

Spatial planning principles & assessment framework for climate adaptive & resilient cities in China

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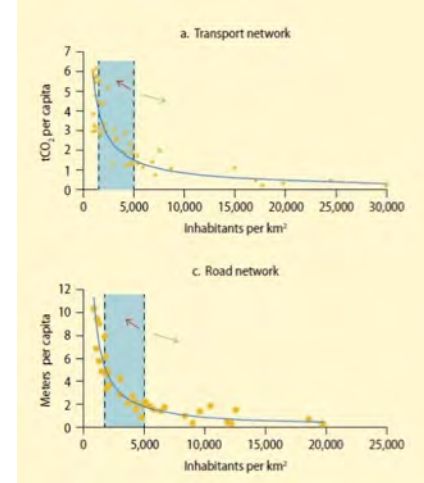
URBAN MORPHOLOGY
— & —
COMPLEX SYSTEMS INSTITUTE

NDRC/MOHURD/ADB INTERNATIONAL WORKSHOP ON URBAN ADAPTATION TO CLIMATE CHANGE
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Who we are

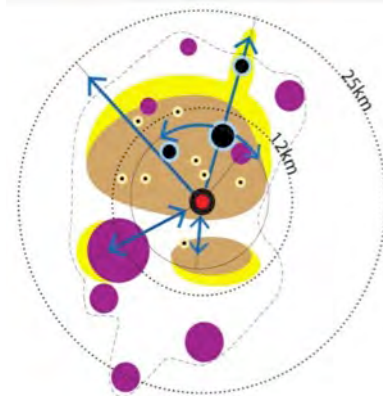


Internationally recognized expertise on sustainable urbanization

- Contribution to IPCC WGIII, Ch12, “Human Settlements, Infrastructure and Spatial Planning”, focusing on the link between urban forms, infrastructure stocks, energy and GHG emission patterns
- Contribution to the joint DRC/World Bank report, Urban China: Toward Efficient, Inclusive and Sustainable Urbanization, leading to major recommendations for reforming urban planning and design and a new model of urbanization for China
- Contribution to the Spatial Development Strategy of the City of Johannesburg, South Africa



URBAN MORPHOLOGY & COMPLEX SYSTEMS INSTITUTE



Who we are

Consulting services to communities, developers, local and national governments and international organizations: innovative design strategies, quantitative methods and cutting-edge tools supporting decision-making processes in the field of sustainable urban development.

- **Design and Transit Oriented Development strategies:** well designed urban forms with walkable neighborhoods around mass transit hubs and nodes, and with a dense mix of housing, retail, offices and other amenities.
- **Urban Assessment:** quantitative and robust assessment tools to implement new paths to urban sustainability
- **Urban Development Strategies:** guidelines, tools and strategies to assist national & local government & international organizations in the field of urban development.
- **Urban Energy Planning:** integrated strategies for spatial planning and energy planning

**What does
resilience mean
for cities**



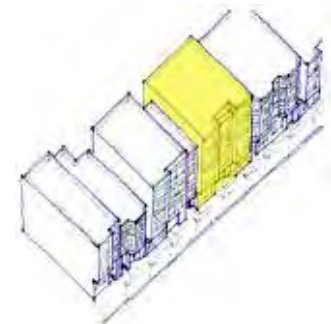
Adapting | Reinventing | Complexifying

Adapting to a rapidly changing environment

- **Climate resilient cities** can adapt to the increase in the likelihood of weather-related **natural disasters**
 - Floods and drought
 - Storms

Most of Chinese cities above 5 million and two of its main metropolitan regions are located in the low elevation coastal zone
- **Energy resilient cities** are highly adaptive to:
 - Increases in energy prices
 - Fluctuations in energy prices

Energy resilience cities are on a low dependency path to energy
- **Economic resilient cities** are highly adaptive to real estate and financial markets fluctuations



**Main conclusions of DRC/
World Bank
China Urbanization study
& IPCC report**

**Chinese cities are currently
on a non resilient path:**

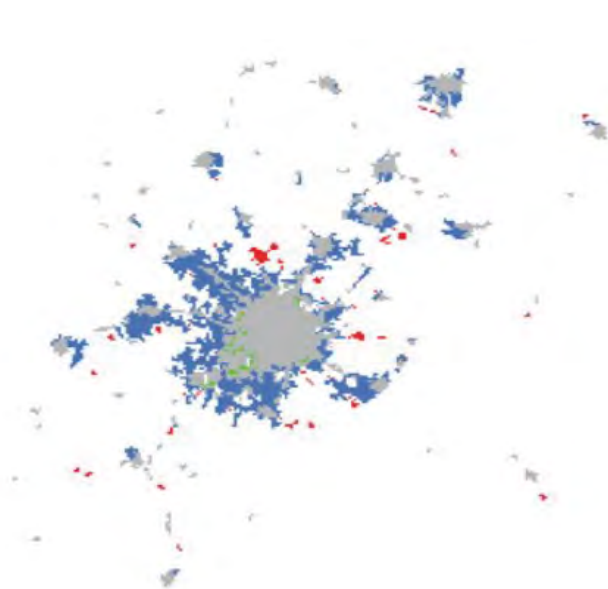
**Fragmentation,
Sprawl
& Energy dependency**

A paradigm shift is needed

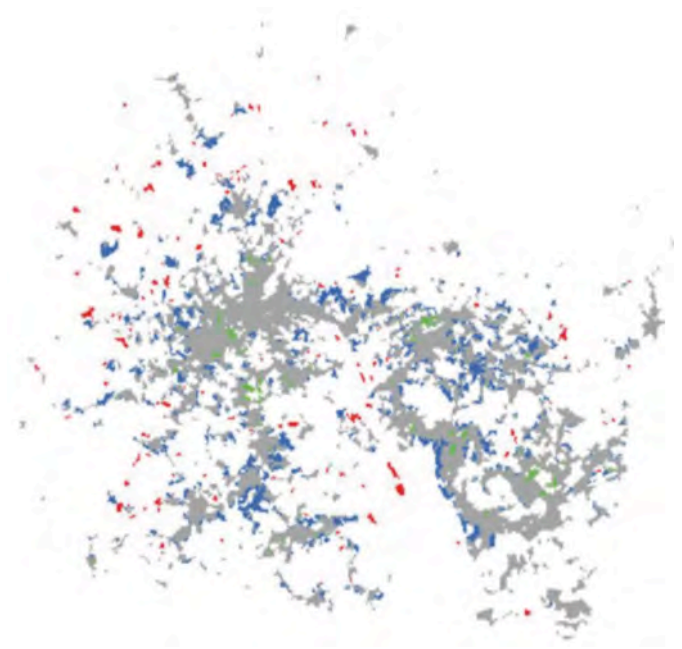
Urban growth in China rests upon edge growth and fragmentation 城市区域大幅度扩展和碎块化

在成都和广州可以看到类似上海的情况

In Chengdu and Guangzhou edge and leapfrog growth in the last 10 years represent 97% and 93% of urban spatial expansion, respectively.



Chengdu
成都



Guangzhou
广州

Edge growth and fragmentation lead to dividing by 2 urban density in 20 years in China

城市区域大幅度扩展和碎块化

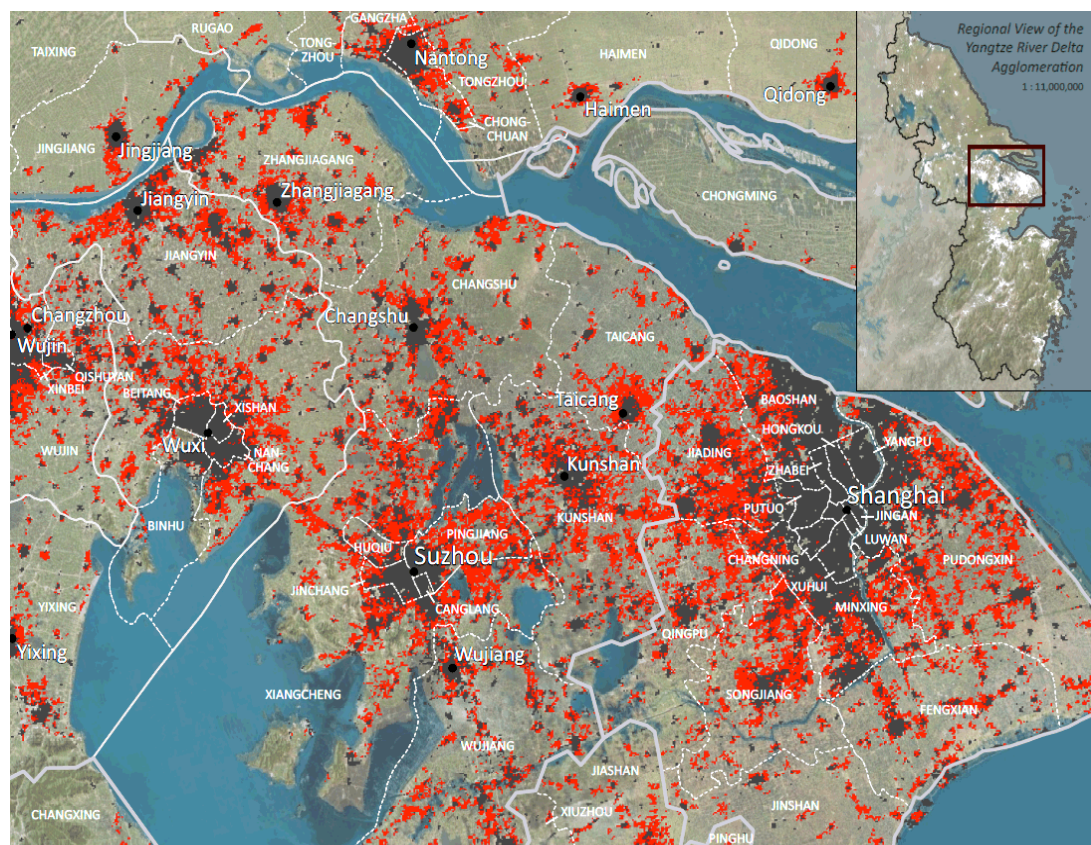
- Massive conversion of urban to rural land feeds urban sprawl
- **Built up areas have been multiplied by 3.3 in 20 years**, much faster than population growth

以上海为例，过去十来年其99%的人口增长 来自外围核心及郊区



Shanghai 1990- 2000

Shanghai 2000-2010

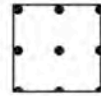


Low density = Low resilience

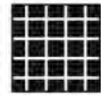
High per capita infrastructure costs and car dependency



ATLANTA
pop 3 499 840 area 511 952 ha



6.8 pop/ha



8.7 m/pers

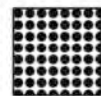


95%

Scale



BERLIN
pop 3 920 547 area 99 650 ha



39.3 pop/ha



1.5 m/pers



44%

Scale



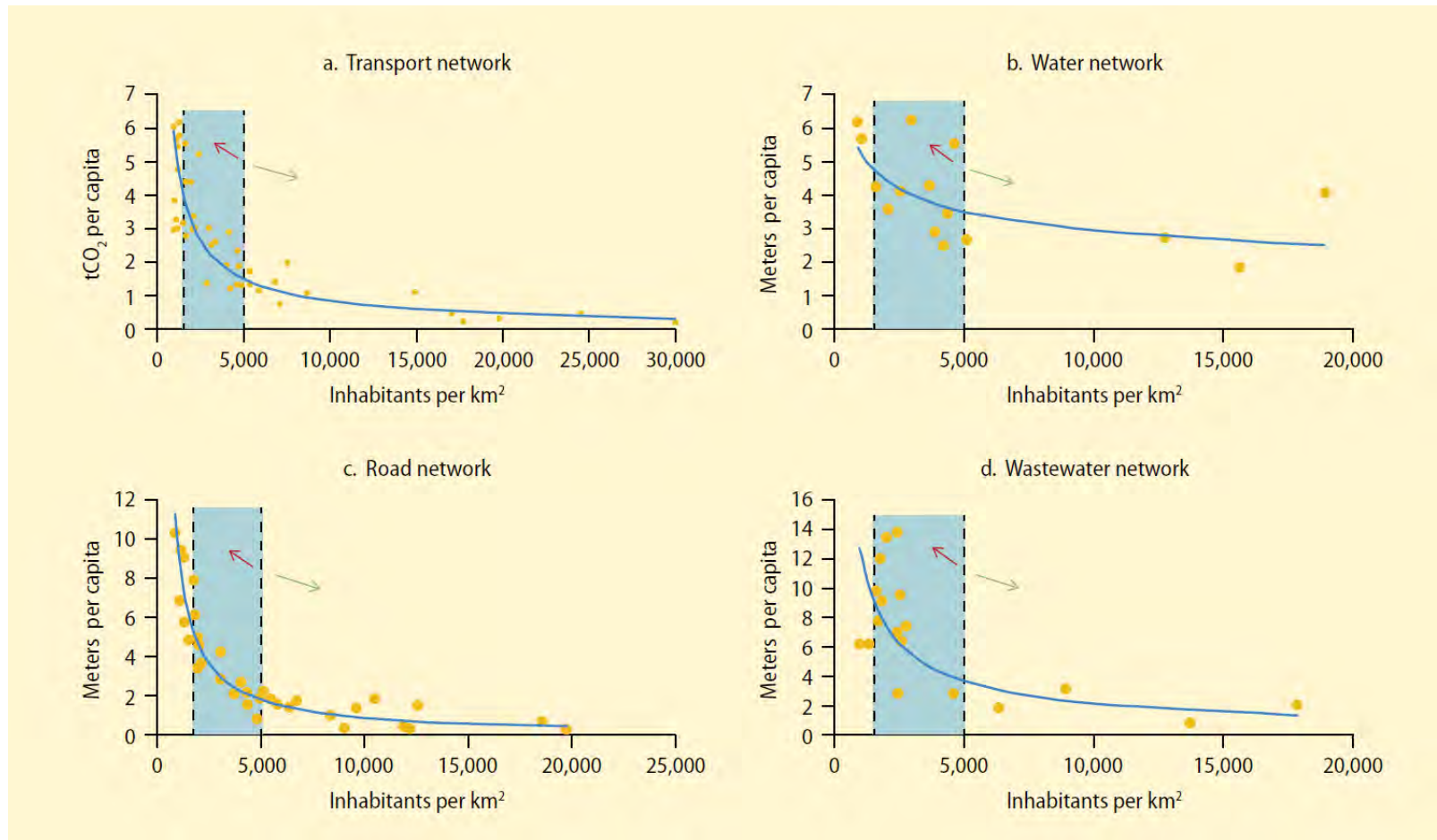
With a similar population, Atlanta is 6 times less dense than Berlin

Infrastructure costs are 6 times higher in Atlanta than in Berlin

95% of people use a car in Atlanta, 44% in Berlin

Low density = Low resilience

Higher infrastructure costs, energy consumption and carbon emissions



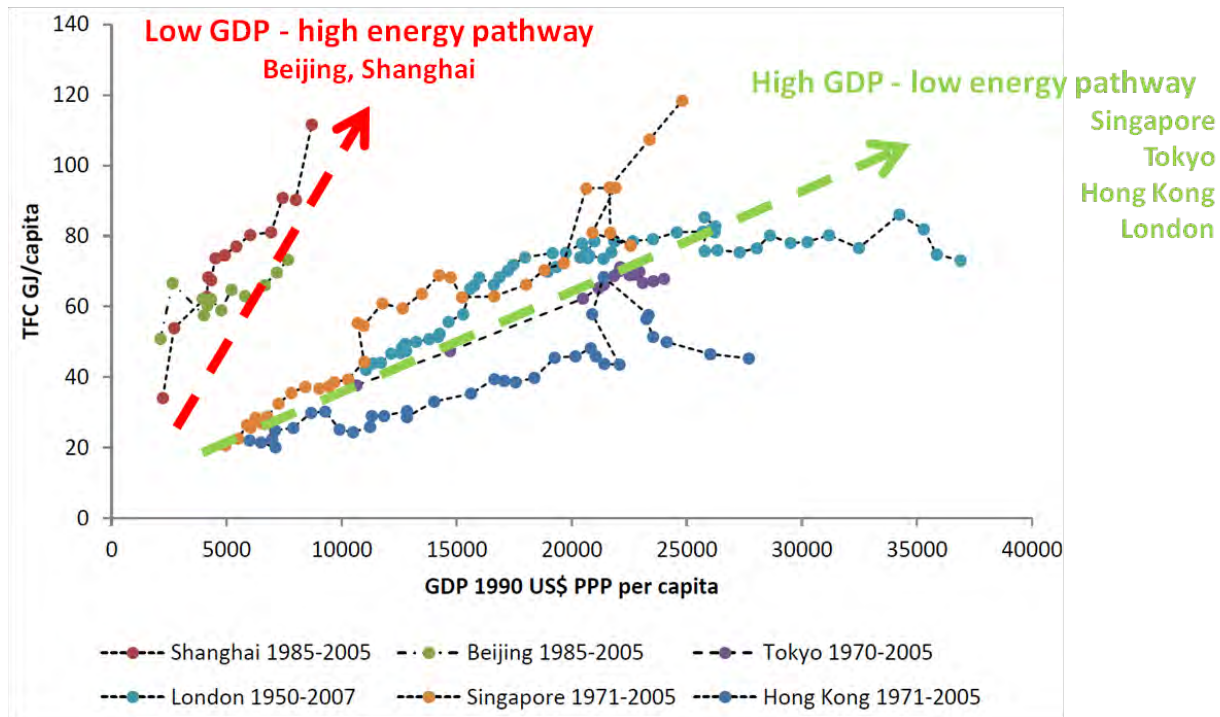
From Paris or Manhattan ($\approx 20,000$ inhab/ km^2) to an average density of $5,000$ inhab/ km^2

- Road network investment cost per capita **is multiplied by 4**
- Water network investment cost per capita increases **+ 40%**
- Waste water network investment cost per capita **is multiplied by 3**
- Carbon emissions for transportation per capita **are multiplied by 2.5**

Energy dependency = Low resilience

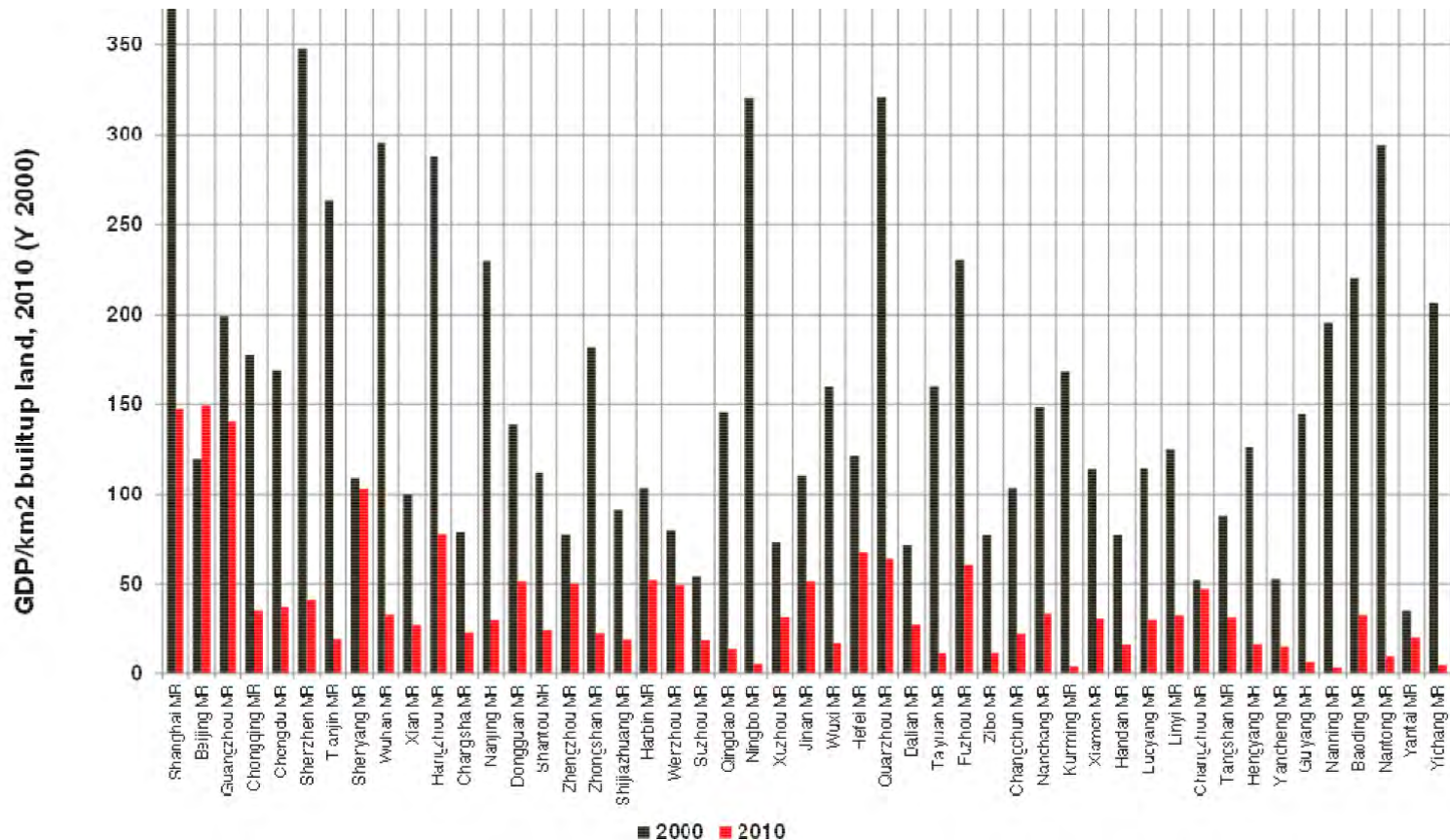
Urban sprawl and fragmentation lock Chinese cities in a high energy dependency pathway

- A dense city (Manhattan, Paris, Seoul), 15,000 to 20,000 inhab/km², needs 2.5 times less energy per capita than a low density city (5,000 inhab/km²)
- **Non compact cities such as Beijing or Shanghai need 6 times more energy than Hong Kong or Tokyo to produce one unit of GDP**



Urban sprawl = Low economic resilience

Urban sprawl jeopardizes agglomeration economies



Source: Chreod 20113

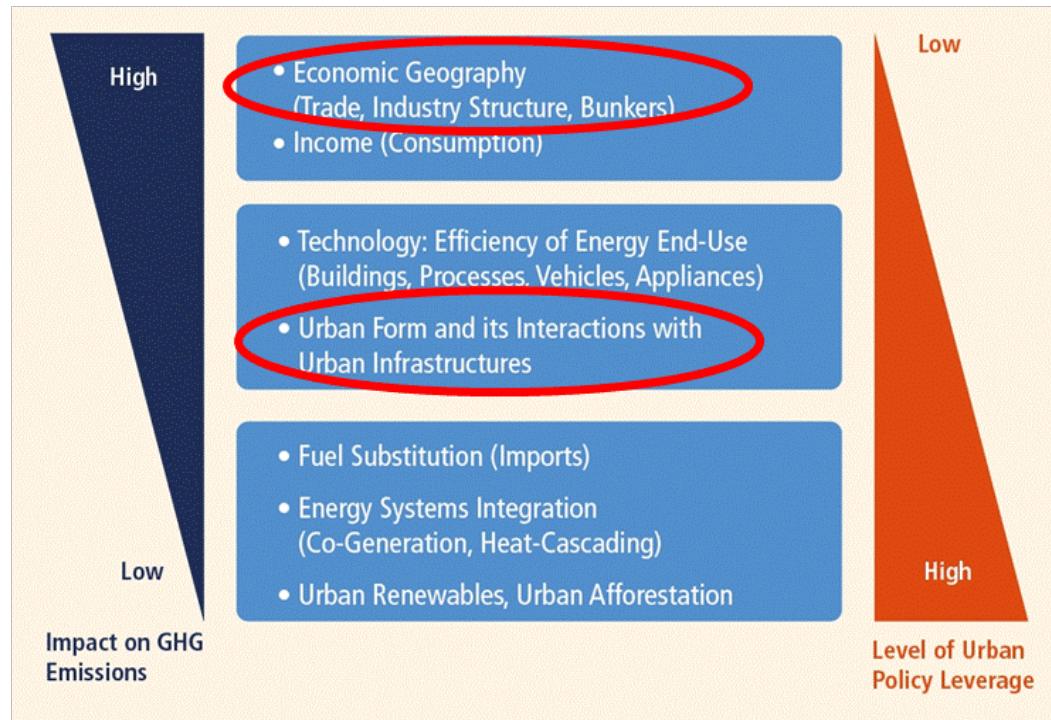
Additional GDP/Additional km² in Shenzhen divided by 10
 Additional GDP/Additional km² in Shanghai divided by 2.5

- 1 COMPACT DENSIFICATION
- 2 SCALING
- 3 FUNCTIONAL FLEXIBILITY
- 4 FINE GRAIN DIVERSITY
- 5 HIGHLY CONNECTED NETWORKS
- 6 SYNERGY
- 7 GREENING AND WATER RECYCLING
- 8 URBAN-RURAL INTEGRATION

8 spatial planning principles for resilient cities in China

1 Compact densification

According to IPCC, options for rapidly developing economies such as China should focus on shaping urban and infrastructure development trajectories. All approaches include co-locating high residential with high employment densities, achieving high land-use mixes, investing in public transit and articulating density around transit hubs (TOD).



1 Compact densification

Why it matters for urban resilience

- Transport energy can be divided by 2 to 4 by planning more compact, mixed use cities where most of urban amenities are reachable on foot at less than 10 minutes walk.
- Planning more compact and mixed use cities contributes to significantly decreasing energy dependency. Modal switch towards low carbon and low energy transportation means, such as mass transit, walking and cycling, is indeed made easier in compact and mixed use cities.
- Climate change and increasing scarcity in fossil energy sources will induce a steady and long term increase in energy prices. **With a lower energy dependency, compact and mixed use cities will be more adaptive to energy price increases, and, as a result, more resilient.**

1 Compact densification

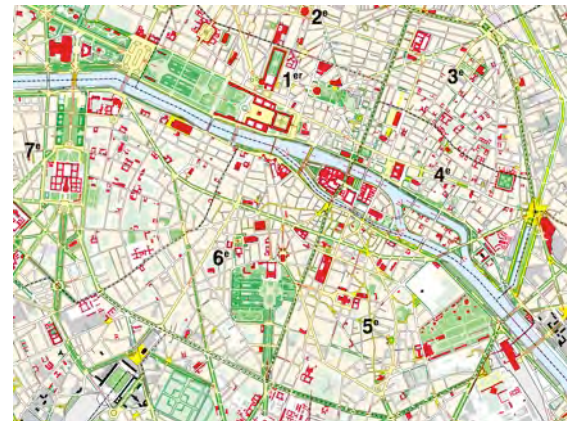
Metrics

- Density can measure a series of different urban parameters at different scales. Measuring urban density requires first answering two questions:
 - What is measured: population, jobs, activities, housings, floor area, legal entities, etc.
 - At which scale: city, district, neighborhood, block, plot or building.
- Once these two key elements defined, density is measured as a simple ratio. Population density at the neighborhood scale for instance captures the ratio of the number of inhabitants to the neighborhood area.

Taiyuan Shanxi Science Town, Core Area
20km², 7,500 inhabitants per km² and
10,000 jobs per km²



Paris, district scale (17 km²)
20-25,000 inhabitants per km² and
20-30,000 jobs/km²



2 Scaling

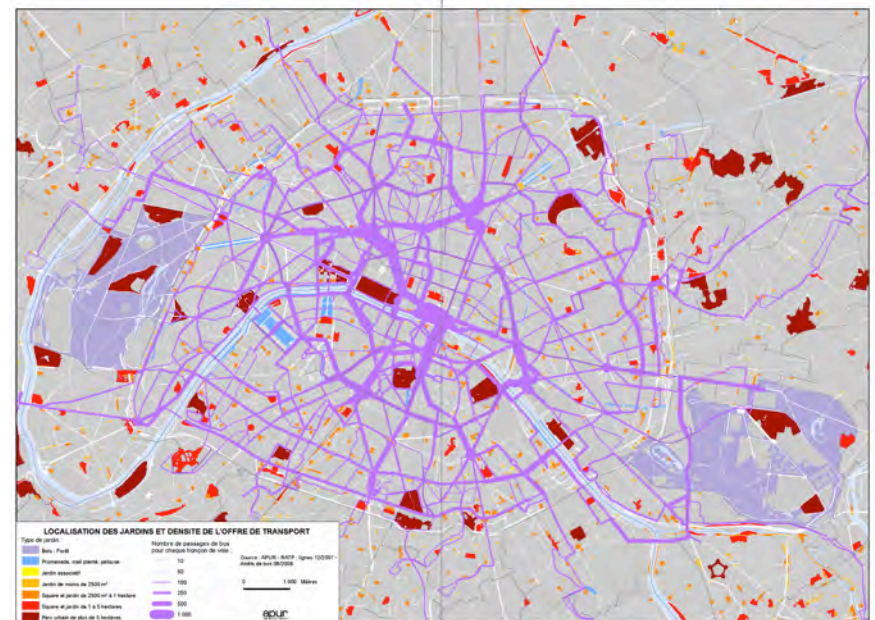
In resilient cities one can observe, like in nature, the same level of complexity on several scales. The local and the global are linked by a successive series of connections that show structure and organization at each scale. This is called a **scale-free structure**.

- When we look at a district in Paris or Manhattan, we find the same relative distribution of large public parks, medium scale and pocket parks smaller than half hectare, than in the whole city.
- When we look at the distribution of sizes of streets in Paris, we find at city scale and at district scale the same blend of 20 meters wide boulevards, 12 meters wide streets, 10 meters wide, 8 meters wide. Each sub pattern of streets at neighborhood and district scales presents the same distribution properties as the whole city.



Left: Street patterns

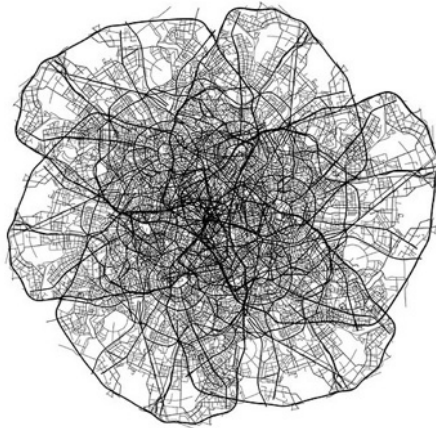
Right: Frequency of buses



2 Scaling

Why it matters for urban resilience

Herbert A. Simon's Watchmaker parable highlights the role of scale hierarchy within complex systems: a complex system made up of coherent subassemblies has a greater ability to evolve and adapt quickly to change, accident and fluctuation. Adaptability has crucial implications on climate resilience ability. For a property to emerge at a higher scale, smaller scales need to exist to foster its emergence. Each spatial scale supports the higher scales in the ascending hierarchy of an emergent complex order. These emergent properties allow the system to repair, stabilize itself and to evolve.



2 Scaling Metrics

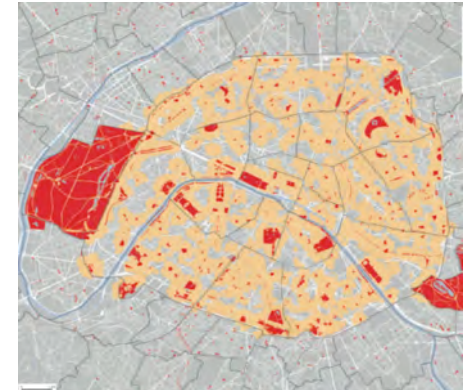
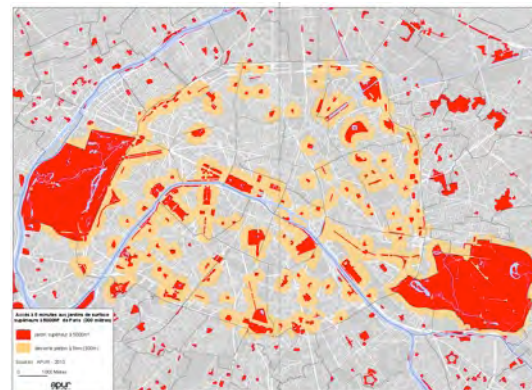
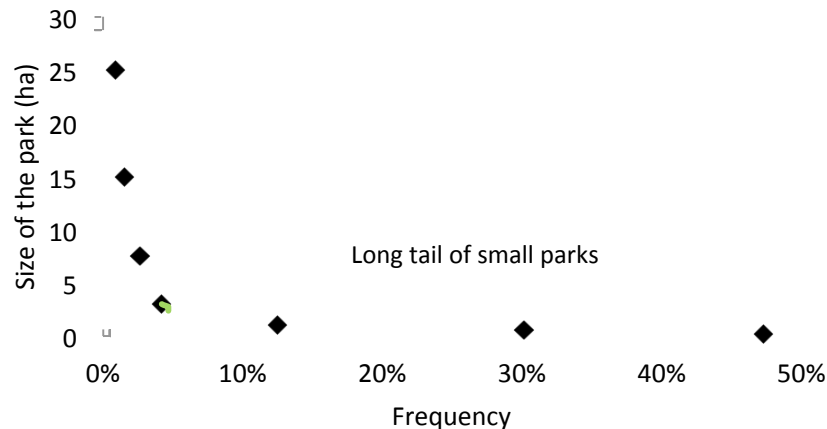
When we look at a district in Paris or Manhattan, we find the same relative distribution of large public parks, medium scale and pocket parks smaller than half hectare, than in the whole city. in a complex well-balanced system the frequency of an element of size x is proportional to the inverse of its size at an exponent m characteristic of the system:

$$freq \propto \frac{1}{size^m}$$

In Paris for instance, the distribution of public parks follows the following distribution:

$$size(ha) = \frac{487}{rank^{1.42}}$$

This long tail spatial distribution of parks ensures an optimal accessibility to green spaces to Parisians, with a constrained area of green spaces on the city scale, as shown in the following map (orange areas correspond to a 10 minute walk accessibility).



3 Functional Flexibility

Why it matters for urban resilience

- A climate resilient city has to be able to evolve and to adapt to new conditions, which necessarily implies evolution of its initial plan. Resilient cities grow in a constant interaction between urban planning and processes of adaptive self-organization that make the regular aspects of the initial organization more complex.
- In functionally flexible cities, urban forms can easily adapt (with limited investment needs) to a redistribution of urban functions. In other words, office buildings for instance can be easily transformed into housing.



3 Functional Flexibility

Metrics

- Functional flexibility can be measured on the city, district, neighborhood and building scale.
- It can be measured as the ratio of « flexible floor area » over the total floor area:

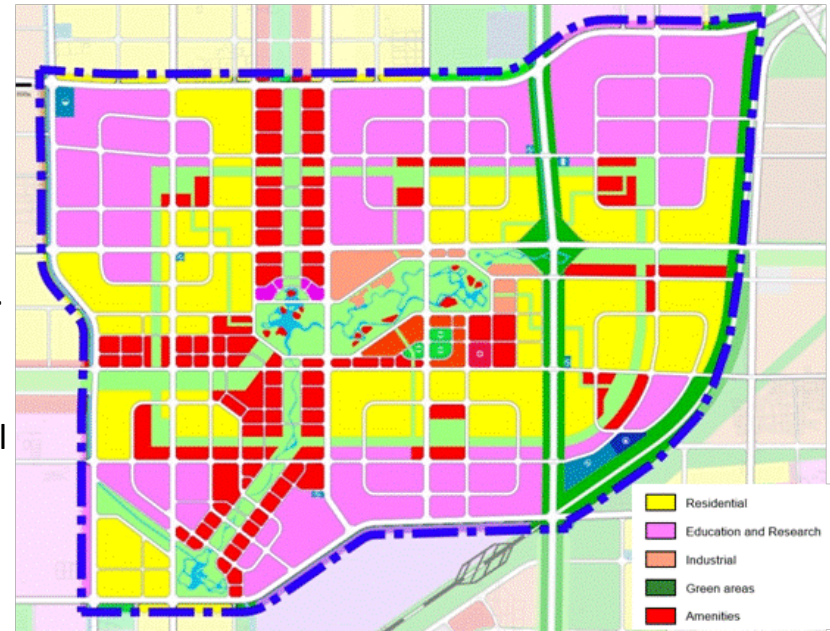
$$\text{Functional Flexibility} = \frac{\text{Flexible Floor Area}}{\text{Total Floor Area}}$$

- Functionally flexible floor areas or buildings are those which function can be changed (for instance from housing to offices) with a limited investment need, generally taken as 20% of the construction cost.

4 Fine grain diversity

Why it matters for urban resilience

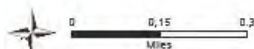
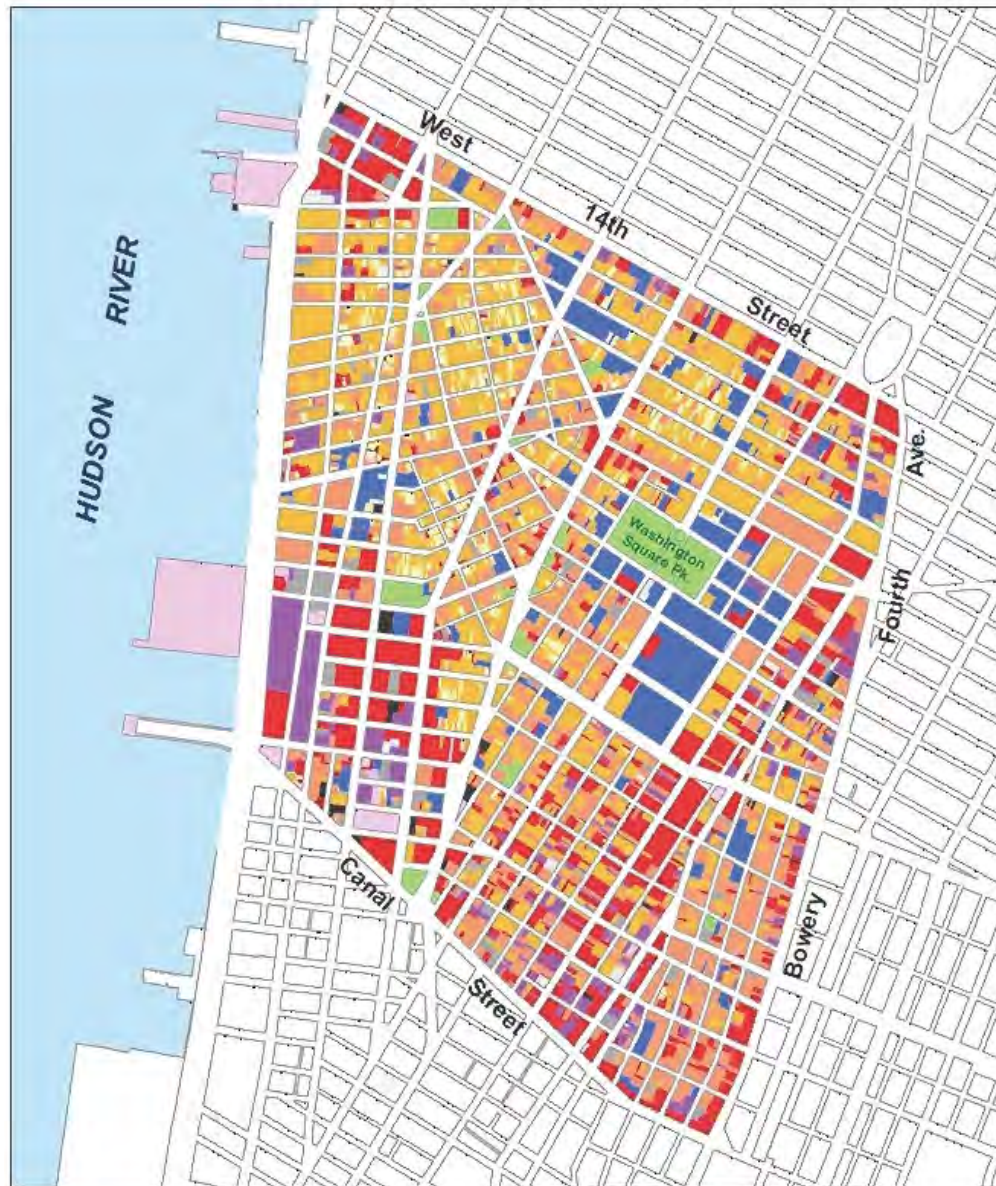
- Fine grain diversity refers to mixed use at the neighborhood and block scale:
 - At the neighborhood scale, it refers to a “smart” mix of residential buildings, offices, shops, and urban amenities.
 - At the block and building scale, mixed use consists of developing small-scale business spaces for offices, workshops, and studios on the ground floor of residential blocks and home-working premises.
- A number of studies of such single-use zoning show strong tendencies for residents to travel longer overall distances and to carry out a higher proportion of their travel in private vehicles than residents who live in mixed land use areas in cities. Single-use zoning is a low resilience urban development, because it is highly dependent to individual cars and fossil fuel energy
- Fine grain mixed-use development shortens journeys and promotes transit/walking/cycling and adaptive re-use of buildings. As such it widely contributes to urban resilience.



**Zoning in Taiyuan
Shanxi Science
Town**

**Fine grain mix use in
Manhattan at the
same scale**

Manhattan Community District 2



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NYC Department of City Planning

Source: MapPLUTO™ Release 11v1

Residential Land Uses

- One & Two Family Buildings
- Multi-Family Buildings
- Mixed Residential and Commercial Buildings

Non-Residential Land Uses

- Commercial / Office Buildings
- Industrial / Manufacturing
- Open Space and Outdoor Recreation
- Public Facilities and Institutions
- Transportation and Utility
- Parking Facilities
- Vacant Land
- All Others or No Data

4 Fine Grain Diversity Metrics

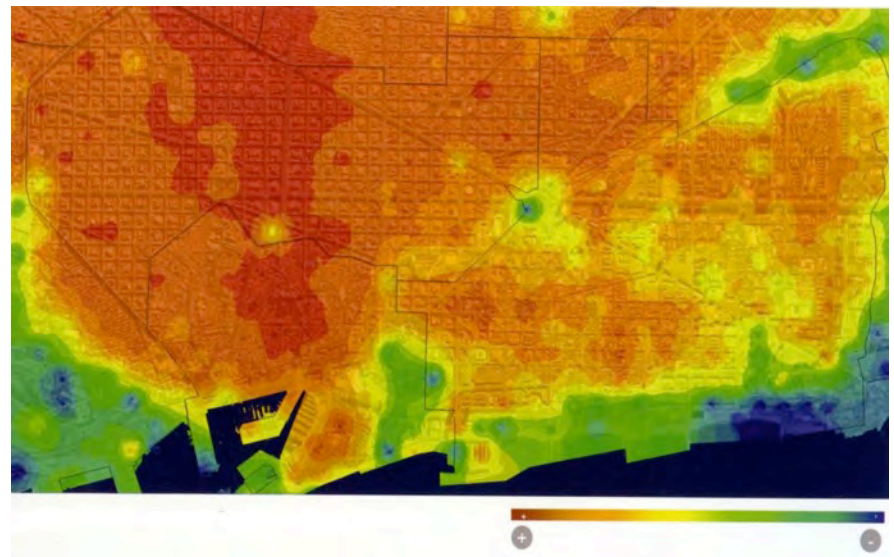
- Diversity and mixed use can be assessed through different mathematic formulas. The most commonly used are Simpson's and Shannon indexes. Both capture the local diversity of the urban fabric and of urban activities. The diversity of building types on the neighborhood scale for instance can be assessed using these two indexes.
- If the floor area of each building use i (office, residential, shop, retail, etc.) is A_i , the respective proportion of each use, noted p_i , is equal to the ratio of A_i over the total floor area. The two diversity indexes can be computed using the following formulas:

- Simpson's diversity index:

$$D_{\text{Simpson}} = 1 - \sum_i p_i^2$$

- Shannon's diversity index:

$$D_{\text{Shannon}} = - \sum_i p_i \log(p_i)$$



Diversity of economic activity in Barcelona (Shannon's index)

5 Highly connected networks

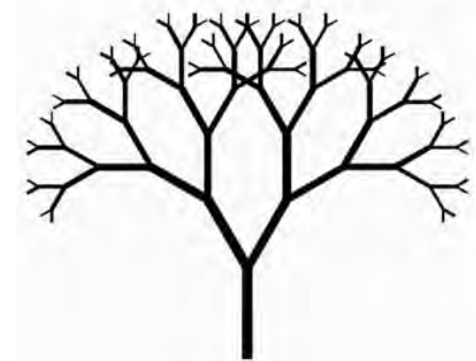
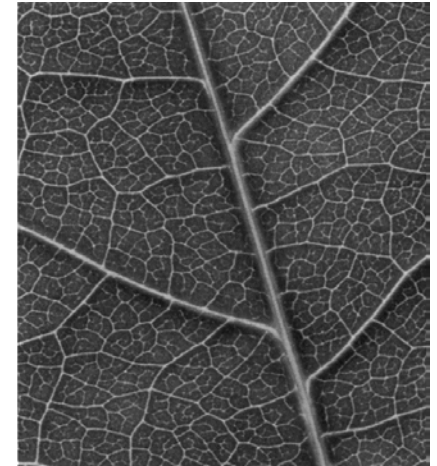
The street network should include a variety of street types based on adjacent land uses and character of streets. Street connectivity should be promoted and accessibility should be enhanced, using a balanced street network:

- A human scale, highly walkable, dense, fine grain and connected network of narrow streets that improves accessibility, recognizing walking access, instead of speed of travel, as a priority
- A network of wider streets that rapidly connect distant parts of the city and connect the city to neighboring jurisdictions, while making good use of public transportation systems (i.e., tramway, bus rapid transit).

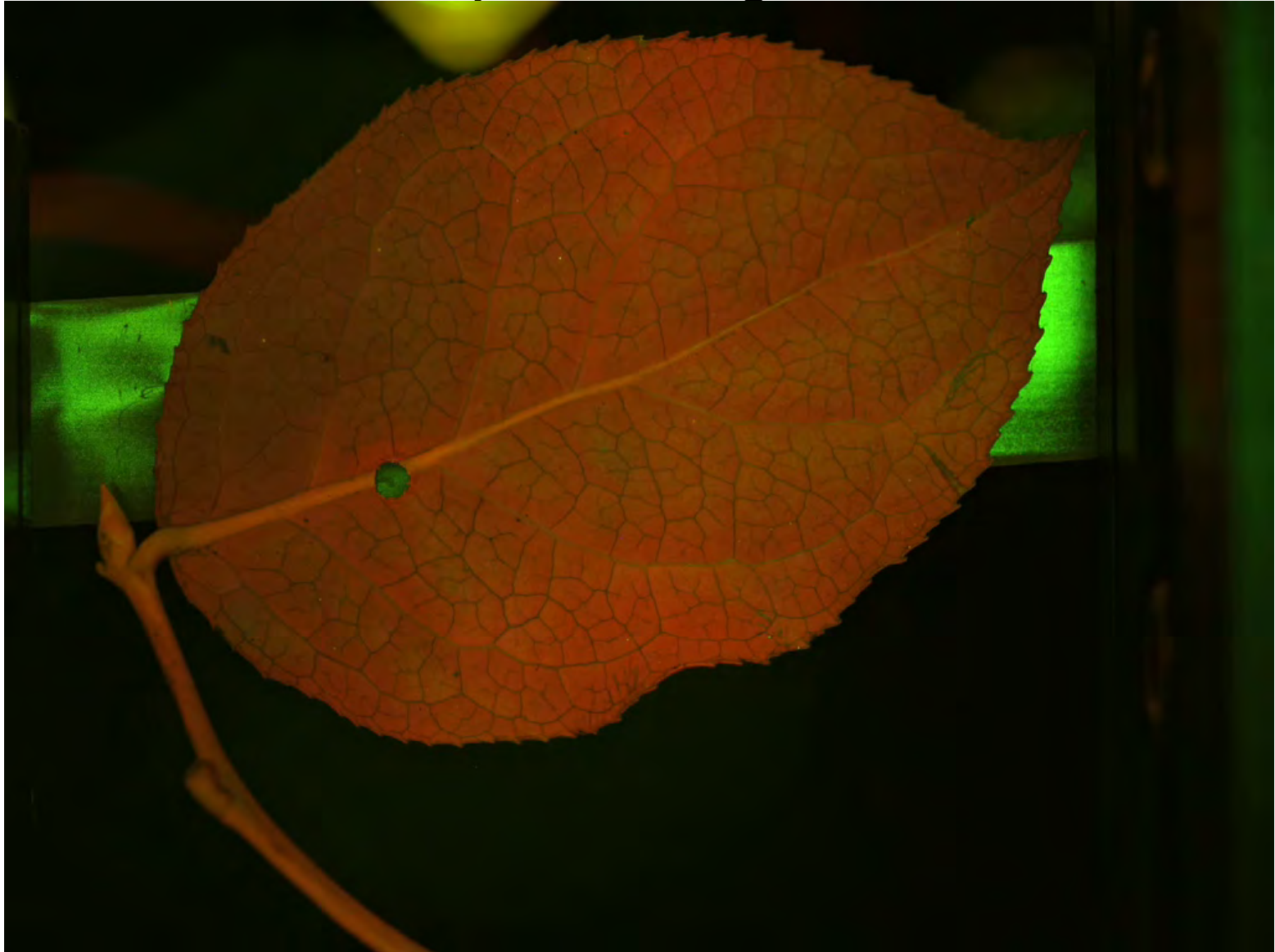
5 Highly connected networks

Why it matters for urban resilience

- Highly connected networks are much more robust against random failures than disconnected ones. Such failures might be small-scale failures (local transport network disruption, local energy supply disruption, etc.) or large-scale ones. London or New York subways are for example resilient as there are alternative paths when one connection between stations is randomly cut.
- For the same reason, the channeling of car traffic into a very reduced number of very large channels (the urban highways and ring roads) is responsible for the congestion problems in Beijing and will lead to a complete disruption in case of natural disaster due to climate change. Too many connections of the same type in a single channel may overload the channel's capacity.
- In constrained hierarchical systems, collector roads gather the traffic from lower-level paths and end up congested. Non-constrained connections of a wide variety of types create a less hierarchical network that is connected in a much more diversified way. This prevents the saturation of a single channel or gridlock caused by congestion at a node where all paths converge. The different networks, on different scales, need not coincide. If they do, network saturation will take place faster.



A leaf structure is resilient and reorganizes its flows when a part is damaged

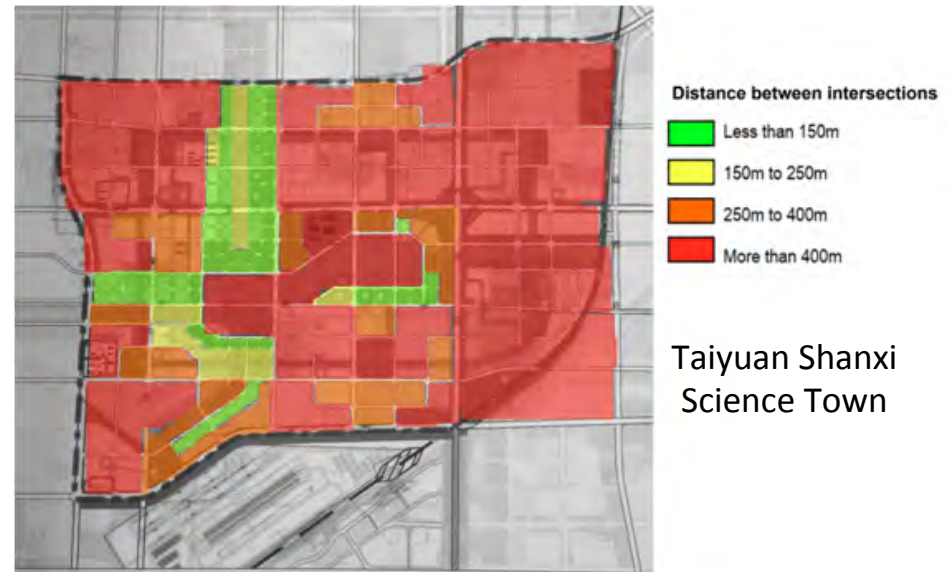


5 Highly connected networks

Metrics & international benchmarks

A series of metrics can capture the connectivity of street networks, from the most simple metrics to complex metrics resting upon graph theory:

- Number of intersections per km²
- Distance between intersections
- Cyclomatic number
- Clustering coefficient
- Betweenness centrality



Average distance between intersections



Number of intersections per km²

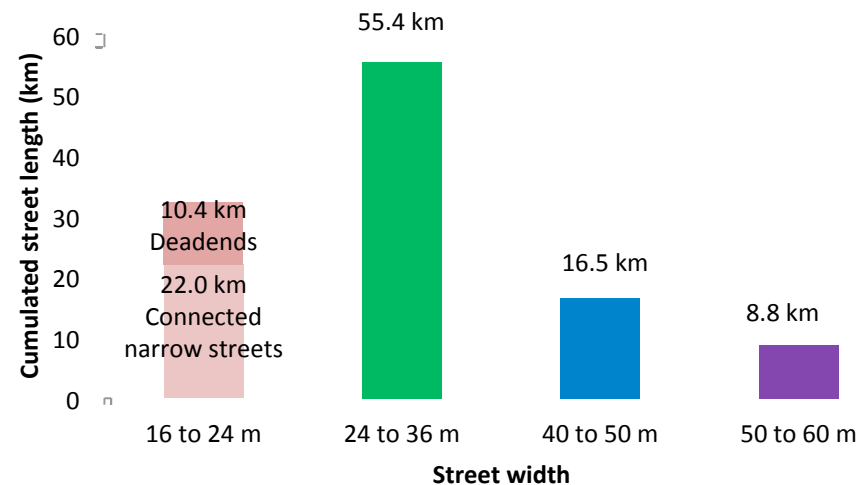
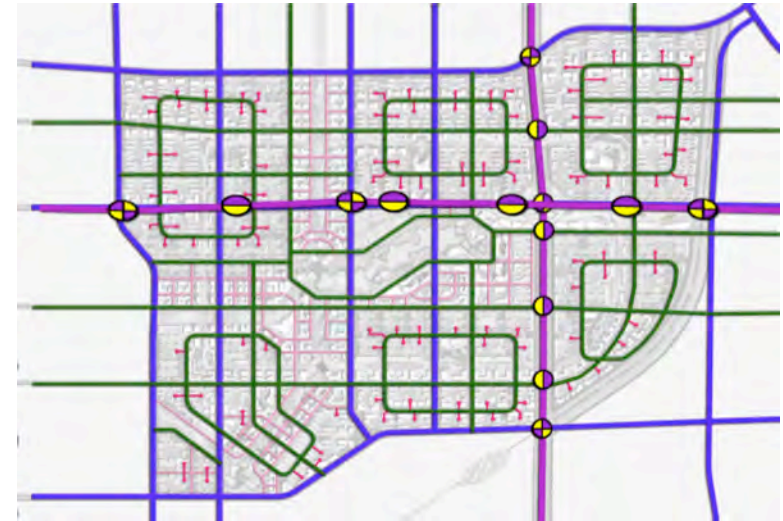
5 Highly connected networks

Assessment in Taiyuan Shanxi Science Town

For the World Bank, the Urban Morphology Institute has carried a comprehensive assessment of the core area of **Taiyuan Shanxi Science Town**, including an extensive street network analysis.

The street network of the master plan displays four street width:

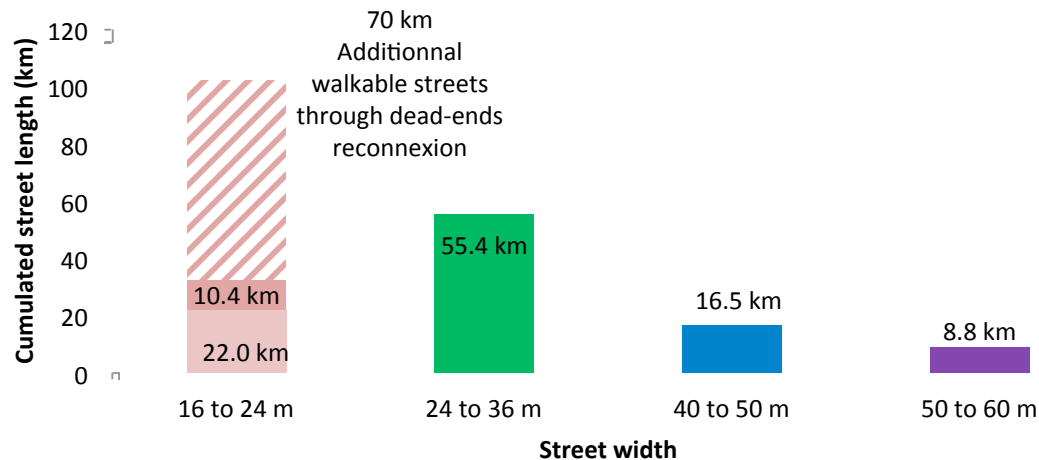
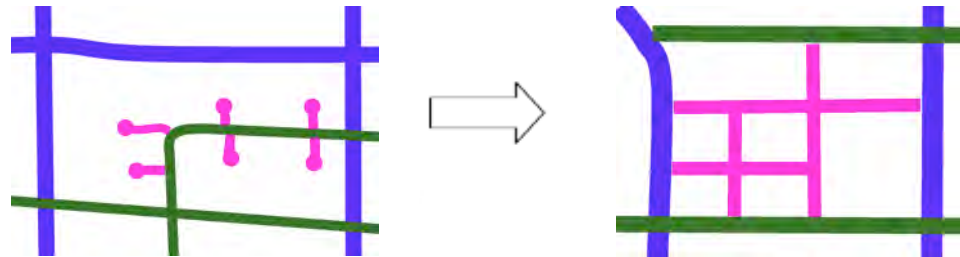
- Large arterials (purple), 50 to 60 m wide
- Secondary arterials (blue), 40 to 50 m wide,
- Connectors (red), 24 to 36 m wide
- Two types of distributors of 16 to 24 m wide: dead ends (pink) and connected narrow streets (light pink). The connected narrow streets correspond to the above mentioned small block fine grain areas.



5 Highly connected networks

Opportunities in Taiyuan Shanxi Science Town

Design strategy to increase connectivity in Taiyuan Shanxi Science Town core area



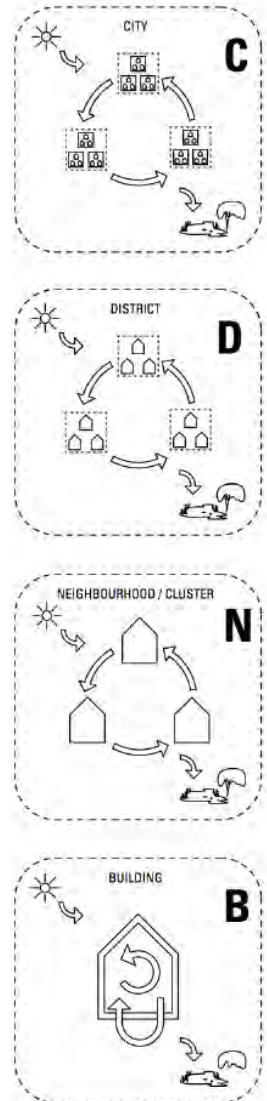
6 Synergy

Why it matters for urban resilience

- Most of the energy consumption is lost as non-functional waste energy. So the initial demand for useful energy can be reduced by more effective usage. Synergy strategies consist in cascading and recycling energy flows according to their quality (electricity, mechanical, thermal) to improve the energy process overall.
- Synergy strategies increase the resilience of urban energy systems. Indeed, cascading and recycling energy flows according to their quality (electricity, mechanical, thermal) improves the stability and the resilience to unexpected events (flood, drought, storm, peak load, etc.) of energy networks.
- A key issue in improving the efficiency of urban energy systems is an optimal matching of various energy-demand categories with energy-conversion processes. Housing, office, shop, retail or public buildings have very different load profiles. This diversity of load profiles supports the implementation of synergy strategies such as:
 - Peak shaving strategies: as consumption peaks in different buildings types do not happen at the same time of the day, high levels of local mixed use contribute to shaving consumption peaks
 - Synergy grids, consisting in recycling all energy and material flows according to their quality



Energy mix on the district scale (REAP)



7 Greening & Water Recycling

- Changes in extreme rainfall could cause the amount of sewage released to the environment from combined sewage overflow spills and flooding to increase by 40% in some cities.
- Responses include strengthening wastewater, stormwater and runoff infrastructure.
- Risks to freshwater resources, such as drought, can cause shortages of drinking water, electricity outages, water-related diseases, higher food prices and increased food insecurity from reduced agricultural supplies.
- Responses include encouraging water recycling and grey water use, improving runoff management and developing new/alternative water sources; storage facilities and autonomously powered water management and treatment infrastructure.
- On the one hand, the city's green infrastructure helps reduce GHG emissions by serving as a carbon sink, enhancing the pedestrian and cycling environment, regulating energy consumption, enabling environmentally sustainable nutrient recycling and local food production. On the other, it improves resilience through flood mitigation, erosion control, and maintaining water availability.

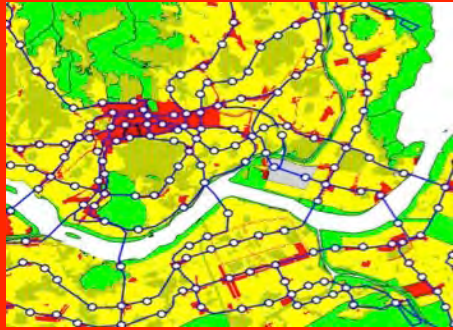
8 Urban-Rural Integration

- All aspects of food security are potentially affected by climate change, including access to food, food utilization and price stability.
- Local responses include
 - Preserving arable land by limiting sprawl and by efficient land use
 - Immersion of compact urban nodes (less than 10 minutes walk) within accessible continuous green spaces.
 - Support for urban and peri-urban agriculture through green roofs, urban farms and local markets
 - Develop alternative food sources including inland aquaculture, to replace ocean-based resources under threat



Leveraging on China Urbanization study and on TOD projects, next steps proposed by the Urban Morphology Institute to contribute to the paradigm shift for China's urbanization are:

- Master plans climate change mitigation and adaptation assessment frameworks and guidelines for capacity building**
- Integrated TOD strategies from city to neighborhood scale**
- Innovative and creative design for TOD demo projects**



Thank you for your attention

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