A Spatio-Temporal Betweenness Centrality Measure for the Micro-Scale Estimation of Pedestrian Traffic

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Context

Spatio-Temporal Analysis of Terrorism Vulnerability:
A Case Study of Central Tokyo, Japan

A Dissertation Submitted to
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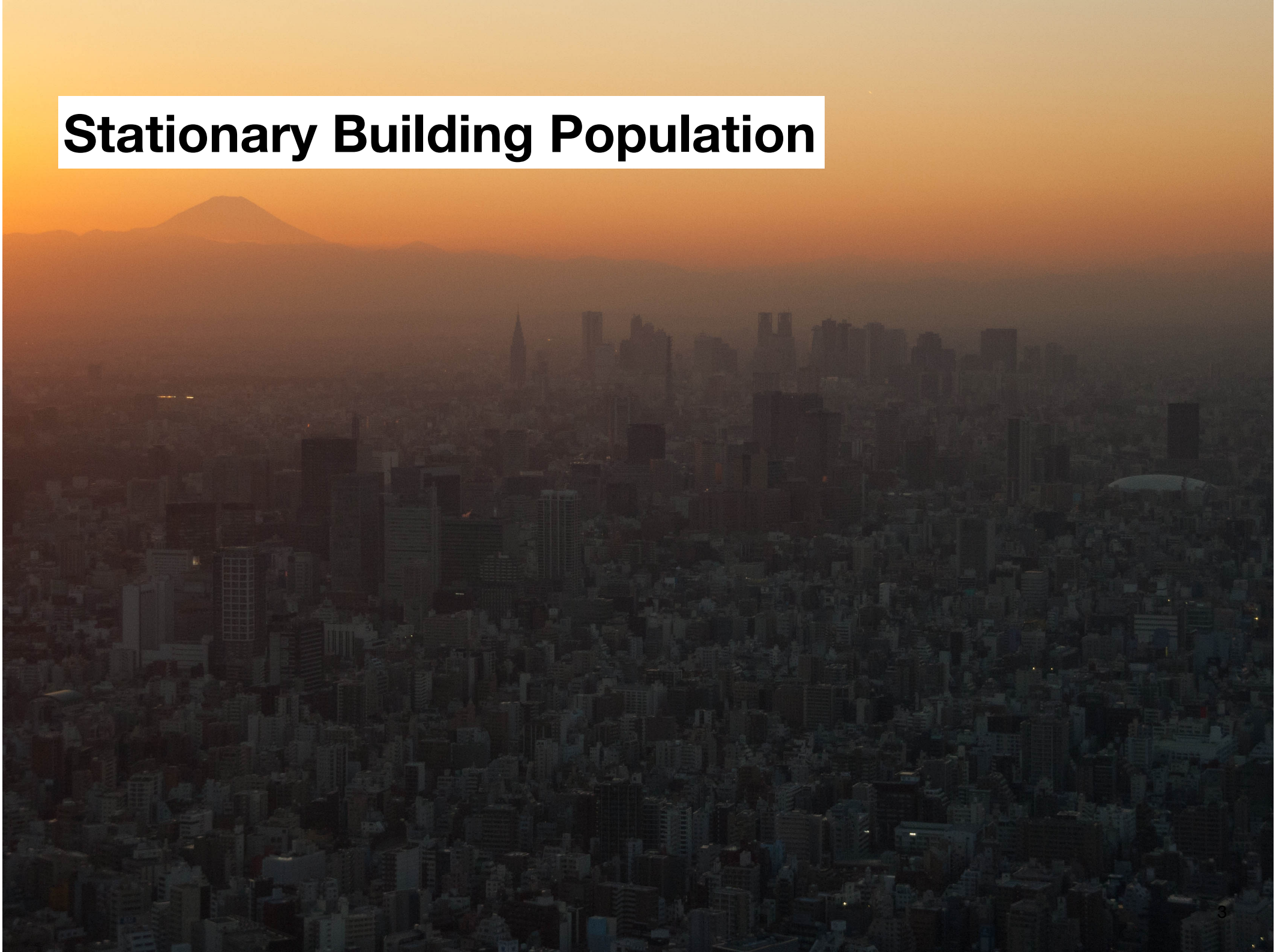
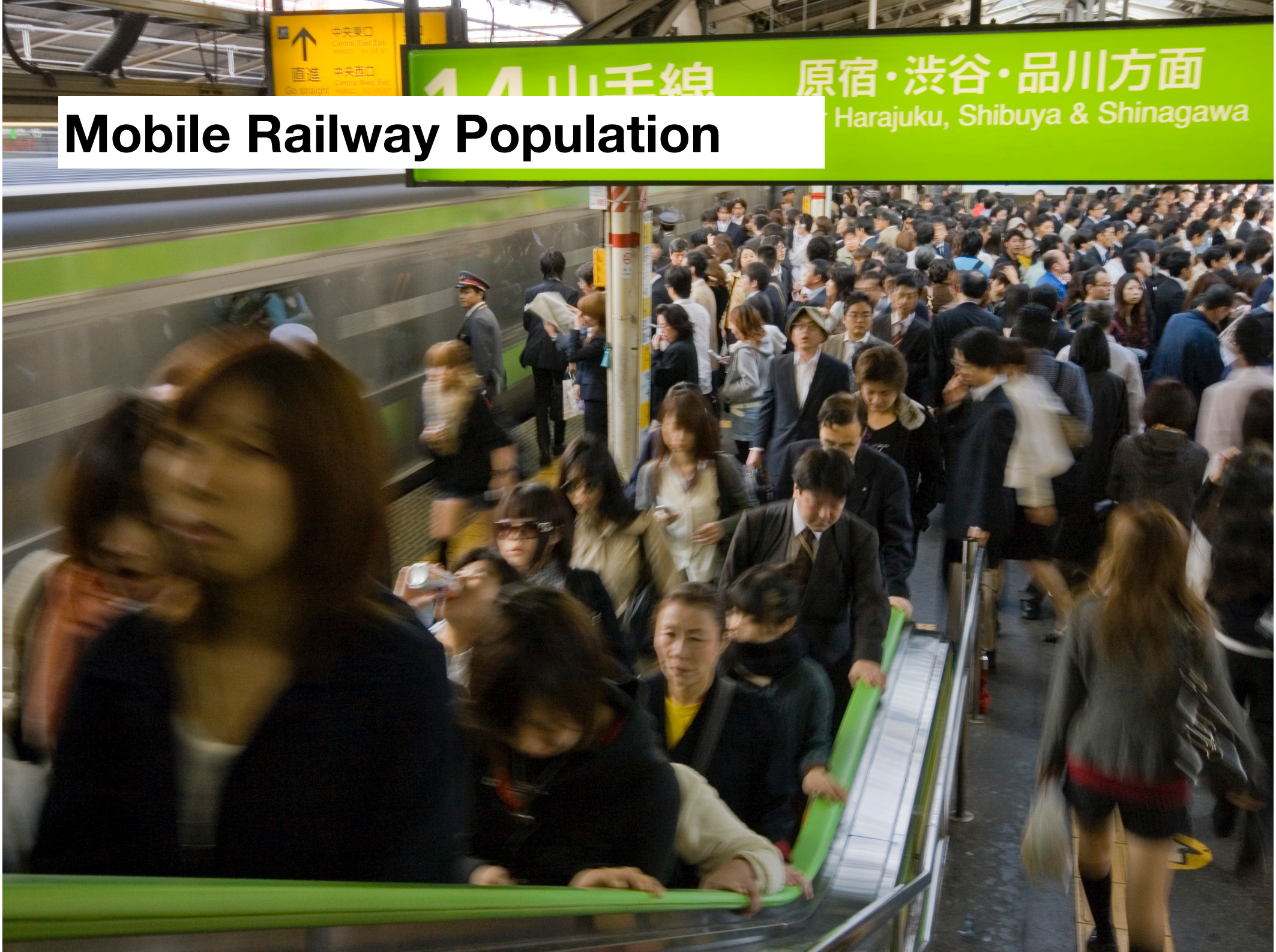
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy in Science
(Doctoral Program in Geoenvironmental Sciences)

Konstantin GREGER

Stationary Building Population



Mobile Railway Population



Mobile Pedestrian Population

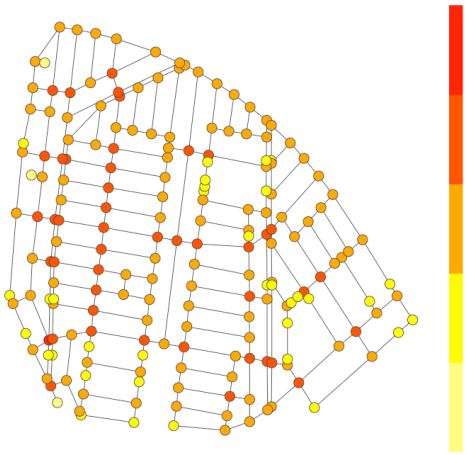
Photo: https://www.flickr.com/photos/simonippon/5779763300 (cropped)

Part 1:
Spatial Graph Centrality Analysis

Graph Centrality Measures

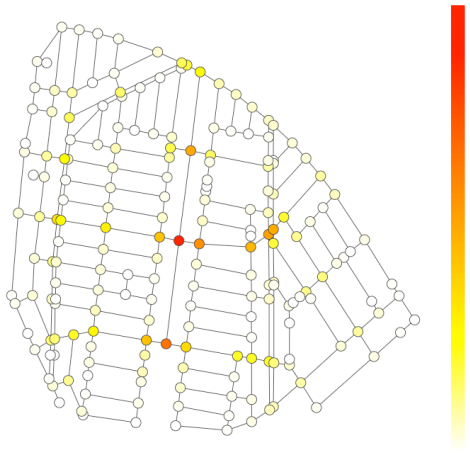
Degree centrality

$$C_D(v)=deg(v)$$



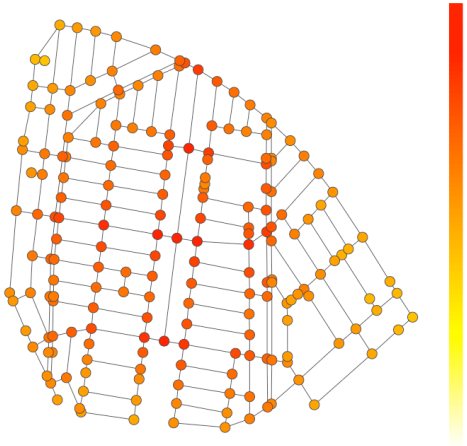
Betweenness centrality

$$C_B(v)=\sum_{s\neq v\neq t\in V}\frac{\sigma_{st}(v)}{\sigma_{st}}$$



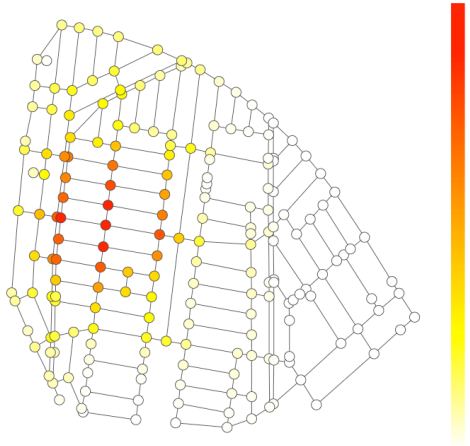
Closeness centrality

$$C_C(v)=\sum_{t\in V\setminus v}2^{-d_G(v,t)}$$



Eigenvector centrality

$$C_E(v)=\frac{1}{\lambda}\sum_{t\in G}a_{v,t}C_E(t)$$



Betweenness Centrality Measure

Number of shortest paths from all vertices to all other vertices that pass through that node

Originated in social network analysis (BAVELAS 1948; SABIDUSSI 1966; ANTHONISSE 1971; FREEMAN 1977, 1979)

Original implementations suffered from $\mathcal{O}(n^3)$

Improved algorithm by BRANDES (2001) reduced complexity to $\mathcal{O}(nm + n^2 \log n)$ and $\mathcal{O}(n+m)$

Does not account for topological and spatial impedance (e.g. distance, angularity, …)

Spatial Weighted Betweenness Centrality Measure

Implementation by Sevtsuk & Mekonnen (2012) in *Urban Network Analysis Toolbox* (for Esri ArcGIS)

Building on previous efforts in the area of spatial network analysis (Martin & March 1971; Hillier & Hanson 1984; Porta, Crucitti et al., 2005)

Allows vertices to be weighted according to particular characteristics (e.g. volume, population, importance)

Does not account for temporal differences in real-world applications

Spatio-Temporal Betweenness Centrality Measure

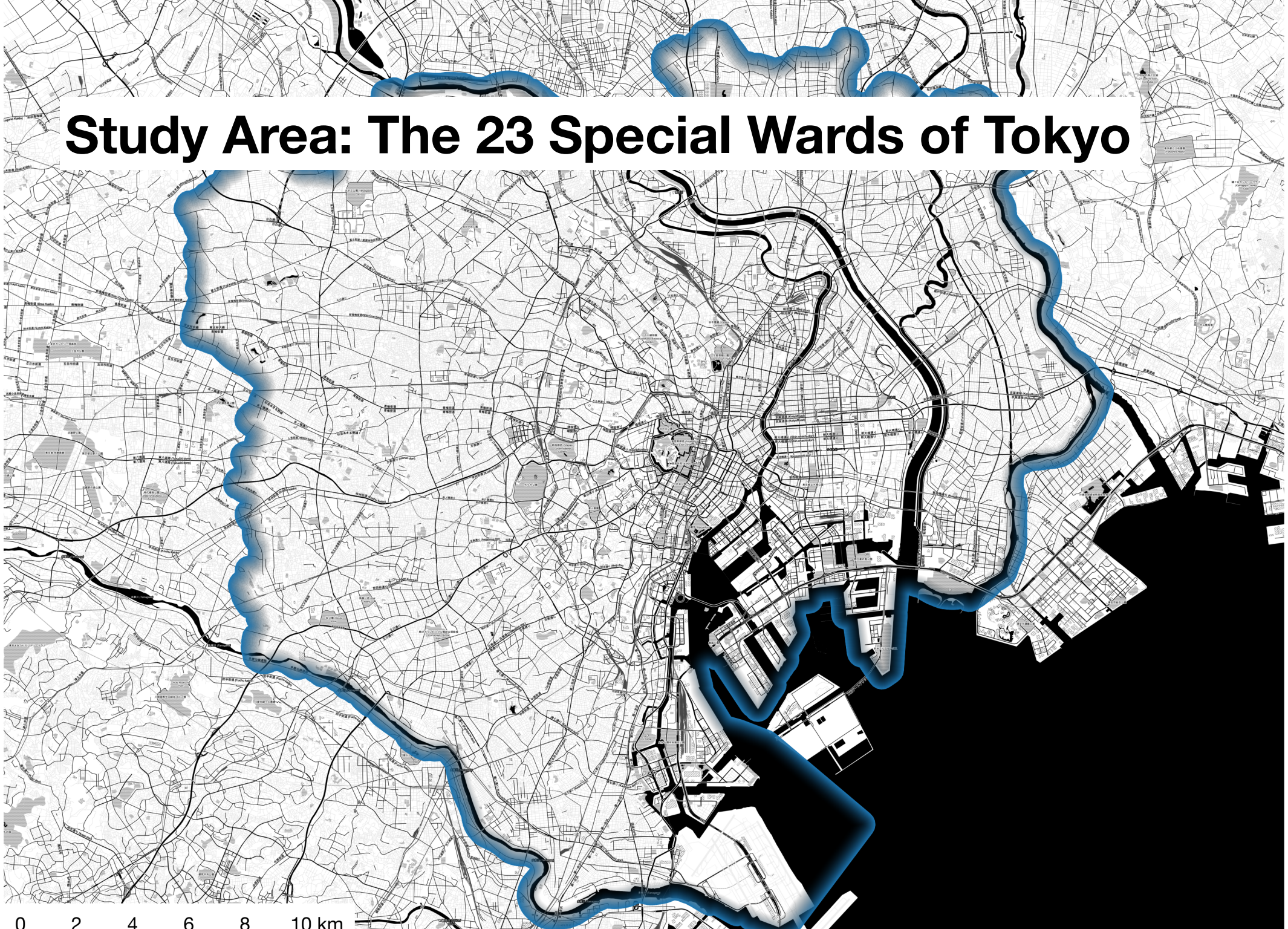
Introducing the spatio-temporal betweenness centrality measure as

$$C^{r}_{STB}(i,t) = \sum_{j \neq k \in \{G \setminus i | \delta_{jk} \leq r\}} \frac{\sigma_{jk}(i)}{\sigma_{jk}} \cdot w(j,t) \quad ,$$

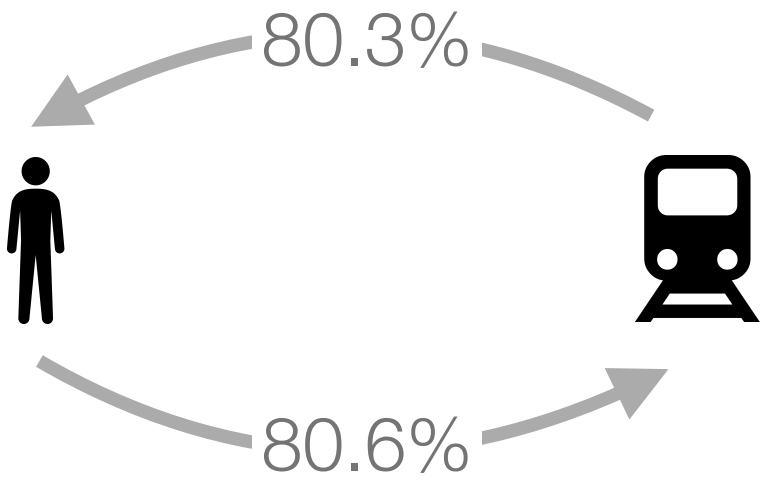
where $\sigma_{jk}(i)$ is the number of shortest paths between vertices j and k passing through vertex i, σ_{jk} is the total number of shortest paths between vertices j and k, $w_{j,t}$ is the weight of vertex j at time t, with network distance δ_{jk} between vertices j and k within network radius r

Part 2:
Case Study

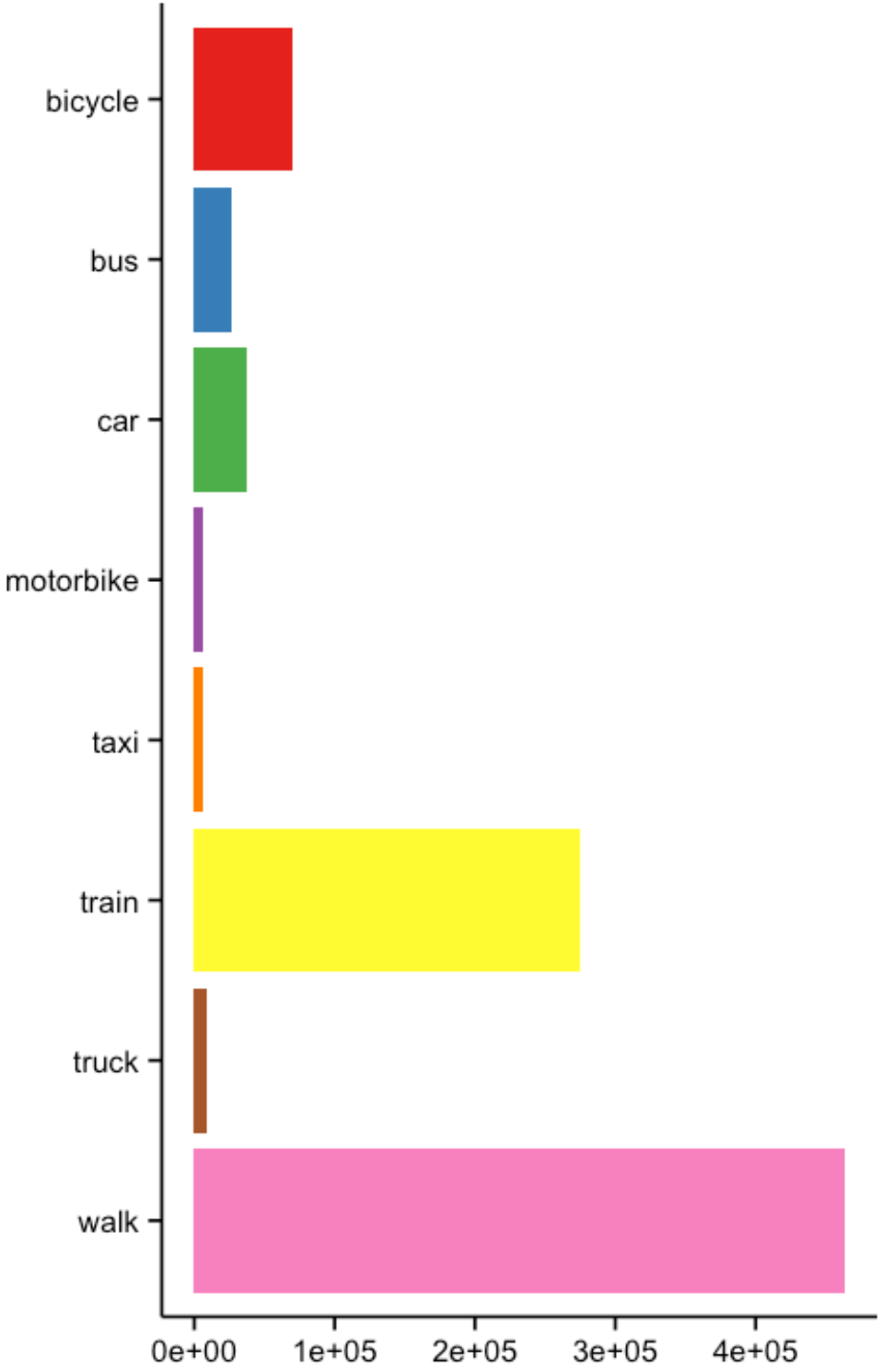
Study Area: The 23 Special Wards of Tokyo



Use Case: Pedestrian Traffic



Datasource:
PersonFlow data by CSIS at the University of Tokyo



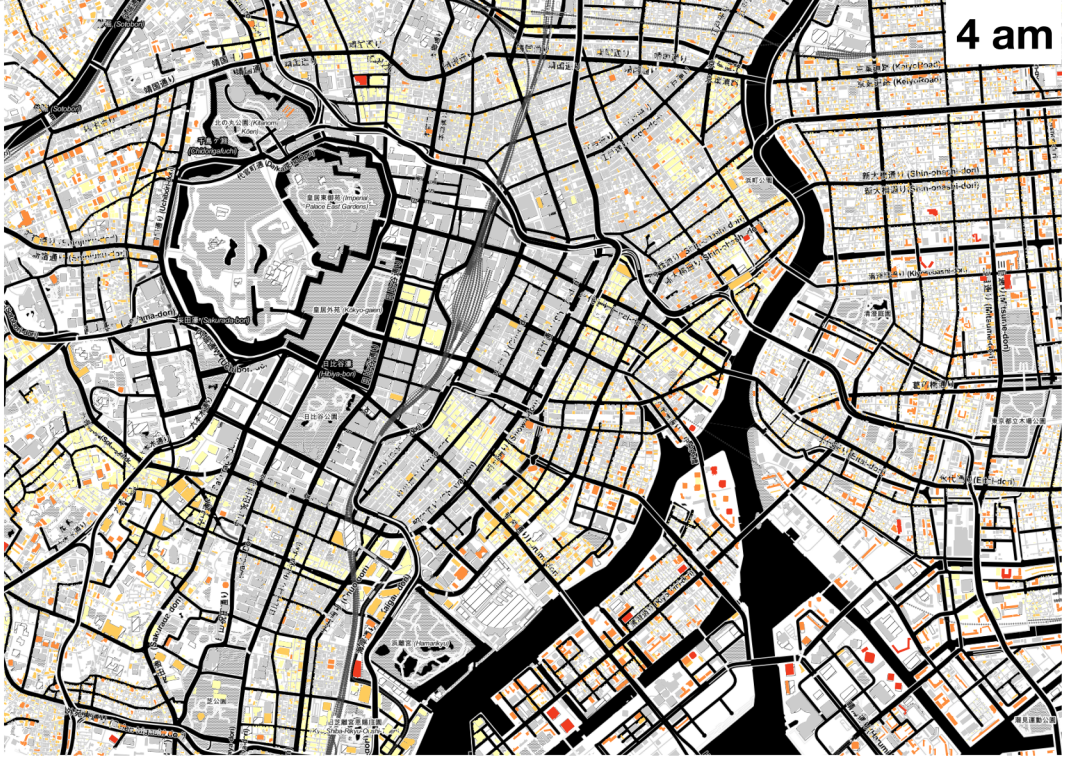
Calculation Process

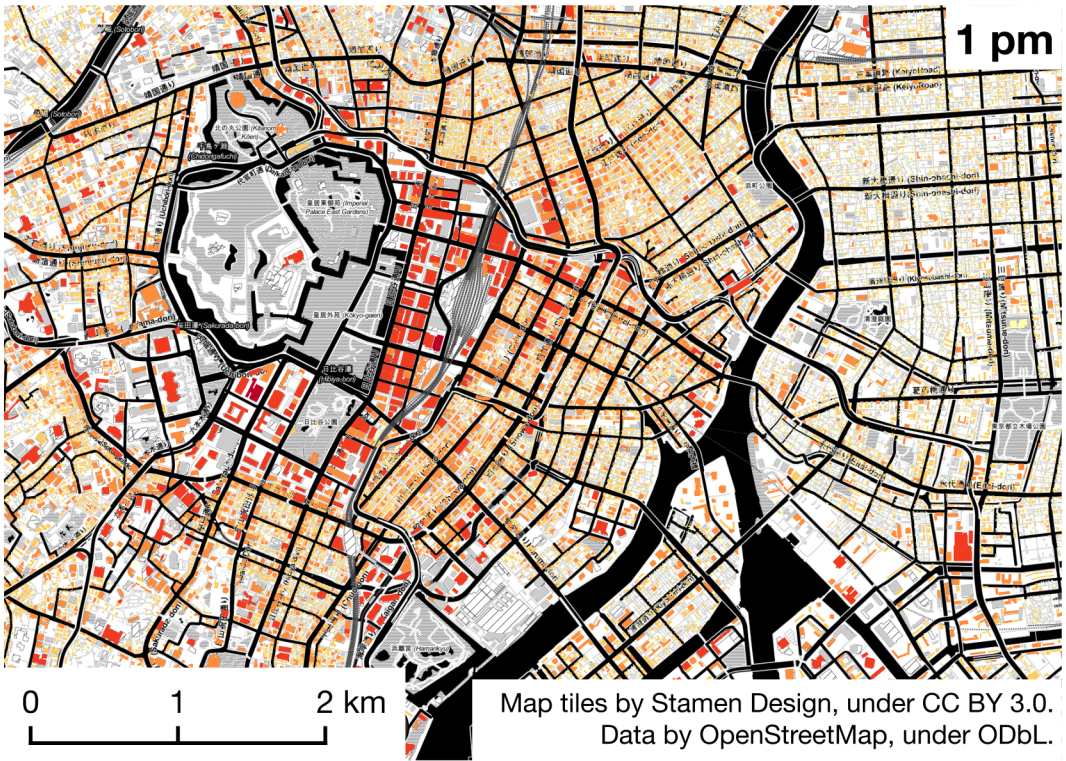
1) Calculation of building population at each time t_i
2) Determination of building access
3) Calculation of train station usage at each time t_i
4) Calculation of road network betweenness centrality at each time t_i

Building Population and Building Access

Stationary building population algorithm explained in GREGER (2015)

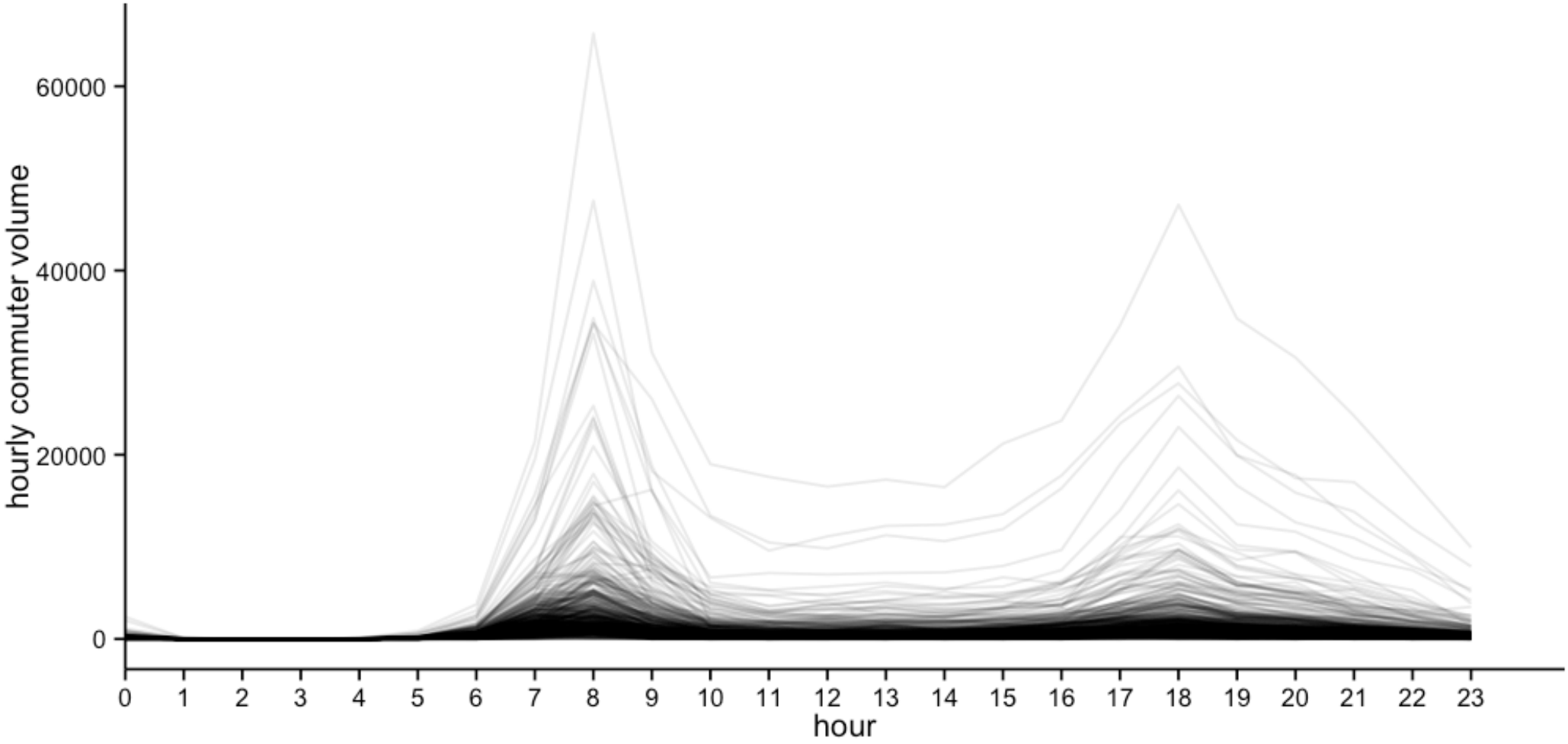
Building access from closest road segment



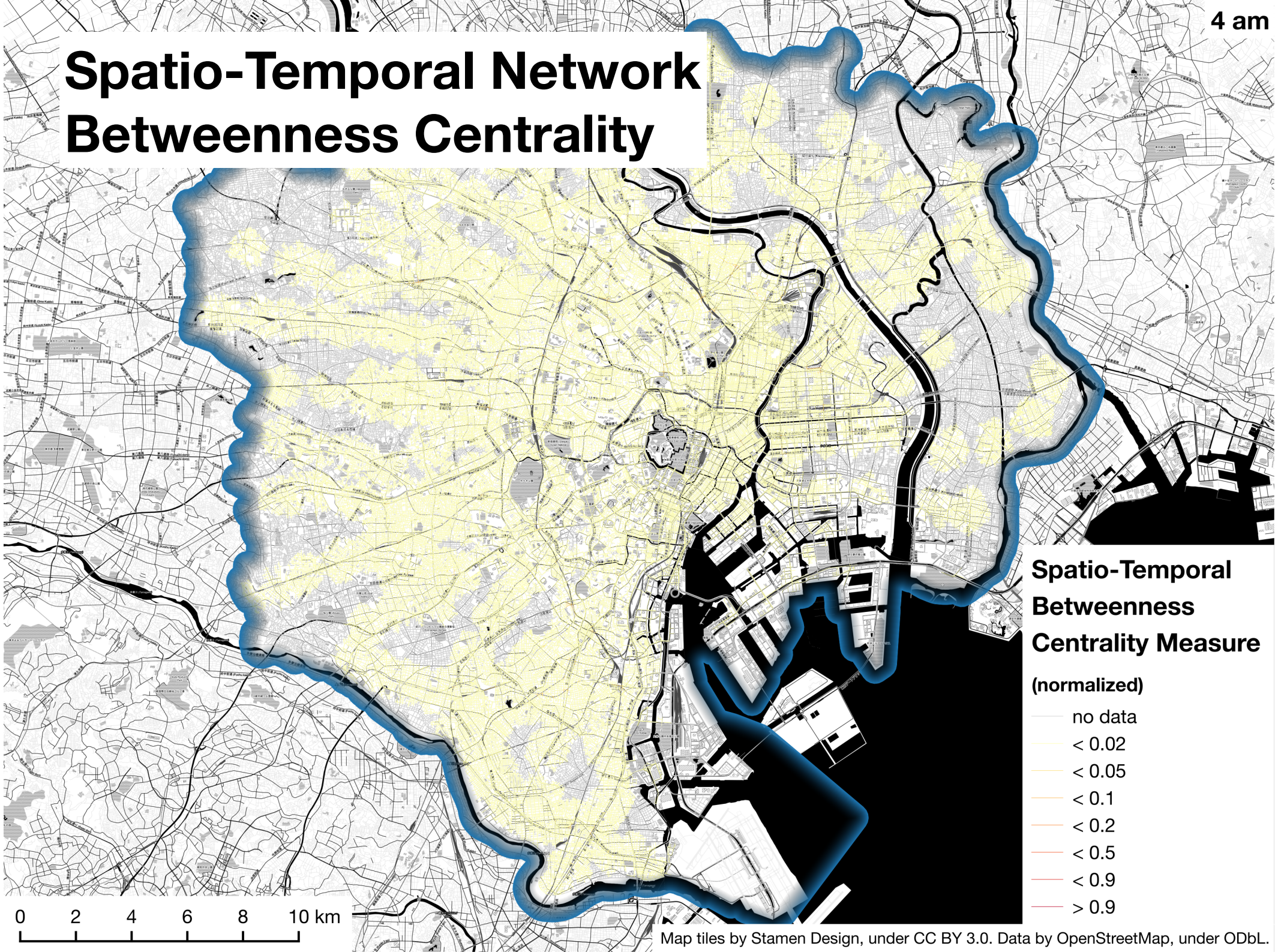


Train Station Usage

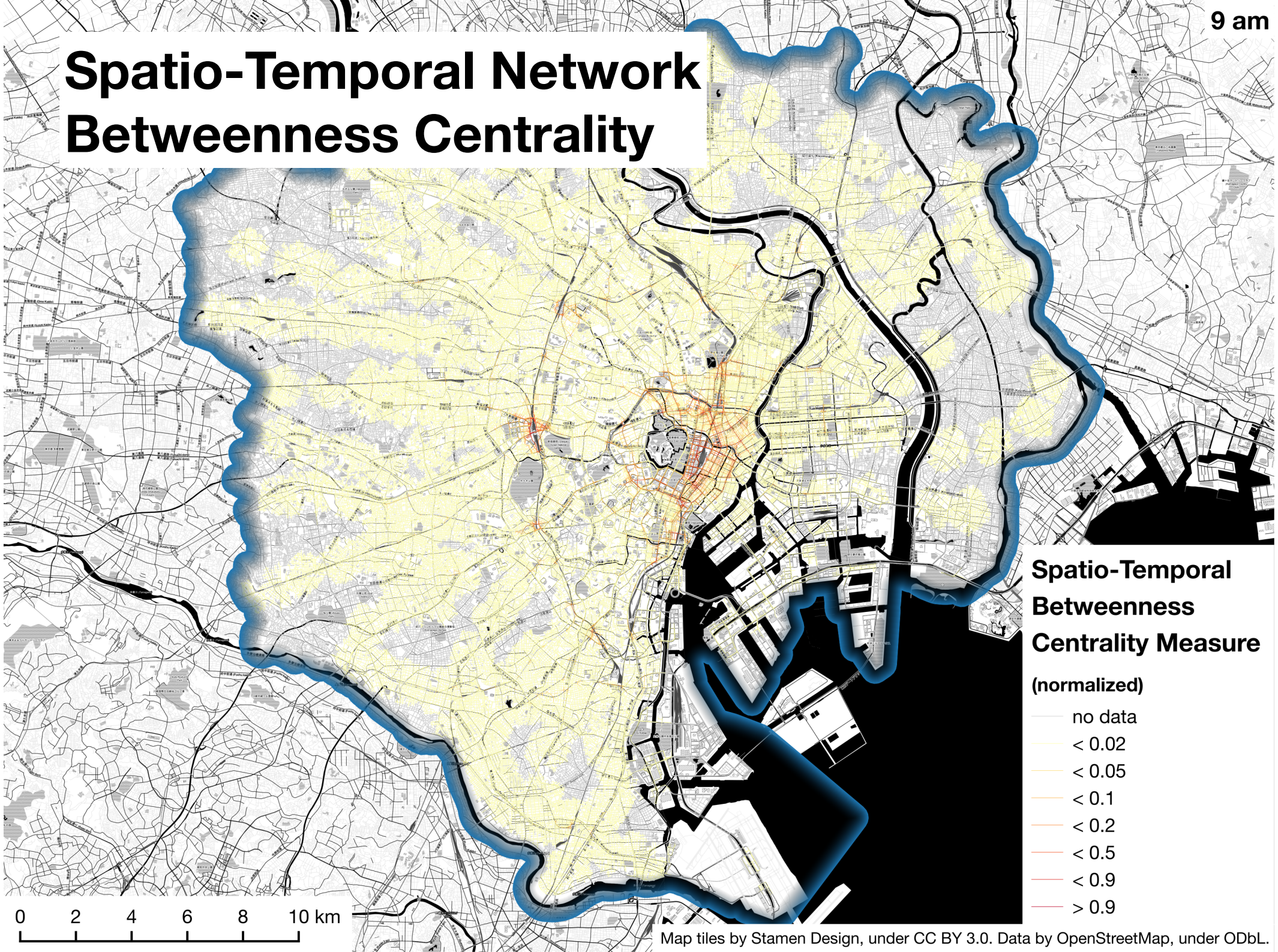
Derivation of hourly number of passengers using daily train station passenger volumes and *PersonFlow* data



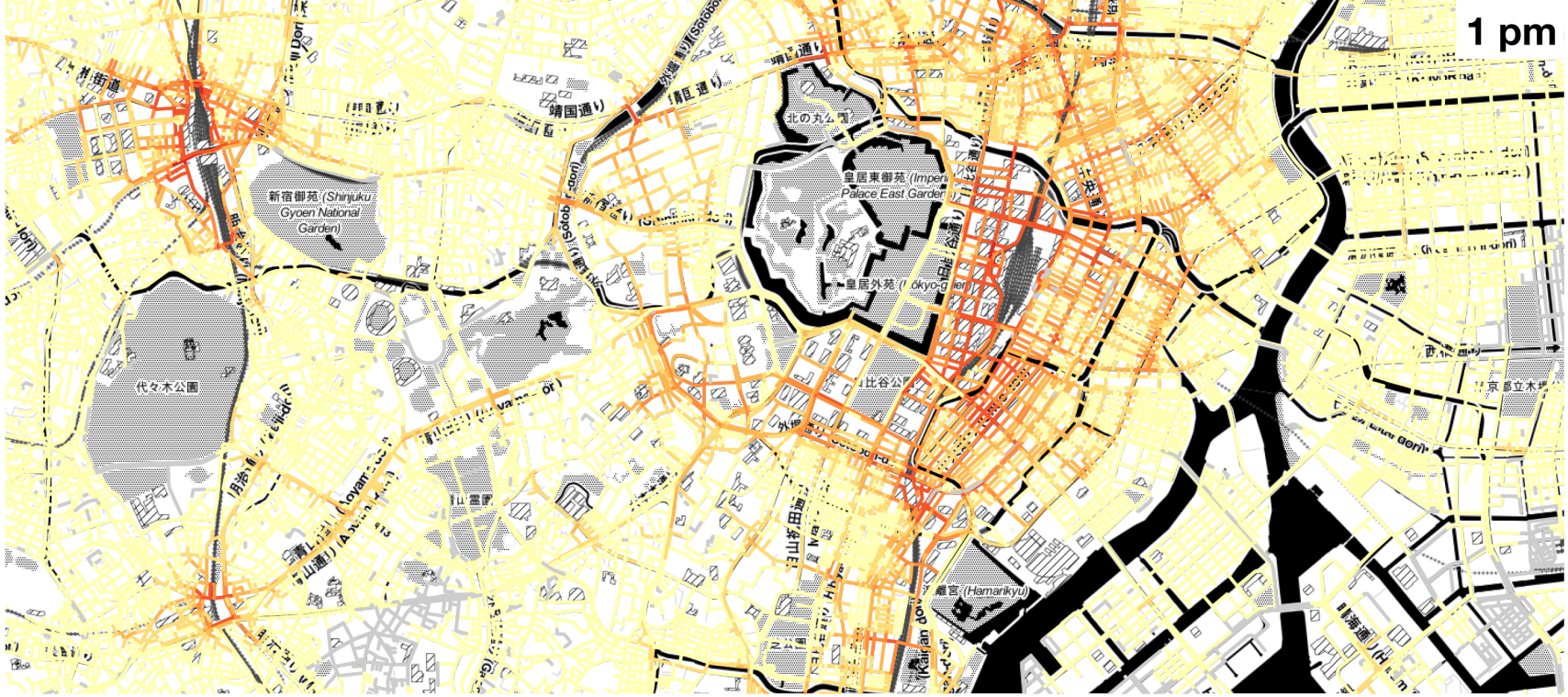
Spatio-Temporal Network Betweenness Centrality



Spatio-Temporal Network Betweenness Centrality



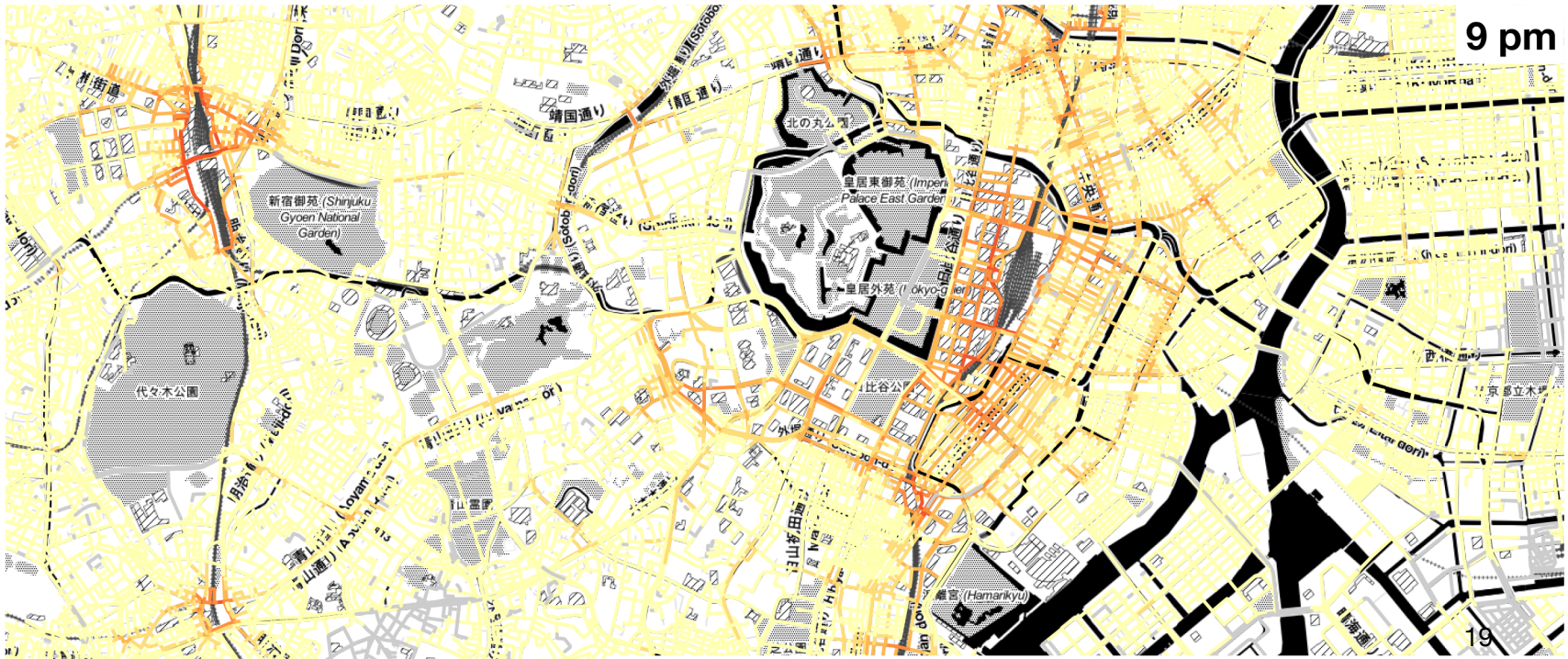
STBC Details



Spatio-Temporal Betweenness Centrality Measure

(normalized)

- no data
- < 0.02
- < 0.05
- < 0.1
- < 0.2
- < 0.5
- < 0.9
- > 0.9



0 1 2 km

Summary

Extension of existing betweenness centrality measures

Allows for fine-grained micro-scale spatio-temporal analysis of centrality of transportation networks

Results useful for city planning, retail management and emergency preparedness

Shortcomings & Outlook

Rather data intensive	➡ Use of OSM and other open data sources
Proprietary implementation for Esri ArcGIS	➡ Implementations in Python (for use in QGIS) and R
Error-prone assignment of buildings' network access	➡ ? (entrance data)

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Thank you for your attention

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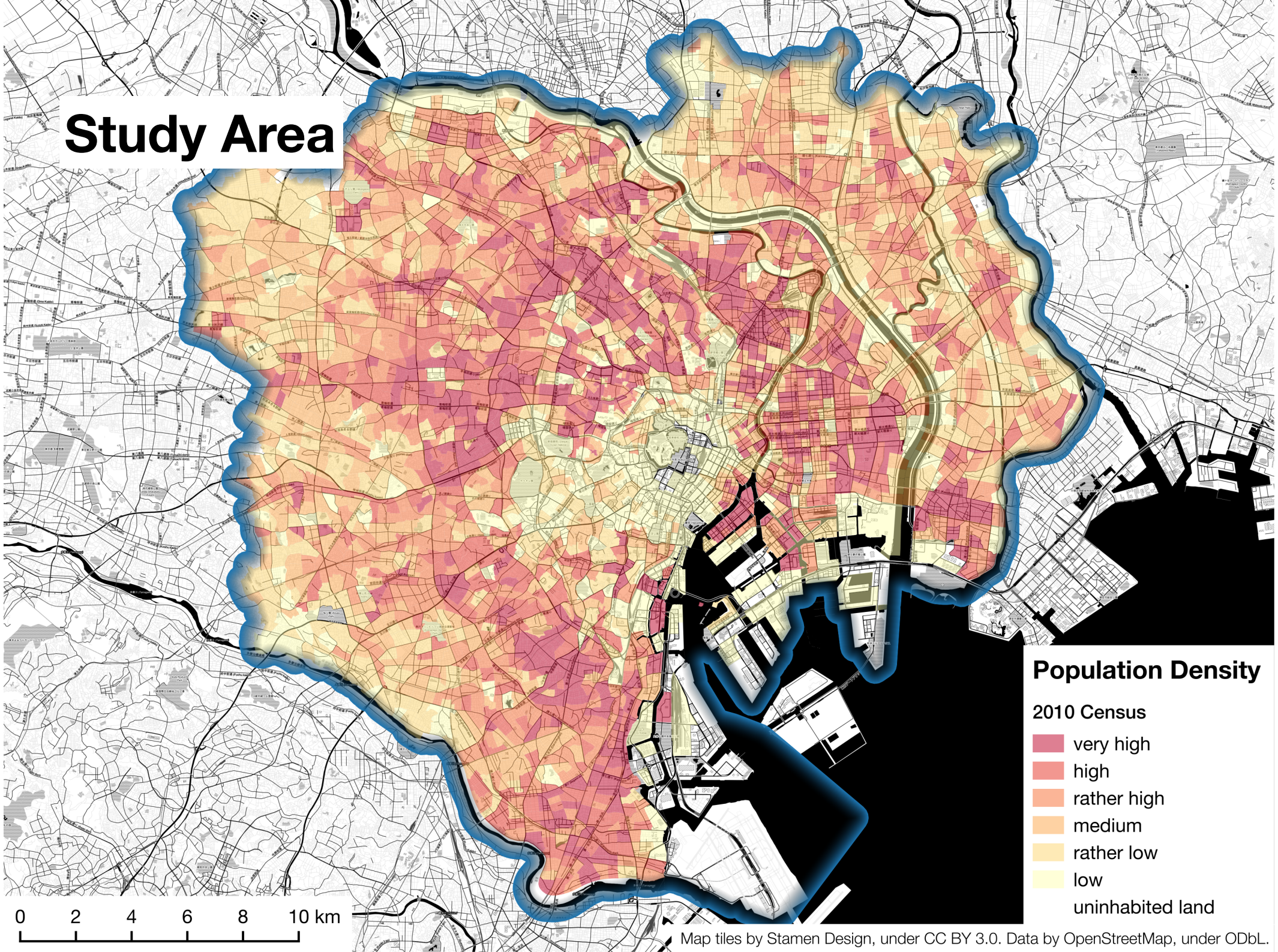
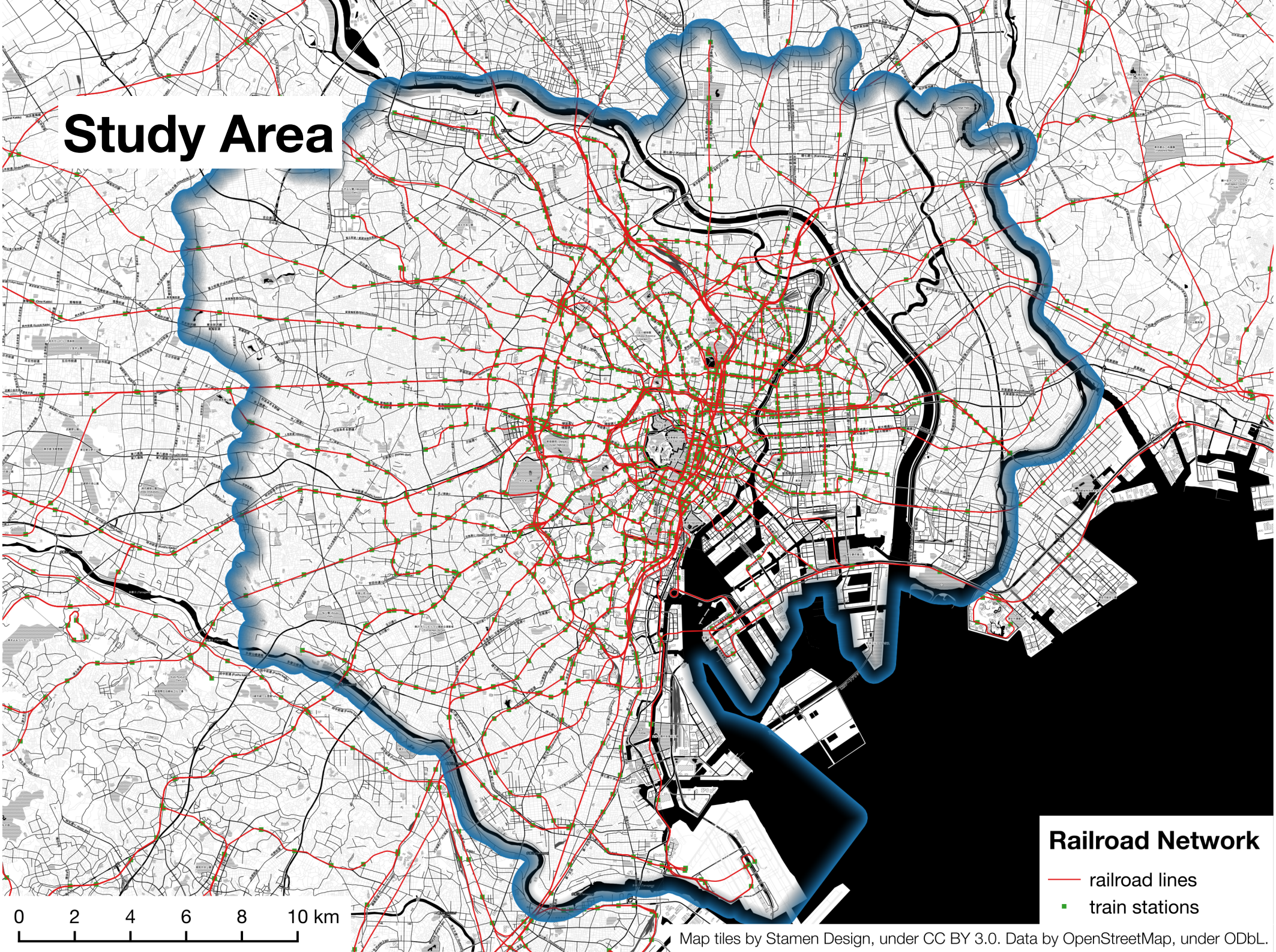
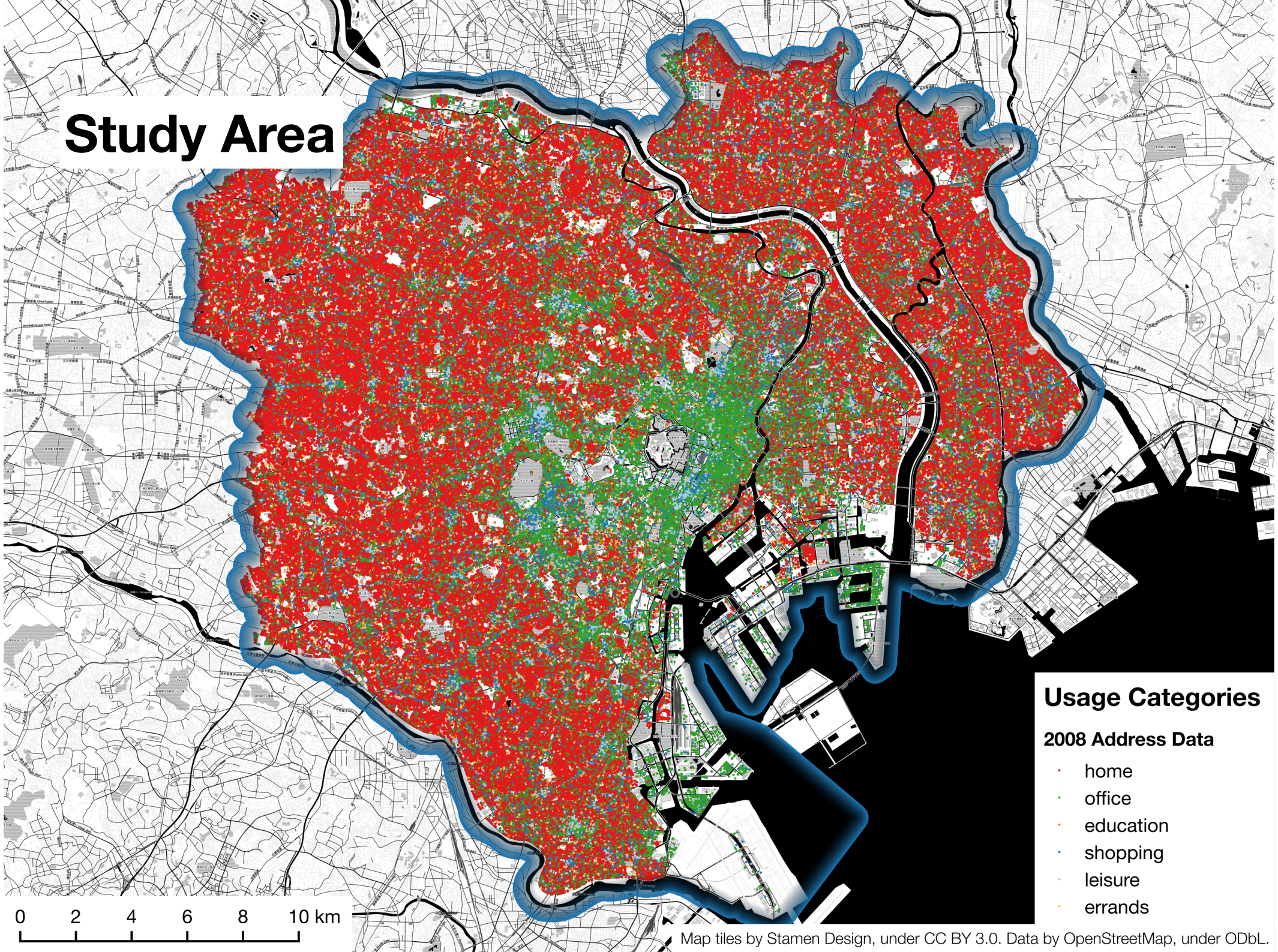
github.com/kogreger/stbc


Study Area
Population Density
2010 Census
very high
high
rather high
medium
rather low
low
uninhabited land
0 2 4 6 8 10 km
Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL.


Study Area
Railroad Network
railroad lines
train stations
0 2 4 6 8 10 km
Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL.

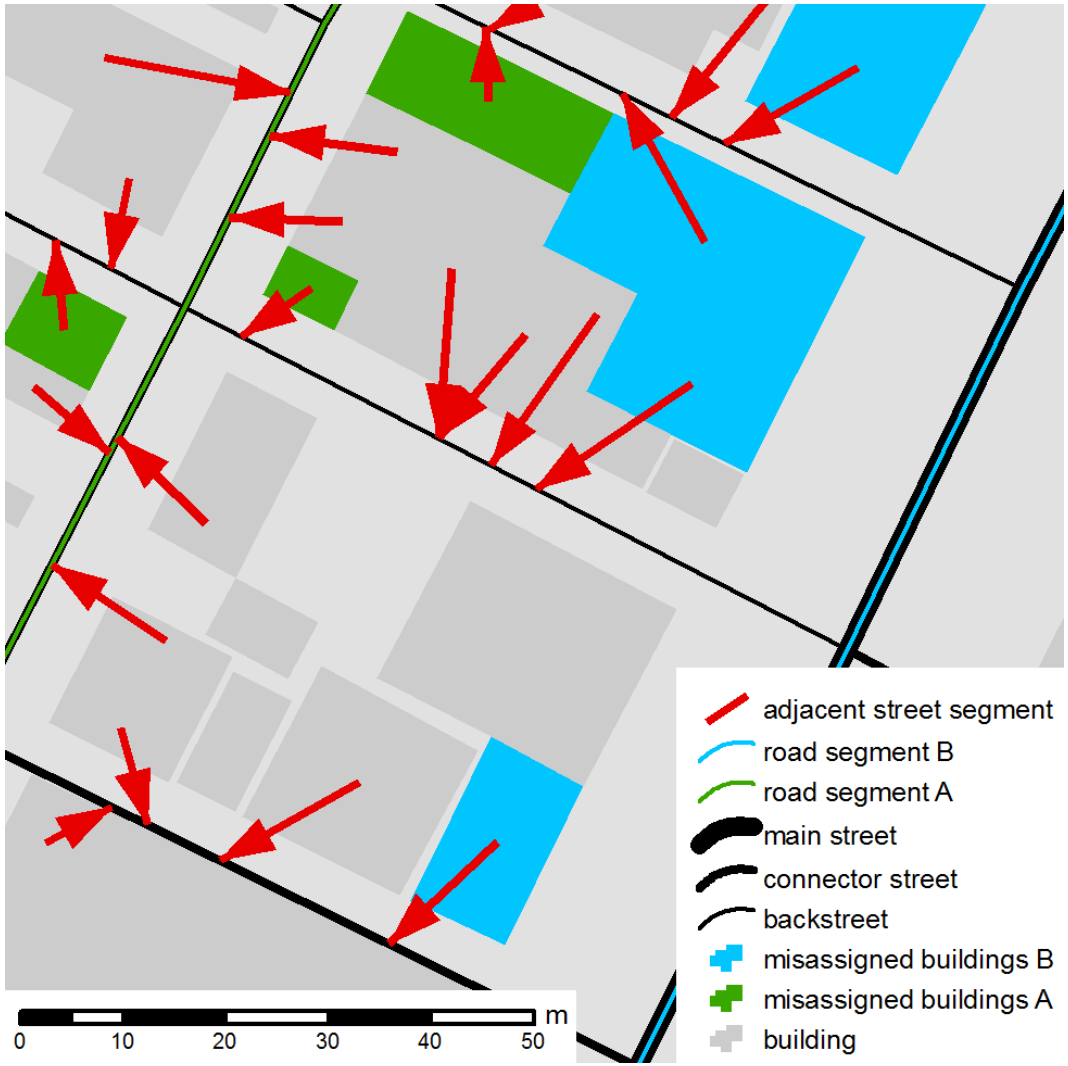

Study Area
Usage Categories
2008 Address Data
home
office
education
shopping
leisure
errands
0
2
4
6
8
10 km
Map tiles by Stamen Design, under CC BY 3.0. Data by OpenStreetMap, under ODbL.

Building Access

Building access from closest road segment

Introduces errors:

- misassignments
- multiple entrances



Data Dimensions

Study area
627 km^2

Train stations
~ 3,656 platforms
~ 457 separate stations

Buildings
~ 260,000 buildings
19 attributes per building
usage per building known
hourly population known

***PersonFlow* data**
~ 600,000 people
24 h * 60 min = 1,440 min
~ 834×10^6 in total
~ 217×10^6 in study area
12 attributes per point

Road network
~240,000 vertices
29 attributes per vertex
~ 350,000 edges
69 attributes per edge