

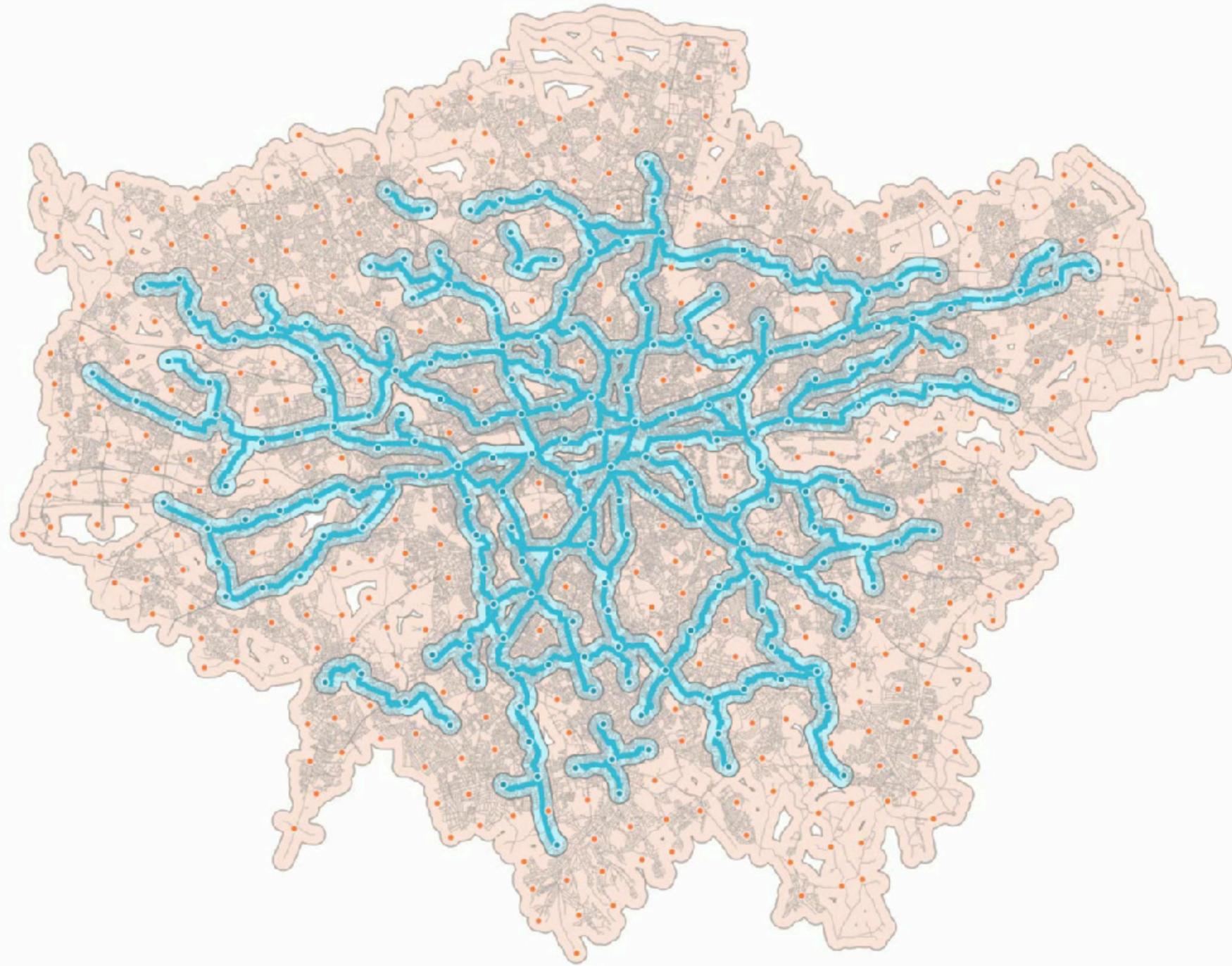
Establishing a quantitative science of bicycle networks

Michael Szell

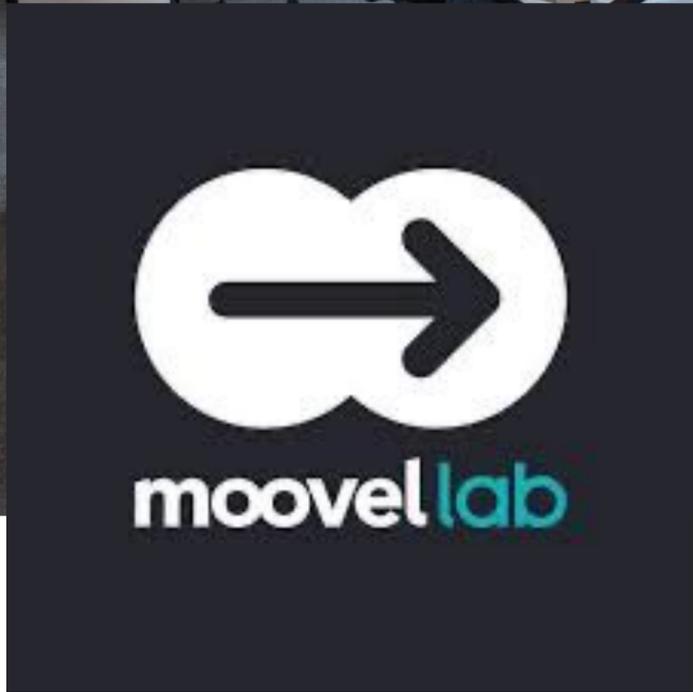
NEtwoRks, Data, and Society (NERDS)

with:

S. Mimar, T. Perlman, G. Ghoshal, R. Sinatra,
A. Vybornova, T. Cunha, A. Gühnemann,
L.G. Natera Oroczo, F. Battiston, G. Iñiguez,
M. Lynghede, C.L. Kolding Andersen,
M. Klanjčić, L. Gauvin, M. Tizzoni, moovel lab

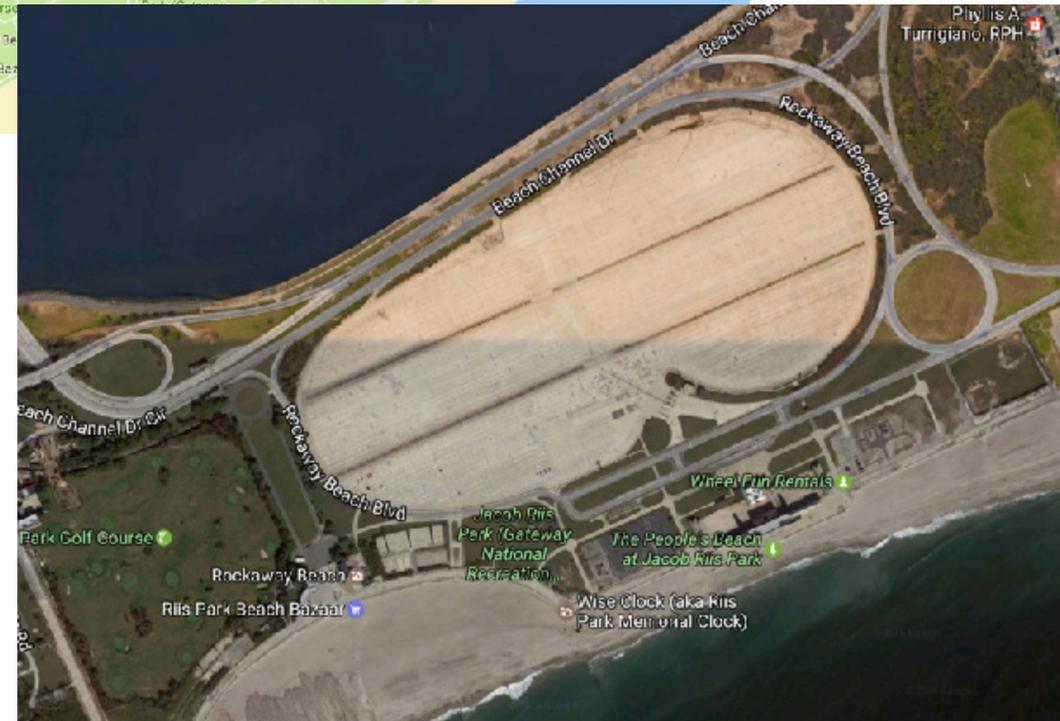
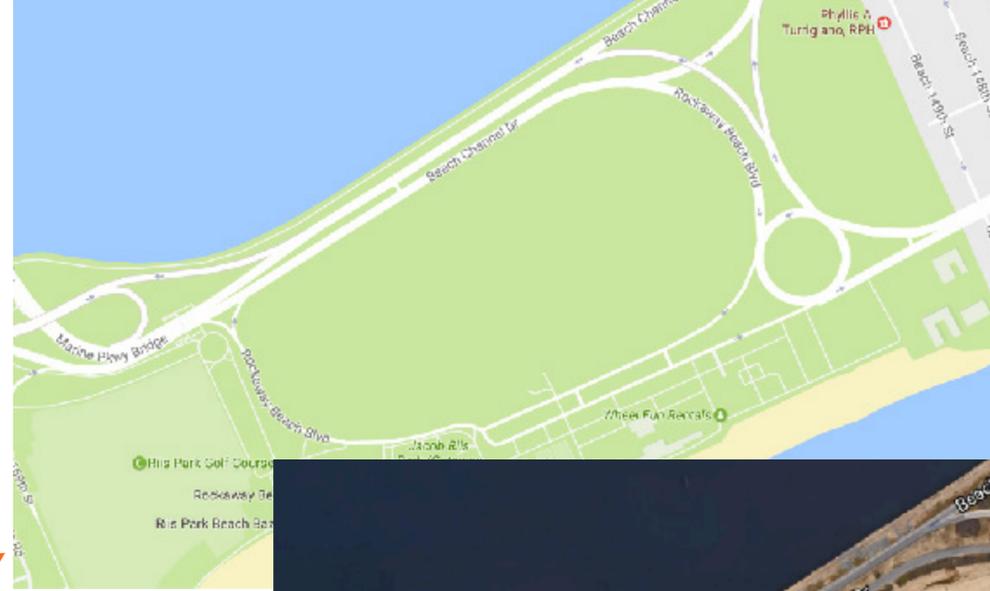
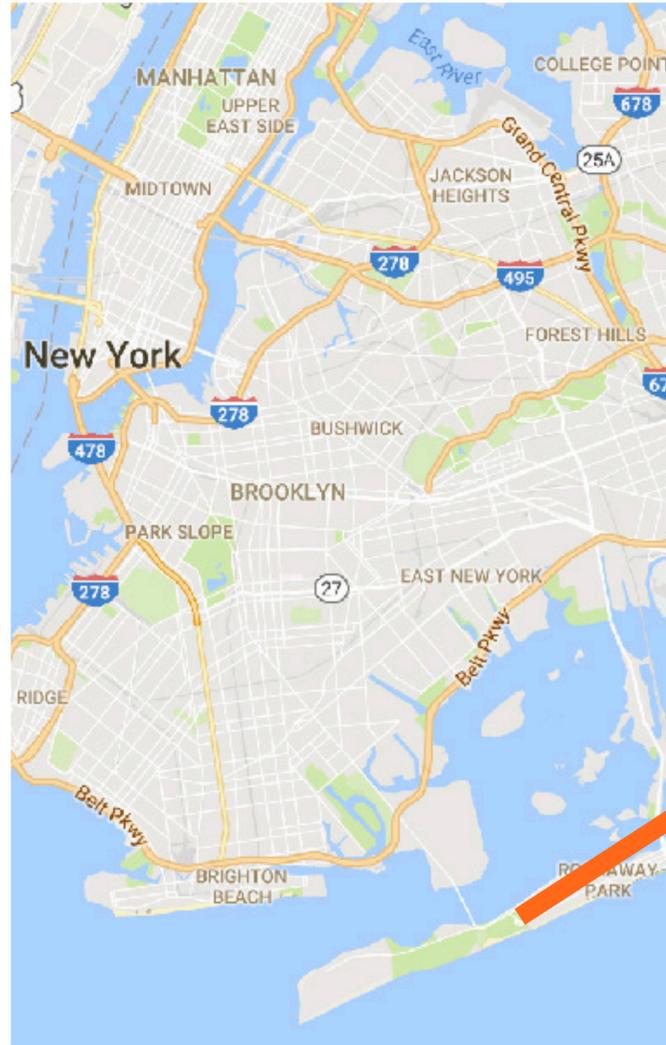


IT UNIVERSITY OF COPENHAGEN

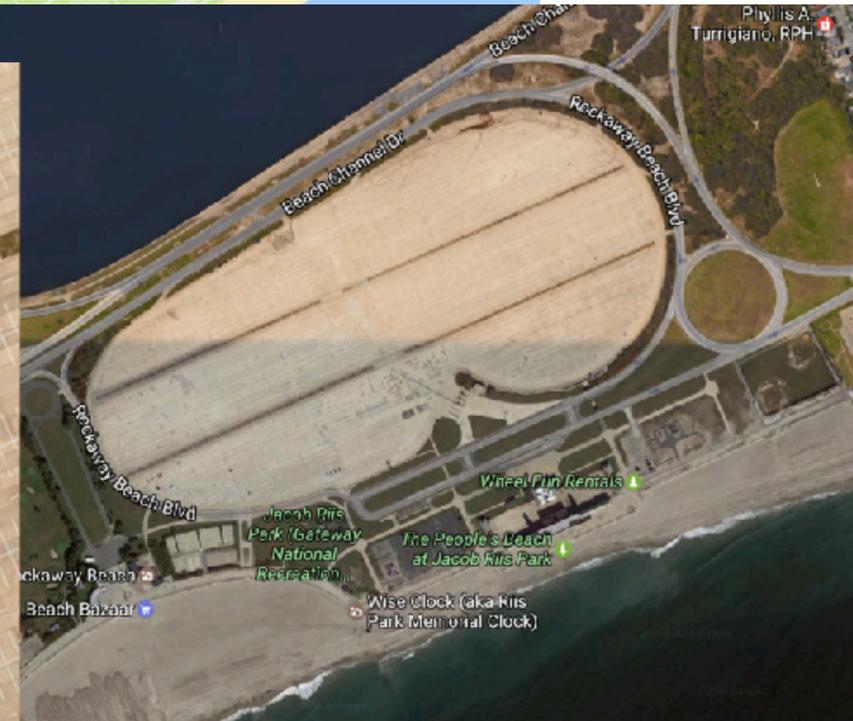
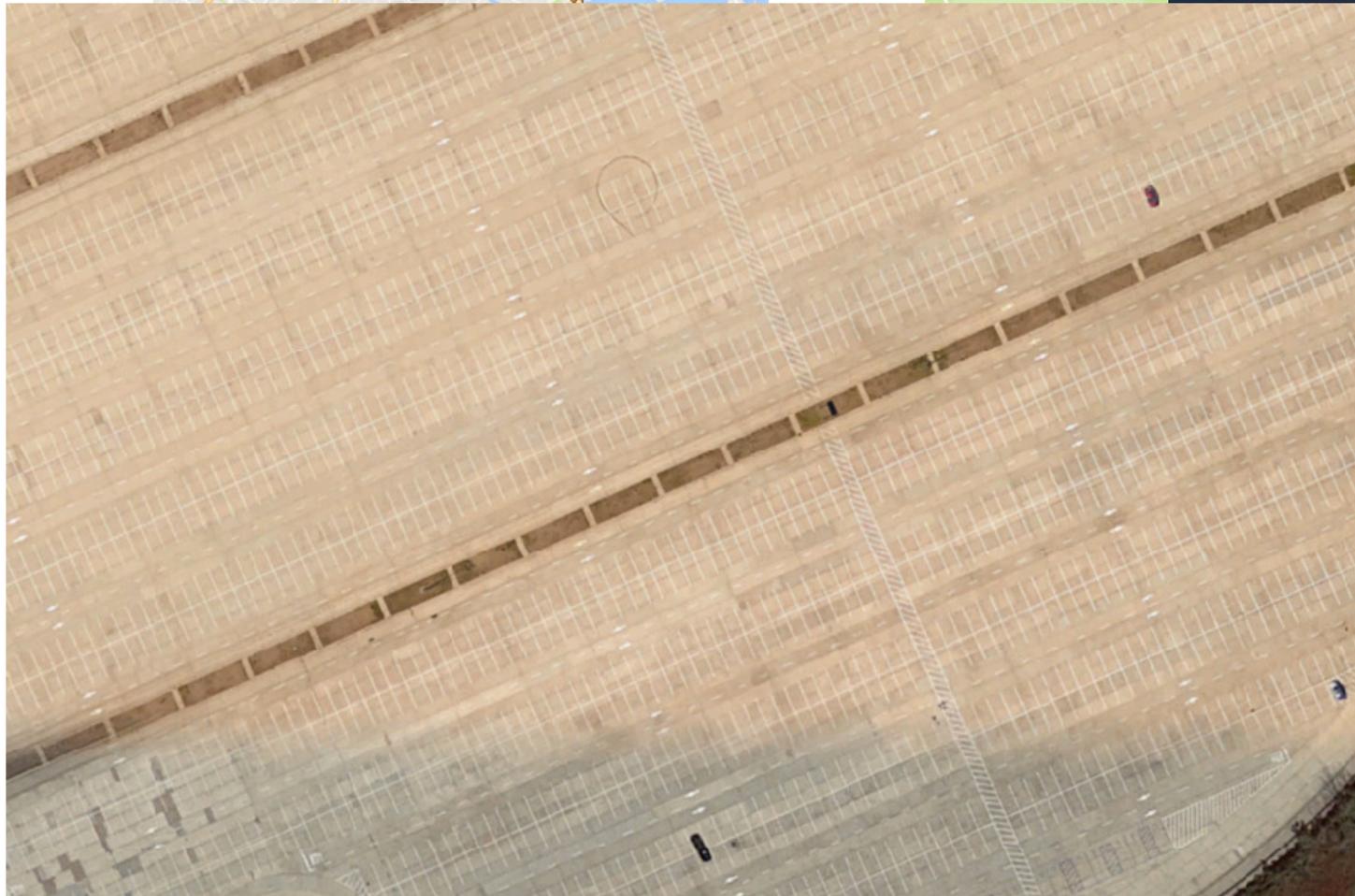
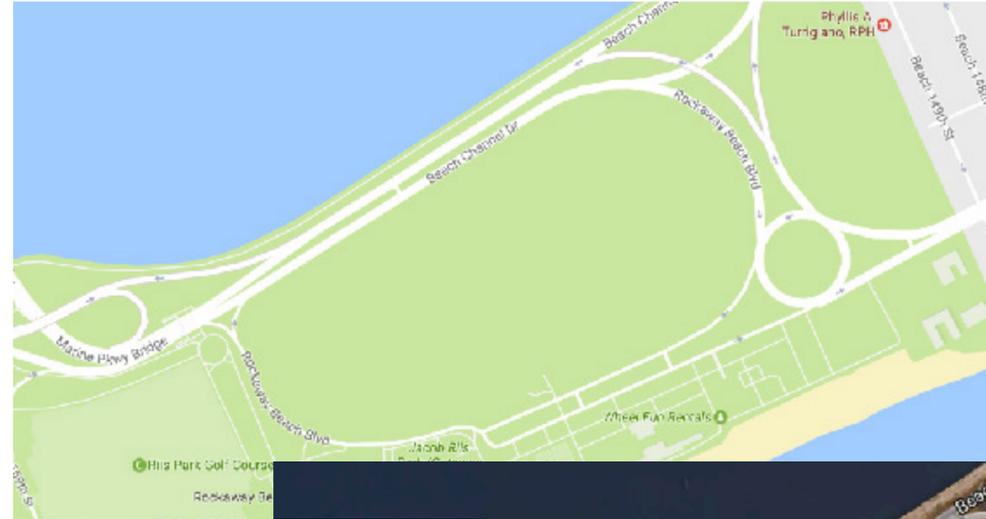
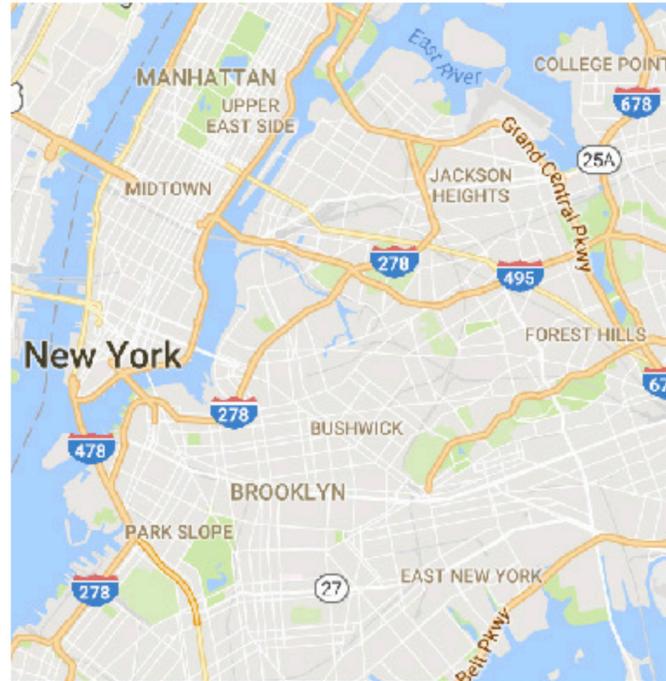


2016

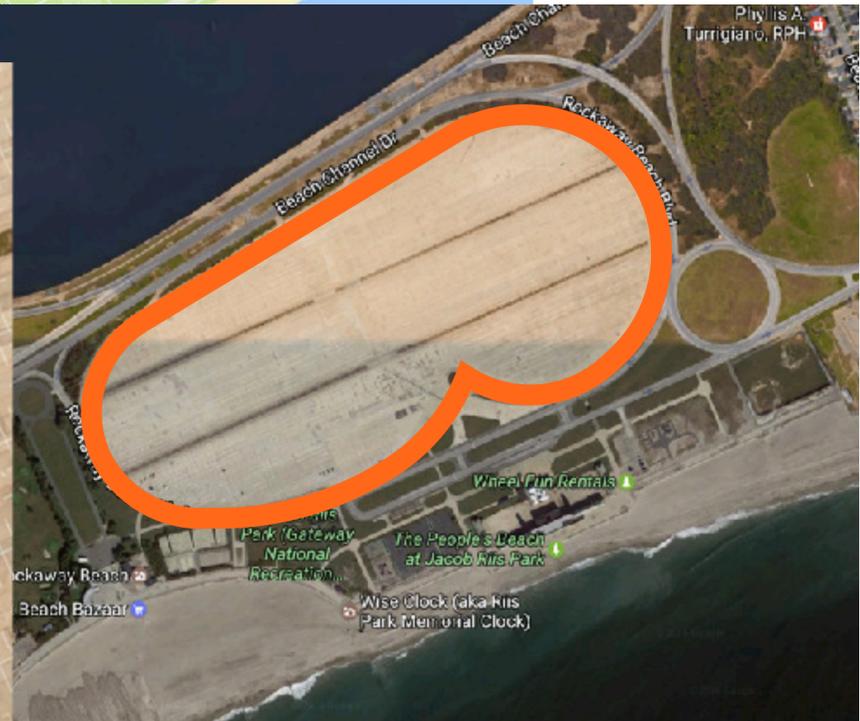
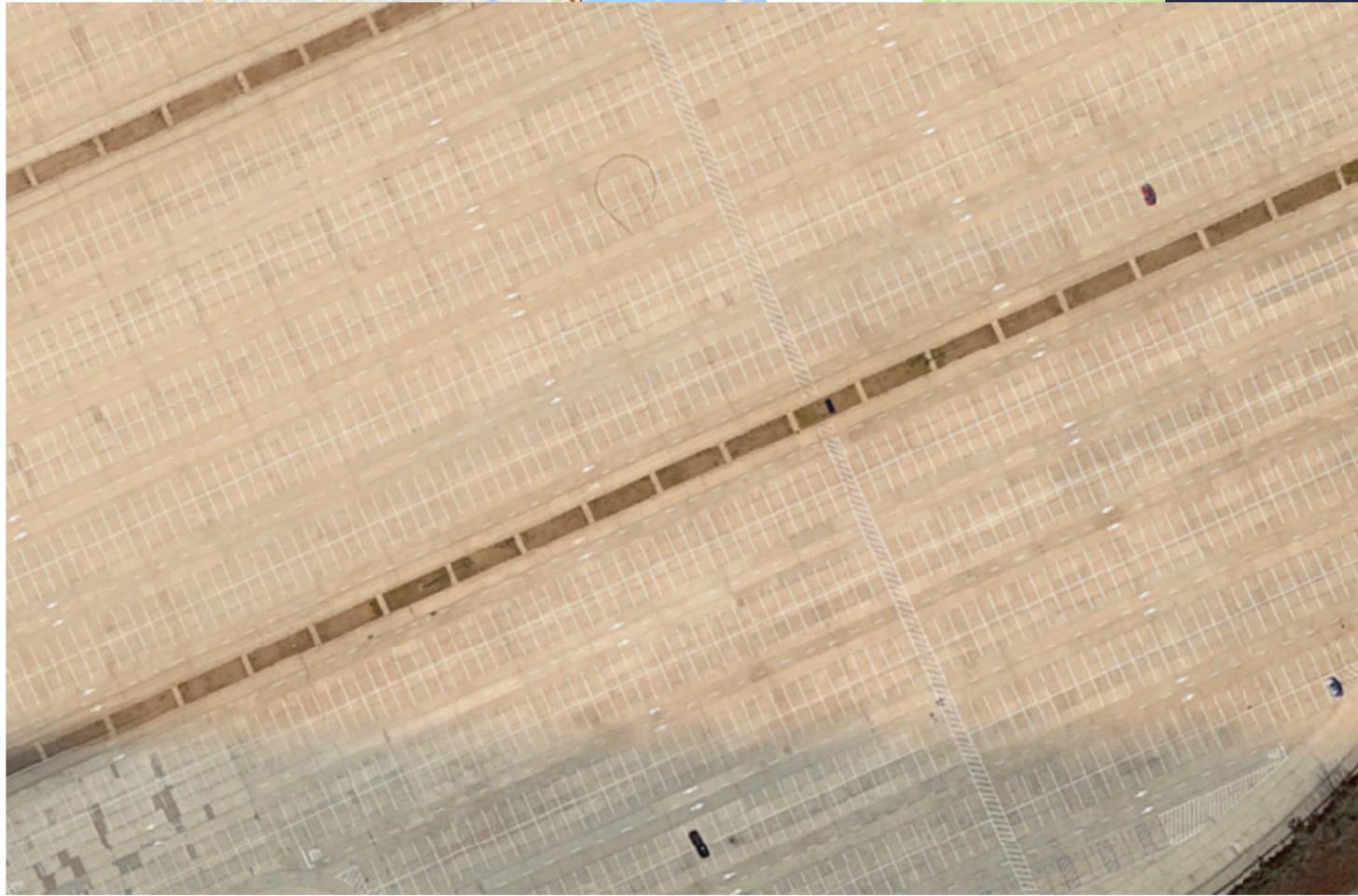
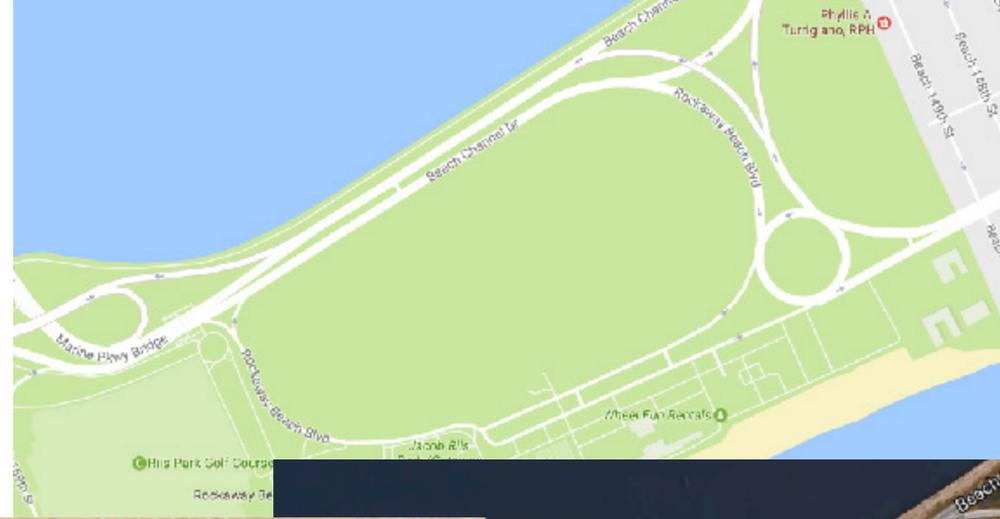
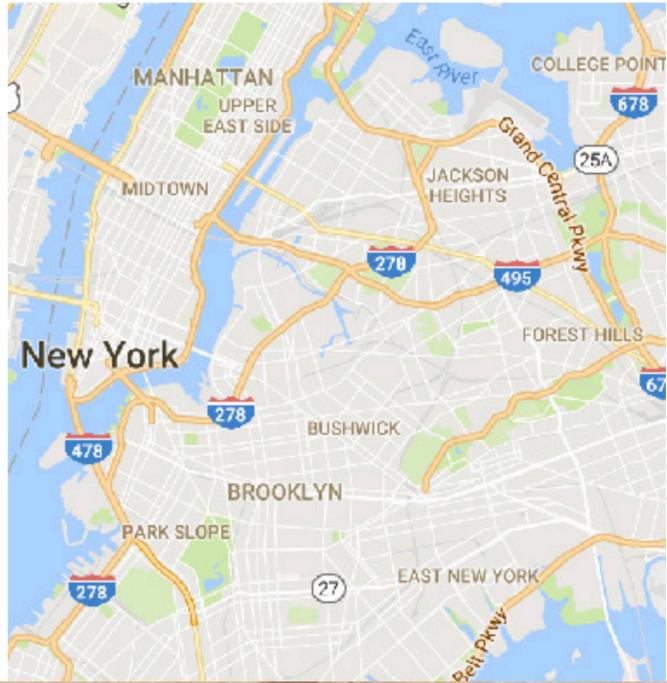
What a lovely green..



What a lovely green.. MONSTER



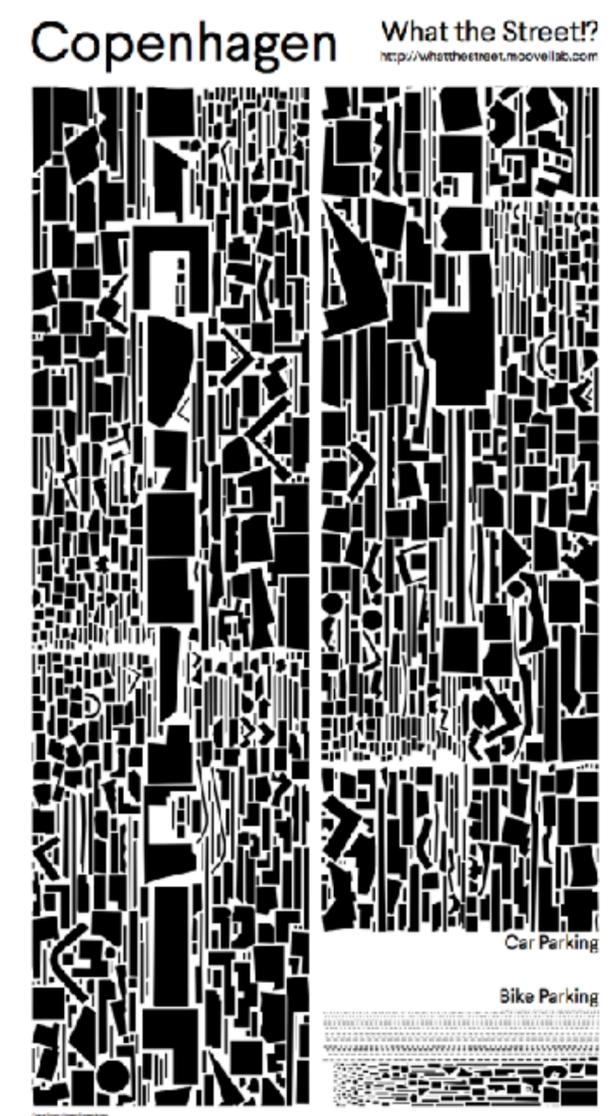
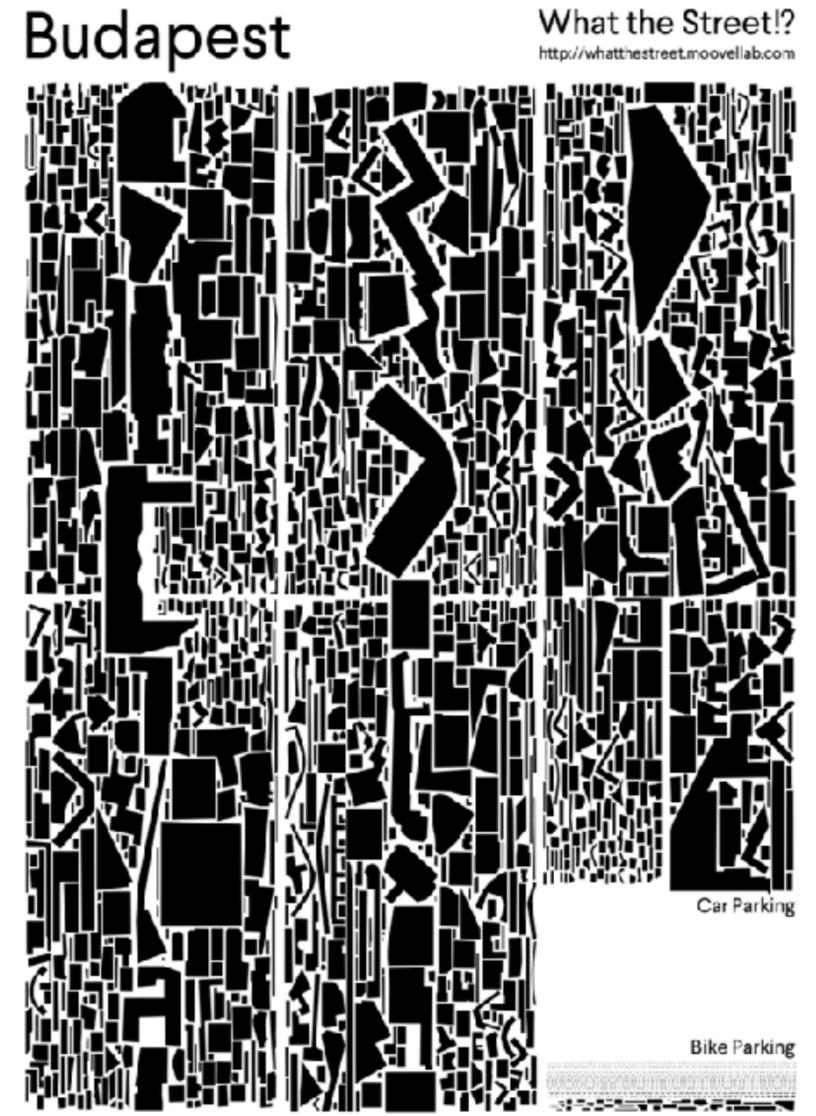
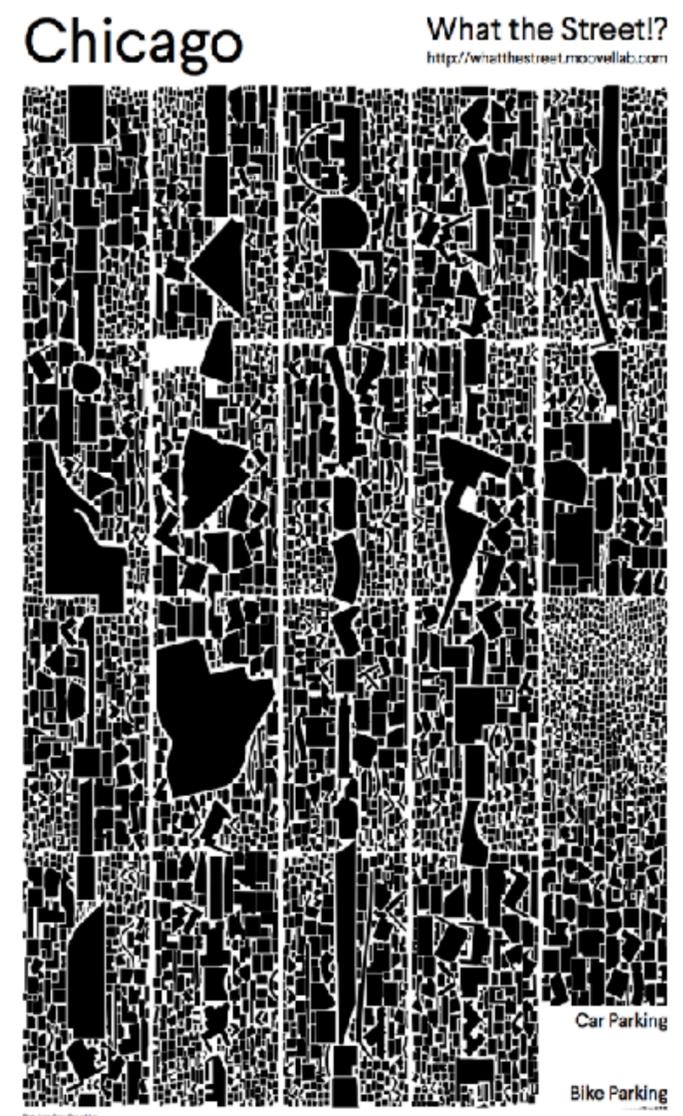
800m x 500m



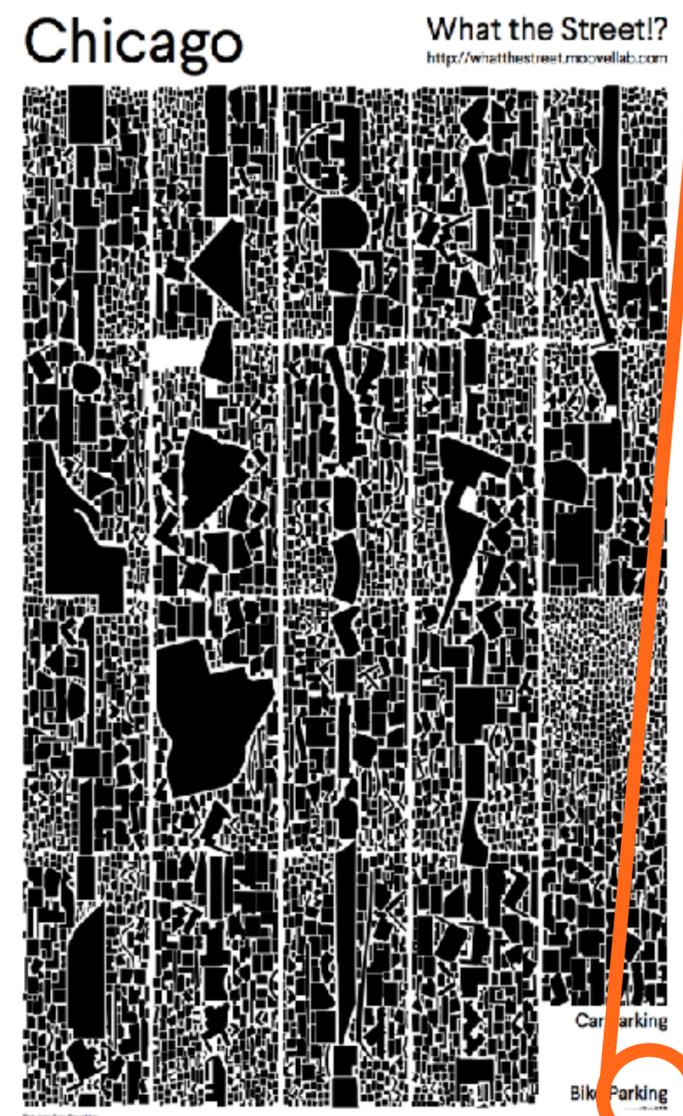
We visualized ALL parking spaces with polygon packing



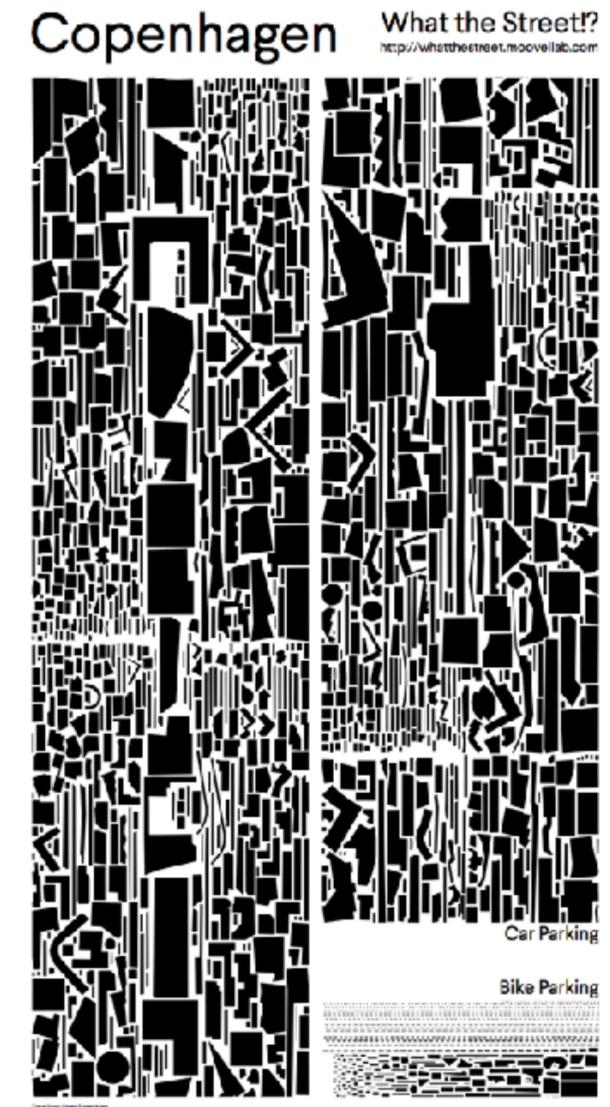
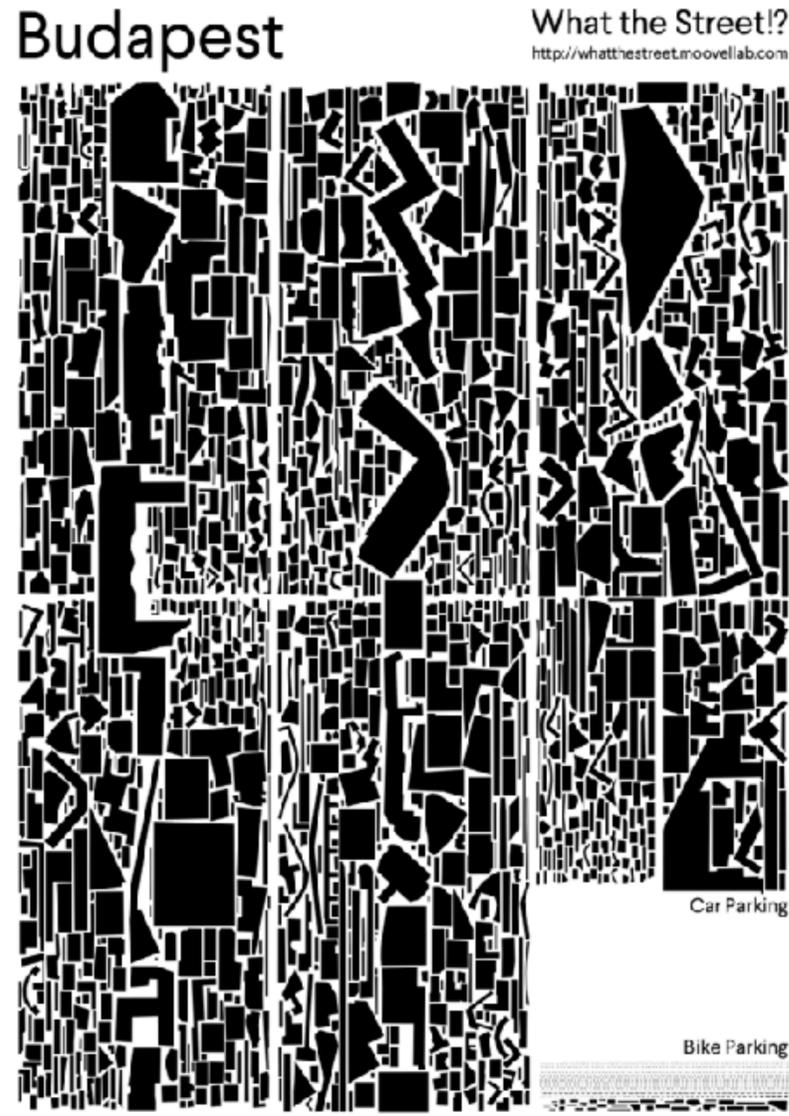
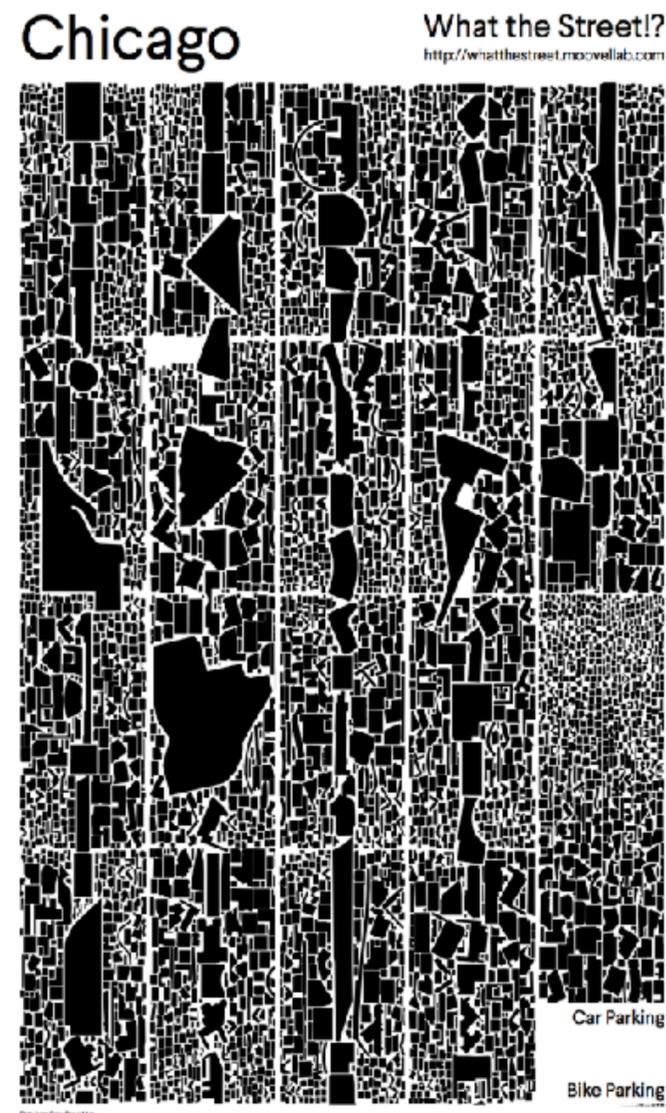
There are huge differences between car and bike parking



There are huge differences between car and bike parking

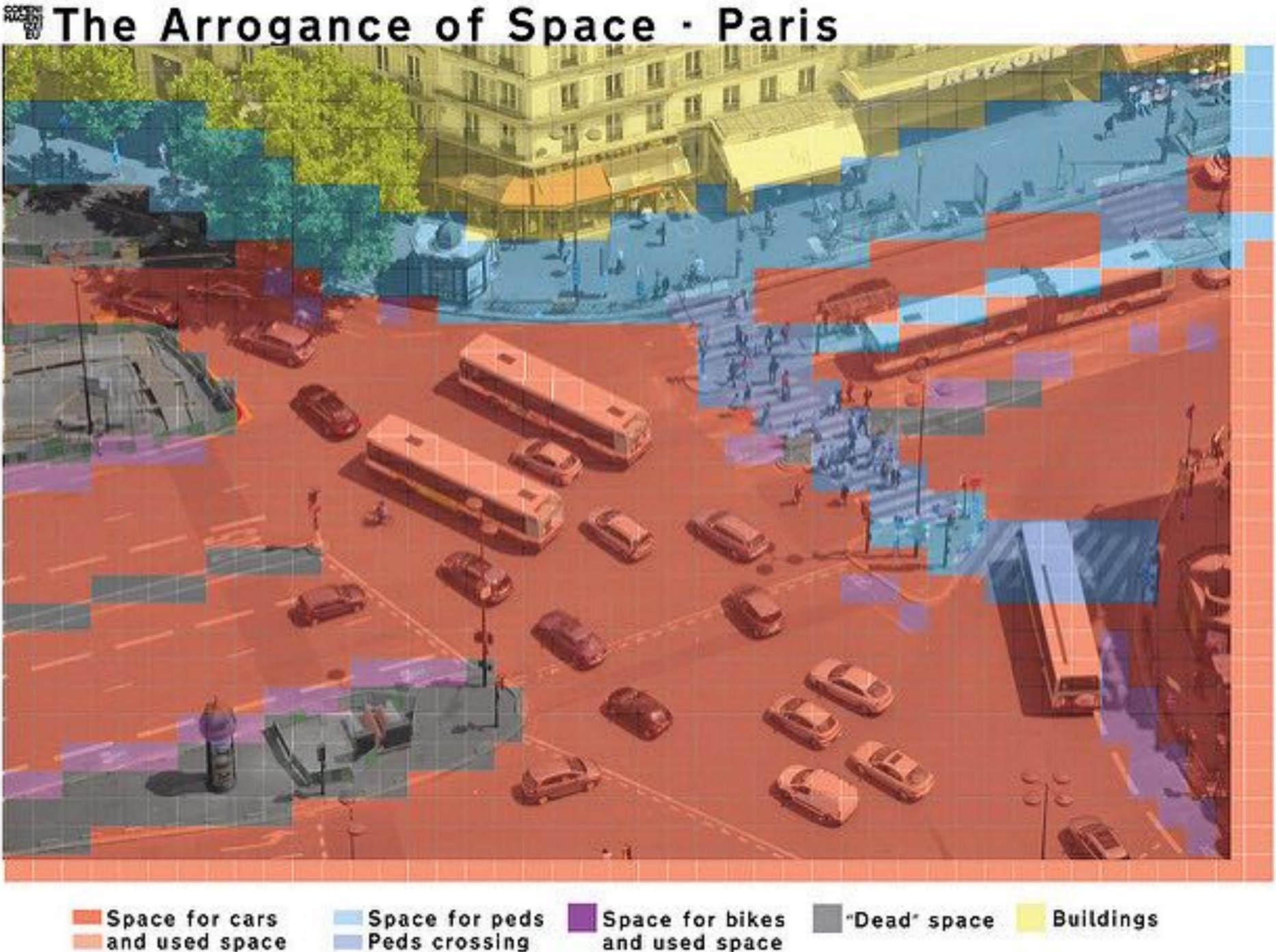


There are huge differences between car and bike parking



whatthestreet.com

Space is not distributed in a fair way between different modes of transport



Most space is for cars, but most people use bicycles



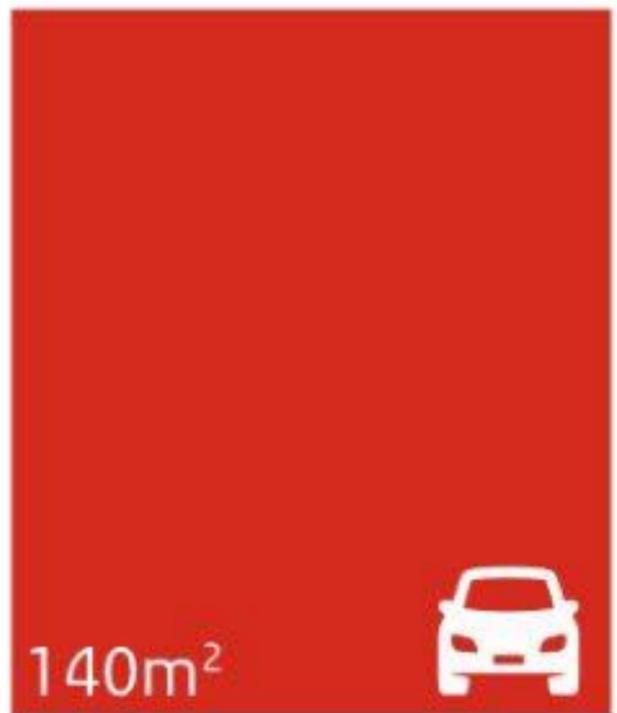
Modal Share for Copenhageners Commuting to Work/Education



Allocation of Transport Space in Copenhagen



You can't beat geometry: Cars will ALWAYS be inefficient



Car
50 kmh, 1 occupant



Car
parked



Tram
50 occupants



Pedestrian
walking



Pedestrian
standing still



Cyclist
15 kmh



Bicycle
parked

Harms and Kansen, Netherlands Institute for Transport Policy Analysis (2017)
Szell, Urb Plan 3, 1-20 (2018)
Euclid (300 BC)

Cars are used 36 minutes per day

Cars are not used 1404 minutes per day

Cars are used 36 minutes per day

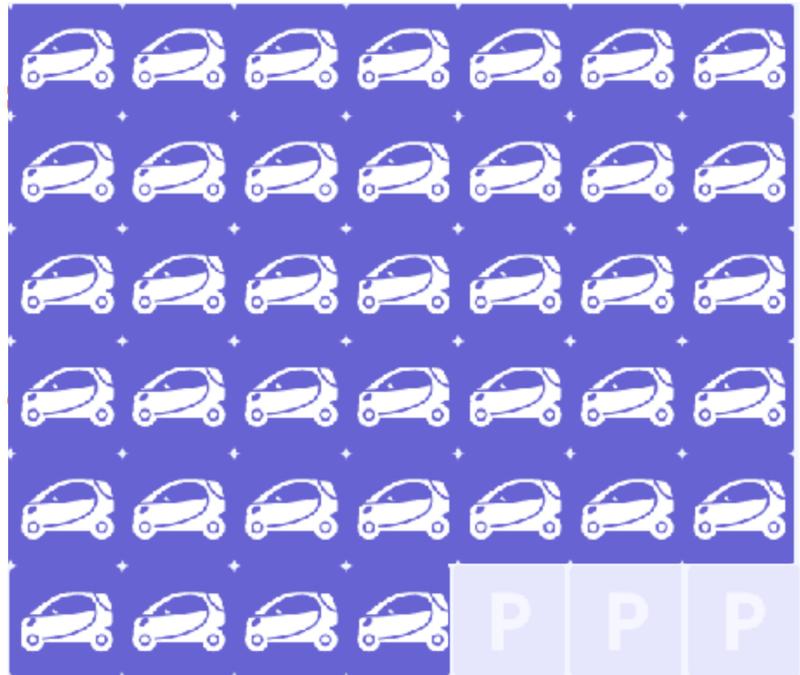
Cars are not used 1404 minutes per day

A typical snapshot of Copenhagen

5,500 cars moving



250,000 cars parked



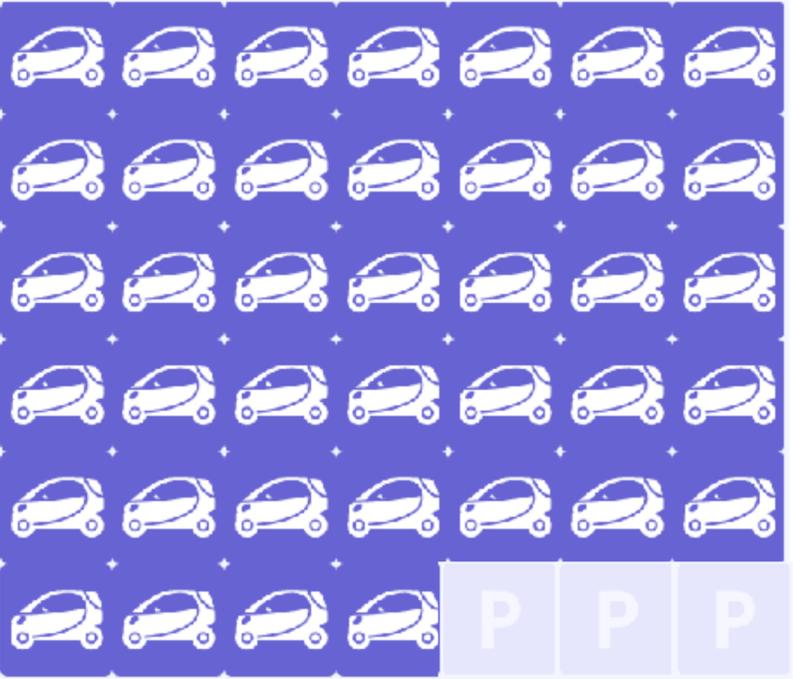
We are wasting space worth 6,000 playgrounds!

A typical snapshot of Copenhagen

5,500 cars moving

250,000 cars parked

6,000
Playgrounds



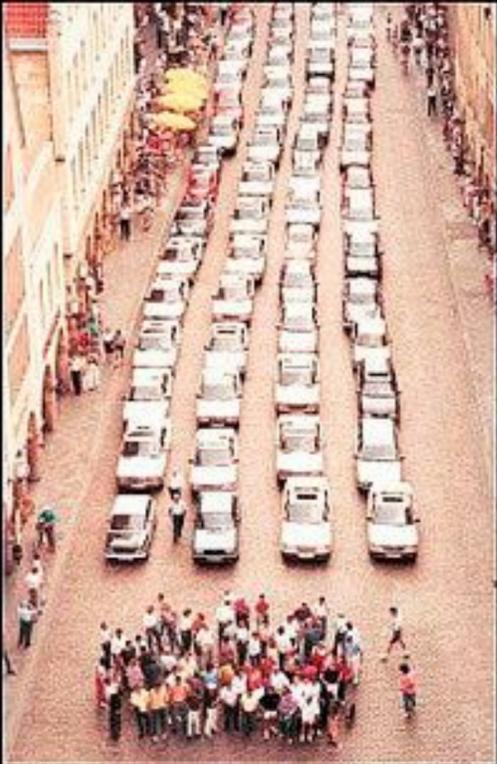
Cars eat up our living space in cities



Denver

Cars eat up our living space in cities

space required
to transport 60 people



car
E-car

bus

bicycle



Life without electric cars



Life with electric cars

All hail the revolution!



Apart from space, there is
another problem.

Apart from space, there is another problem.

Every year, 1,350,000 people die on the road.

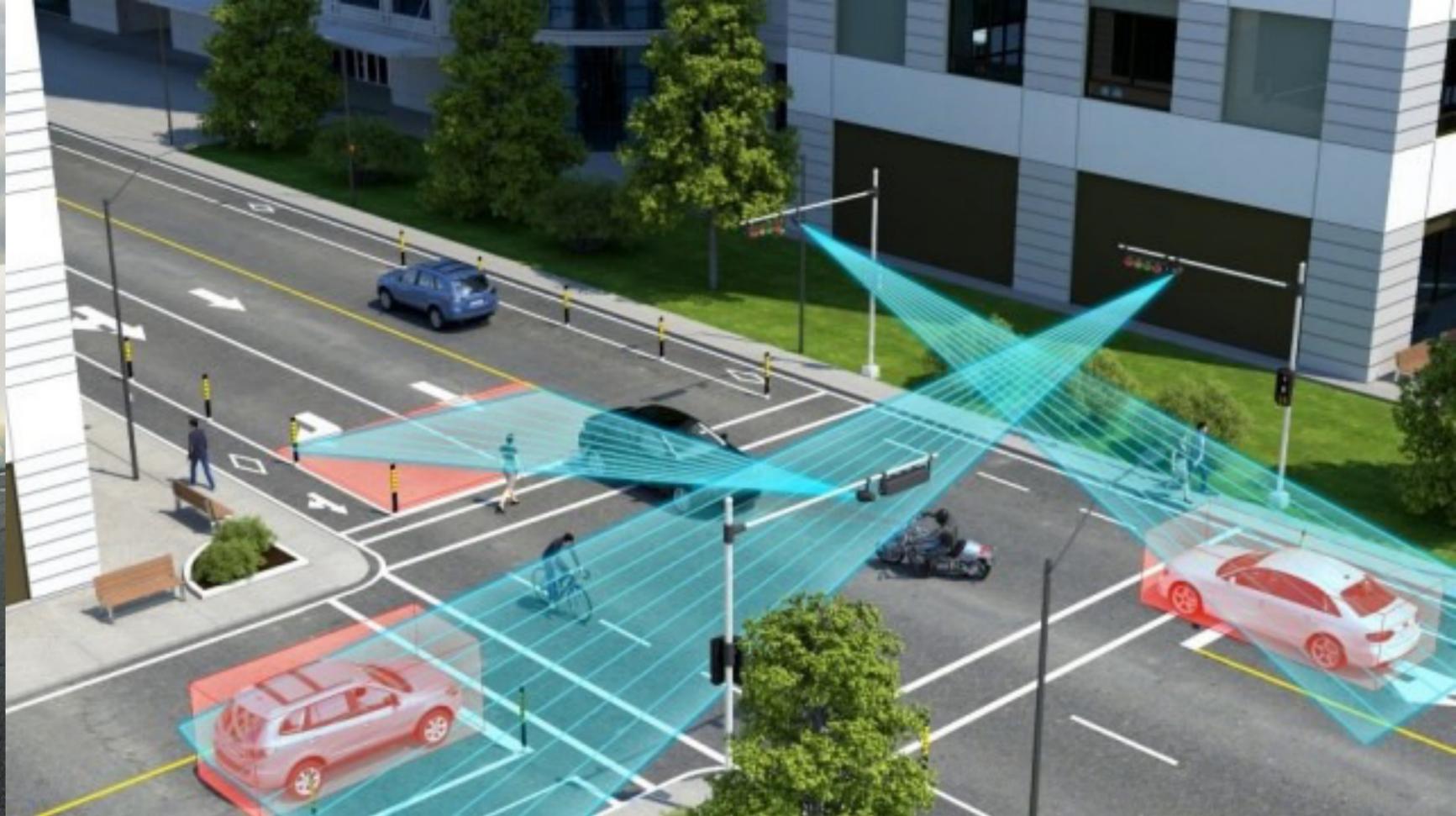
Laetitia will show you at 12:15 how cars are a public health hazard



Cars take away our living space.
Cars are a public health hazard.

Cars take away our living space.
Cars are a public health hazard.

We need better technology.





Rosenbergstr.

Schwabstr.

MEHRWEG
UNSER WEG ZUR WEITSE

Volk



Cycling is a time-tested technology that delivers on 11 SDGs



CYCLING DELIVERS ON THE GLOBAL GOALS

Shifting towards a better economy, society, and planet for all

<https://unric.org/en/sustainable-development-goals-cycling/>

More active travel is also an *economic "no-brainer"*

Cost-benefit analysis in EU that accounts for

- Health
- Environment
- Travel / Congestion

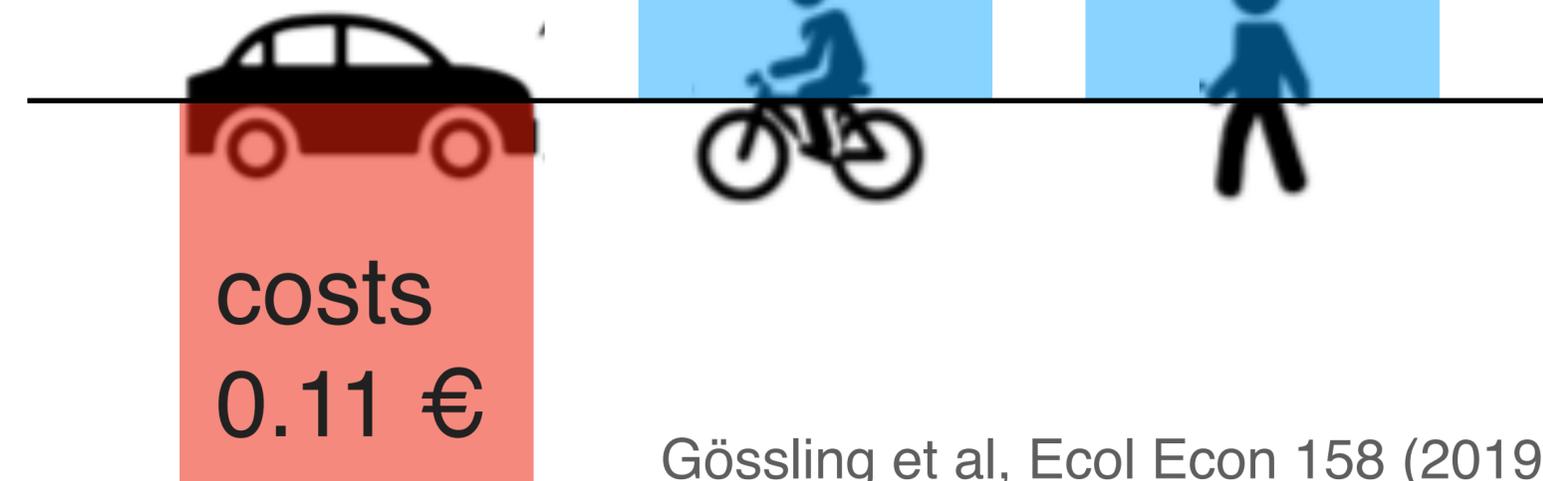
shows:

More active travel is also an *economic* "no-brainer"

Cost-benefit analysis in EU that accounts for

- Health
- Environment
- Travel / Congestion

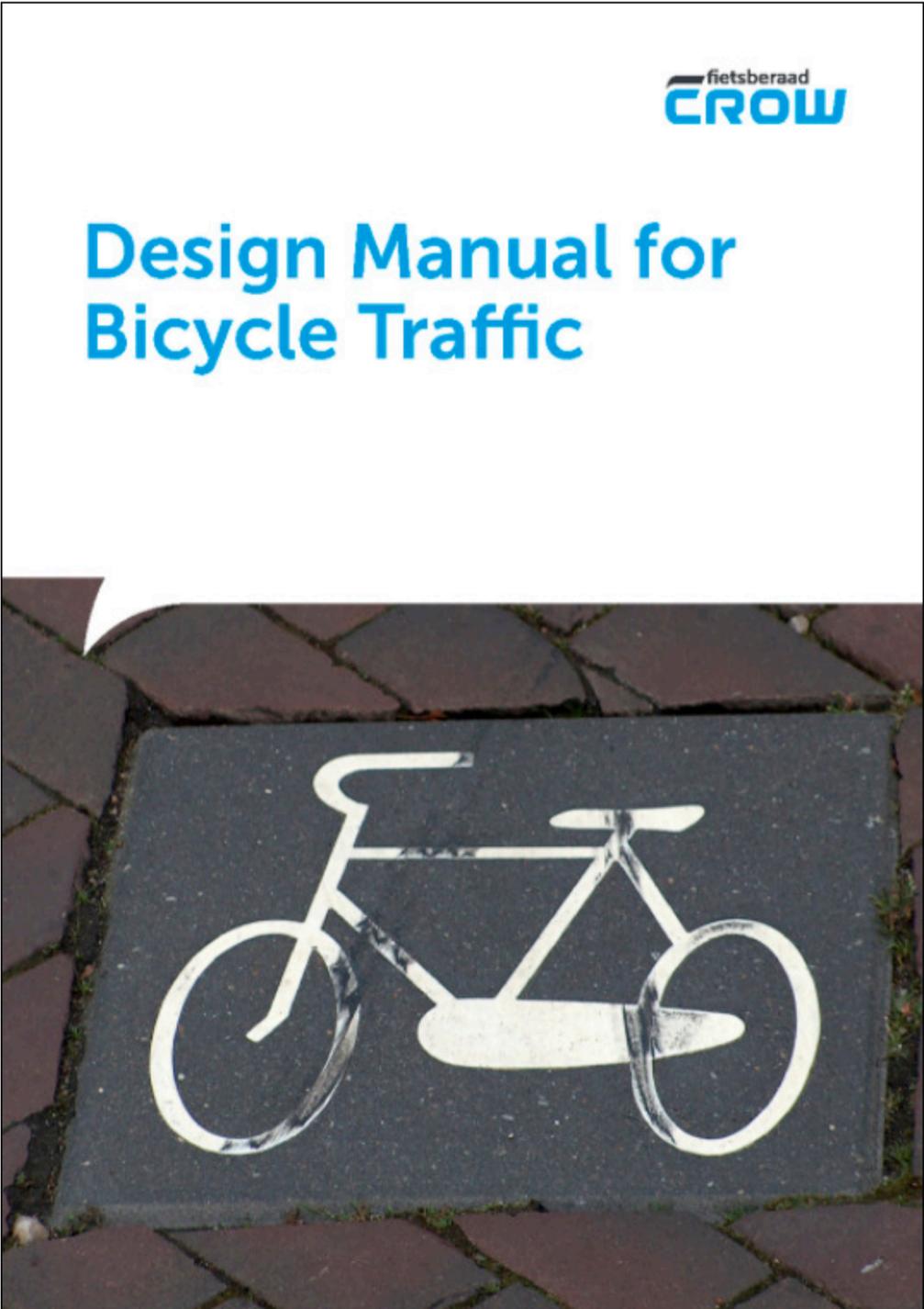
shows: 1 km travelled by



More active travel is crucial to
make cities better.

How to build bicycle infrastructure?

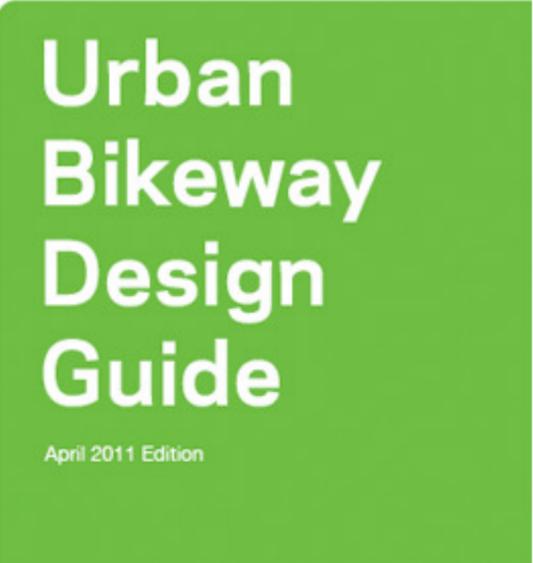
How to build bicycle infrastructure?



We have great
planning guides.



NACTO



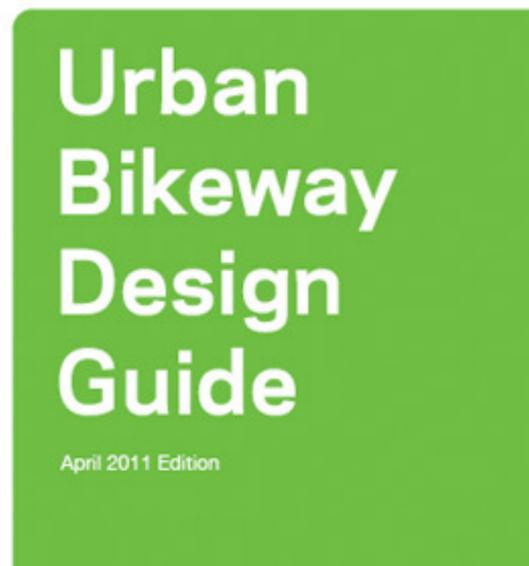
How to build bicycle infrastructure?



We have great planning guides.



NACTO

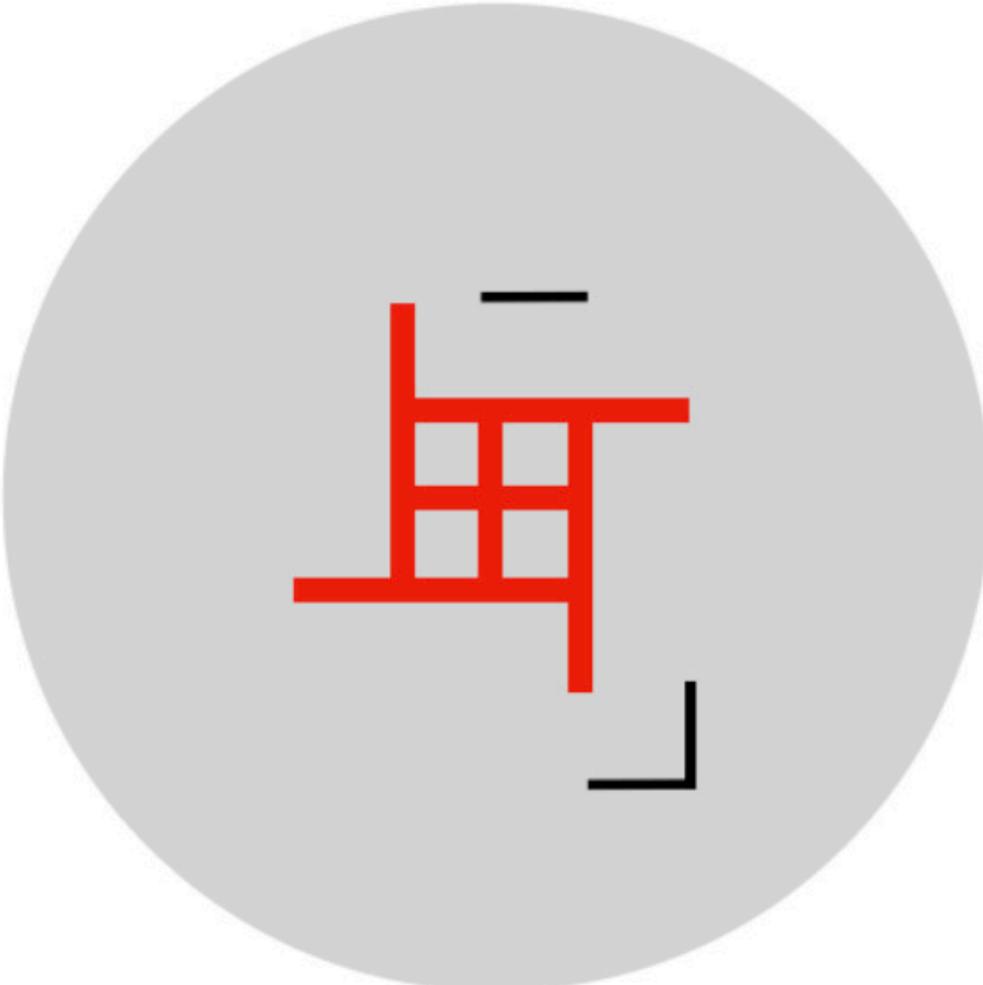


But no knowledge:

- on the fundamental topological limitations of network growth
- or on how hard/easy it is to fix existing networks

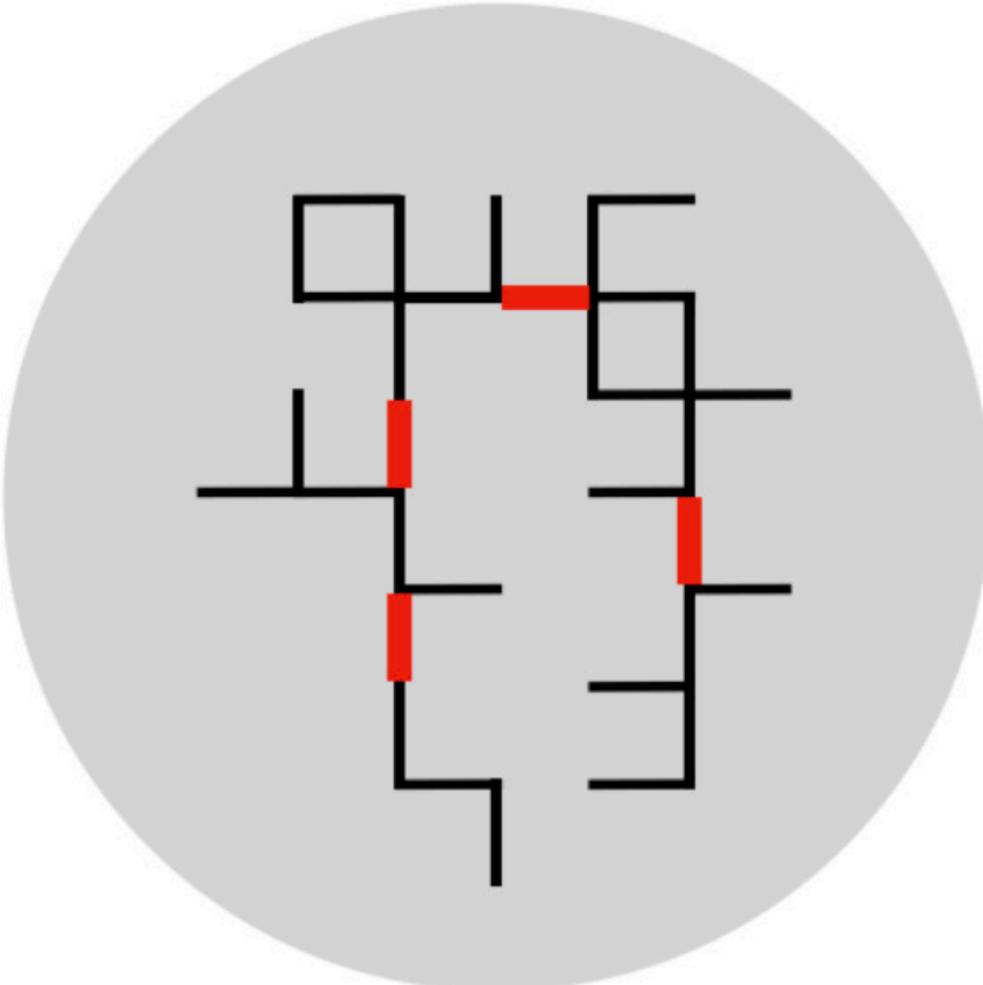
Different cities need different strategies

Most cities
Not developed



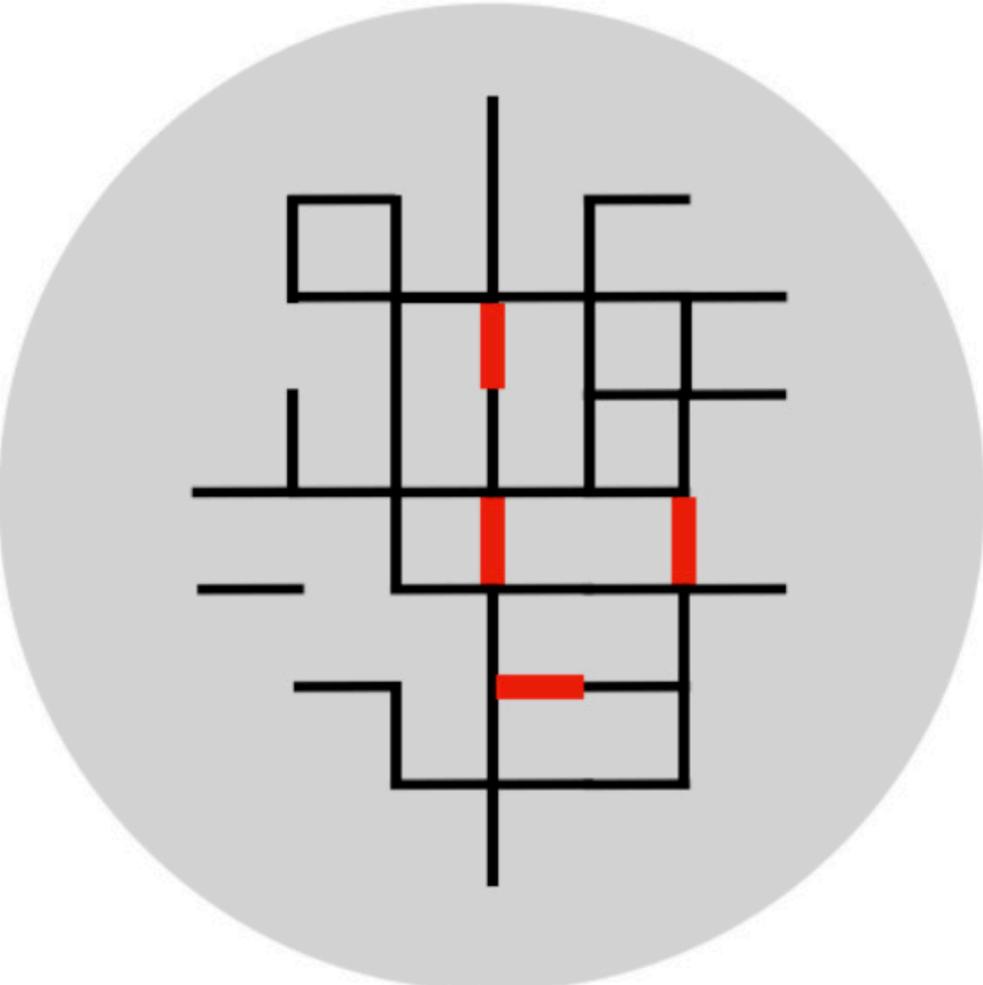
Grow from scratch
GrowBike.Net

Some cities
Developed but
disconnected



Connect components
LinkBike.Net

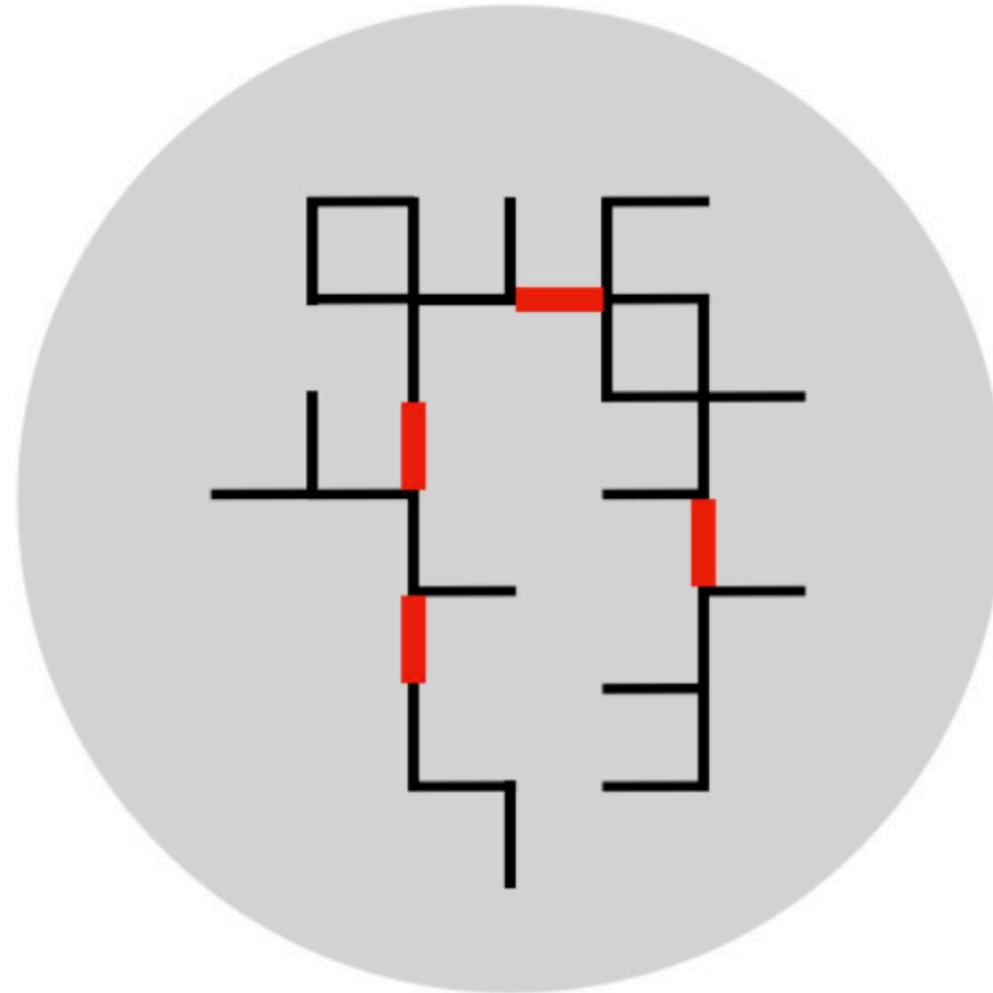
Few cities
Developed and
mostly connected



Find missing links
FixBike.Net

1) Connecting bicycle networks

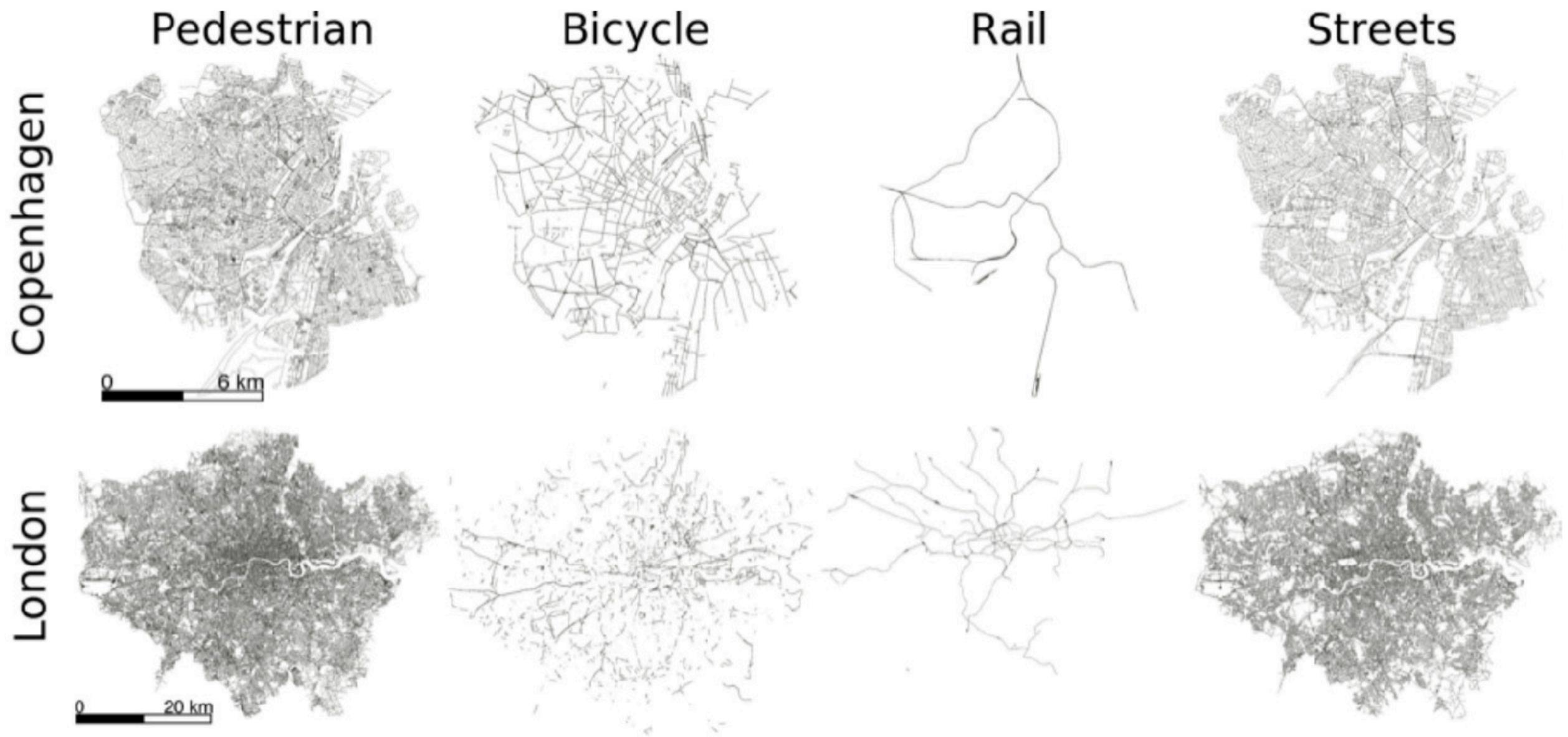
Some cities
Developed but
disconnected



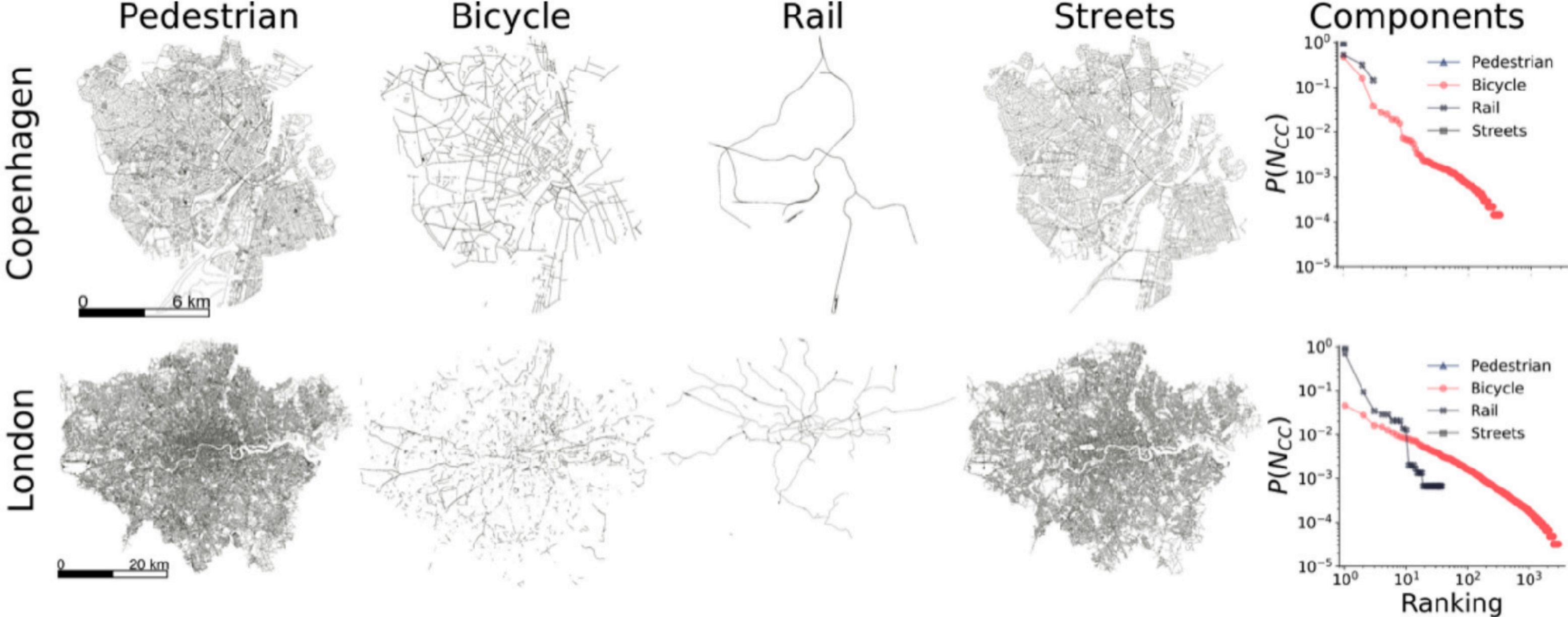
Connect components

LinkBike.Net

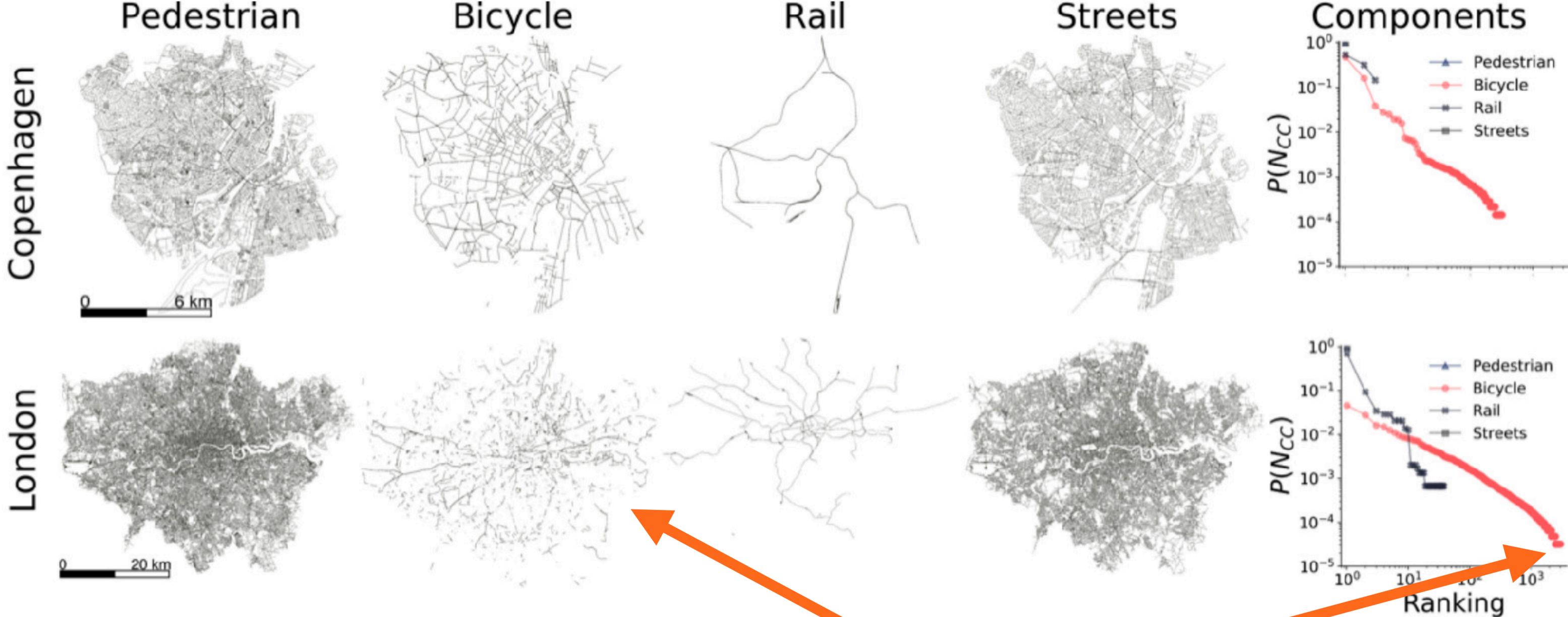
Cities have different transport network layers



Bicycle networks are highly fragmented

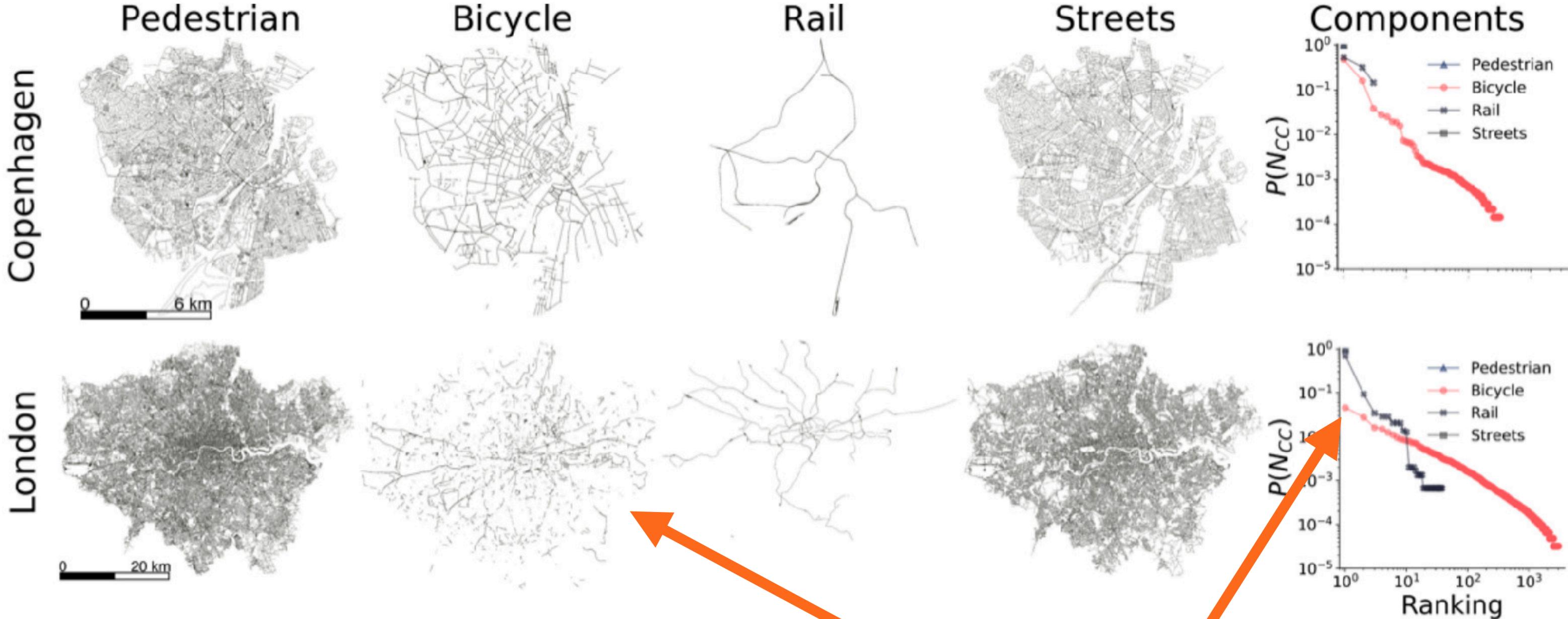


Bicycle networks are highly fragmented



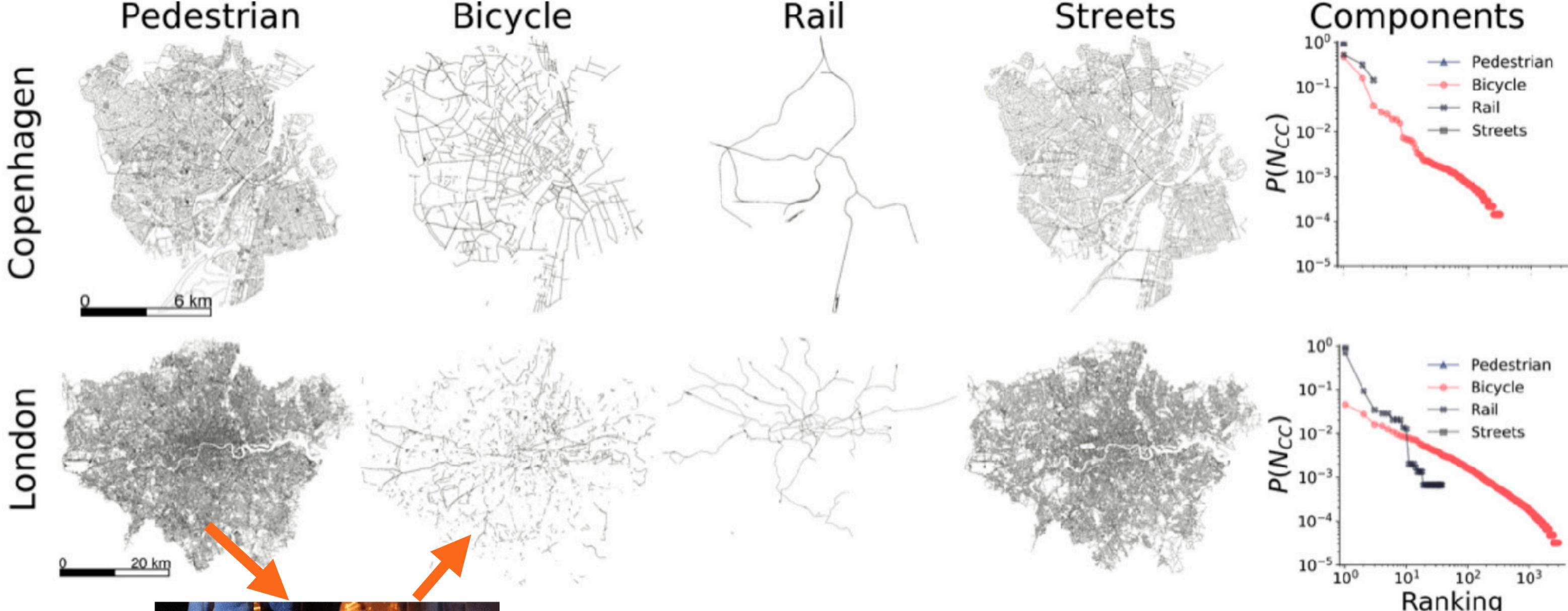
2) In London, the bicycle network has >3000 disconnected components

Bicycle networks are highly fragmented



1) In London, the largest connected bicycle component covers only 5% of nodes

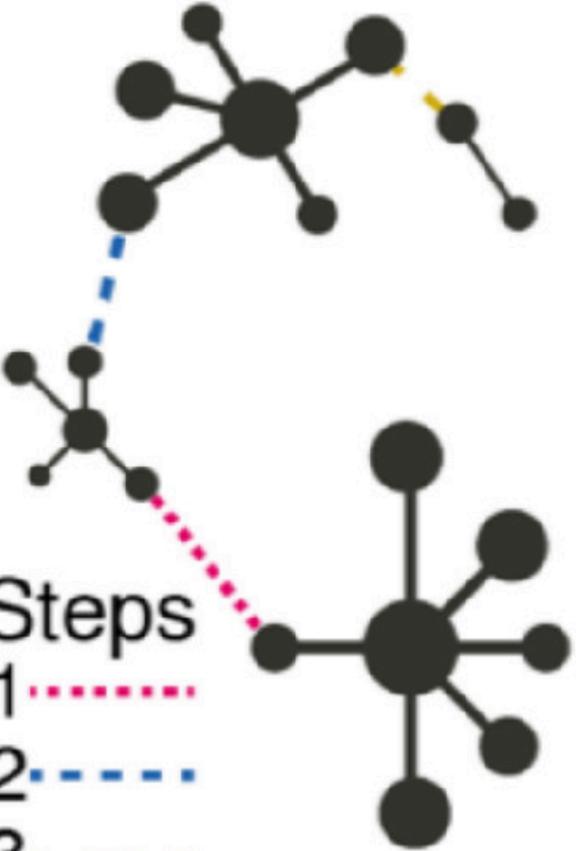
Bicycle networks are highly fragmented



How should we connect the components?

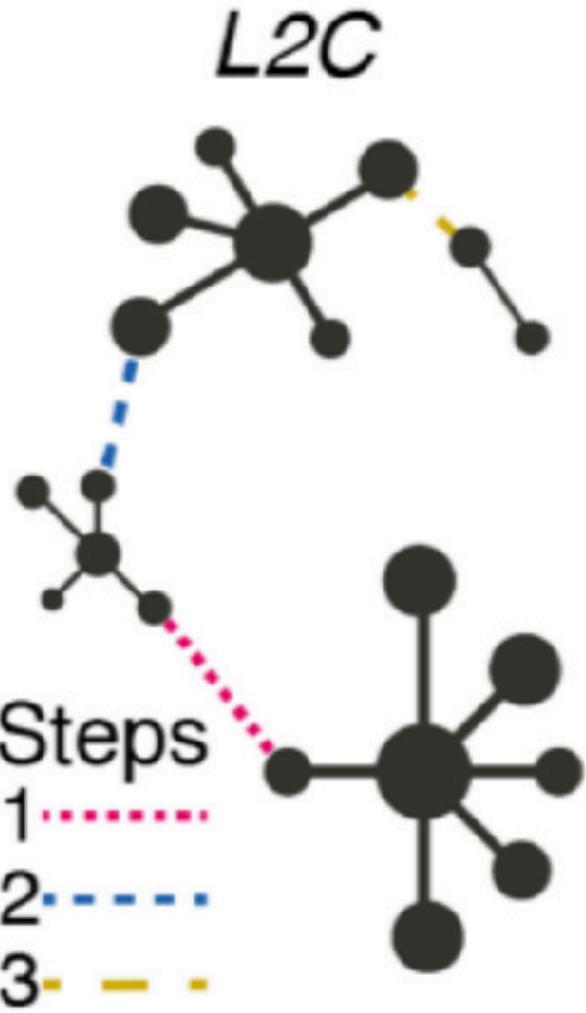
Largest to
closest

L2C

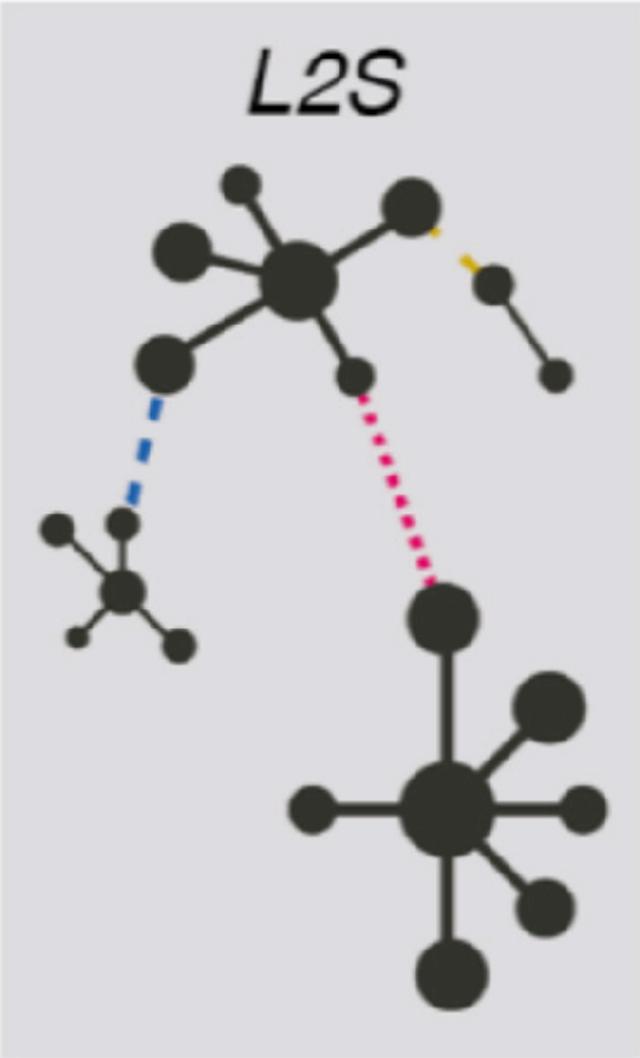


How should we connect the components?

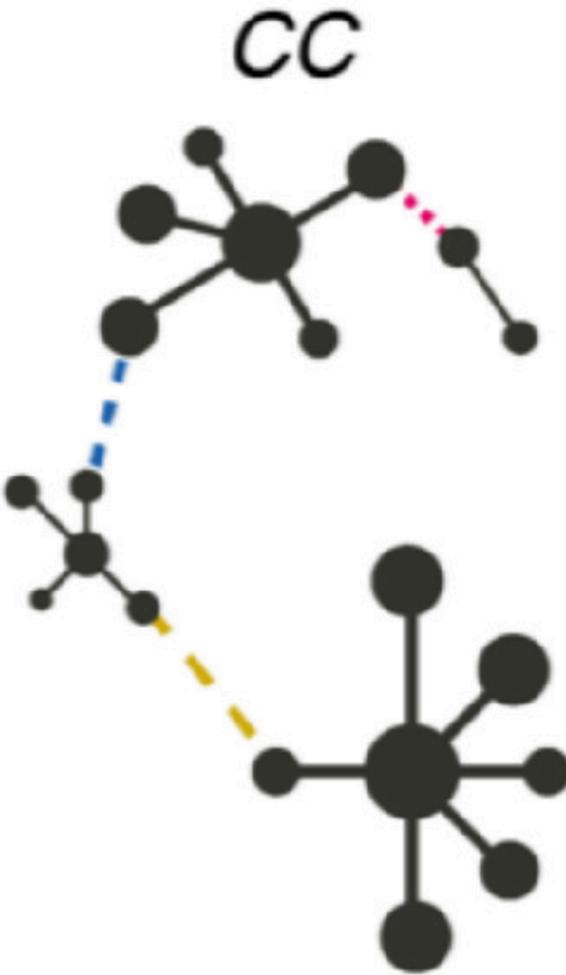
Largest to closest



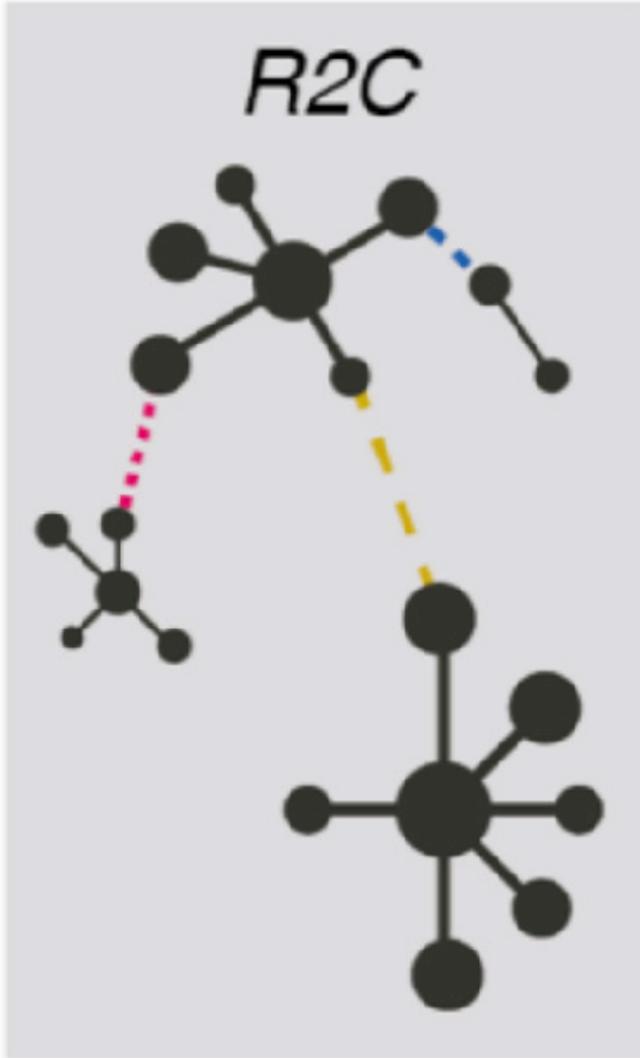
Largest to second largest



Closest components



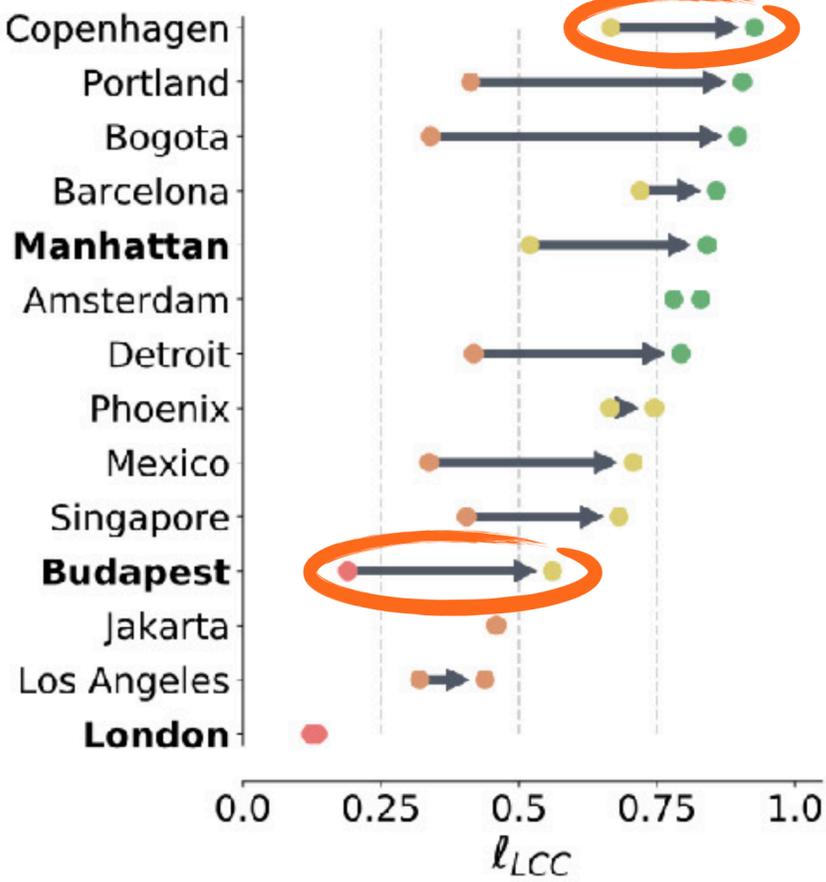
Random to closest



Effective connectivity improvements are possible

Small but **focused** investments connect the bicycle network effectively

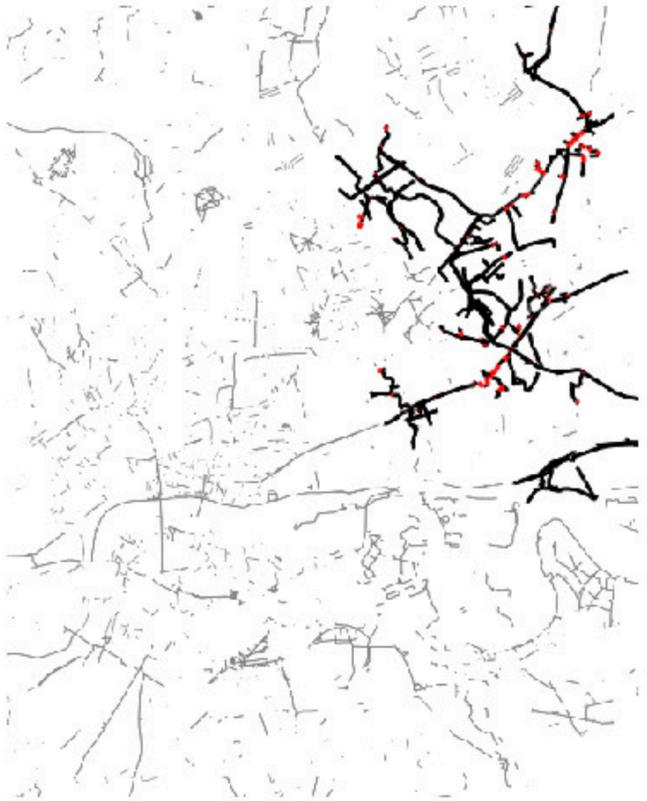
(a) 5 km investment



Manhattan



London



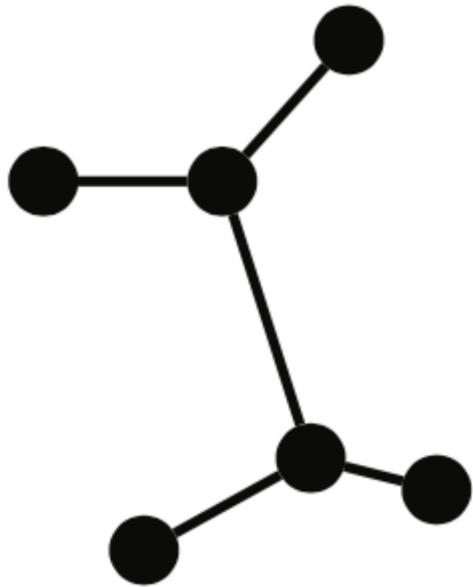
Budapest



Just connecting components comes with 3 issues

1) No resilience

Minimum spanning tree



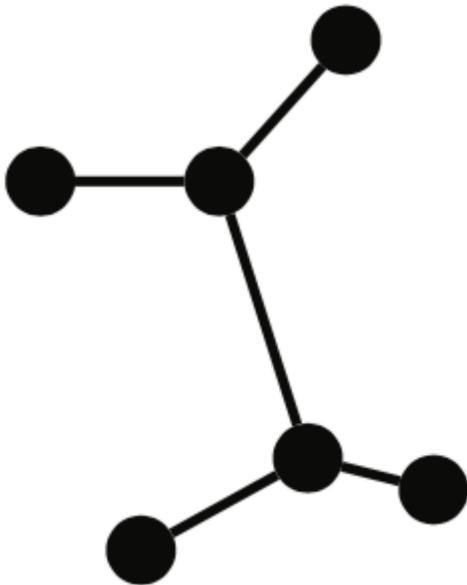
Investor's
optimum

Just connecting components comes with 3 issues

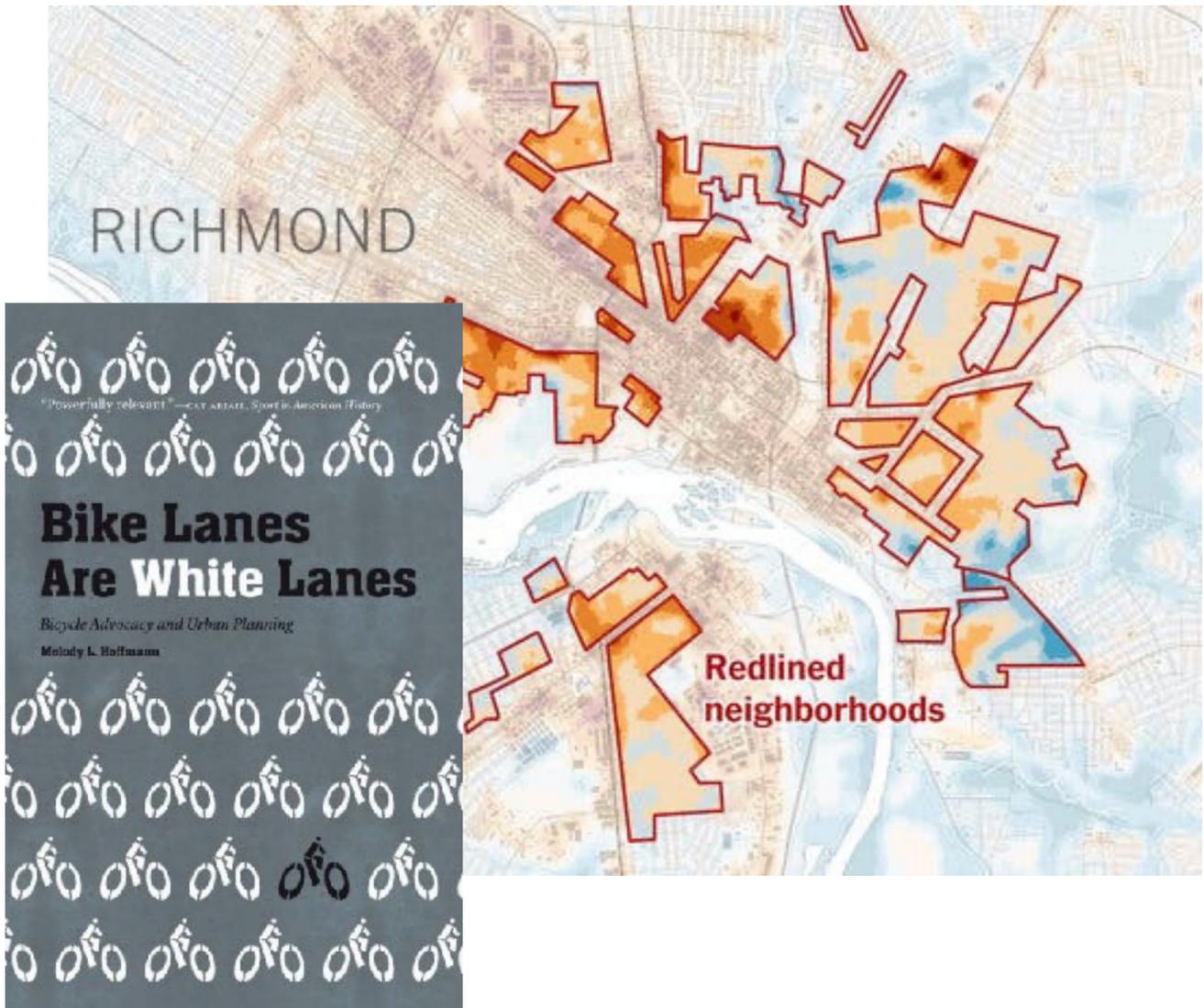
1) No resilience

2) Develops only developed areas

Minimum spanning tree



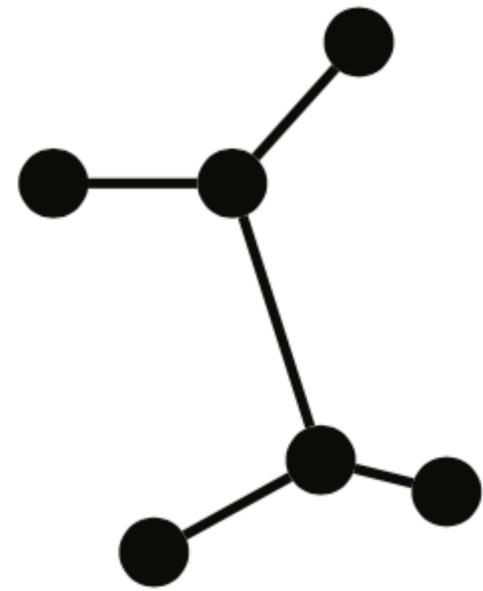
Investor's optimum



Just connecting components comes with 3 issues

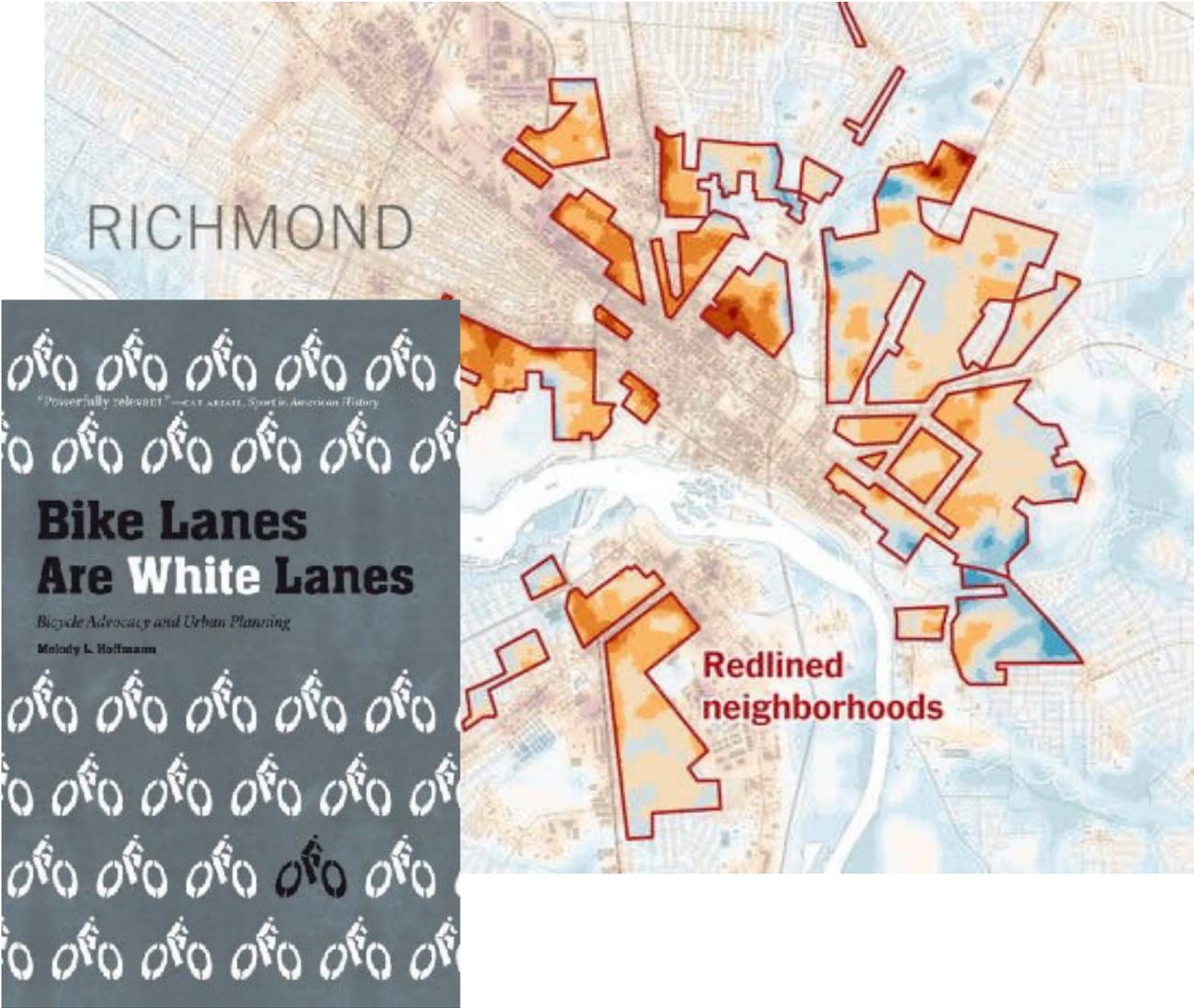
1) No resilience

Minimum spanning tree

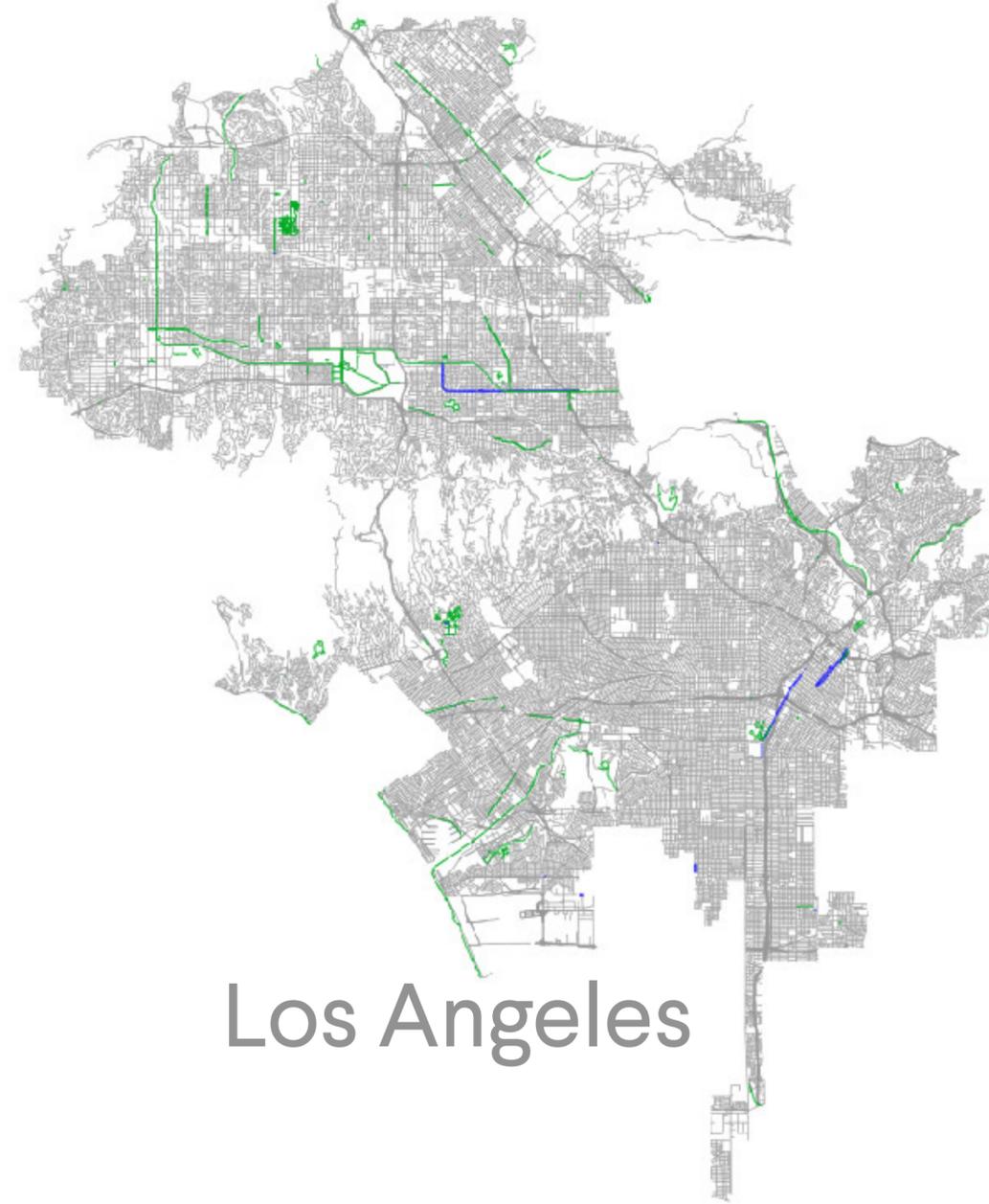


Investor's optimum

2) Develops only developed areas



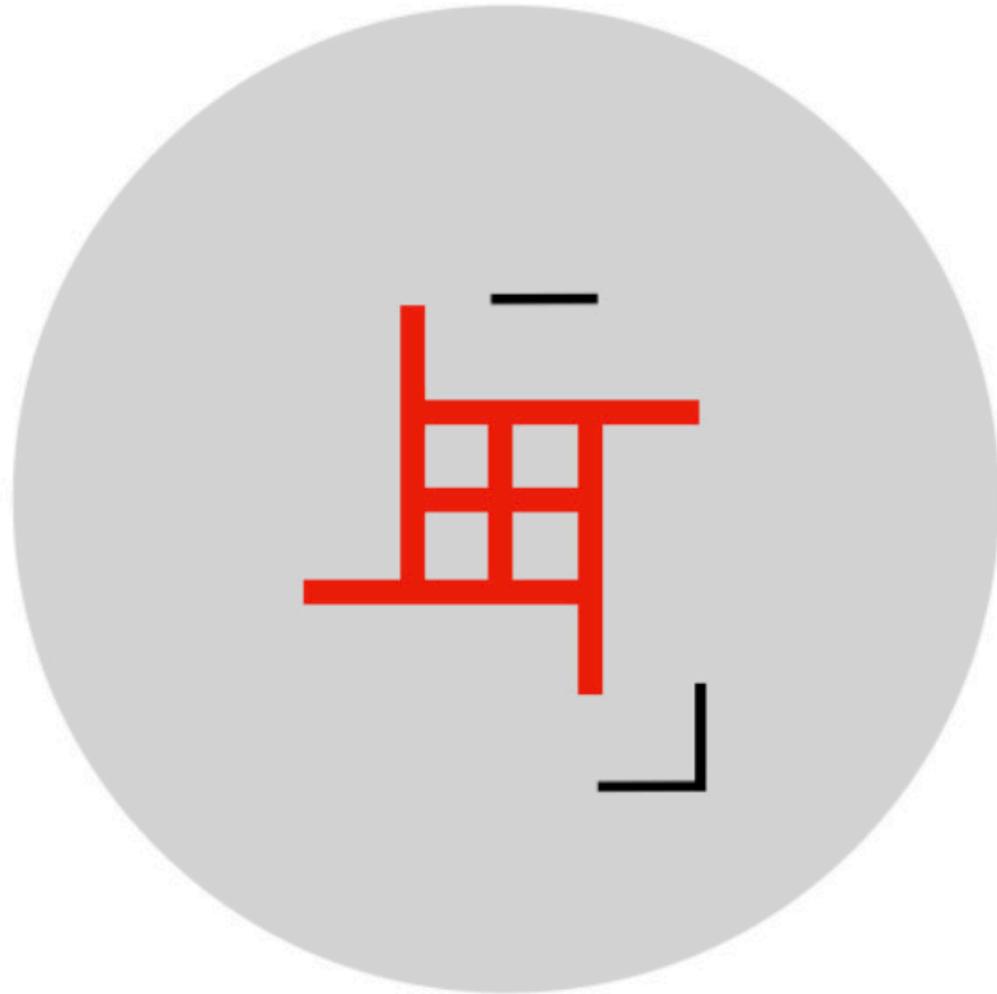
3) Irrelevant for >99% of cities on the planet



Let's grow networks
from scratch

2) Growing bicycle networks

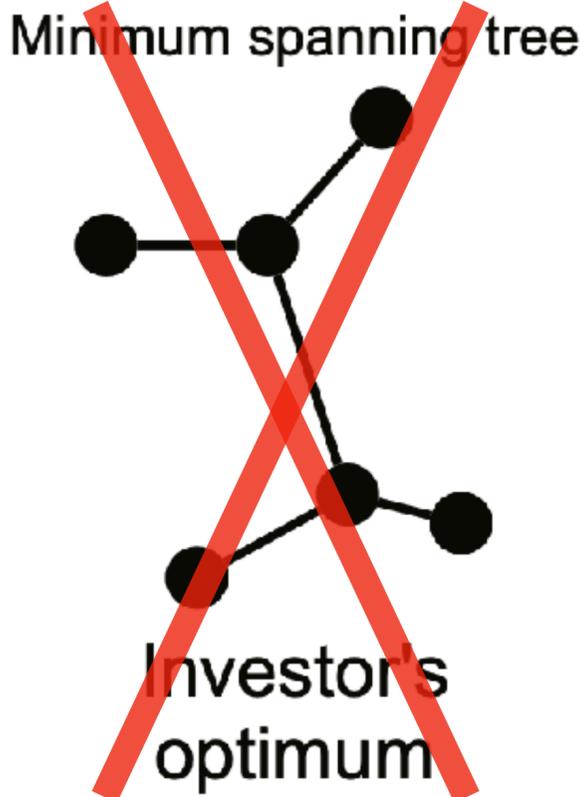
Most cities
Not developed



Grow from scratch
GrowBike.Net

Inspired by CROW, we want a **cohesive** network

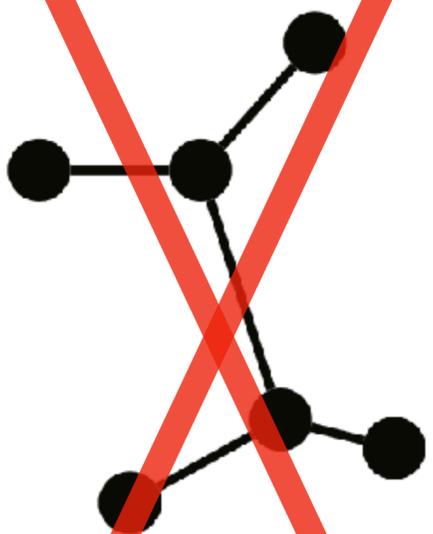
Connectedness & Resilience



Inspired by CROW, we want a **cohesive** network

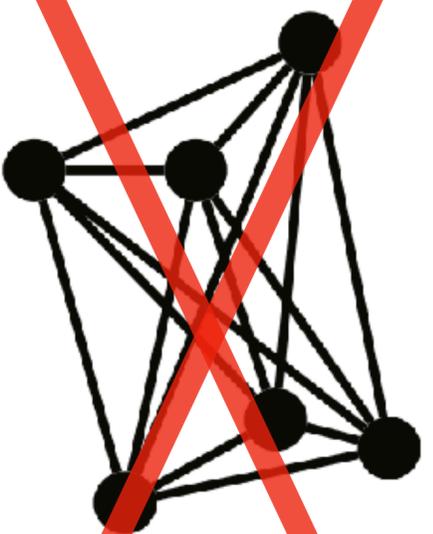
Connectedness & Resilience

Minimum spanning tree



Investor's optimum

Fully connected

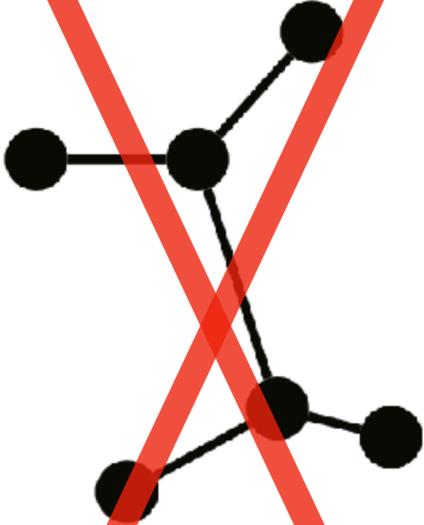


Traveler's optimum

Inspired by CROW, we want a **cohesive** network

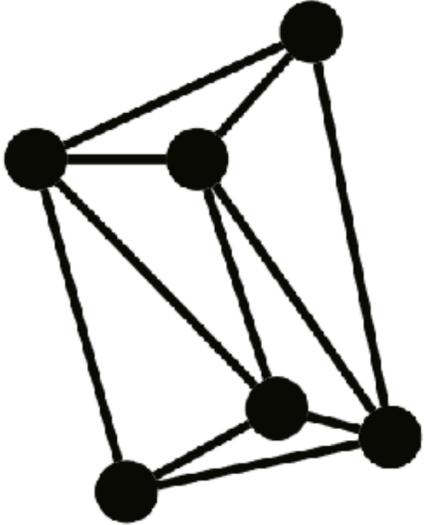
Connectedness & Resilience

~~Minimum spanning tree~~



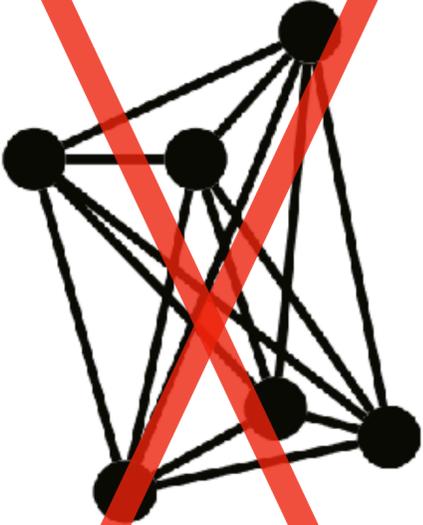
~~Investor's optimum~~

Triangulation



Cohesive planar network

~~Fully connected~~



~~Traveler's optimum~~

Economic

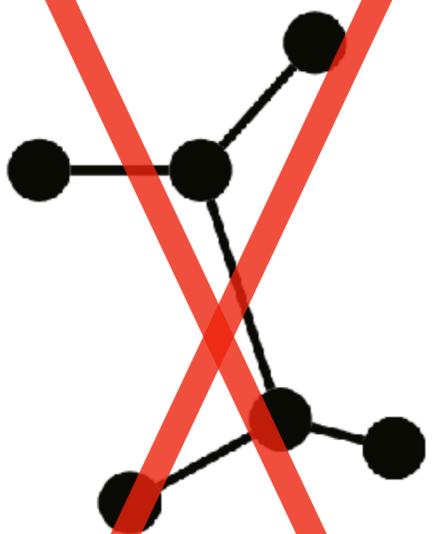
Resilient

Inspired by CROW, we want a **cohesive** network

Connectedness & Resilience

& Coverage

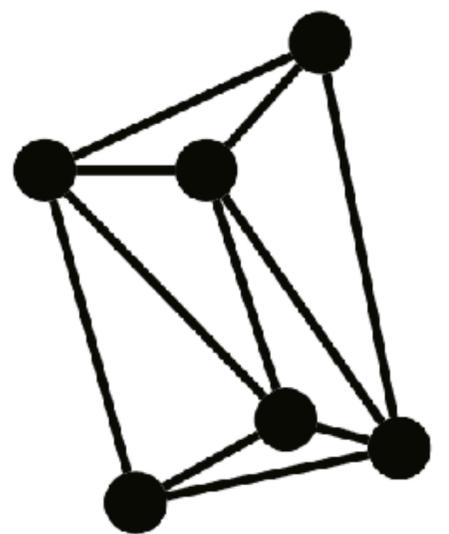
~~Minimum spanning tree~~



~~Investor's optimum~~

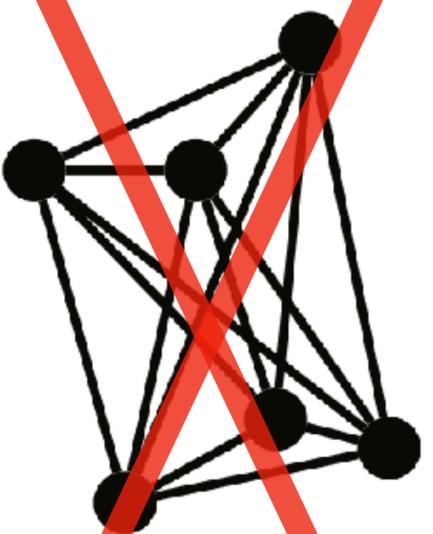
Economic

Triangulation



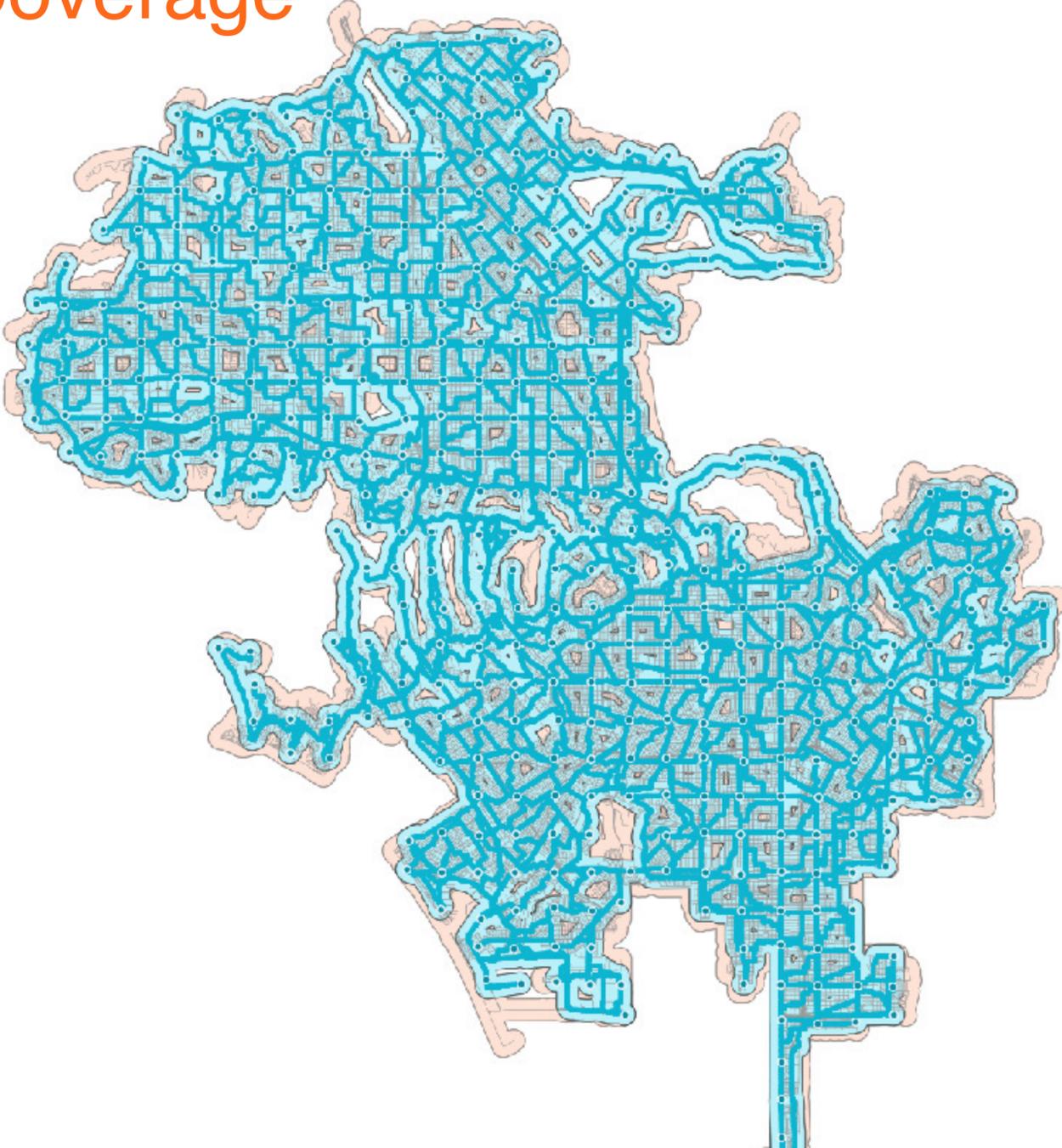
Cohesive planar network

~~Fully connected~~



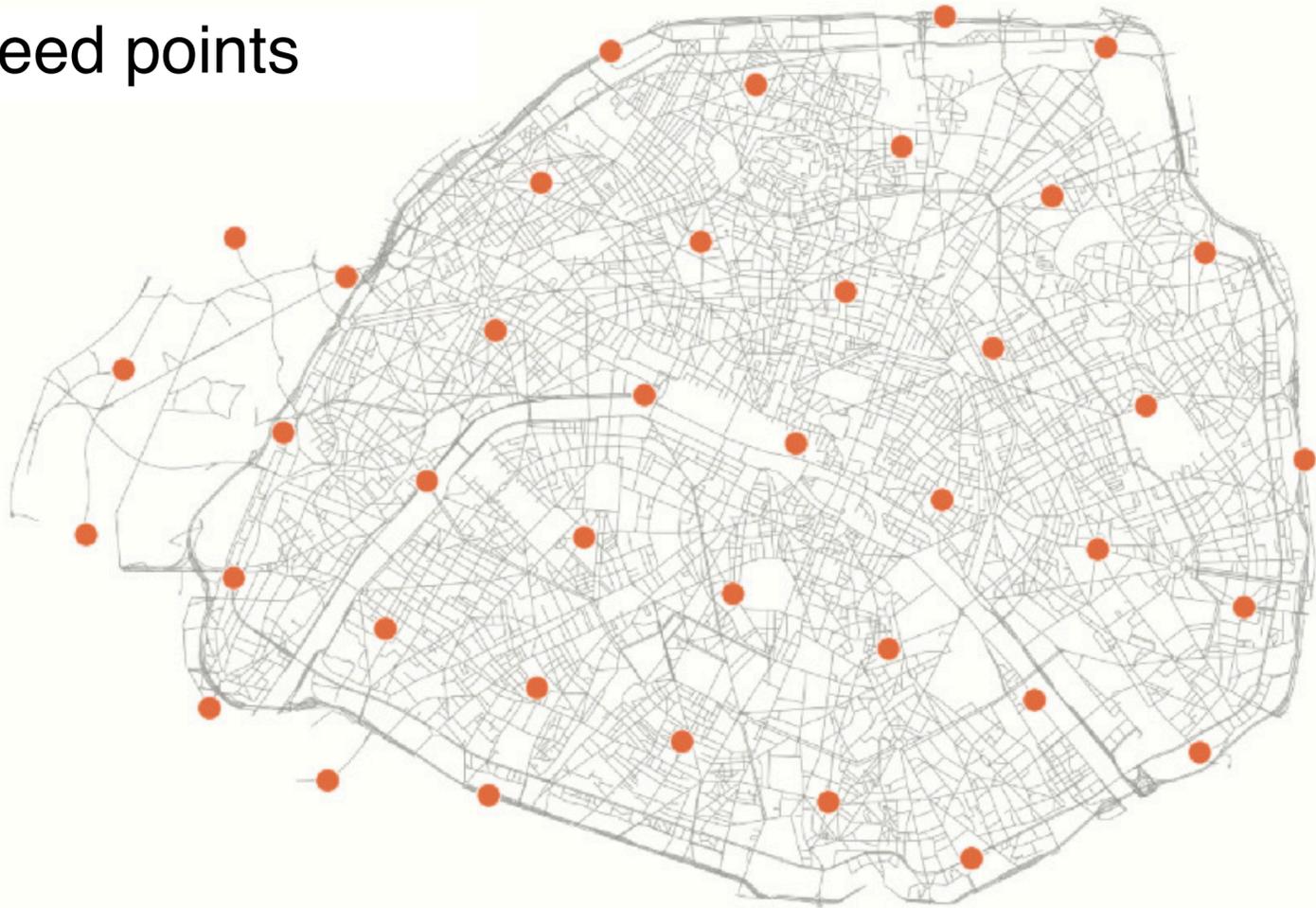
~~Traveler's optimum~~

Resilient

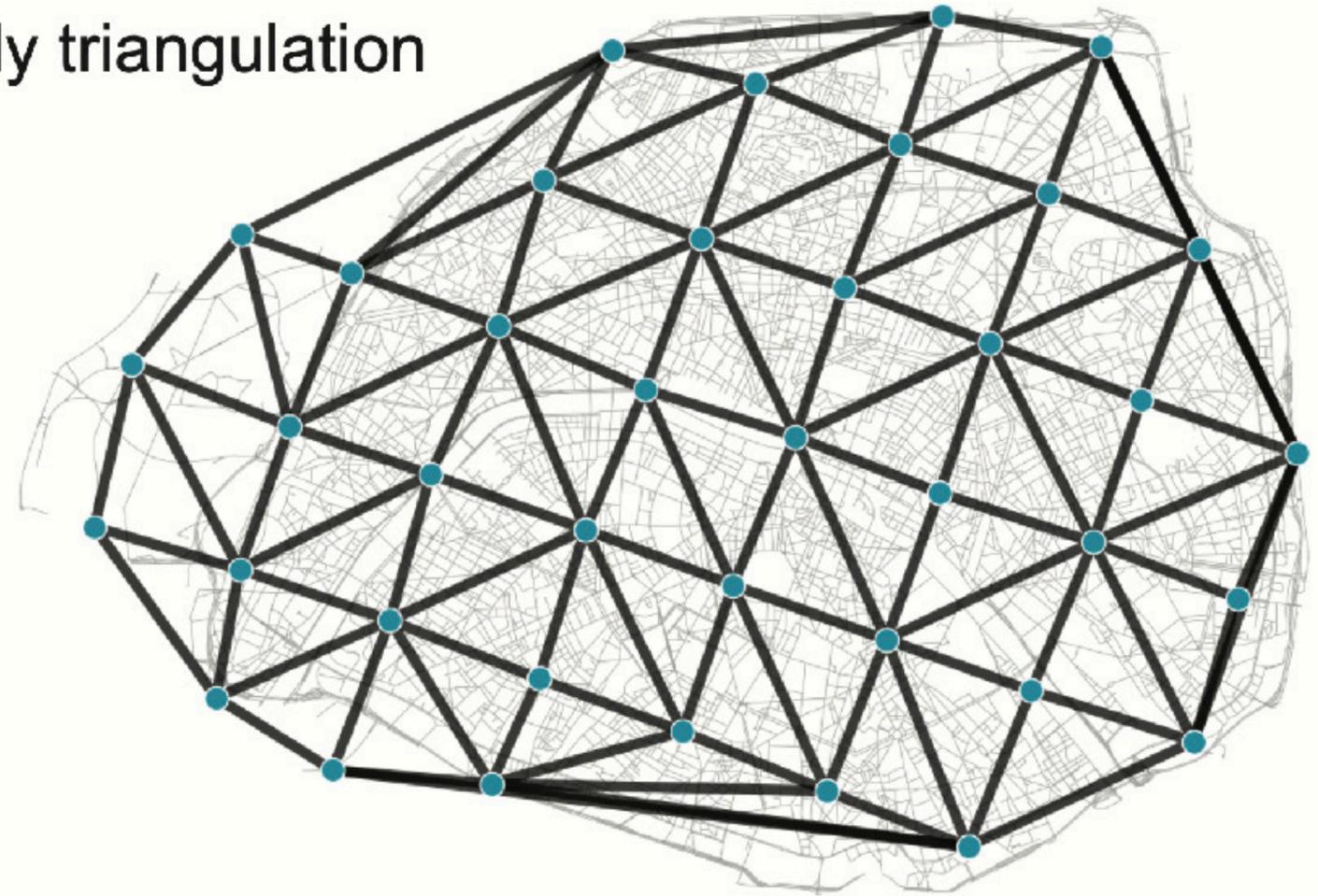


We build a greedy triangulation between points of interest

1) Seed points



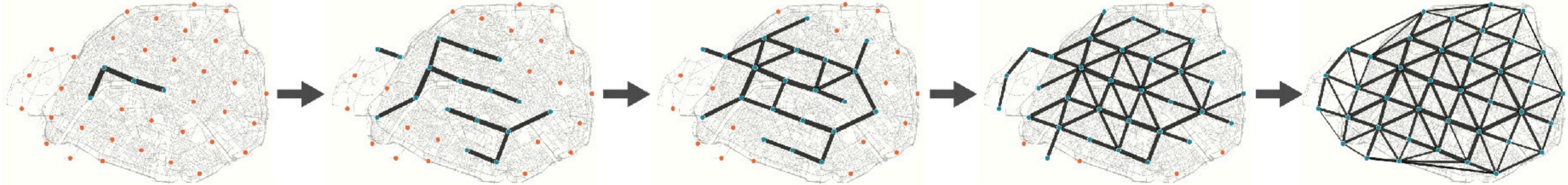
2) Greedy triangulation



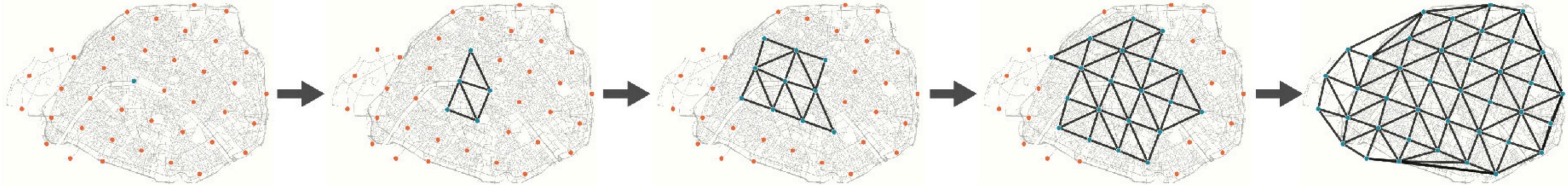
We build a greedy triangulation between points of interest

3) Order by growth strategy

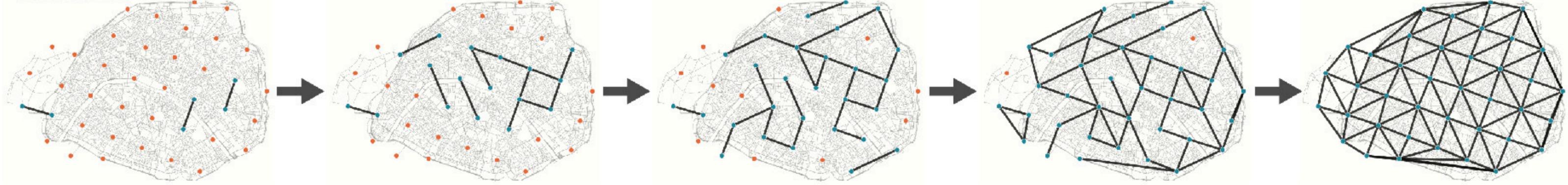
Betweenness



Closeness



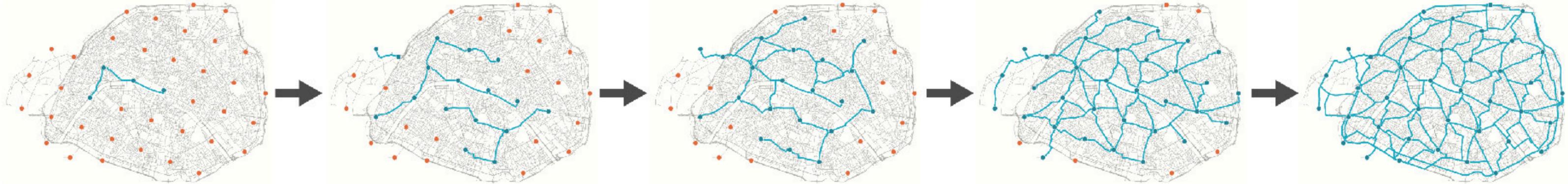
Random



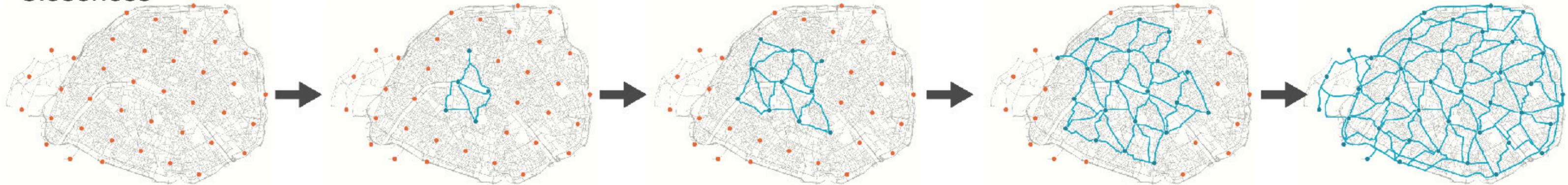
We build a greedy triangulation between points of interest

4) Route on street network

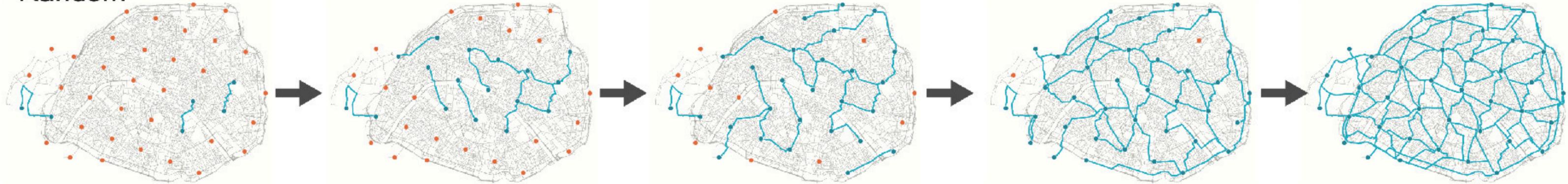
Betweenness



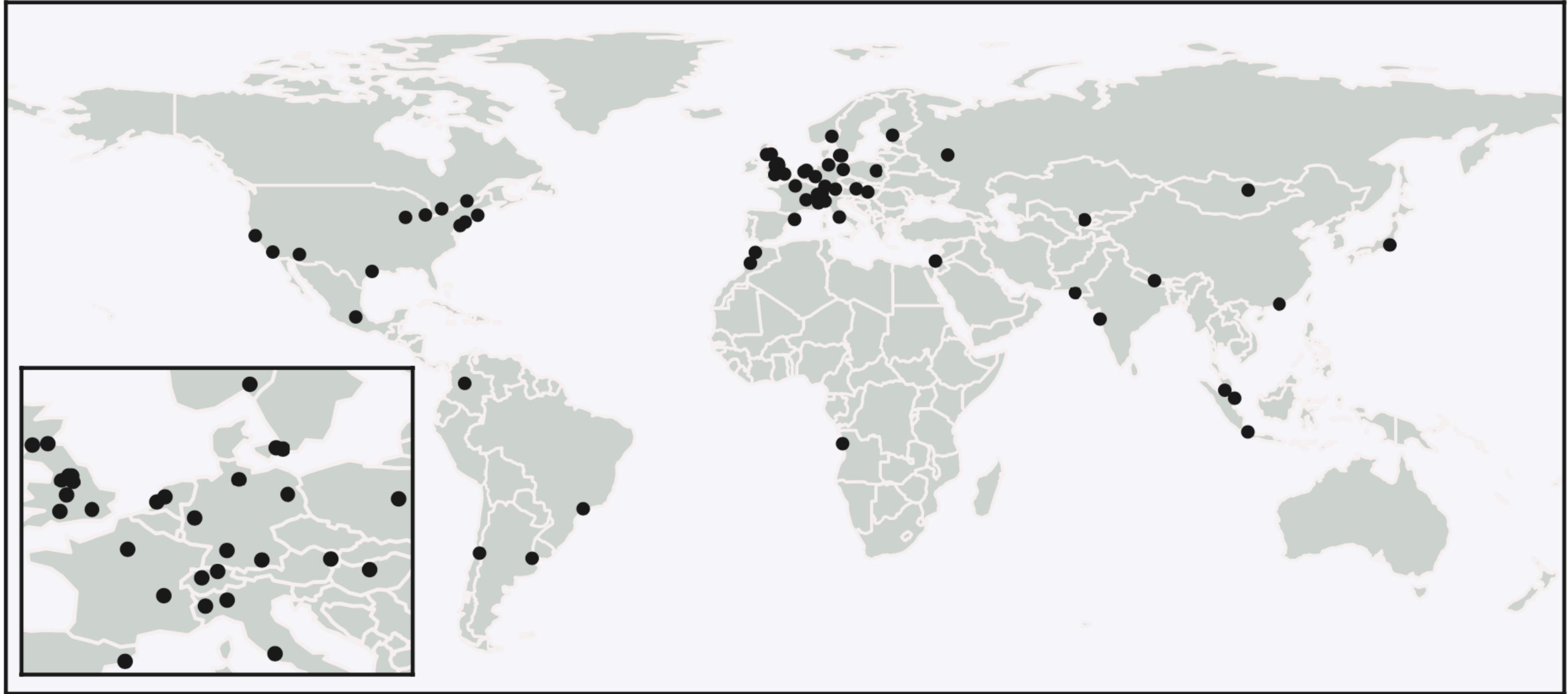
Closeness



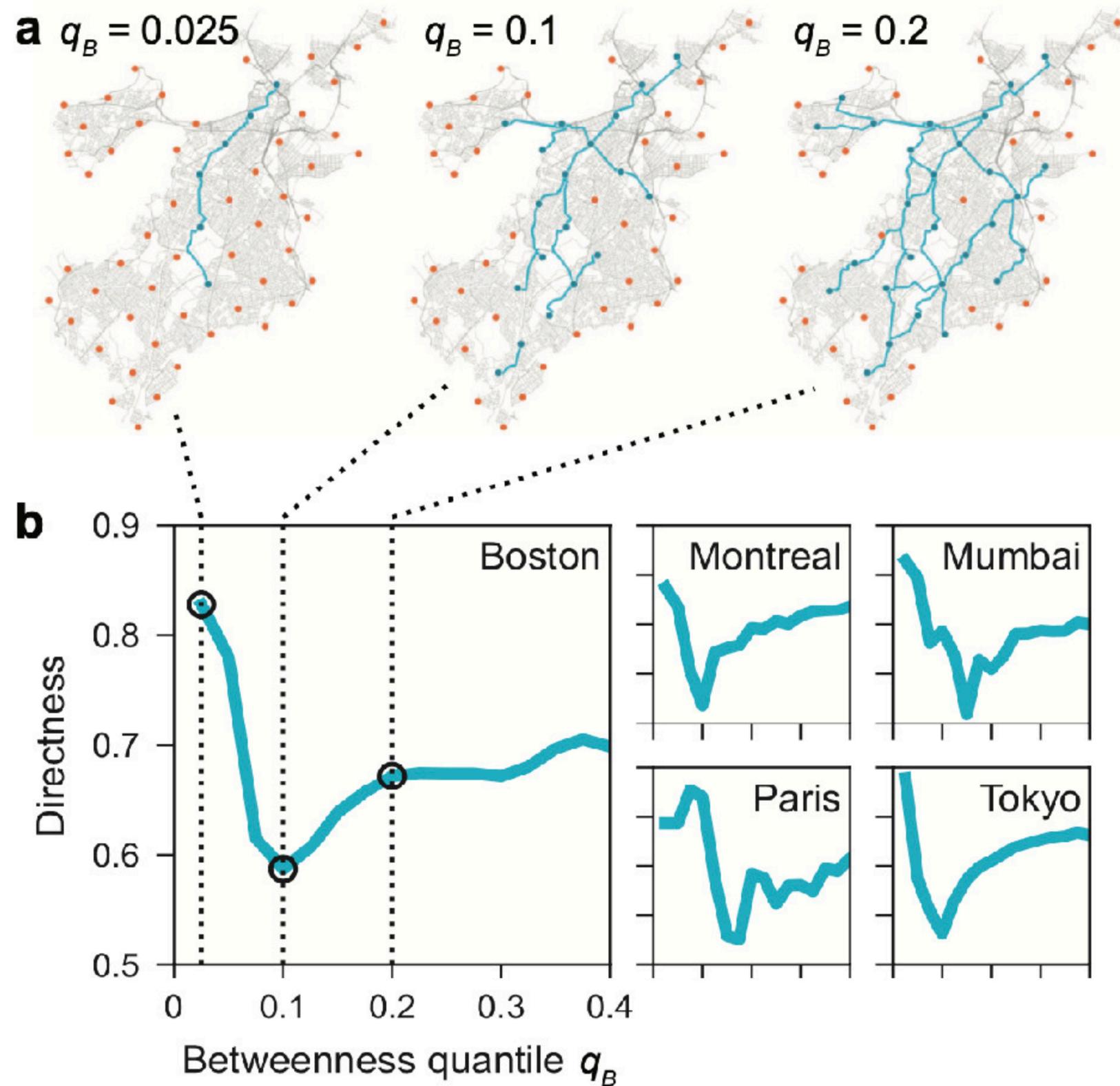
Random



We explore 62 cities



Result 1: Investments need to surpass a **critical threshold**



The pieces need to connect and to form cycles

Policy implication 1: **Invest persistently!**



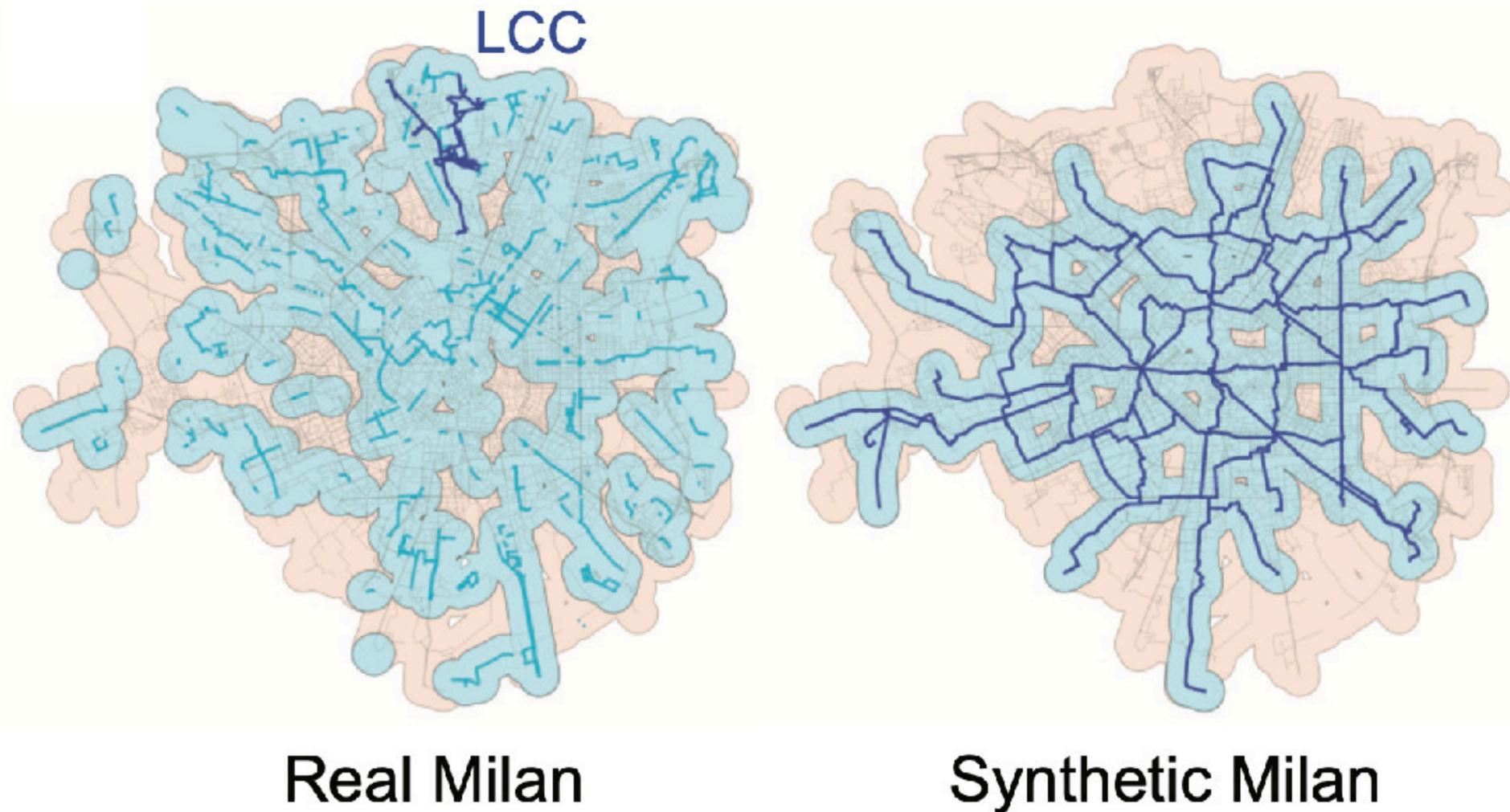
Brent Toderian  @BrentToderian · Jul 30



My real advice for ambitious municipal elected leaders on building a safe, connected network of REAL (not painted lines or sharrows) bike infrastructure — **direct your staff to do ALL of the work that you're currently planning to build over the next 5-10 years, ALL IN ONE YEAR.**

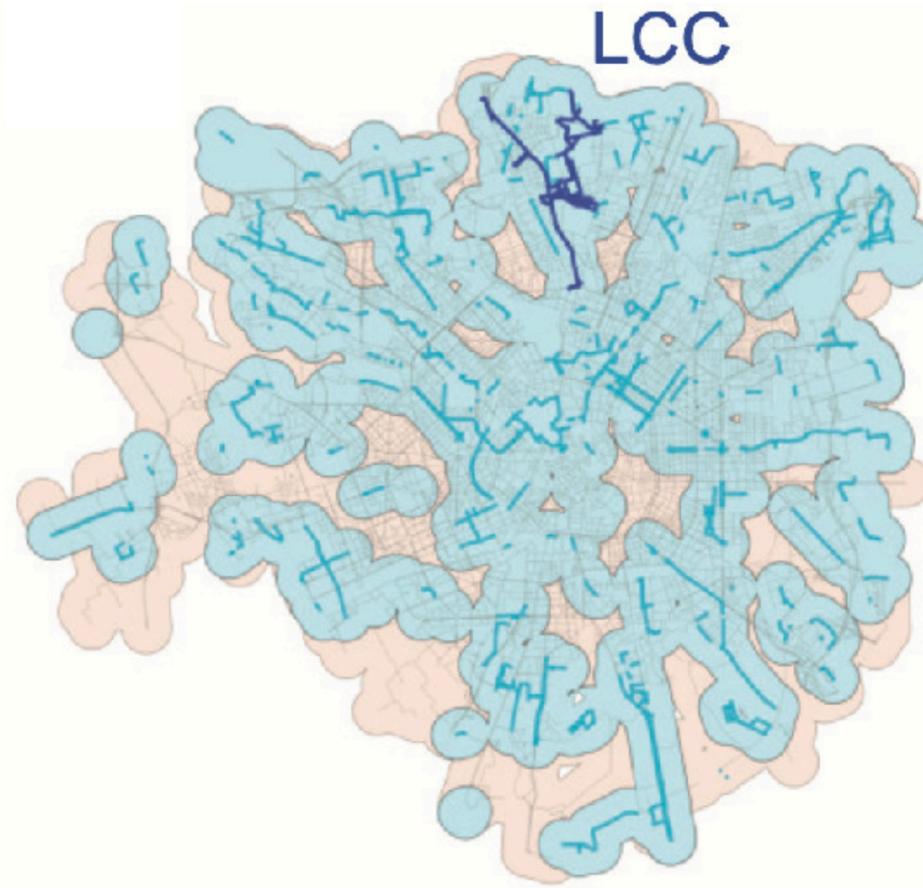
Result 2: It's not a network's length that matters but how you grow it

At same length, we could
do much better

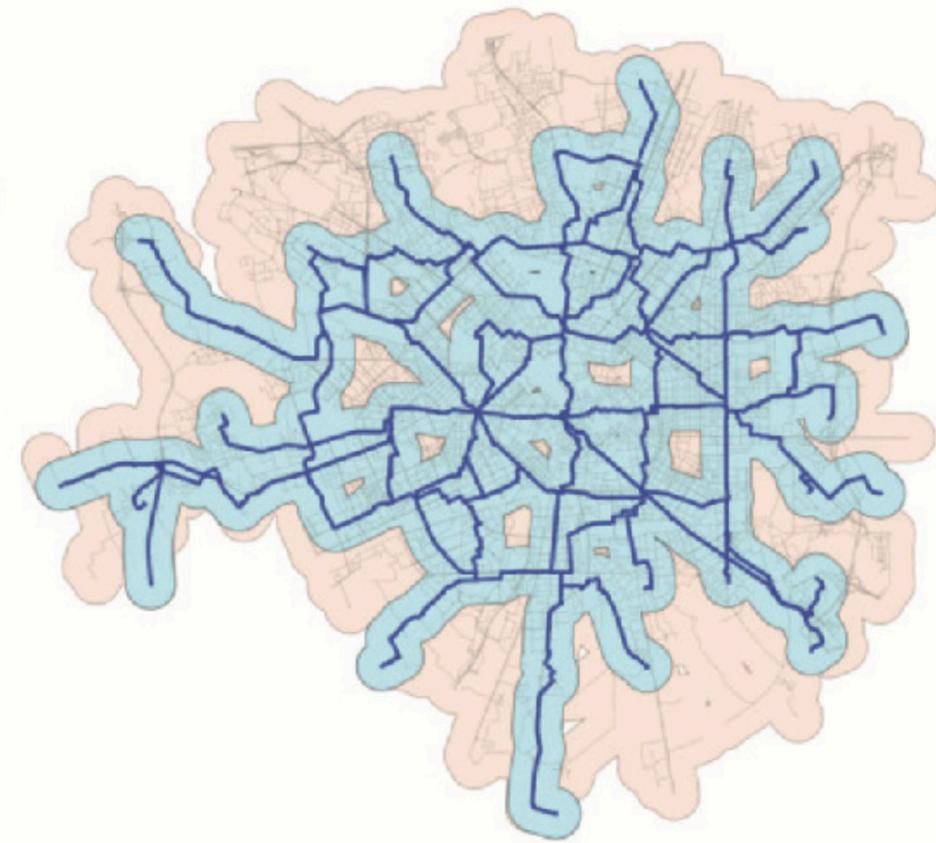


Policy implication 2: Strategy matters: **Build for the whole city**

Avoid "random-like",
piecewise growth

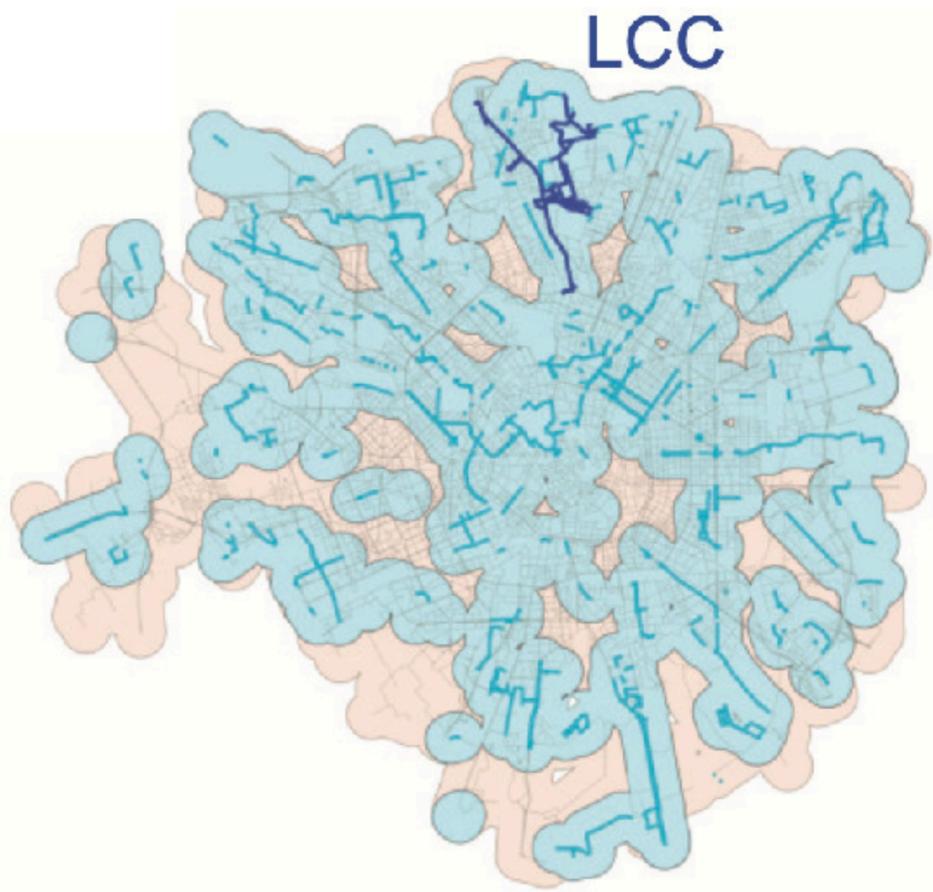
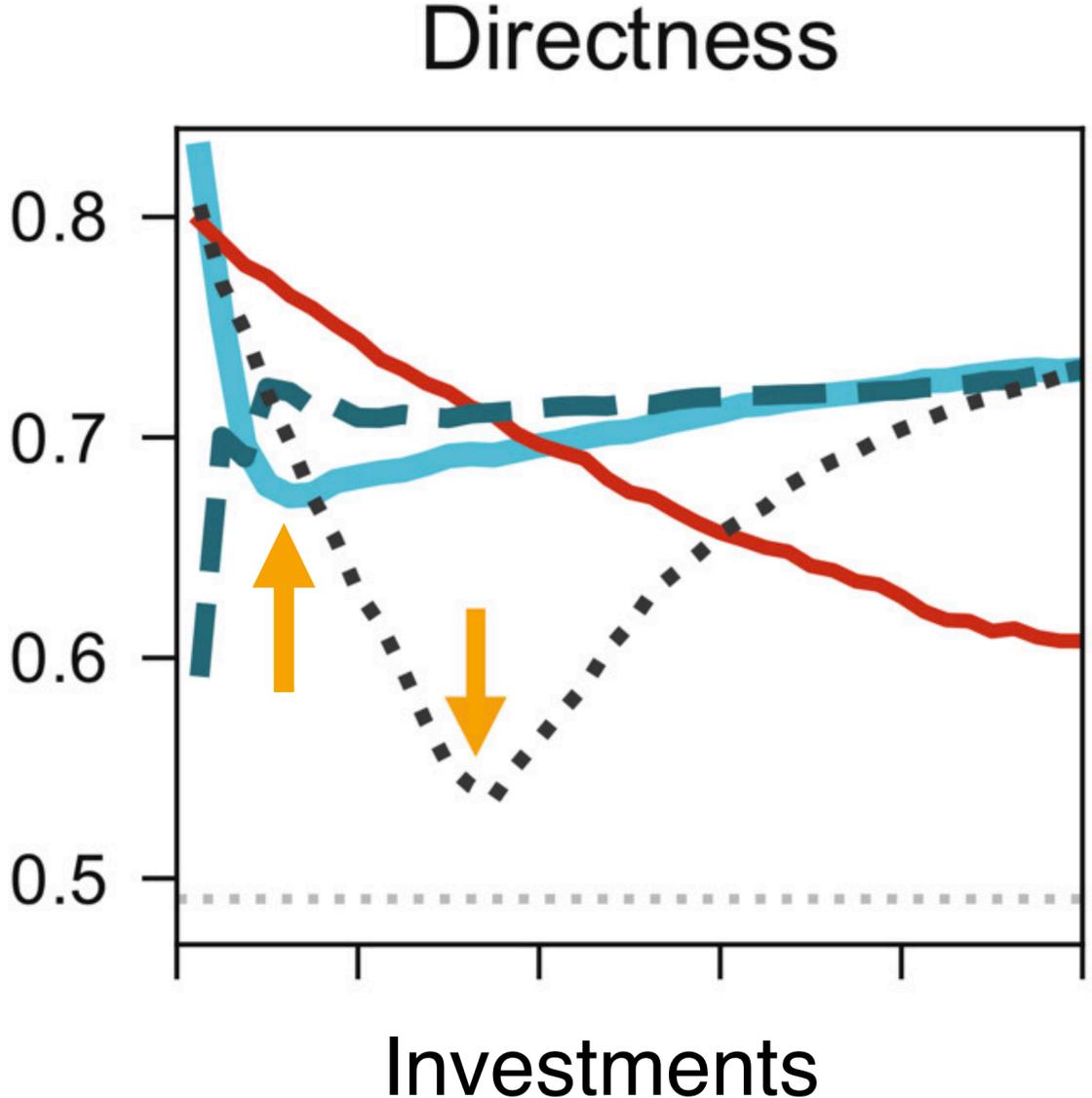


Real Milan

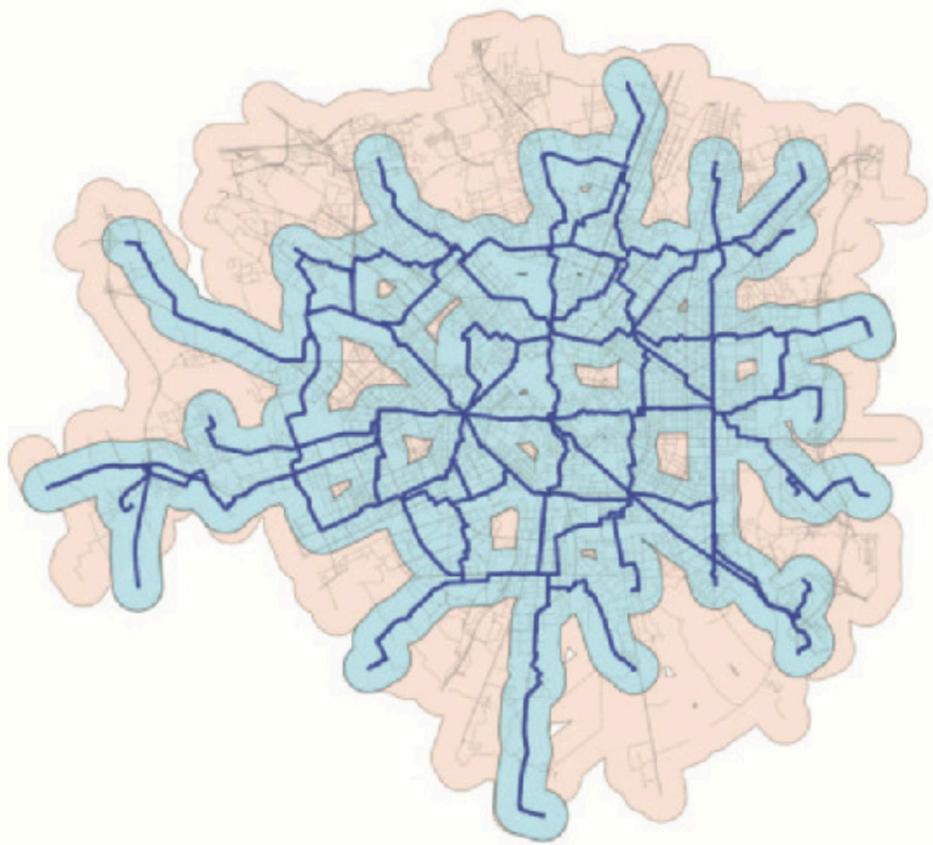


Synthetic Milan

Policy implication 2: Strategy matters: **Build for the whole city**



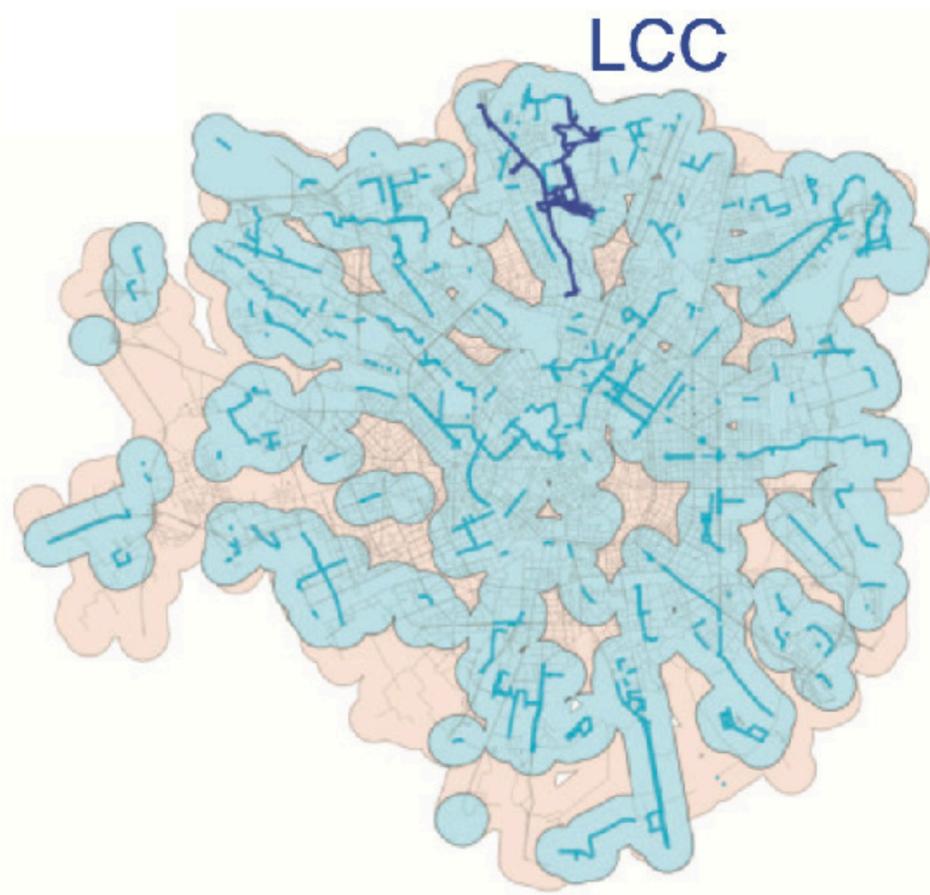
Real Milan



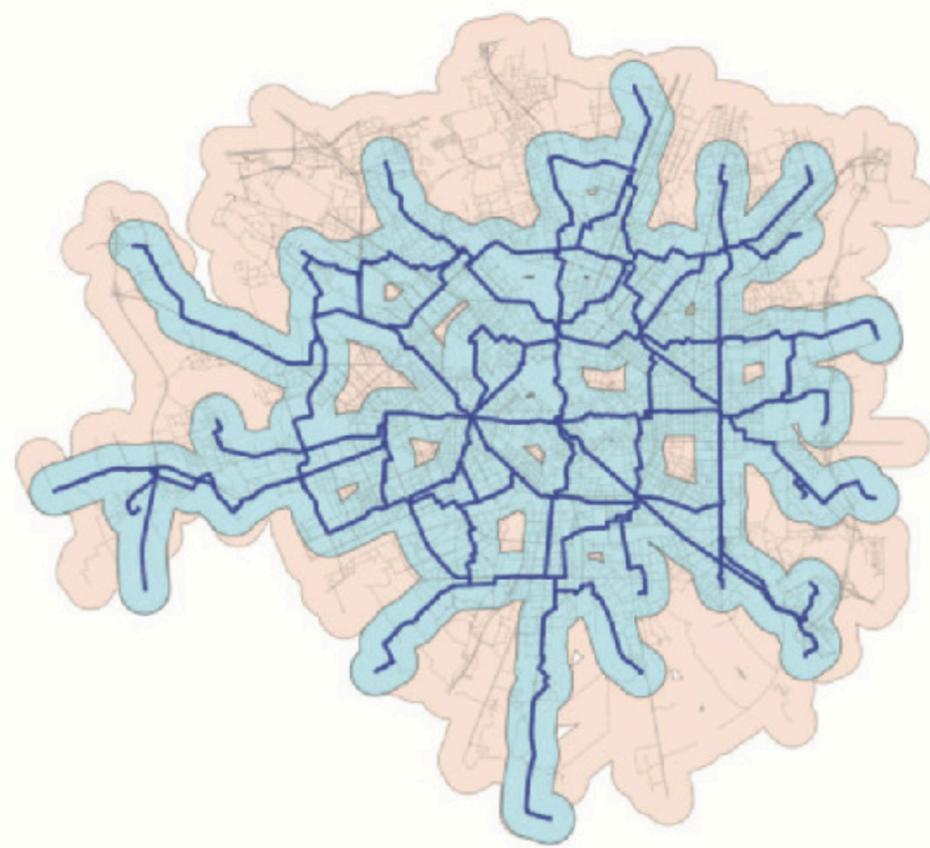
Synthetic Milan

Random growth **needs 3x the investments than a global strategy**

Easier said than done - Isn't this unrealistic??



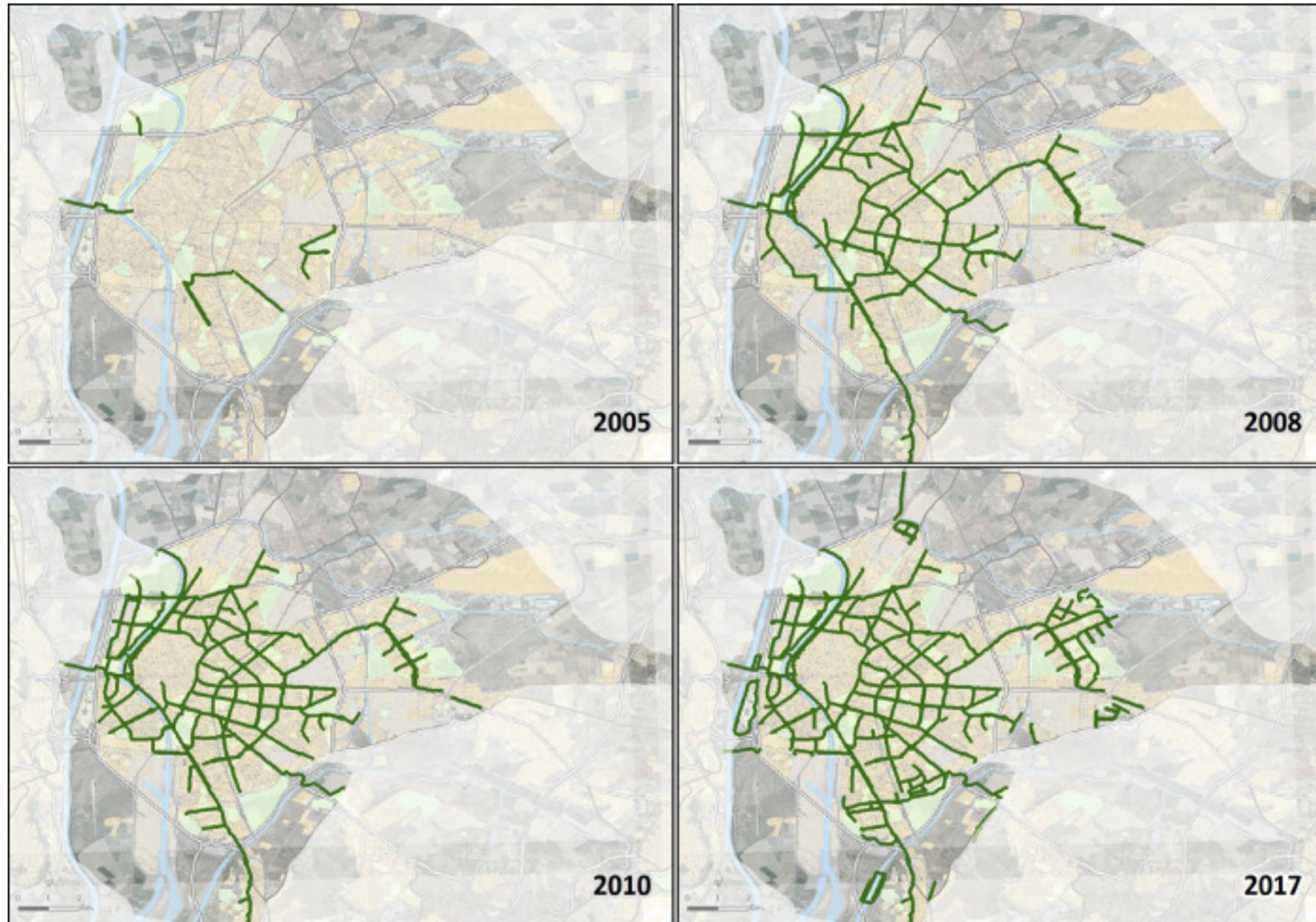
Real Milan



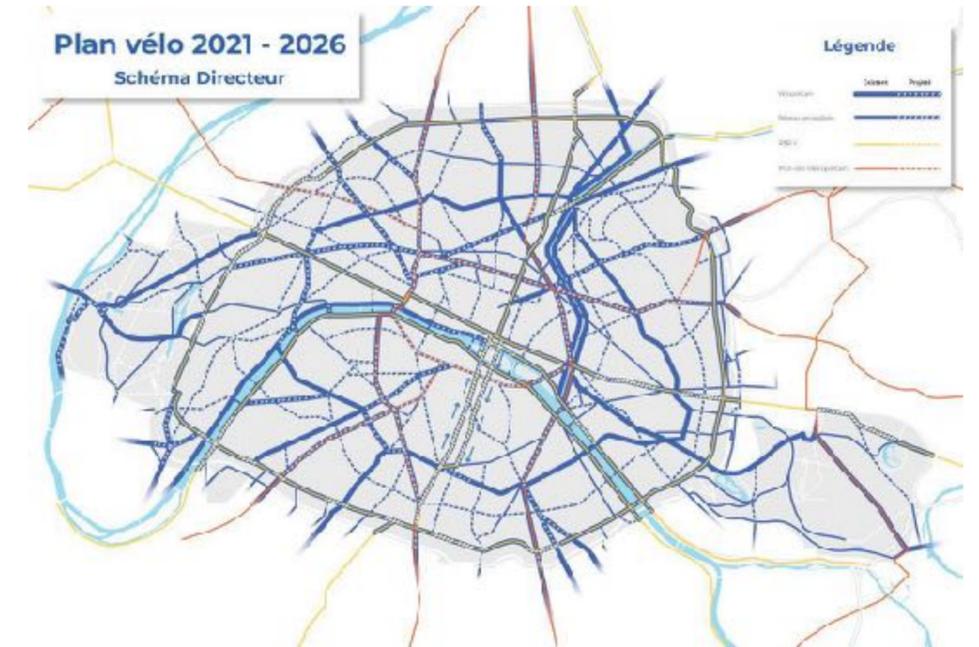
Synthetic Milan

Easier said than done - Isn't this unrealistic??

Nope: See Seville



Also: Paris, Oslo, ...



There is
no excuse

Explore your city at [GrowBike.Net](https://growbike.net)

The interface features a sidebar on the left with the following city selection options:

- Search city or country
- LONDON ENGLAND
- LOS ANGELES USA
- LUANDA ANGOLA
- LYON FRANCE** (selected)
- MALMO SWEDEN
- MANCHESTER ENGLAND
- MANHATTAN USA
- MARRAKESH MOROCCO

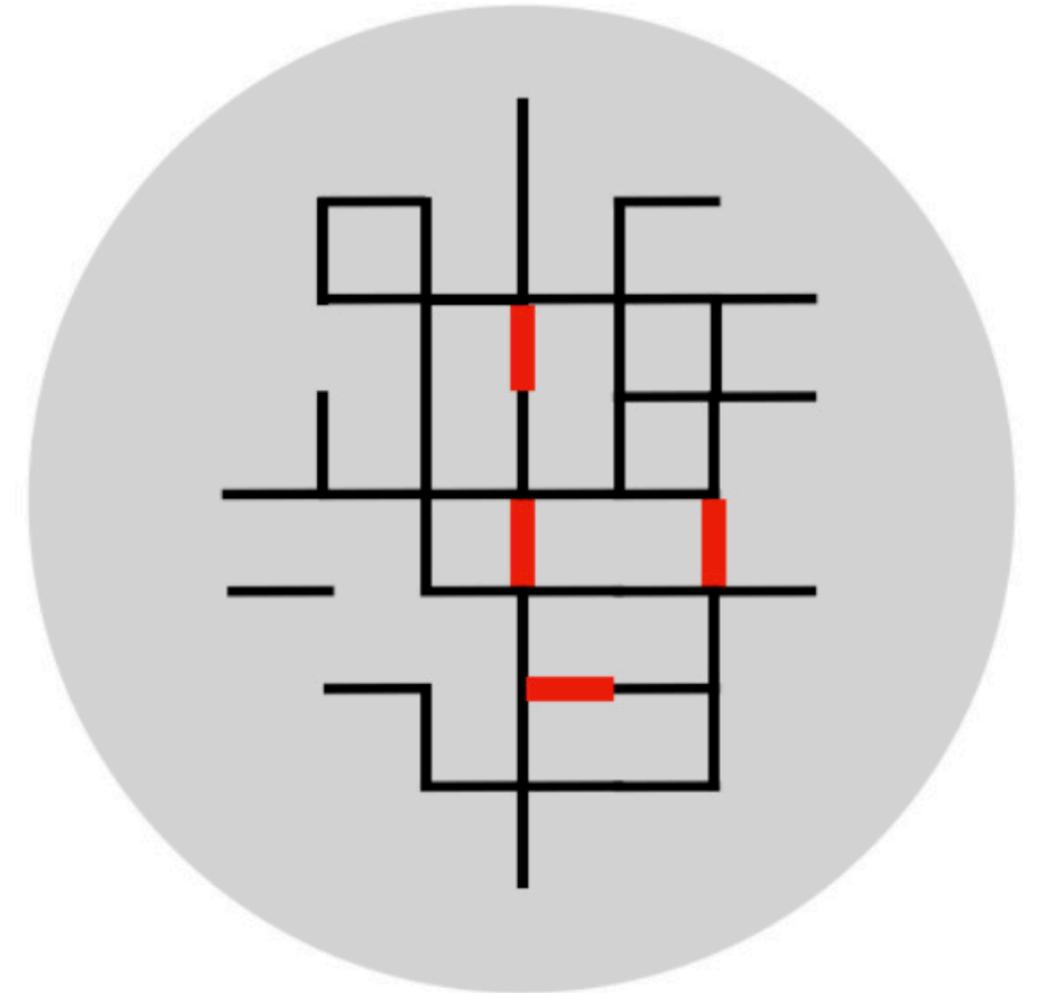
The main map area displays a cycling route in blue over a dark map of Lyon and its surroundings. The route covers various districts including the 9th, 6th, 3rd, 7th, and 8th arrondissements of Lyon, as well as areas like Caluire-et-Cuire, Villeurbanne, and Bron. A play button and a progress slider are located at the bottom of the map.

At the bottom center, the stage information is displayed: **Stage 24 | 69 km**. Below this, there are buttons for 'Rail', 'Grid', 'B', 'C', and 'R'.

Mapbox and OpenStreetMap logos are visible in the bottom left and right corners, respectively.

3) Fixing bicycle networks

Few cities
Developed and
mostly connected



Find missing links

FixBike.Net

How to find the missing links in well-developed networks?

In Copenhagen, most of the network is 1 connected component.



How to find the missing links in well-developed networks?

In Copenhagen, most of the network is 1 connected component.

Still, there are a lot of "missing links".

How to find them?

How to prioritize them?



From map to gap: **IPDC**

- 1) **I**dentify gaps
- 2) **P**rioritize gaps
- 3) **D**ecluster gaps
- 4) **C**lassify gaps



1) Identify: We need a formal definition of “gap”

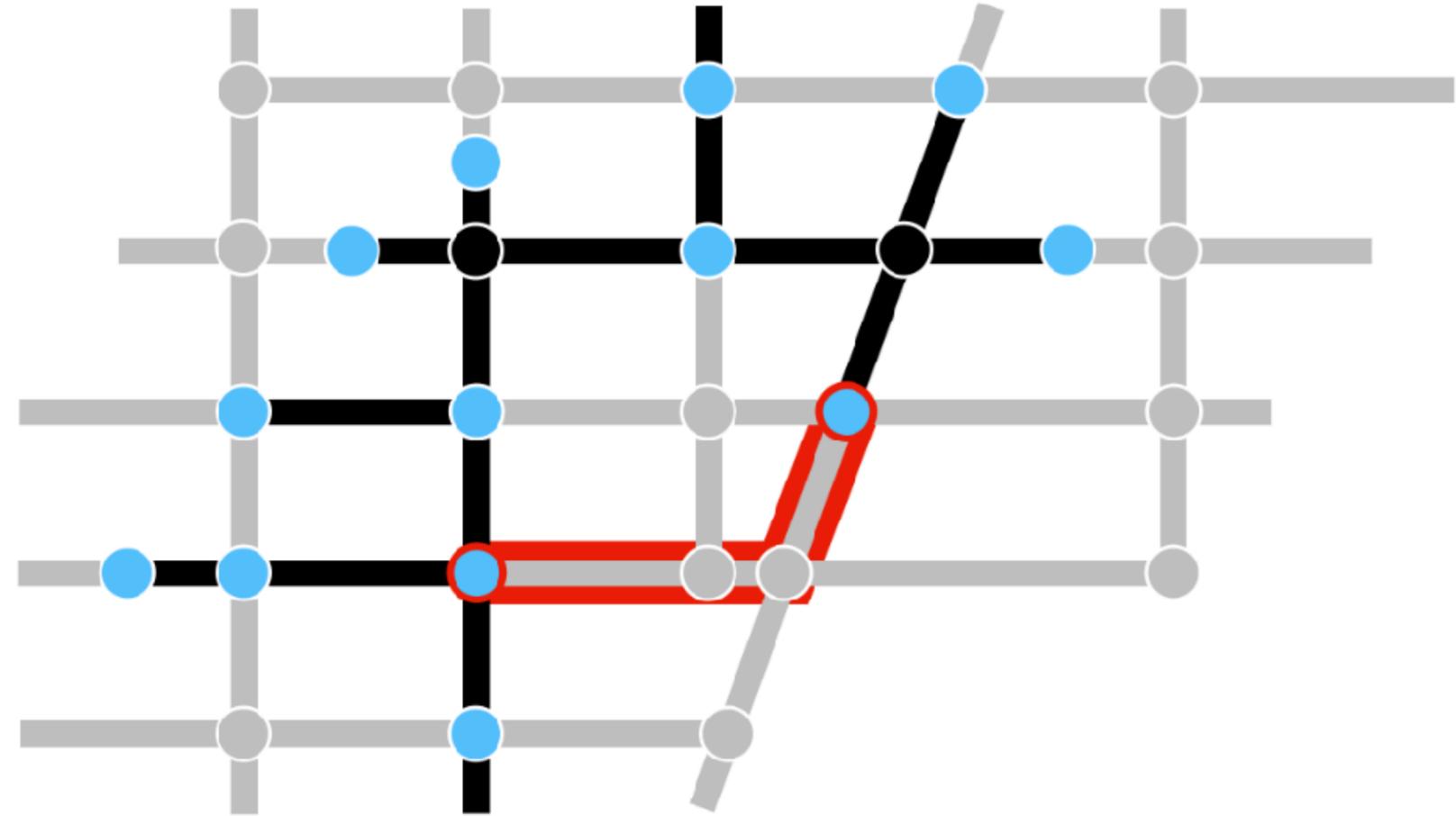
Multiplex network

Links

- 1) unprotected
- 2) protected

Nodes

- 1) unprotected
- 2) protected
- 3) **contact**



A **gap** is a shortest path between two **contact nodes** that consists only of unprotected links

2) Prioritize

We could find millions of gaps...

We need a metric to prioritize them.



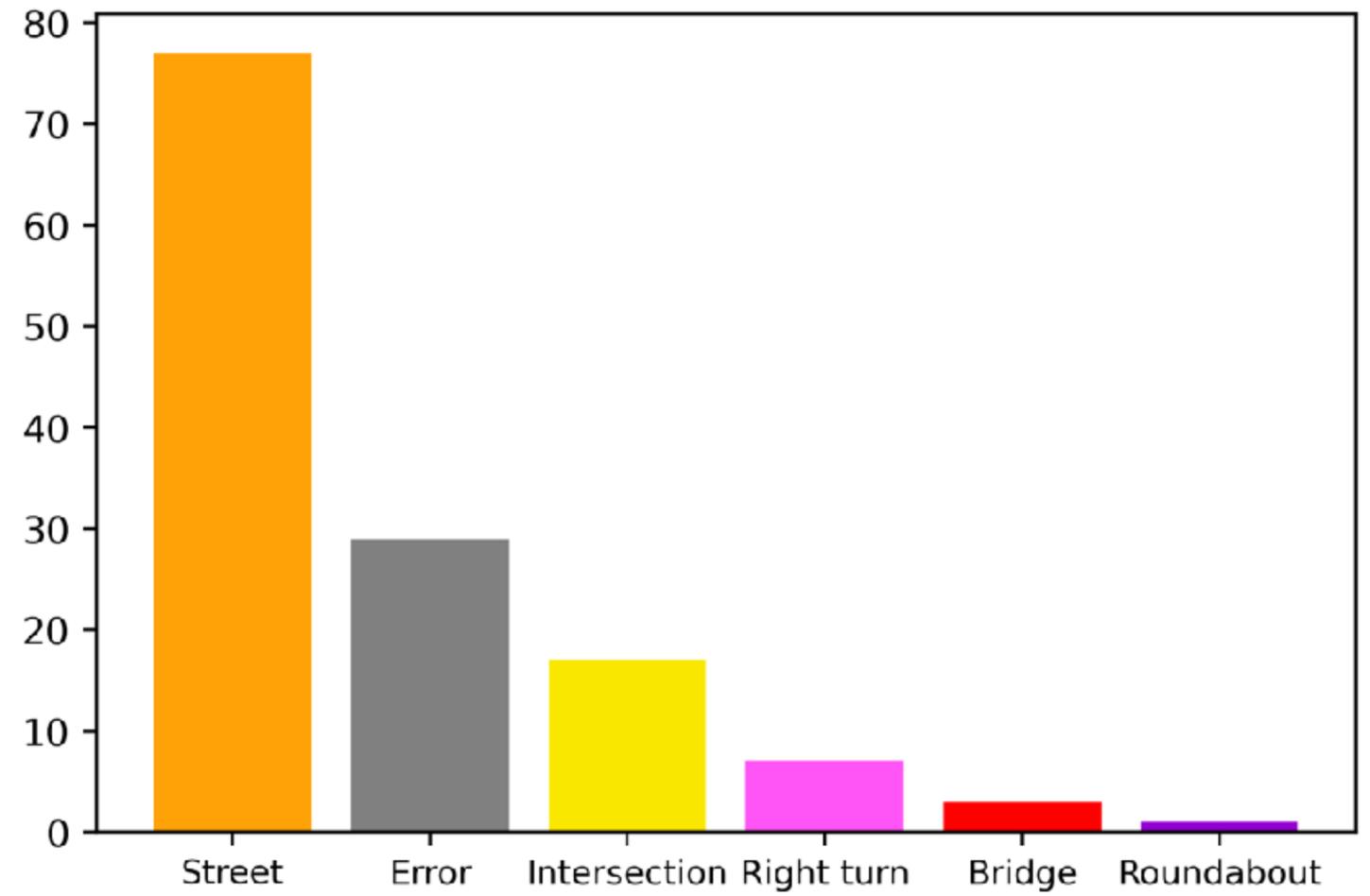
2) Prioritize



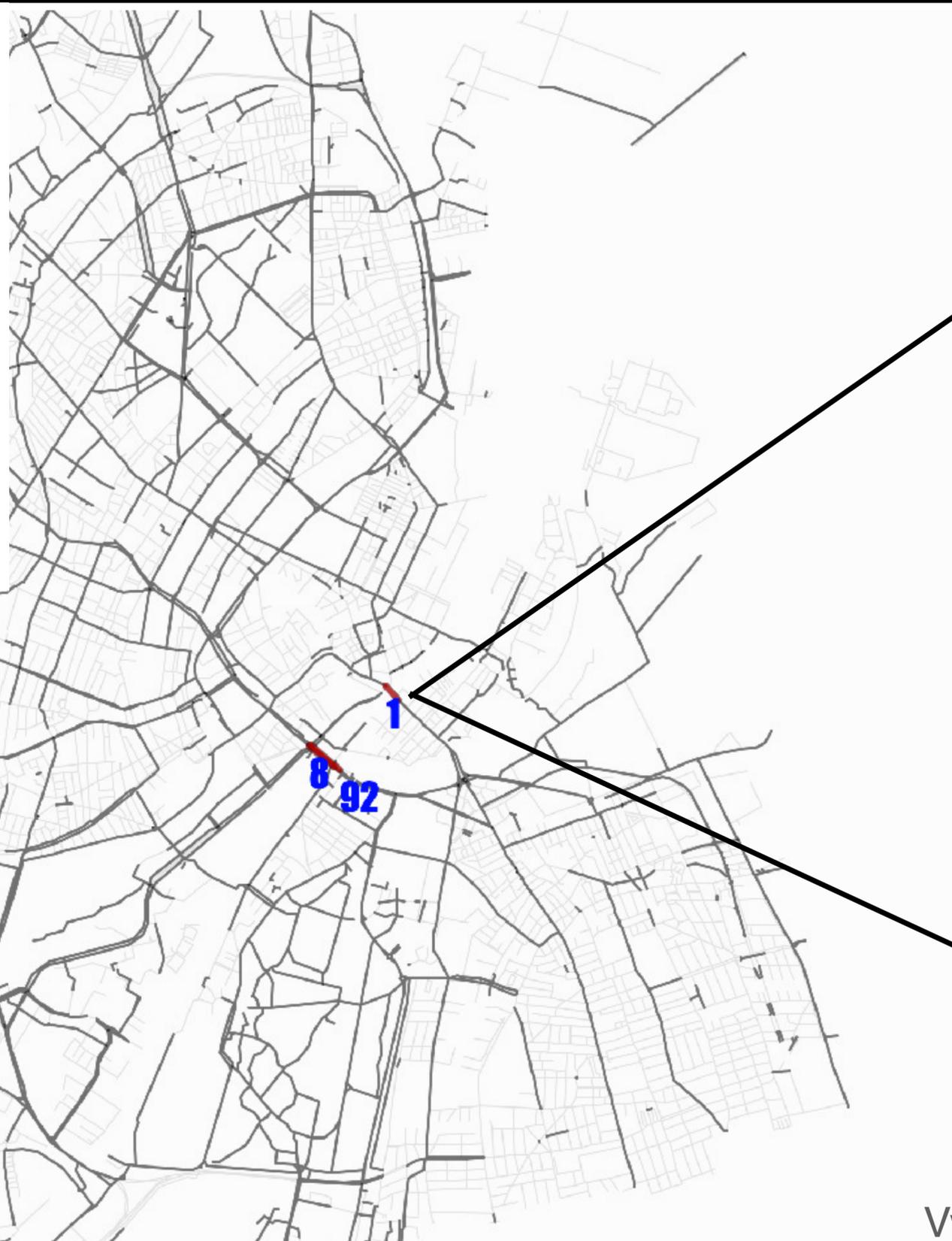
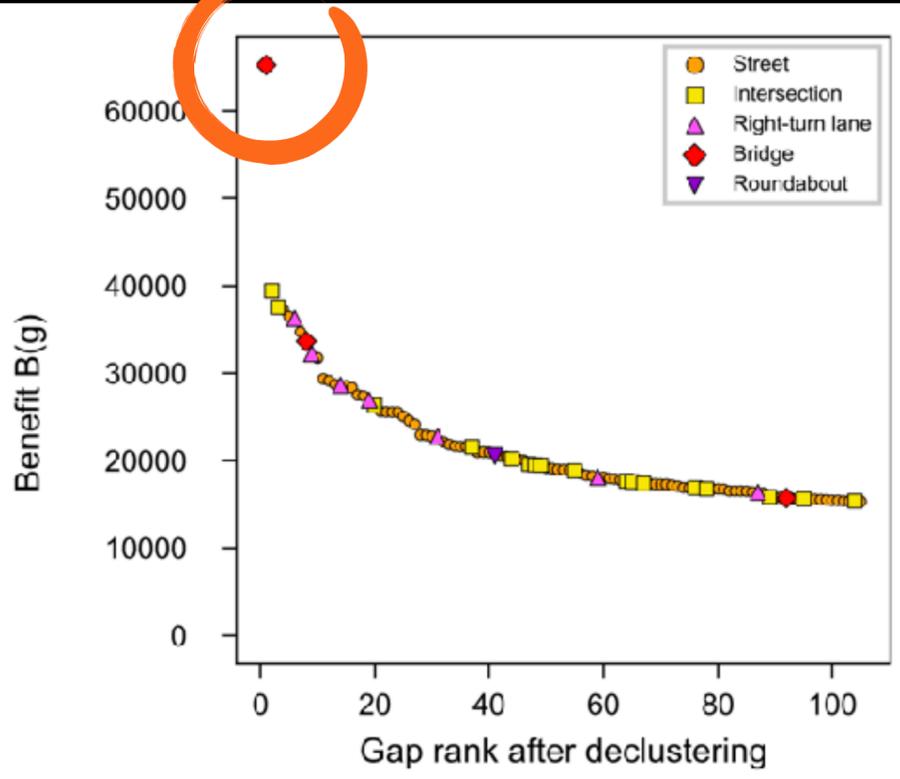
“If this gap was closed, how many meters cycled in mixed traffic would be avoided per investment unit?”



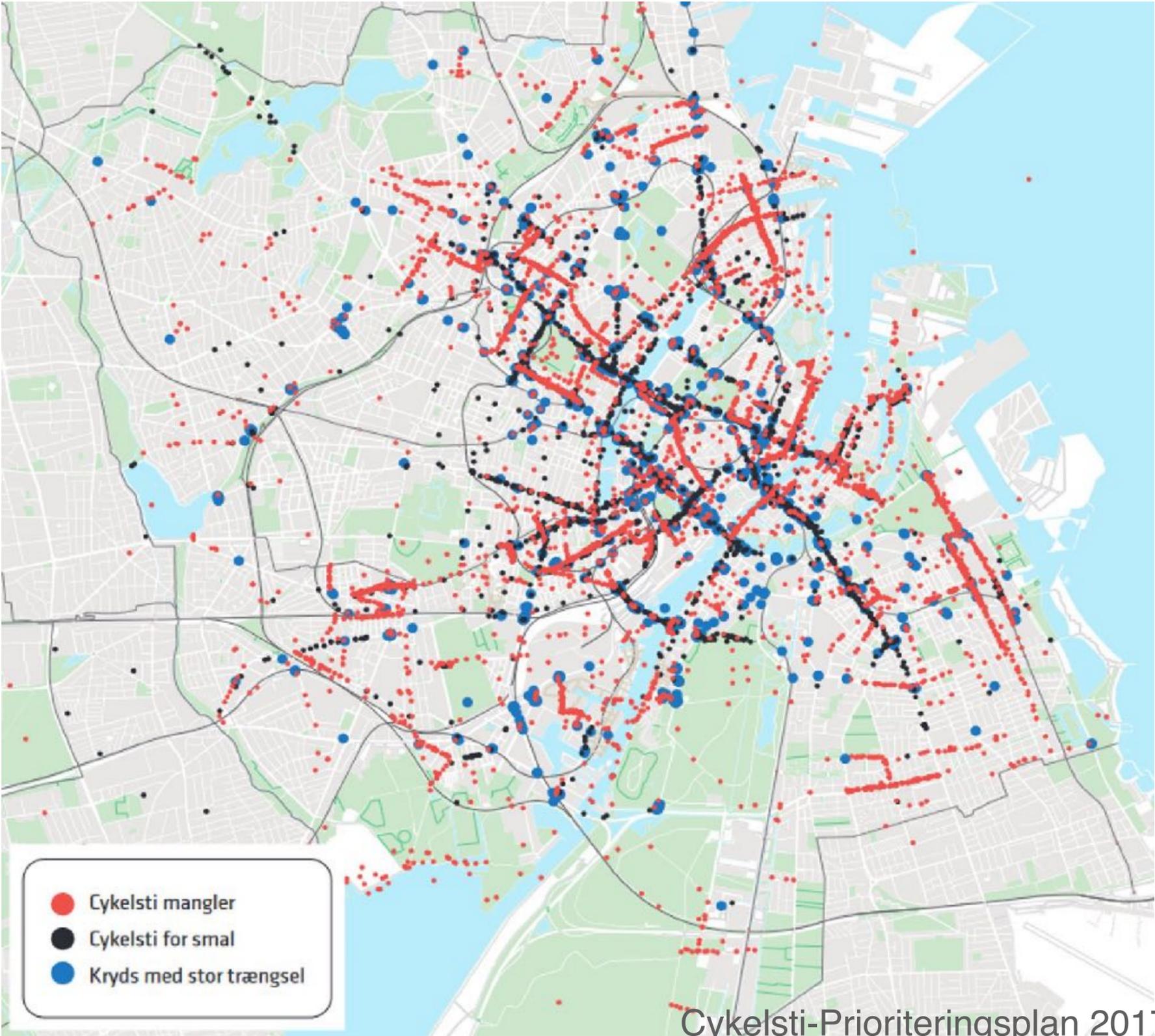
4) Classify: Our top 105 gaps



The most important gaps are bridges



Evaluation: Comparison with Cykelsti-Prioriteringsplan



Cykelsti-Prioriteringsplan 2017

Evaluation: Comparison with Cykelsti-Prioriteringsplan



Evaluation: We find many overlaps

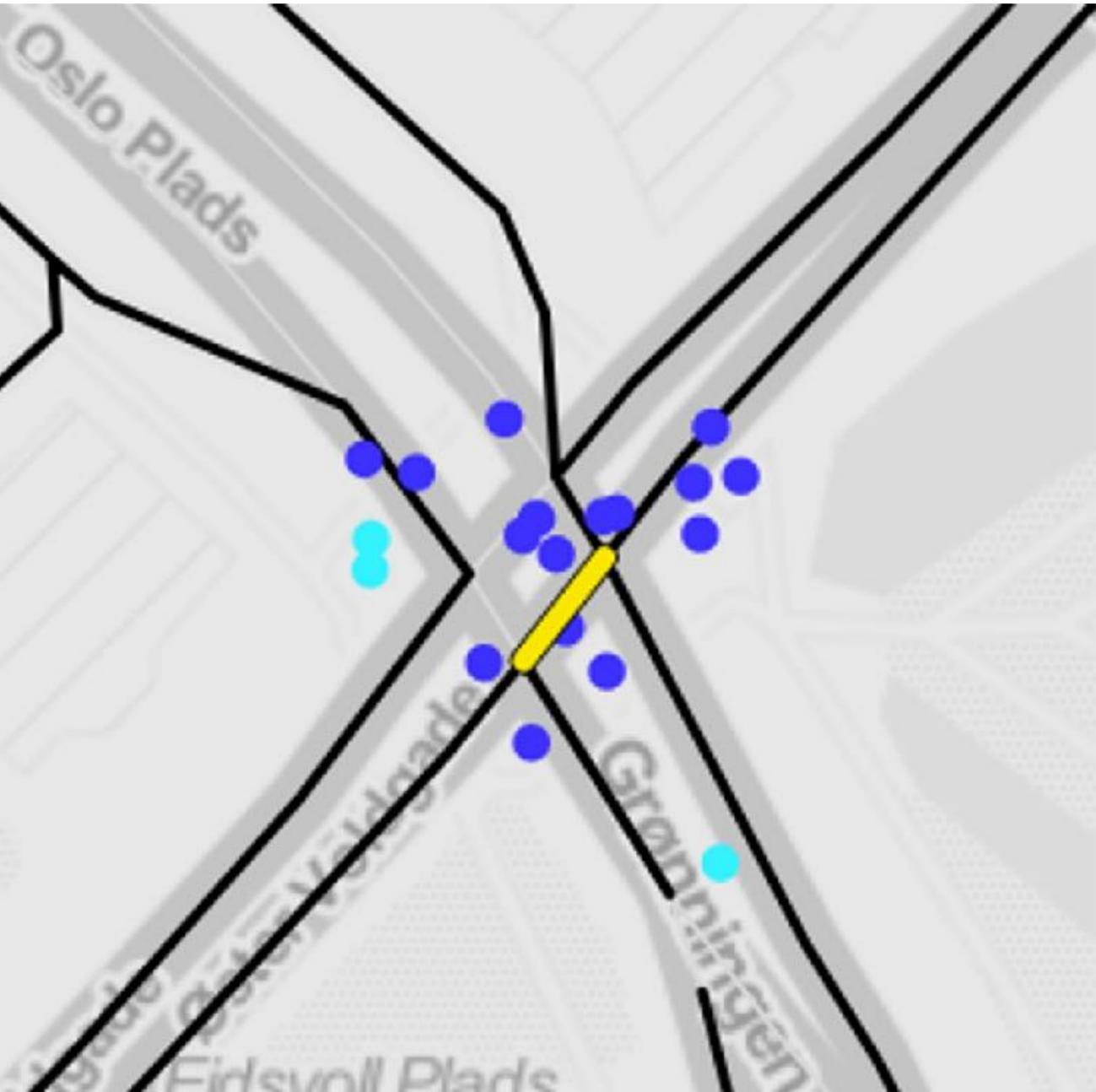


Nørregade



Rantzausgade

Evaluation: We find many overlaps



Østerport



Sølvtorvet

If your city is:

not developed

Los Angeles



Grow persistently with
focused investments

If your city is:

not developed

Los Angeles



Grow persistently with
focused investments

medium developed

Budapest



Connect with
right strategy

If your city is:

not developed

Los Angeles



Grow persistently with
focused investments

medium developed

Budapest



Connect with
right strategy

well developed

Copenhagen



Close the most
important gaps

If your city is:

not developed



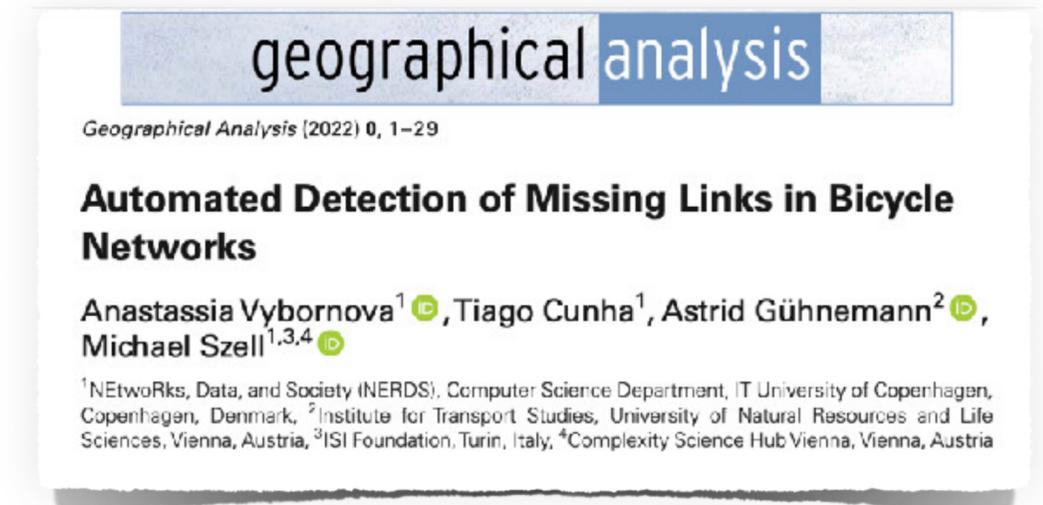
Grow persistently with focused investments

medium developed

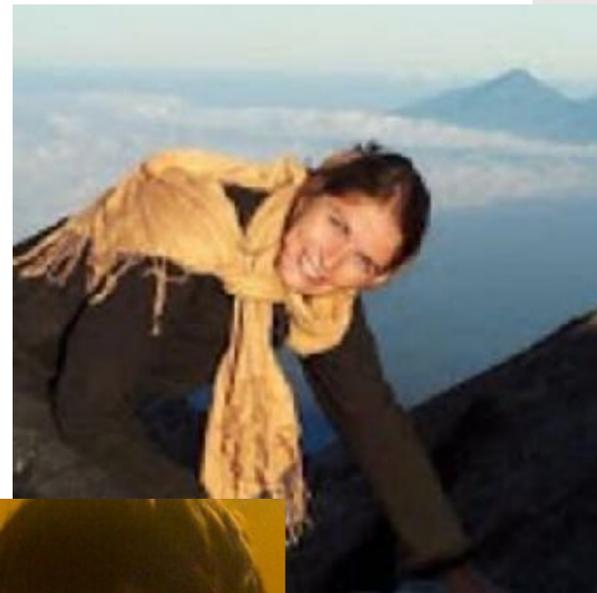
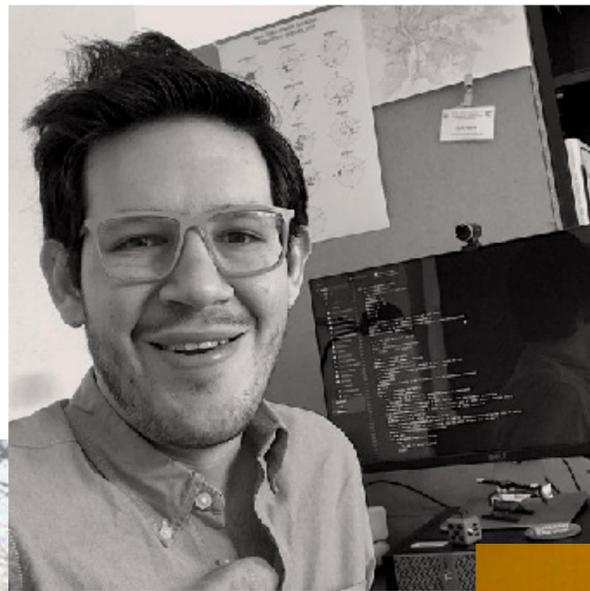


Connect with right strategy

well developed



Close the most important gaps



Szell et al., Sci Rep 12, 6765 (2022)
 Klanjic et al, EPJ Data Sci 11, 27 (2022)
 Natera Oroczo et al, R Soc Open Sci 7 (2020)
 Vybornova et al, Geographical Analysis (2022)

What's next in bicycle network
research?

More data / perspectives

We can add more data:

Contents lists available at [ScienceDirect](#)

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

ELSEVIER

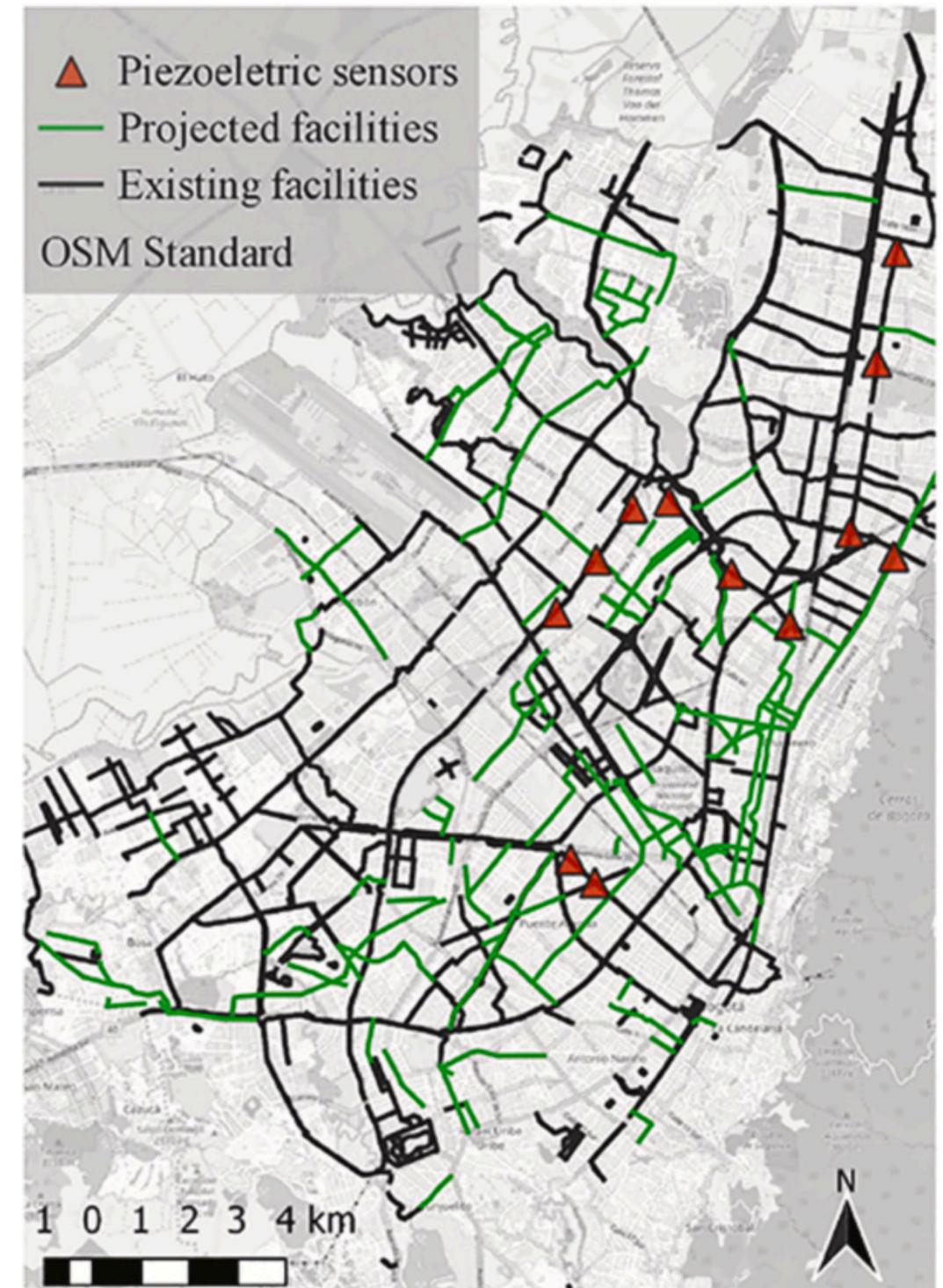
TRANSPORTATION RESEARCH

A data science framework for planning the growth of bicycle infrastructures[☆]

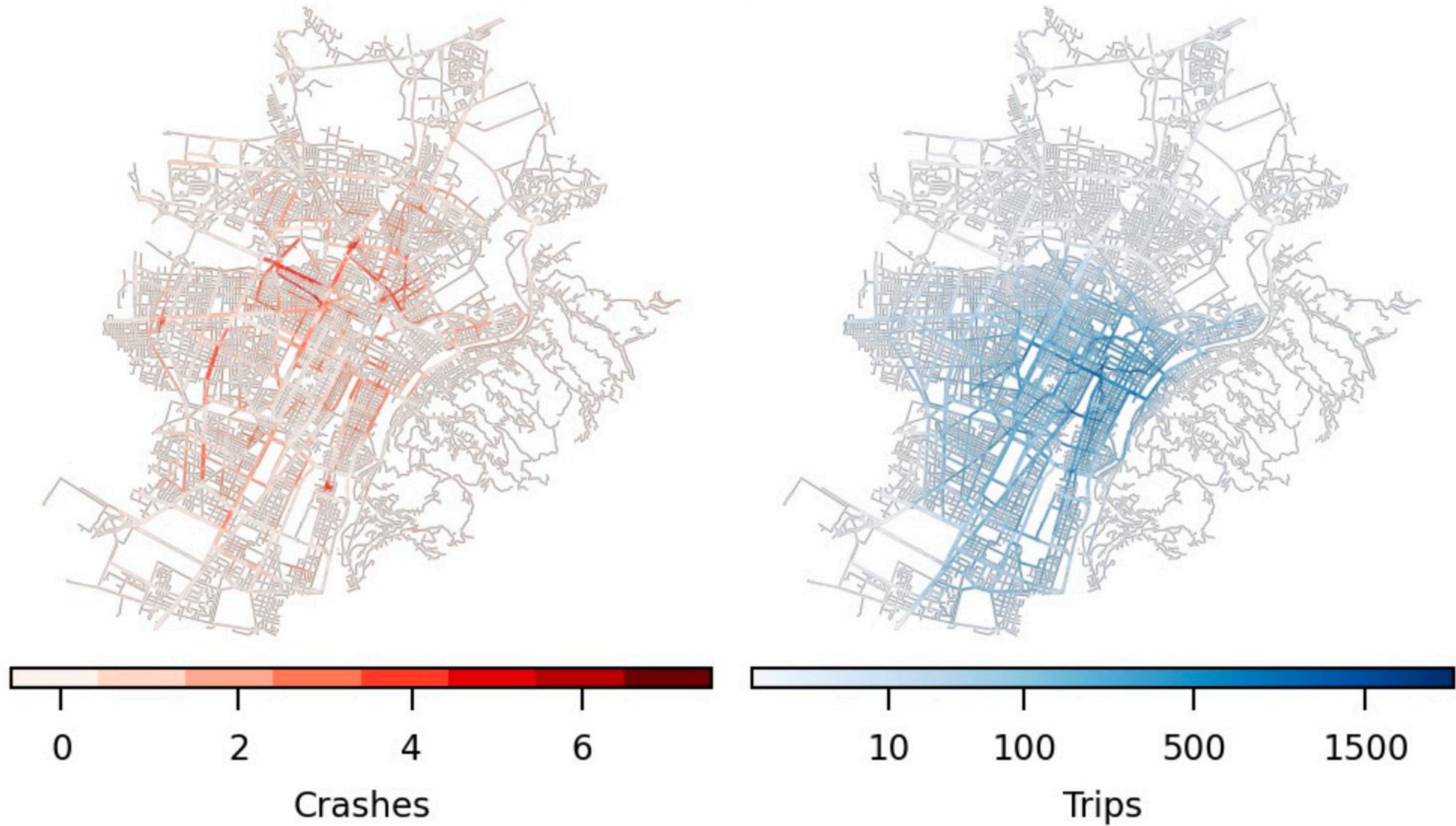
Luis E. Olmos^{a,*,1}, Maria Sol Tadeo^{b,1}, Dimitris Vlachogiannis^b, Fahad Alhasoun^c, Xavier Espinet Alegre^d, Catalina Ochoa^d, Felipe Targa^d, Marta C. González^{a,b,e}

Check for updates

- OD matrices
- Mobile phone GPS
- Census
- Mobility surveys
- Bicycle counters
- Planned bicycle networks



We can add more data: Crashes and empirical trips in Turin



We can add more data: Crashes and empirical trips in Turin

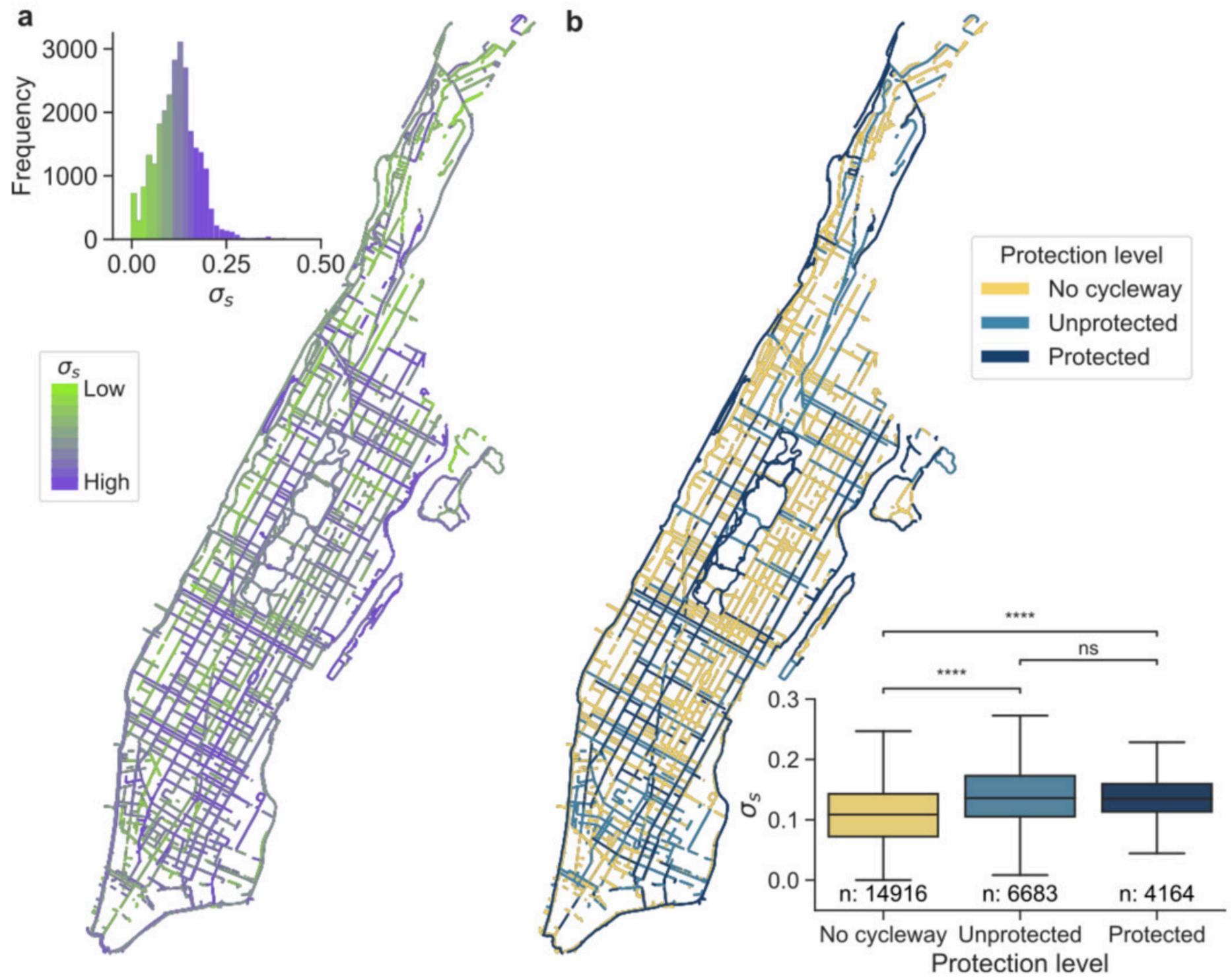


Build for safety

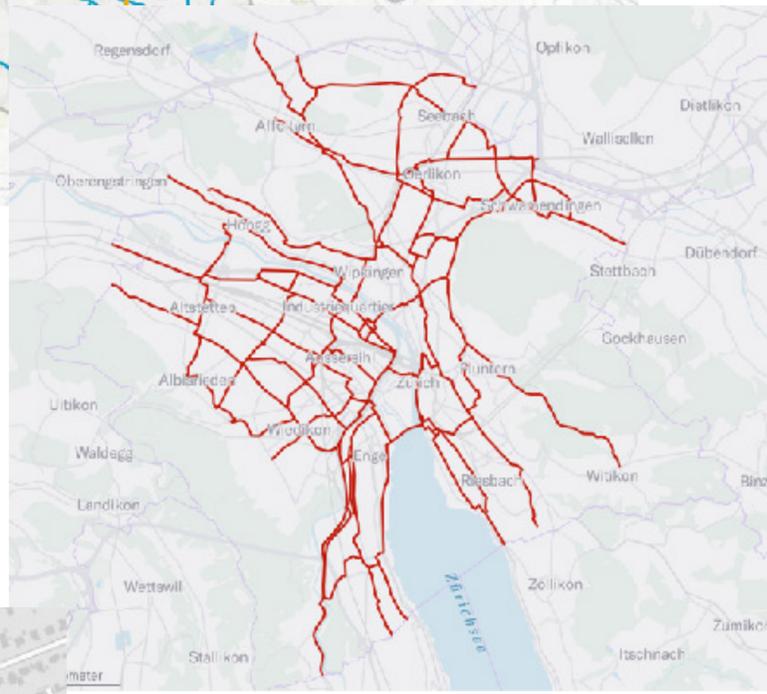
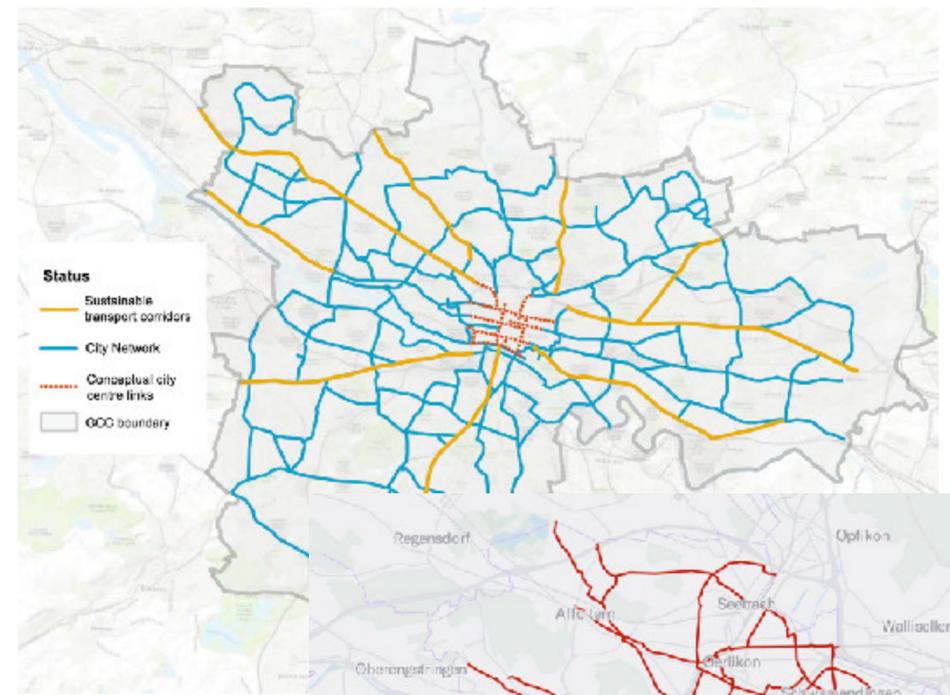
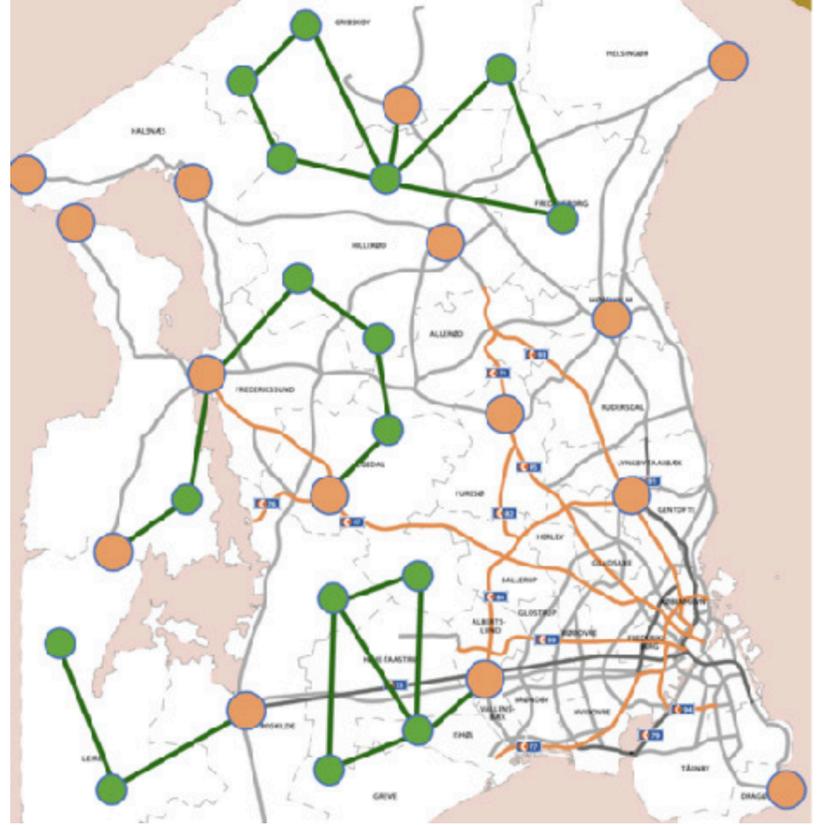
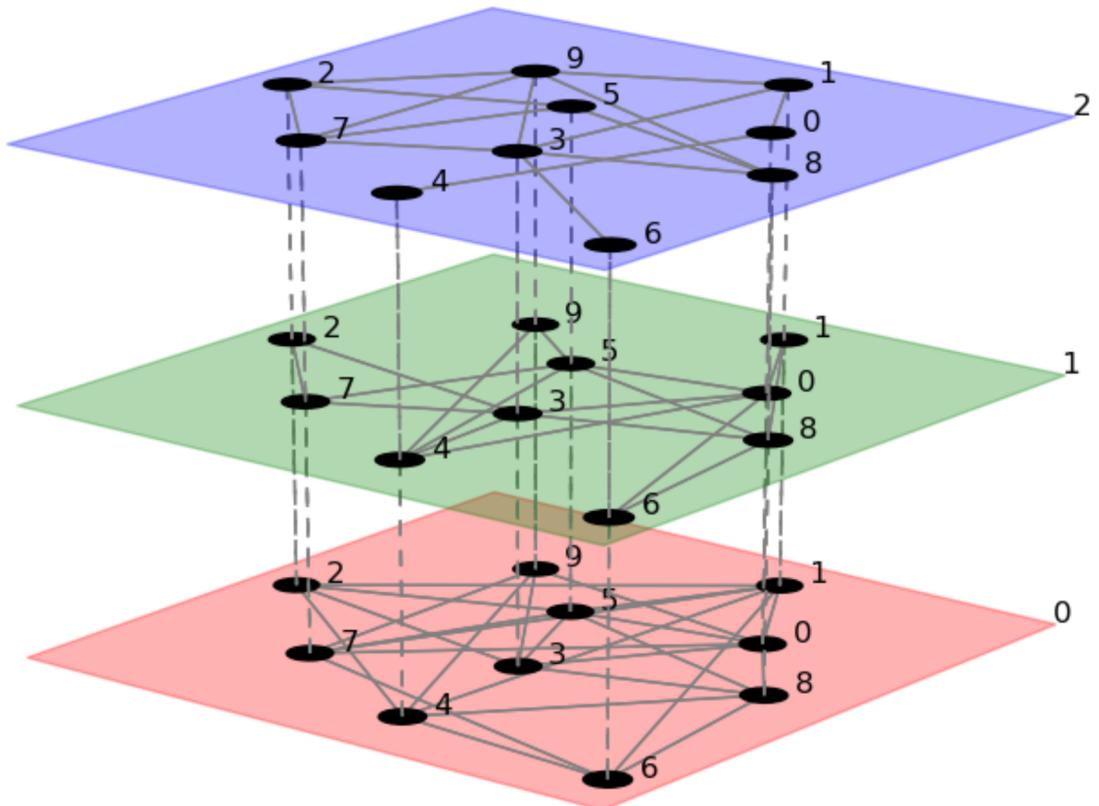


Build for flow

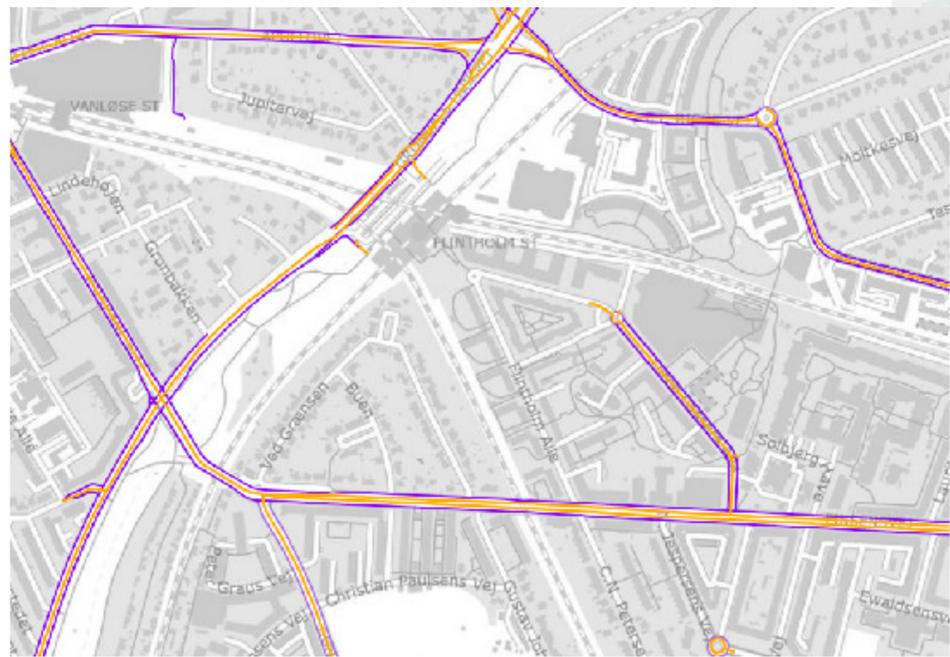
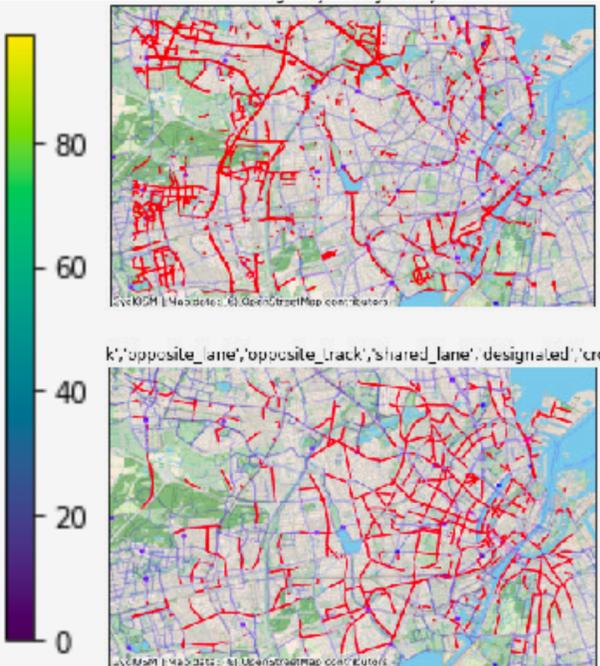
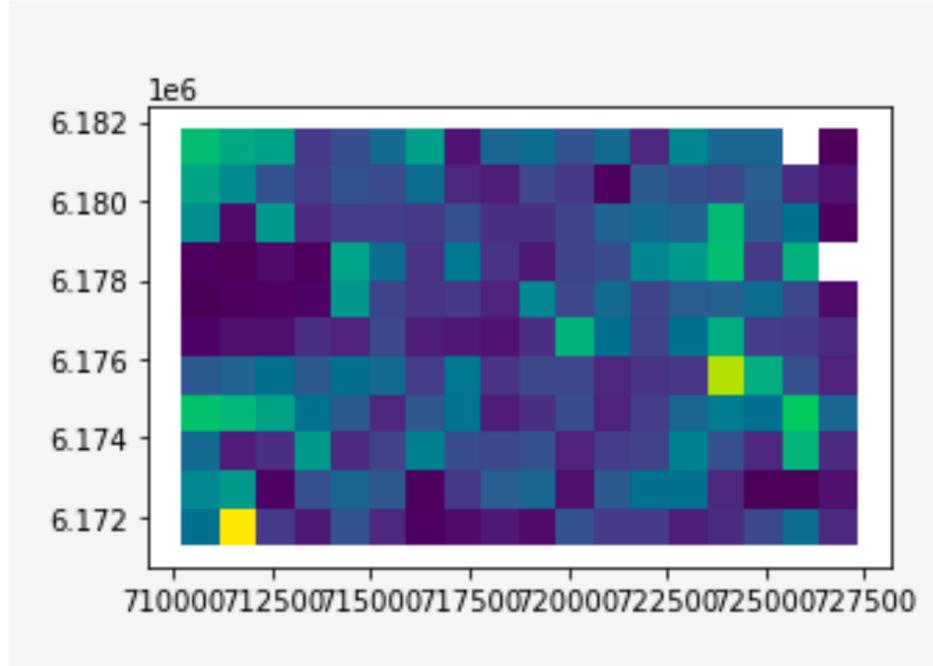
We can add more context: Gender



Streets with safer infrastructure have a smaller gender gap



and much more...



Which European city is this?



Amsterdam



1978



Today

Amsterdam



1920



1978

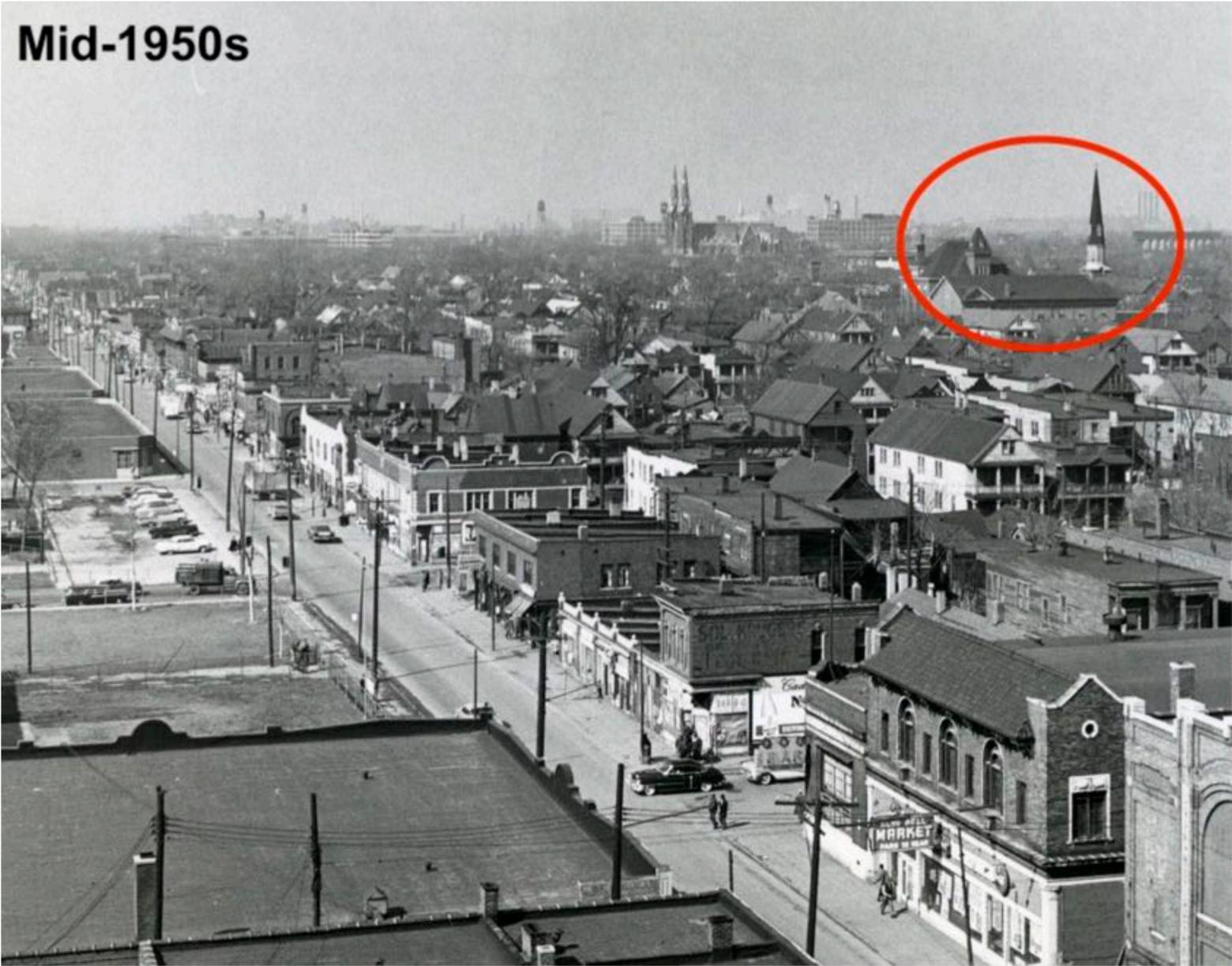


2015

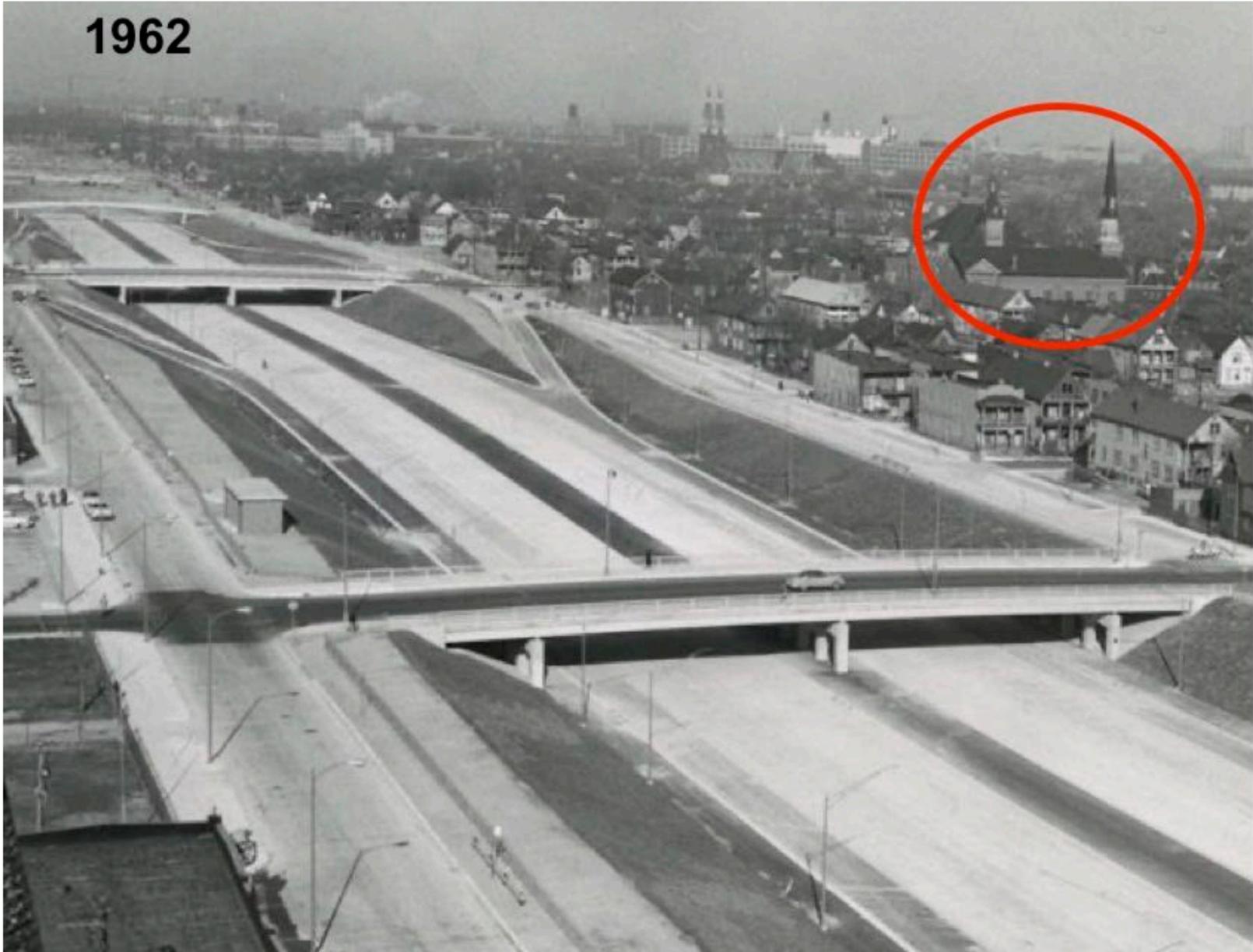


Detroit

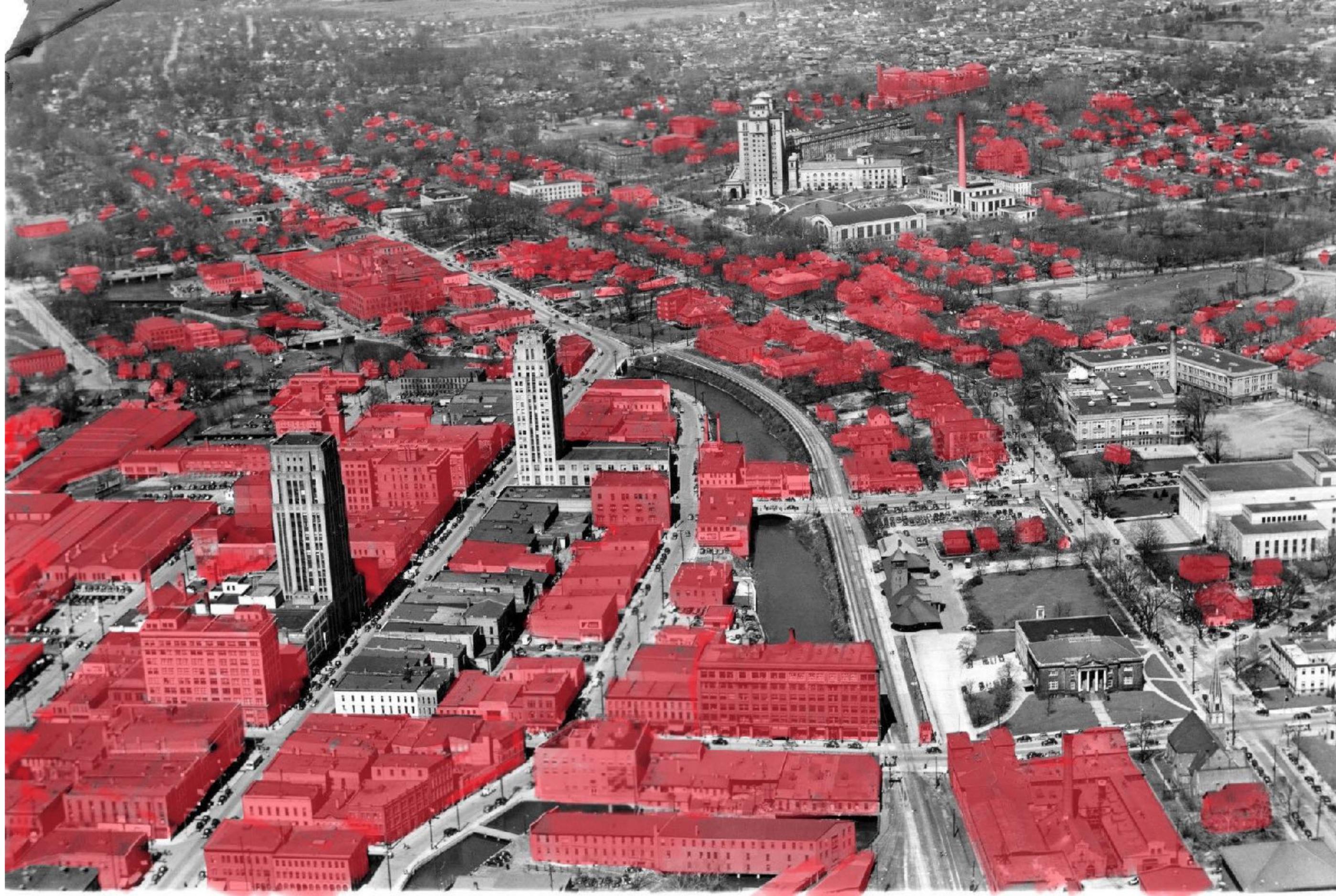
Mid-1950s



1962



Battle
Creek,
MI



Battle
Creek,
MI





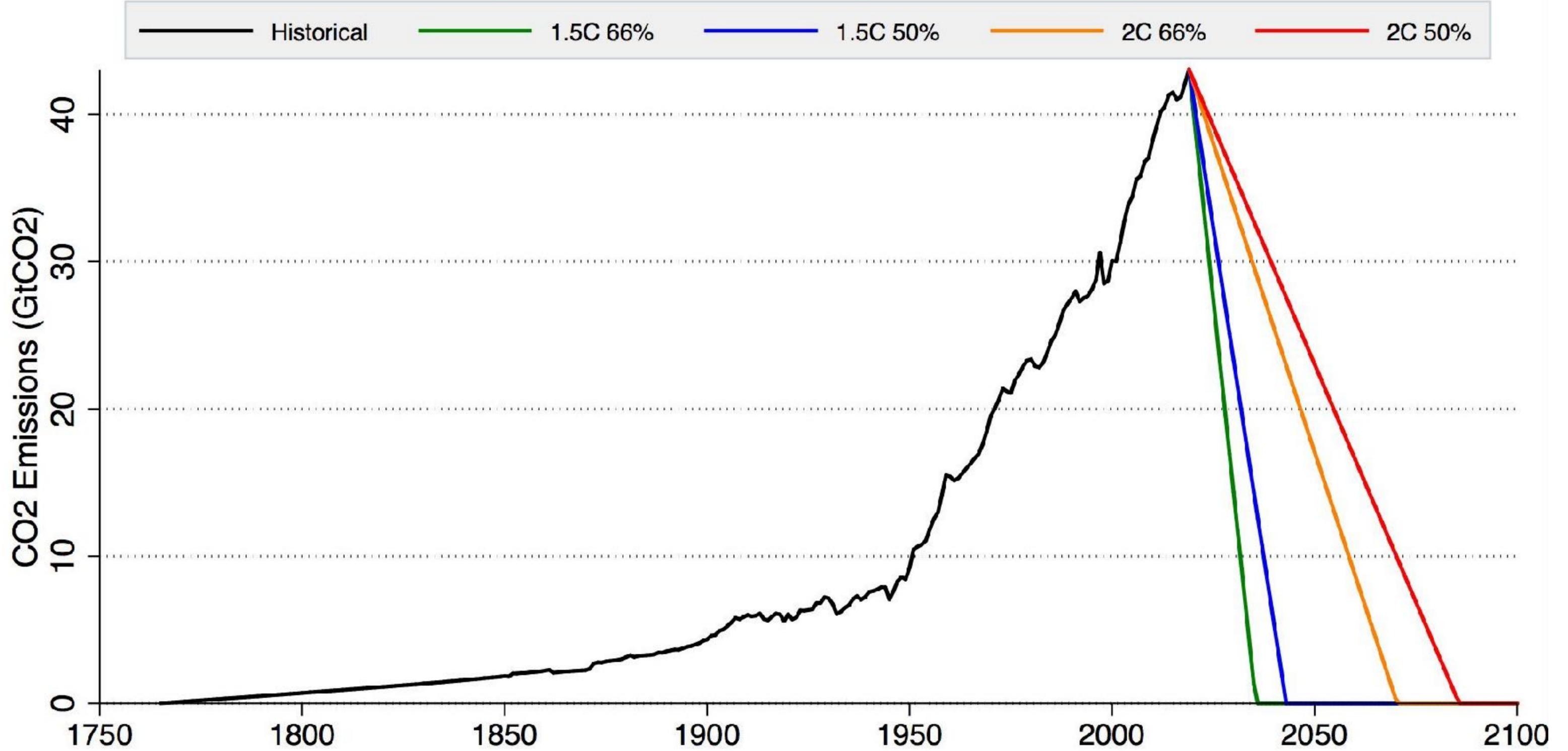
Groningen



Cities can change radically
within a few decades

We **must** make this radical transformation on a global level

Simplified Emissions Pathways for Climate Targets



health. **Any further delay** in concerted anticipatory global action on adaptation and mitigation **will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all.**

Among 60 identified actions that could change individual consumption, individual mobility choices [like cycling] have the largest potential to reduce carbon footprint.

Editorial

Human-Centric Data Science for Urban Studies

Bernd Resch ^{1,2,*}  and **Michael Szell** ^{3,4,5,*} 

¹ Department of Geoinformatics, Paris-Lodron University of Salzburg, 5020 Salzburg, Austria

² Center for Geographic Analysis, Harvard University, Cambridge, MA 02138, USA

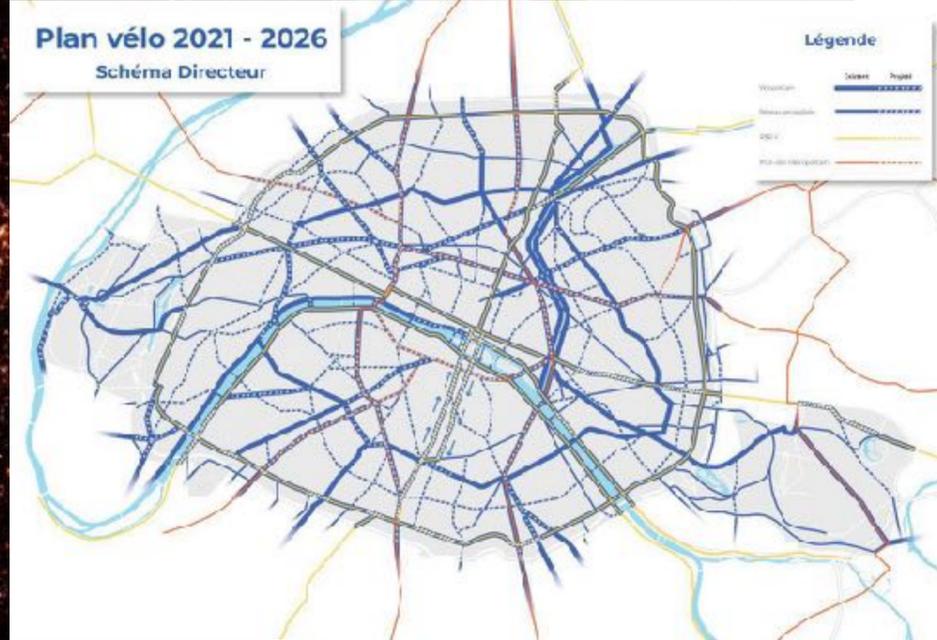
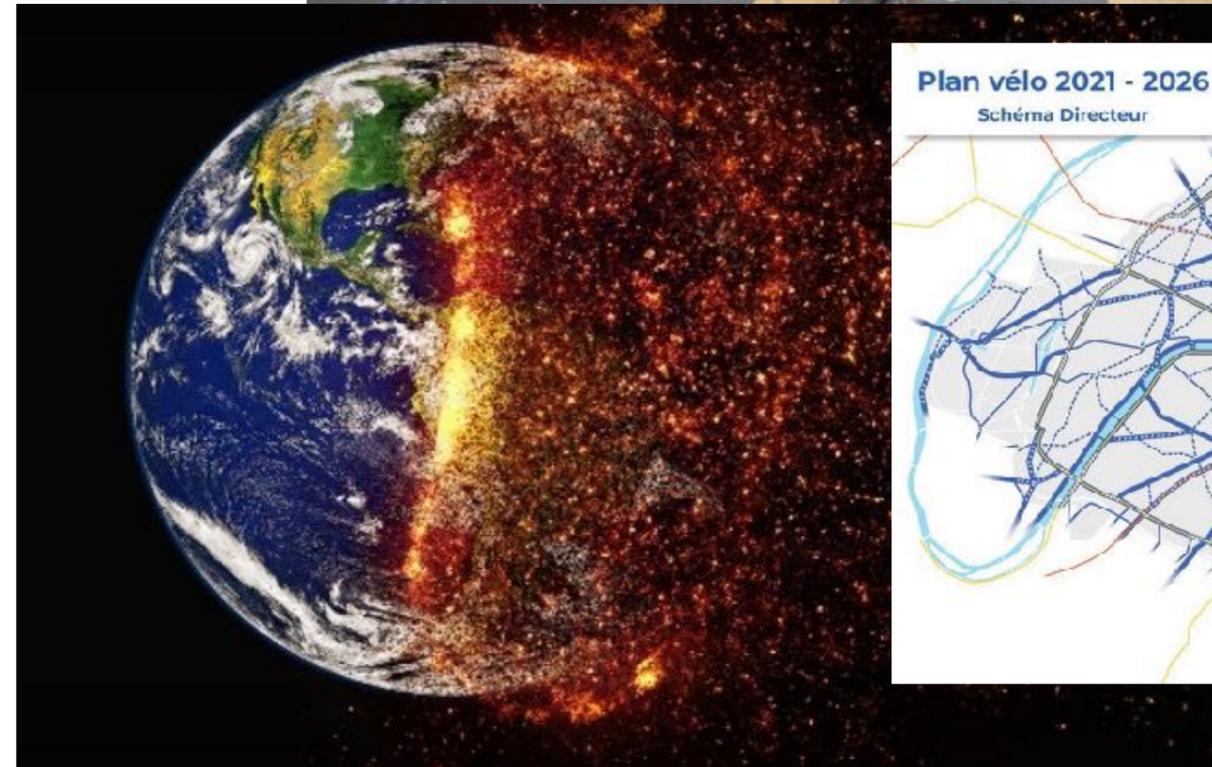
³ NEtworks, Data, and Society (NERDS), IT University of Copenhagen, 2300 Copenhagen, Denmark



nerds.itu.dk @nerdsitu

Michael Szell @mszll

To make cities better, we need *radical* transformation ASAP



nerds.itu.dk @nerdsitu
Michael Szell @mszll