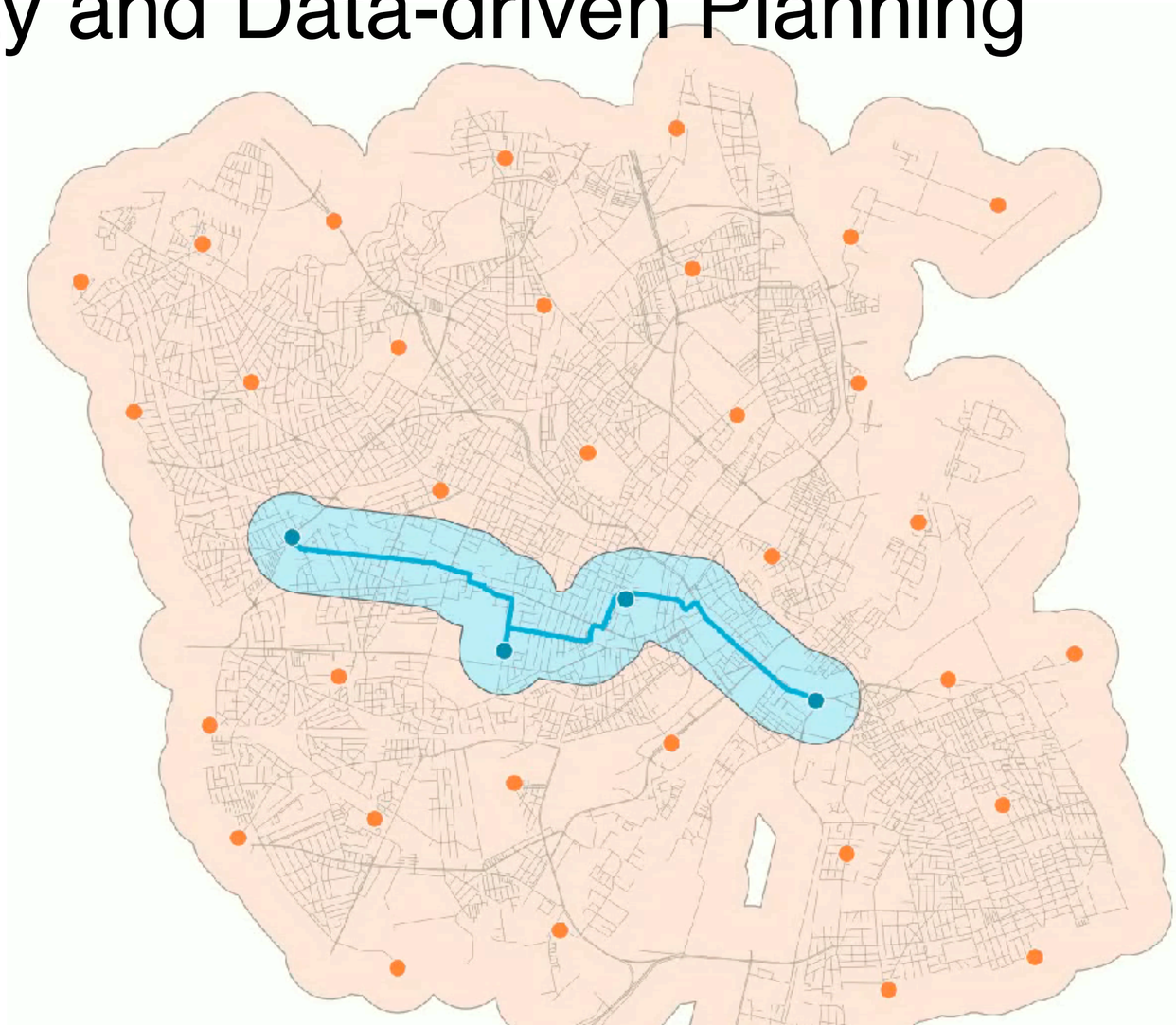
IT and Green Transitions, Fall 2025

Lecture 3: Sustainable Mobility and Data-driven Planning

Instructors:
Michael Szell

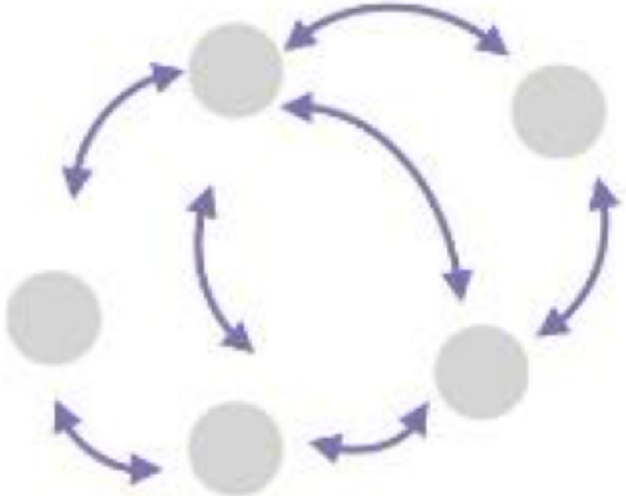
Sep 10, 2025



IT UNIVERSITY OF COPENHAGEN

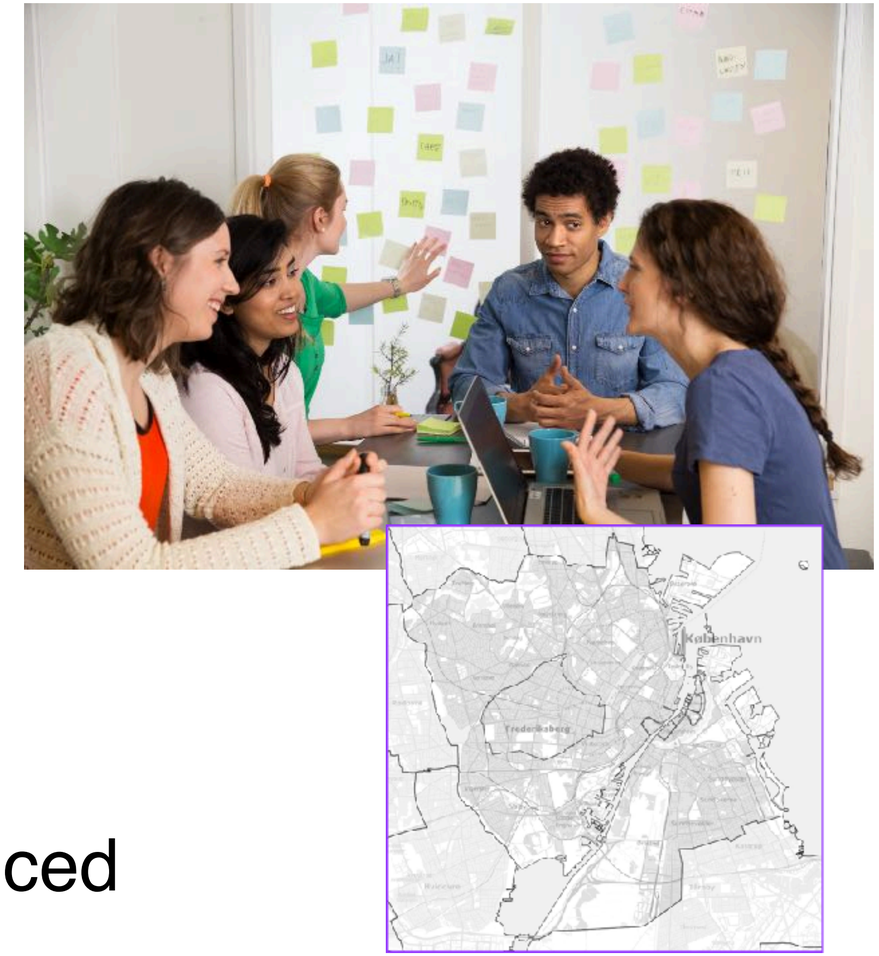
Today you will learn about IT and sustainable mobility

Part I: Bicycle network planning with data science

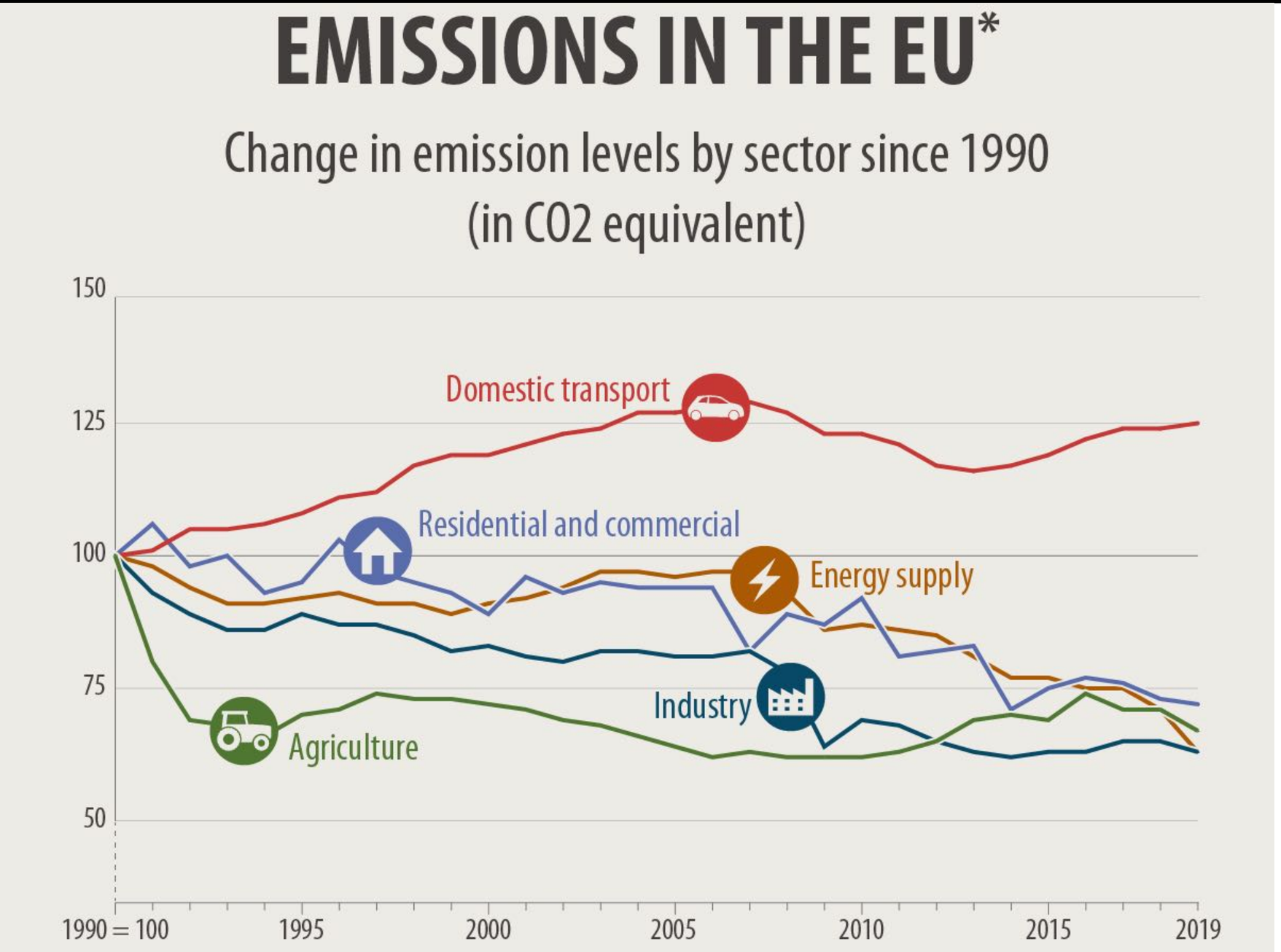


Part II: Systems thinking, induced demand, motonormativity

Exercise: Hands-on:
How to spend money in Copenhagen?



Transport plays a key role in the climate crisis

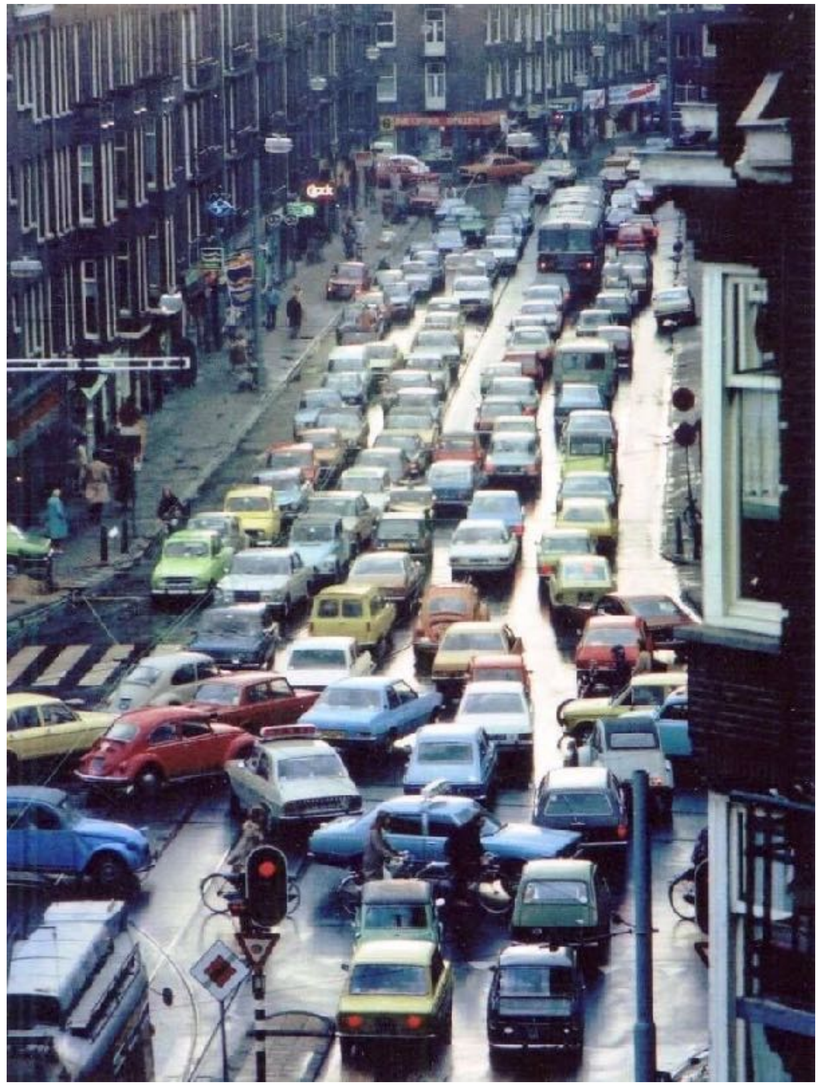


Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities.

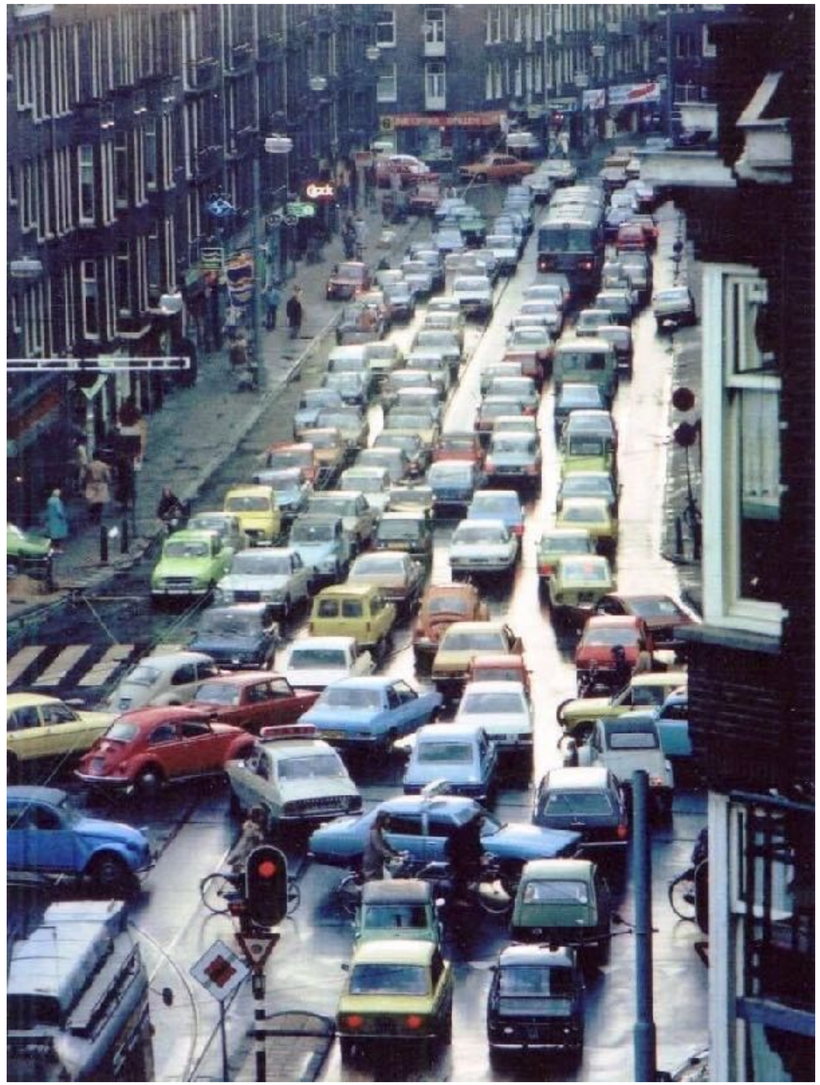
https://ec.europa.eu/clima/policies/transport_en

Which European city is this?

Mentimeter



Amsterdam



1978

Today

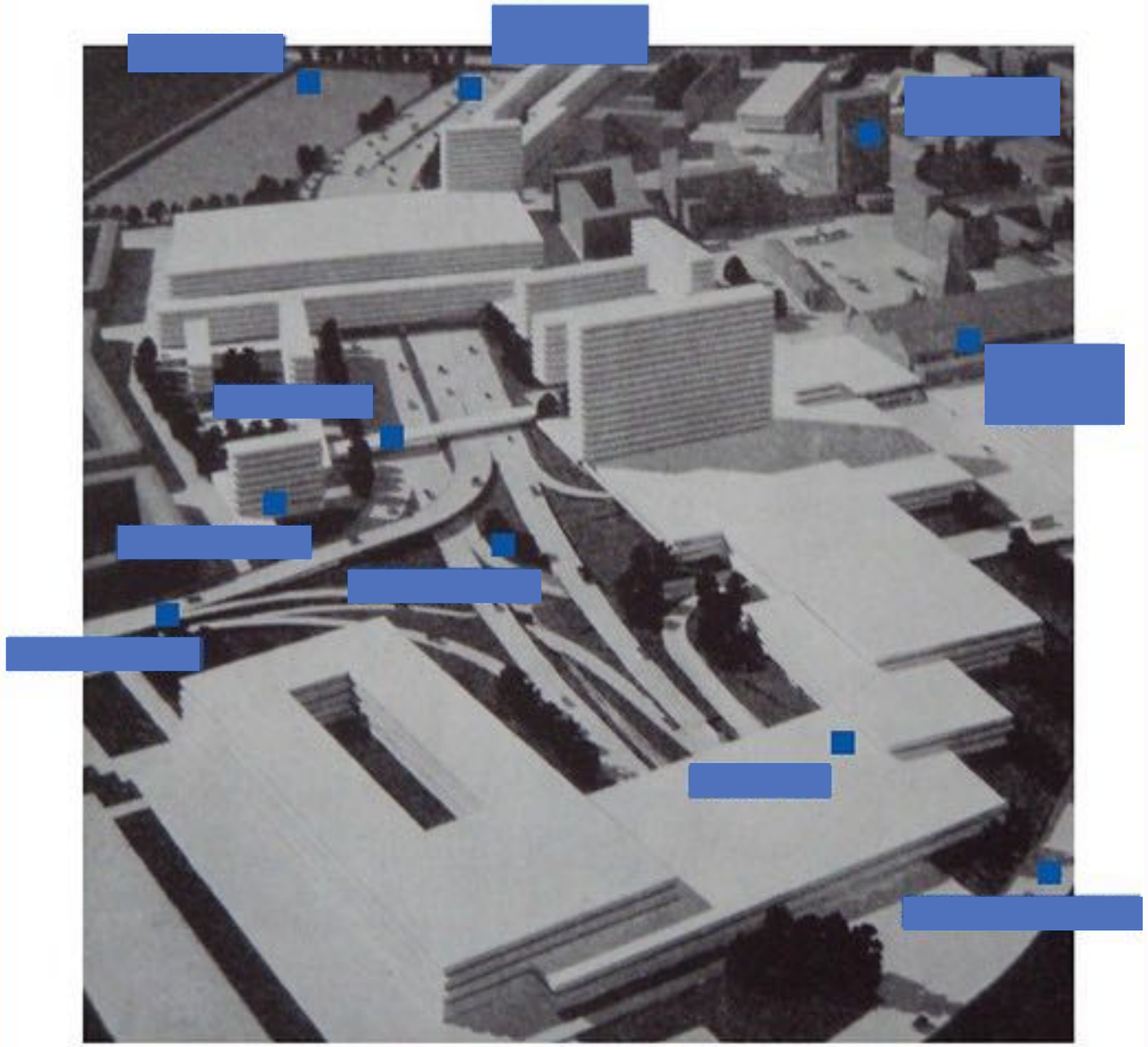
Amsterdam

1920

1978

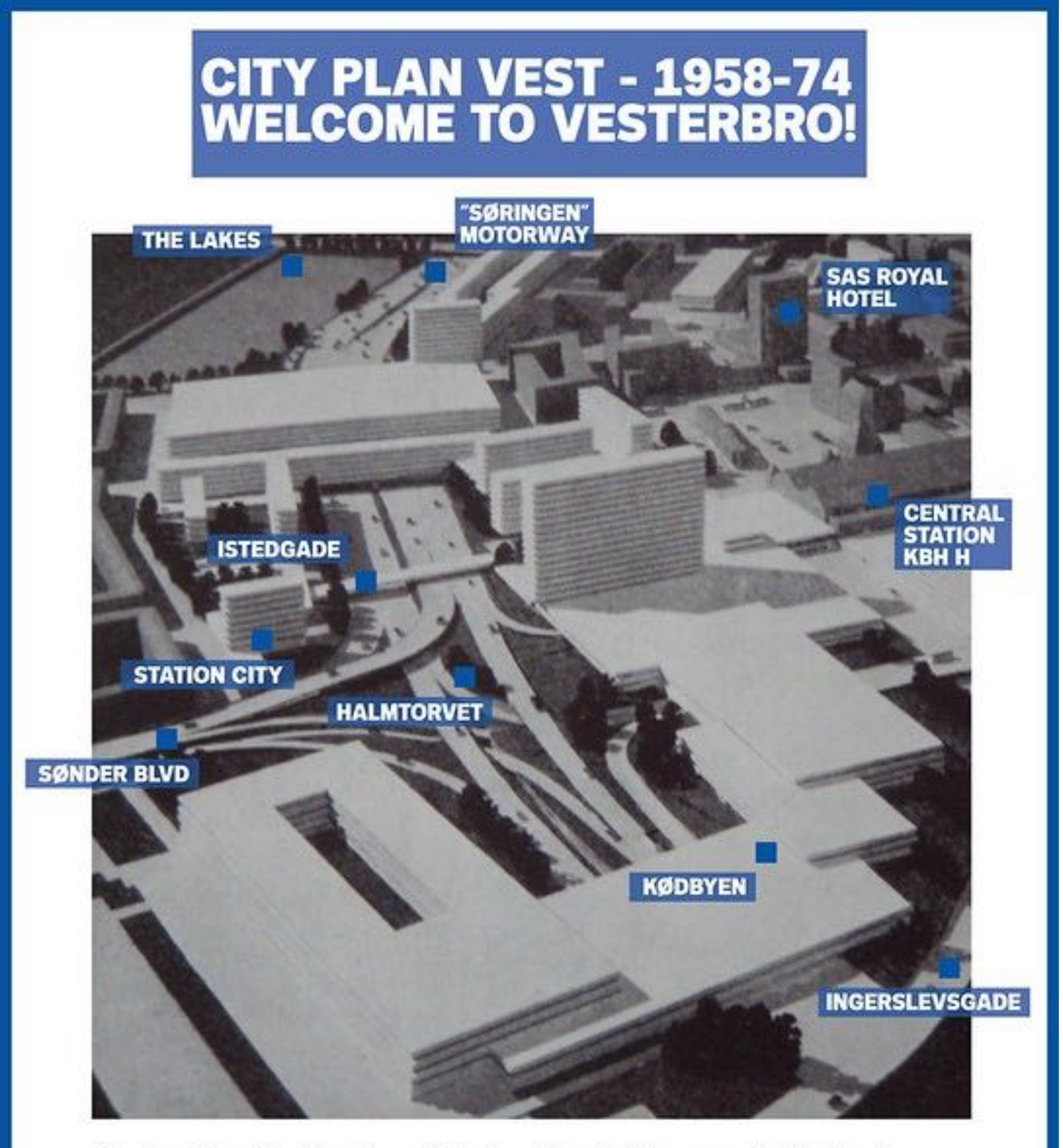
2015

https://www.fastcompany.com/3052699/these-historical-photos-show-how-amsterdam-turned-itself-into-a-bike-riders-paradise



?

Søringen



https://monocle.com/radio/shows/the-urbanist/tall-stories-322/

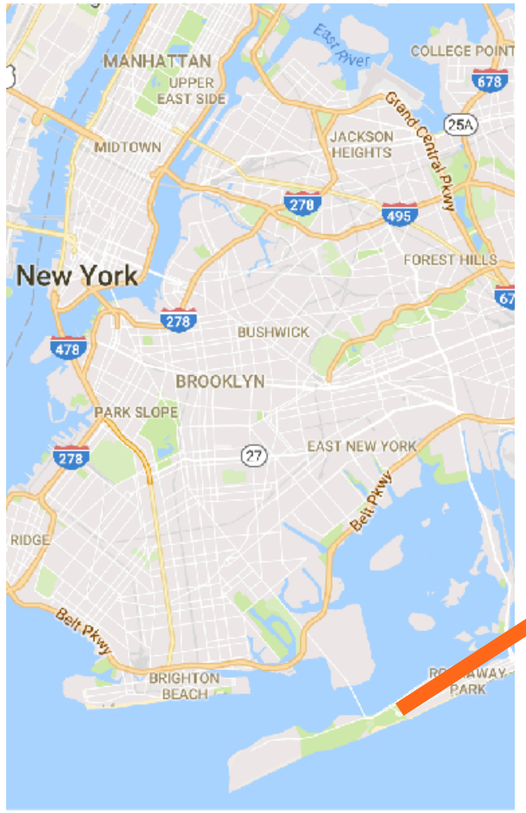
http://www.copenhagenize.com/2012/11/city-plan-vest-and-sringen-1958-1974.html

B 14 546
DK
A 79 676
K 80 502

Why is a city planned with a focus on cars not sustainable*?

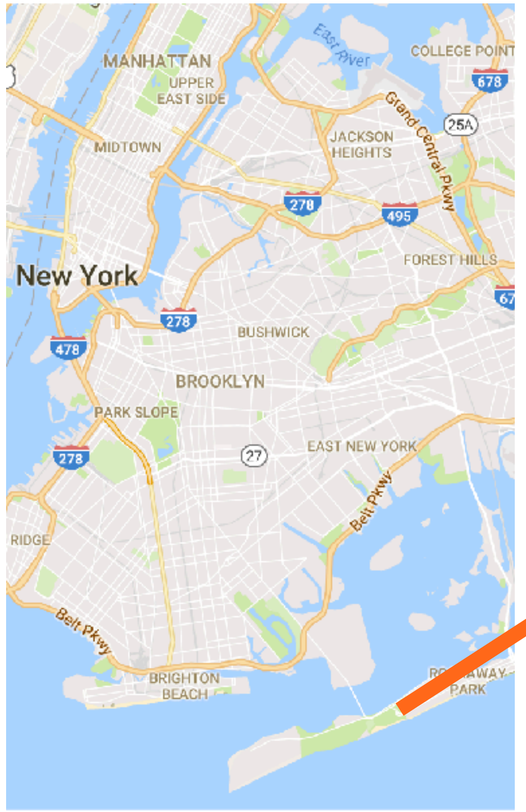
*sustainable system = system with the possibility to continue a specific behaviour over long periods of time

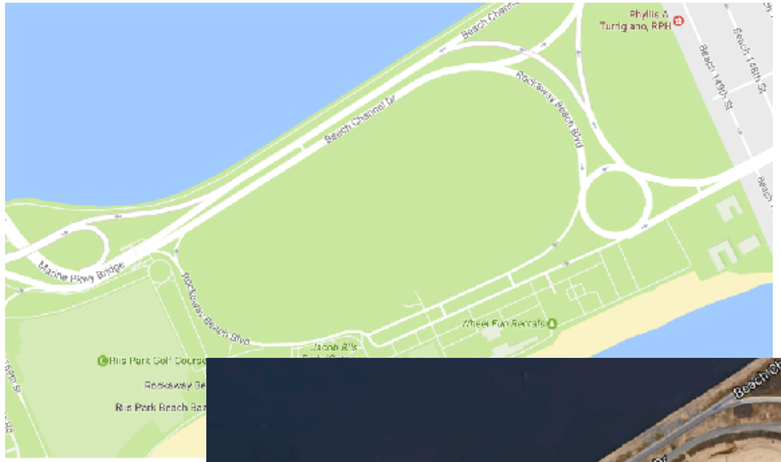
SPACE


MANHATTAN
UPPER EAST SIDE
MIDTOWN
East River
COLLEGE POINT
678
25A
Grand Central Pkwy
JACKSON HEIGHTS
278
495
FOREST HILLS
New York
278
BUSHWICK
478
BROOKLYN
PARK SLOPE
EAST NEW YORK
27
278
Belt Pkwy
RIDGE
Belt Pkwy
BRIGHTON BEACH

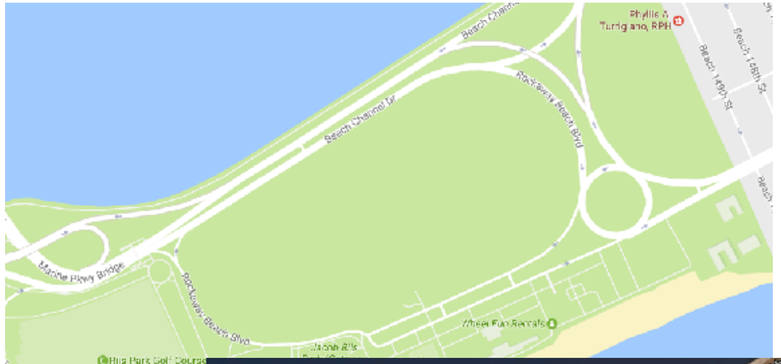
Phyllis & Turing and RPH
Beach Channel Dr
Rockaway Beach Blvd
Beach 149th St
Beach 138th St
Marine Pkwy Bridge
Rockaway Beach Blvd
Riis Park Golf Course
Rockaway Beach
Riis Park Beach Bazaar
Wise Clock (aka Riis Park Memorial Clock)
The People's Beach at Jacob Riis Park

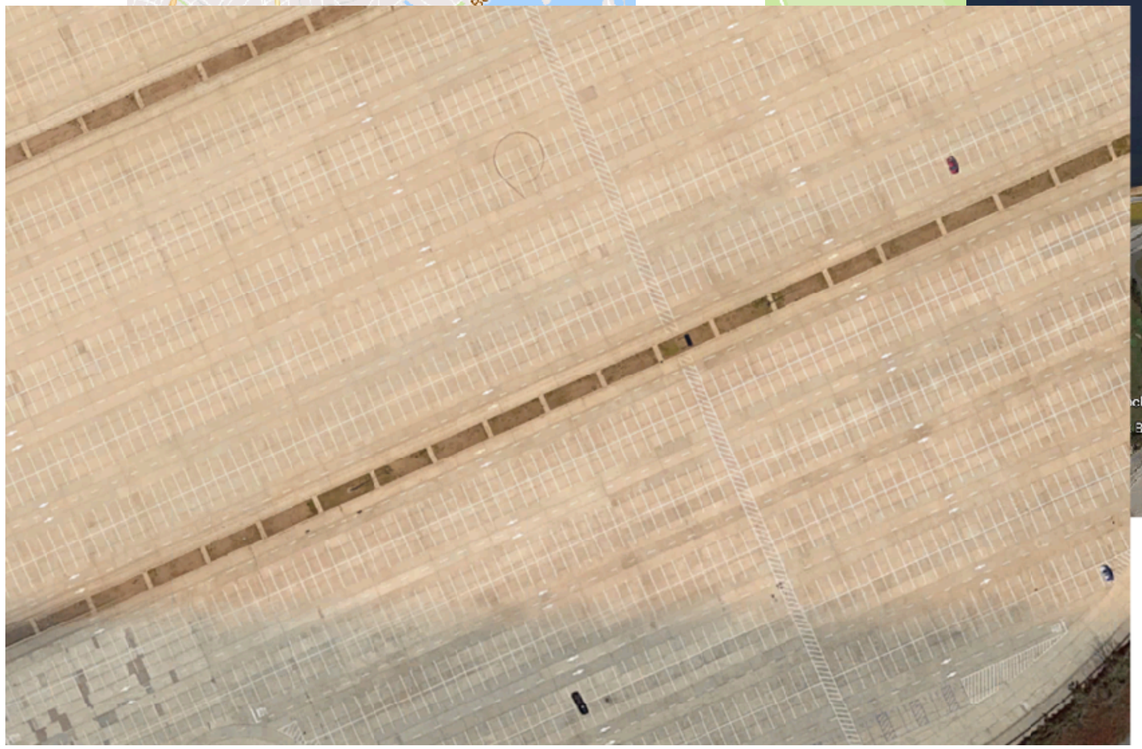
What a lovely ~~green~~..

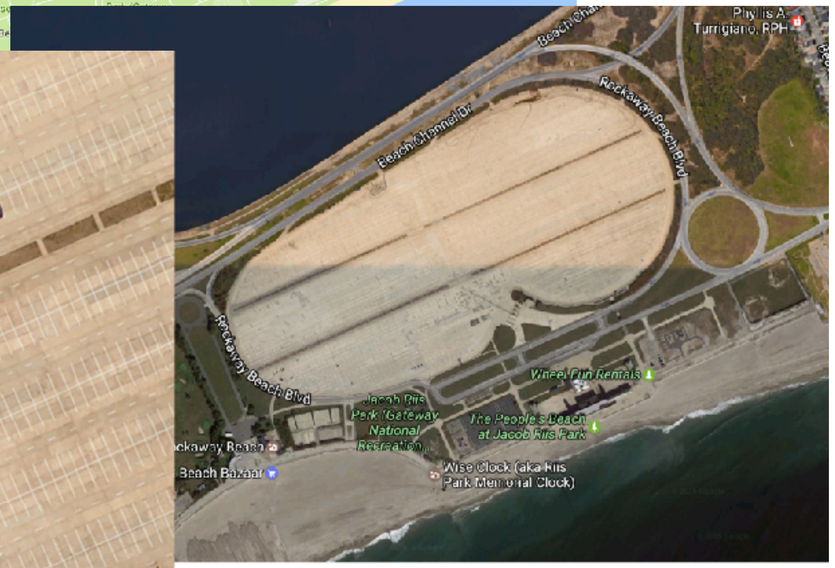




What a ~~lovely~~ ~~green~~.. MONSTER







800m x 500m

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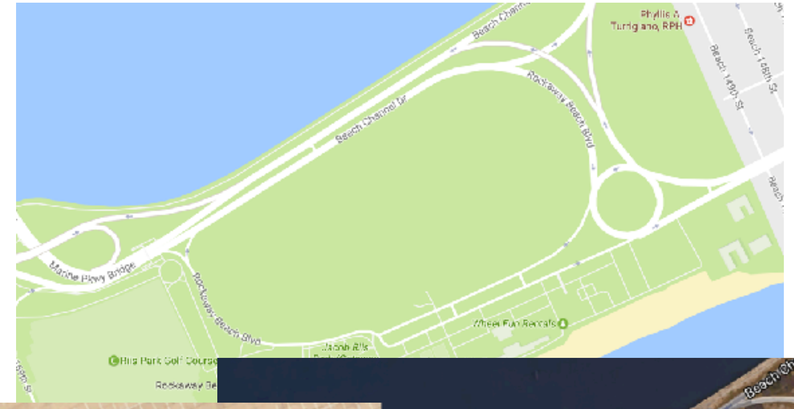
Phyllis A. Turrigiano, RPH
Beach Channel Dr
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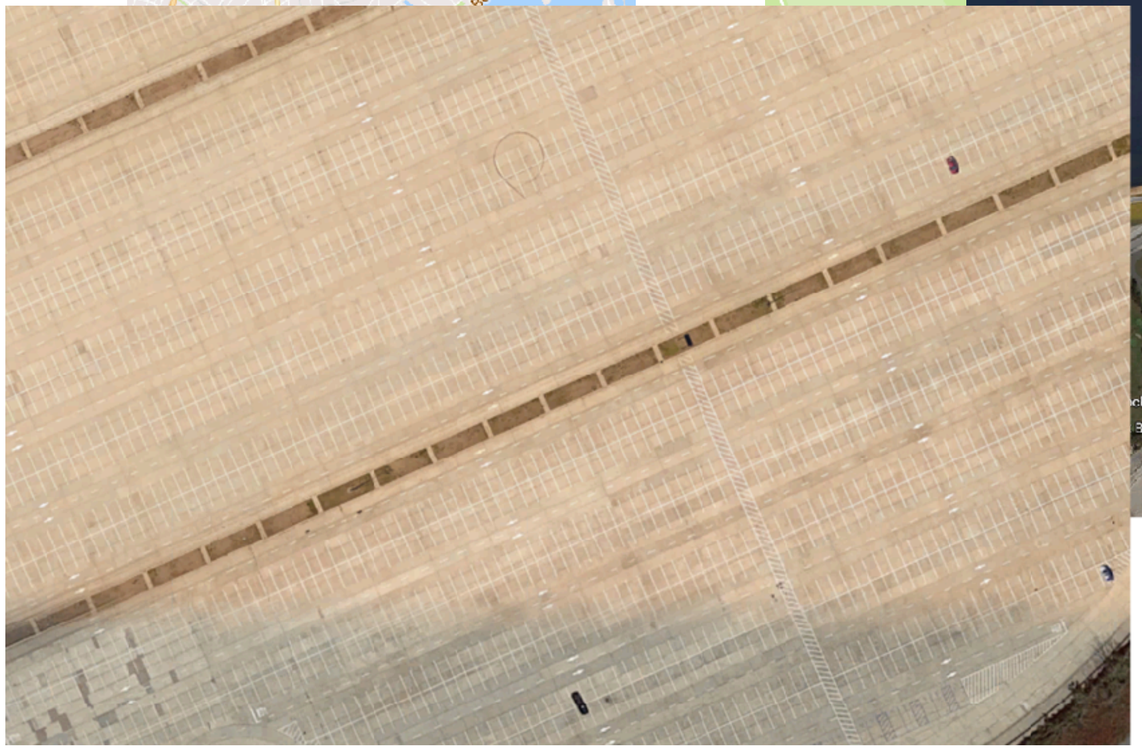
Marine Pkwy Bridge
Rockaway Beach Blvd
Wheel Fun Rentals
Hiss Park Golf Course
Rockaway Beach



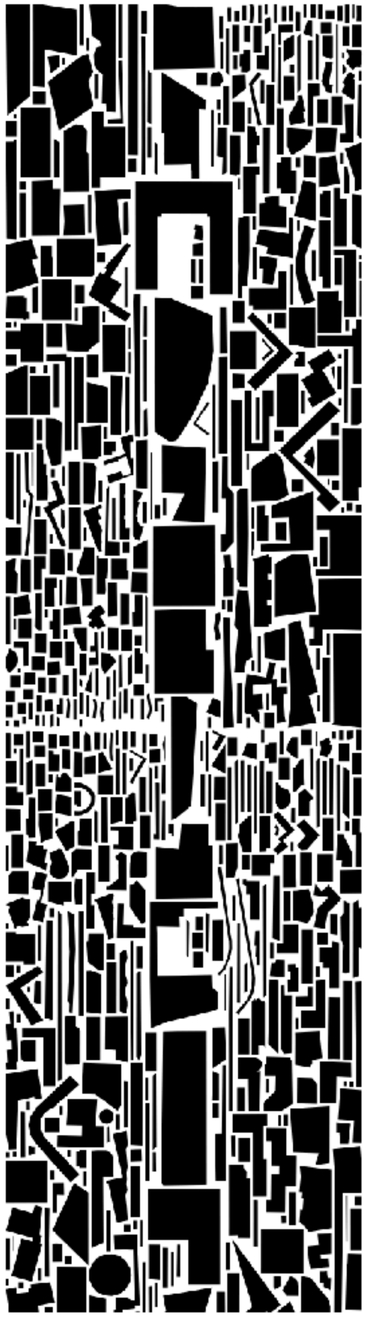
Phyllis A. Turrigiano, RPH
Beach Channel Dr
Rockaway Beach Blvd
Wheel Fun Rentals
Park Gateway National Recreation...
The People's Beach at Jacob Riis Park
Rockaway Beach
Beach Bazaar
Wise Clock (aka Riis Park Memorial Clock)

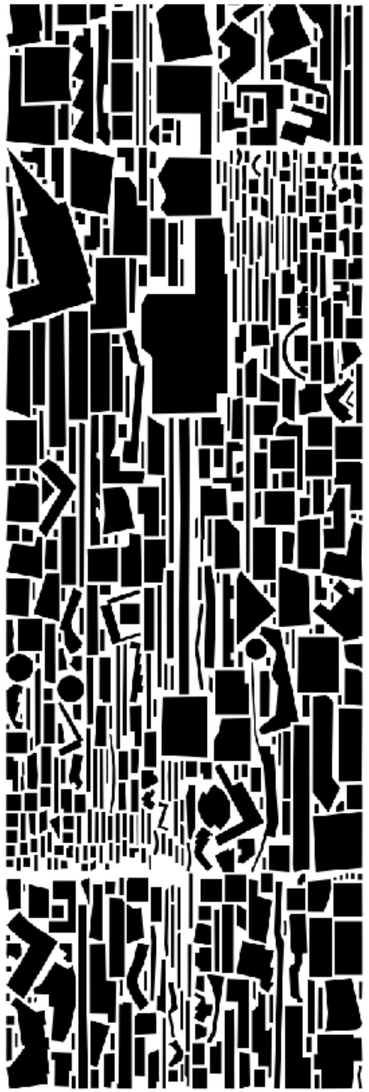
We visualized ALL parking spaces with polygon packing

Copenhagen

What the Street!?

http://whatthestreet.moovellab.com



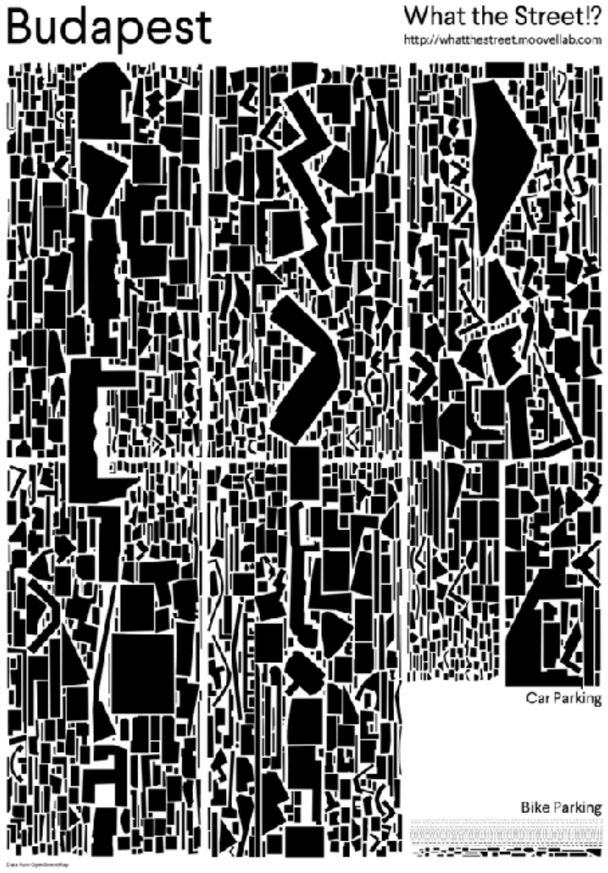


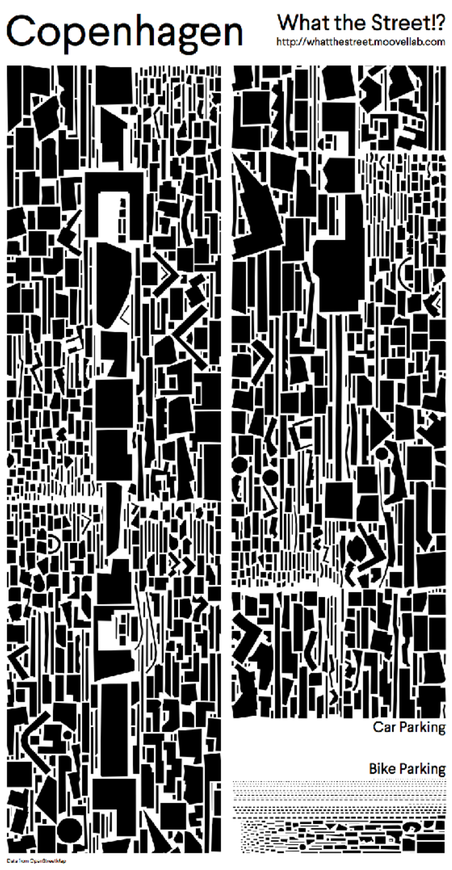
Car Parking

Bike Parking

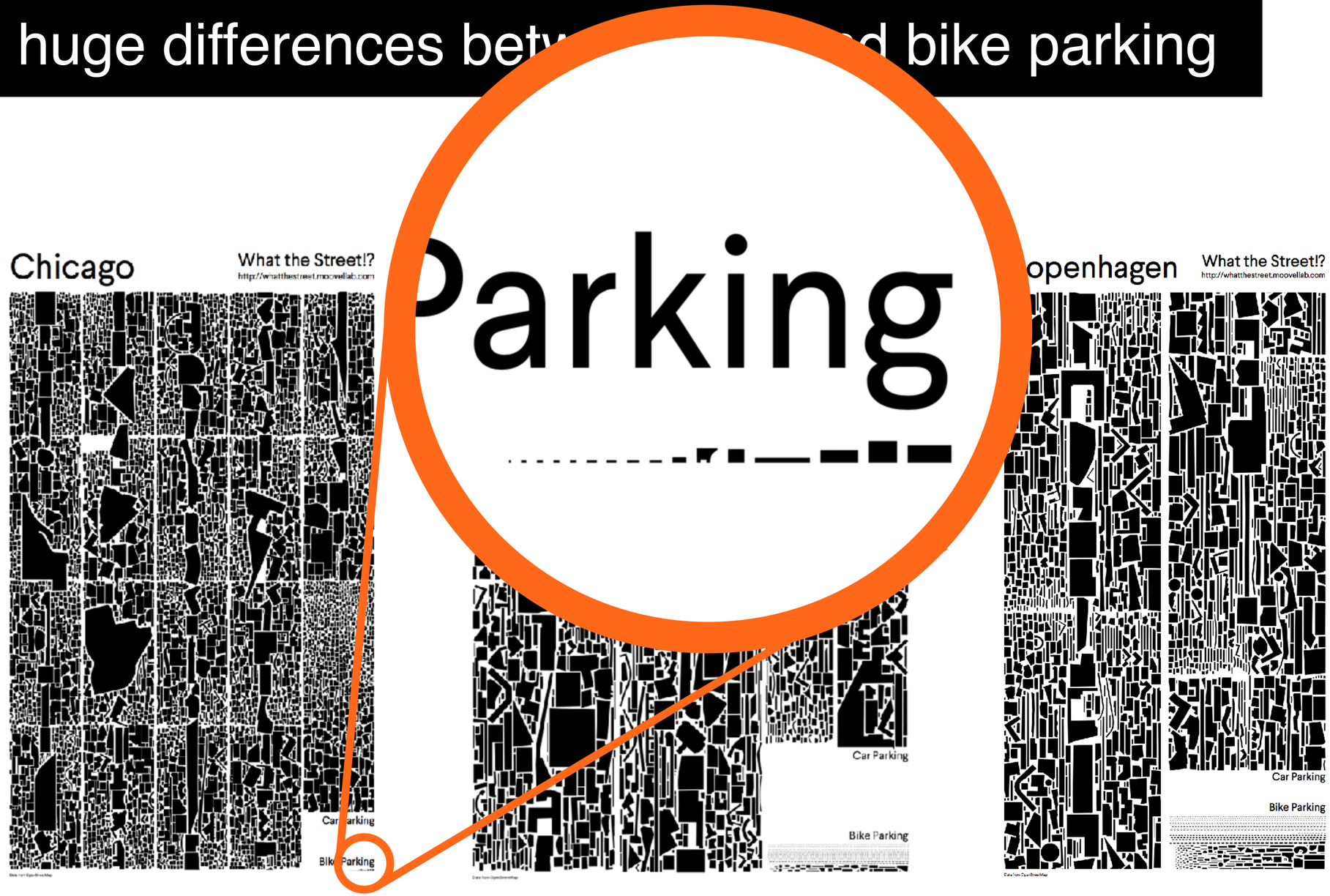
Data from OpenStreetMap

There are huge differences between car and bike parking





There are huge differences bet d bike parking



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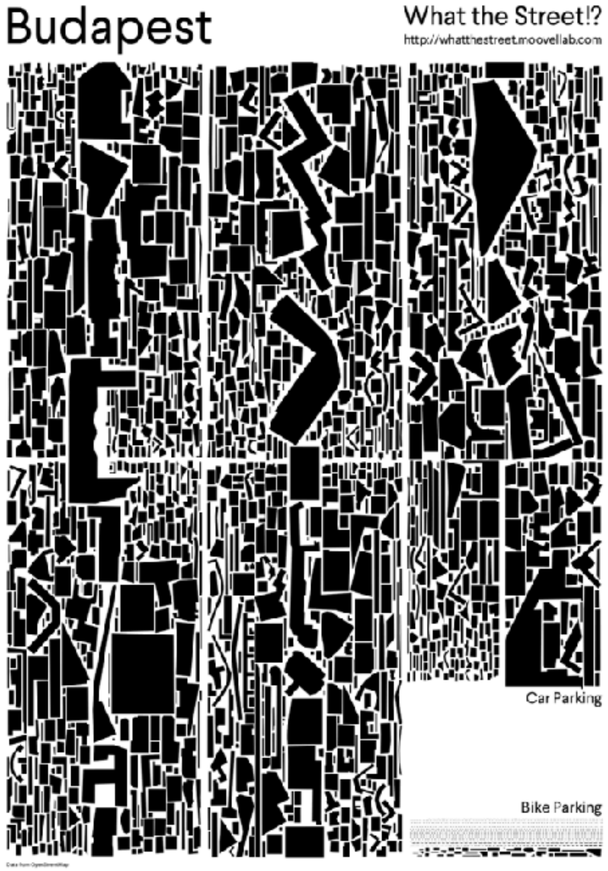
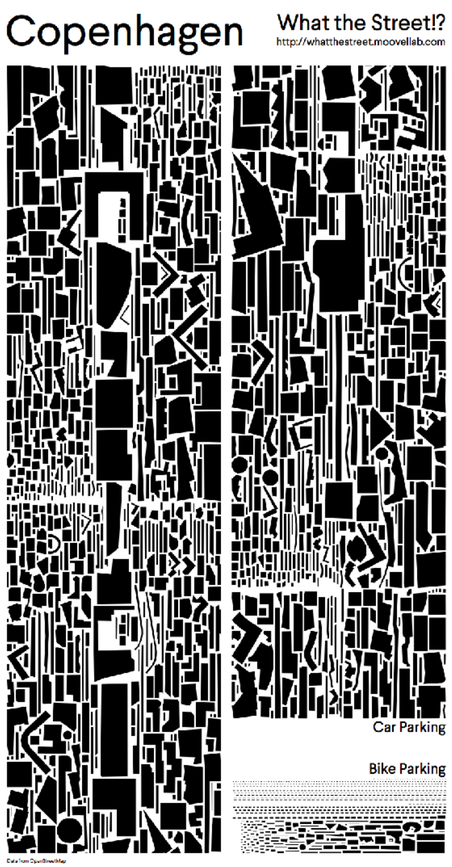
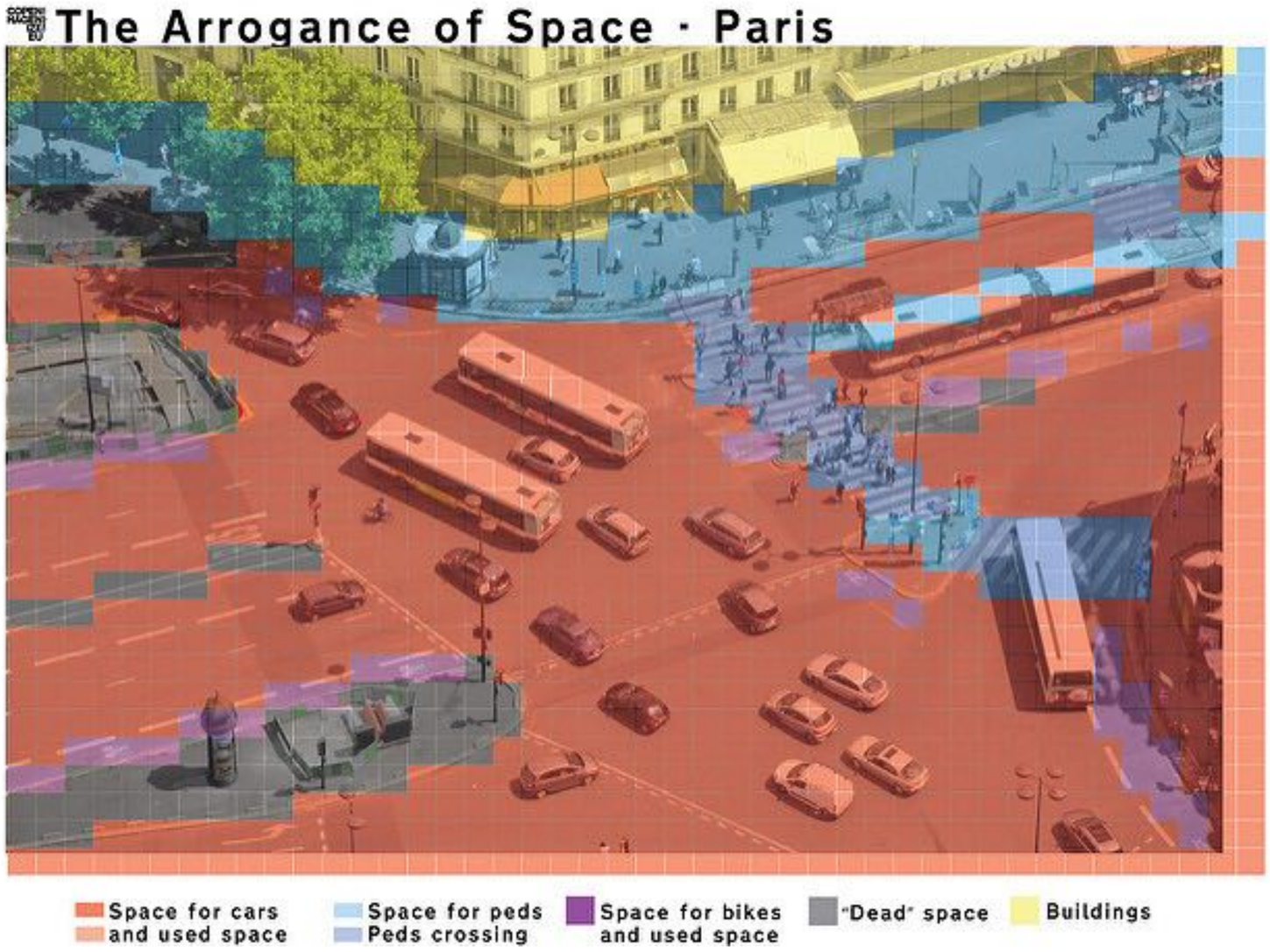




whatthestreet.com

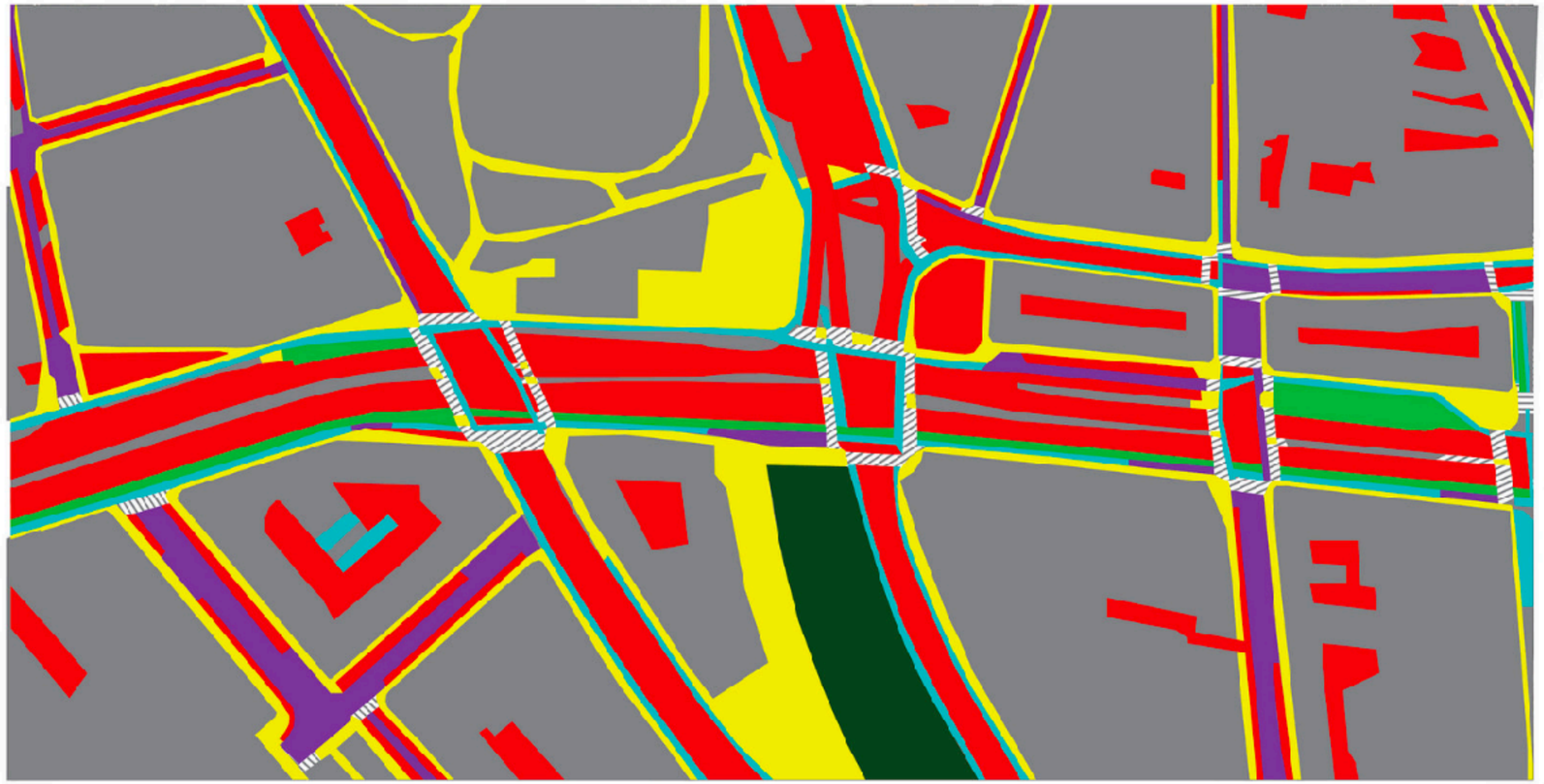
Szell, Urb Plan 3, 1-20 (2018)
Gössling, J Tran Geo 54, 1-9 (2016)

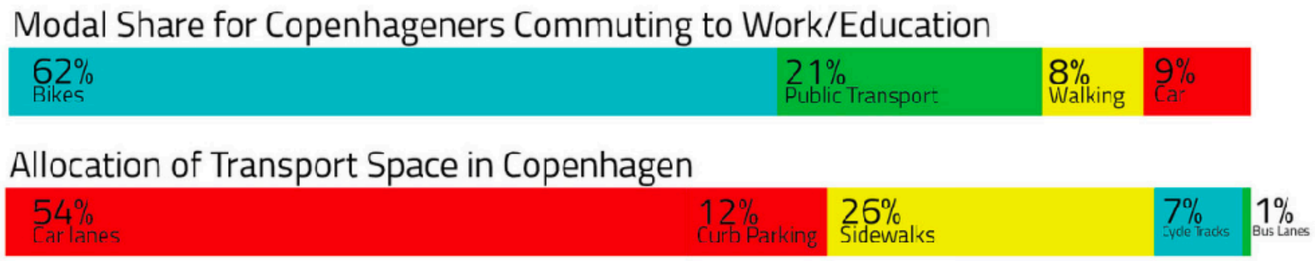
Space is not distributed in a fair way between different modes of transport



Copenhagenize

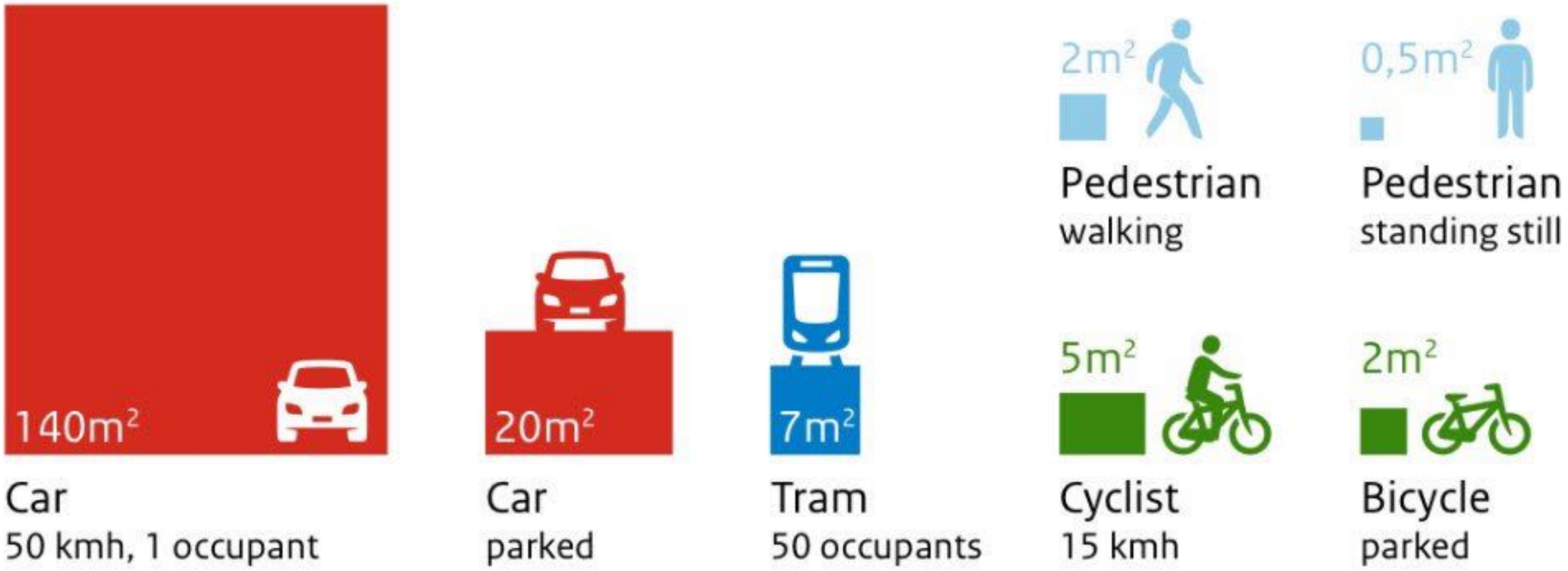
Most space is for cars, but most people use bicycles





Copenhagenize

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



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

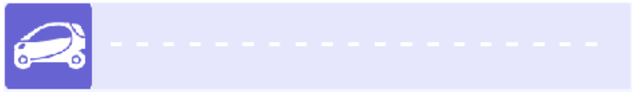
Cars are used 36 minutes per day
Cars are not used 1404 minutes per day

Civity (2016)

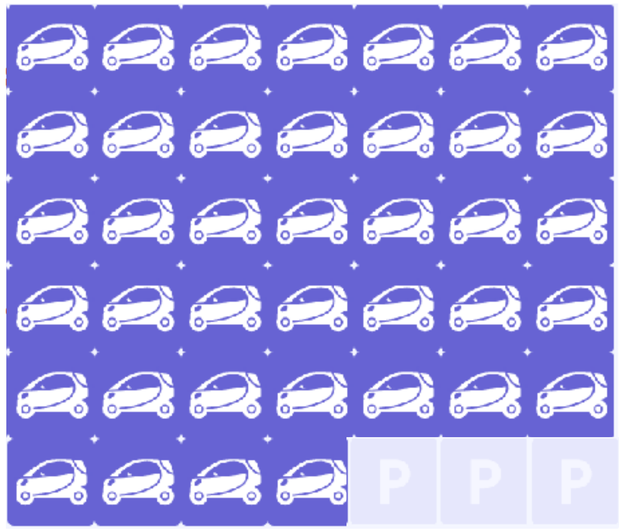
Cars are used 36 minutes per day
Cars are not used 1404 minutes per day

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

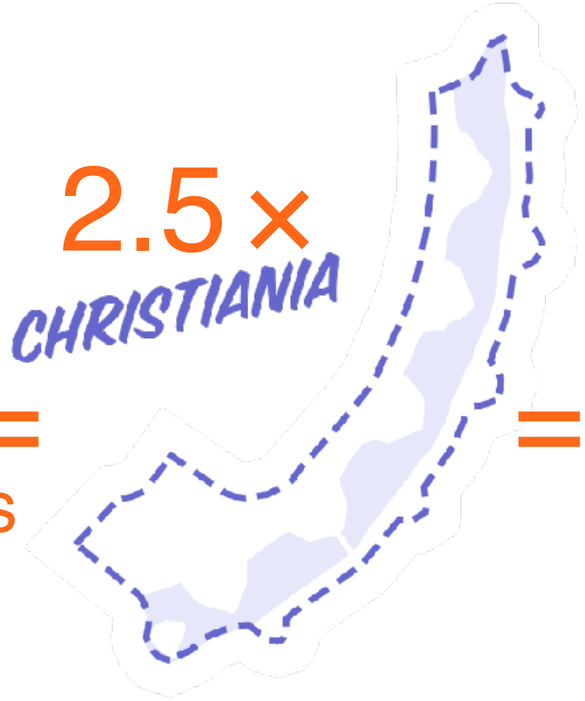
5,500 cars moving

250,000 cars parked

6,000
Playgrounds

=

2.5 ×



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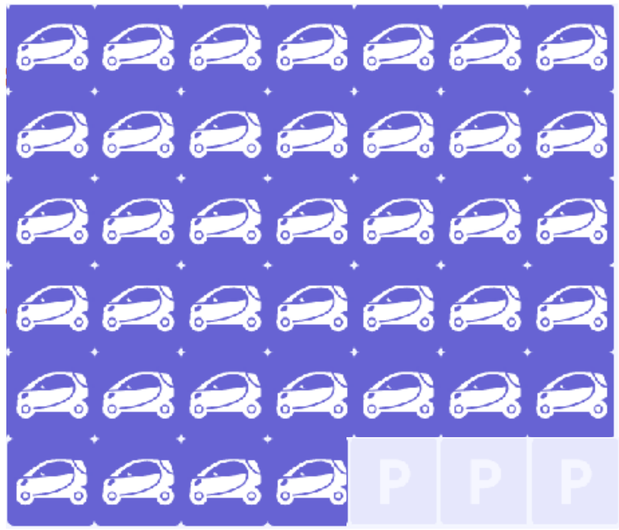
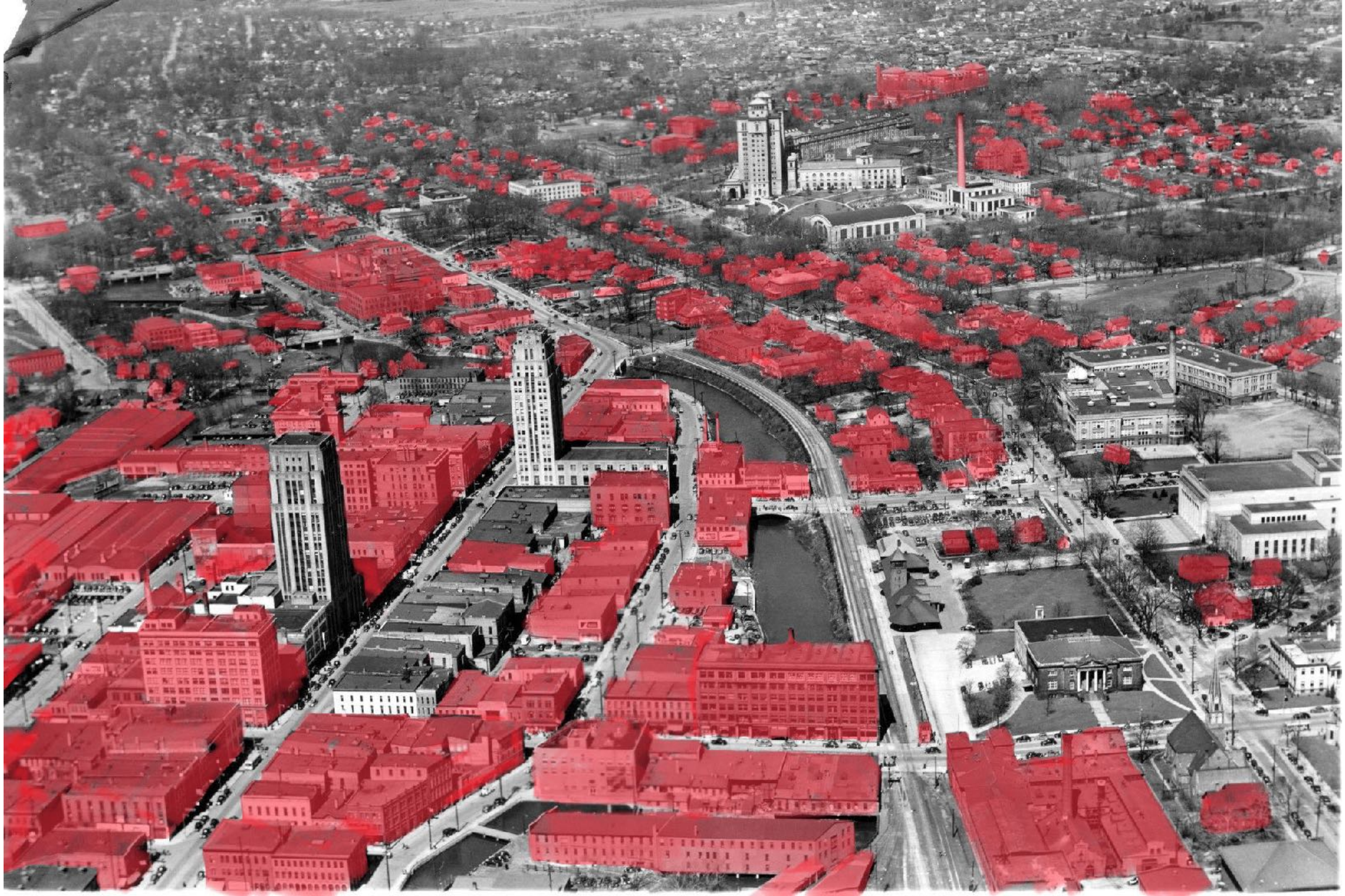




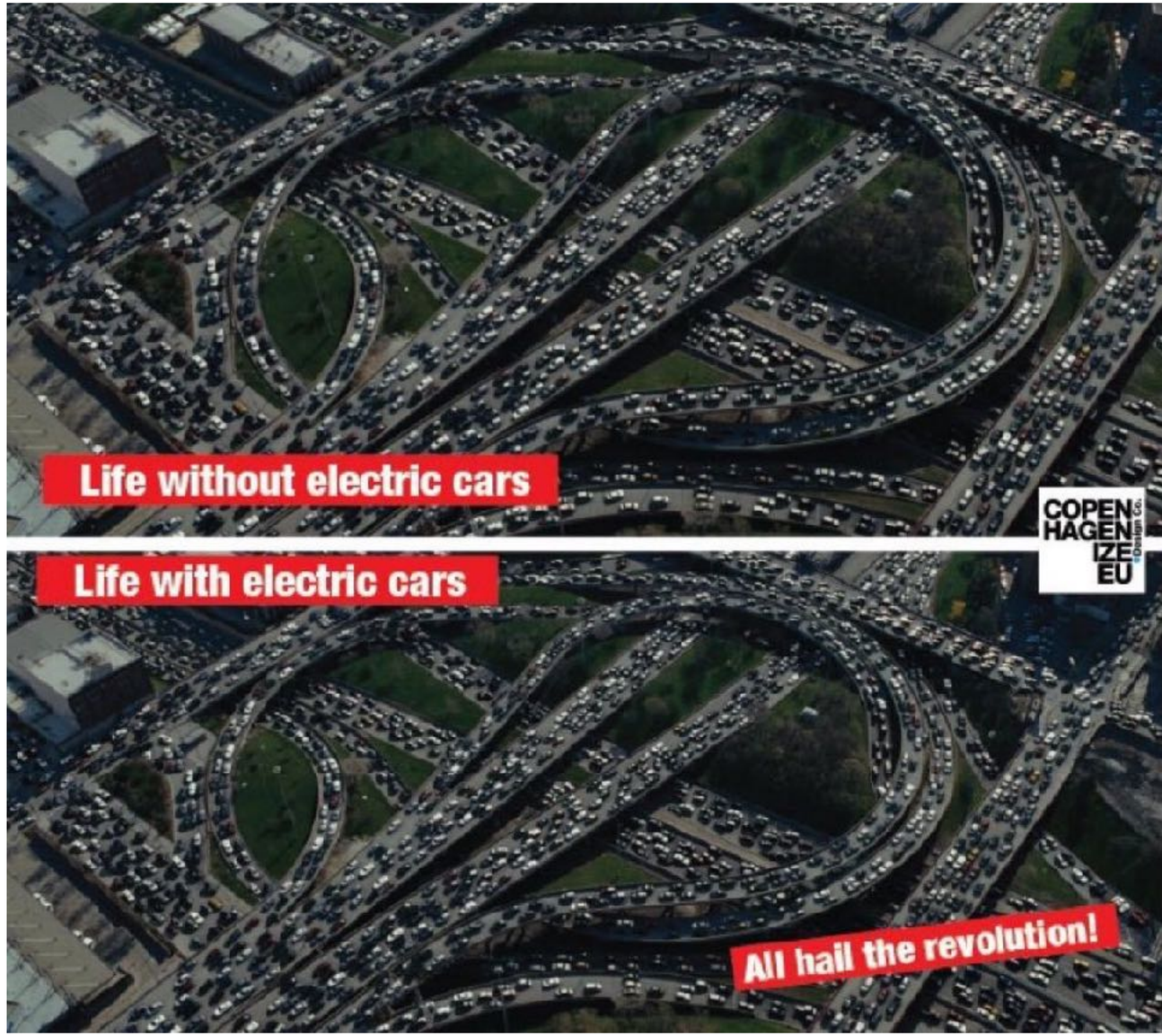
Battle Creek, MI

Battle Creek, MI

Car-centric urban planning eats up our living space in cities

Denver

Car-centric urban planning eats up our living space in cities



POLLUTION

~9.000.000

https://ourworldindata.org/data-review-air-pollution-deaths

E-cars are not THE solution: >50% of particles are from non-exhaust

Jeong, Ryu, & Ra, Env Pol 292 (2022)

ANYTHING ELSE?

1.350.000

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 an *economic* "no-brainer"

Cost-benefit analysis in EU that accounts for

- Health
- Environment
- Travel / Congestion

shows:

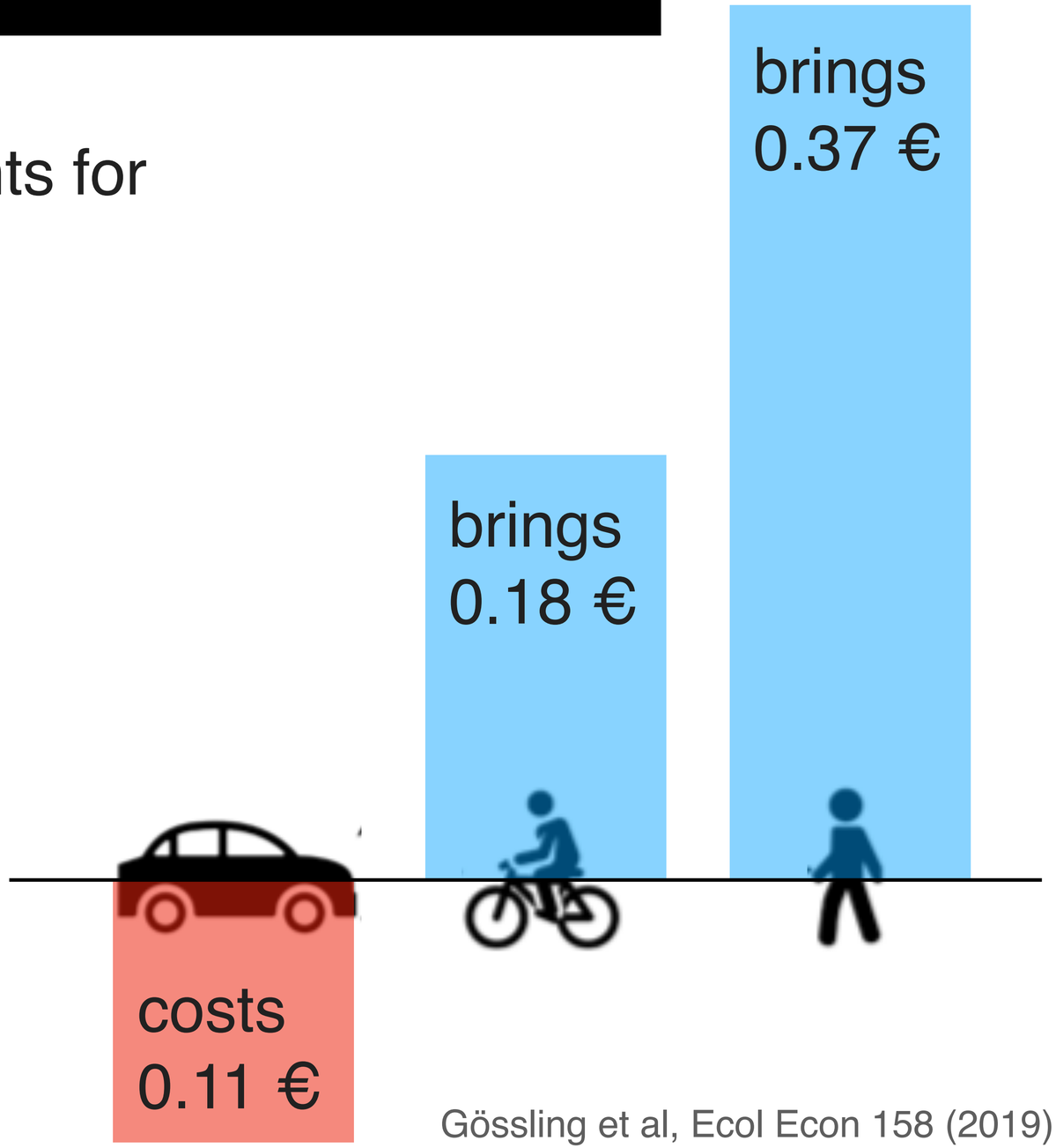
Gössling et al, Ecol Econ 158 (2019)

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

Cost-benefit analysis in EU that accounts for

- Health
- Environment
- Travel / Congestion

shows: 1 km travelled by



Gössling et al, Ecol Econ 158 (2019)

How to build bicycle infrastructure?

microscopic

How to build bicycle infrastructure?

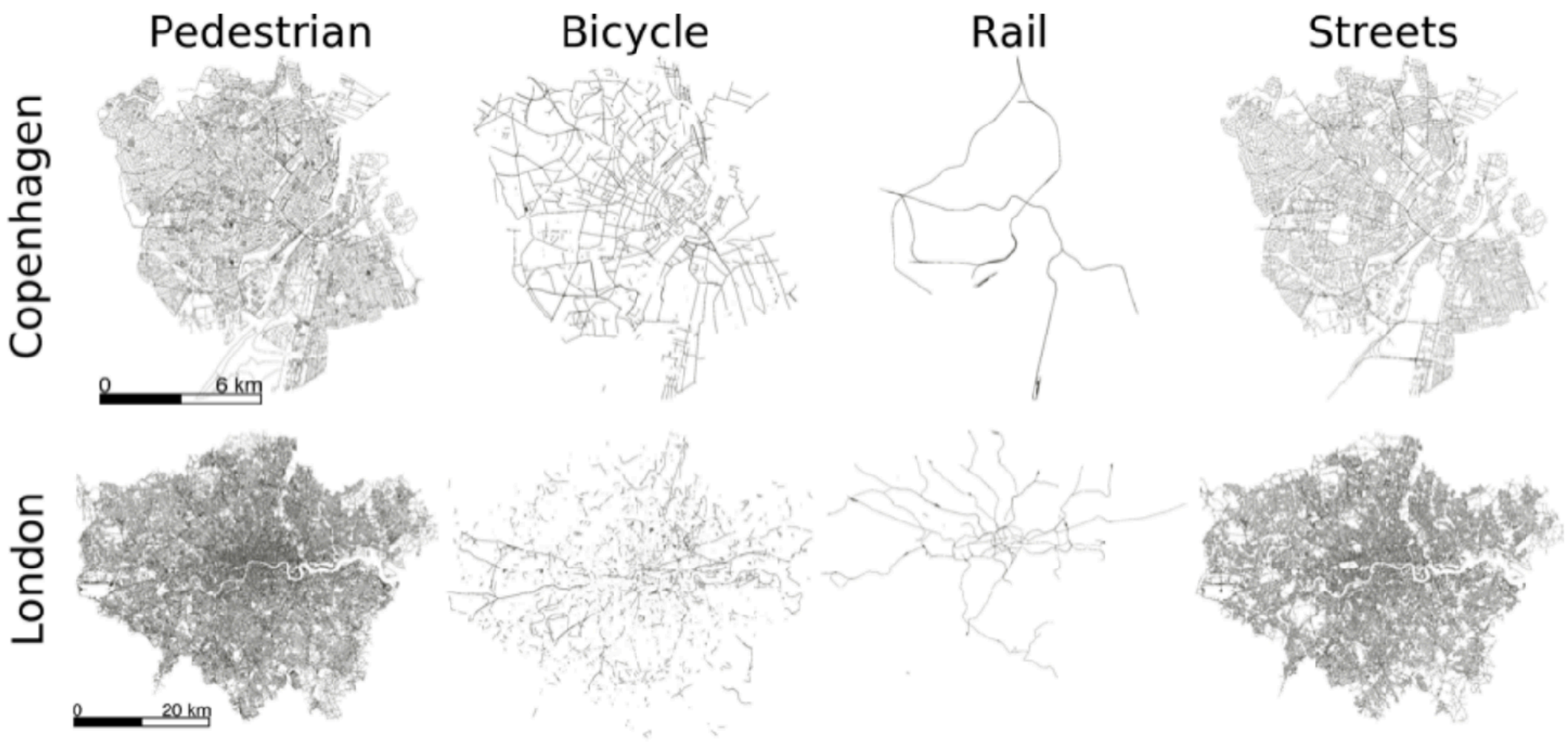
microscopic

macroscopic

Blackboard

Network Science 101

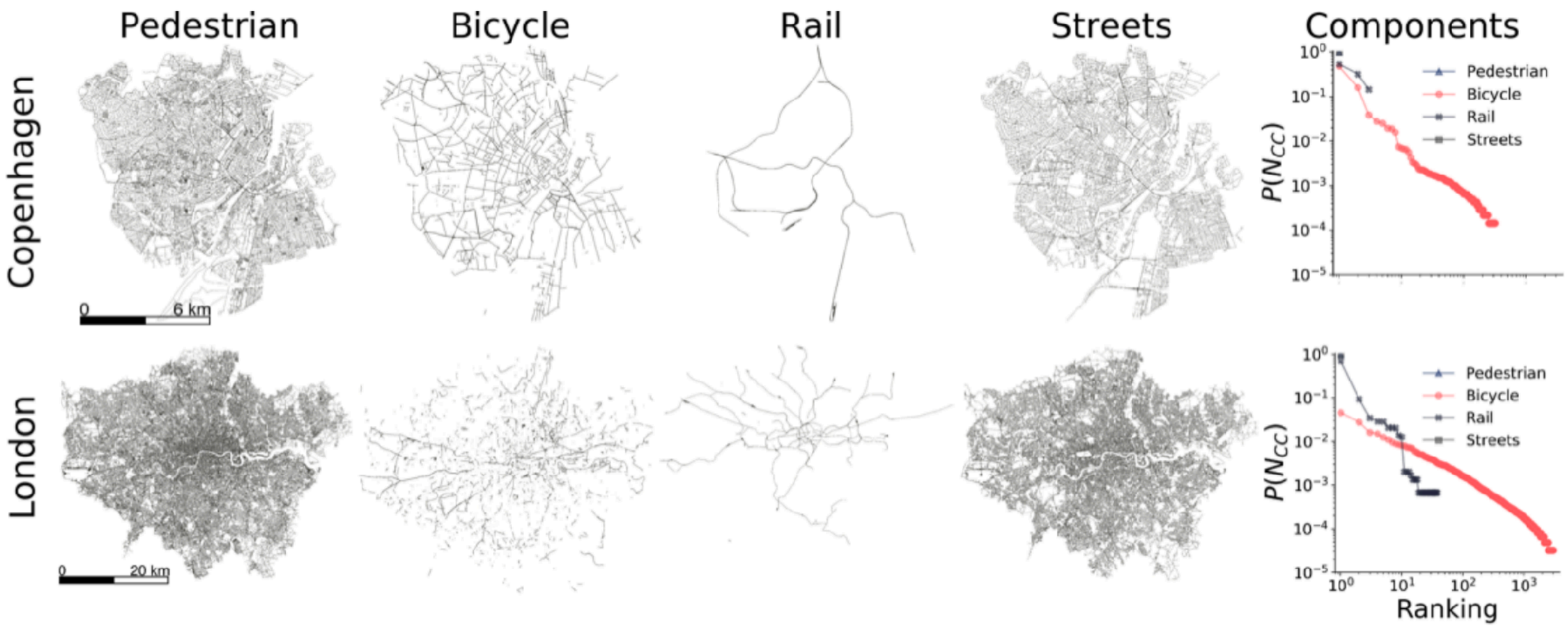
Cities have different transport network layers



Natera Oroczo et al, R Soc Open Sci 7 (2020)

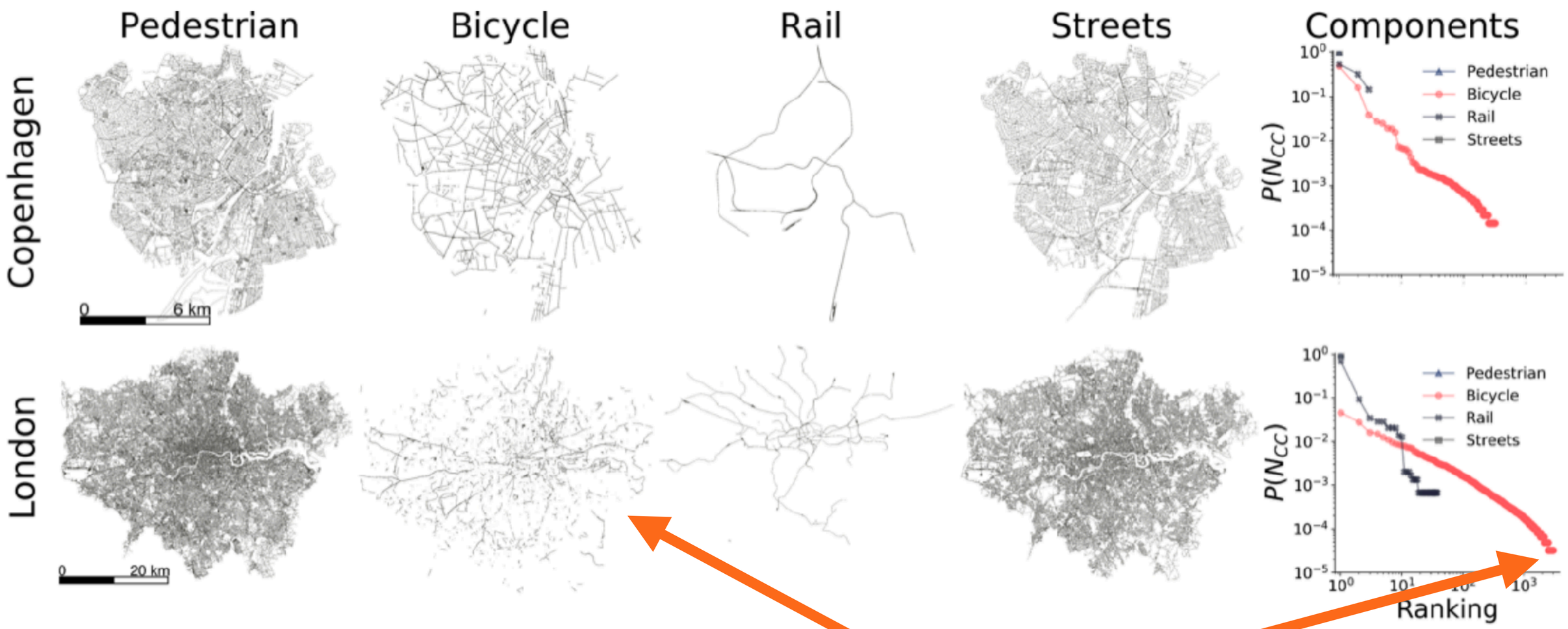
Bicycle networks are highly fragmented

Blackboard



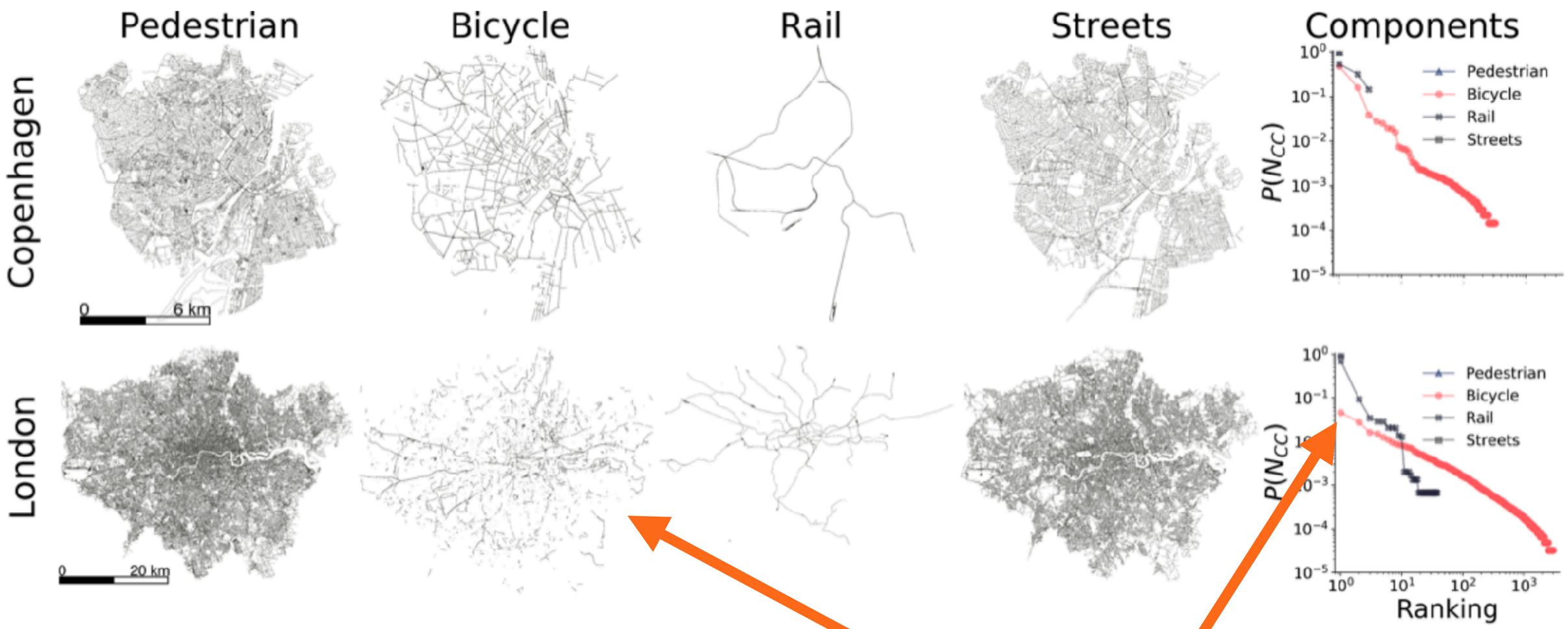
Natera Oroczo et al, R Soc Open Sci 7 (2020)

Bicycle networks are highly fragmented



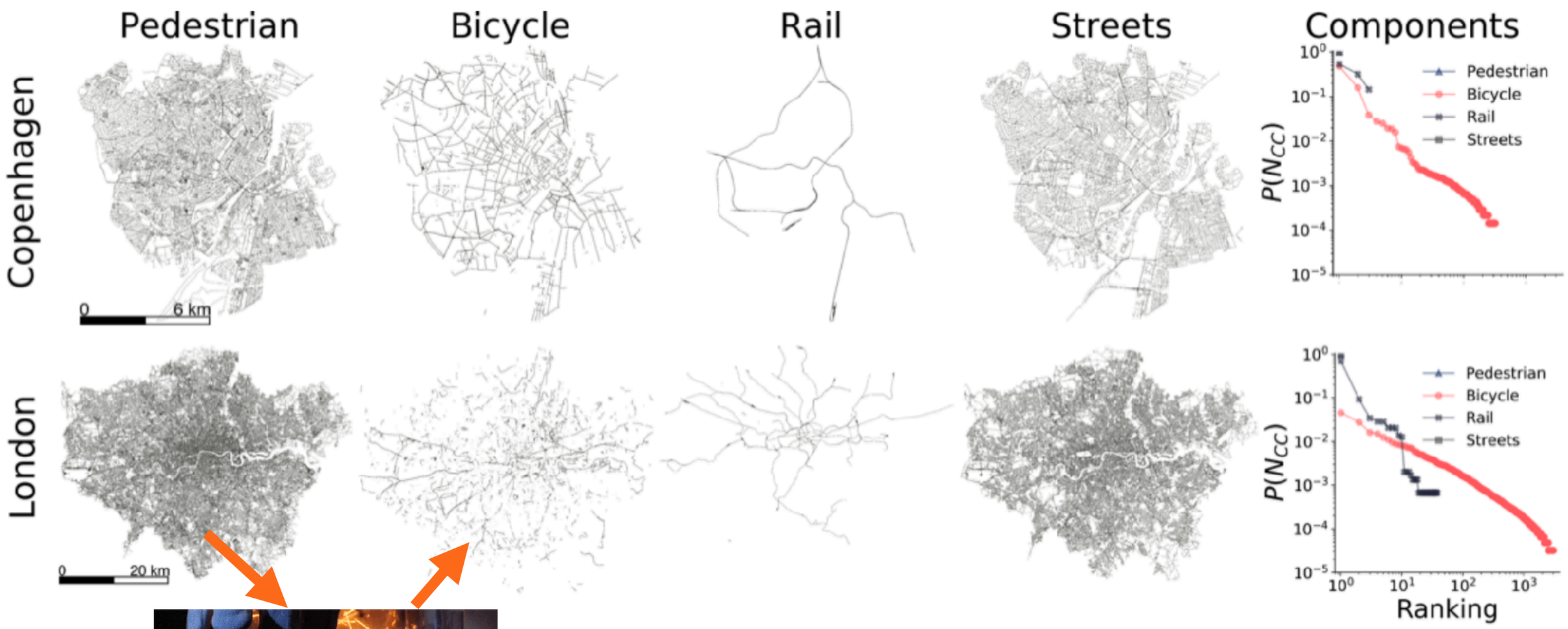
2) In London, the bicycle network has >3000 disconnected components

Bicycle networks are highly fragmented



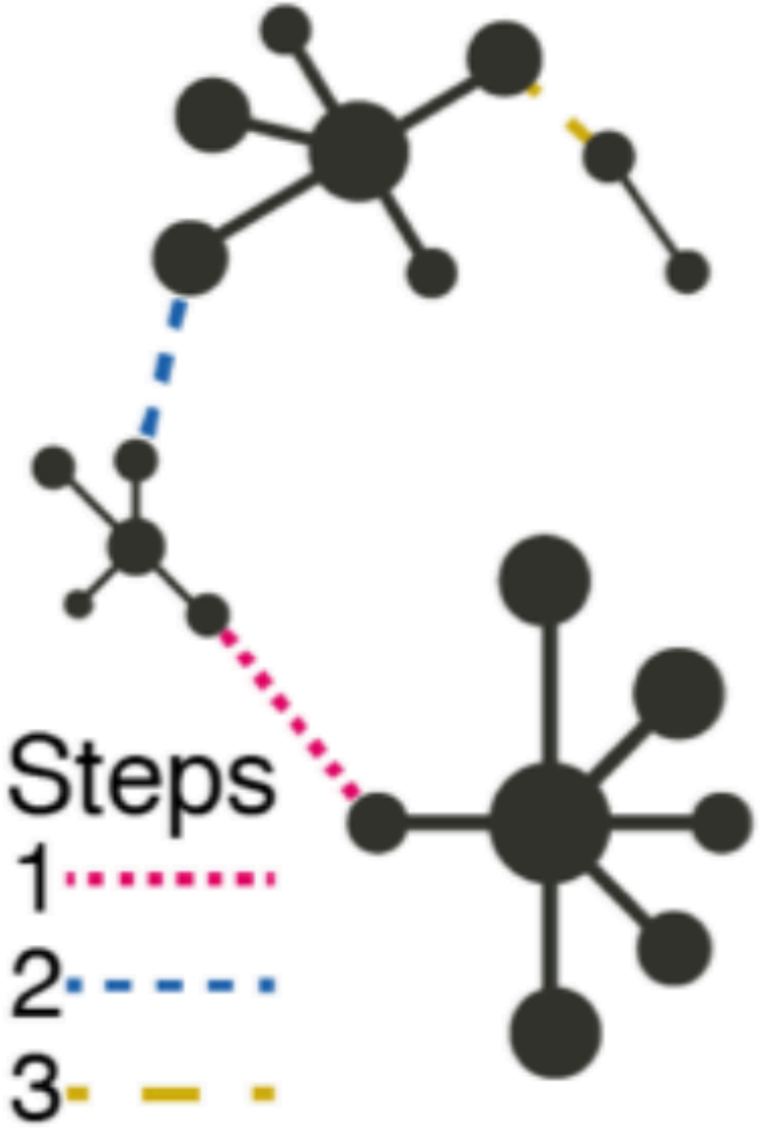
1) In London, the largest connected bicycle component covers only 5% of nodes

Bicycle networks are highly fragmented



Natera Oroczo et al, R Soc Open Sci 7 (2020)

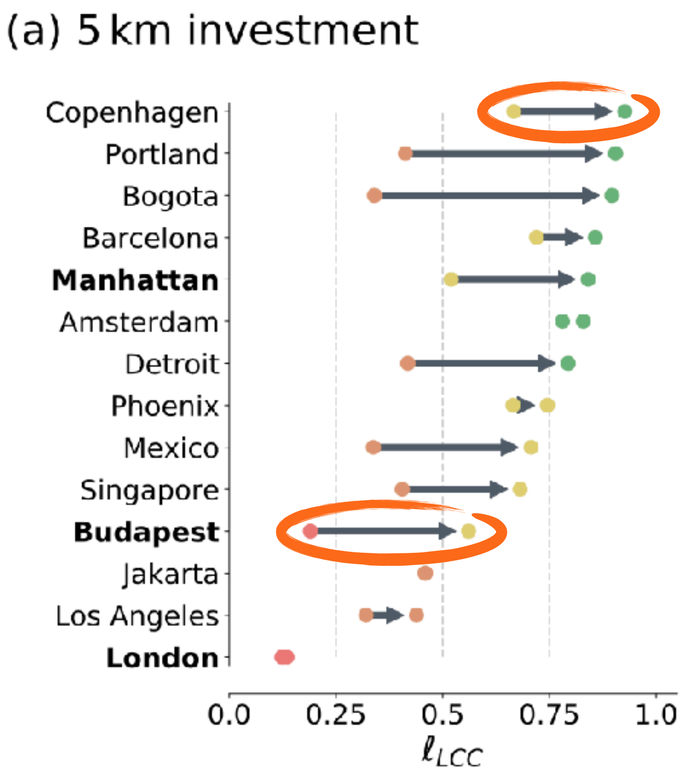
How should we connect the components?

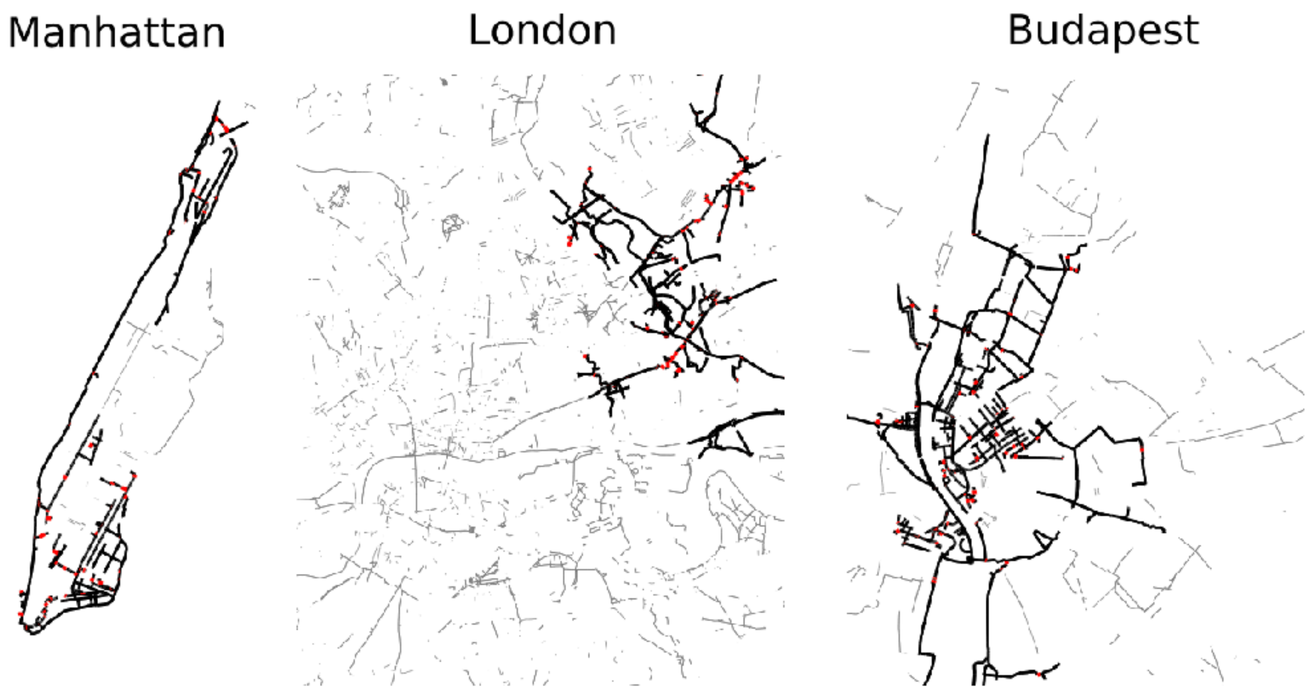


Natera Oroczo et al, R Soc Open Sci 7 (2020)

Effective connectivity improvements are possible

Small but focused investments connect the bicycle network effectively



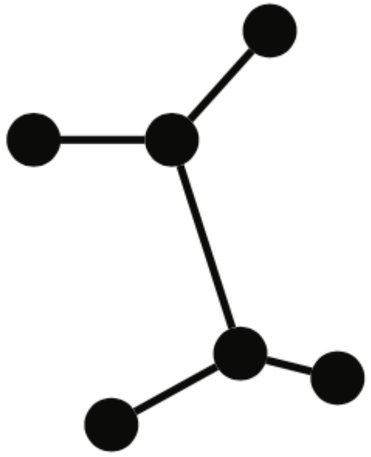


Natera Oroczo et al, R Soc Open Sci 7 (2020)

Just connecting components comes with 3 issues

1) No resilience

Minimum spanning tree



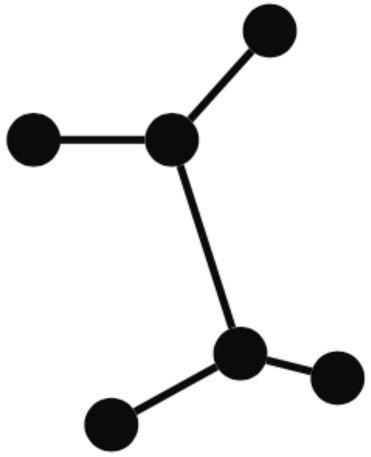
Investor's optimum

Just connecting components comes with 3 issues

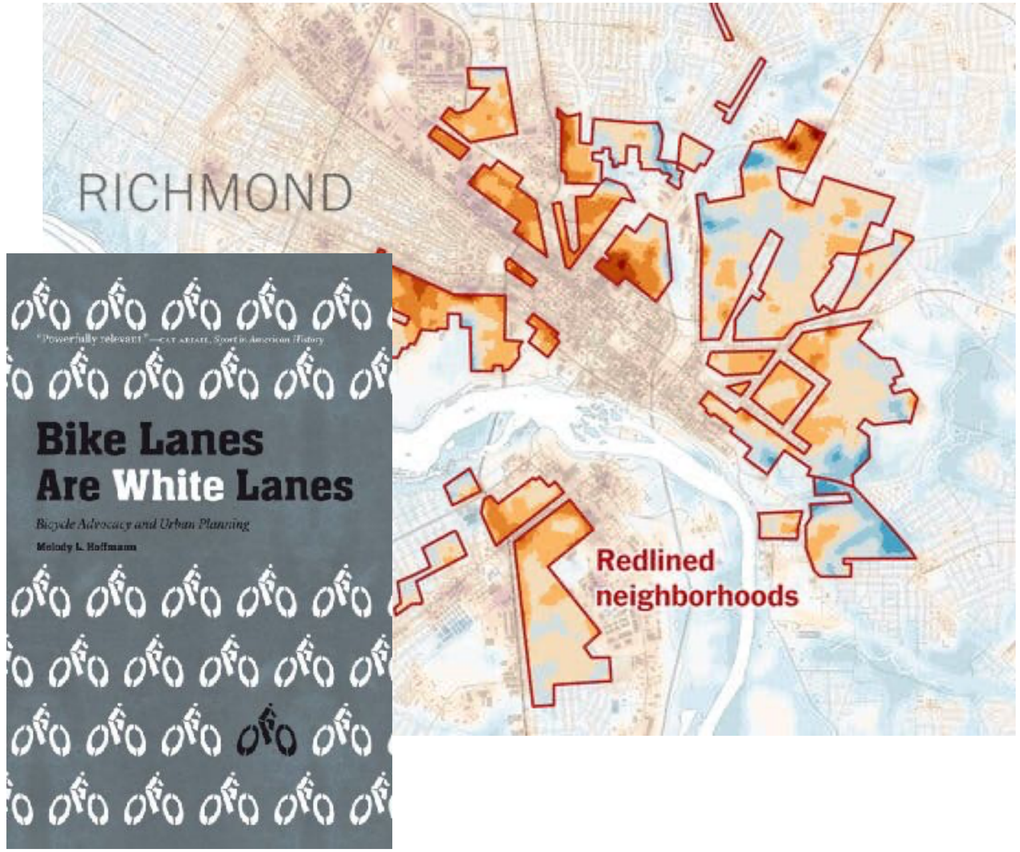
1) No resilience

2) Develops only developed areas

Minimum spanning tree



Investor's optimum

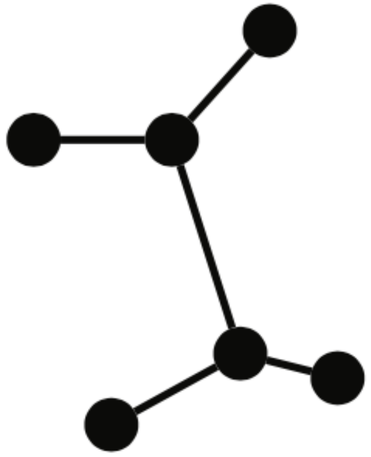


Pereira, Schwanen & Banister, Trans Rev 37 (2017)

Just connecting components comes with 3 issues

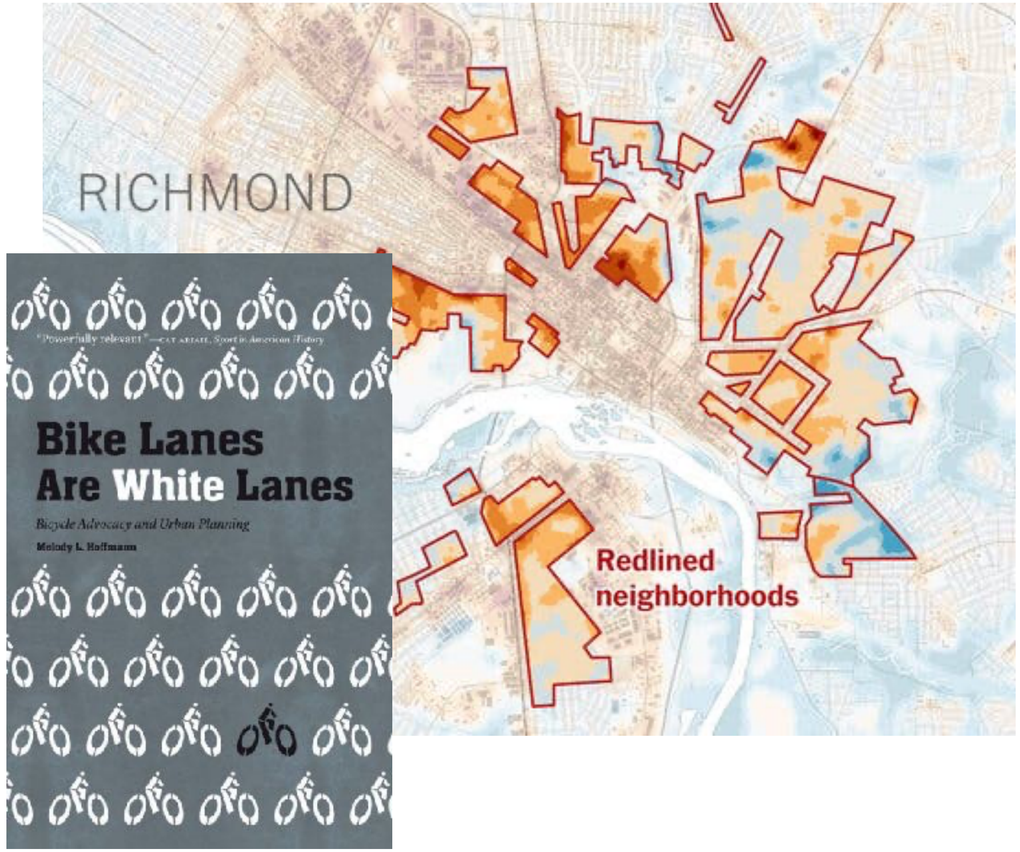
1) No resilience

Minimum spanning tree

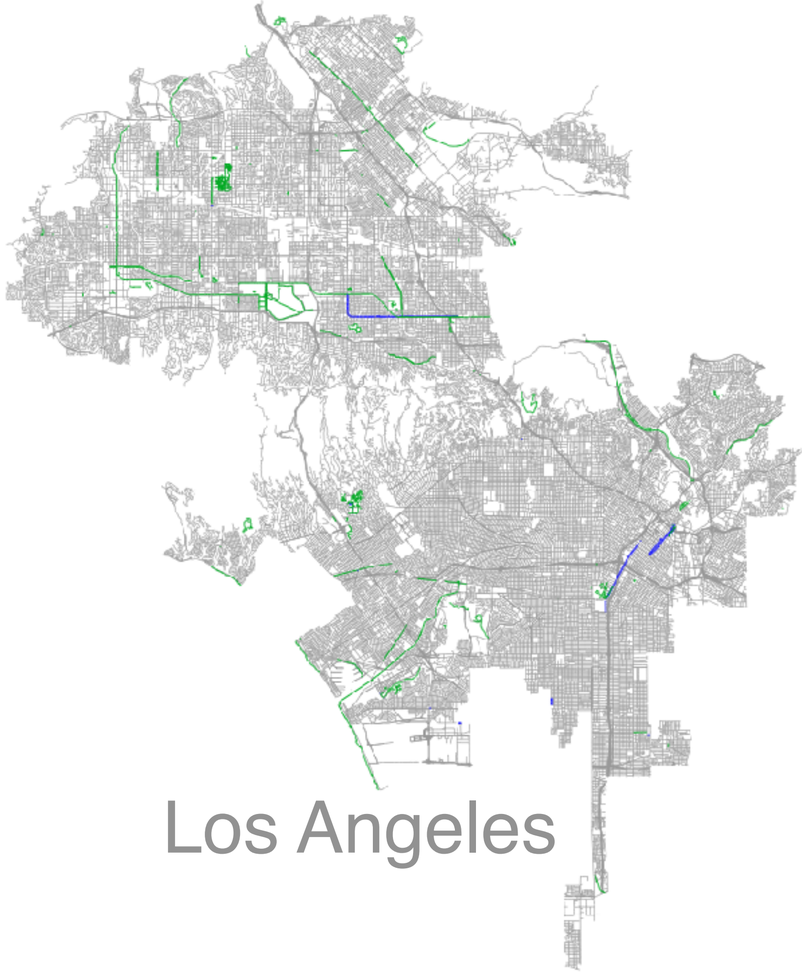


Investor's optimum

2) Develops only developed areas



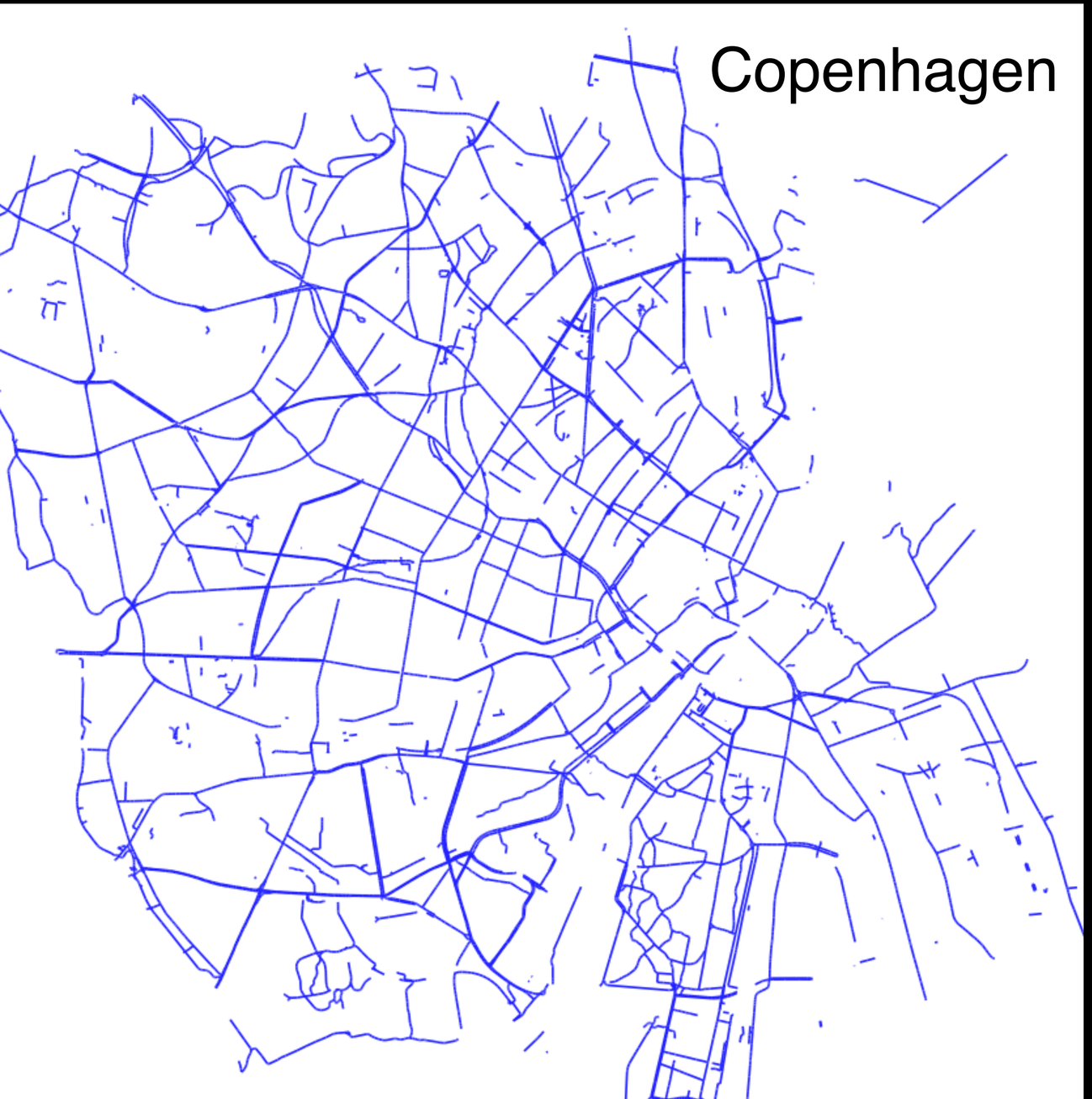
3) Irrelevant for >99% of cities on the planet

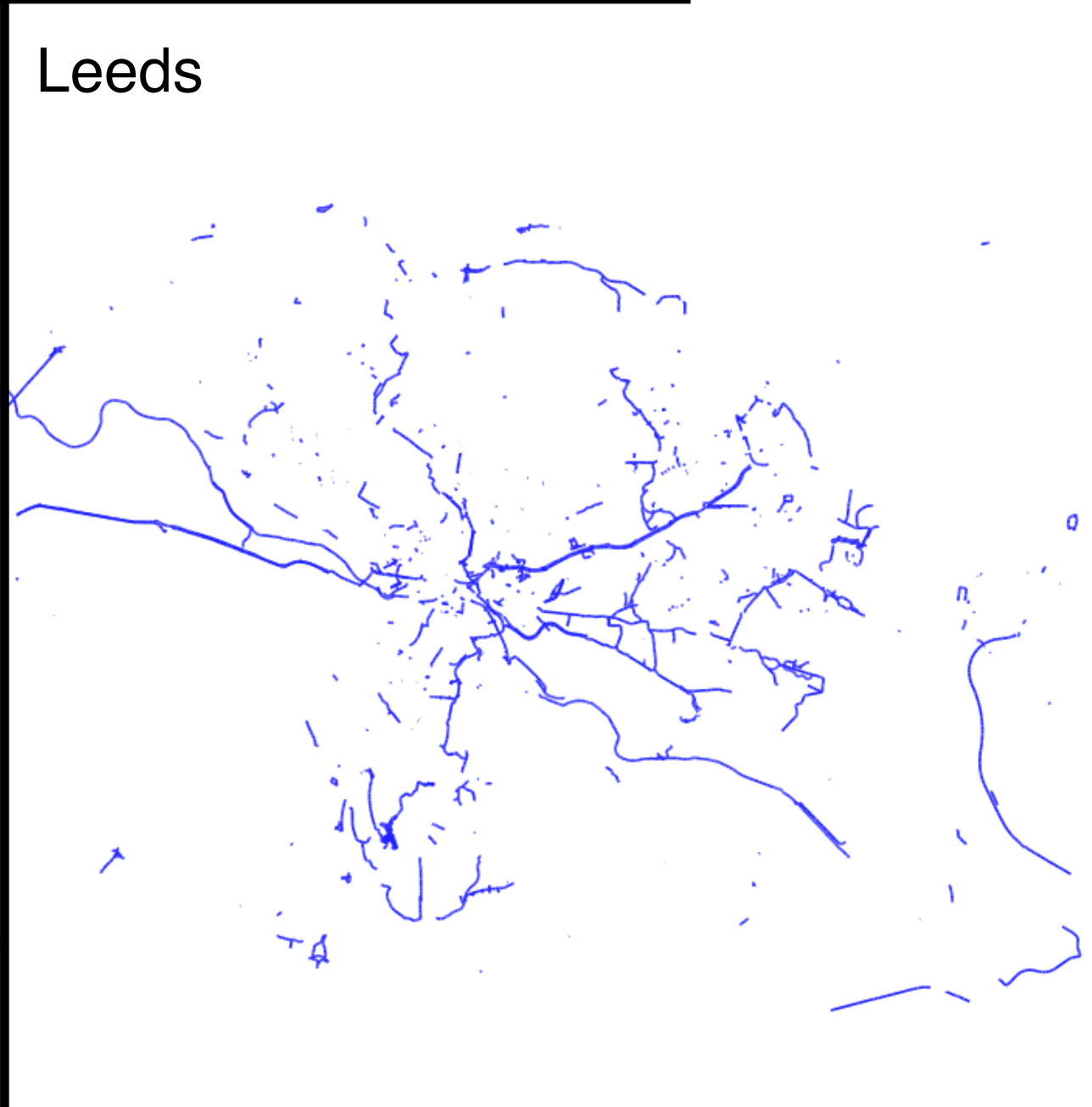


Los Angeles

Let's grow networks
from scratch

What properties should a good bicycle network have?





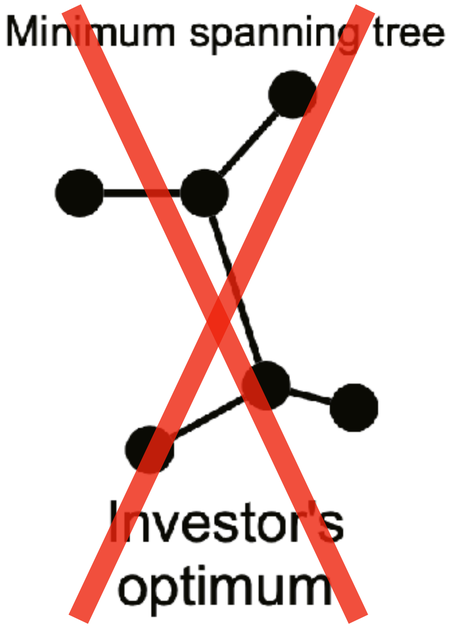
fietsberaad CROW

Design Manual for Bicycle Traffic

Inspired by CROW, we want a cohesive network

Inspired by CROW, we want a cohesive network

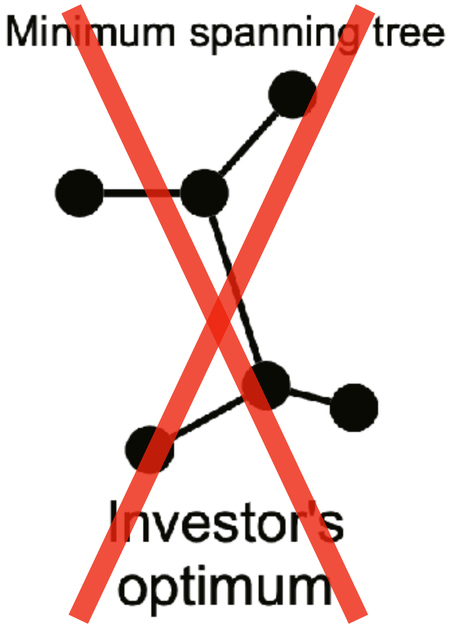
Connectedness & Resilience

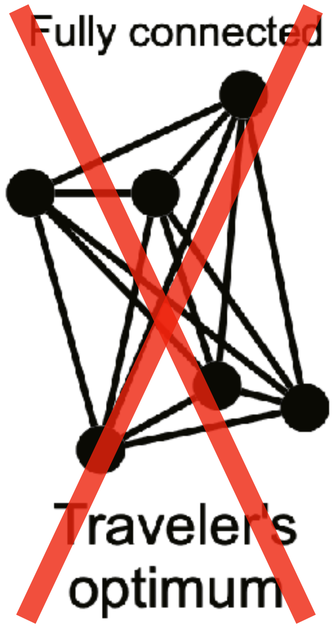


Szell et al., Sci Rep 12, 6765 (2022)

Inspired by CROW, we want a cohesive network

Connectedness & Resilience

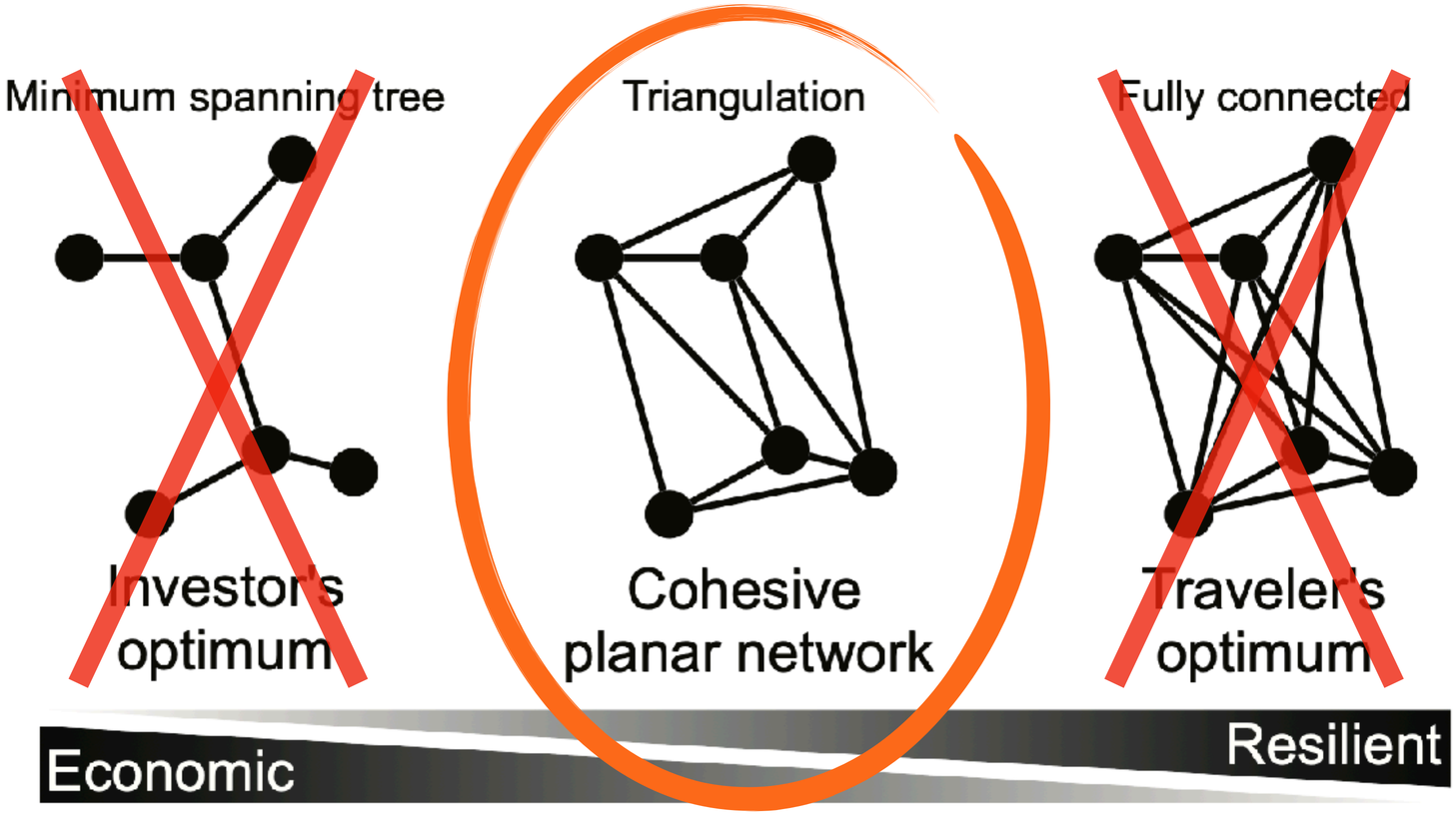




Szell et al., Sci Rep 12, 6765 (2022)

Inspired by CROW, we want a cohesive network

Connectedness & Resilience

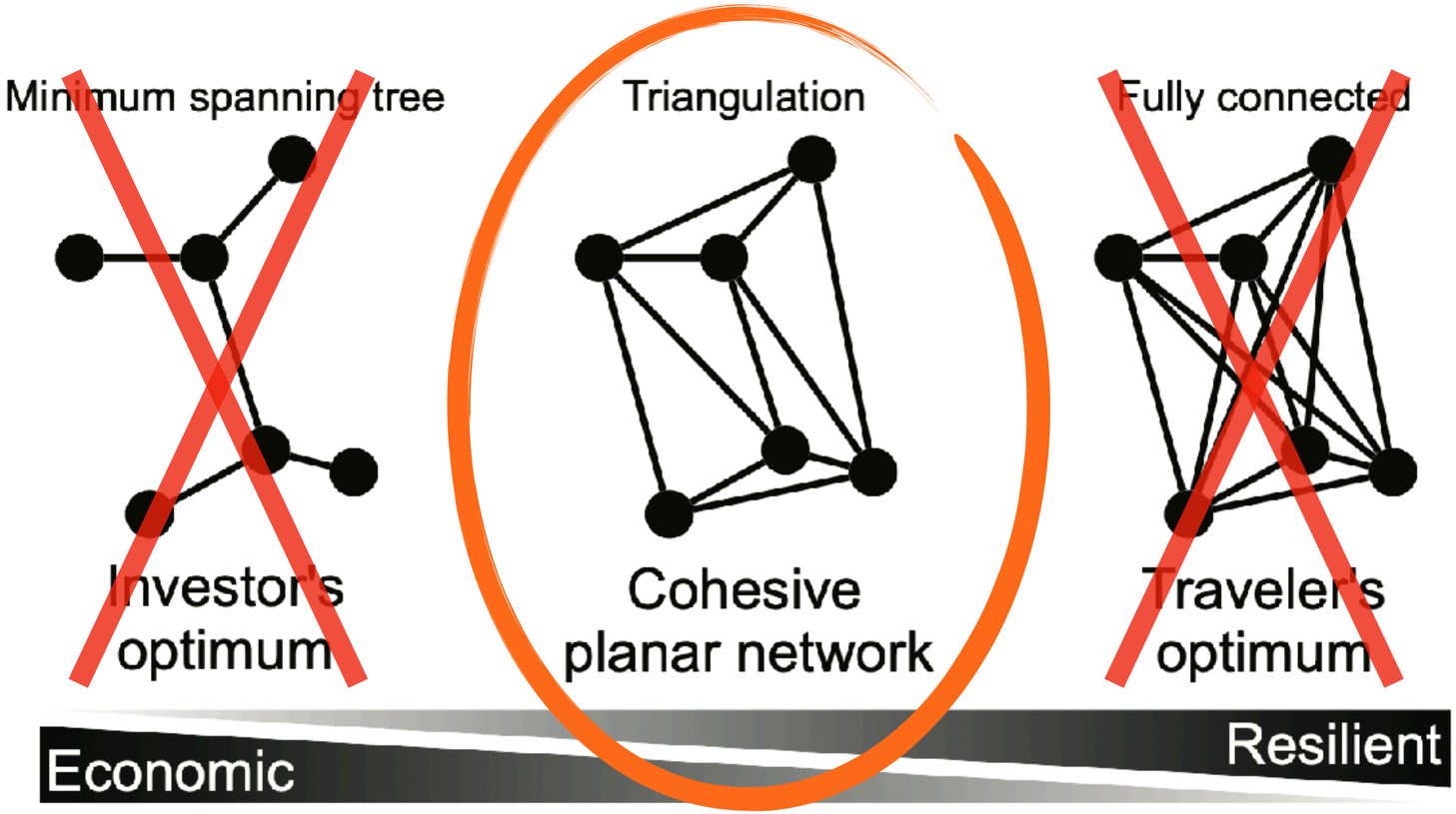


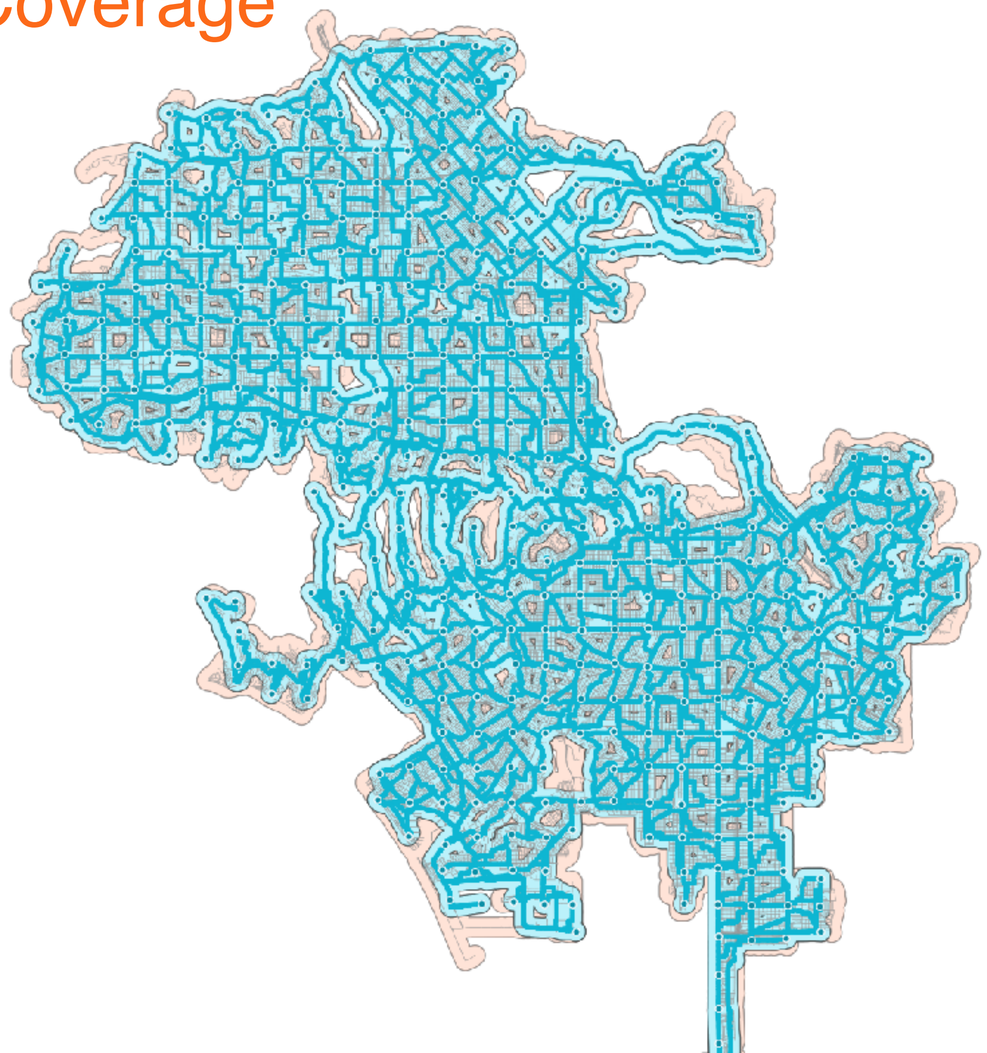
Szell et al., Sci Rep 12, 6765 (2022)

Inspired by CROW, we want a cohesive network

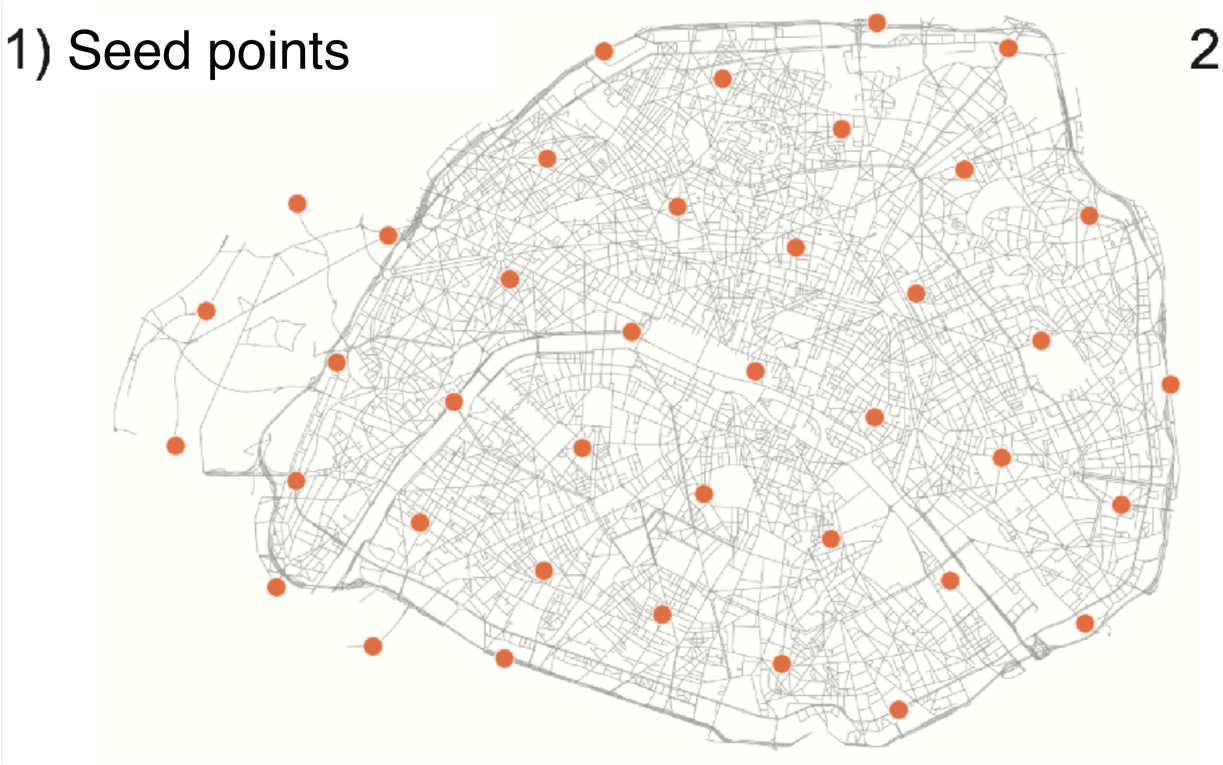
Connectedness & Resilience

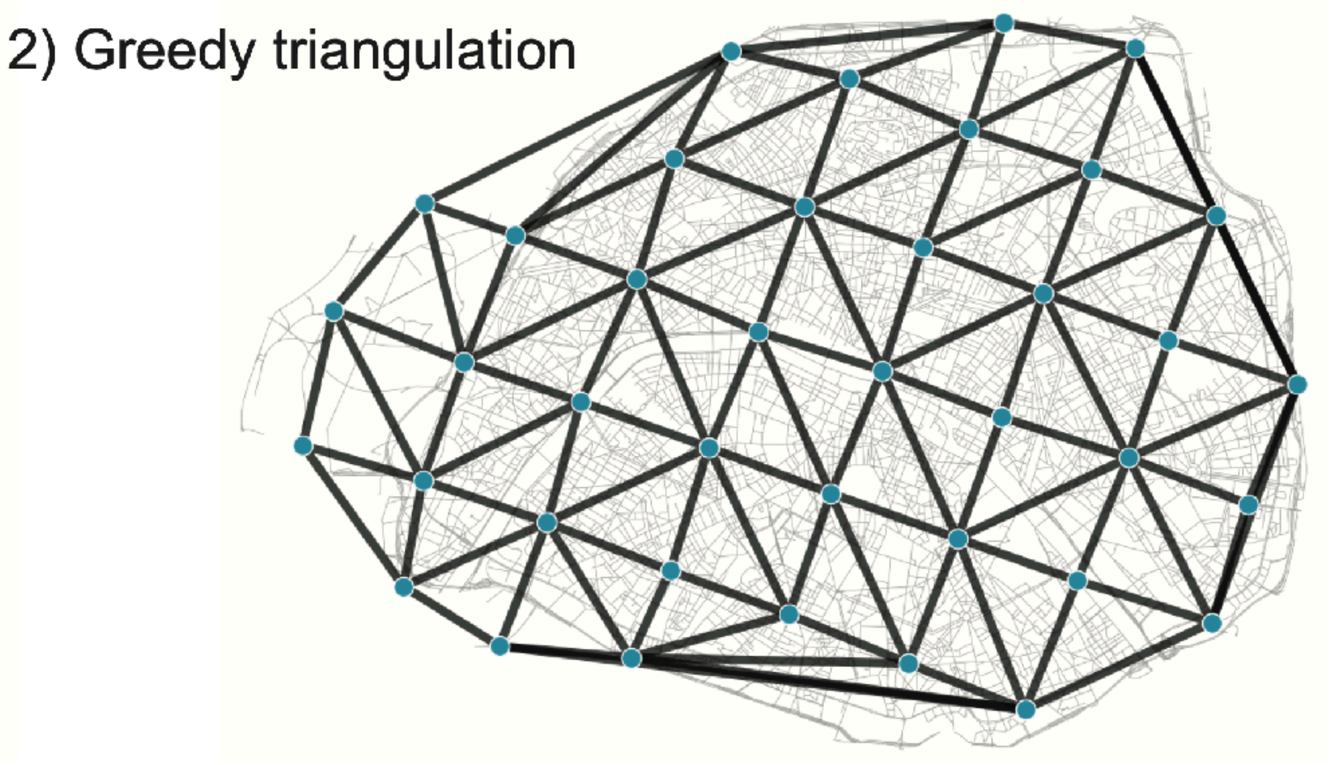
& Coverage





We build a greedy triangulation between points of interest

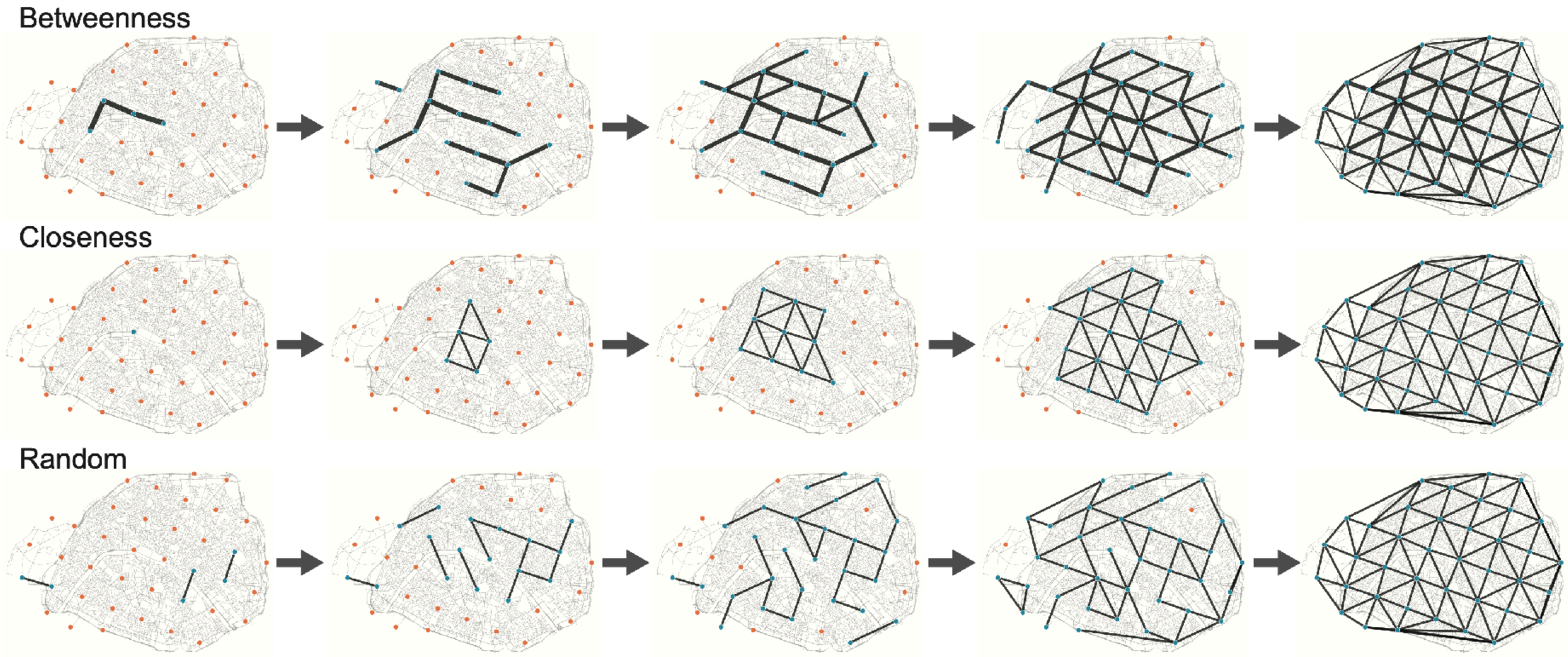




Szell et al., Sci Rep 12, 6765 (2022)

We build a greedy triangulation between points of interest

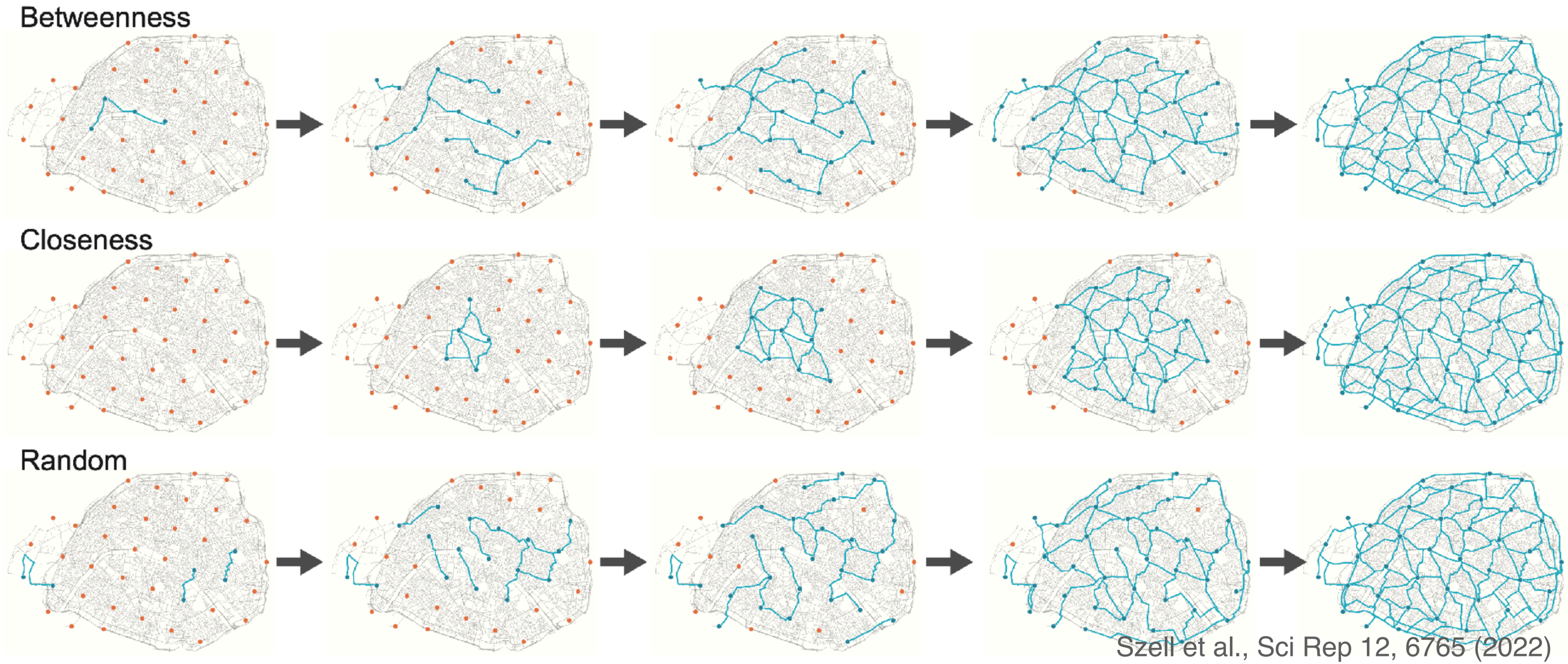
3) Order by growth strategy



Szell et al., Sci Rep 12, 6765 (2022)

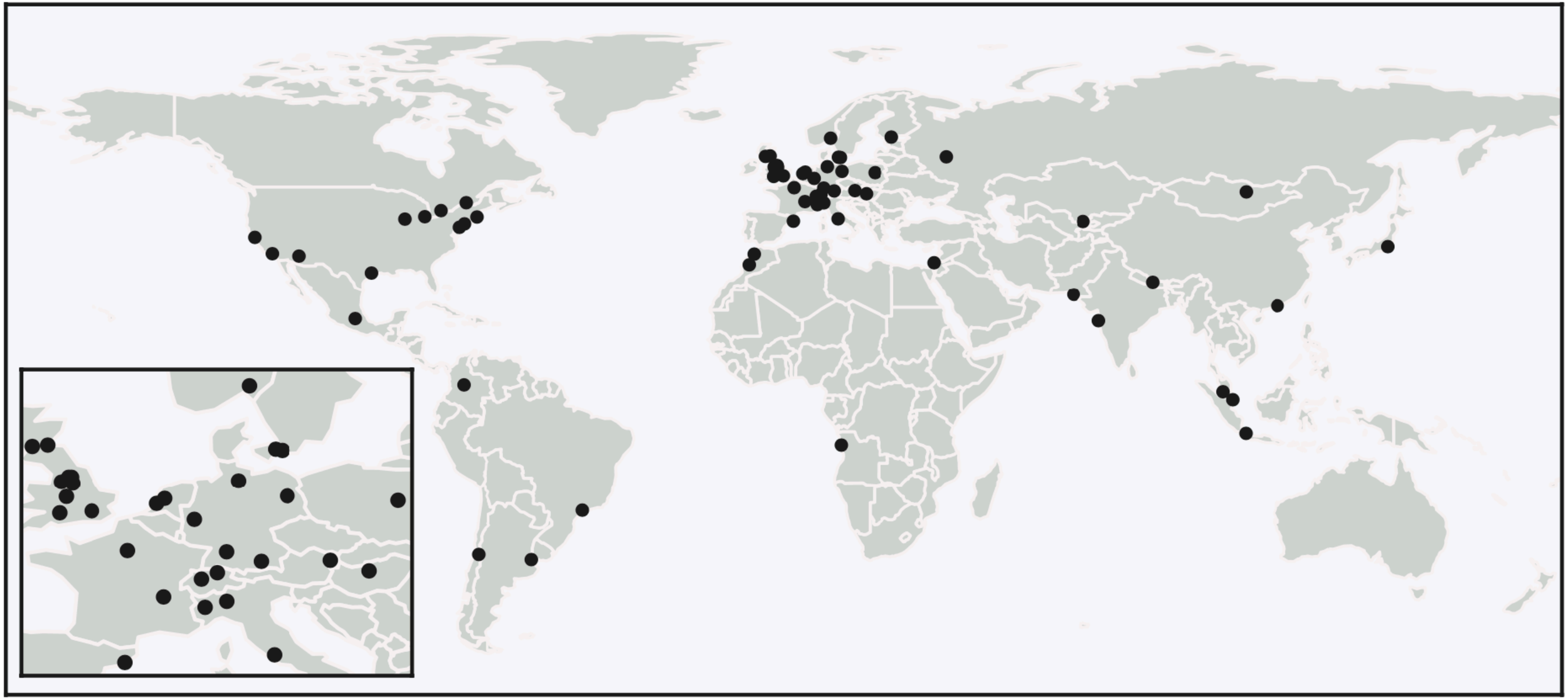
We build a greedy triangulation between points of interest

4) Route on street network



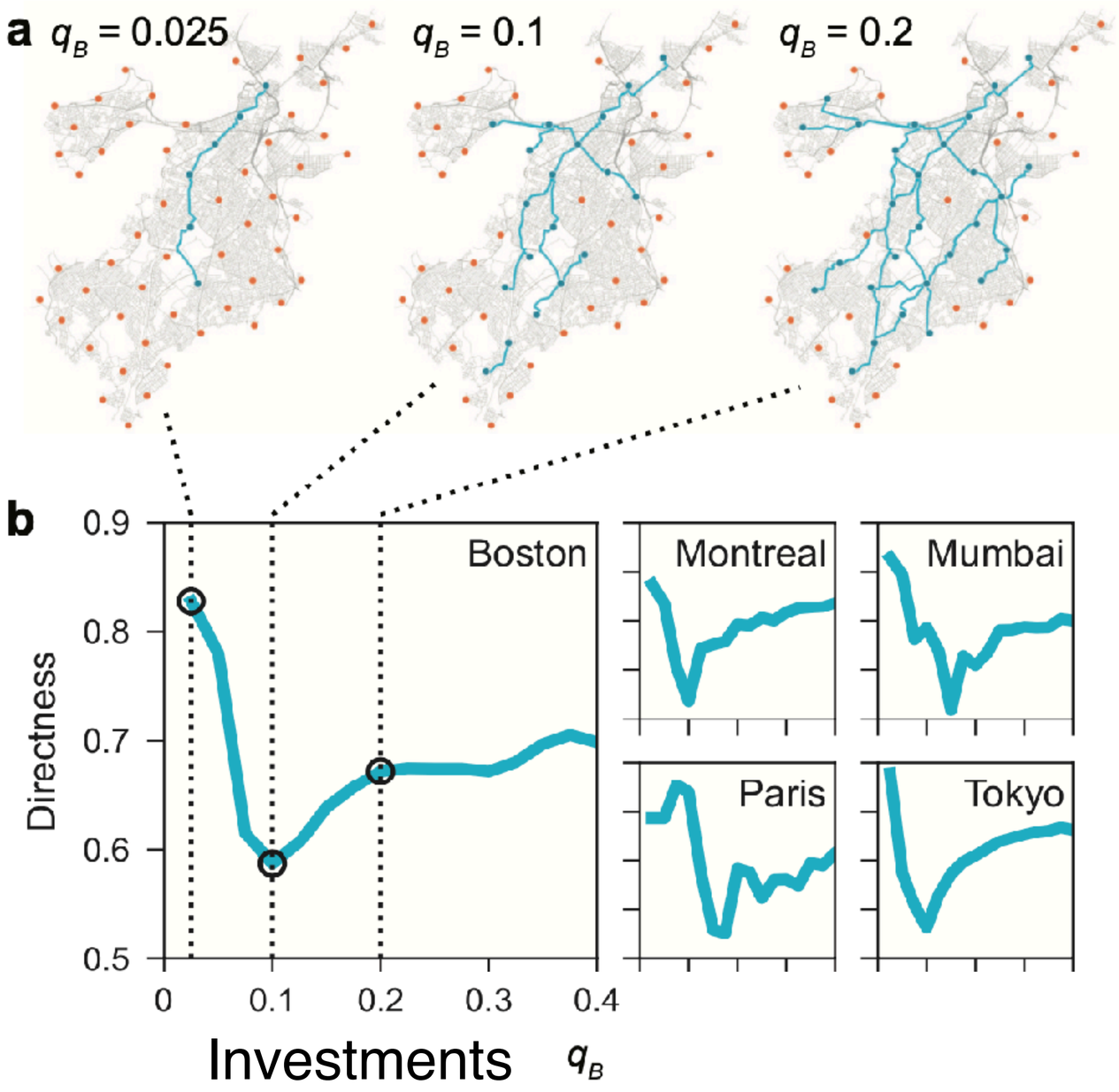
Szell et al., Sci Rep 12, 6765 (2022)

We explore 62 cities



Szell et al., Sci Rep 12, 6765 (2022)

Result 1: Investments need to surpass a critical threshold



The pieces need to connect and to form cycles

Szell et al., Sci Rep 12, 6765 (2022)

Policy implication 1: Invest persistently!

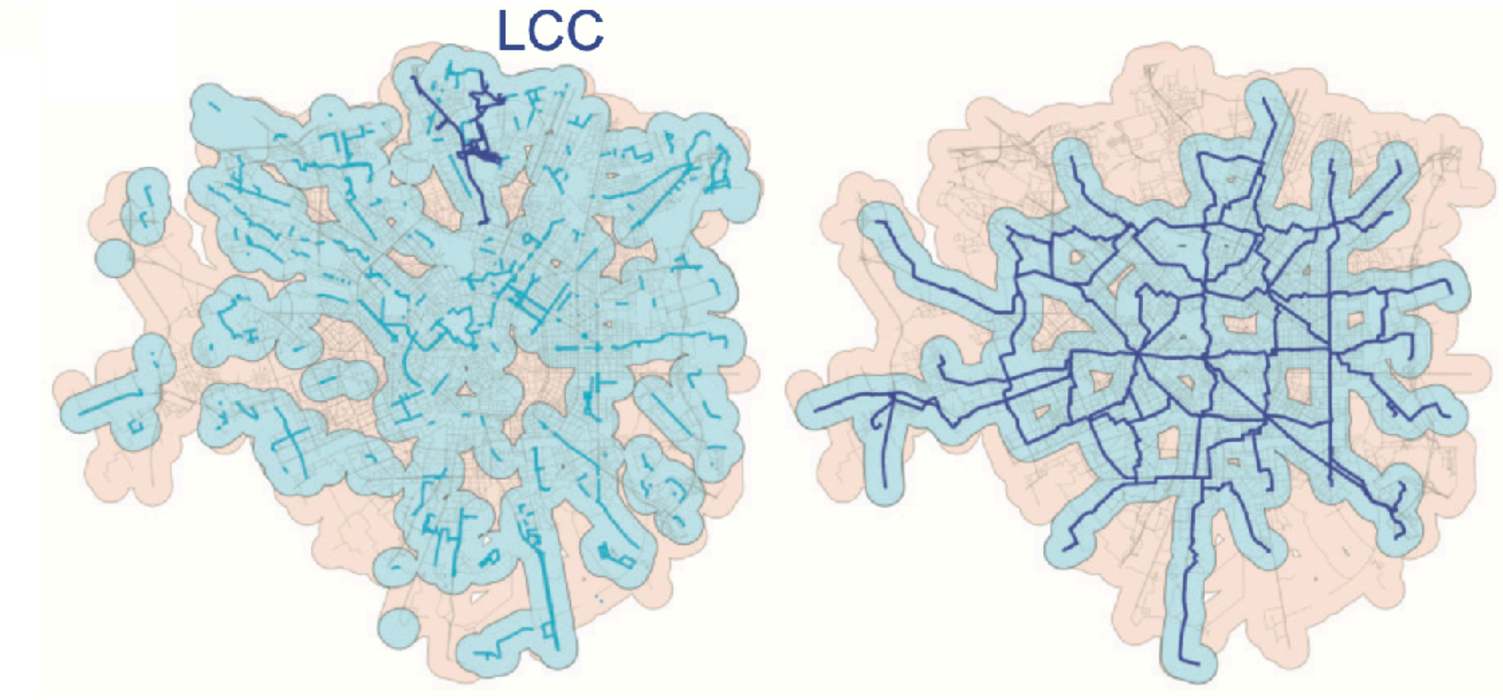
Brent Toderian @BrentToderian · Jul 30

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.

https://twitter.com/BrentToderian/status/1420907319982915587?s=20

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

At same length, we could do much better

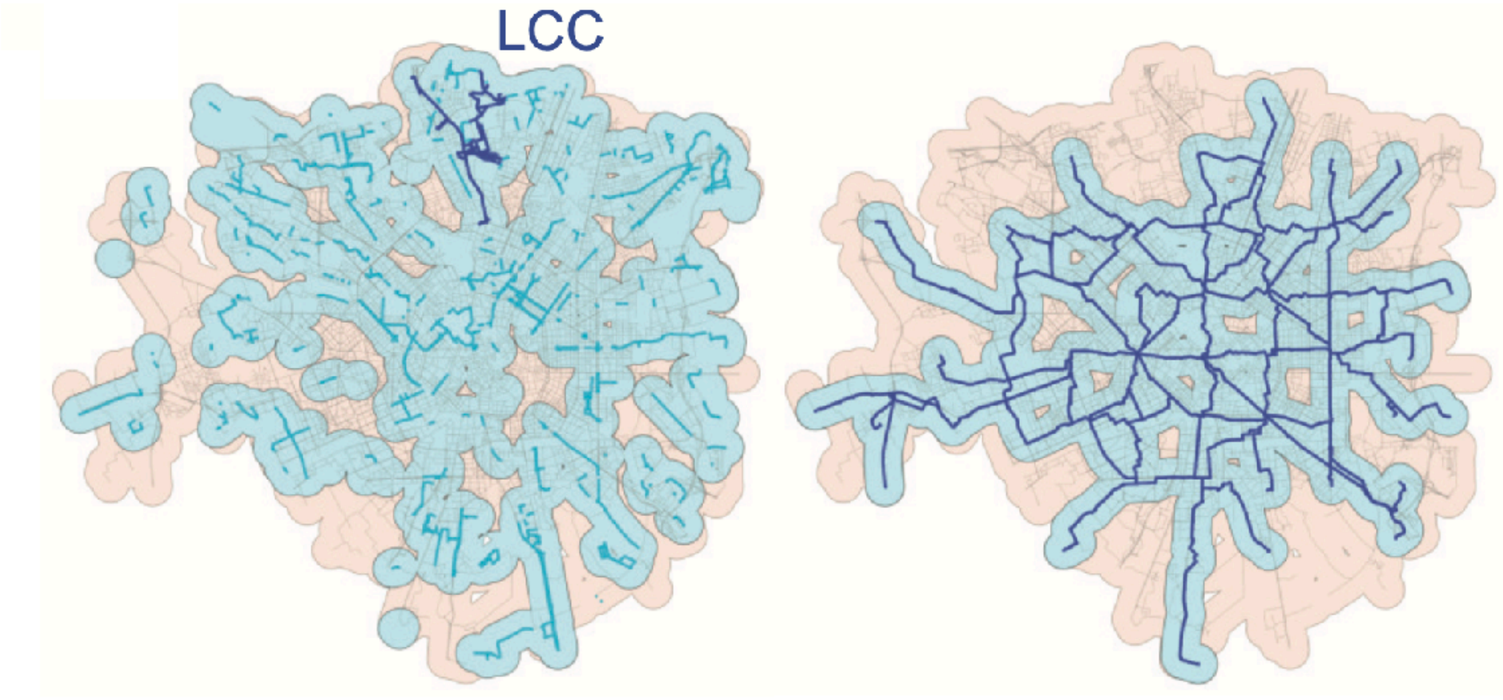


Real Milan

Synthetic Milan

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

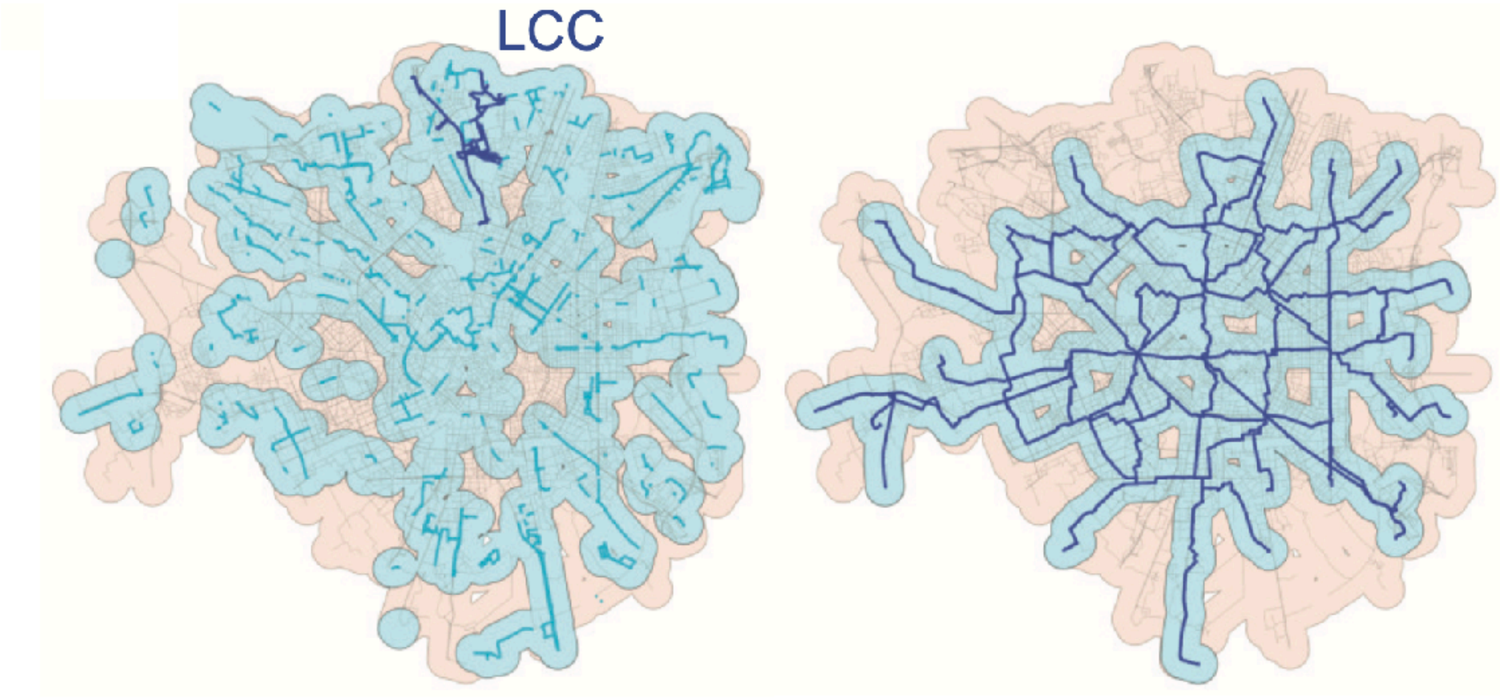
Avoid "random-like", piecewise growth



Real Milan

Synthetic Milan

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

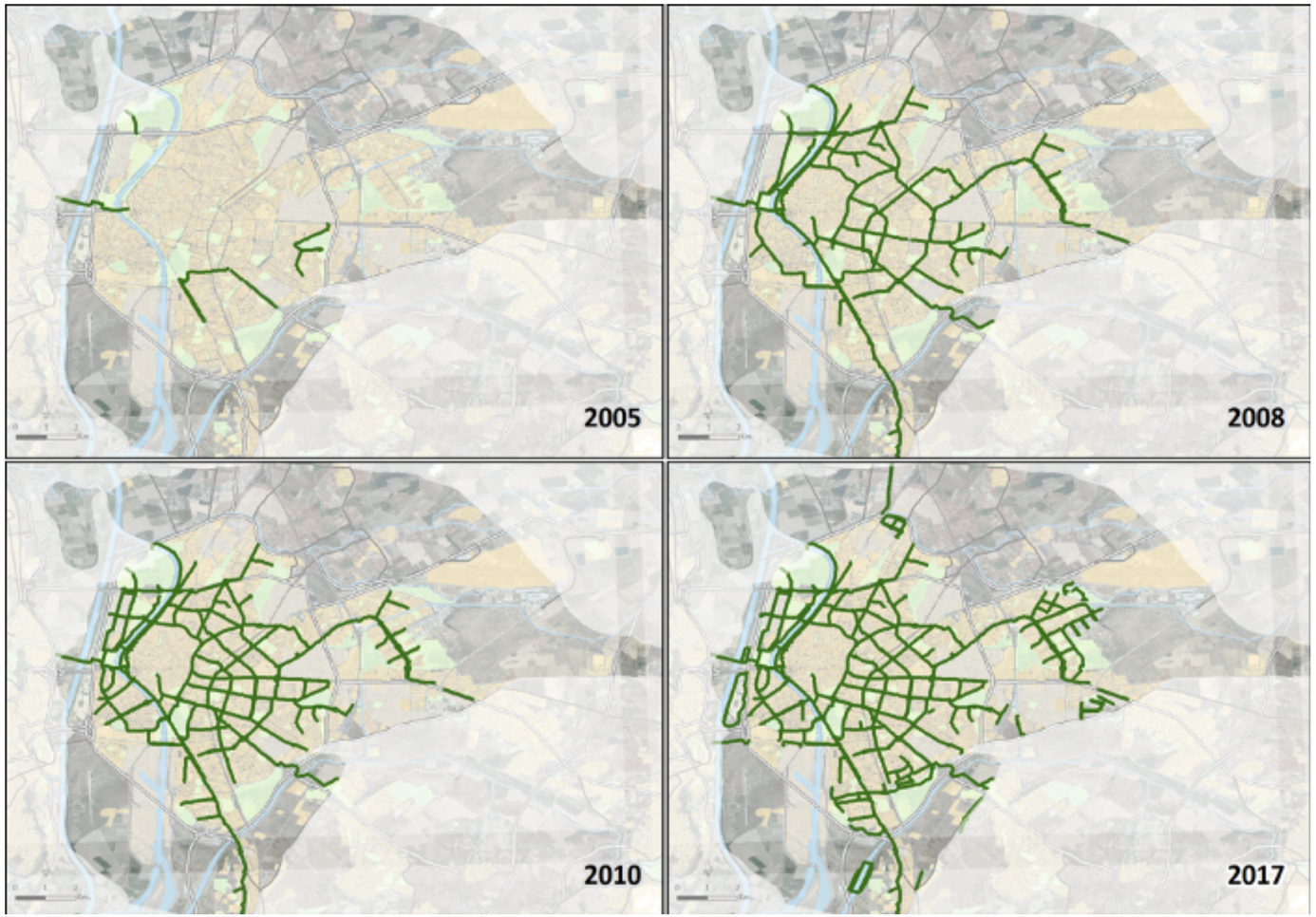


Real Milan

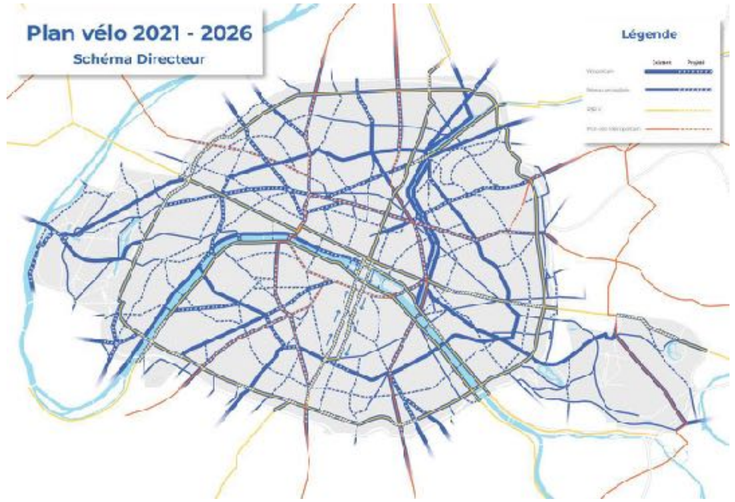
Synthetic Milan

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

Nope: See Seville



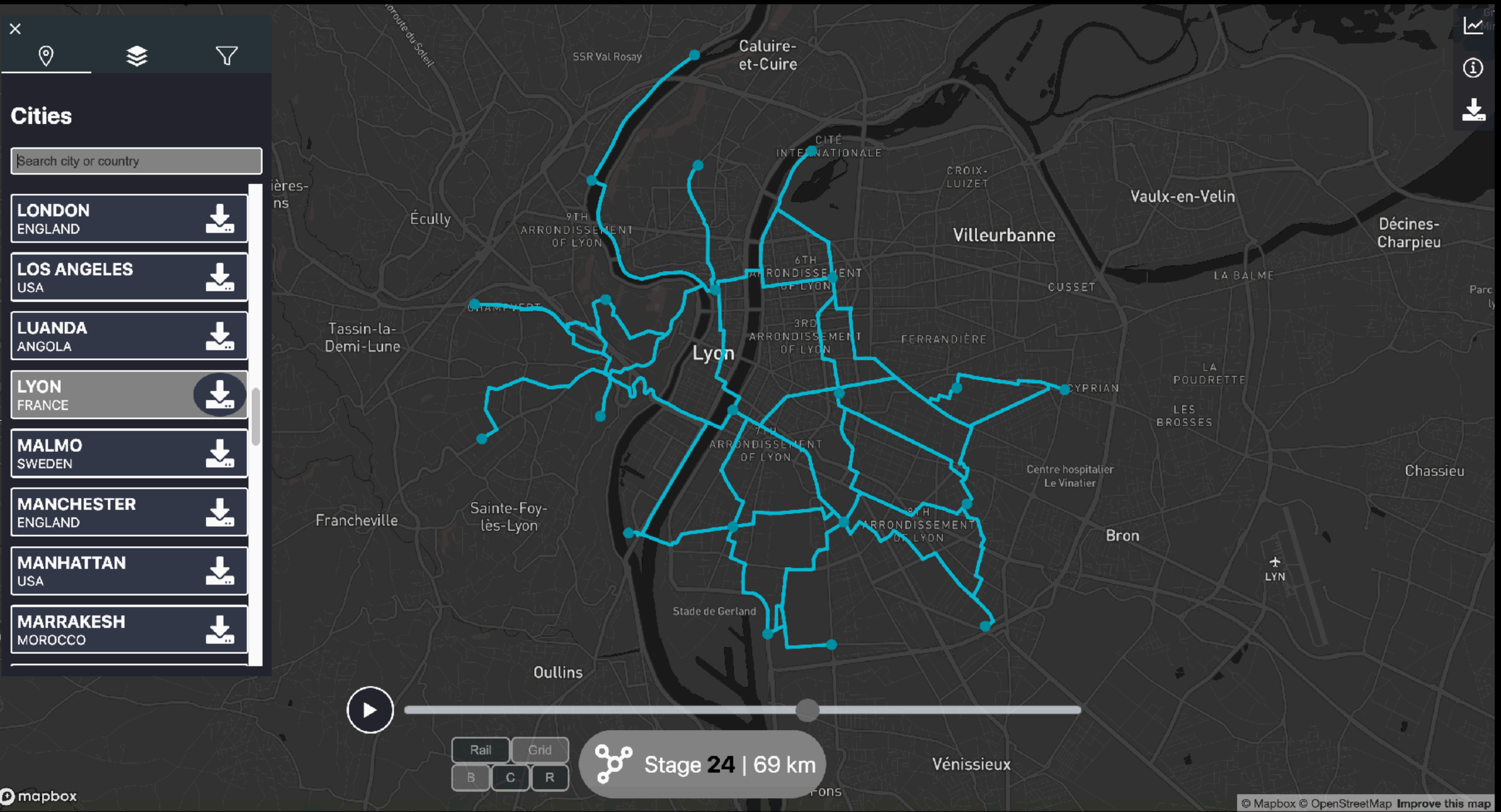
Also: Paris, Oslo, ...



There is no excuse

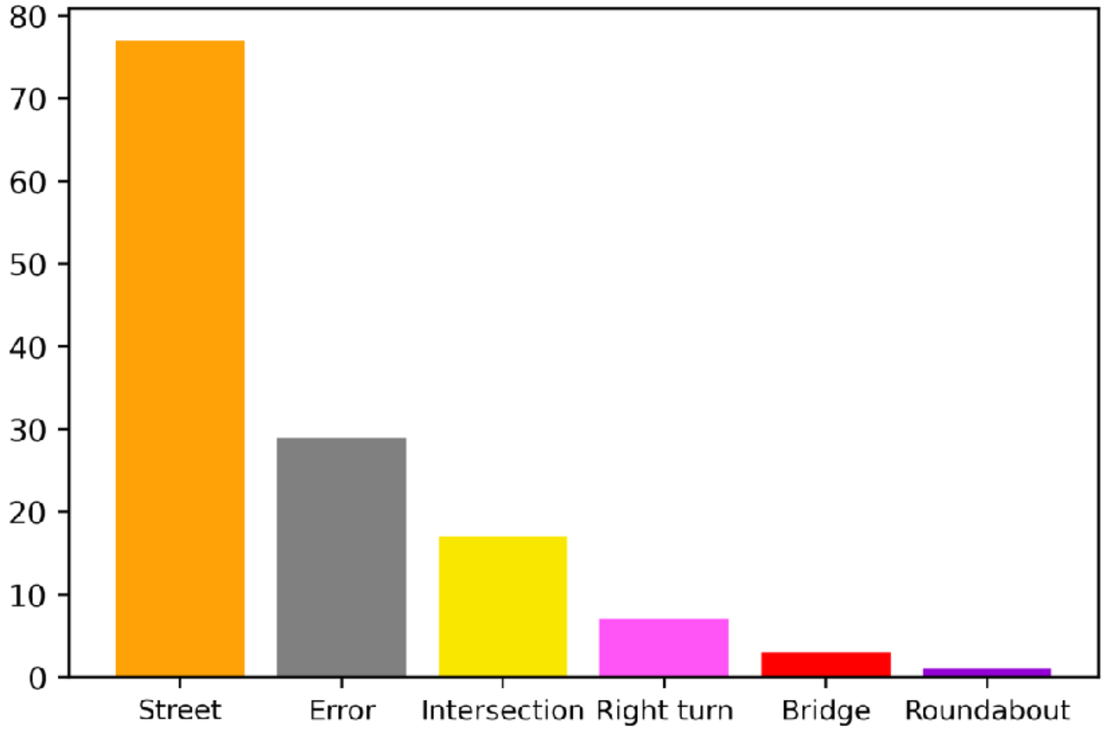
https://usa.streetsblog.org/2020/10/13/best-practices-how-seville-became-a-city-of-cyclists/

Explore your city at GrowBike.Net



What to do if your bike network is already pretty good?

Our top 105 gaps, see fixbike.net

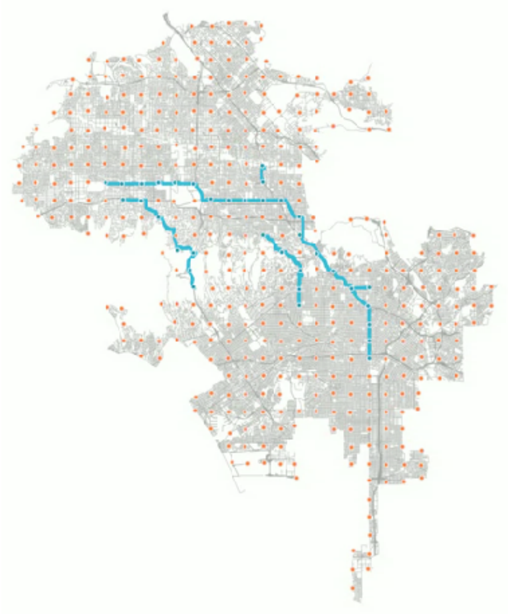


Vybornova et al, Geographical Analysis (2022)

If your city is:

not developed

Los Angeles

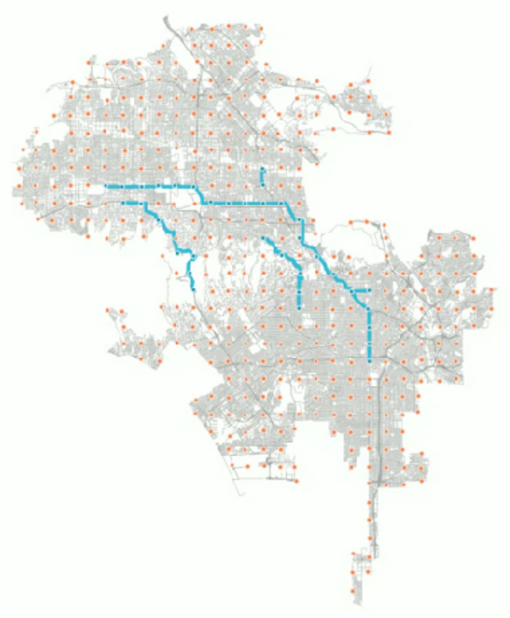


Grow persistently with focused investments

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

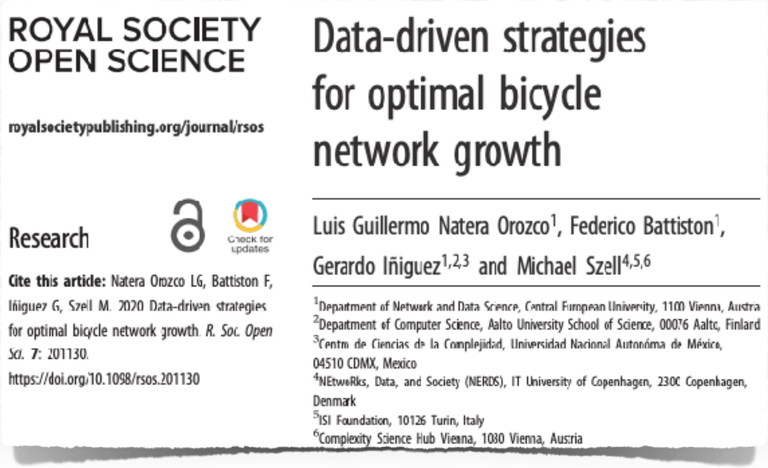
scientific reports

OPEN **Growing urban bicycle networks**

Michael Szell[1,2,3], Sayat Mimar[4], Tyler Perlman[4], Gourab Ghoshal[4] & Roberta Sinatra[1,2,3,5]

Grow persistently with focused investments

medium developed


ROYAL SOCIETY OPEN SCIENCE

royalsocietypublishing.org/journal/rsos

Research

Cite this article: Natera Orozco LG, Battiston F, Iñiguez G, Szell M. 2020 Data-driven strategies for optimal bicycle network growth. *R. Soc. Open Sci.* **7**: 201130.
https://doi.org/10.1098/rsos.201130

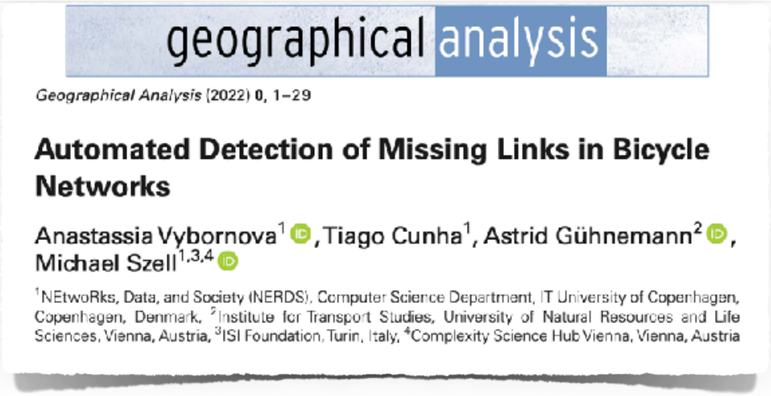
Data-driven strategies for optimal bicycle network growth

Luis Guillermo Natera Orozco[1], Federico Battiston[1], Gerardo Iñiguez[1,2,3] and Michael Szell[4,5,6]

[1]Department of Network and Data Science, Central European University, 1100 Vienna, Austria
[2]Department of Computer Science, Aalto University School of Science, 00076 Aalto, Finland
[3]Centro de Ciencias de la Complejidad, Universidad Nacional Autónoma de México, 04510 CDMX, Mexico
[4]NEtwoRks, Data, and Society (NERDS), IT University of Copenhagen, 2300 Copenhagen, Denmark
[5]ISI Foundation, 10126 Turin, Italy
[6]Complexity Science Hub Vienna, 1080 Vienna, Austria

Connect with right strategy

well developed


geographical analysis

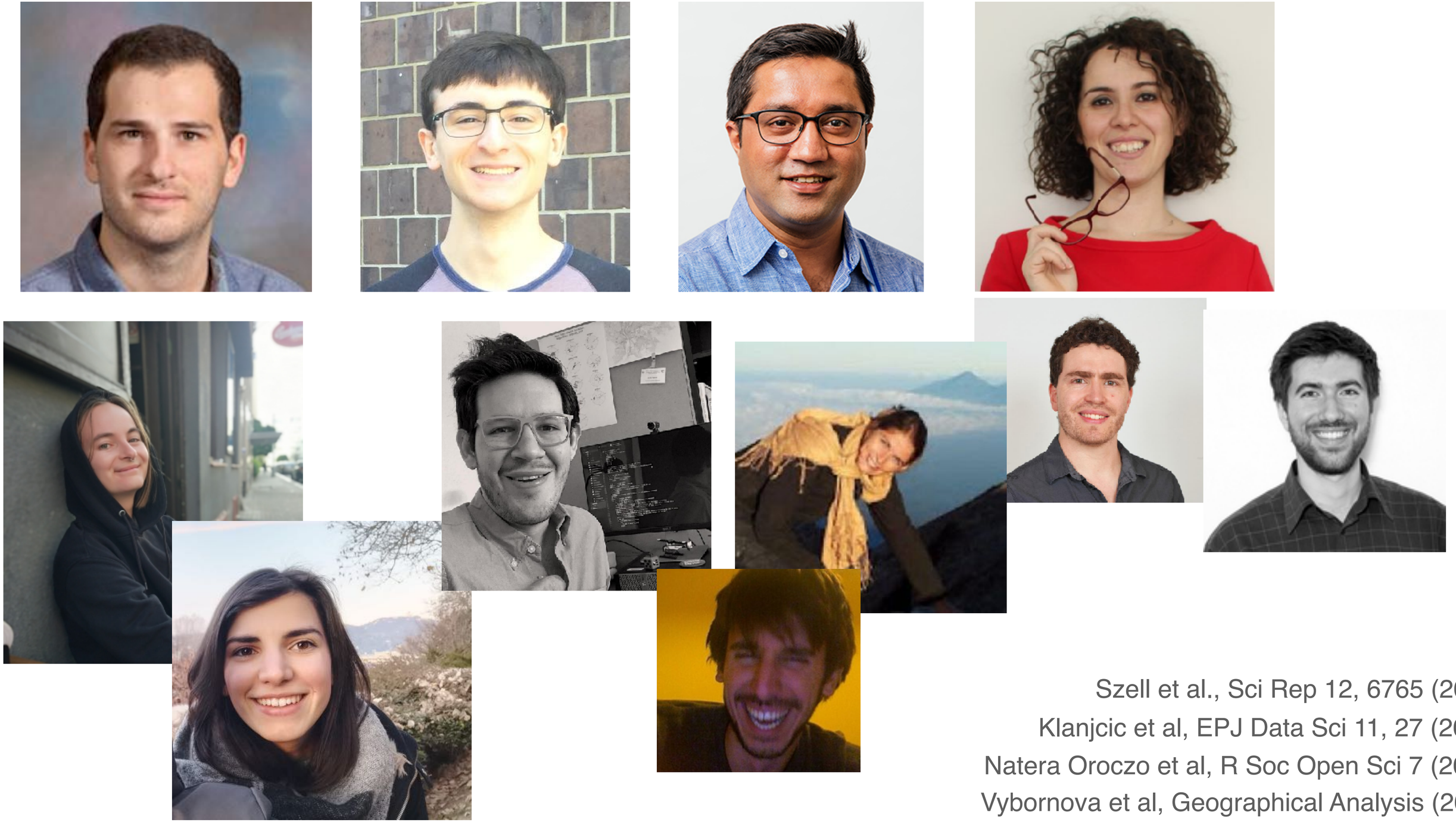
Geographical Analysis (2022) **0**, 1–29

Automated Detection of Missing Links in Bicycle Networks

Anastassia Vybornova[1], Tiago Cunha[1], Astrid Gühnemann[2], Michael Szell[1,3,4]

[1]NEtwoRks, Data, and Society (NERDS), Computer Science Department, IT University of Copenhagen, Copenhagen, Denmark, [2]Institute for Transport Studies, University of Natural Resources and Life Sciences, Vienna, Austria, [3]ISI Foundation, Turin, Italy, [4]Complexity Science Hub Vienna, Vienna, Austria

Close the most important gaps



Szell et al., Sci Rep 12, 6765 (2022)

Klanjcic et al, EPJ Data Sci 11, 27 (2022)

Natera Oroczo et al, R Soc Open Sci 7 (2020)

Vybornova et al, Geographical Analysis (2022)

Break

How are cities planned?

What should you do to relieve congestion?

Building more roads to prevent congestion

is like a fat man loosening his belt to prevent obesity

Lewis Mumford

Induced demand

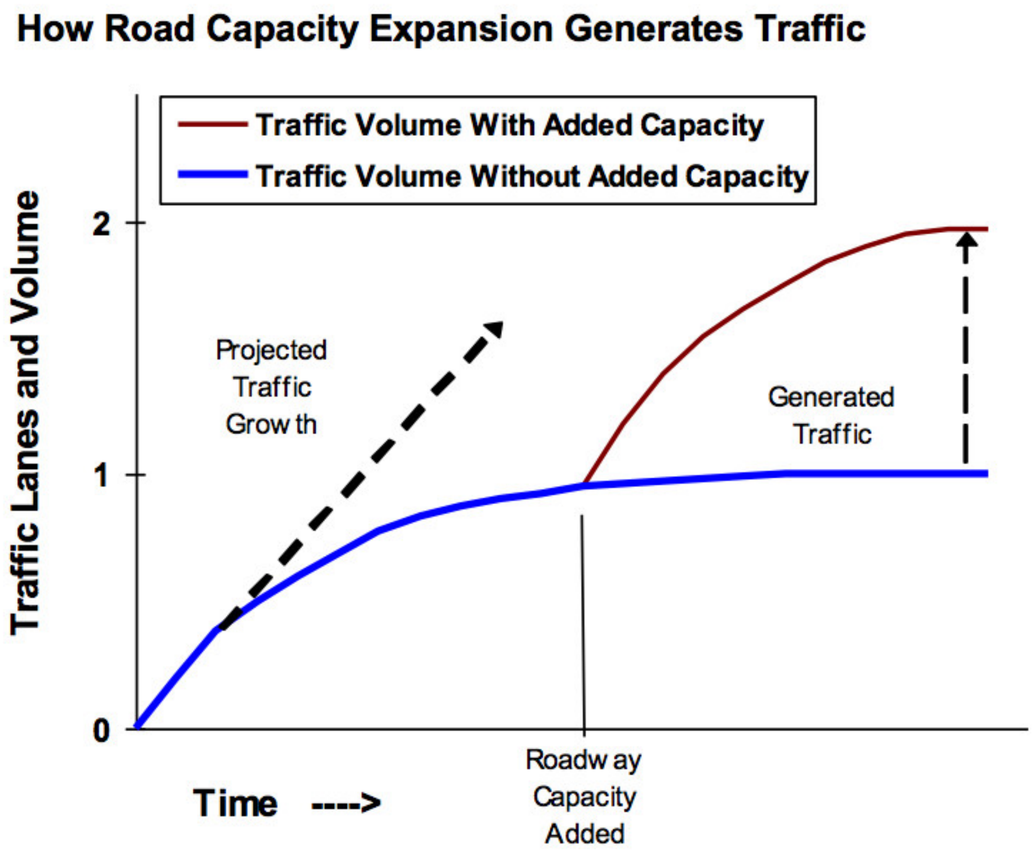
If you widen roads, you create more traffic

https://www.governing.com/now/why-the-concept-of-induced-demand-is-a-hard-sell

https://www.bloomberg.com/news/features/2021-09-28/why-widening-highways-doesn-t-bring-traffic-relief

Induced demand

If you widen roads, you create more traffic



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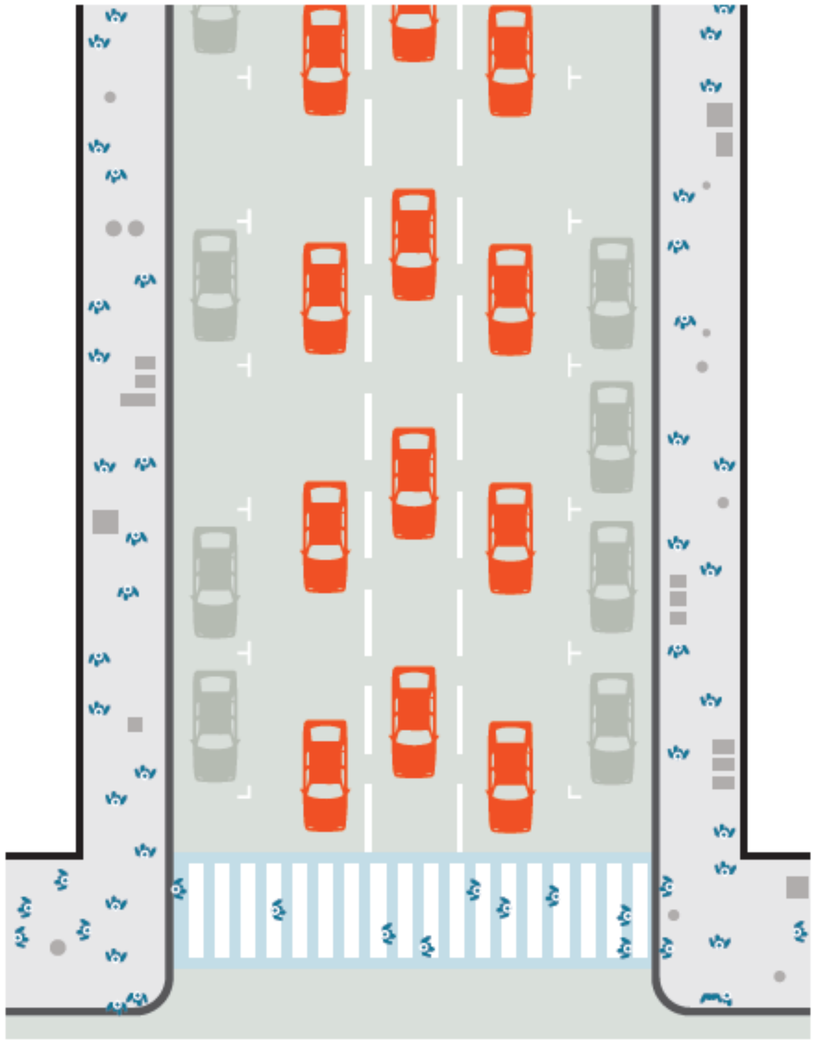
https://www.bloomberg.com/news/features/2021-09-28/why-widening-highways-doesn-t-bring-traffic-relief

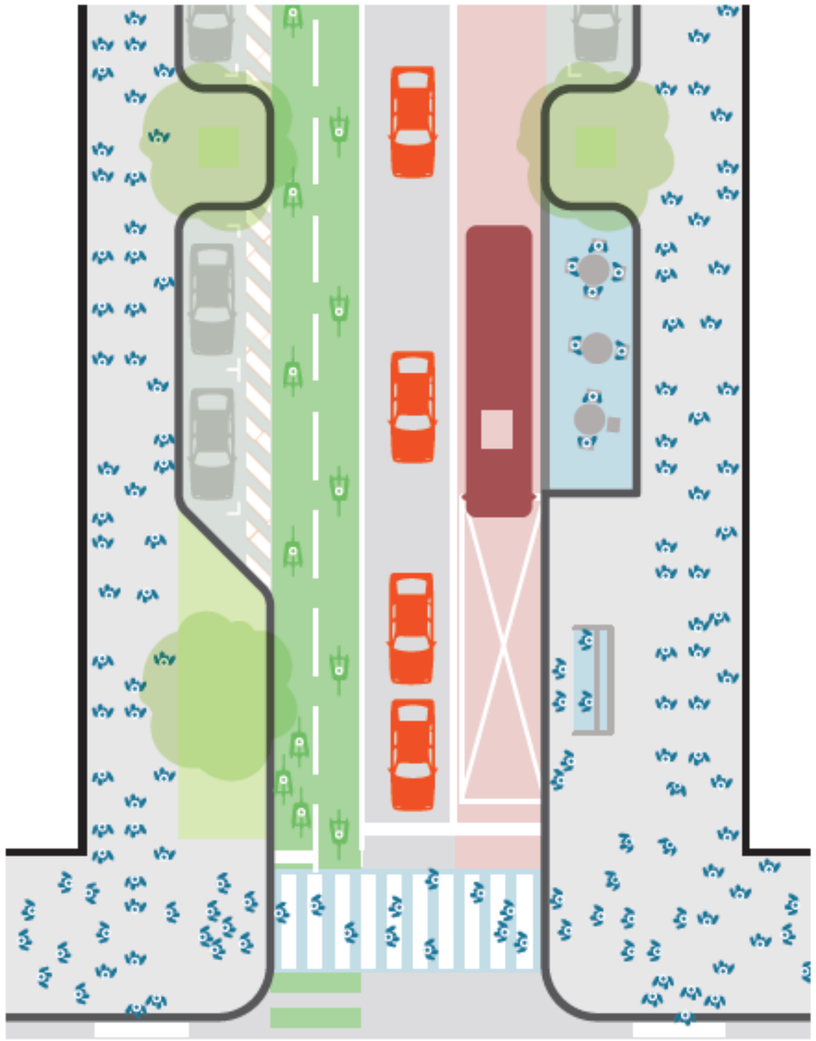
The opposite of induced demand is disappearing traffic

Car-Oriented Street



Road diet

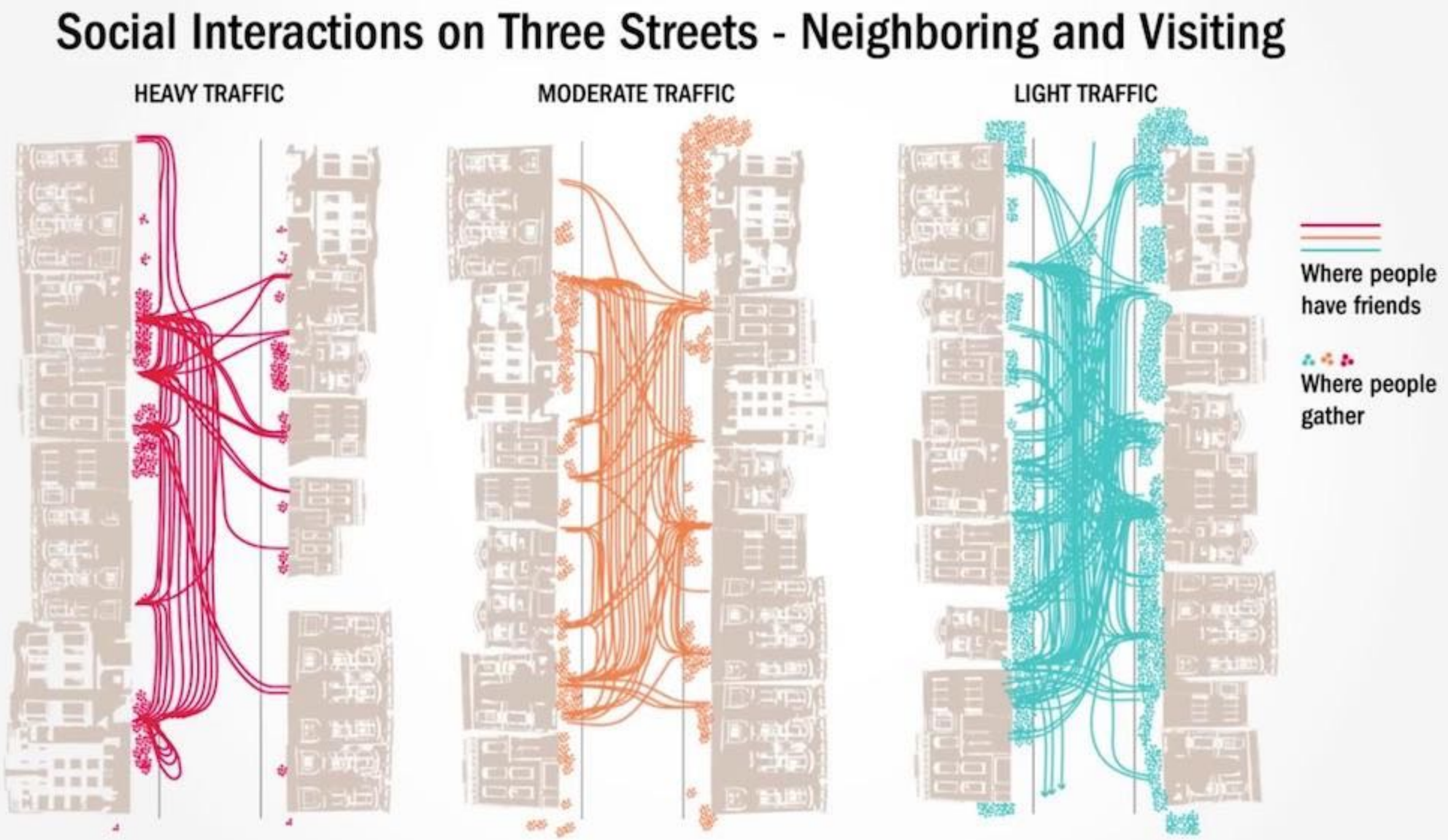
Multimodal Street



https://www.icevirtuallibrary.com/doi/full/10.1680/muen.2002.151.1.13

The effect of transport infrastructure on social ties

The bigger the street, the fewer social interactions

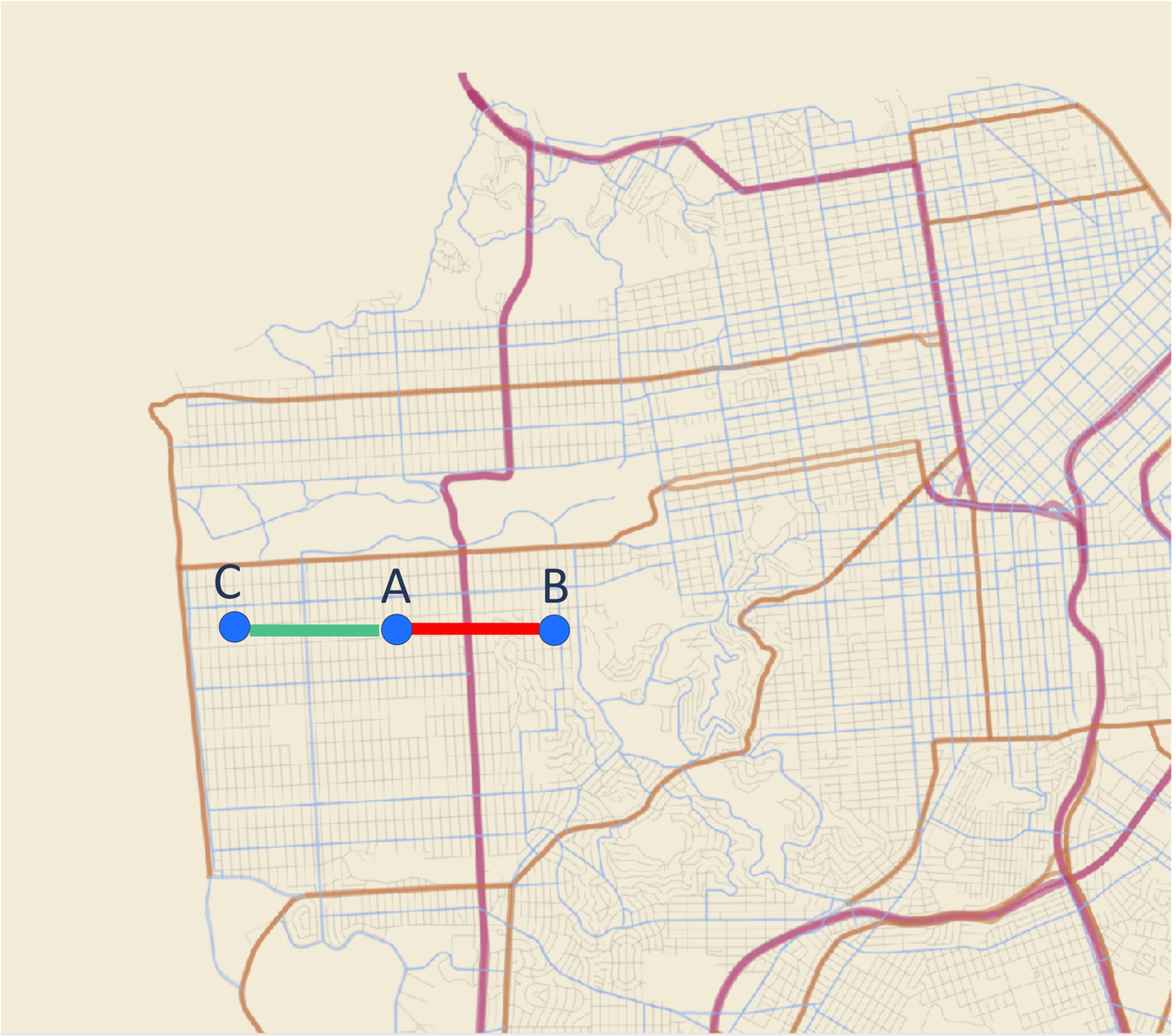


Appleyard, D. (1981) Livable Streets

Now we have large-scale data to quantify this effect!

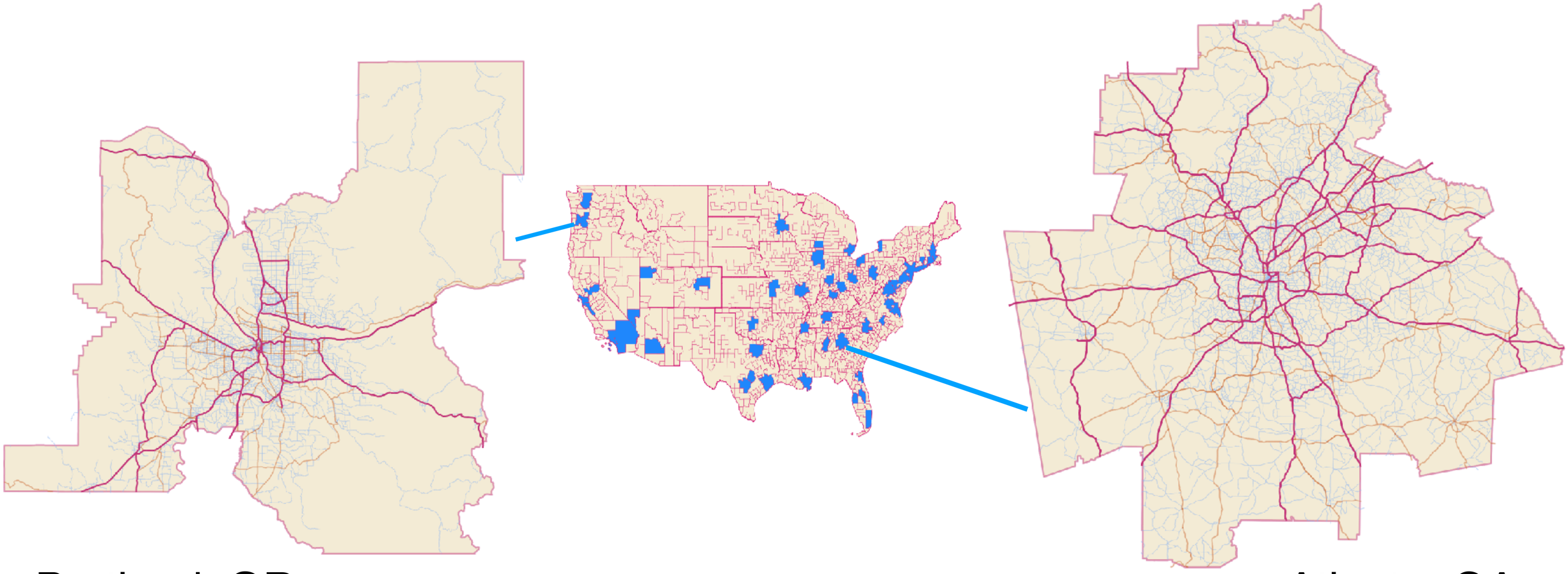
Goal:
A scalable method to quantify how physical barriers impact the probability of a social tie

Example: A is less likely to be friends with B than C



Aiello et al., PNAS 122 (2025)

Data set 1: Urban highways (OpenStreetMap)

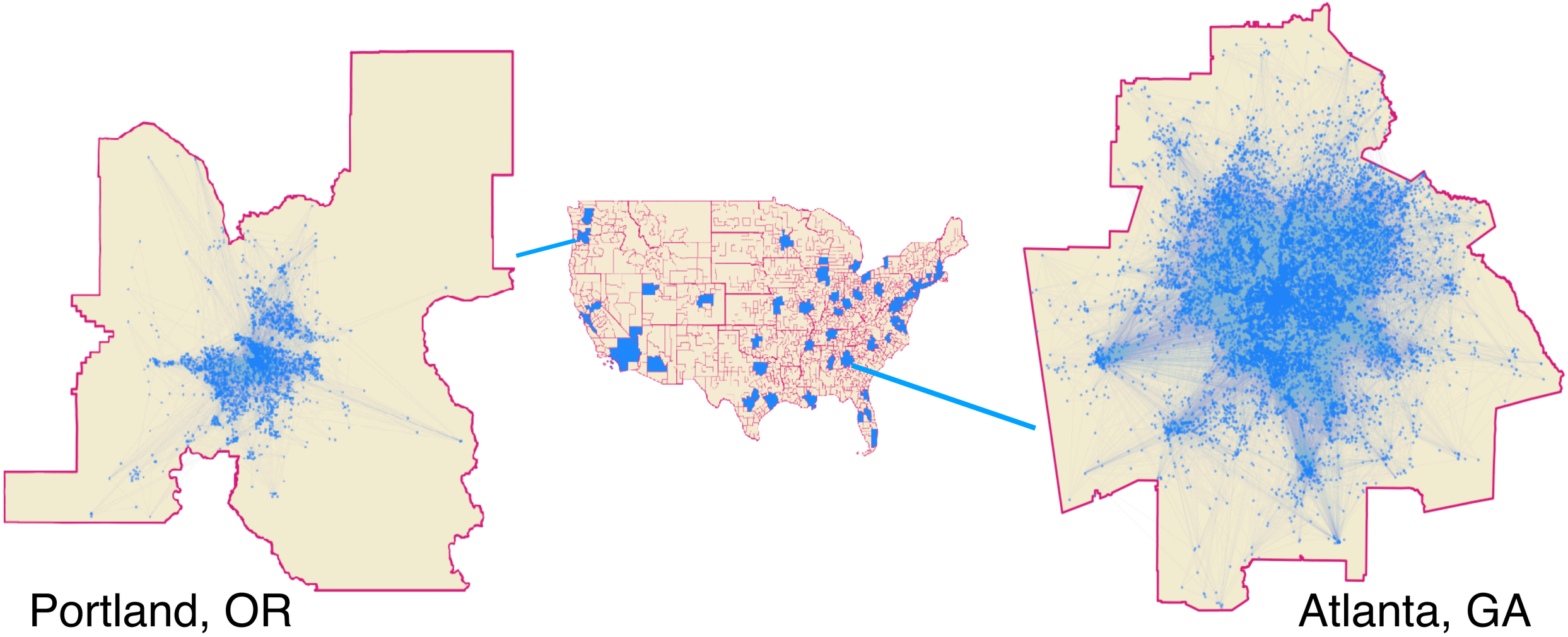


Portland, OR

Atlanta, GA

Aiello et al., PNAS 122 (2025)

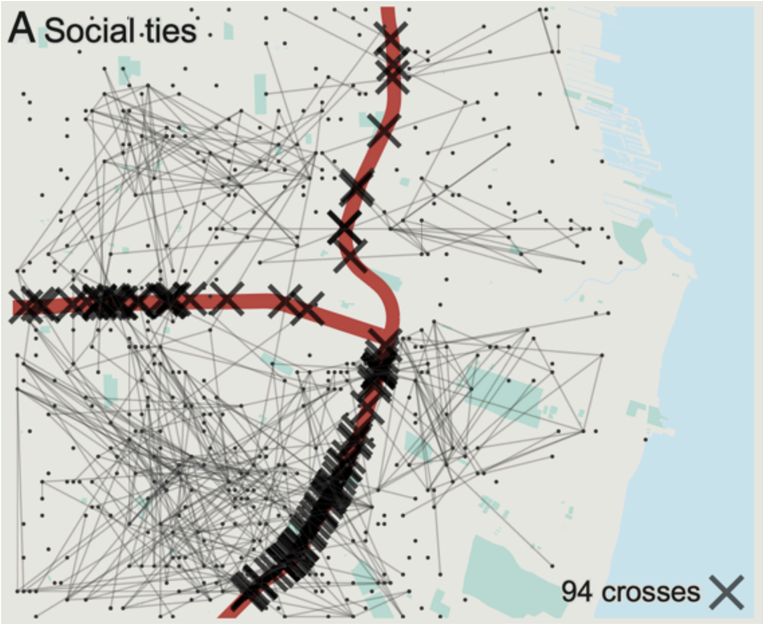
Data set 2: 1M social ties (Twitter mutual followers)



Aiello et al., PNAS 122 (2025)

We define a Barrier Score by rewiring social ties

Step A: Count crosses of social ties with highways

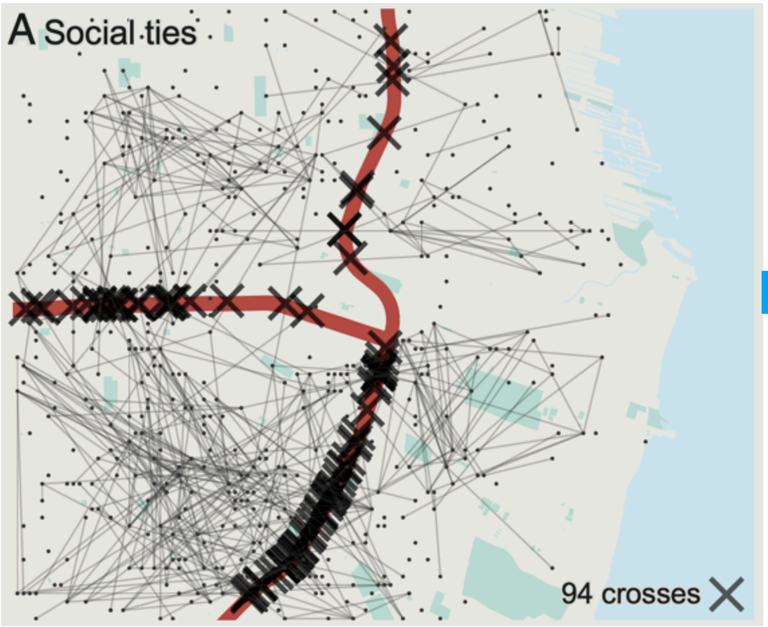


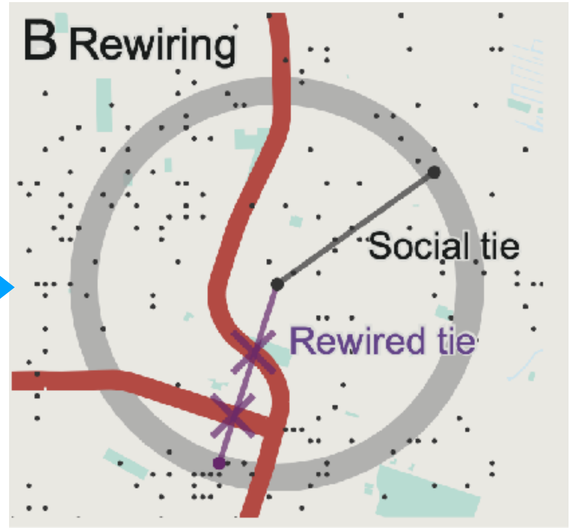
Aiello et al., PNAS 122 (2025)

We define a Barrier Score by rewiring social ties

Step A: Count crosses of social ties with highways

Step B: Rewire social ties





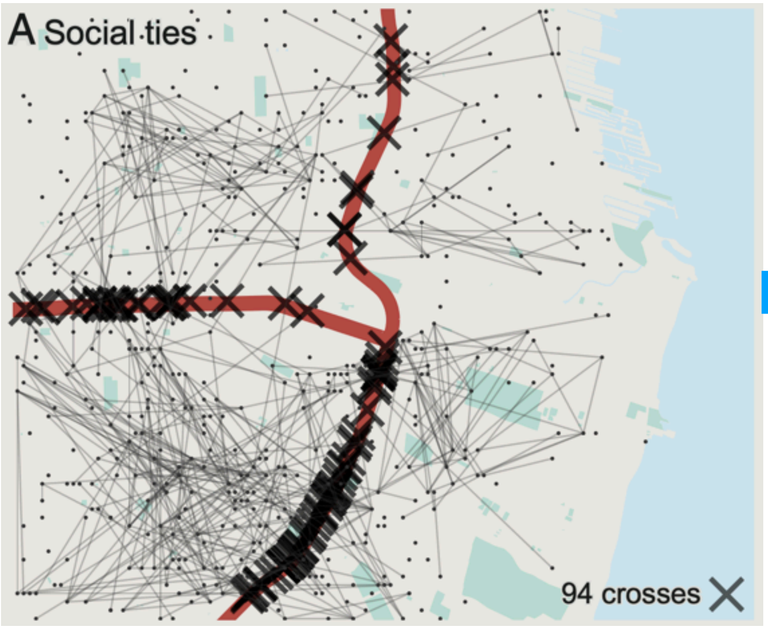
Aiello et al., PNAS 122 (2025)

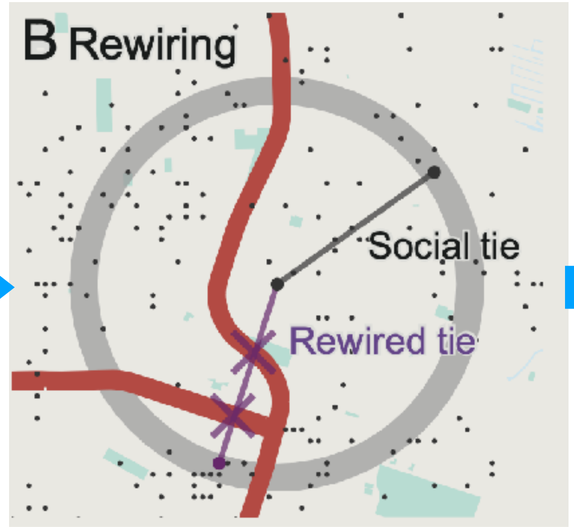
We define a Barrier Score by rewiring social ties

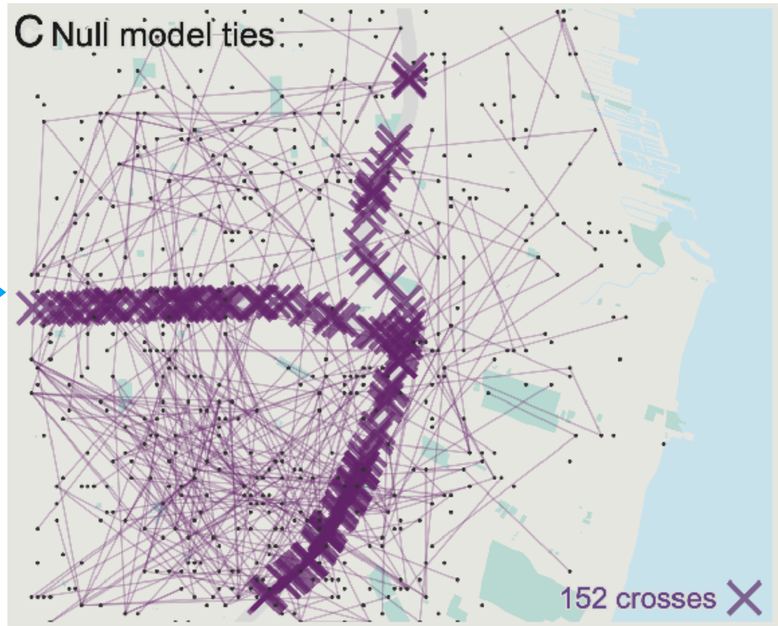
Step A: Count crosses of social ties with highways

Step B: Rewire social ties

Step C: Re-count crosses of rewired ties with highways



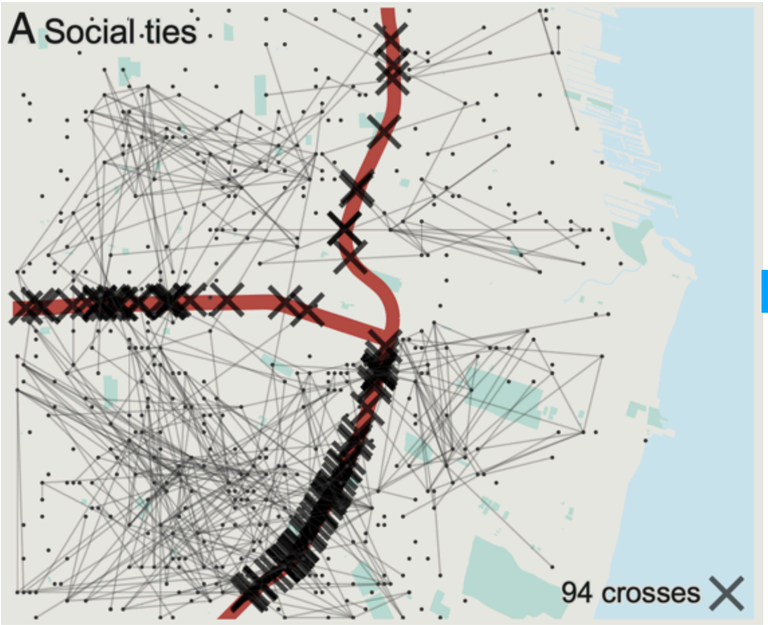




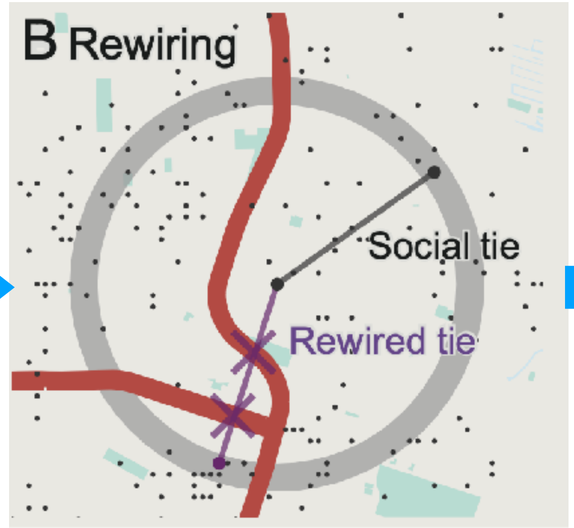
Aiello et al., PNAS 122 (2025)

We define a Barrier Score by rewiring social ties

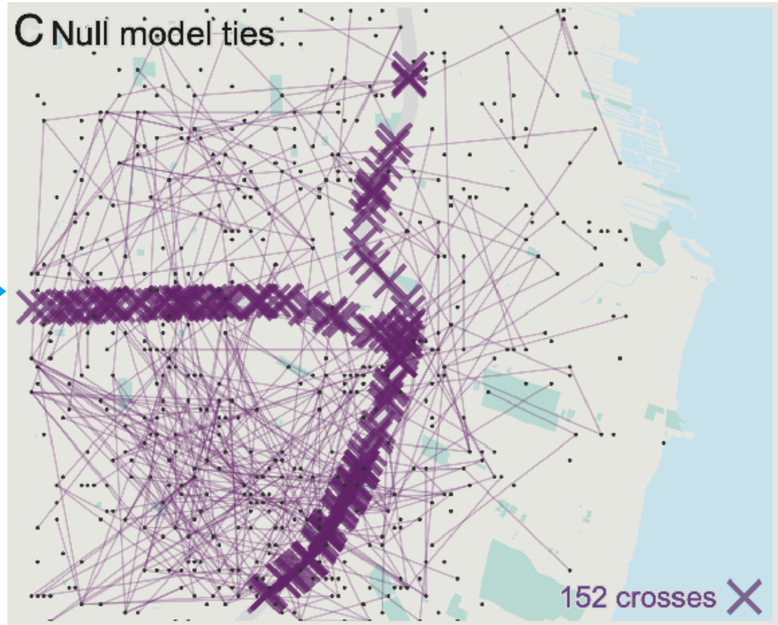
Step A: Count crosses of social ties with highways



Step B: Rewire social ties



Step C: Re-count crosses of rewired ties with highways



Step D: Compare the two numbers

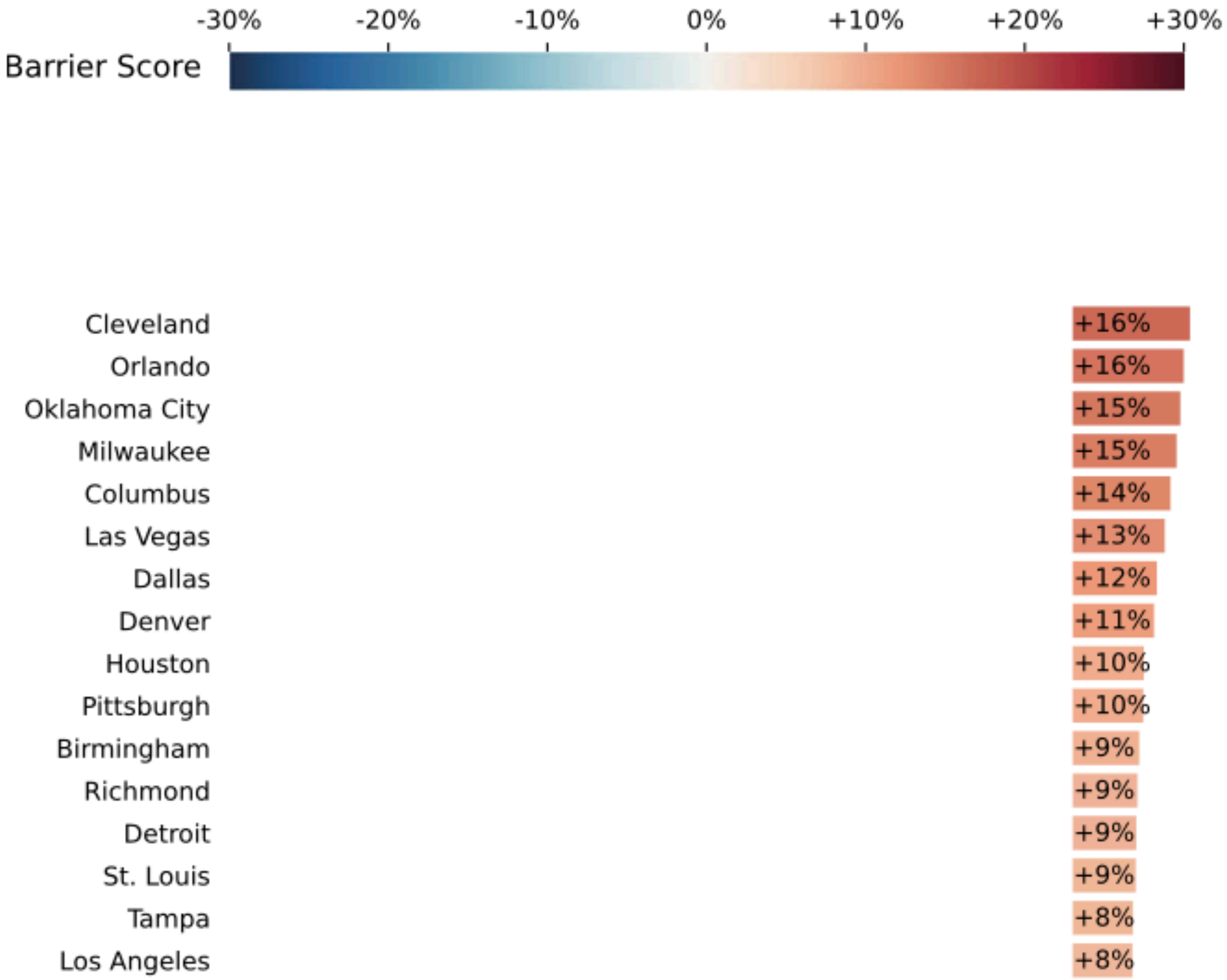
D Barrier Score

$$B_i = \frac{152-94}{94}$$

$$= +62\%$$

Aiello et al., PNAS 122 (2025)

All cities have positive Barrier Scores!



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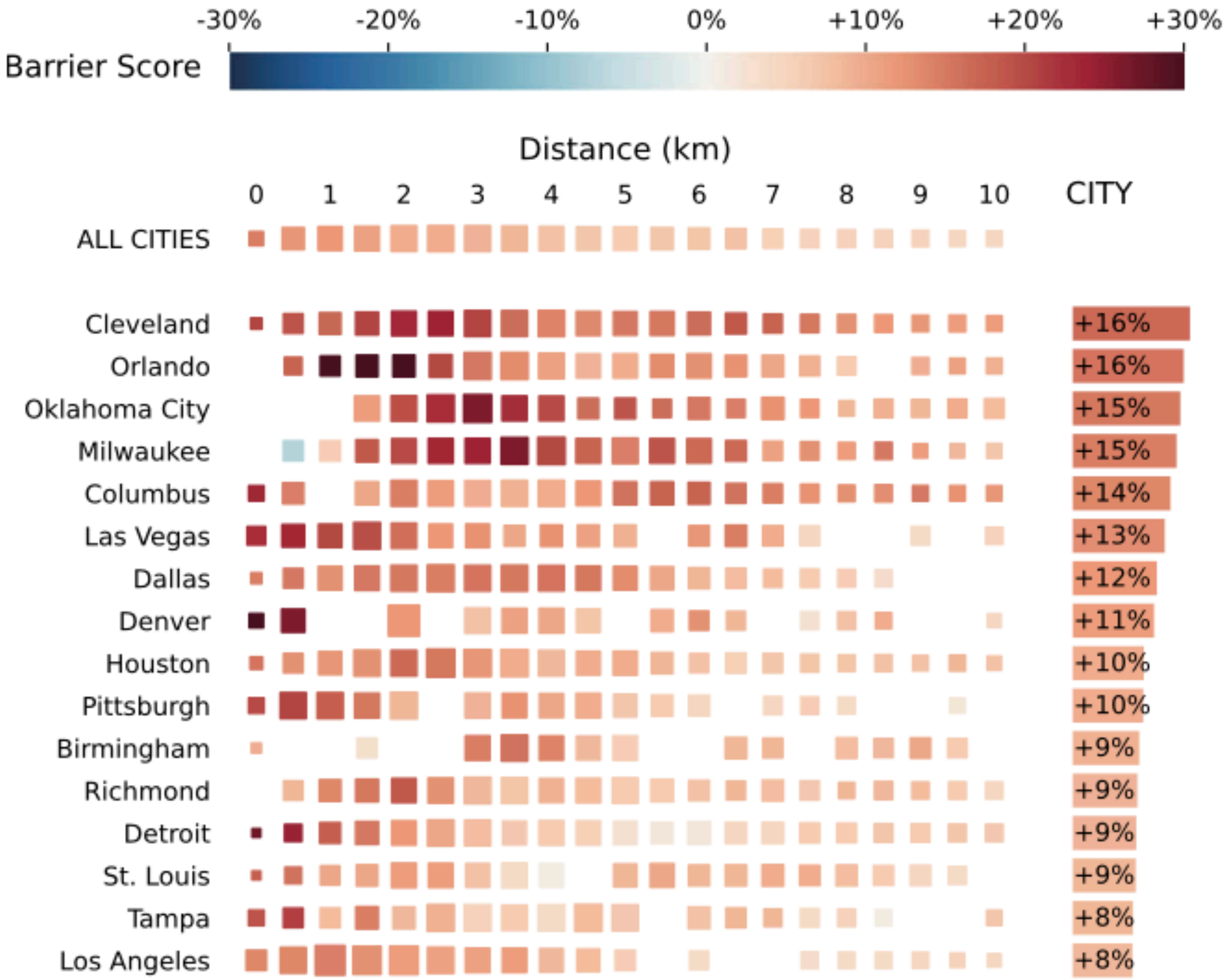


Aiello et al., PNAS 122 (2025)

Criticisms of this approach?

Aiello et al., PNAS 122 (2025)

Criticisms of this approach?

Are mutual Twitter followers really "social ties"? Is the data biased?

Aiello et al., PNAS 122 (2025)

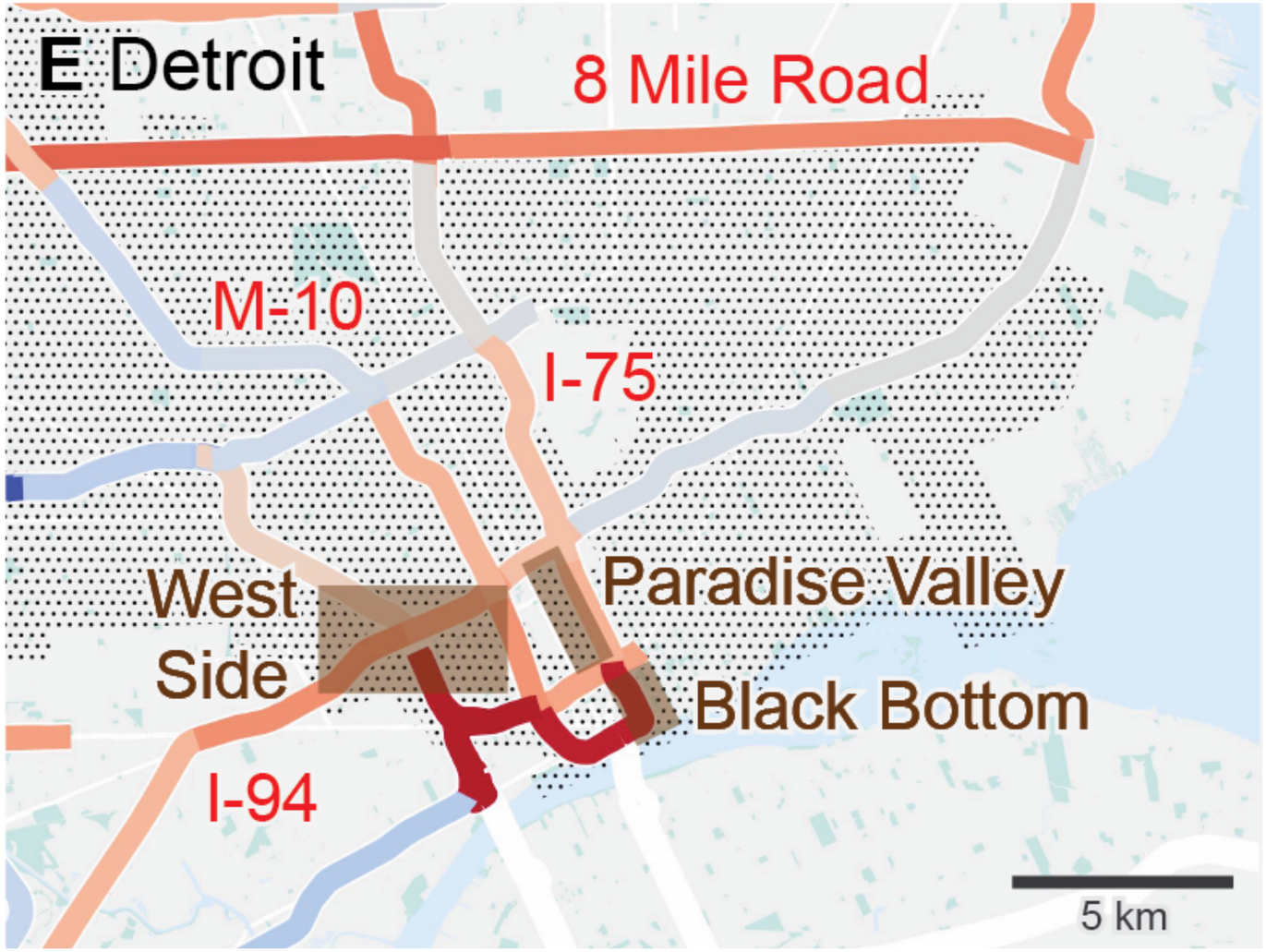
Criticisms of this approach?

Causality: Maybe there was already a racial divide and the highway was built afterwards?

Aiello et al., PNAS 122 (2025)

We find historical cases consistent with this idea

Causality: Maybe there was already a racial divide and the highway was built afterwards?



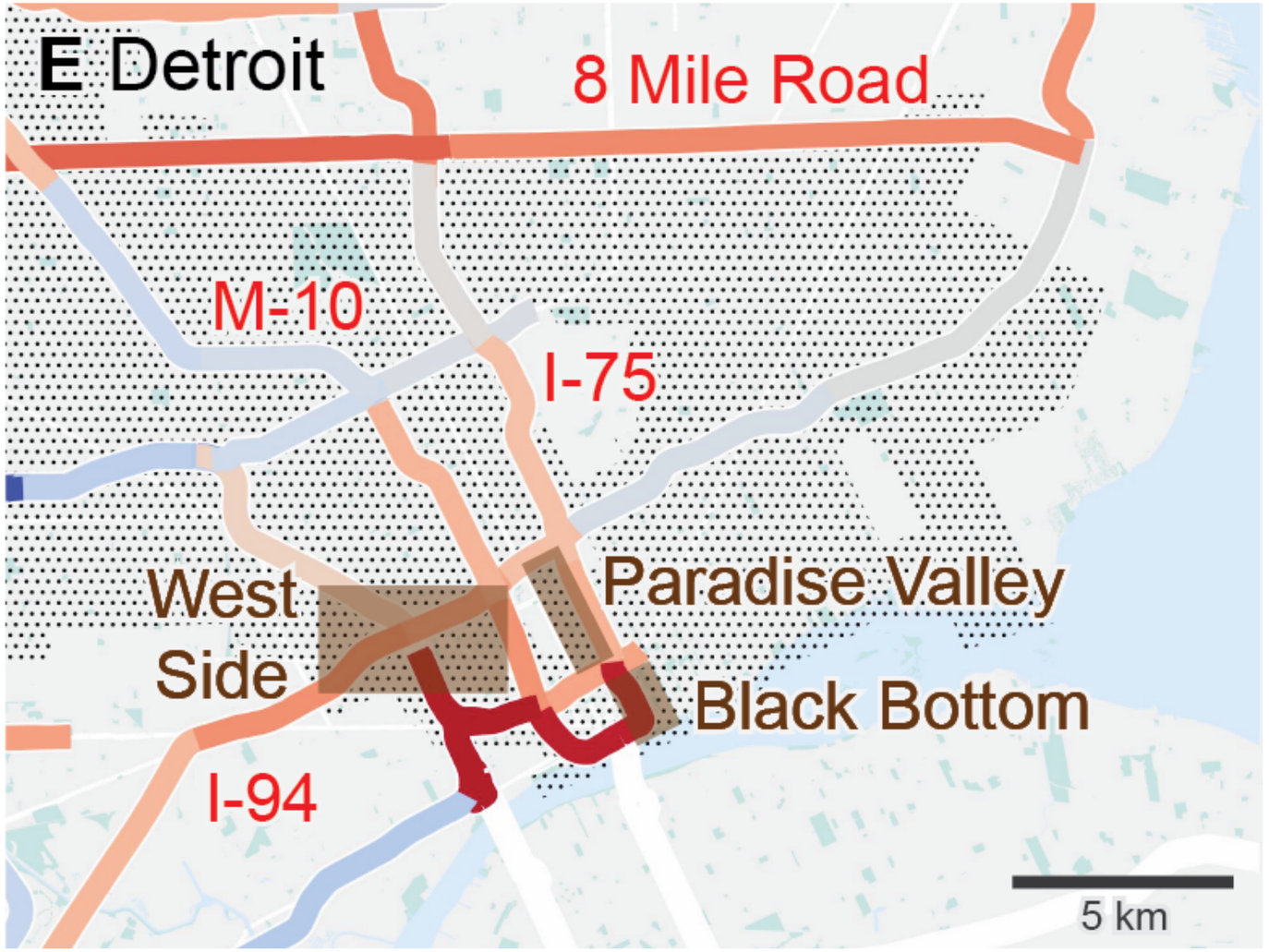
Area of interest | Black, upper quartile | Barrier Score: −30% | −15% | 0% | +15% | +30% | No data

Aiello et al., PNAS 122 (2025)

We find historical cases consistent with this idea

Causality: Maybe there was already a racial divide and the highway was built afterwards?

To answer causality rigorously, we would need data over time!



Area of interest | Black, upper quartile | Barrier Score: −30% | −15% | 0% | +15% | +30% | No data

Aiello et al., PNAS 122 (2025)

But: Over long distances, the highways connect more people

So, are urban highways good?? Should we build more?

Aiello et al., PNAS 122 (2025)

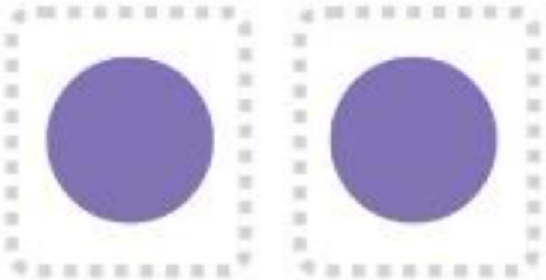
Short-term engineering thinking

vs

Long-term systems thinking

20th century: Short-term engineering thinking

Compartmentalization: We can study a subsystem on its own



20th century: Short-term engineering thinking

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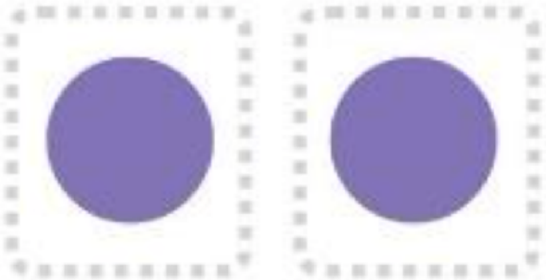
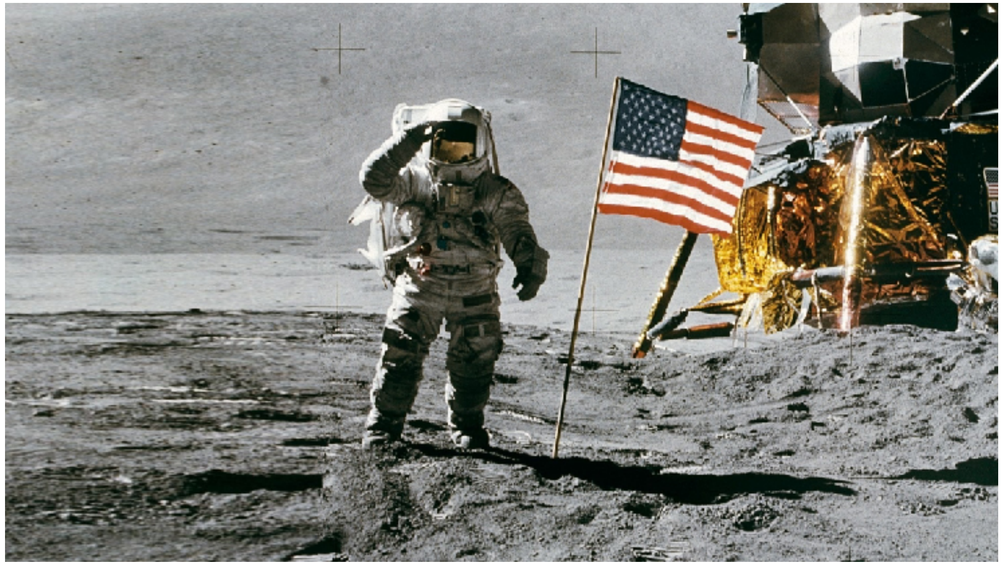
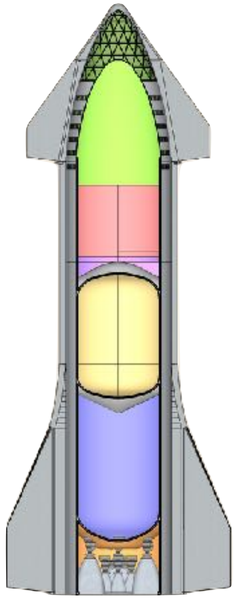
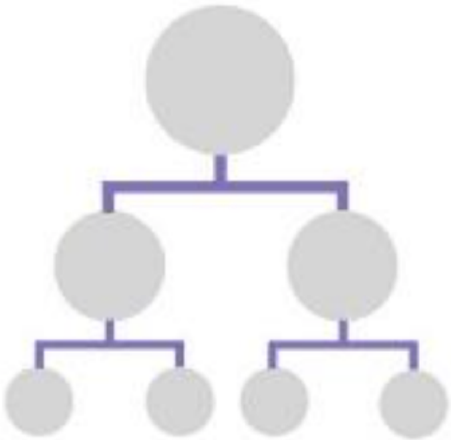


How do we build & shoot a rocket to the moon?







20th century: Short-term engineering thinking

How to optimize traffic flow?

https://www.youtube.com/watch?v=yITr127KZtQ

21th century: Also consider long-term systems thinking

Complexity: We cannot study a subsystem on its own

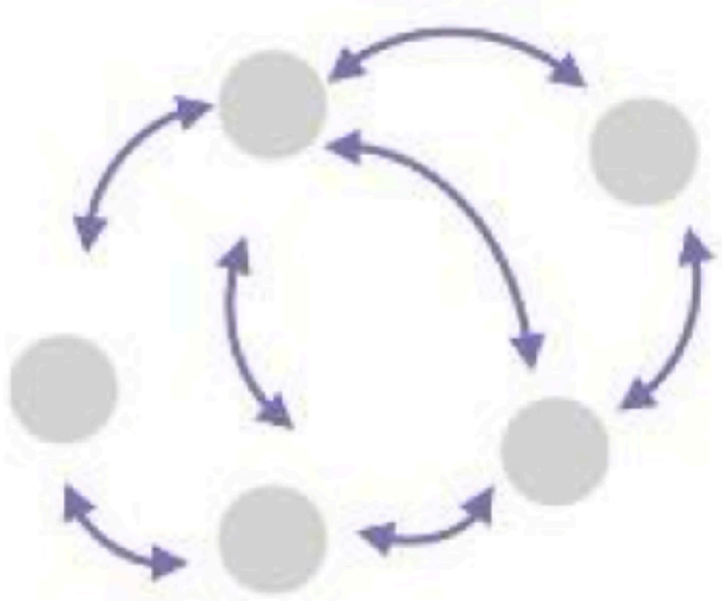
There are strong interactions or feedback loops

21th century: Also consider long-term systems thinking

Complexity: We cannot study a subsystem on its own

There are strong interactions or feedback loops

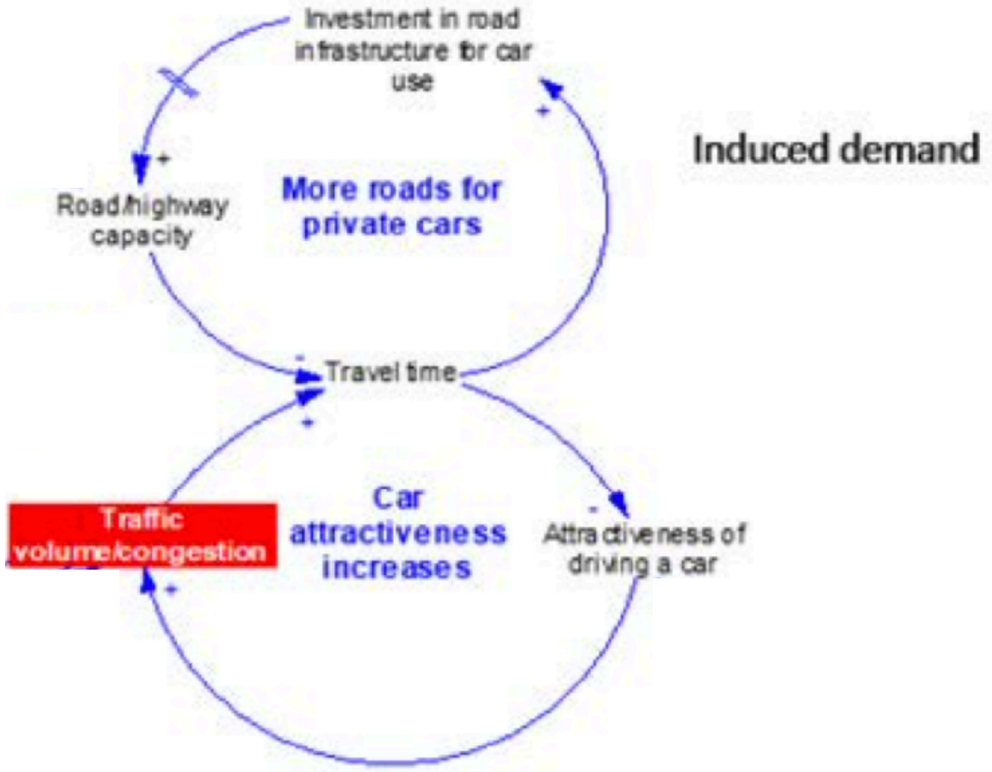
How do cities develop if we optimize streets for traffic flow?



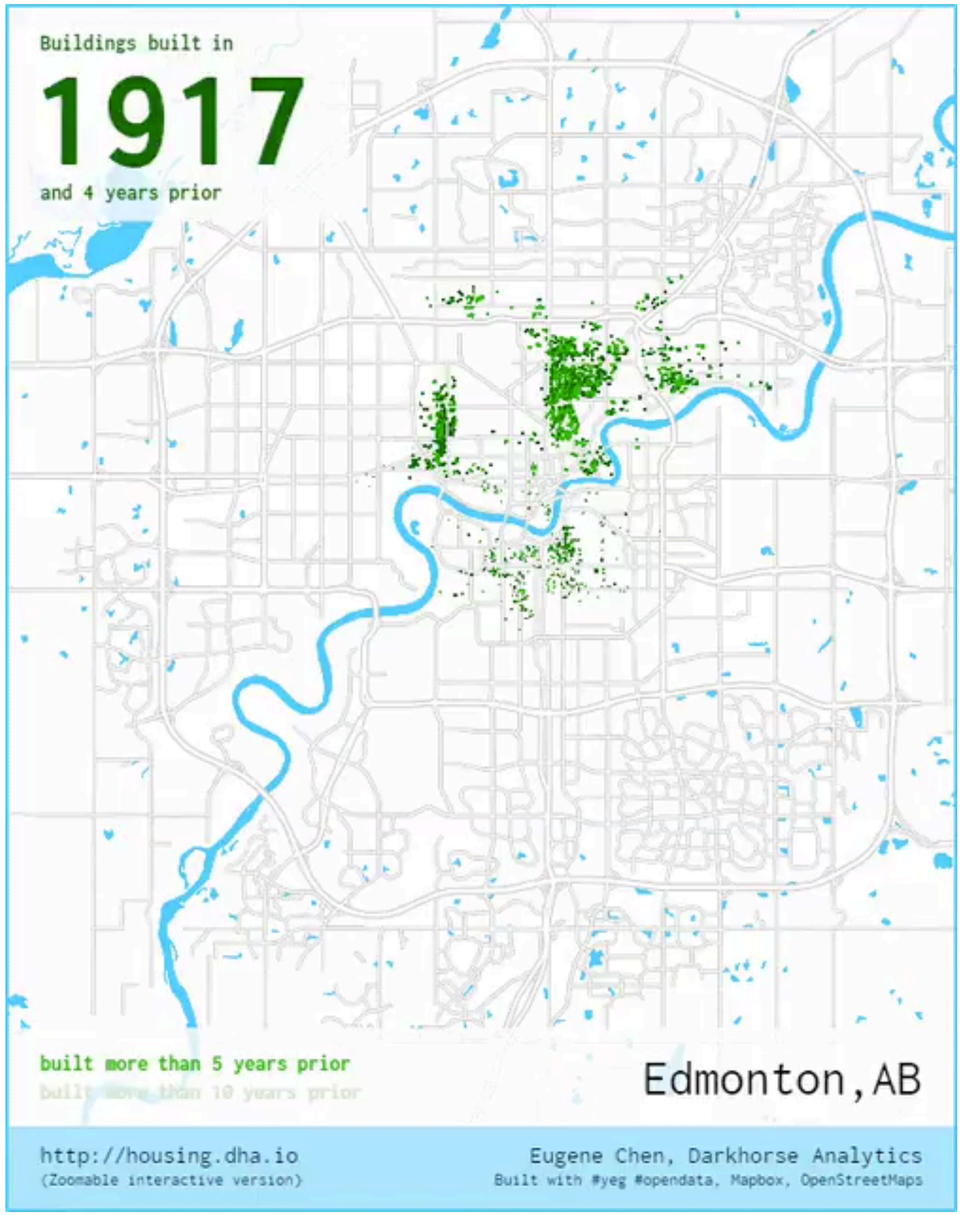
Systems-thinking reveals feedback-loops & long-term dynamics

Causal loop diagram https://www.oecd.org/environment/transport-strategies-for-net-zero-systems-by-design-0a20f779-en.htm

Systems-thinking reveals feedback-loops & long-term dynamics



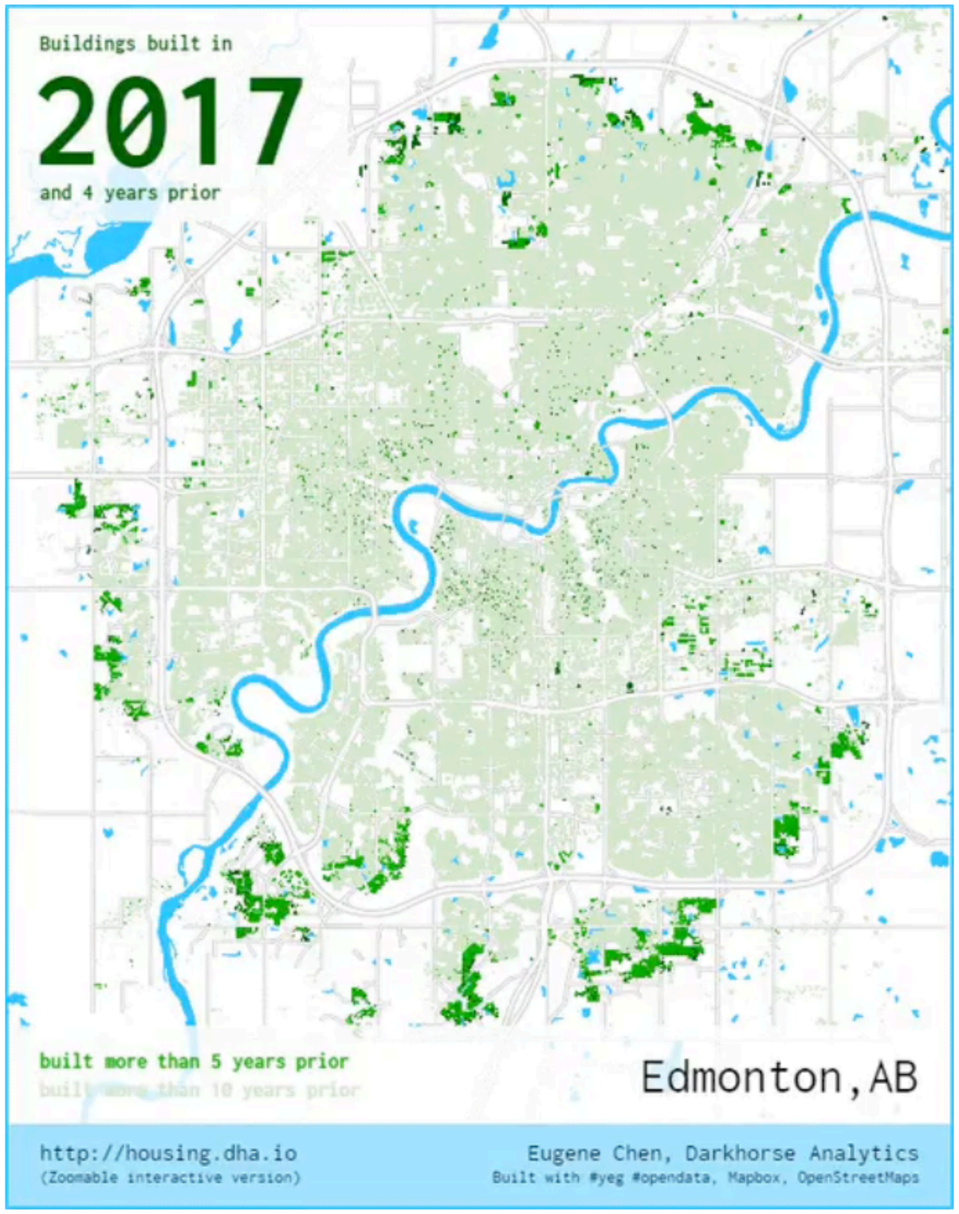
Systems-thinking reveals feedback-loops & long-term dynamics



Urban sprawl

http://housing.dha.io/

Systems-thinking reveals feedback-loops & long-term dynamics



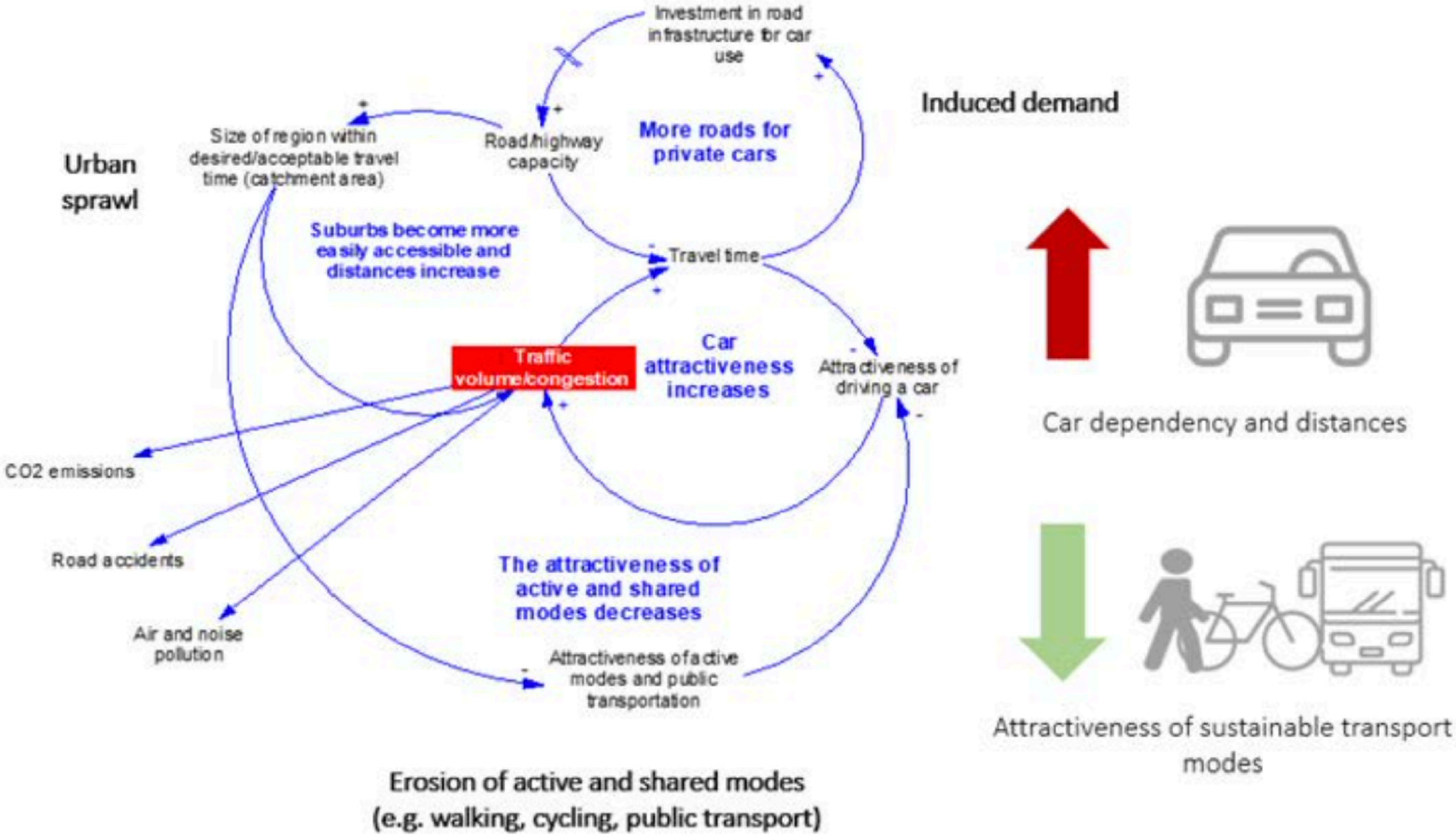
Urban sprawl

As the size of the region accessible by road increases, density decreases and the number of places conveniently accessible by public transport decrease.

Thus, as the region expands, places may be less well served by public transport, reducing the attractiveness of public transport and increasing the attractiveness of its alternative: the car.

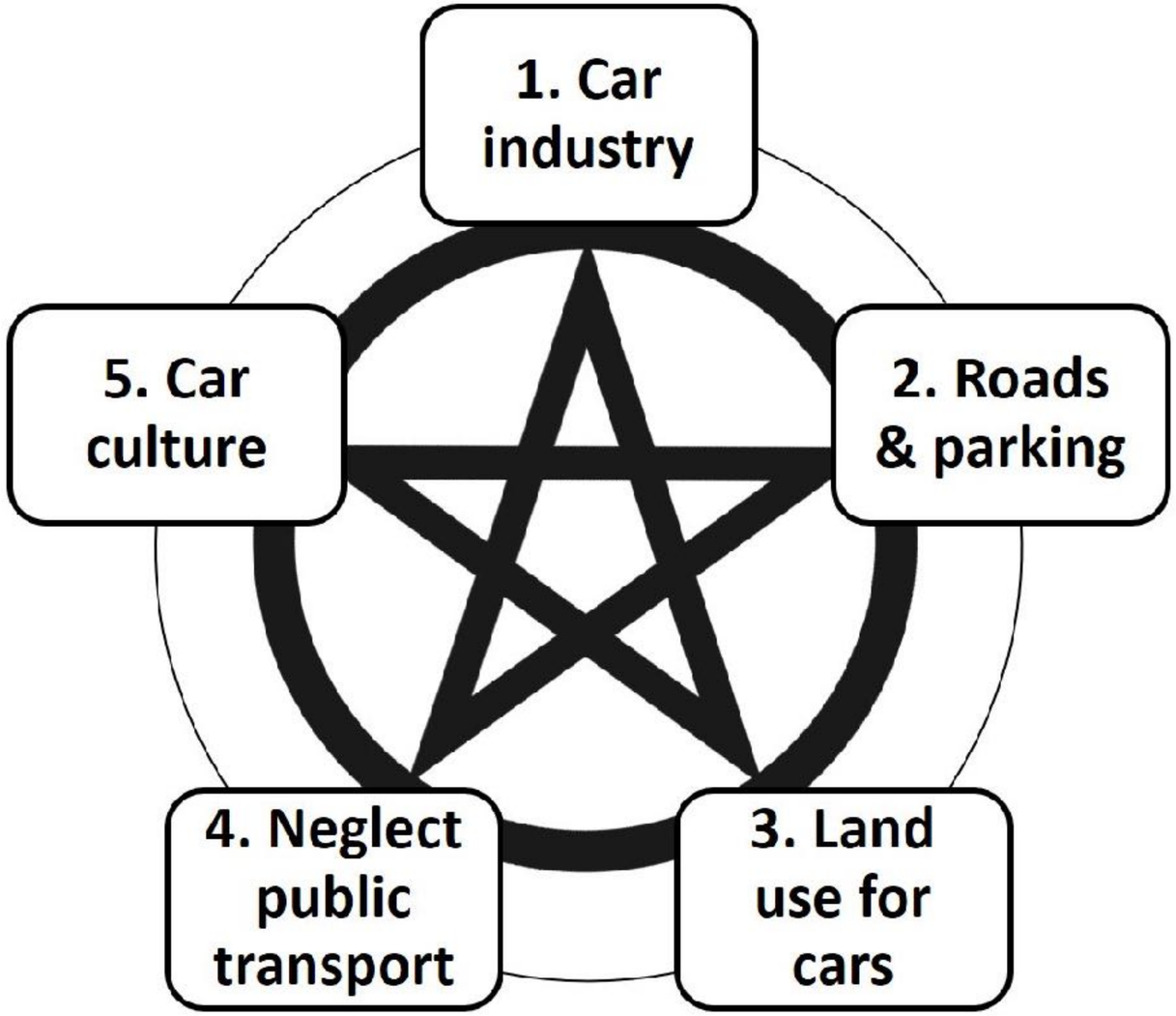
http://housing.dha.io/

Systems-thinking reveals feedback-loops & long-term dynamics



Optimizing one part of a complex system can come with unintended consequences

A wicked problem: It is hard to change the system



Mattioli et al, Energy Research & Social Science 66 (2020): 101486

We are part of the system

We can change it

We need to understand our own biases

Motonormativity

Motonormativity: How social norms hide a major public health hazard

Ian Walker

School of Psychology, Swansea University

Alan Tapp

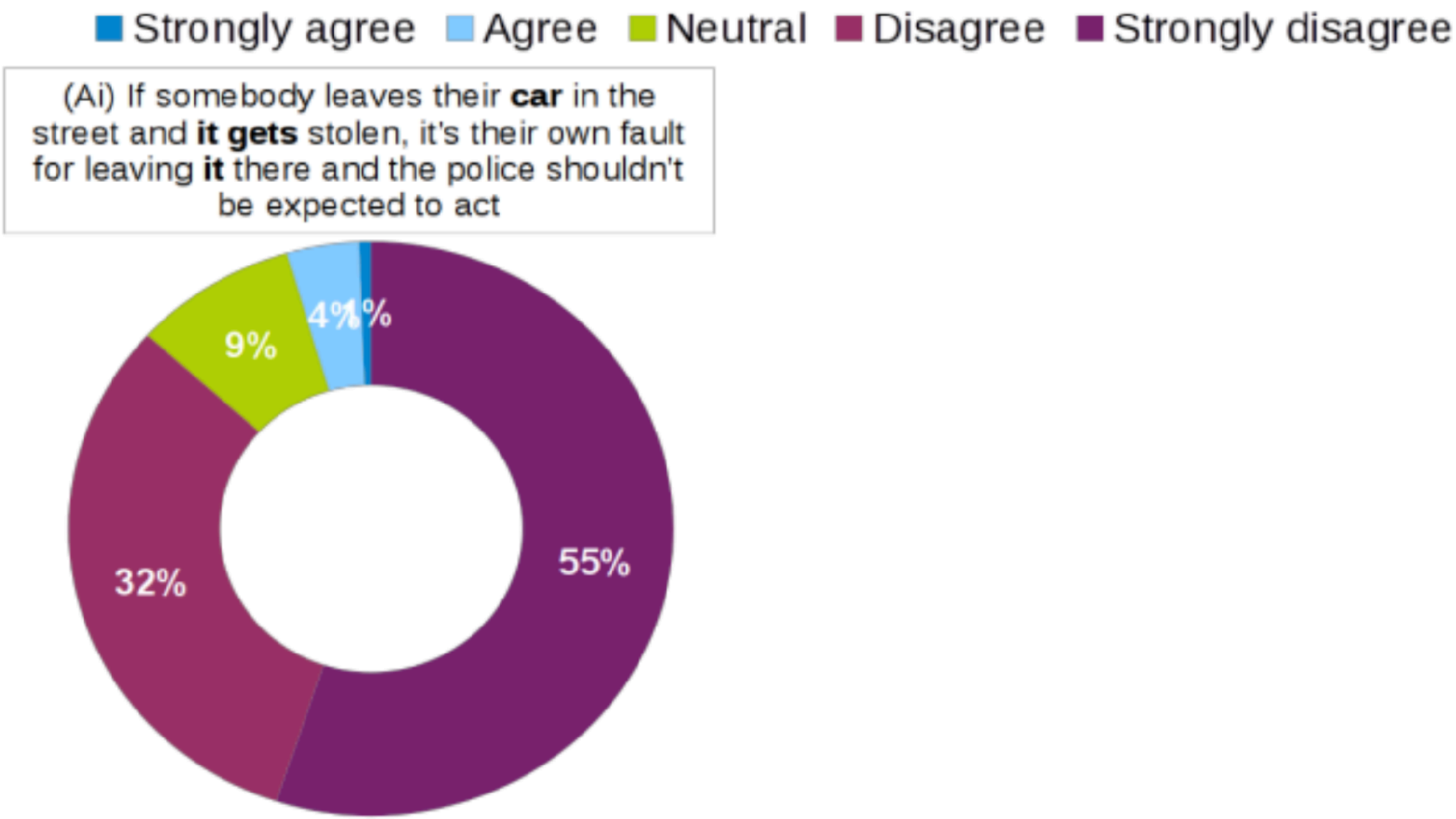
Bristol Business School, University of the West of England

Adrian Davis

Bristol Business School, University of the West of England

Transport Research Institute, Edinburgh Napier University

https://psyarxiv.com/egnmj



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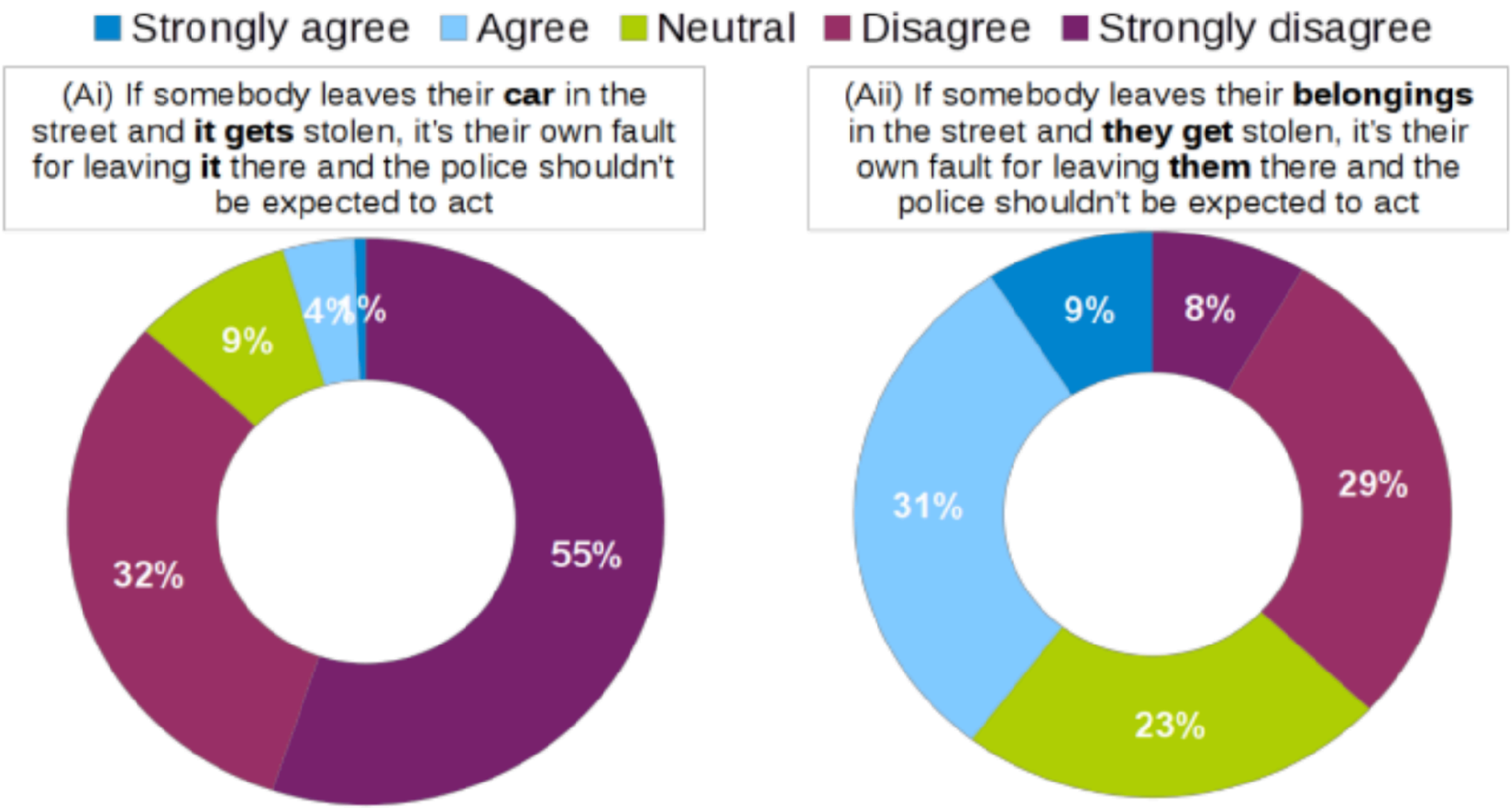


https://psyarxiv.com/egnmj

Motonormativity is a status quo bias

The *shared, largely unconscious assumptions how travel is, and must continue to be, primarily a car-based activity*.

https://psyarxiv.com/egnmj

Motonormativity has crept up over time

Were cars invented today, no device killing 35 people in the UK each week would be permitted in our streets, however convenient.

https://psyarxiv.com/egnmj

Motonormativity distorts health and policy decisions

Copenhagenize, Island Press (2018)

Motonormativity distorts health and policy decisions

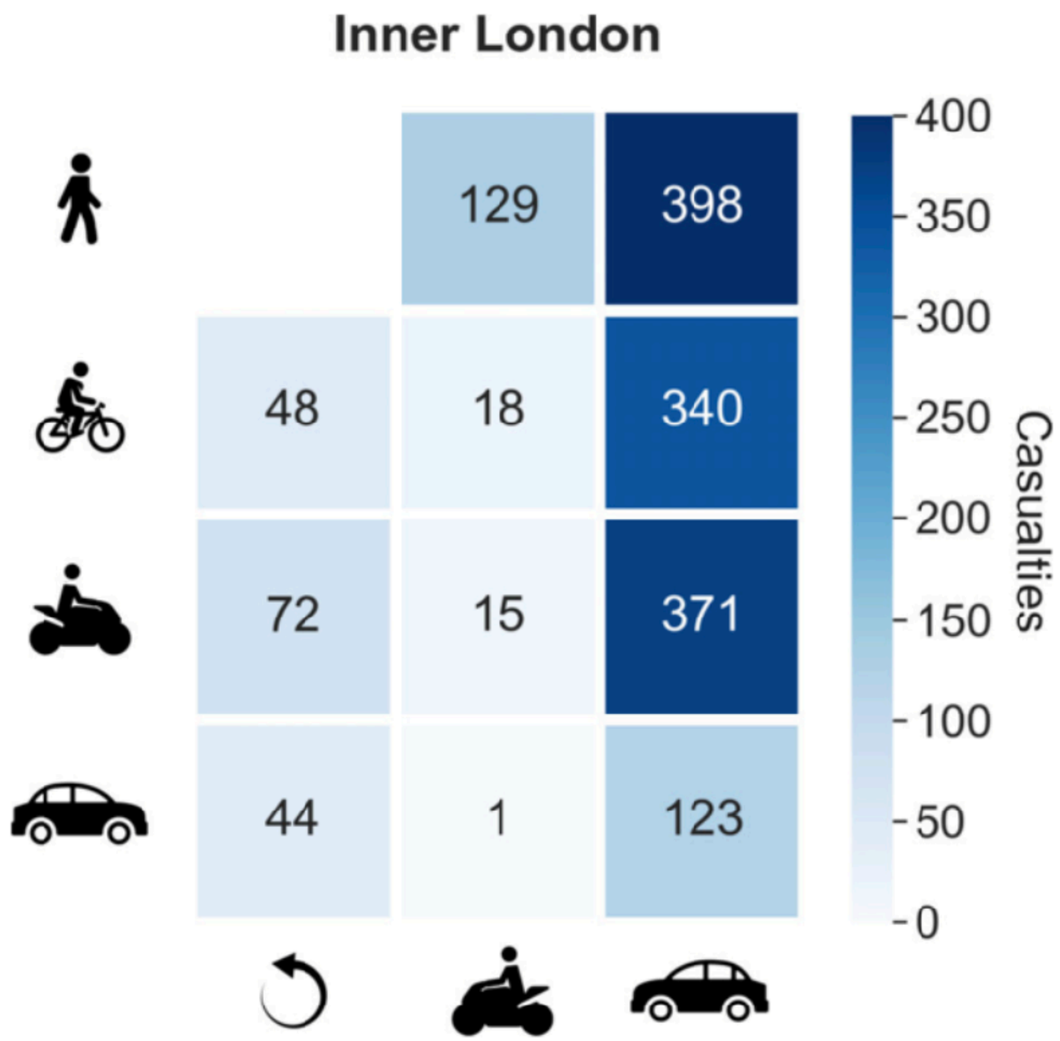
Half of serious head injuries happen inside cars
Australia: AU$ 380,000,000

Copenhagenize, Island Press (2018)

Road safety campaigns focus on motonormative victim-blaming

Road safety campaigns focus on motonormative victim-blaming

We know the danger comes from cars..



Klanjcic et al, EPJ Data Sci 11, 27 (2022)

Road safety campaigns focus on motonormative victim-blaming

We know the danger comes from cars..

..yet we blame those who are least responsible

Copenhagenize, Island Press (2018)

Denmark is a cycling nation

Cycling: 3bn DKK

New roads: 64bn DKK

Denmark is a cycling nation

Cycling: 3bn DKK

New roads: 64bn DKK

Er Danmark en cykelnation?

CYKLING

ANDRÉS FELIPE VALDERRAMA PINEDA,
LEKTOR, AALBORG UNIVERSITET
ANDERS FJENDBO JENSEN,
LEKTOR, DTU
CAROLINE SAMSON,
PH.D.-STUDERENDE, AALBORG UNIVERSITET
HARRY LAHRMANN,
LEKTOR, AALBORG UNIVERSITET
HILDA RØMMER KRISTENSEN,
LEKTOR, KØBENHAVNS UNIVERSITET
JASPER SCHIPPERIJN,
PROFESSOR, SYDDANSK UNIVERSITET
MADS PAULSEN,
POSTDOC, DTU
MALENE FREUDENDAL-PEDERSEN,
PROFESSOR, AALBORG UNIVERSITET
MICHAEL SZELL,
LEKTOR, IT-UNIVERSITETET
OG MICHALA HVIDT BREENGAARD,
POSTDOC, AARHUS UNIVERSITET

'CYKELNATIONEN DANMARK' bliver flittigt fremhævet, i anledning af at Tour de France kommer til Danmark. Vi præsenterer os for omverdenen som det gode eksempel på en nation med mange hverdagscyklister og en succesfuld cykelstrategi. Og i Danmark – særligt i de store byer – er det i store træk godt at cykle.

Der er dog også en anden virkelighed, der presser sig på. Tendensen landet over er, at flere kører i bil og færre på cykel. Data fra den årlige transportvaneundersøgelse (tudata.dk) viser, at ud af det daglige antal kørte kilometer er kun 3,5 procent på cykel, mens mere end 84 procent er i bil m.v. Disse tal virker især påfaldende, når vi sammenholder dem med, at 25 procent af alle daglige rejser er under 4 km, og 46 procent er under 10 km. Der burde være masser af potentiale for at cykle. Det uundgåelige spørgsmål er, om billedet af Danmark som cykelnation er ved at krakelere lidt. Tallene tyder nemlig på, at vi i stigende grad er en bilnation. Det har en lang række konsekvenser – ikke mindst i forhold til folkesundhed, byrum og klimaudfordringen, ligesom det bliver svært fortsat at brande Danmark som 'det gode eksempel' for cyklisme.

Det er blevet fremhævet, at siden 2009 har Danmark investeret mere end 3,5 milliarder i cykling. Derudover er der med 'Infrastrukturplan 2035' kommet en investering i cykling på 3 milliarder kroner. Dette beløb skal dog ses i lyset af, at der i samme periode investeres mere end 64 milliarder i at bygge nye veje. Når der samtidig ikke er en strategisk plan for investeringer i cykling, risikerer vi, at de 3 milliarder ender i fragmenterede små projekter over hele landet, som vi har oplevet de seneste år.

HVIS DANMARK fortsat skal fremstå som den cykelnation, vi praler af, skal der ske et kvantespring i forhold til investeringer og fokus på cykling i hele landet. Vejdirektoratets nye Cykel Videnscenter og cykeltopmødet 30. juni med den fælles deklaration om øget samarbejde på cykelområdet er en start, men det er ikke nok.

Cykling foregår i mange tempi, som er afhængige af lokale og regionale forskelle såvel som borgernes alder, fysik og formål med turen, herunder pendling til arbejde og studie, adgang til fritidsaktiviteter, ærinder, turisme og cykling som aktivitet i sig selv. Hvis vi skal være en cykelnation, er vi nødt til at tænke de forskellige behov ind i vores cykelstrategi.

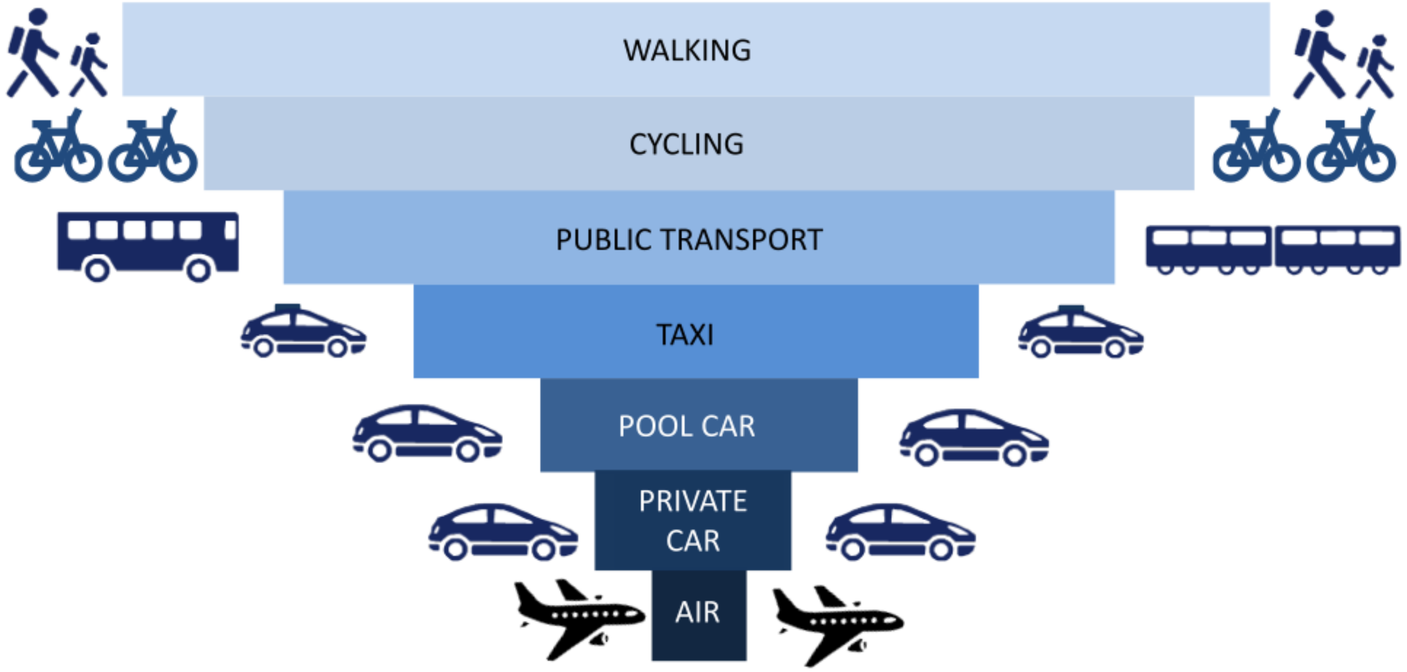
Når der samtidig er evidens for store sundhedsgevinster ved aktiv mobilitet, virker det åbenlyst, at investeringer i cykling har en stor samfundsmæssig gevinst. Samtidig gør det Danmark mindre sårbart over for stigende internationale brændstof- og energipriser. Øget cykling kan også medvirke til at løse de store udfordringer, som vores transport udgør på klimaområdet.

EN CYKELNATION skal for alvor investere i cykelinfrastruktur og -kultur mere bredt. Samtidig bør de nationale infrastruktur- og vidensinstitutioner være med til at sikre, at disse investeringer hænger sammen. Det er essentielt at samle og kommunikere erfaring og viden, hvis vi skal have flere op på cyklen, såvel som for at kunne etablere et landsdækkende cykelsystem, som giver tryg og sikker cykelmobilitet for alle. Det er nødvendigt, hvis vi fortsat gerne vil brande og eksportere den danske cykelmodel til andre lande.

Der er mange lande rundtomkring i verden, der kigger mod Danmark som en model for håndtering af klimaudfordringerne på transportområdet. Det vil vi gerne have, at de bliver ved med. Det kræver dog, at vi værner om det, vi har opnået, og viser, at vi kan gøre det endnu bedre.

Politiken, 2022-06-27

The sustainable travel hierarchy looks like this



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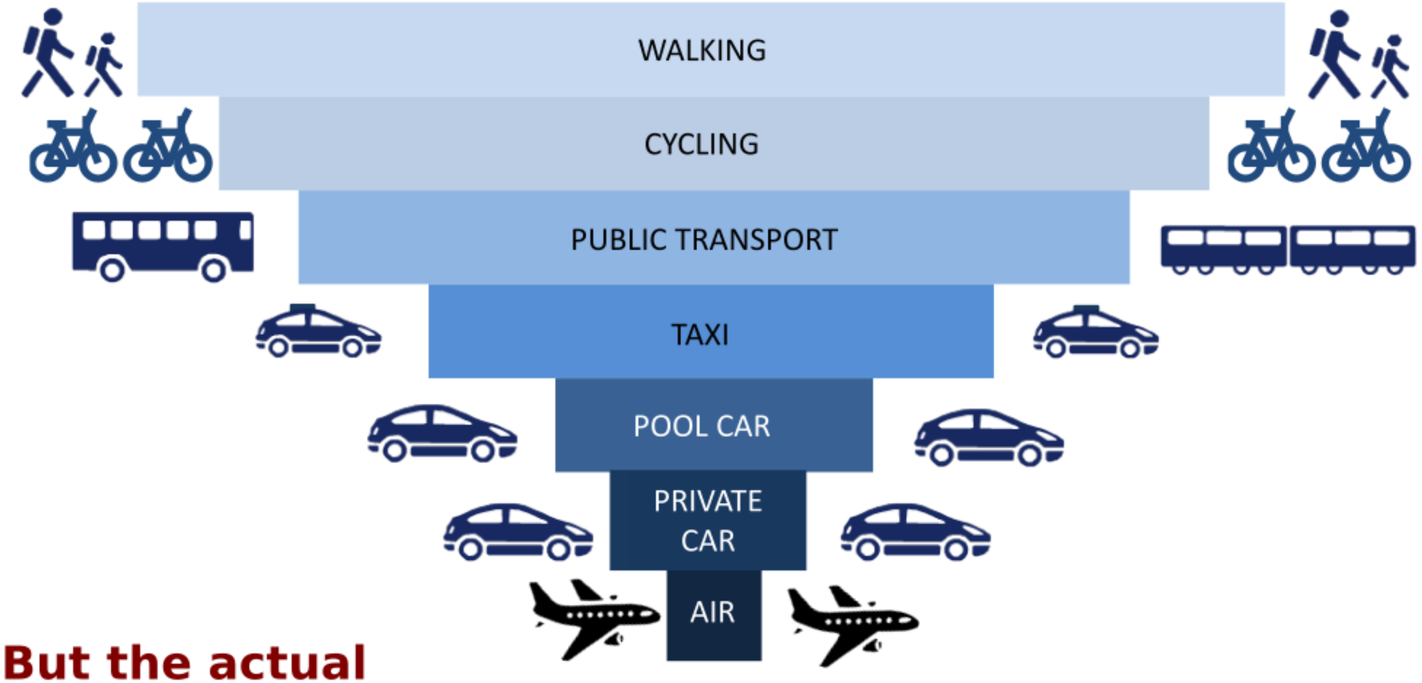
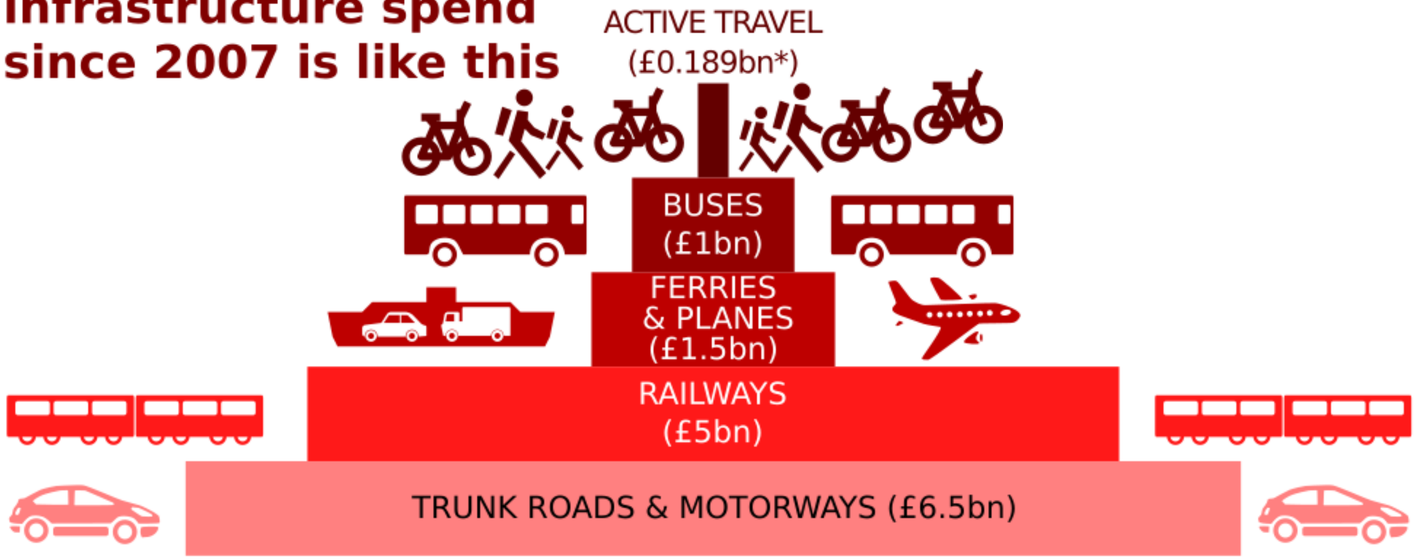


But the actual infrastructure spend since 2007 is like this



Short-term thinking & biases have led to

predict and provide

"We model the future on our past & biases"

Short-term thinking & biases have led to

predict and provide

"We model the future on our past & biases"

But we should

decide and provide

"We shape the future that we want"

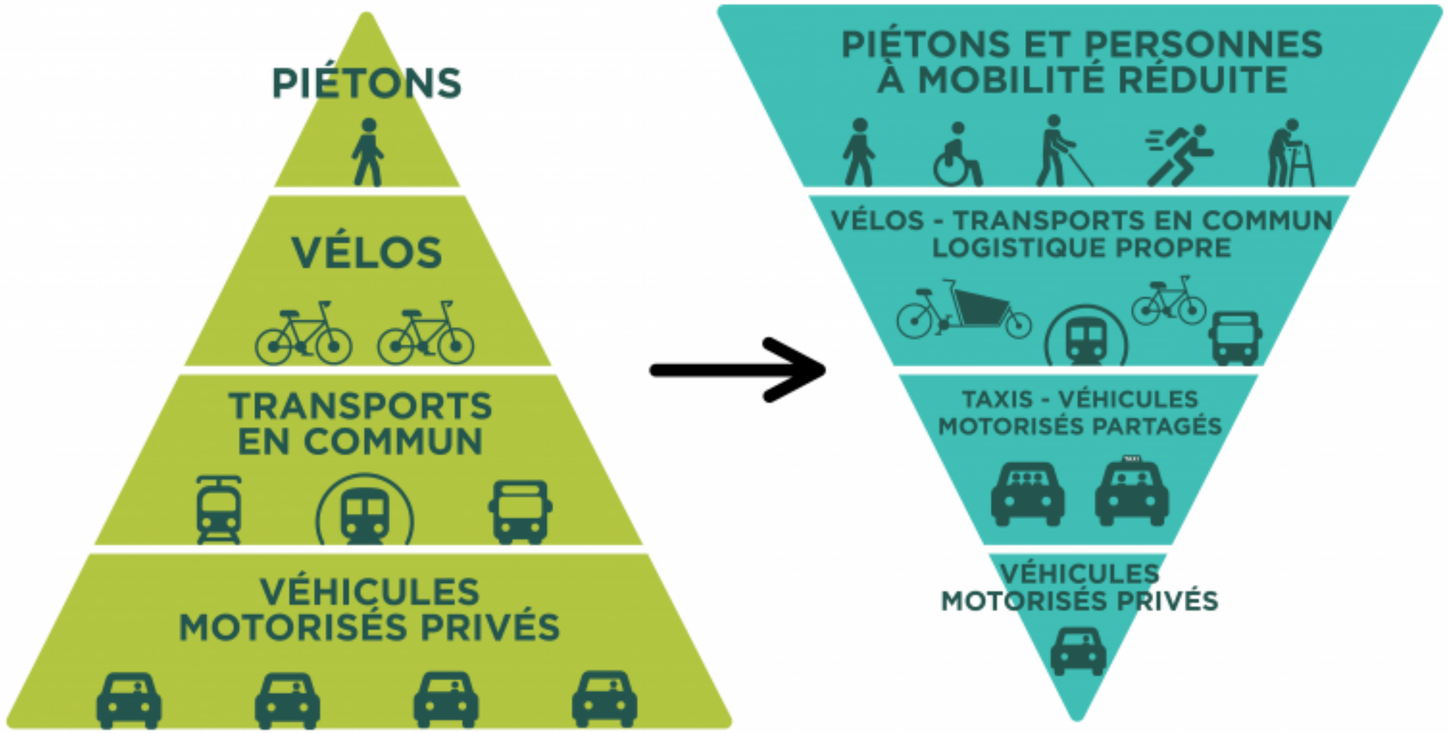
www.jan-kamensky.de

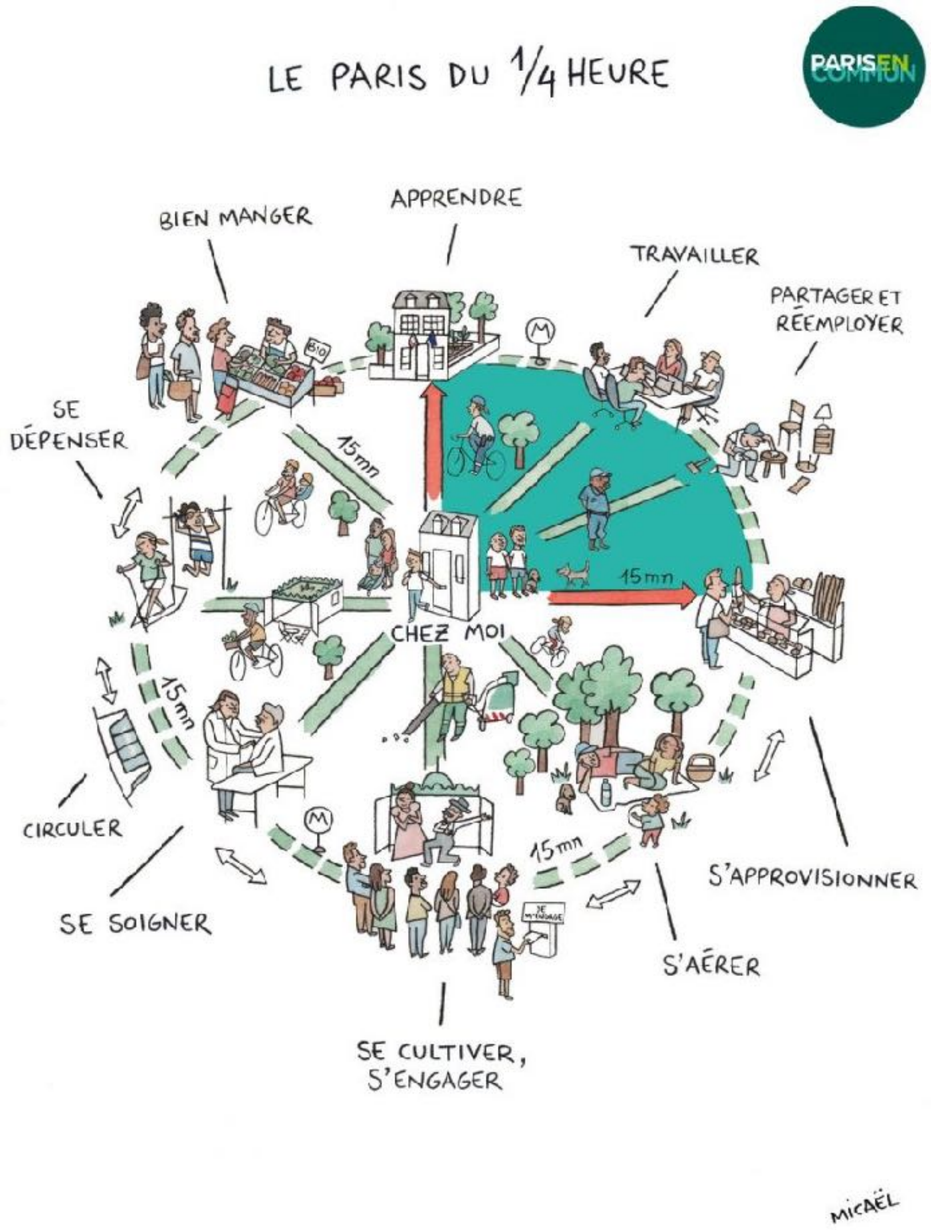
Our top priority should be building sustainable systems

Not just removing cars

Not just building bike networks

...

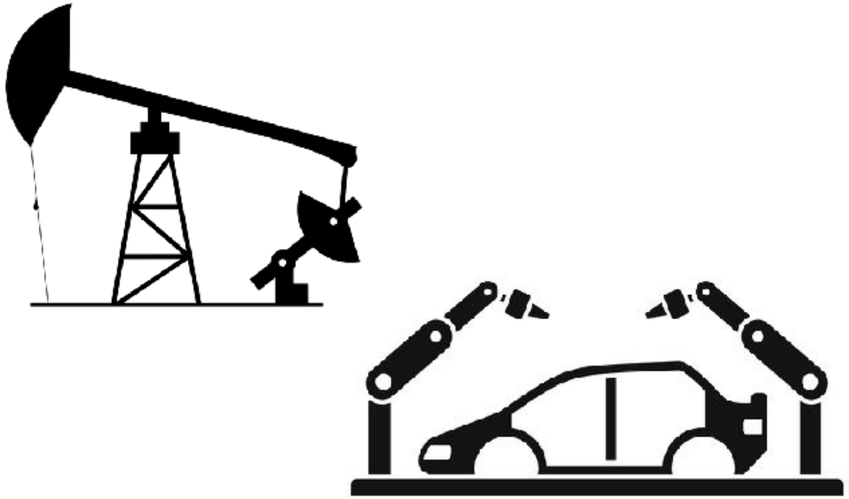




Building sustainable cities is 99%
a political, not a technical question

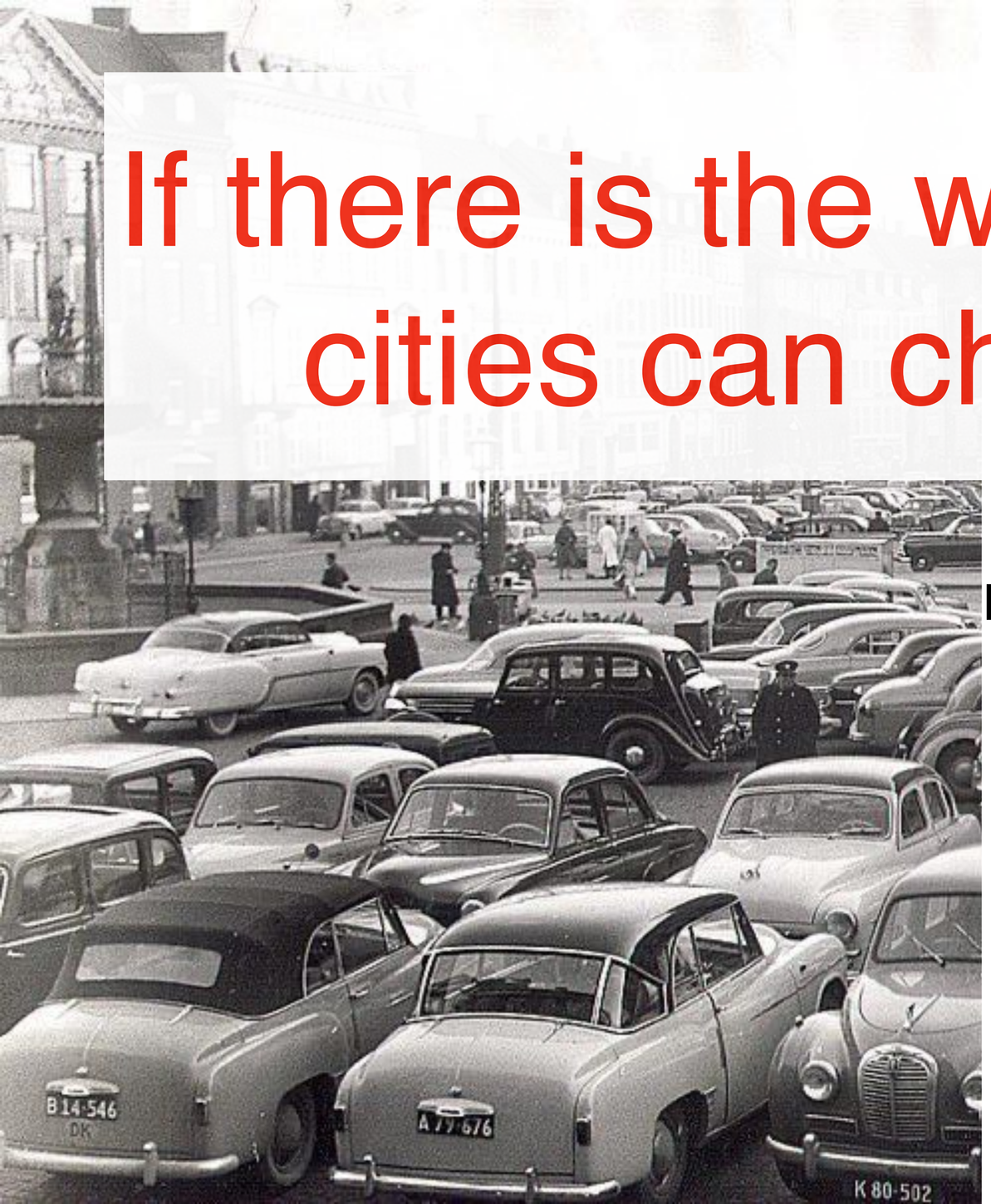
To be clear:

The underlying problem is not cars or people who drive cars, but actors who create a car-dependent system that forces car-ownership



But still all of us have an effect!

If there is the will (and pressure), cities can change radically



Take-home messages

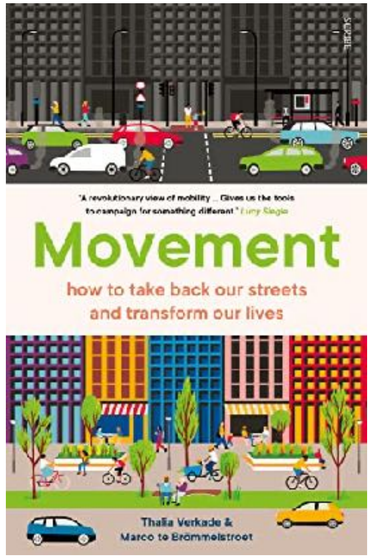
We can use IT to help design better, sustainable cities, but:

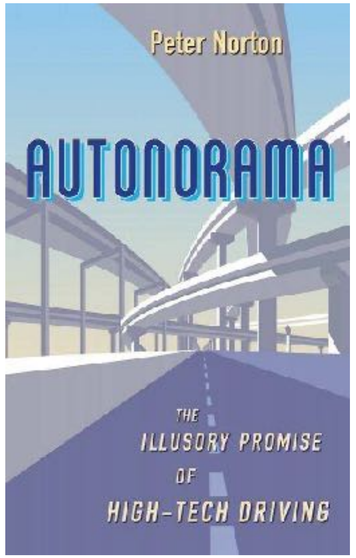
1) Inadequately applying engineering thinking can lead to unintended consequences

2) Induced demand: Widening or building new roads cause more traffic

3) We can't use tech like e-cars to "solve mobility", but must rebuild the whole system, including overcoming our biases & perverted political priorities

Further materials





https://github.com/mszell/geospatialdatascience

THE WAR ON CARS

thewaroncars.org

Episode on motonormativity

NOT JUST BIKES

Not Just Bikes

Walker et al (2022): Motonormativity

Henderson (2020): EVs are not the answer

Gössling (2016): Urban transport justice

Exercises: Very hands-on!

How to spend money in Copenhagen?