A photograph of a busy city street at sunset. The scene is filled with the silhouettes of many pedestrians walking across a paved plaza. In the background, there are several modern buildings with glass facades. The sun is low on the horizon, creating a strong backlighting effect that casts long, dark shadows of the people and buildings onto the ground. The sky is a mix of orange, yellow, and blue. The overall atmosphere is one of a bustling, modern urban environment.

Lecture 06

Sustainable mobility

CIVIL-239: Engineering a
sustainable built environment

15 October 2025

Andrew Sonta

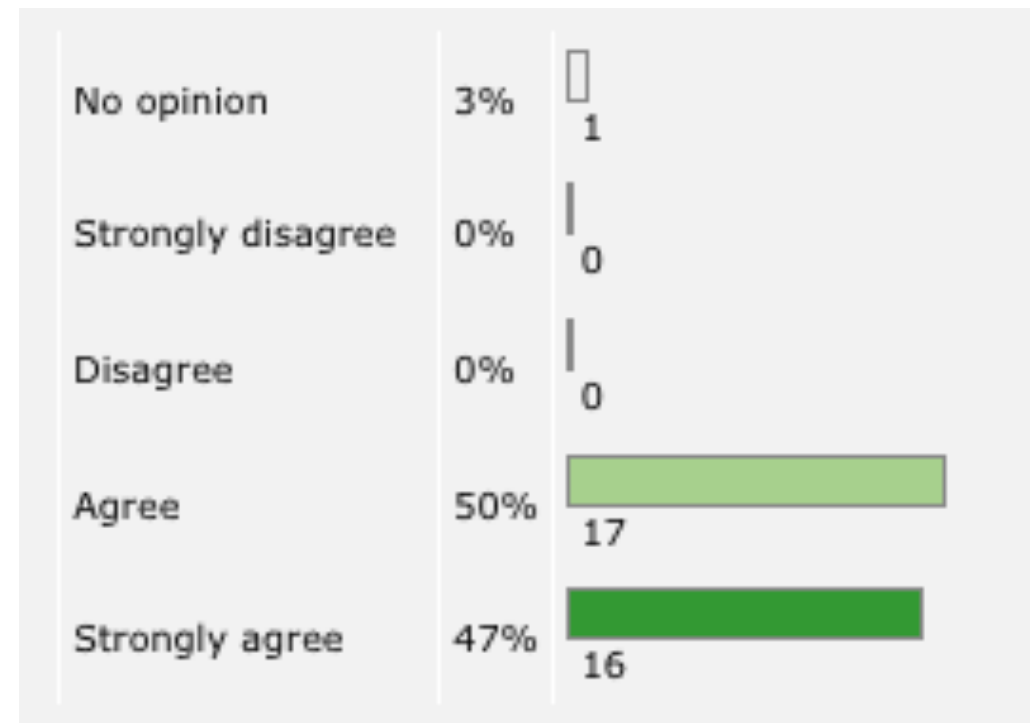
Midterm exam

- How to prepare:
 - Review **slides** and your **notes**, including **in-class exercises**
 - Review **assignments**
- Oct 29, 10:15-12:00
- 3 rooms: AAC 014, 008, 020
 - Last name A-D: 014
 - Last name F-M: 008
 - Last name N-Z: 020
- Closed book and notes
- Bring a simple calculator
- Mix of multiple choice and open-ended questions
- Not intended to test memorization, but rather understanding of the material

Indicative feedback

- Slides and lectures
 - Interesting
 - Some things you have already seen in SHS courses
 - Will be less true going forward, but good for me to know
 - Not clear what's useful for the exam
 - Plan: provide a summary at the end of today's class, provide hints on what to study
- Assignments
 - Also interesting
 - Some say too much work, some say not deep enough
 - Purpose is to provide an opportunity to work with course material
 - First assignment was very high level (topic introduction)

The running of the course enables my learning and an appropriate class climate



Outline

- Review systems thinking theory
- In-class exercise
- System archetypes
- Sustainable and active mobility
- Walkability
- The 15-min city
- Systems thinking and social aspects of sustainability

Transportation is a complex *system*

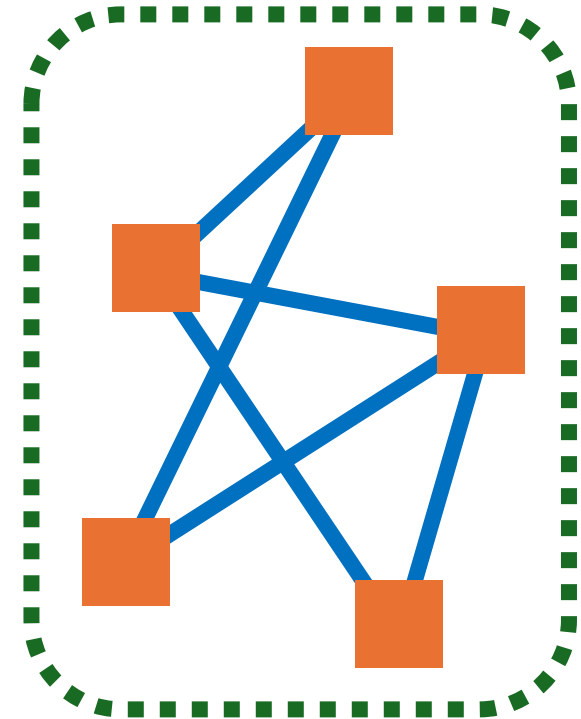
A system is...

a set of
elements

interconnected
coherently organized

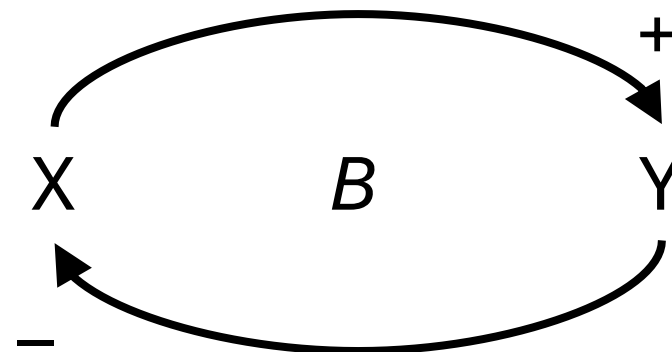
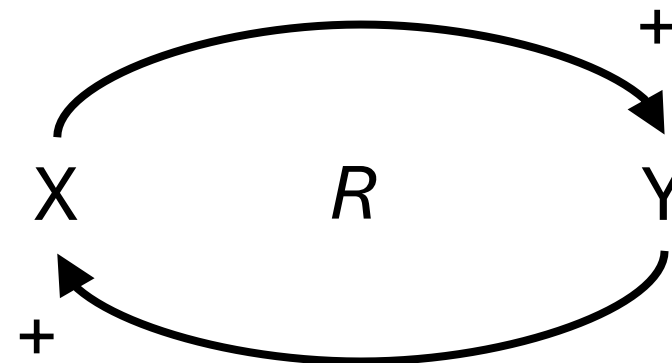
in a way that achieves
something

- Multiple parts without interdependencies are just collections
- The structure helps to drive the system toward its purpose



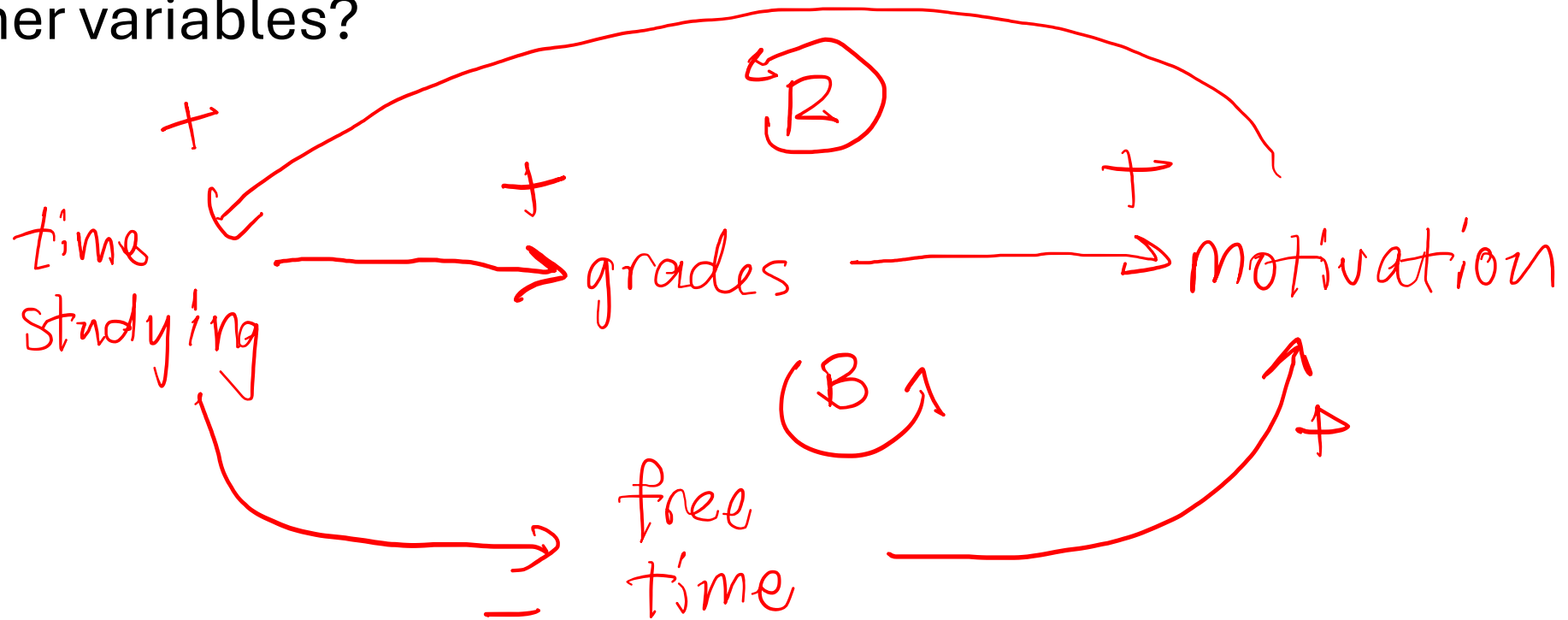
Visualizing systems with causal loop diagrams

- Causal loop diagrams (CLDs) are visual tools to represent how different variables are related and highlight feedback loops
- Components of a CLD:
 - Variables (components)
 - Arrows (connections)
 - Signs (indicate positive or negative relationships)
 - Variables move in same direction: +/S
 - Variables move in opposite direction: -/O



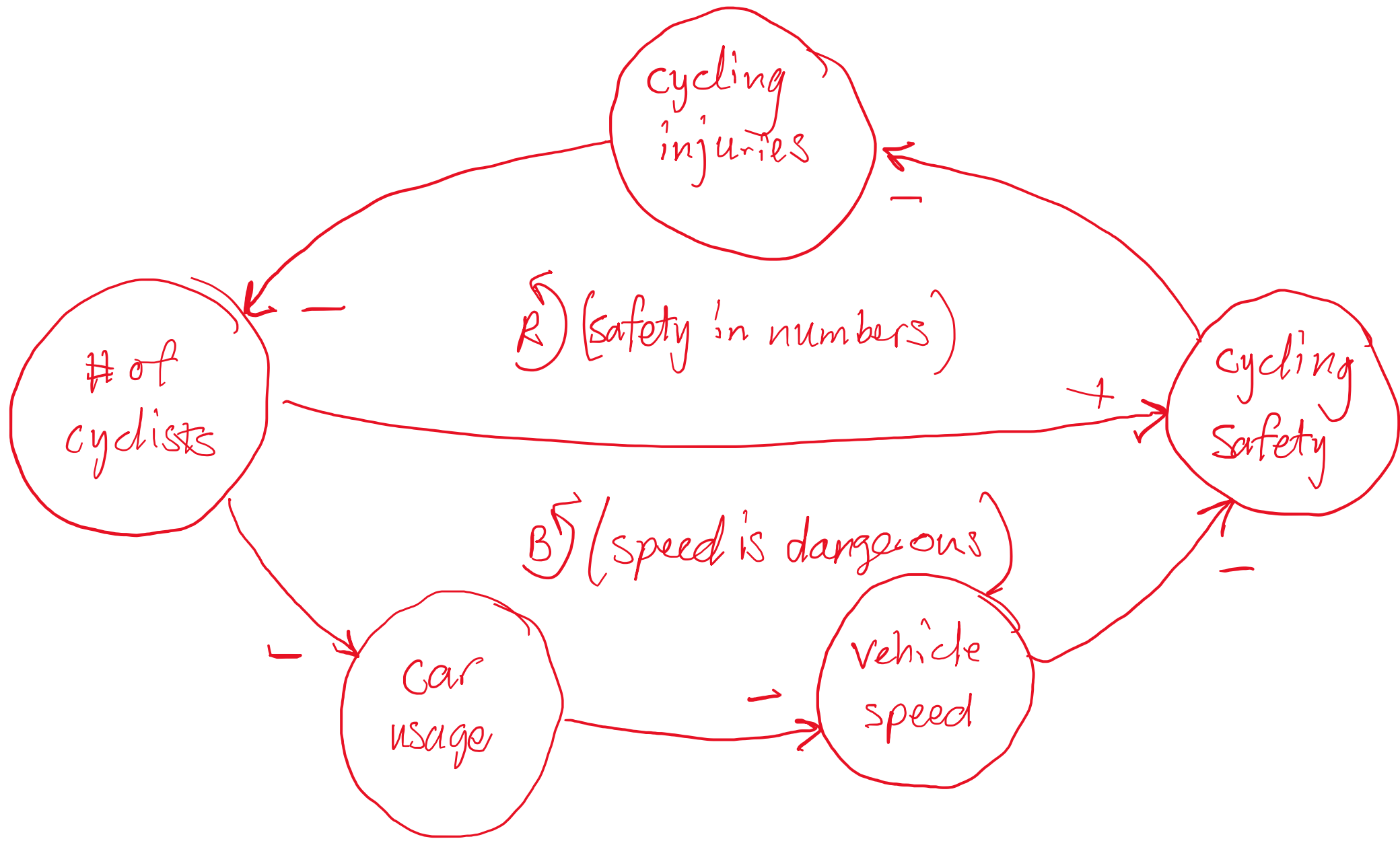
Simple CLD

- Variables: (1) time spent studying, (2) grades
- Other variables?



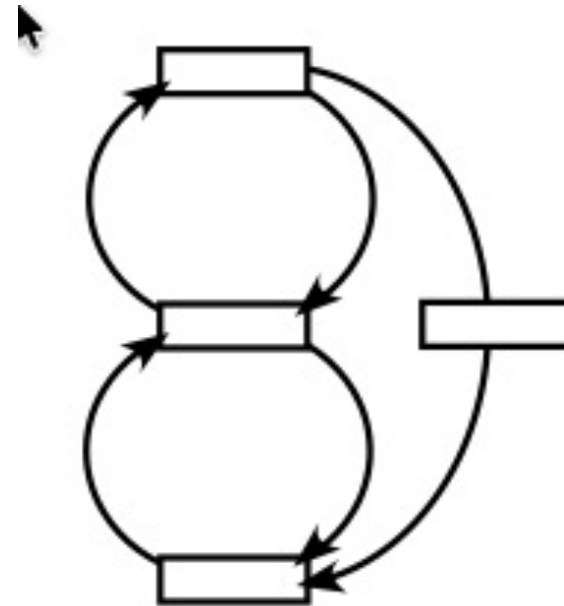
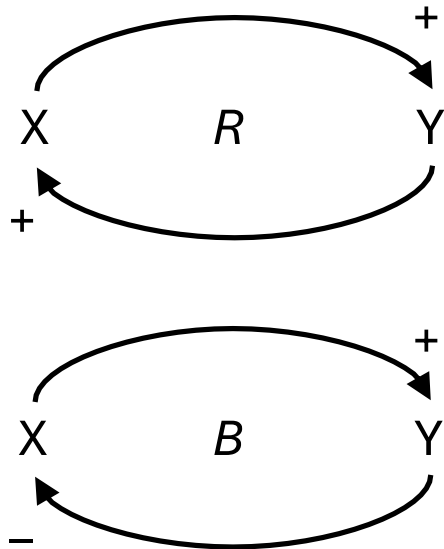
In-class exercise: Create a CLD

Lausanne is considering adding more bike lanes in particular places in the city. As a systems thinker, you believe you can help in their decision-making by pointing out the relationships between (1) **number of cyclists**, (2) **real and perceived cycling safety**, (3) **car usage**, (4) **vehicle speed**, and (5) **cyclist injuries**. Identify 1 balancing feedback loop and 1 reinforcing feedback loop and draw them in a CLD to explain to the city.

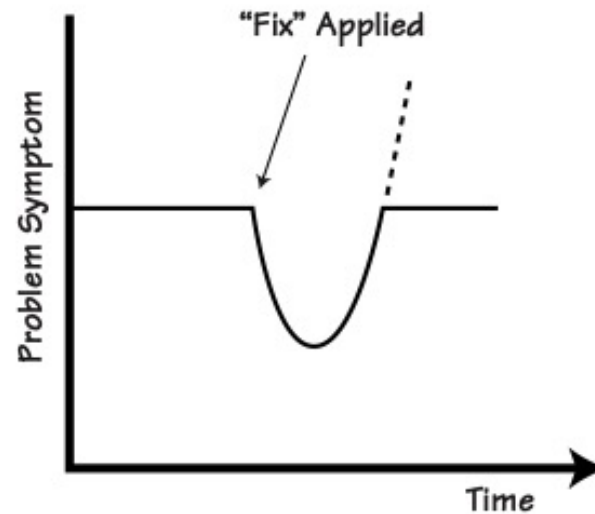
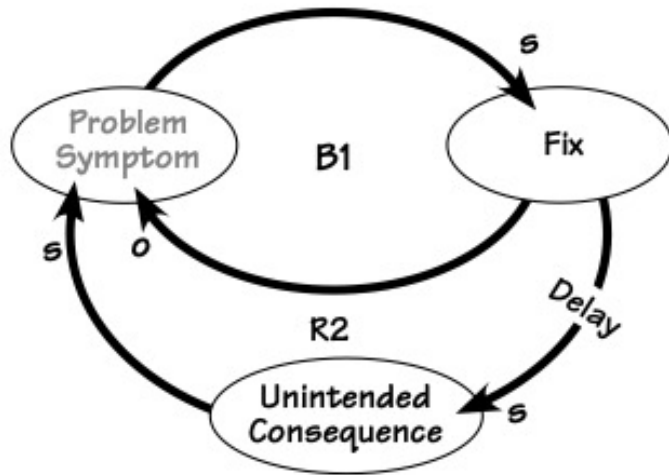


Some system structures are archetypes

- Causal loop diagrams help you identify reinforcing and balancing processes
- System archetypes help you recognize common system behavior patterns

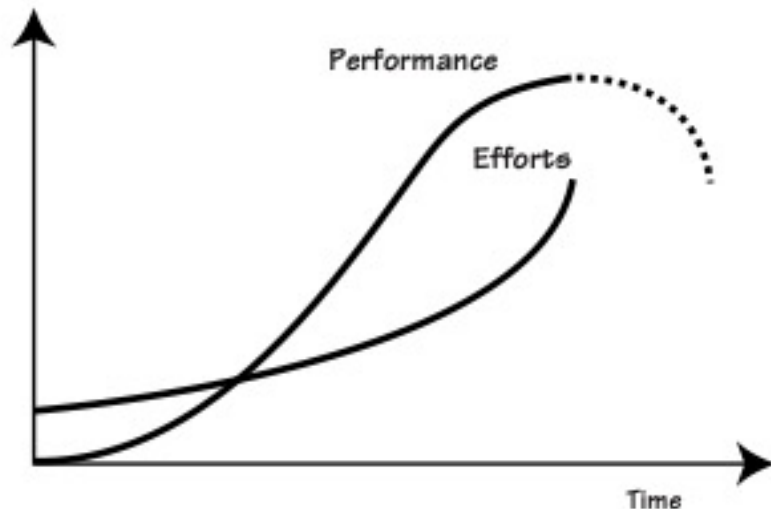
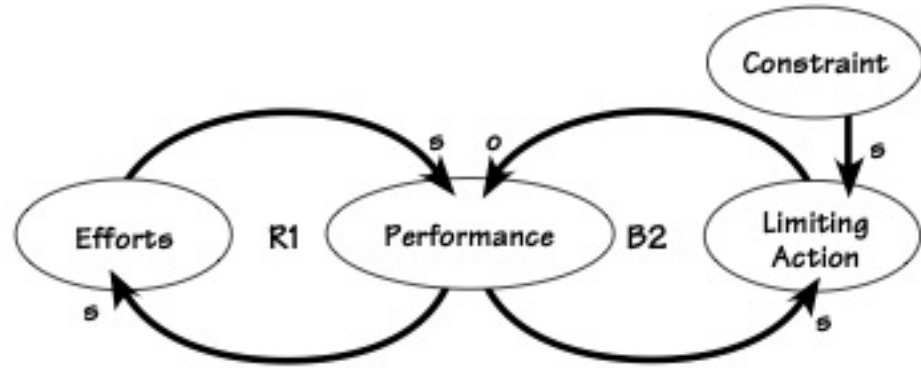


Archetype: Fixes that fail



- We observe a symptom of a problem
- A fix is implemented to reverse the problem
- The fix causes unintended consequences that exacerbate the problem, returning the symptom to its previous level (or worse)

Archetype: Limits to success



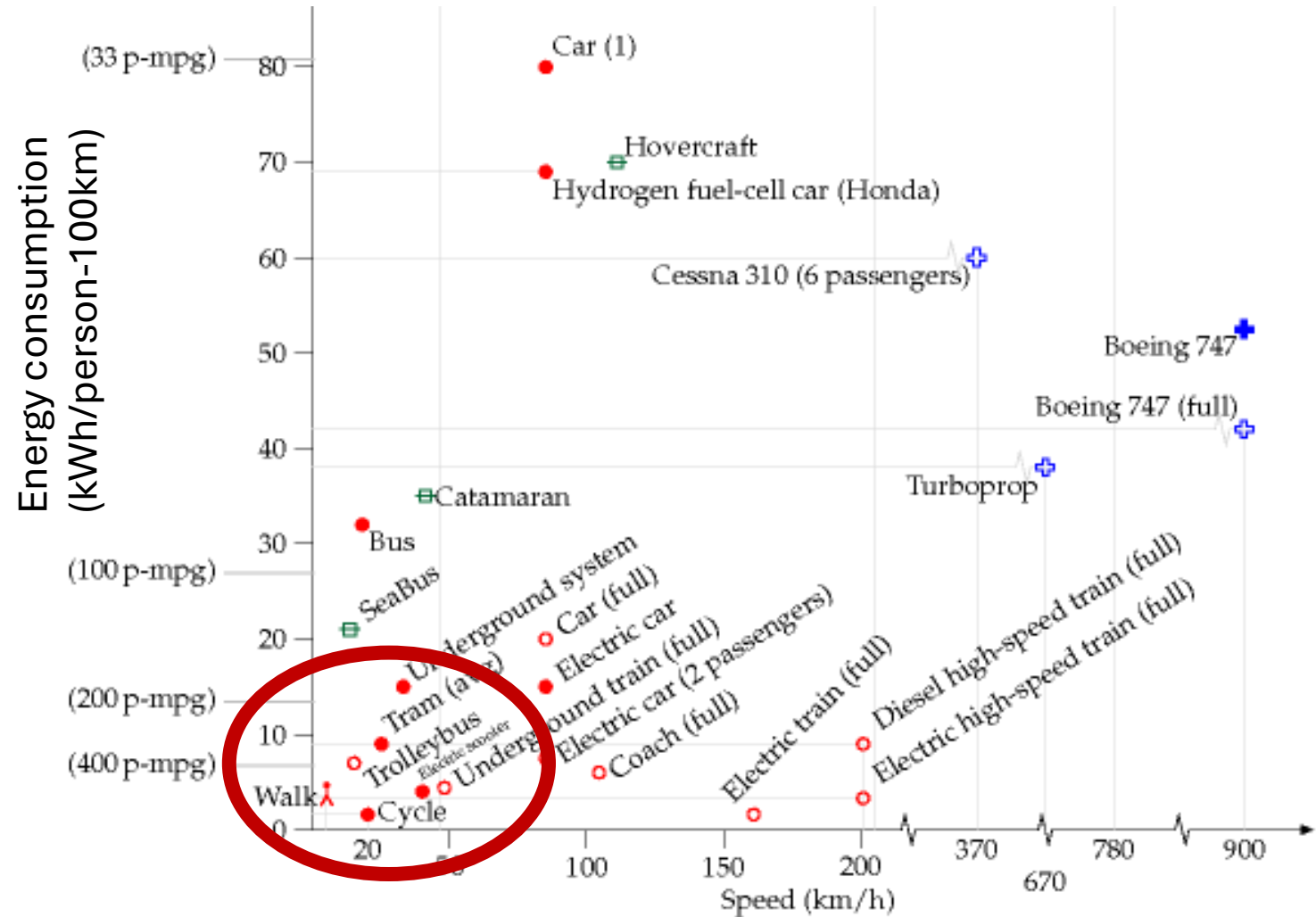
- Continued efforts lead to improved performance (reinforcing loop dominates)
- Over time, the system encounters a limit (balancing loop) that causes the performance to slow down or even decline

Other archetypes:

- **Success to the successful:** Something or someone performs well because it has more resources, which is used as a justification to provide it with more resources
- **Shifting the burden:** A symptom of a problem is experienced, and a solution is applied to the symptom rather than the underlying problem, diverting attention away from the underlying problem
- Read more here if interested:
[Systems Archetypes I: Diagnosing Systemic Issues and Designing High-Leverage Interventions by Daniel H. Kim](#)

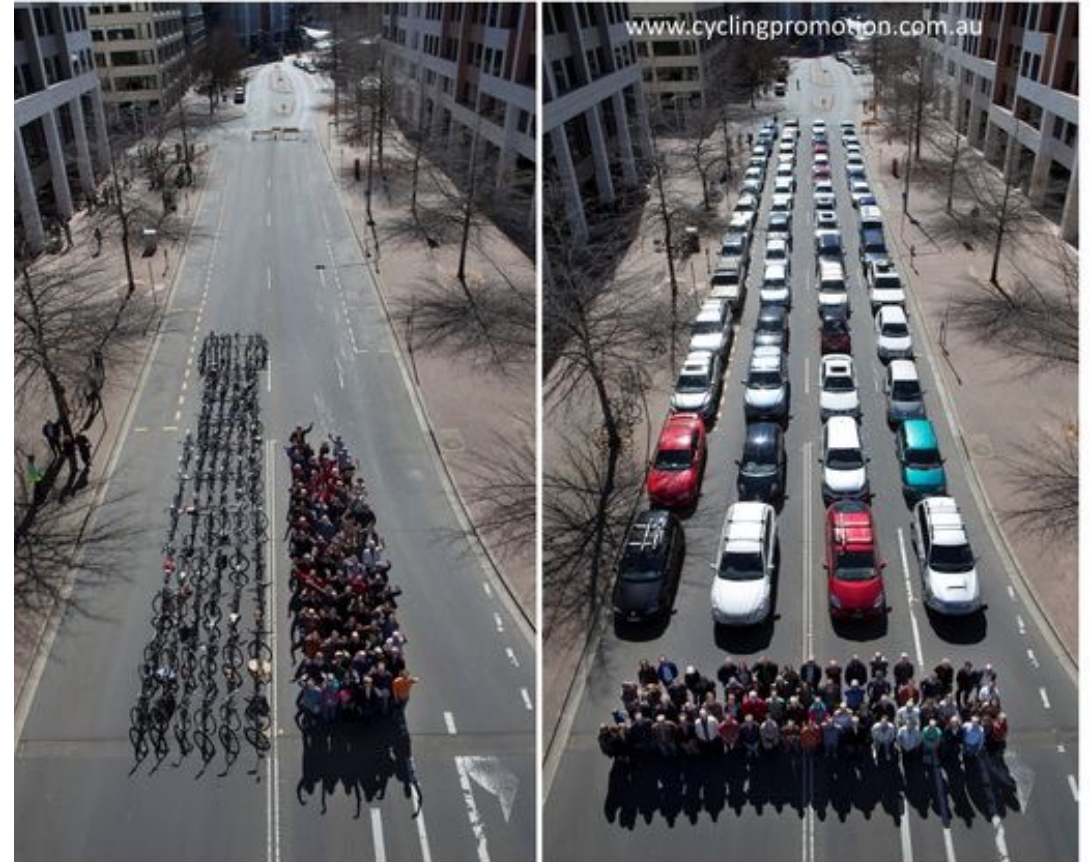
Sustainable mobility

- Focus on low-energy forms of transportation, specifically public transportation, walking and cycling



Active mobility (soft mobility)

- Human-powered mobility
- Clear energy benefits
- Benefits beyond energy
 - Health: reduced air pollution, physical health, mental health
 - Space: less space required vs personal vehicles
 - Economic: people pass by local shops
 - Other environmental benefits: noise pollution
 - Social?



Walkability (and bikeability)

- Walkability is the degree to which the built promotes walking (cycling) by providing safe, accessible, and convenient infrastructure
- Accessibility of amenities by foot (bicycle) is key
 - Amenities: destinations in an urban environment like stores, restaurants, schools, offices, healthcare facilities, ...
- Also influenced by many other factors
 - Density: things need to be close enough for walking (cycling) to be feasible
 - Land use: need a diversity of amenities nearby
 - Quality of the paths for walking
 - Safety
 - ...

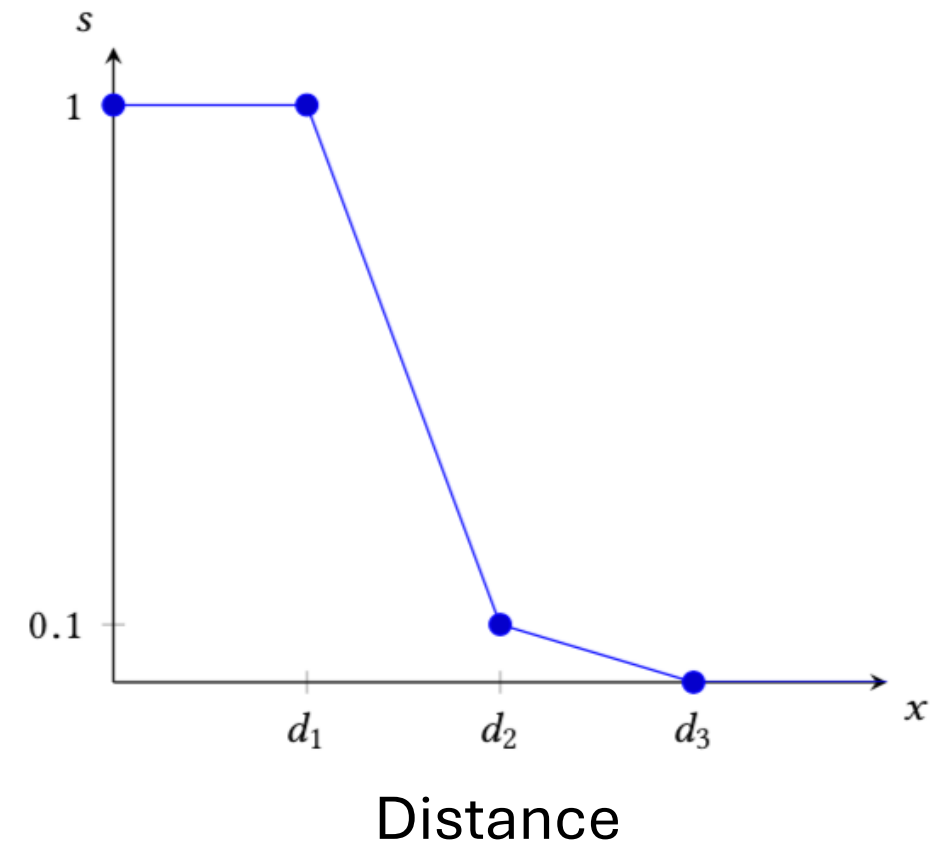


First walkability metrics: WalkScore

- Goal: calculate score for walkability for an individual residential unit

$$Score = \frac{1}{\sum_{a=1}^A \|\mathbf{w}_a\|_1} \left(\sum_{a=1}^A \mathbf{w}_a \cdot \mathbf{s}_a \right) 100$$

- a : amenity type
- \mathbf{w}_a : vector of weights for amenity type
- \mathbf{s}_a : vector of distance scores for amenity type
 - distance score (s) is a function of distance (d)
- Note: each amenity type can have different vector lengths (e.g. 2 grocery stores vs. 10 restaurants)
 - Requiring more of an amenity type implies the importance of multiple of that type

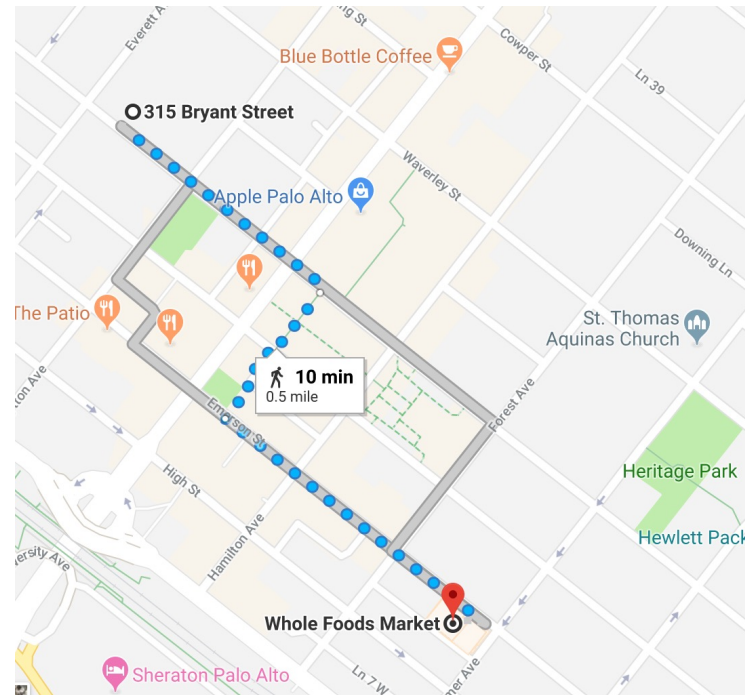


Calculating WalkScore

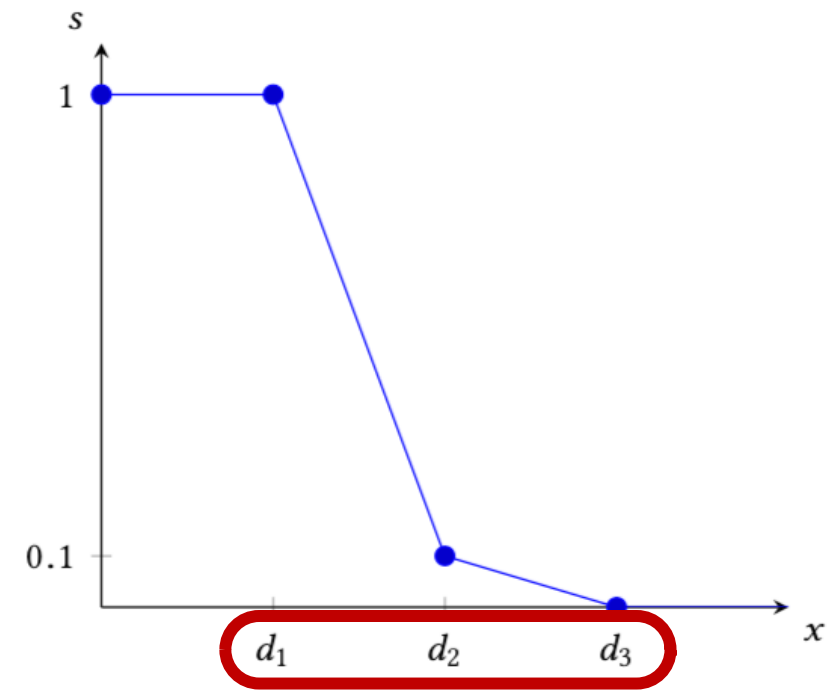
Define amenities

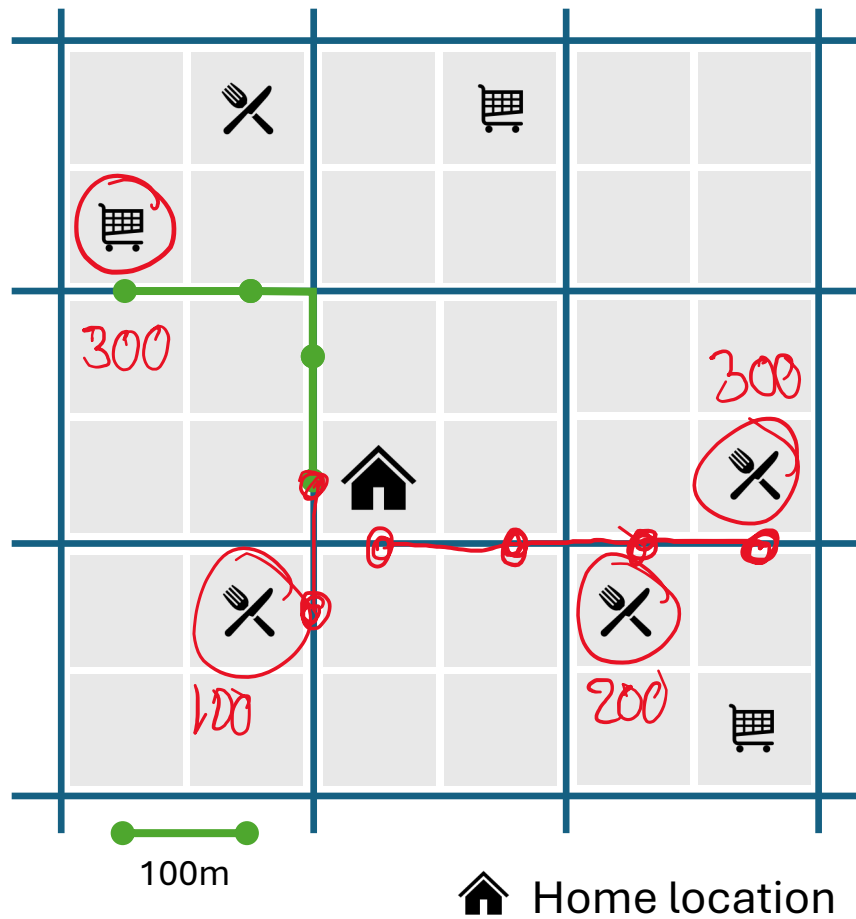
Amenity	Weight
Grocery	[3]
Restaurants	[.75, .45, .25, .25, .225, .225, .225, .2, .2]
Shopping	[.5, .45, .4, .35, .3]
Coffee	[1.25, .75]
Banks	[1]
Parks	[1]
Schools	[1]
Books	[1]
Entertainment	[1]

Measure distances



Assign scores





Amenity (a)

Weight vector (w_a)

Grocery store	[3]
Restaurant	[2 1 0.5]

Distance function:

$$s(d) = \max\left(0, 1 - \left(\frac{d}{400}\right)^2\right)$$



Sum of weighted scores:

$$\sum_{a=1}^2 w_a \cdot s_a = [3] \cdot \left[1 - \left(\frac{300}{400}\right)^2\right] + \begin{bmatrix} 2 \\ 1 \\ 0.5 \end{bmatrix} \cdot \begin{bmatrix} 1 - \left(\frac{100}{400}\right)^2 \\ 1 - \left(\frac{2}{4}\right)^2 \\ 1 - \left(\frac{3}{4}\right)^2 \end{bmatrix}$$

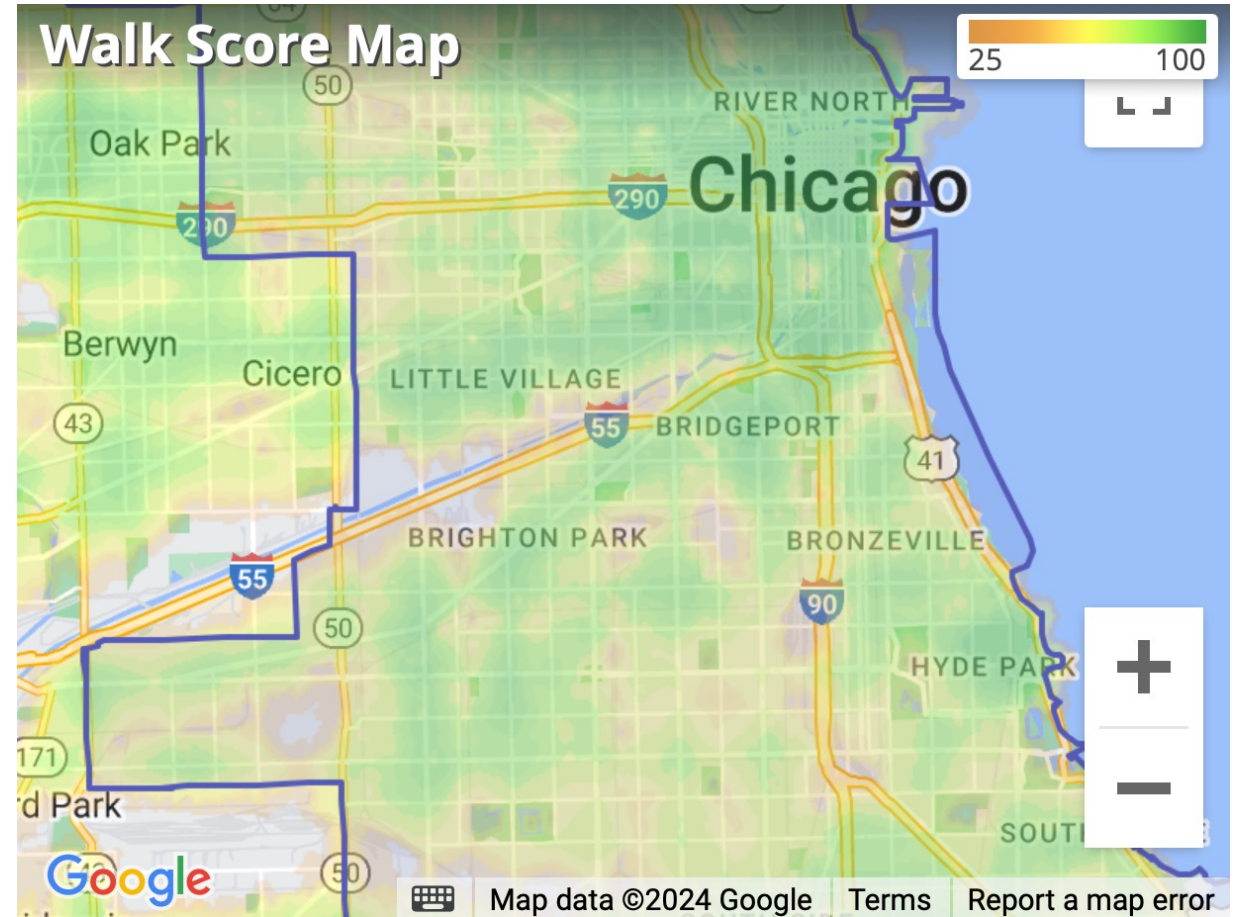
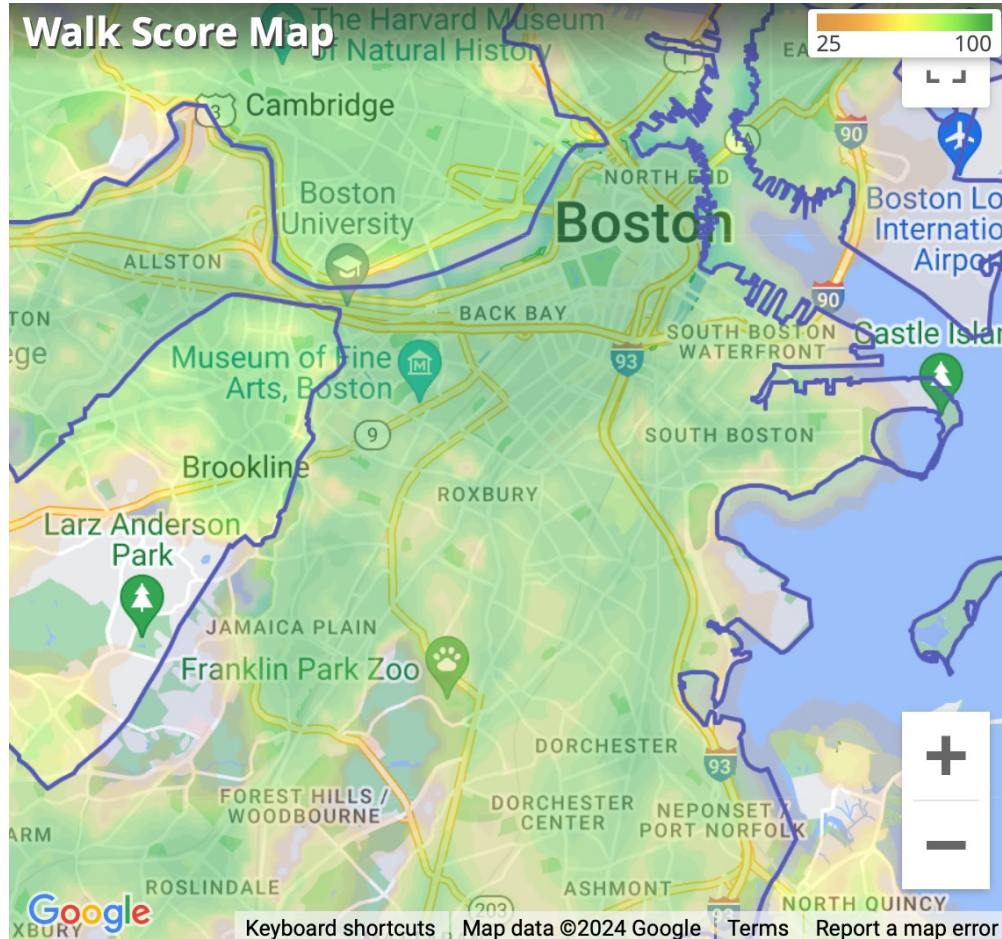
Normalization:

$$\frac{1}{\sum_{a=1}^2 \|w_a\|} = \frac{1}{3 + (2 + 1 + 0.5)} = \frac{1}{6.5}$$

Walk score:

$$\frac{4.16}{6.5} \cdot 100 = \textcircled{64}$$

WalkScore.com



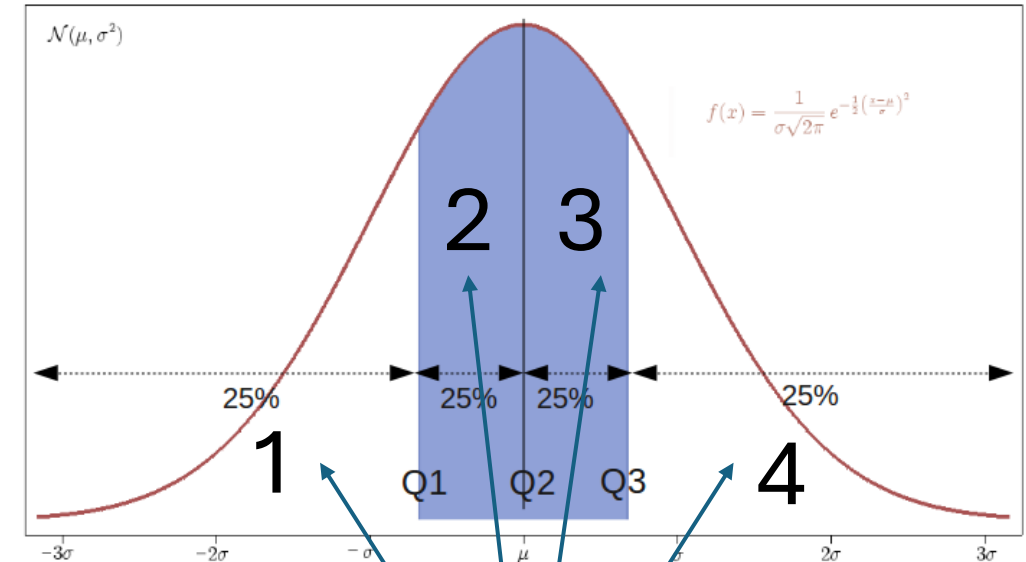
Smart Location Database National Walkability Index

- Calculates a walkability score for each neighborhood as an average of:
 - Intersection density
 - Diversity of land uses
 - Proximity to transit stops
- Each neighborhood is defined as a “Census Block Group,” an area of land with between 500 and 3,000 residents



Smart Location Database National Walkability Index (NWI)

- Four variables:
 - **Intersection density:** number of walkable intersections divided by land area
 - **Proximity to transit stops:** distance from population-weighted center of CBG to nearest transit stop
 - **Entropy of households and commercial jobs** (households, retail, office, industrial, service, entertainment)
 - **Entropy of households and all jobs** (previous categories plus education, healthcare, and public administration)
- Each CBG is ordered for each variable and assigned a **quantile rank** (20 quantiles)



Quantile rank

Each quantile has the same number of data

Why “entropy”?

- Entropy in thermodynamics measures the state of disorder, randomness, or uncertainty
- Entropy in information theory (**Shannon’s entropy**) measures how many different types of something there are in a dataset:
 - Higher entropy: more equal number of each type (households, jobs in different categories)

$$H = -\frac{1}{N} \sum_{i=1}^N \frac{p_i}{P} \ln \left(\frac{p_i}{P} \right)$$

where N is total number of household or job categories, p_i is the number of entities within category i , and P is the total number of entities across all categories

- What happens if one category dominates?
 - Scenario 1: $0.99 \cdot \ln(0.99) + 0.01 \cdot \ln(0.01)$
 - Scenario 2: $0.5 \cdot \ln(0.5) + 0.5 \cdot \ln(0.5)$

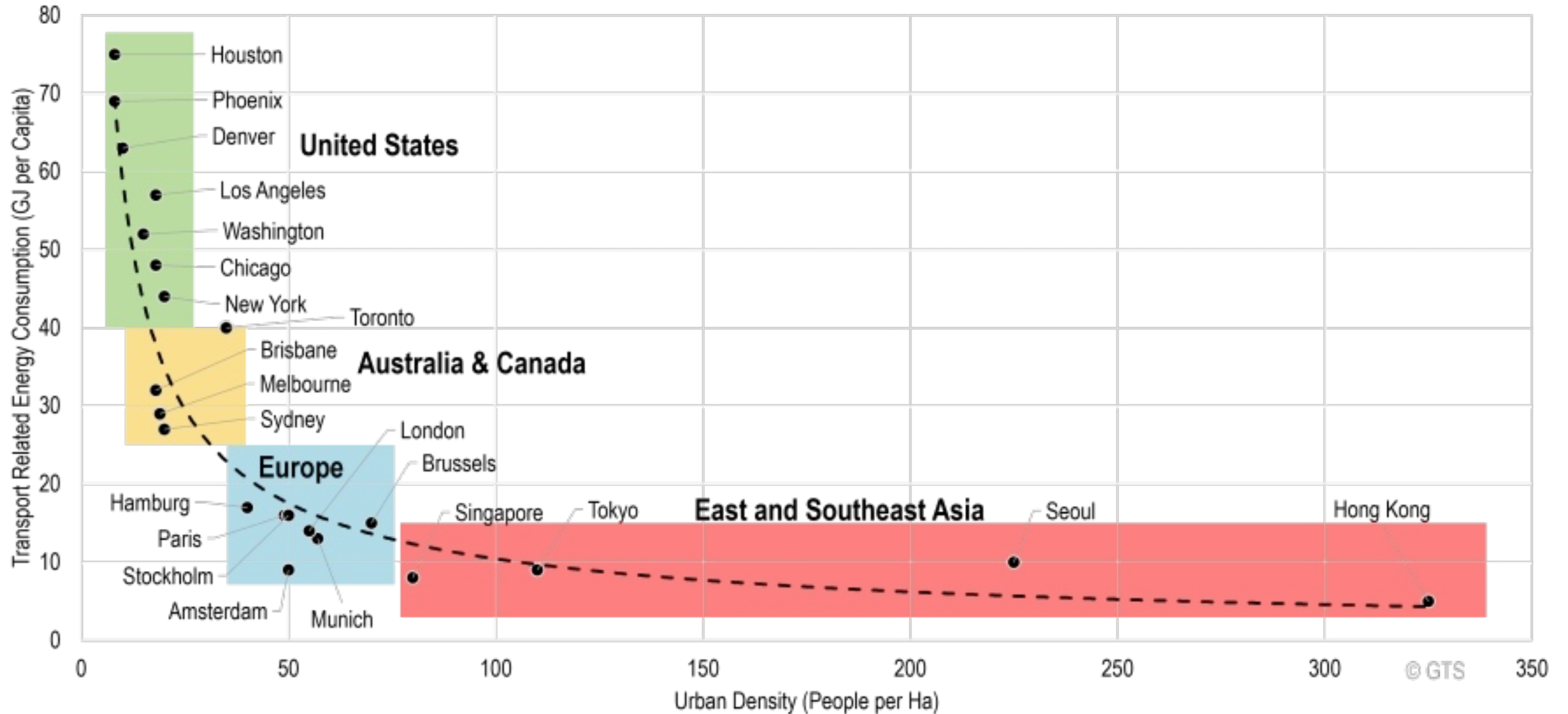
Smart Location Database National Walkability Index (NWI)

$$NWI = \frac{w}{3} + \frac{x}{3} + \frac{y}{6} + \frac{z}{6}$$

- w: quantile rank of intersection density (1-20)
- x: quantile rank of proximity to transit (1-20)
- y: quantile rank of household+commercial entropy (1-20)
- z: quantile rank of household+all entropy (1-20)



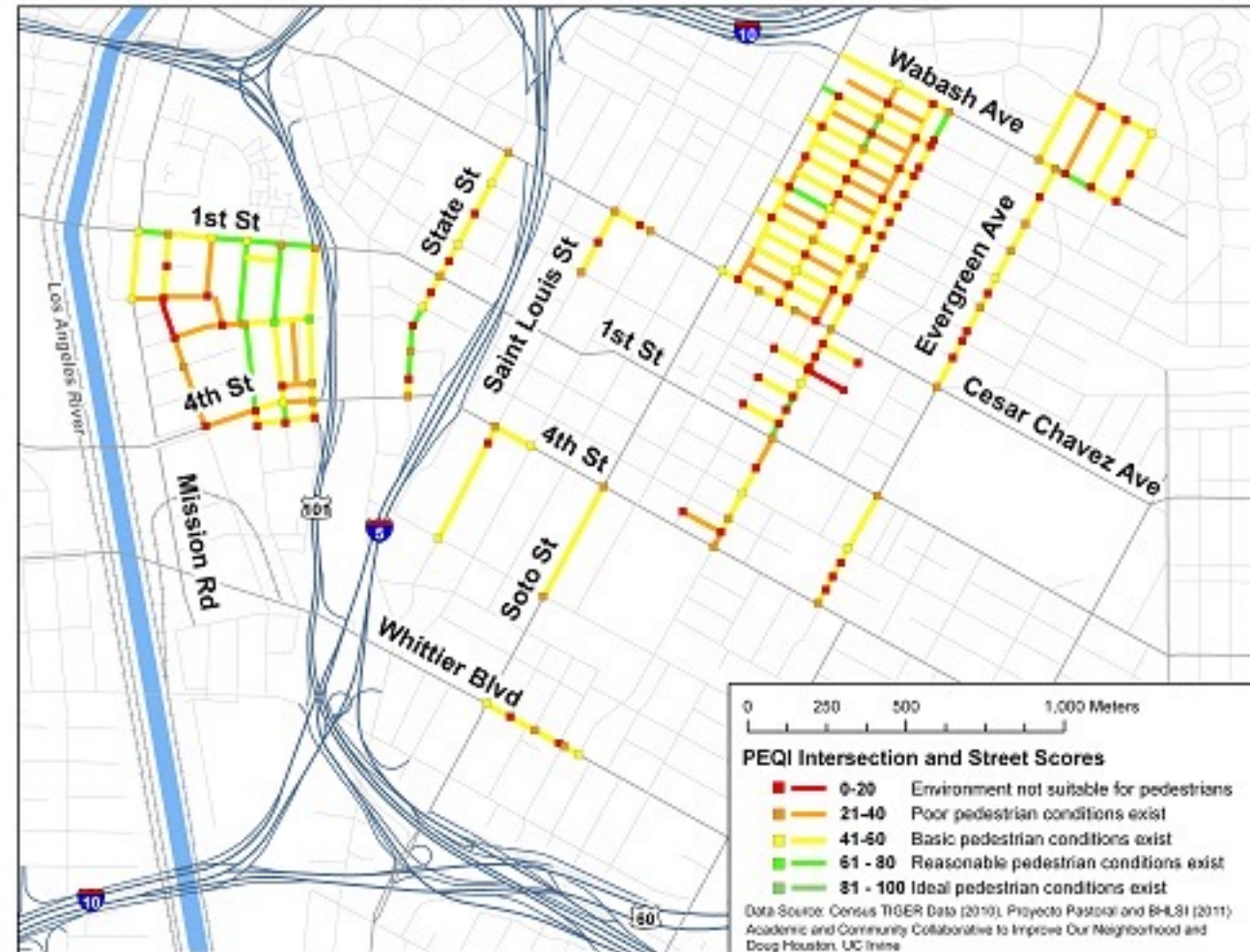
Energy benefits of density



What do Walkscore and NWI measure?

- These metrics focus on accessibility
- Researchers have developed indicators to measure other aspects of walkability

INTERSECTION	STREET SEGMENT			
Intersection Safety	Traffic	Street Design	Land Use	Perceived Safety
Crosswalk	Number of lanes	Sidewalk width	Storefronts/retail use	Illegal graffiti
Ladder crosswalk	Two-way traffic	Sidewalk impediments	Public art/historical sites	Litter
Pedestrian signal	Vehicle speed limit	Sidewalk obstructions		Pedestrian scale lighting
Traffic signal	Traffic volume	Presence of curb		Construction sites
Crossing speed	Traffic calming features	Driveway cuts		Abandoned buildings
Crosswalk scramble		Trees		
No turn on red signs		Planters/gardens		
Traffic calming features		Public seating		
Additional signs for pedestrians		Presence of buffer		



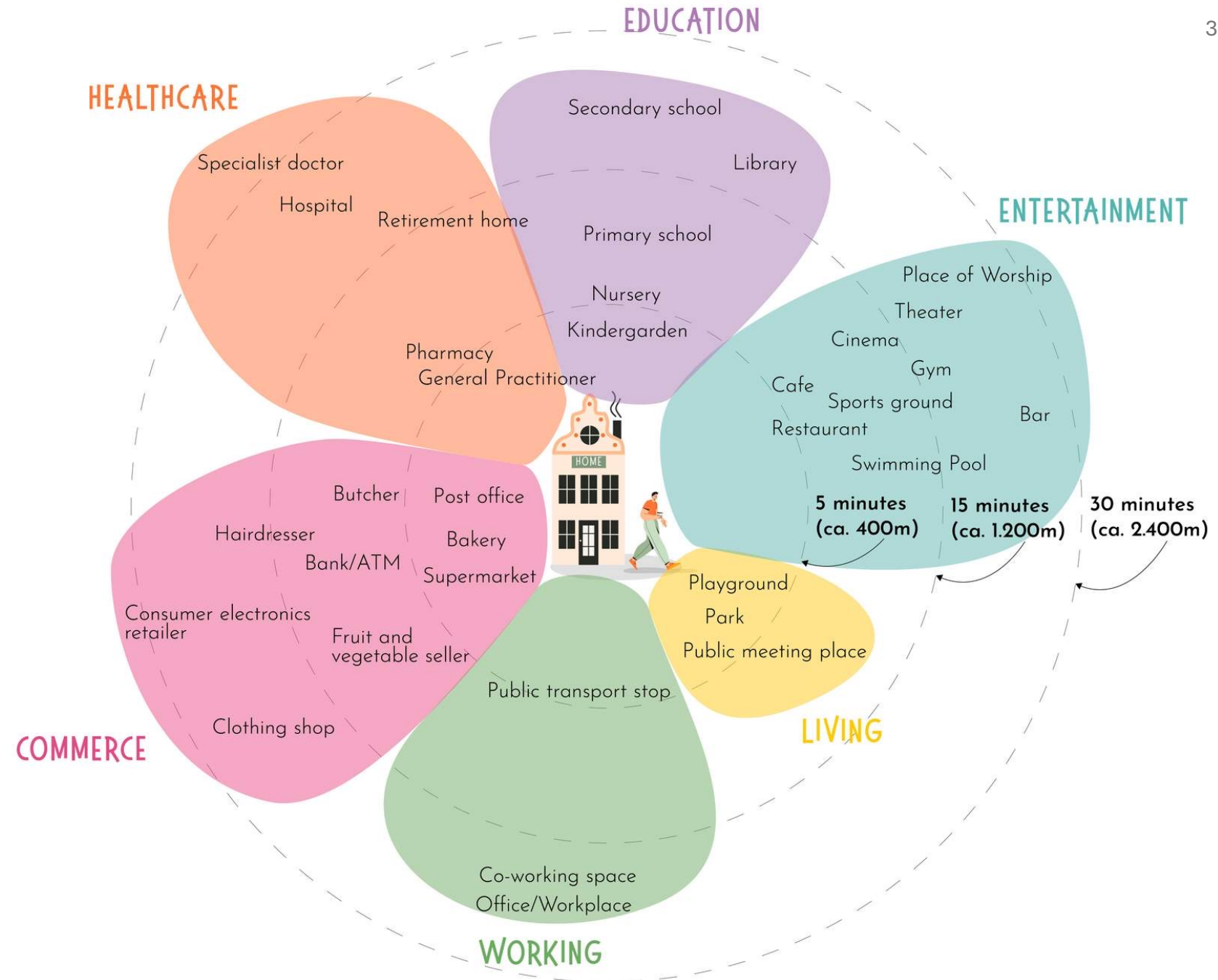
15-min city

- Proposed by Carlos Moreno
- Four key characteristics
- **Proximity:** Things must be close to each other
- **Diversity:** Land uses must be mixed
- **Density:** There must be enough people to support a diversity of businesses in a compact land area
- **Digitalization:** Digital tools enable data collection, smarter operation of systems, and citizen participation



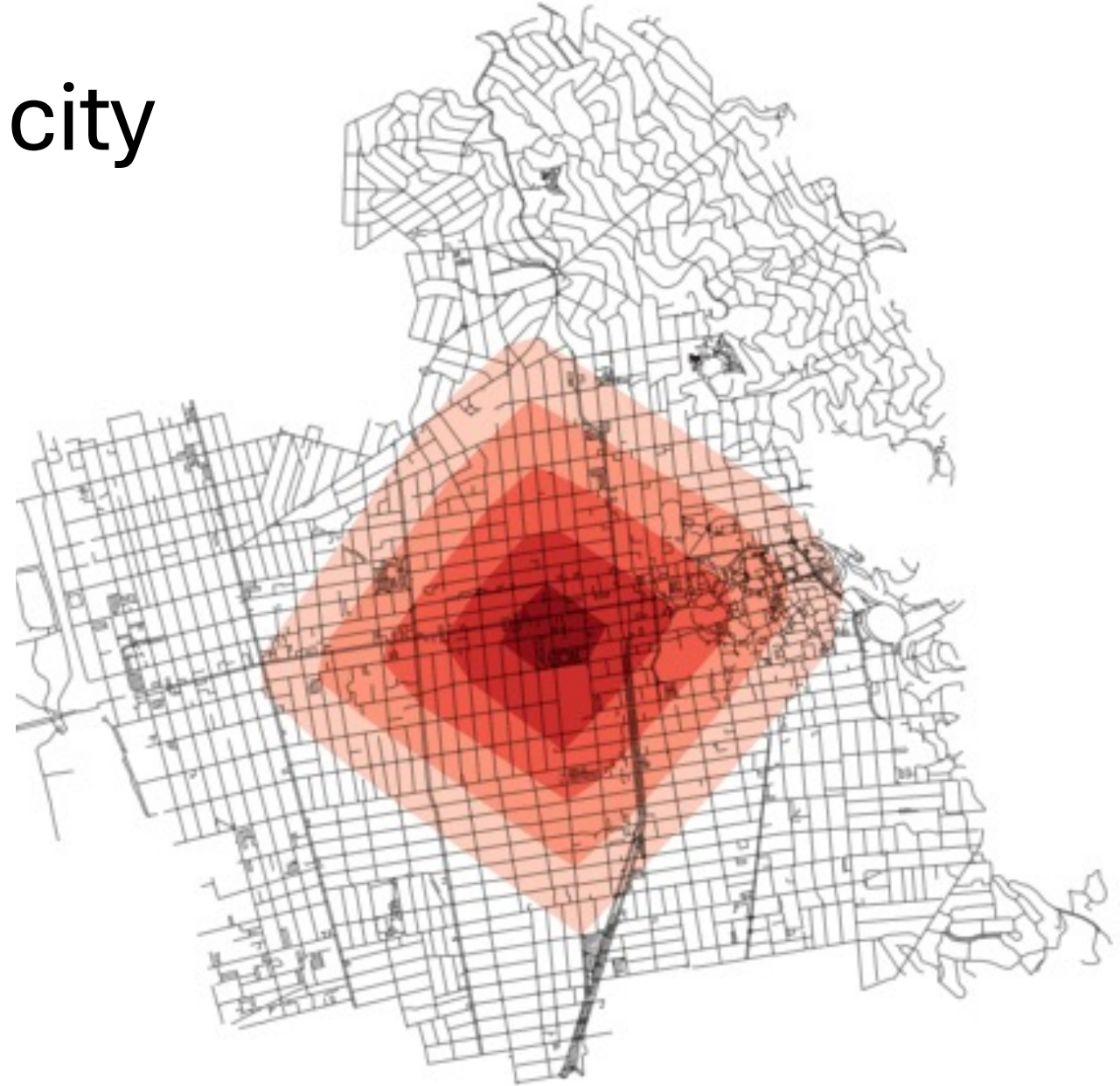
15-min city

- “15-min” is arbitrary
- Needs vary for amenities within a particular type
- Example: Kindergartens vs universities

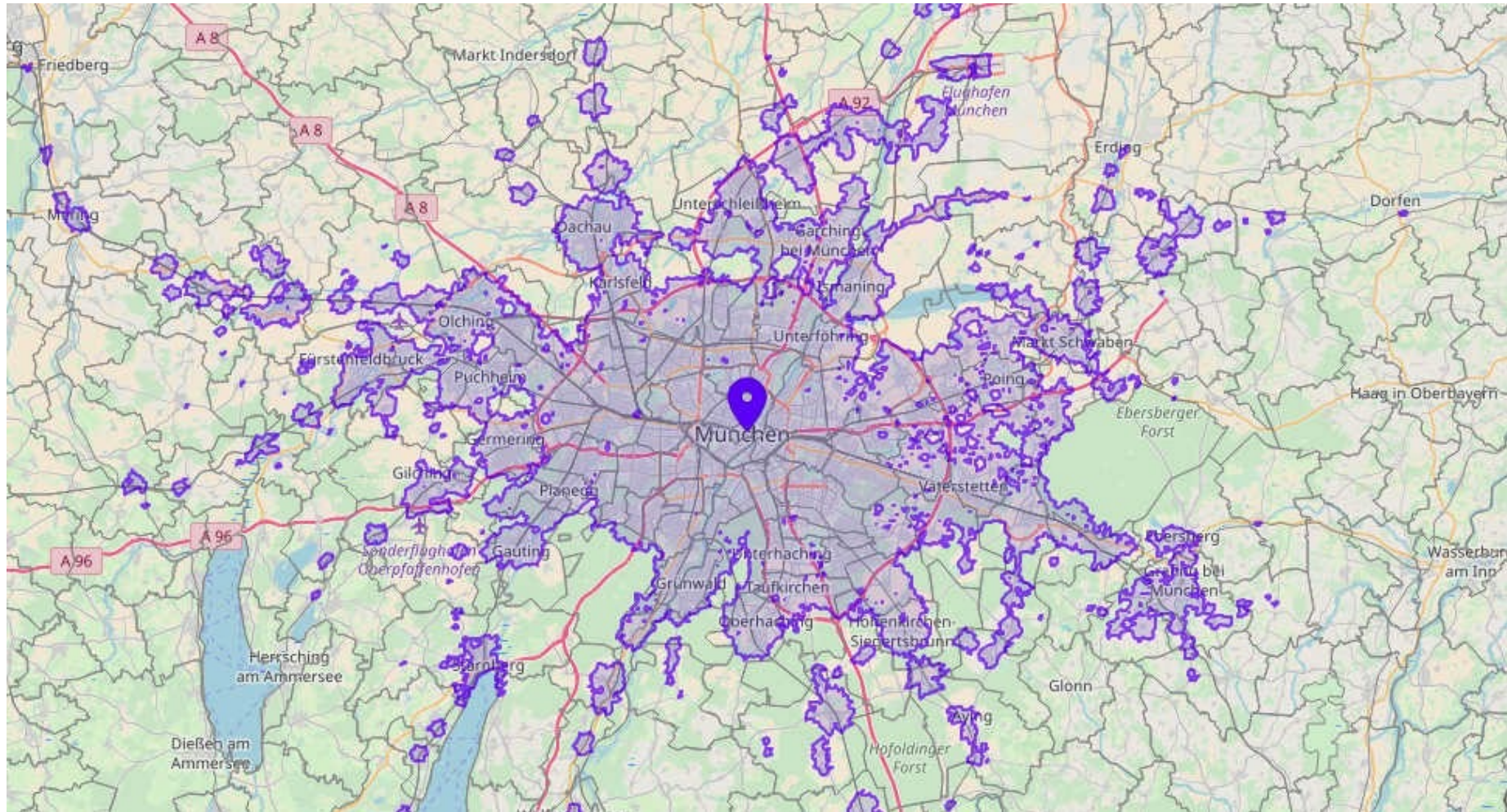


Measuring the 15-min city

- Isochrones tell you what is contained within a trip by a particular mode for a specific time
- Iso: equal
- Chrono: time
- The figure to the right shows 5, 10, 15, 20, and 25-min walks in Berkeley, CA, USA

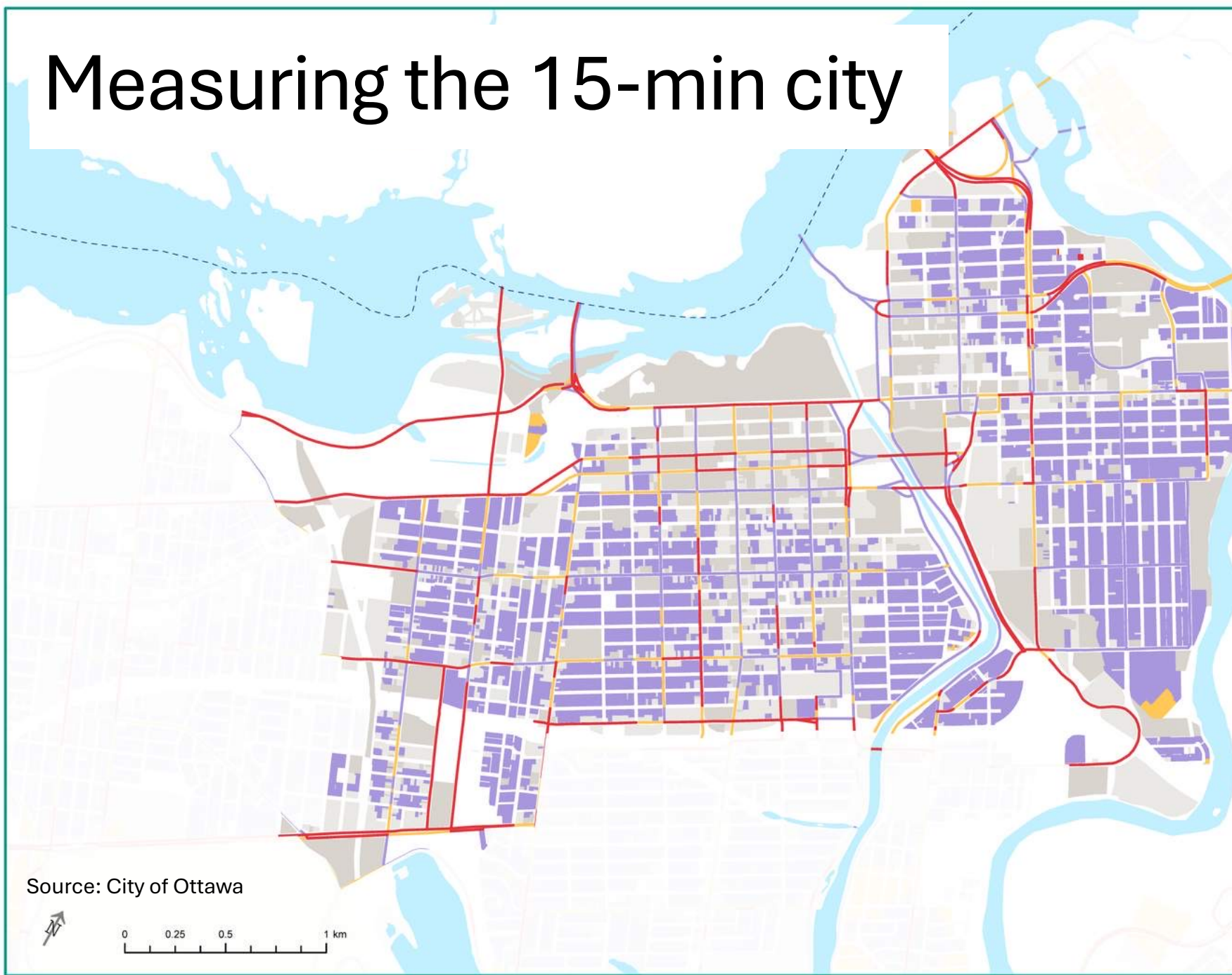


Public transport isochrones



Measuring the 15-min city

The quality of the paths themselves can be a barrier to walking (or cycling)



Access to Services and Amenities

- High
- Moderate
- Low
- N/A

Non-Residential Parcel with Service or Amenity

Pedestrian Environment Score

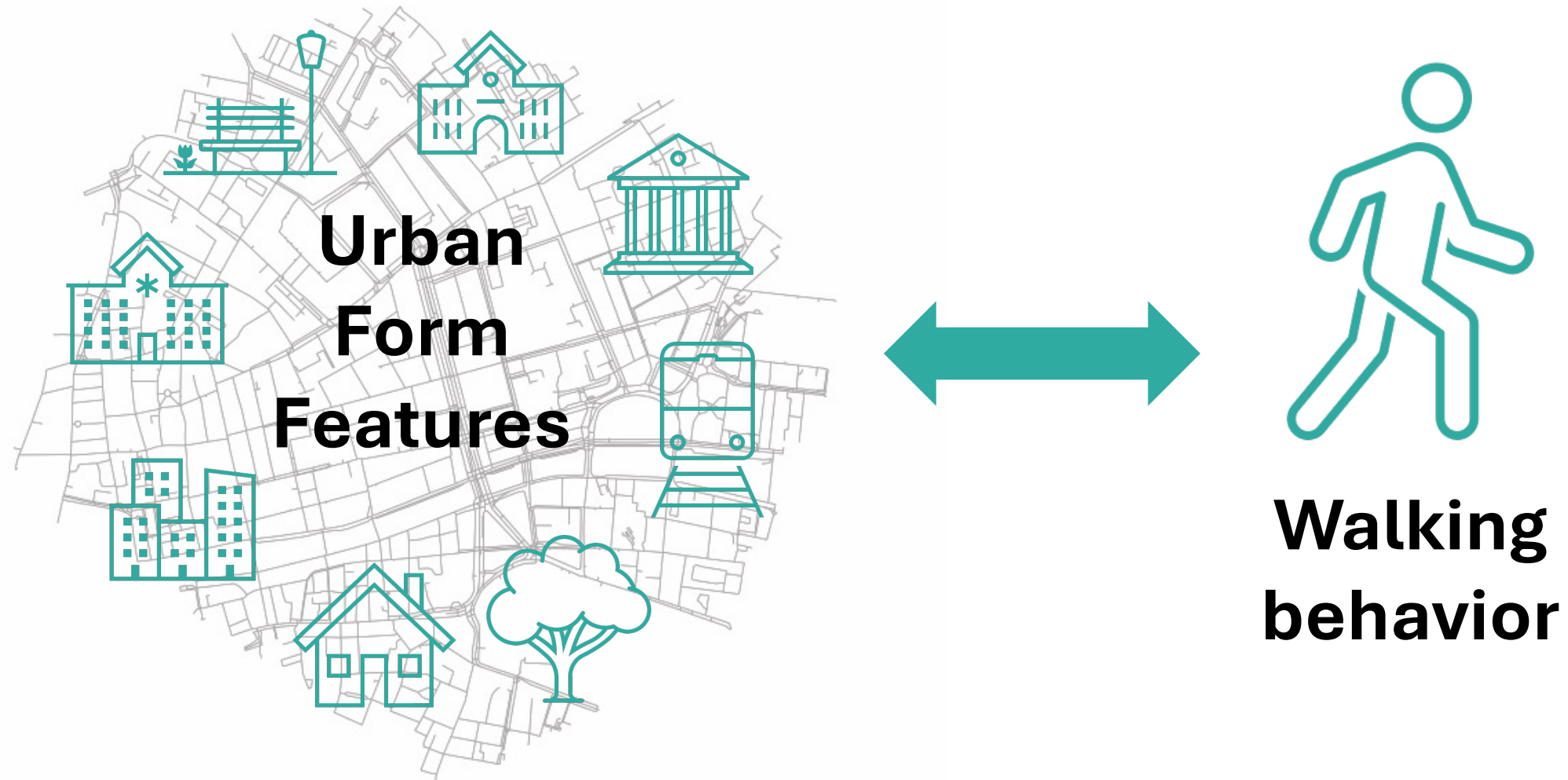
- High
- Moderate
- Low

Urban Boundary (Official Plan)

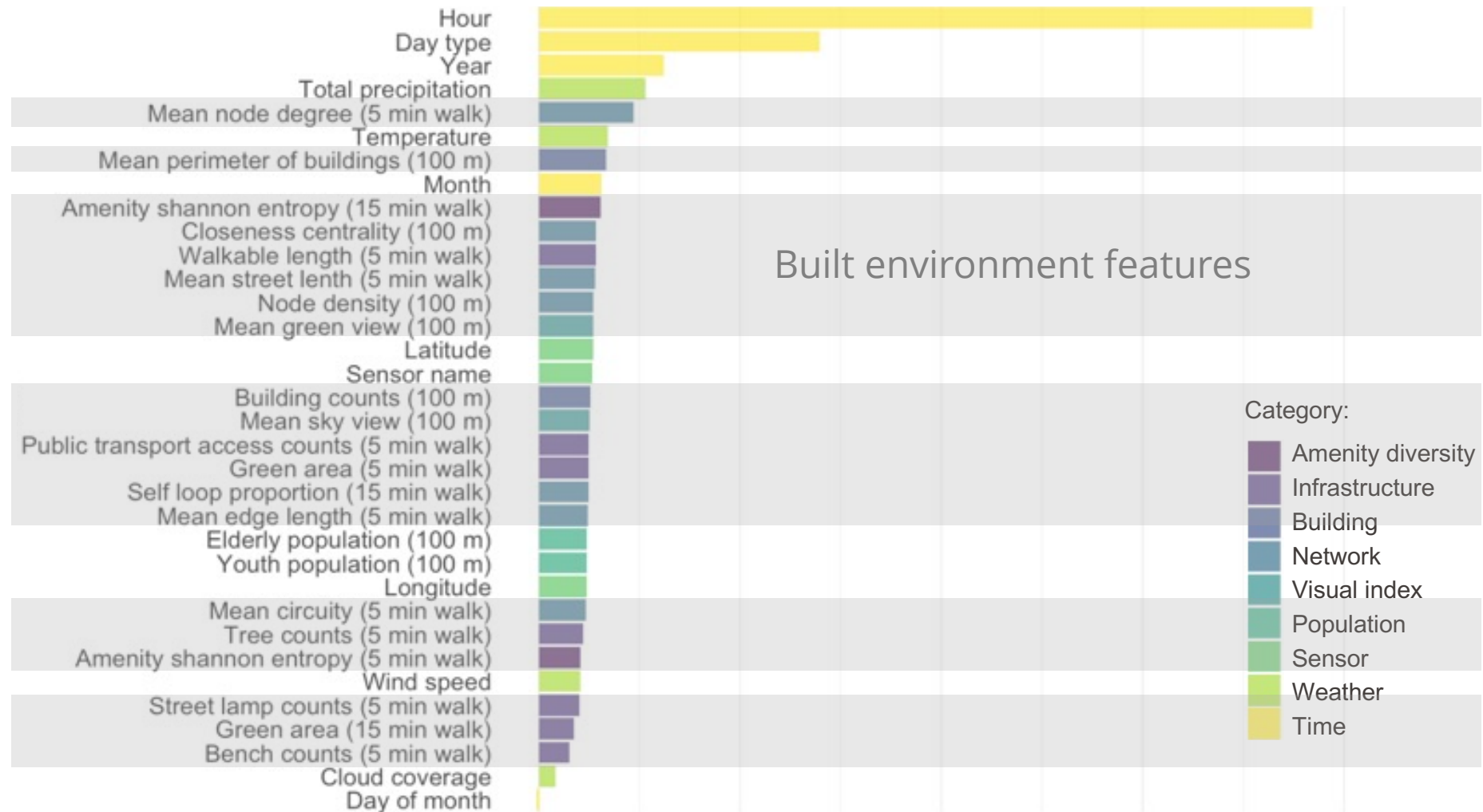
Experimental Farm

Water

Research on walkability at ETHOS

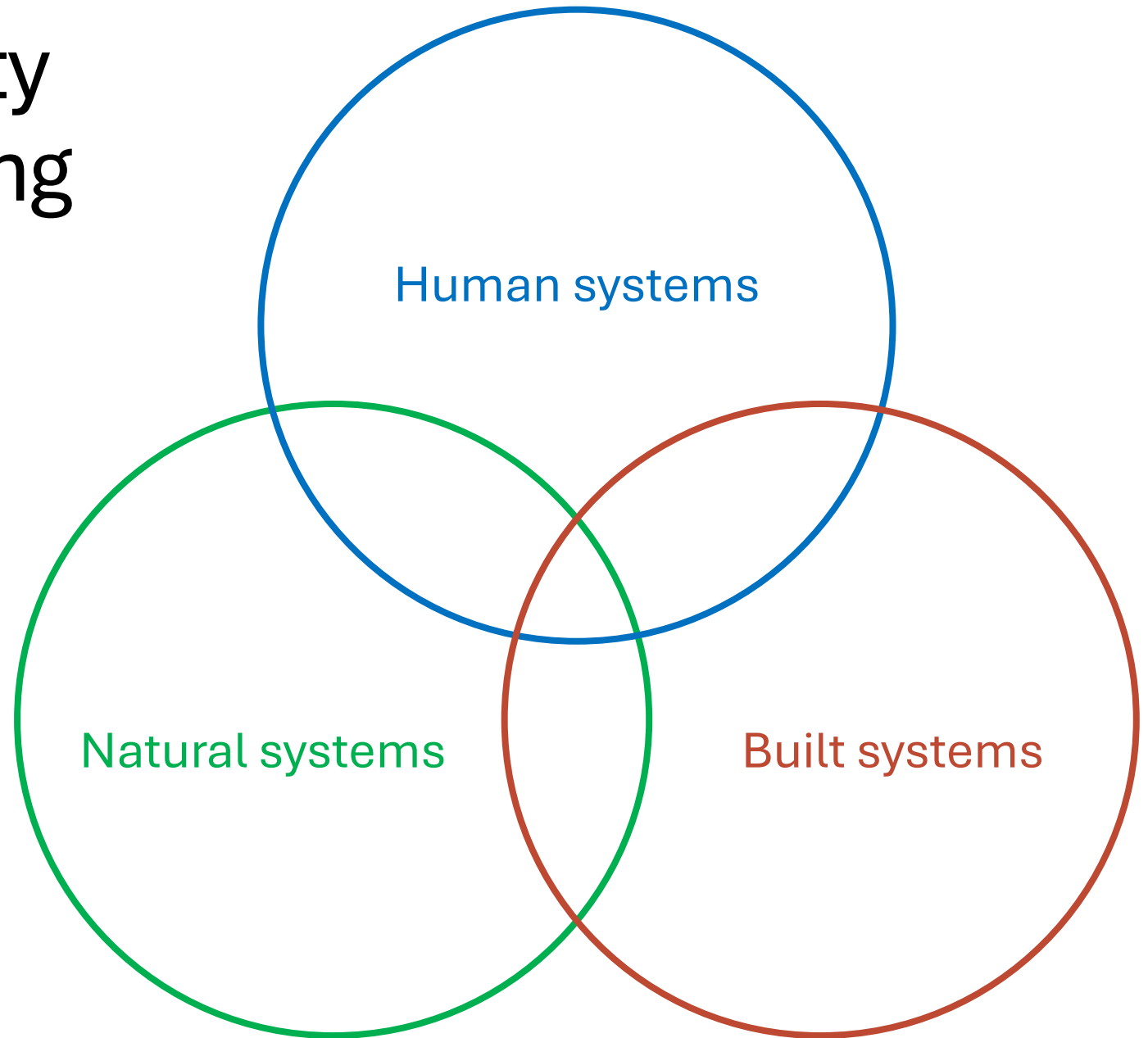


Feature importance (from machine learning)



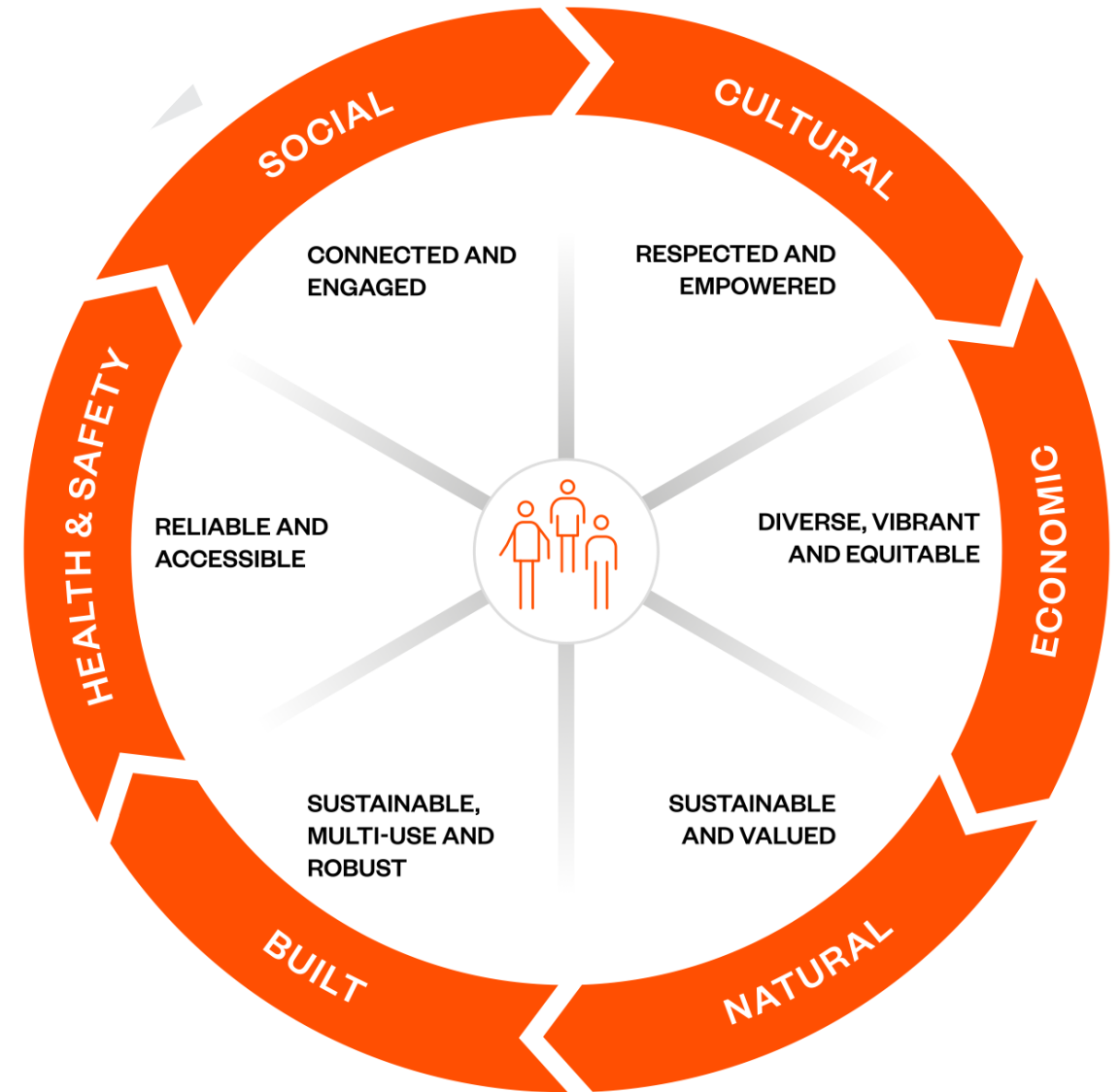
Sustainable mobility and systems thinking

- Complex transportation systems involve relationships between human, natural, and built systems
- Example: sustainability mobility and social resilience

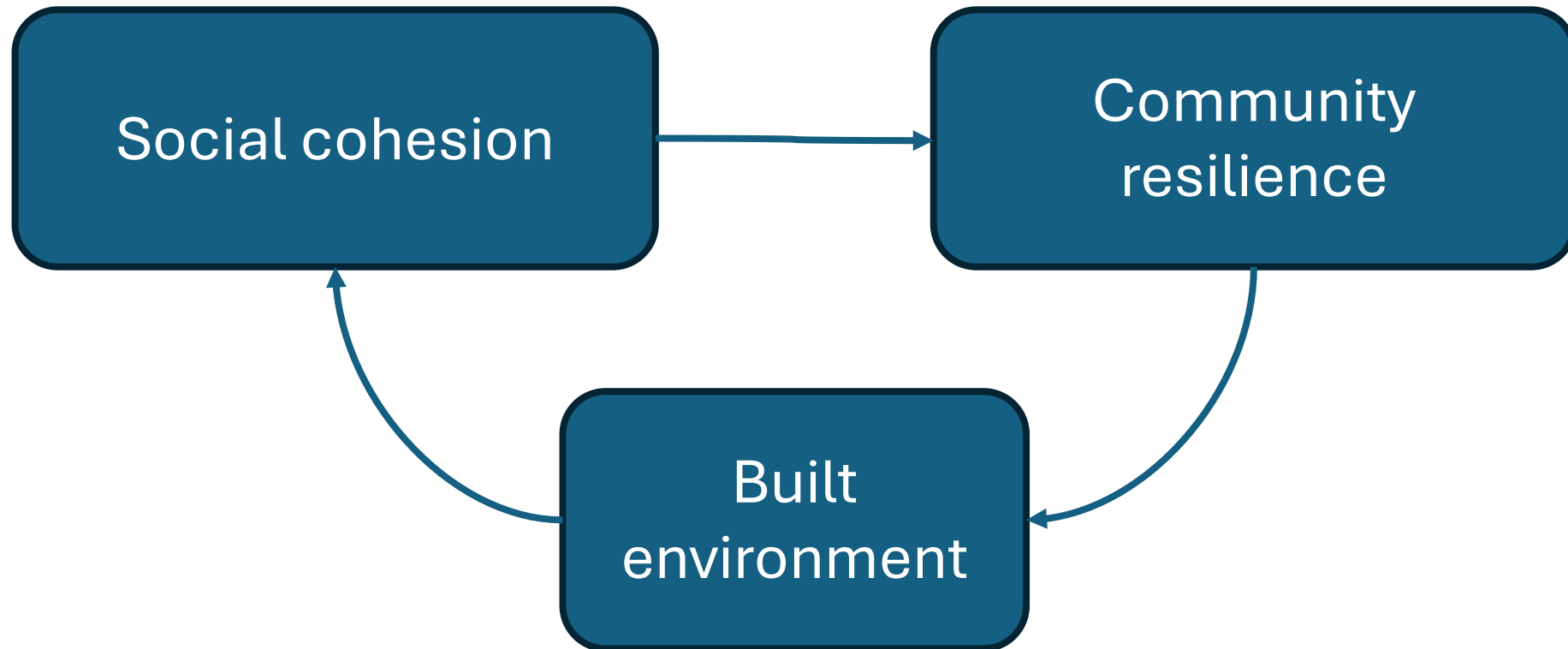


Resilient communities

“Strong social systems within a community – those that promote high levels of **social cohesion**, integration and trust – are among the most important determinants of how well a community will perform in the face of disasters.”



Resilience example: social cohesion

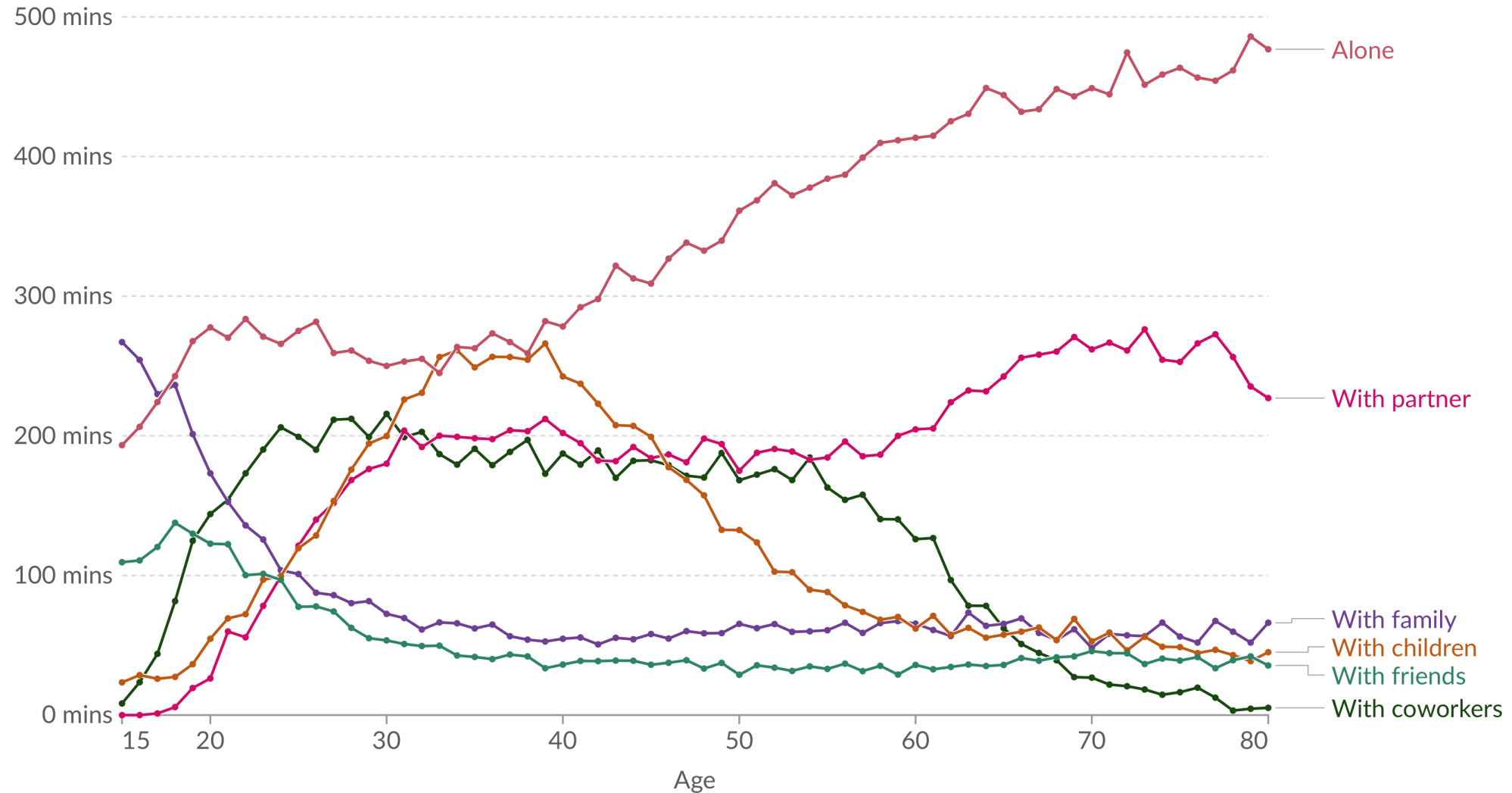


Transportation, urban planning, and cohesion

- Option A
 - Live in a single-family home outside the city. Drive from your home to your workplace. After work, drive from your home to the nearest supermarket to buy groceries, then drive home.
- Option B
 - Live in a multi-family residential building in a neighborhood of the city. Walk 2 blocks to the nearest public transport stop for commute to work. After work, take public transport home. Stop at market and bakery on the walk home.
- In which transportation and urban planning situation would you have an easier time getting to know your neighbors?

Who Americans spend their time with, by age

Measured in minutes per day, based on averages from surveys in the United States between 2009 and 2019.



Data source: American Time Use Survey (2009-2019) and Lindberg (2017)

OurWorldinData.org/time-use | CC BY

Note: Relationships used to categorize people are not exhaustive. Additionally, time spent with multiple people can be counted more than once (e.g., attending a party with friends and partner counts toward both "friends" and "partner").

Transportation, urban planning, and cohesion

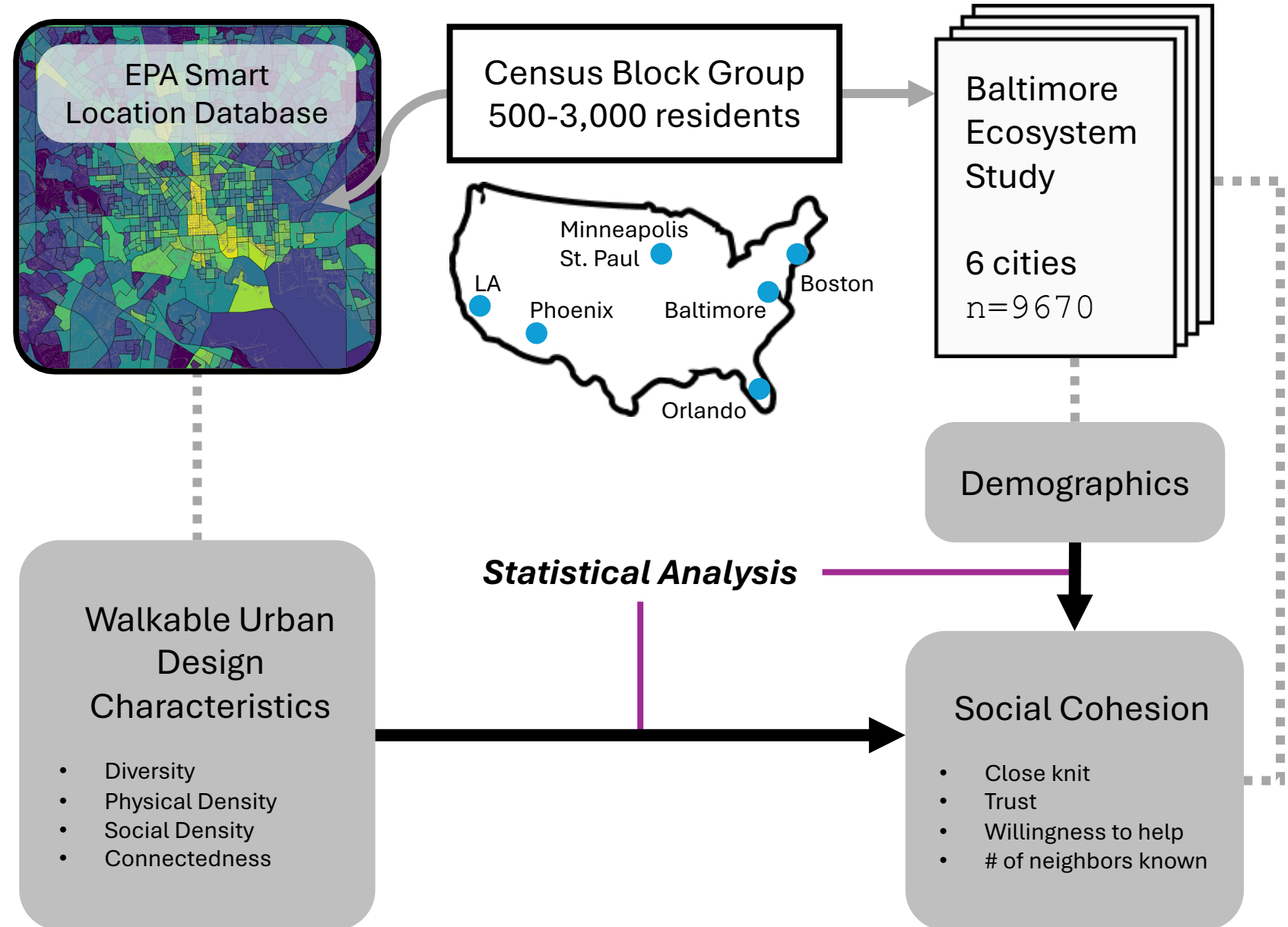
- Proponents of the 15-min city, “New Urbanism,” and walkable cities have argued that active mobility results in:
 - stronger social bonds
 - tighter social networks
 - more social cohesion
- Some scholars have warned that highly dense places are overwhelming to city dwellers
- What does the data say?



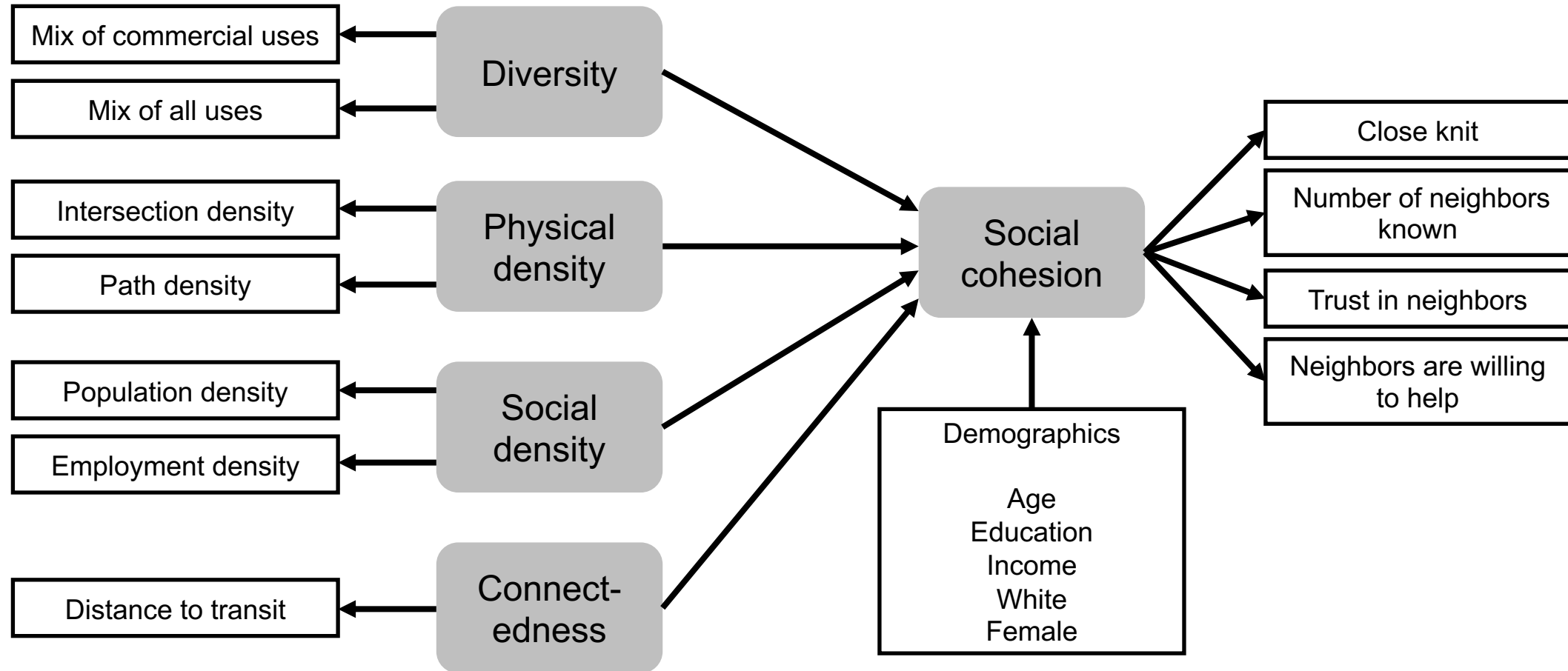
Jane Jacobs, author of “The Death and Life of Great American Cities” Source: Wikimedia Commons

Research example

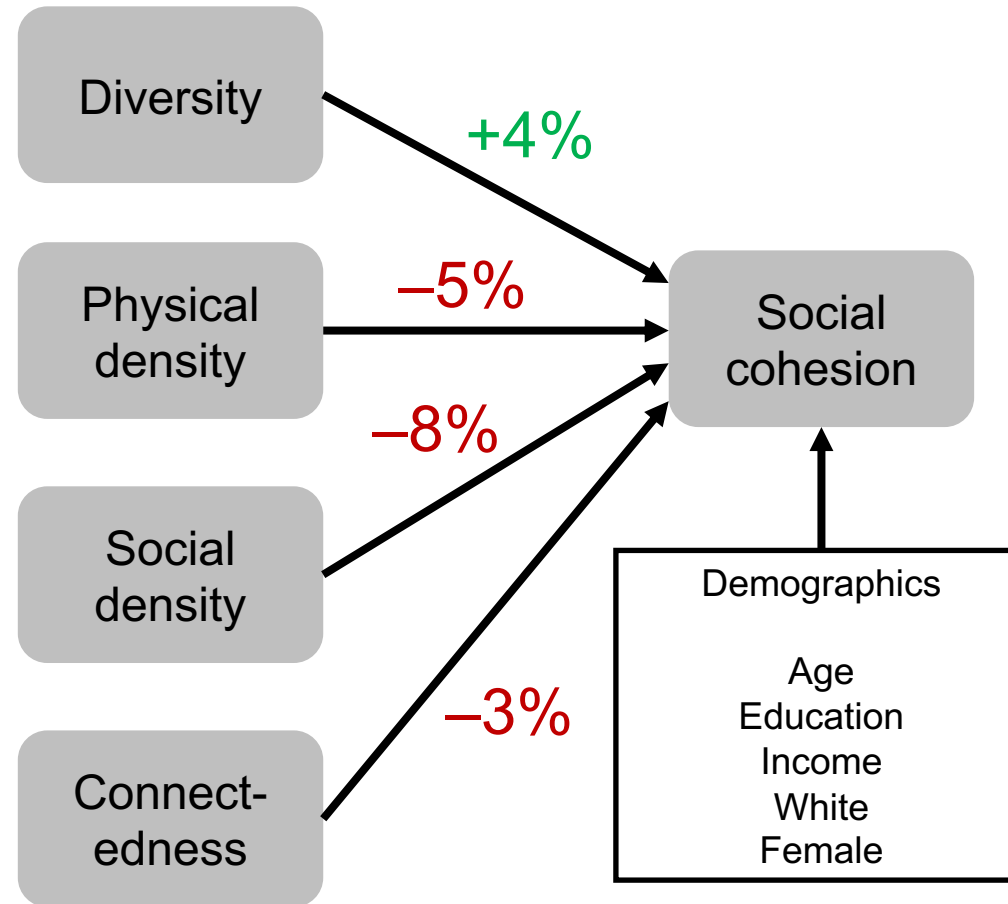
Does walkable design impact social cohesion?



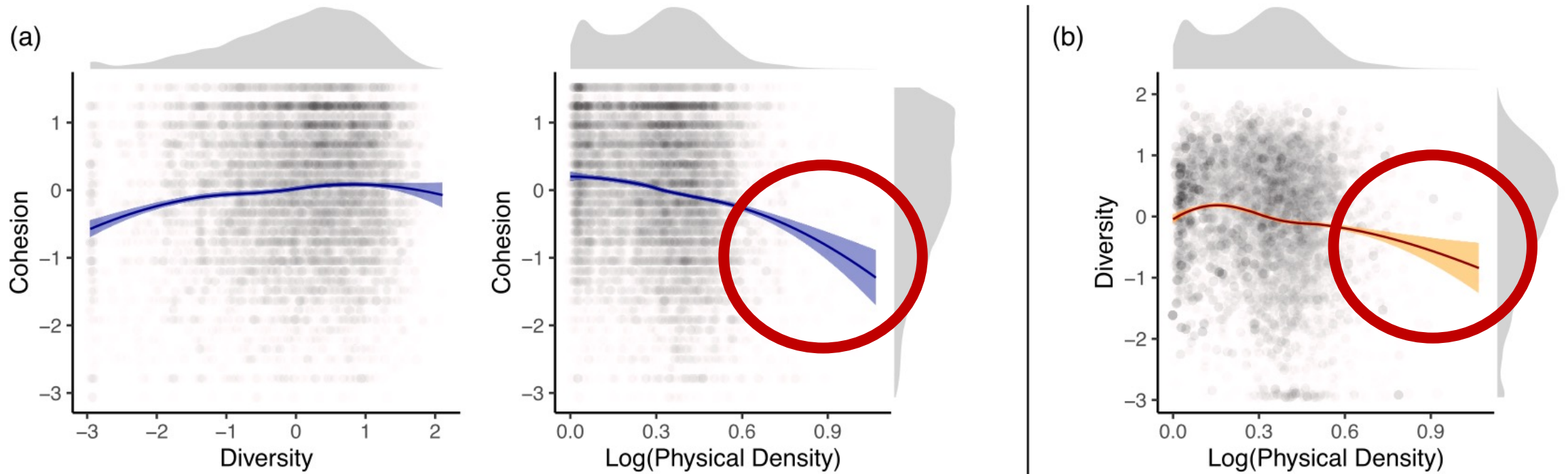
Modeling



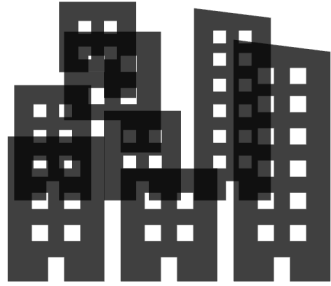
Results



Results



Takeaways



Density

Higher density associated with less cohesion

vs.



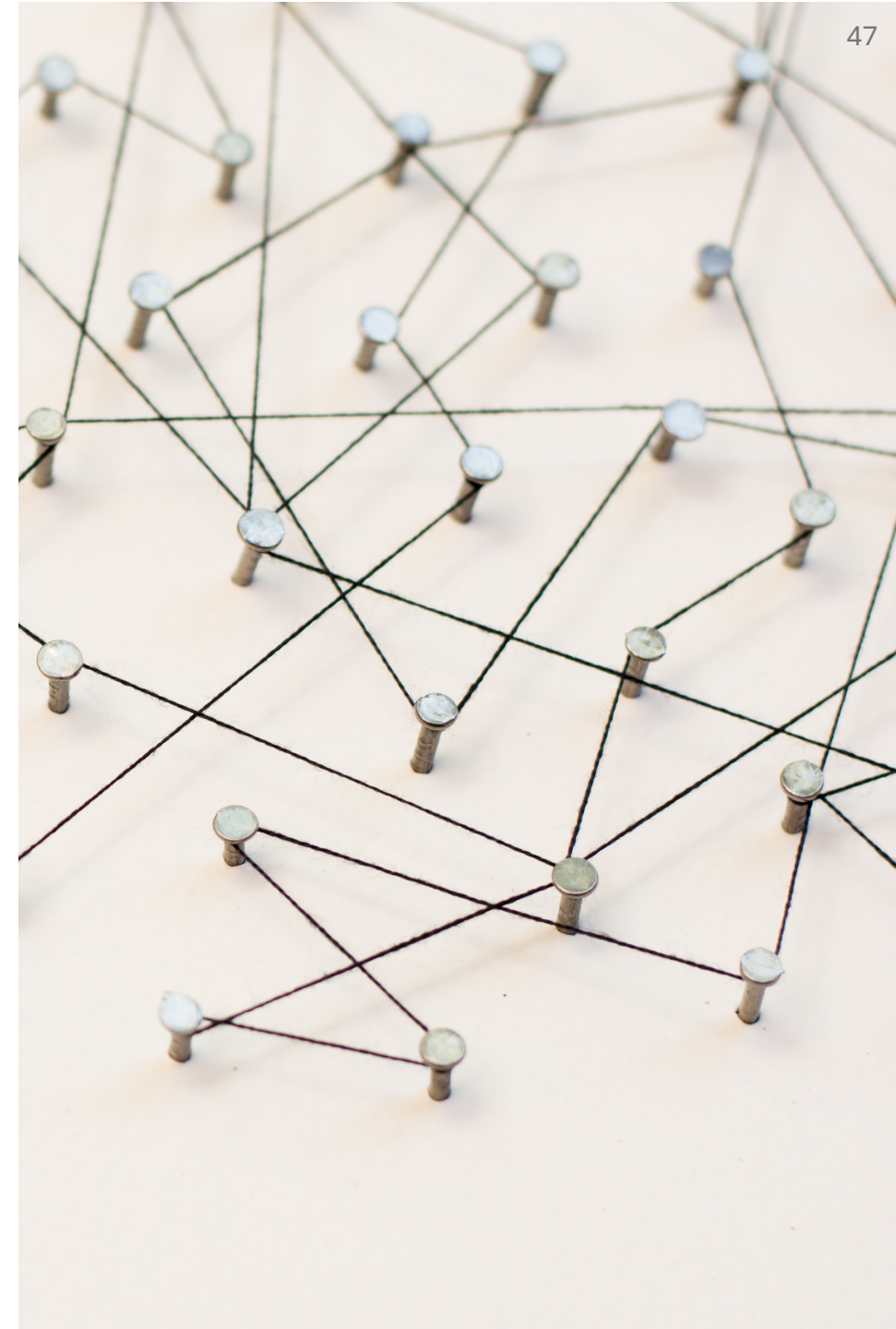
Diversity

Higher diversity (mix of use) associated with more cohesion

➤ Adds nuance to discussion on how we can improve our cities

Sustainable mobility

- Mobility systems are complex
- Transportation impacts many systems including energy, environment, social, economic, and health
- Understanding (and continuing to study) the complex nature of links between systems can create holistically people-centered cities
- Systems thinking (including causal loop diagrams) is a tool to make sense of this complexity




15-min city backlash

- In 2023, conspiracy theories about the 15-min city emerged
- These described the model as an instrument of government oppression
 - Confining people to particular parts of the city by limiting mobility
- The 15-min city concept claims no limitation of movement and aims to make mobility easier

He Wanted to Unclog Cities. Now He's 'Public Enemy No. 1.'

Researchers like Carlos Moreno, the professor behind a popular urban planning concept, are struggling with conspiracy theories and death threats.

 Share full article



Review of concepts from lecture

Lecture 01: introduction and the climate crisis

- Drivers of the climate crisis
- CO₂ and other greenhouse gas emissions
- Trends in energy, CO₂ emissions, and global temperatures
- Economic growth and CO₂ emissions
- Territorial vs. consumption-based emissions
- Climate change impacts
- Definitions of sustainability
- Motivations for addressing sustainability in civil engineering

Lecture 02: Sustainability indicators

- Foundational measures: GDP
- Sufficiency
- Human Development Index
 - Construction of index
- Health: HDI approach, DALYs
- Education
- Inequality: Gini coefficient
- Biodiversity
- Ecological footprint

Lecture 03: Energy demand and buildings

- Energy units, unit conversions
- Building electricity consumption
- Heating and cooling fundamentals
- Heat transfer
- Heat pumps and COP
- Active vs. passive heating and cooling

Lecture 04: Energy supply

- Energy supply definitions
- Levelized cost of electricity and discounting
- Wind energy
- Solar energy
- Hydropower
- Energy storage
- Matching electricity supply and demand

Lecture 05: Transportation

- Transportation energy sources
- Vehicle fuel efficiency and electric vehicles
- The transportation system
- Systems thinking
- Causal loop diagrams

Lecture 06: Sustainability mobility

- Feedback loops
- System archetypes
- Active mobility
- Walkability metrics
- Link between active mobility and social systems