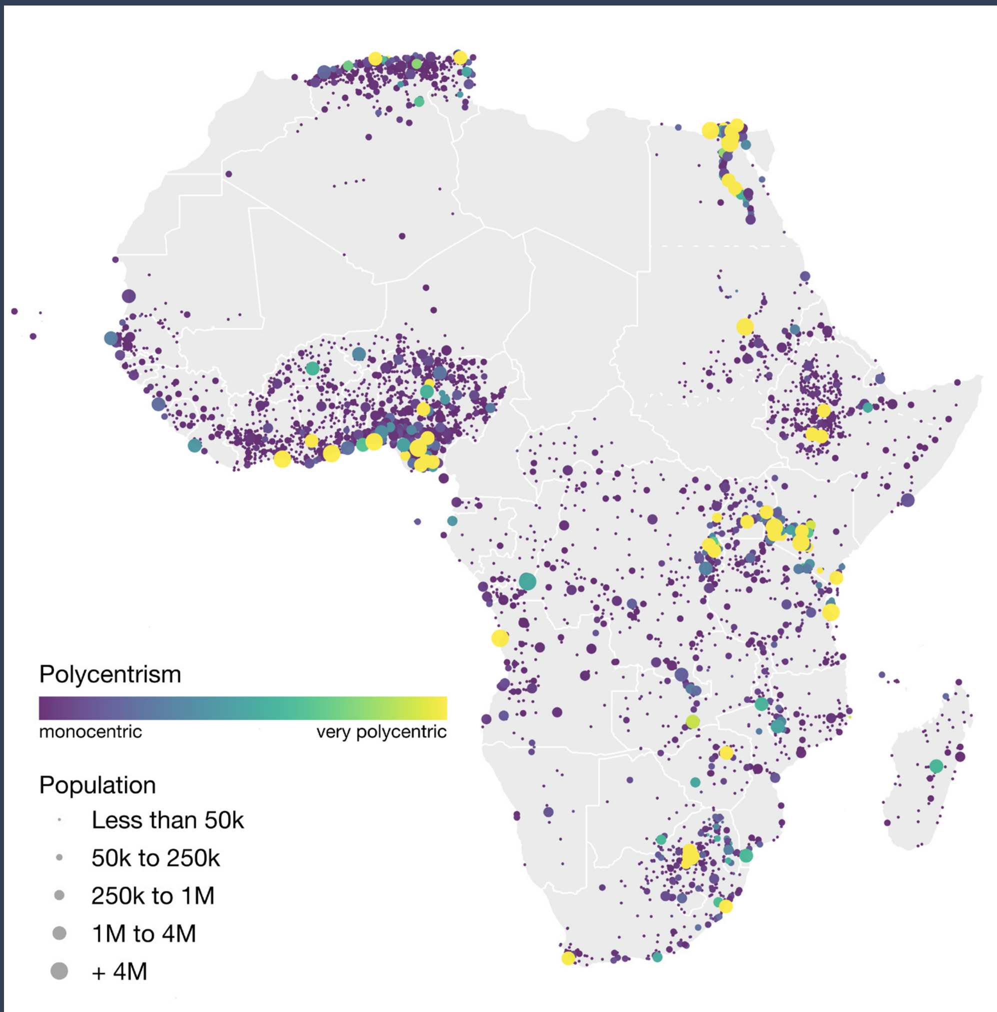
Box 3.

Polycentricism in agglomerations across Africa

Larger cities tend to be more polycentric, while smaller cities are monocentric (purple). No clear differences between regions exist.

Map 10.

Polycentricism



Note: Size of the bubble relates to population. The colour relates to the level of polycentricity.

Source: Authors' calculations.

COMPACTNESS, SUSTAINABILITY, LIVEABILITY AND RESILIENCE

Urban form affects the sustainability and resilience of cities, and in consequence, liveability for urban residents. This section shows that agglomerations with greater fragmentation have higher energy demands for mobility; how sprawl reduces accessibility to services on foot and encourages car dependency; and the links between green spaces and UHI effects, even with similar urban forms.

Costs of less compact cities: Longer distances

One of the most significant downsides of living in a large city is that with more people, there is also, on aggregate, more pollution, noise, congestion and other by-products of accommodating a bigger population. One of them is related to distances. Since more populated cities occupy larger areas, the distance between places also increases. In a large city, the commuting distance to work or school increases, and with it, the time and energy invested for mobility also grow. Longer commuting distances discourage active mobility (such as walking and cycling), tend to increase the cost of public transport, lead to higher energy demand and increase the emissions of private vehicles.

Moderating future energy demand from end uses (such as industry, transport and building) is a key adaptation priority for African urban agglomerations (IEA, 2022[7]). Energy underpins the continent's future economic prosperity. If the energy supply struggles to meet demand (as is already the case today), spikes in energy prices will continue. Providing subsidies (for example, to industry) is already starting to be untenable for many African countries facing debt distress (IEA, 2022[7]).

Understanding how different people move in cities requires vast amounts of data that are not available for most African cities. To model commuting distances based on the average distance between the buildings in a city, the average distance for each city is approximated by taking pairs of buildings in the city and measuring the distance between them (more details in Appendices A and B). Although the distance between all buildings in a city is not the same as the commuting distance, it gives an approximate idea of how distances grow with the population. Ignoring sprawl, distances in a city grow almost with the square root of the city's population (Prieto-Curiel, Patino and Anderson, 2023[29]). Without any elongation or sprawl, distances between buildings can be expected to be 41% longer, on average, in a city with twice the population.

Although increasing distances with more population is an inevitable consequence of larger cities, compactness plays a crucial role in expanding distances beyond just the population effect. Greater elongation and sprawl translate into larger distances, increasing the commuting distances and the emissions and time invested in moving people. For example, in Durban (South Africa), with 3.1 million inhabitants, commuting distances are ***double*** what could be predicted for a compact shape of the same population, since the urban form is elongated (with an index of 5.3) and sprawls (with an index of 0.8). In some cities, this additional cost of the urban form is exceptionally high. In Asyut (Egypt), with 1.3 million inhabitants), commutes are 3.3 times longer. By contrast, in Kisii (Kenya), with approximately 3.4 million people, commutes are four times longer, due to the elongated and sprawl-out urban form – i.e. less compact.

A comparison of Ibadan (Nigeria) and Durban (South Africa), both of which have roughly 3.2 million inhabitants, offers one example. The average distance between any two buildings in Ibadan is 12.3 kilometres, whereas in Durban, the average distance is 44% longer (17.7 kilometres), due to the less compact urban form.

Finally, in large cities, the long commutes produce emissions from which everyone suffers. Even though private vehicles are less typical in African cities, in large cities, more people must travel longer distances. Not only are the distances longer, but more people are travelling the longer distances. One way to measure this impact is by the total kilometres travelled in a city. In general, when a city doubles in size, the total kilometres travelled by the whole population in that city increase by a factor of 2.8, according to analysis. Consider, for example, Ibadan and Nairobi (in Kenya, with 5.8 million inhabitants). Based on the distance between buildings, it is estimated that the average commute in Nairobi is 80% longer than the average commute in Ibadan. The total distance travelled in a city depends on population and on distance (Prieto-Curiel, Patino and Anderson, 2023[29]). Since more people travel these longer distances in Nairobi, an estimated 3.4 times more kilometres are travelled in Nairobi than in Ibadan. Even if only a fraction of the population travel by private car in both cities, this fraction creates 3.4 times more emissions in Nairobi.

The burden of a less compact urban agglomeration, with an elongated and sprawl distribution of its infrastructure, translates directly into longer commutes, more time and energy invested in mobility and more emissions shared by its population.

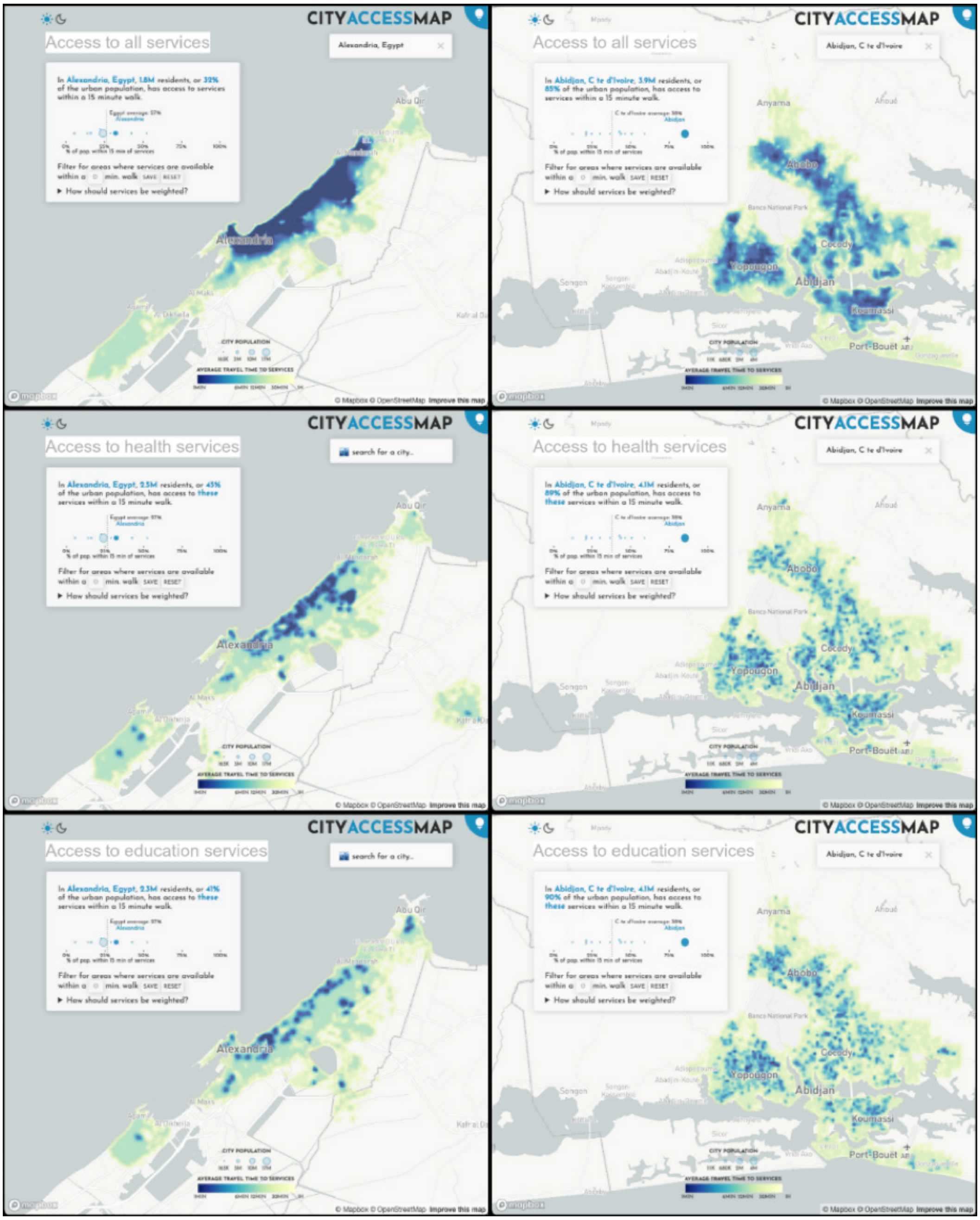
Mobility: Sprawl lowers accessibility on foot

Longer distances ultimately lower accessibility – i.e. reducing access to services and opportunities within a reasonable distance. If cities have lower accessibility, there is a risk of locking in unsustainable transport modes, such as private vehicles, instead of low-carbon modes, such as walking, cycling or public transport. This can lead to higher pollution and the associated effects on health.

Take, for example, a comparison of Abidjan (Côte d'Ivoire) with 4.7 million people and a sprawl index of 0.6, and Alexandria (Egypt) with 6.6 million people and a sprawl index of 1.6 (Map 11) using CityAccessMap. In Abidjan, a compact city, 85% of the population can access all services available in less than 15 minutes on foot (top right, Map 11), while in Alexandria, which is elongated, with sprawl, the percentage is 32% (top left, Map 11) (which includes public transit stations; education facilities; pharmacies, clinics and hospitals; parks, stadiums, and gyms; libraries and community centres; restaurants, food trucks and supermarkets). Residents living in the neighbourhoods of El Dekheila, El Mandarah and Abu Qir, on the ends of Alexandria's elongated shape, take over 30 to 60 minutes to reach these services on foot. Likewise, 89% of the population can access health facilities on foot within 15 minutes in Abidjan, and only 45% in Alexandria (middle row, Map 11). Similarly, 90% of the population can walk to education facilities within 15 minutes but only 41% in Alexandria (bottom row, Map 11).

Map.11

Estimated accessibility levels in Abidjan and Alexandria from CityAccessMap



Note: Left: Alexandría (6.6 million, sprawl: 1.6). Right: Abidjan (4.7 million, sprawl: 0.6). Estimated walking travel time to services. From top to bottom: areas of the city that can access all services, health services and education services. Dark blue represents less time than the lighter colours. The accessibility on foot of two urban agglomerations of similar population size is compared using CityAccessMap, developed by the Centre for Urban Science and Policy from TU Delft University (Nicoletti, L., M. Sirenko and T. Verma, 2022[40]). The tool quantifies which services can be accessed in a 15-minute walk based on the street network and Google API.

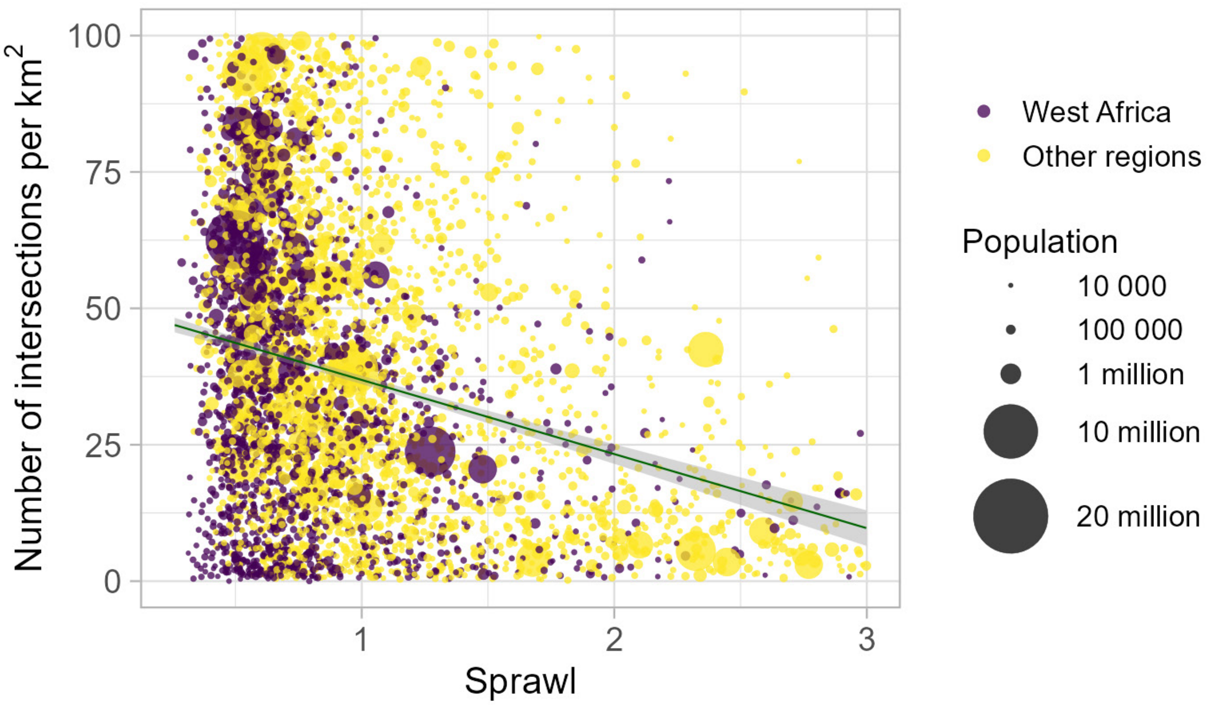
Source: (Nicoletti, L., M. Sirenko and T. Verma 2022[40]), https://www.cityaccessmap.com.

In Abidjan, it is easier to meet daily needs on foot than in Alexandria. What this means from a sustainability perspective is that the use of a car (or private vehicle) runs the risk of becoming the de facto means of transport in Alexandria, since this is one factor, among others, such as income and history, that influences differences in car ownership. Approximately 20% of urban residents live in households that own a car in Alexandria, as opposed to approximately 8.5% of urban residents in Abidjan (World Bank, 2019[35]). Of course, with greater car use comes more energy use, pollution and congestion.

More sprawl, fewer intersections, less walkable

The greater the number of intersections per square kilometre, the more walkable a street network is in an urban agglomeration (even without sidewalks). Calculating the average intersections per square kilometre using OpenStreetMap,[10] Figure 13 illustrates that as sprawl increases, the number of intersections per square kilometre decreases, limiting the walkability. This is problematic, since walking is the dominant means of transport for most residents in African urban agglomerations.

Figure. 13
More sprawl, less walkable



Note: Sprawl (horizontal) and number of street intersections per square kilometre (vertical axis) across cities in Africa.

Source: Authors' calculations using OpenStreetMap.

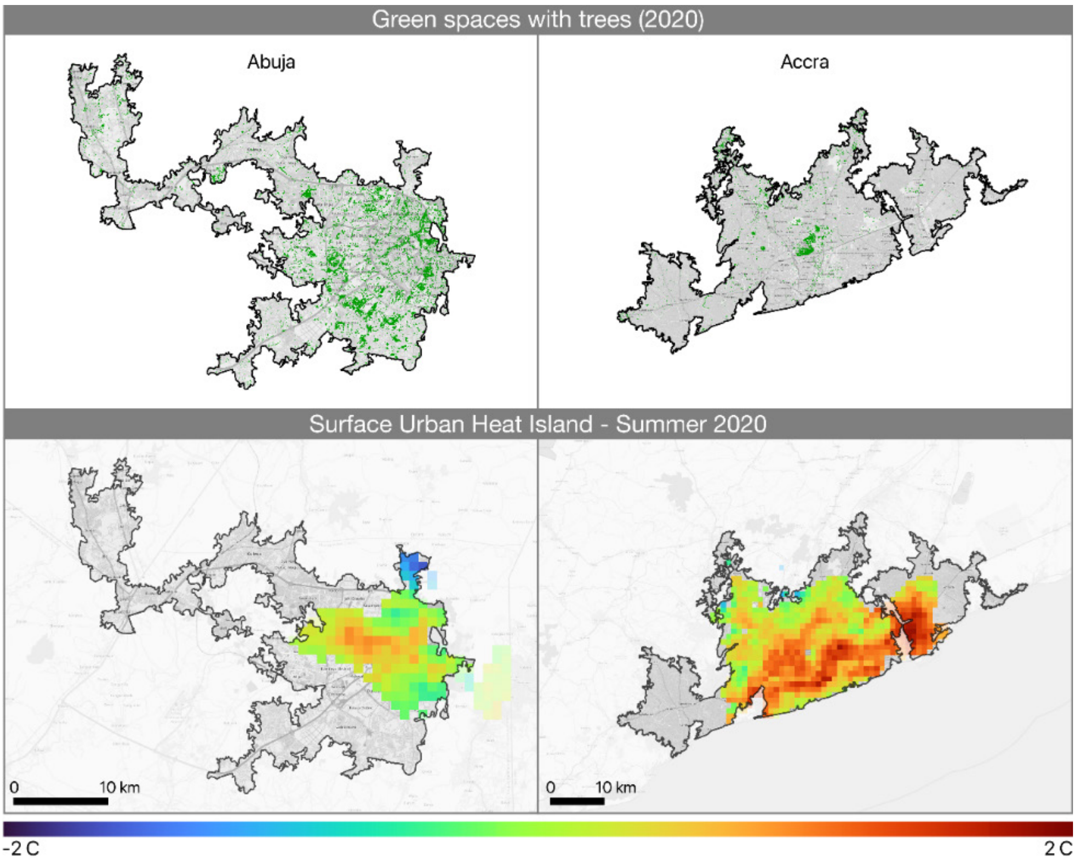
Enhancing resilience to the urban heat island effect

Urbanising agglomerations are at risk of the UHI effect, given their greater concentrations of paved roads, buildings and other surfaces that absorb and retain heat. This leads to higher daytime temperatures, but also reduces nighttime cooling. As a result, people (especially the elderly and the young) may suffer from heat-related deaths and illnesses. Monitoring green spaces is thus imperative as cities urbanise.

Patches of trees can limit the UHI effect, especially within 300 metres of a patch, because the trees' shadow can create a cooling effect of up to 2°C. Monitoring how land is being used in compact cities is critical. For example, comparing the UHI effects in summer 2020 in Accra and Abuja in 2020 (Map 12), parts of Accra were regularly 2°C higher than outside the city. Accra and Abuja have the same absolute availability of green space (33% in percentage terms), but trees are more dispersed in Abuja than in Accra. Earlier studies found that as African urban agglomerations become increasingly compact, less green space is available (in absolute percentage terms).

Map.12

The urban heat island effect is greater in Accra than Abuja



Note: Green spaces with trees within the urban agglomeration in green for year 2020 (top) and surface heat island (SUHI) intensity for 2020 summer daytime (bottom). Darker shades of red mean hotter temperatures.

Source: Green spaces from ESA WorldCover 2020 ((Zanaga et al., 2021[36]) and SUHI from Global Surface UHI Explorer (Chakraborty and Lee, 2019[37]).

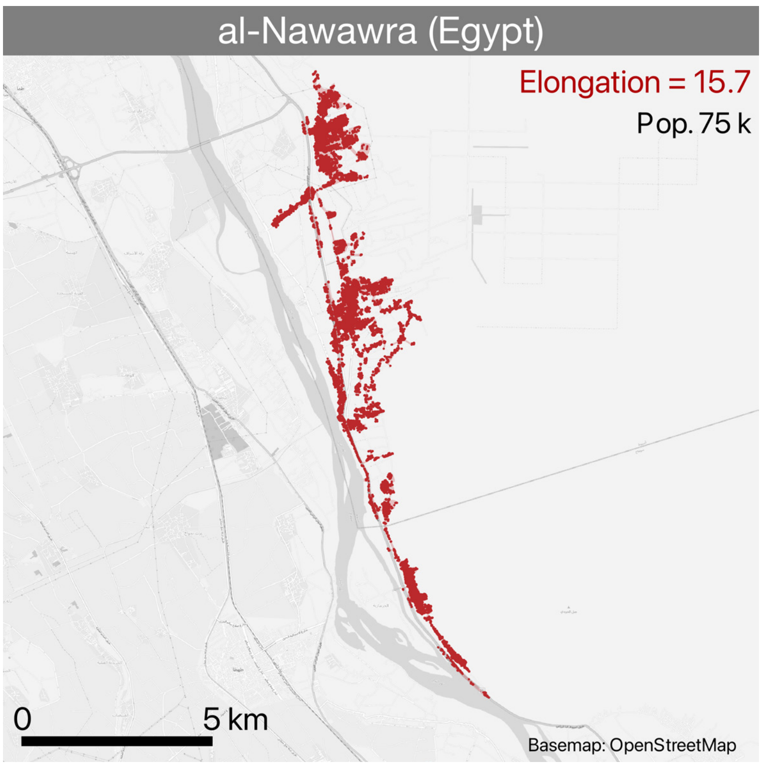
These dynamics are likely to become critical in the next few decades. All of Africa will experience rising temperatures, but West Africa is likely to face nearly half of the year in extreme heat, even in scenarios where the predicted rise in global temperature stays well below 2°C. Cities like Accra and Abuja are at a high risk of UHI. In Accra, only 11% of the population lives within 300 metres of a patch of trees (1 hectare or larger), compared to nearly 54% of the population in Abuja. Trees could thus be a nature-based solution to moderate the heat in Abuja in the coming decades (Anderson, Patiño Quinchía and Prieto-Curiel, 2022[3]).

More elongated cities, higher air pollution

The most elongated cities are often urban agglomerations with a single main road and small secondary roads connecting to it in a fishbone structure. Most of the city traffic is forced along one main corridor, leading to high levels of congestion and high fuel consumption, because most trips need to use the same road. This translates into higher air pollution, according to the models (even after controlling for the level of sprawl, region, availability of green space, city size, polycentrism and other factors) (Anderson, Patiño Quinchía and Prieto-Curiel, 2022[3]). Map 13 shows the elongation in al-Nawawra (Egypt), where $PM_{2.5}$ pollution in 2019 averaged 53.6, compared to the national average in Egypt of only 45.

Map.13

Elongated cities lead to higher-than-average air pollution



Source: Authors' calculations.

LOOKING AHEAD: FUTURE RESILIENT CITIES

Spatial data, combined with easily interpretable indicators, can help public authorities plan, manage and guide urban development, and meet the twin challenges of rapid urbanisation and climate change. African agglomerations and their partners must be able to rely on all available tools, including open databases – which are more and more numerous – to draw up an informed diagnosis of urban realities, anticipate and design more territorialised options.

The heterogeneity of urban development, a contextualised and more decentralised approach

Urban development varies greatly across regions and city sizes, with factors like urban form, heat islands, and accessibility influencing environmental effects. Each city possesses unique characteristics and very large cities tend to exhibit greater compactness compared to smaller counterparts. As intermediate cities play a crucial role in integrating urban and rural territories and are experiencing rapid urbanisation, it is essential to equip them with the means to assess their dynamics and future needs.

Determining whether a city's flat, low-building landscape results from policy choices, preferences of residents, funding constraints, or geographical factors is critical. Co-ordinating national policies at the local level is essential for addressing urban and climate issues effectively.

Unfortunately, national governments often underestimate the significance of African cities in climate action, as evident in their rare mention in NDCs (Anderson, Rhein and Acosta, 2022[9]). However, the Paris Agreement (COP 21) recognises the leading role of cities in the fight against climate change. Enhancing political decentralisation and allocating budgets can empower local actors in urban planning and climate responsibilities. This necessitates better data accessibility, knowledge of the existing situation, and building human capacities for policy definition, implementation and monitoring.

Planning African cities and integrating informality

In the planning of African cities, the co-existence of formal and informal urban growth presents a complex challenge that demands comprehensive integration. The prevailing reality reveals a blend of planned and spontaneous movements, with a significant portion of urban regulation and construction remaining informal. While efforts are made to foster better compactness and durability, it is imperative to address existing precarious areas, often characterised by low-rise and inaccessible buildings. These fragmented urban developments have led to adaptive practices and informalities primarily concentrated in peripheral regions with limited access to essential urban services. This, in turn, exacerbates environmental disparities and exclusion.

To initiate a necessary and inclusive diagnosis, a strategic approach involves adopting a framework that incorporates existing infrastructure and services while capitalising on their resilience. It is essential to engage in horizontal and vertical governance, collaborating with the local populations rather than imposing plans on them. Empowering inhabitants, particularly those in vulnerable conditions, as crucial actors in the city-building process, is crucial, acknowledging their informal practices and economies.

Promoting horizontal and vertical governance to plan with local inhabitants – and not for them – is critical, to ensure investment in the formal sector builds integration with informal habitats' inhabitants – especially the most precarious. These inhabitants – "are important players in the process of building cities, notably through informal practices and economies" (Cisse, 2018[38]).

If, "the formalisation of the informal sector starts from the implementation of strict procedures: delimiting the urban fabric, prohibiting and safeguarding spaces not conducive to housing (areas at risk and natural and agricultural areas), ensuring the 'occupation of spaces intended for public facilities' (Cisse, 2018[38]), it can only be built through an integrative approach (Cisse, 2018[38]).

Mayors must look at the cities in their hinterland and think about integrated territories (urban, periphery and rural which form a whole). The growth of the outskirts of cities should, for example, be better informed and modes of transport, which can represent a tremendous economic opportunity for cities to build territorial climate adaptation and resilience.

By fostering participatory approaches and embracing the unique dynamics of African cities, city planners and decision makers can forge a path towards sustainable urban development that blends formal and informal elements, creating inclusive and resilient urban landscapes for the future.

NOTES

1 - https://mapping-africa-transformations.org/climate-urbanform/.

2 - https://africapolis.org/.

3 - Throughout the report, the reader will be introduced to these metrics and further details on methodology (Annex A explains the underlying model and Annex B describes the sensitivity analysis). Further details on the methodology can be found in (Prieto-Curiel, Patino and Anderson, 2023 [29]).

4 - https://www.thegpsc.org/sites/gpsc/files/c40_johannesburg_peer_exchange_report_11.11.2019.pdf.

5 - https://guardian.ng/property/lagos-new-rail-transport-system-to-trigger-shift-in-land-use-pattern-hike-in-property-prices/.

6 - The recently produced dataset of the German Aerospace Centre (DLR) of building heights in urban areas (Esch et al., 2020 [20]) was used to estimate average building heights at the agglomeration level and at concentric rings from their maximum building's footprint density points.

7 - The densest point in cities, i.e. the most built-up area, is still rather empty in many agglomerations. The distribution of building footprint density in African urban agglomerations was calculated here using a technique known as a "kernel density" that helps identify the most constructed areas across cities, described as the maximum density point in each city.

8 - Thresholds determined based on distribution of data.

9 - The Open Buildings data is used here to discern whether agglomerations develop multiple centres morphologically by examining the clustering of buildings throughout the urban fabric. The functionality of these centres cannot be determined, since the use of buildings is unclear (e.g. commercial, industrial, residential). Other researchers use night time light data, for example, to identify functional centres (in terms of generating economic activity) (Yang et al.,2021 [34]), but it is unclear to what extent night time light data truly reflect informal economic activity.

10 - The number of intersections per square kilometre is calculated here for all the urban agglomerations in the dataset, using OpenStreetMap (Open Street Map, 2022 [18]). Open Street Map is not ideal for measuring urban form, but it is the most readily available dataset on the street networks.

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ANNEX A. THE BASE MODEL

The objective of this paper is to characterise different urban forms depending on the distribution of the physical distribution and the size of their buildings. First, the buildings in each city are identified by considering its polygon in the Africapolis dataset and all the buildings that fall inside it. Thus, for the city $\mathbf{i}$, the number of buildings inside its polygon are identified as, say $\mathbf{B_i}$, and their average size in metres computed, say $\mathbf{A_i}$. The constructed area of a city can be expressed as $\mathbf{B_i}\,\mathbf{A_i}$, which gives the total footprint of a city, considering all constructed buildings inside its polygon. Then, considering distinct pairs of buildings inside the city, distance attributes are measured: the mean distance between buildings, say $\mathbf{D_i}$ and the maximum distance between them, say $\mathbf{M_i}$. Computing pairwise distances between too many buildings is not computationally feasible, so when cities have more than 10 000 buildings, a random sample of 10 000 buildings is taken and used to compute the mean distance and the maximum distance in a city. Although it is a sample, it has no impact on the distance metrics (see Annex D, where the calculations are based on a different number of buildings).

Cities with more population have more buildings and the average and the maximum distance between buildings in larger cities thus also tends to be longer. Classifying urban form directly from distance metrics does not give an accurate measurement, since the result is mostly dependent on city size. A different set of indicators thus needs to be constructed that does not depend directly on city size. Based on the distance metrics, the elongation of city $\mathbf{i}$ as $\mathbf{E_i}$, is defined as inspired on an ellipse, as

$$\mathrm{E_i} = \frac{\sqrt{\pi}\mathrm{M_i}}{2\sqrt{\mathrm{B_i}\mathrm{A_i}}} ,$$

where the coefficient $\mathbf{E_i}$ is always greater than 1. Smaller values correspond to cities with a round shape, and larger values are for more elongated cities. One way to interpret the elongation is that the average distance between buildings in cities increases proportional to $\sqrt{\mathrm{E_i}}$. If a city has an elongation value of 4, then the mean distance is double, because the city is elongated. Similarly, if a city has an elongation value of 9, the average distance is three times larger.

The sprawl of city $\mathbf{i}$ is then defined as $\mathbf{S_i}$, given by

$$\mathrm{S_i} = \gamma\frac{\mathrm{D_i}^2}{\mathrm{M_i}\sqrt{\mathrm{B_i}\mathrm{A_i}}},$$

where $\gamma = 1.38$ is a constant value. The sprawl coefficient, $\mathbf{S_i}$, like the elongation, can be interpreted as a factor that increases distances in cities. If the sprawl of a city has a value of 4, then the average distance between buildings is double, due to the sprawl between buildings.

These metrics divide the reasons why the average distance between buildings in a city increase: (1) the city has too many buildings, (2) its buildings are bigger, (3) buildings are arranged in a dispersed manner, and (4) the city has an elongated shape. This offers the equation:

$$D_i = \frac{128}{45\pi}\sqrt{B_i A_i S_i E_i},$$

where the first two terms inside the square root, $B_i A_i$ are the footprint of the city and correspond to its infrastructure, and the last two terms, $S_i E_i$ conform to the city's shape. The formula for the distance between buildings in a city resembles the expression for the average distance between any two points inside a circle. Two components (B_i and A_i) are measured directly from the data, and a mathematical expression is constructed for S_i and E_i , the sprawl and elongation.

The mean distance between buildings in city if it had no elongation ($E_i = 1$) and no sprawl ($S_i = 1$) gives how distances increase only due to the footprint of the city.

The elongation and the sprawl are city metrics that help characterise different urban morphologies. It is possible to distinguish between the morphology of cities that have a small sprawl and a small elongation (cities that are compact and round) and cities with high elongation and sprawl (fragmented cities). Since the indicators are coefficients, the elongation, the sprawl and the fragmentation are independent of the scale of the city, meaning that if one city is a scaled version of another city, the indicators should remain the same. Thus, larger cities are not necessarily classified as having a higher elongation or more sprawl.

Another set of indicators is also considered based on the number, the size and the footprint of buildings within 1 kilometre of the city centre. Looking only at buildings less than 1 kilometre from the city centre, the same shape and size for all cities are analysed. In the city centre, the expected average and maximum distance between buildings is thus the same, so there is no elongation factor. Looking at the footprint and the number and size of buildings of a city near its centre can offer further insights on its morphology.

ANNEX B. SENSITIVITY ANALYSIS

There are three sources of uncertainty in these metrics. The first is related to the data related to the buildings and the way the footprint of a city is captured. The second is related to the manipulation of the data to obtain city metrics. The third is related to the models to capture the density of a city.

Uncertainty related to the footprint of a city

Buildings are captured using satellite images on the continent. For each pixel on a satellite image, a label is assigned based on whether it is a building or not. Because of the contrast with the terrain and the materials used for constructions in different cities, the classification of whether a pixel is part of a building may vary considerably. A score is assigned for each pixel, representing the confidence that the pixel is part of a building. Then, constructions are obtained by finding connected pixels classified as building components at some confidence score threshold. For each building, the confidence score is the average of the scores of the components. Thus, each building has a level of confidence assigned. The data comprises only buildings with confidence larger than 0.6. Further, based on the confidence, three colours are assigned to each building: red, yellow, and green. If the confidence is between 0.6 and 0.65, the buildings are coloured red. Above 0.65 and below 0.7 are coloured yellow, and above 0.7 are coloured green.

It is possible to filter out buildings for which confidence is low (for example, by dropping all buildings that are coloured red). Bigger buildings are more likely to inspire greater confidence. In filtering out buildings based on their low levels of confidence, it is thus mostly small buildings that are not considered.

For example, taking all the buildings in Abidjan, it is possible to measure the impact of confidence in buildings. Buildings about which confidence is not high can be dropped from the data and the changes this causes in the urban indicators identified. By filtering out buildings with confidence greater than 0.65 (keeping only yellow and green labels) or larger than 0.7 (keeping only green labels), the filtering yields:

Filter	All buildings (confidence above 0.6)	Yellow and green buildings (confidence above 0.65)	Green buildings (confidence above 0.7)
Buildings kept	100%	85.6%	69.8%
Surface kept	100%	93.8%	85.4%
Mean distance between buildings	12.3 km	12.4%	12.6 km
Maximum distance between buildings	40.9 km	41.3%	41.4 km

Although dropping buildings with less confidence alters the urban indicators, the magnitude of this change is negligible. The mean and the maximum distance between buildings that are the key metrics for constructing city indicators vary less than 2% when different confidence levels are considered.

There is no spatial bias in the confidence of buildings in a city, and the varying level of confidence is thus not a relevant source of uncertainty in the urban indicators.

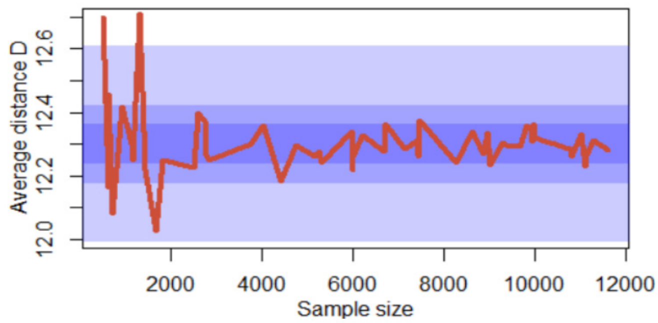
Uncertainty related to the city metrics

The urban indicators related to distance require certain considerations. Measuring the distance between pairs of millions of buildings is not feasible, so the data is sampled. If a city has more than 10 000 buildings, a random sample of 10 000 buildings is taken and used to compute the mean distance and the maximum distance in a city. Some cities, like Johannesburg, Cairo, Lagos, Khartoum or Accra, have millions of buildings, so taking the mean distance between only a sample of the buildings could introduce uncertainty.

Taking only a few buildings in Abidjan shows the impact of the sample size in the metrics. Abidjan has little more than 1 million buildings. Here, sample of varying sizes between 200 buildings and 12 000 buildings is taken and the mean distance between the sampled data measured.

Figure B.1.

Average distance between buildings in Abidjan, considering a sample of varying sizes.



The size of the sample ranges from 200 to 12 000 buildings. The blue intervals represent a precision of 2.5%, 1% and 0.5%, respectively.

The reported mean distance between buildings in Abidjan, if at least 3 000 buildings are sampled, varies by less than 1%. Thus, with a large enough sample, the average distance between buildings varies by less than 1%, meaning that taking a random sample of 10 000 buildings in cities with more than 10 000 buildings does not alter the results significantly. A similar situation occurs with the maximum distance between buildings, which quickly converges to some value when the sample size increases.

Uncertainty related to the models to capture density

Finally, another source of uncertainty is given by the models analysed. The data used here only gives the footprint of a construction but not its height. Ignoring the height of buildings could be problematic if there were to be an abundance of vertical constructions in a city. A region of a city could be denser than expected with more vertical structures. In general, buildings in Africa have a small footprint, suggesting that construction cannot support many floors. Roughly 85% of the buildings in Africa have a footprint of less than 100 square metres. However, large buildings, although not too frequent, contribute greatly to the total footprint of a city. For example, in Abidjan, only 5% of the buildings have a footprint bigger than 250m^2, but they contribute to 30% of the total footprint of the city.

In addition to measuring the distance between buildings, a weighted average is also constructed. For each pair of buildings, the distance between them is measured. Then, the weight assigned to that distance is given by the product of the area of the two buildings. Thus, the distance between small buildings has a small weight, the distance between a small and a big building has a medium weight, and only the distance between big buildings is assigned a large weight. Only in 72 cities (1.2% of the cities), is the discrepancy between the mean distance and the weighted mean distance larger than 500m. In most cases, considering the mean distance and the weighted mean distance between buildings gives roughly the same results and urban form metrics. Thus, although the height of buildings in cities cannot be observed, their impact on the urban form metrics, including elongation, sprawl and fragmentation is, in most cases, negligible.

ANNEX C. MEASURING POLYCENTRISM

Measuring polycentrism is usually based on three methodological stages: delineating urban regions, identifying subcentres and then applying some mathematical function to obtain an index for a city. Here, a kernel density gives an estimate of the intensity of the number of buildings and the constructed surface per unit area. The kernel density is obtained by adding a decaying surface for each building, so hotspots are obtained, based on buildings. Formally, for some point $\mathbf{X}$ in space, the kernel is defined as a function between the number of buildings, their area and the distance between the point $\mathbf{X}$ and the centroid of each building. A Gaussian function is used to obtain the density of buildings. The result is a surface over each urban area that highlights parts with more or larger constructions (peaks), considered as centres of the city. Then, based on the kernel density, a contour-adjacent relation tree is constructed (Li, 2018) where each node on the tree is a new contour. Separate urban centres are identified as branches on a tree, which are connected depending on the different contour levels of the surface. The procedure gives N branches, where $\mathrm{N} = 1$ is a monocentric city. Each branch has three indicators: height (corresponding to the kernel estimate), area (representing the total surface of the city that belongs to that branch) and volume (obtained by multiplying the area and height of each branch). The polycentrism index ϕ_i is defined as

$$\phi_i = \frac{1}{v_1} \sum_{k=1}^{Br_j} k\, v_k \,,$$

where Br_j is the number of branches of the city, v_k is the volume of each branch in decreasing order (so that). $v_1 \geq v_2 \geq \ldots \geq v_{Br_j}$). If $\phi_i = 1$ then the city is monocentric. A city with two distant and equal-sized centres (so that they belong to different branches) has $\phi_i = 3$, whereas a city with three equal-sized centres has a polycentricity index of $\phi_i = 6$.

ANNEX D. IMPACT OF CITY SIZE ON URBAN INDICATORS.

The city indicators are characterised to detect if they vary according to city size. A traditional way in which the impact of city size is detected is by considering a regression between some indicator and the population. Furthermore, taking the logarithm on both sides of the equation of the regression, it is possible to obtain values for a scaling effect of the population when adjusting the linear regression. The critical value to consider in the regression is the exponent of the population, usually called β, since it captures any impact in terms of city size. Values of $\beta < 0$ indicate that things reduce when the population increases. Values of $\beta \approx 0$ indicate that city size has little or perhaps no statistical impact on the corresponding indicator. Values of $\beta \approx 1$ indicate a linear growth, meaning that one extra person in the city is matched with extra units on the left-hand side of the equation. Then values $\beta < 1$ mean there is a sublinear impact of city size, so things grow at a slower rate than the population, whereas values above $\beta > 1$ are known as superlinear impact and mean that things grow faster than the population. Notice that the equation also gives a straightforward way of observing per capita units. Dividing both sides of the regression by the population P_i, the only change in the right-hand side of the equation is that the exponent is $\beta - 1$ (thus, the reason why values of $\beta = 1$ are often considered to be critical).

	$y = logB$	$y = logA$	$y = logS$	$y = logE$	$y = logD$	$y = logFP$
(Intercept)	-0.846^{***}	-10.603^{***}	-0.322^{***}	1.779^{***}	-5.095^{***}	2.366^{***}
	(0.068)	(0.052)	(0.063)	(0.054)	(0.061)	(0.067)
log(Population_2015)	0.981^{***}	0.067^{***}	0.011	0.005	0.532^{***}	1.048^{***}
	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.006)
R^2	0.799	0.031	0.001	0.000	0.594	0.825
Adj. R^2	0.799	0.031	0.000	-0.000	0.594	0.825
Num. obs.	5625	5625	5625	5625	5625	5625

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

The results show that in Africa, the number of buildings grows at a slower pace than the population (since $\beta < 1$), and that buildings are bigger in larger cities (hence the corresponding $\beta > 0$). Further, sprawl in cities increases with city size (hence the corresponding value of $\beta > 0$) but the elongation is statistically the same across cities of all sizes. The mean distance between buildings in the city grows according to $\beta = 0.532$,so slightly larger than the square root of the population (which would be $\beta = 0.5$), and the footprint increases with city size.

This technique makes it possible to consider all the cities in the continent and to consider a subset of cities and detect the impact of city size, for instance, across the five regions of Africa. Results show that across regions, the impact of city size is not uniform.

	$y = logB_N$	$y = logB_W$	$y = logB_E$	$y = logB_C$	$y = logB_S$
(Intercept)	-0.370^{**}	-0.715^{***}	-1.388^{***}	-1.038^{***}	-0.472^{**}
	(0.135)	(0.116)	(0.107)	(0.181)	(0.148)
log(Population_2015)	0.926^{***}	0.957^{***}	1.042^{***}	0.990^{***}	1.005^{***}
	(0.013)	(0.011)	(0.010)	(0.017)	(0.014)
R^2	0.763	0.792	0.886	0.889	0.916
	$y = logA_N$	$y = logA_W$	$y = logA_E$	$y = logA_C$	$y = logA_S$
(Intercept)	-10.300^{***}	-11.264^{***}	-10.413^{***}	-10.992^{***}	-10.151^{***}
	(0.095)	(0.102)	(0.072)	(0.131)	(0.109)
log(Population_2015)	0.044^{***}	0.144^{***}	0.035^{***}	0.076^{***}	0.018
	(0.009)	(0.010)	(0.007)	(0.012)	(0.010)
R^2	0.015	0.100	0.019	0.082	0.007
	$y = logS_N$	$y = logS_W$	$y = logS_E$	$y = logS_C$	$y = logS_S$
(Intercept)	-1.366^{***}	-0.073	-0.351^{*}	1.528^{***}	0.843^{***}
	(0.128)	(0.095)	(0.136)	(0.147)	(0.192)
log(Population_2015)	0.106^{***}	-0.026^{**}	0.026^{*}	-0.156^{***}	-0.078^{***}
	(0.012)	(0.009)	(0.013)	(0.014)	(0.019)
R^2	0.045	0.004	0.003	0.231	0.038
	$y = logE_N$	$y = logE_W$	$y = logE_E$	$y = logE_C$	$y = logE_S$
(Intercept)	0.964^{***}	1.909^{***}	2.094^{***}	3.150^{***}	2.514^{***}
	(0.100)	(0.074)	(0.108)	(0.153)	(0.200)
log(Population_2015)	0.071^{***}	-0.017^{*}	-0.001	-0.109^{***}	-0.065^{***}
	(0.010)	(0.007)	(0.010)	(0.015)	(0.019)
R^2	0.033	0.003	0.000	0.120	0.025

For example, the number of buildings is sublinear with respect to population in North and West Africa (meaning fewer buildings per person in larger cities), linear in Central and South Africa, but superlinear in East Africa (meaning more buildings per person in larger cities). Buildings become considerably bigger in West Africa in larger cities (with $\beta = 0.144$). Also, larger cities have less sprawl in Central Africa (with $\beta = -0.156$) and in West and Central Africa, meaning fewer empty spaces in larger cities. However, the sprawl increases in larger cities in North Africa. In terms of elongation, larger cities in West, Central and South Africa are rounder, but larger cities in North Africa are more elongated.

The BASE model makes it possible to deconstruct the reasons why the mean distance in cities grows into four components: the number of buildings, B_i ,their area, A_i the sprawl of a city, S_i and the elongation, E_i. Writing the scaling expression with respect to population gives an expression for distances in cities that depends on its population. The expression gives:

$$D_i = \alpha P_i^{(\beta_B + \beta_A + \beta_S + \beta_E)/2},$$

meaning that the scaling coefficient of B_i, A_i, S_i and E_i contribute to creating larger distances by dividing the coefficient in half. It is thus possible to compute the scaling coefficient of the mean distance between buildings and detect the reasons why a city has longer or shorter distances. In a city where the number of buildings grows linearly with population, but buildings are the same area, and where the elongation and the sprawl remain the same, i.e. $\beta_D = 0.5,<$ but across regions a different coefficient is obtained.

	$y = logD_N$	$y = logD_W$	$y = logD_E$	$y = logD_C$	$y = logD_S$
(Intercept)	-5.635^{***}	-5.170^{***}	-5.128^{***}	-3.776^{***}	-3.732^{***}
	(0.128)	(0.085)	(0.111)	(0.130)	(0.226)
log(Population_2015)	0.574^{***}	0.528^{***}	0.551^{***}	0.400^{***}	0.440^{***}
	(0.012)	(0.008)	(0.011)	(0.012)	(0.022)
R^2	0.579	0.681	0.672	0.717	0.474

In North Africa, the scaling coefficient of the distances is much longer than 0.5, because, although larger cities in North Africa have fewer buildings per person, ($\beta = 0.926$) , buildings are larger ($\beta = 0.044$) and larger cities have more sprawl ($\beta = 0.106$) and are more elongated ($\beta = 0.071$). The scaling coefficient of distances in North Africa thus gives $(0.926 + 0.044 + 0.106 + 0.071)/2 = 0.574$. A similar situation obtains in East and West Africa. However, in South and Central Africa, the fact that larger cities are considerably less sprawled and elongated slightly counterweighs the impact of having more and bigger buildings in larger cities.

WEST AFRICAN PAPERS

CITY SHAPES AND CLIMATE CHANGE IN AFRICA

Africa is undergoing an unprecedented urban and climate transition; yet, given the right conditions, compact urban forms can encourage greater sustainability, resilience and liveability in the coming decades. Using novel techniques and newly available data, this report fills in existing data gaps by producing measures of compactness for 5 625 urban agglomerations, along with other urban form attributes. Even though urbanisation is often unplanned and uncoordinated, a promising trend has emerged: very large cities (of over 4 million inhabitants) are more compact, discounting the population effect, on average, than larger (1 million to 4 million inhabitants) and intermediate cities (50 000 to 1 million inhabitants). Moreover, less compact agglomerations tend to have smaller buildings, flat, low skylines, less complete centres (reflecting a less optimal use of space) and polycentric patterns (i.e. multiple centres, rather than a single, monocentric city). This report analyses the consequences of less compact agglomerations for sustainability and liveability. The disadvantages include higher energy demand, less accessibility to services and opportunities, less walkable urban landscapes and greater car dependency, in addition to higher outdoor air pollution. It also considers the potential trade-offs with resilience; for example, compactness can lead to a loss of green space and an increase of urban heat island effects. The report offers opportunities in the coming years to single out potential areas of action for resilience, as well as for monitoring and evaluating progress.