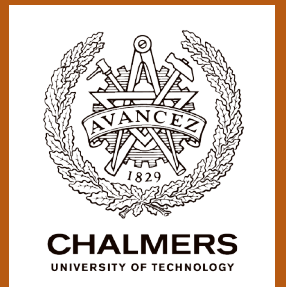


# Methodology and results of an international observational study on pedestrian movement tracking anonymised Wi-Fi signals from mobile phones

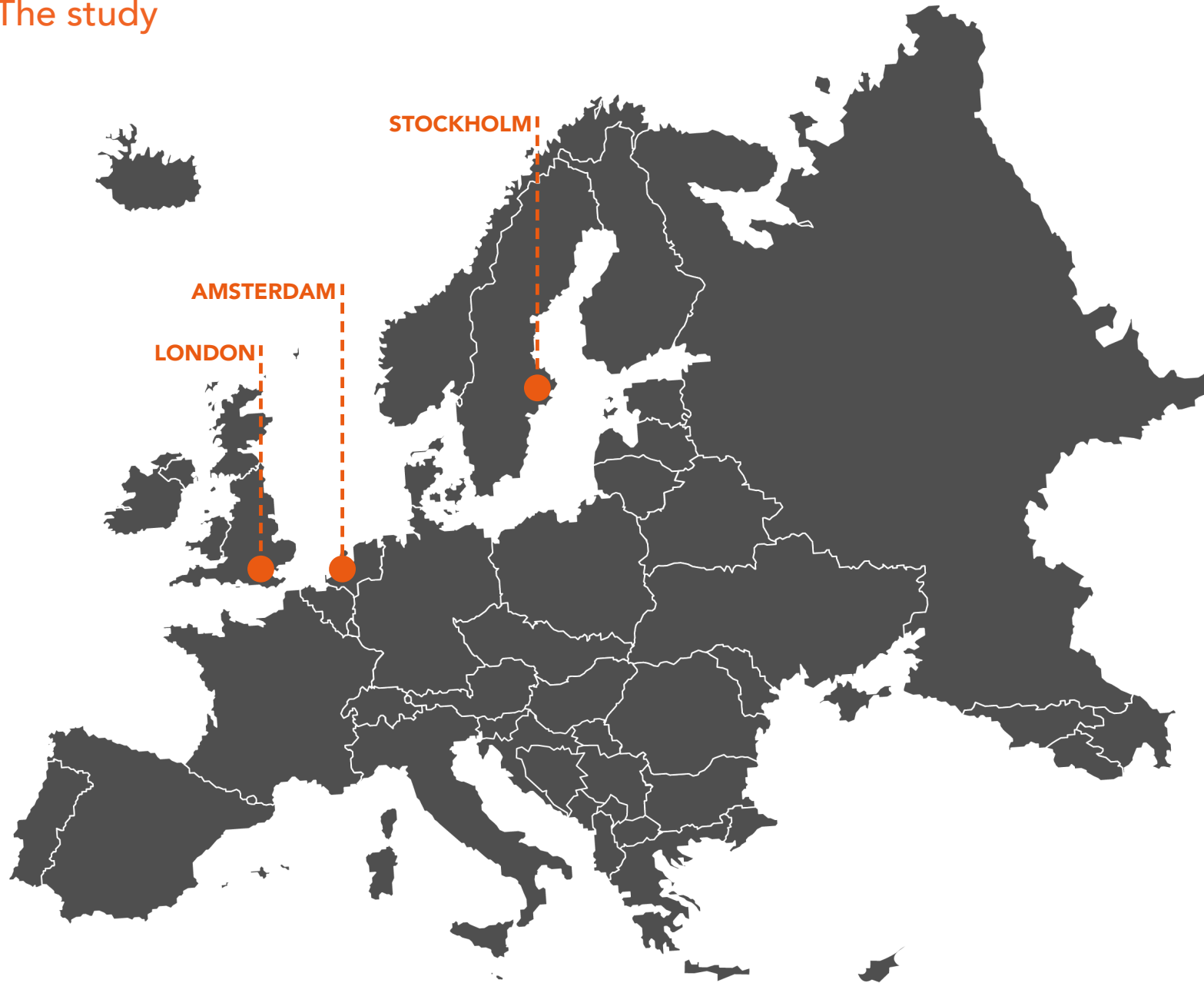
Gianna Stavroulaki<sup>1</sup>, Meta Berghauser Pont<sup>1</sup>, Lars Marcus<sup>1</sup>, Kailun Sun<sup>1</sup>, Staffan Liljestrand<sup>2</sup>

1. Spatial Morphology Group (SMoG),  
Division of Urban Design and Planning,  
Department of Architecture and Civil Engineering  
Chalmers University of Technology

2. Bumble Labs, Consultancy firm, Stockholm



## The study



> tracking anonymised Wi-Fi signals from mobile phones

> the method and anonymization of the data is approved by the Swedish Data Agency (Datainspektionen –no 1702-2015) and GDPR compliant

> 18-20 areas spread in each city

> about 300 streets in each city

> areas with different density types (city centre, suburban, villa areas, modernistic etc.)

> streets with different centrality type ('high' streets, side streets, alleys, pedestrian paths etc.)

> during three weeks in October 2017, one week per city

> counts from 6:00 in the morning to 22:00 in the evening

## The team

### **SPATIAL MORPHOLOGY GROUP, CHALMERS UNIVERSITY OF TECHNOLOGY**

Division of Urban Design and Planning,  
Department of Architecture and Civil Engineering

Lars Marcus, Professor  
Meta Berghauser Pont, Associate Professor  
Gianna Stavroulaki, Researcher  
Kailun Sun, Research Assistant

+ team on site  
Gianna Stavroulaki, Researcher  
Håkan Eriksson, Freelance, Architect  
Kailun Sun, Research Assistant  
Meta Berghauser Pont, Associate Professor  
Antonio Sanna, Freelance, Architect  
Evgenyia Bobkova, PhD student  
Ehsan Abshirini, Research assistant  
Lars Marcus, Professor  
Ann Legeby, Researcher, KTH  
Birgit Hausleitner, PhD student, TU Delft

### **BUMBEE LABS**

Consultancy firm, Stockholm

Staffan Liljestrand, Chief Science Officer & Founder  
Ludvig Kratz, Data analyst  
Christoffer Rydberg, Engineer

+ team on site  
Ludvig Kratz, Data analyst  
Christoffer Rydberg, Engineer

## The team

### STOCKHOLM

2 OCT - 6 OCT

MON to FRI

6:00 to 22:00

#### Spatial Morphology Group

Gianna Stavroulaki, Researcher  
Håkan Eriksson, Freelance, Architect  
Kailun Sun, Research Assistant  
Meta Berghauser Pont, Associate Professor  
Ehsan Abshirini, Research assistant  
Lars Marcus, Professor  
Ann Legeby, Researcher, KTH

#### Bumbee Labs

Ludvig Kratz, Data analyst  
Christoffer Rydberg, Engineer

### AMSTERDAM

9 OCT - 13 OCT

MON to FRI

6:00 to 22:00

#### Spatial Morphology Group

Gianna Stavroulaki, Researcher  
Håkan Eriksson, Freelance, Architect  
Evgenyia Bobkova, PhD student  
Meta Berghauser Pont, Associate Professor  
Antonio Sanna, Freelance, Architect  
Birgit Hausleitner, PhD student, TU Delft

#### Bumbee Labs

Ludvig Kratz, Data analyst  
Christoffer Rydberg, Engineer

### LONDON

16 OCT - 23 OCT

MON to FRI

6:00 to 22:00

#### Spatial Morphology Group

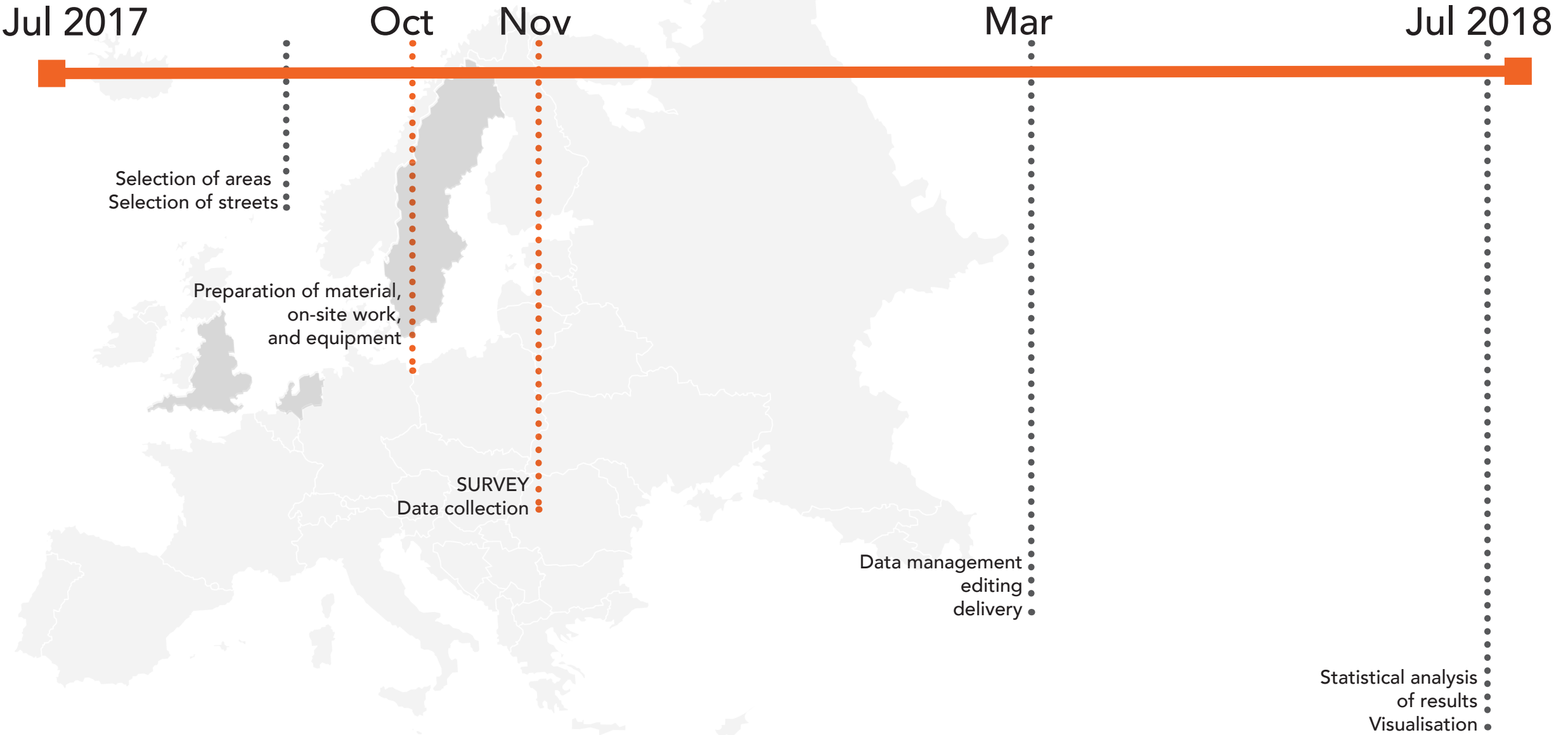
Gianna Stavroulaki, Researcher  
Håkan Eriksson, Freelance, Architect  
Meta Berghauser Pont, Assoc. Professor  
Antonio Sanna, Freelance, Architect

#### Bumbee Labs

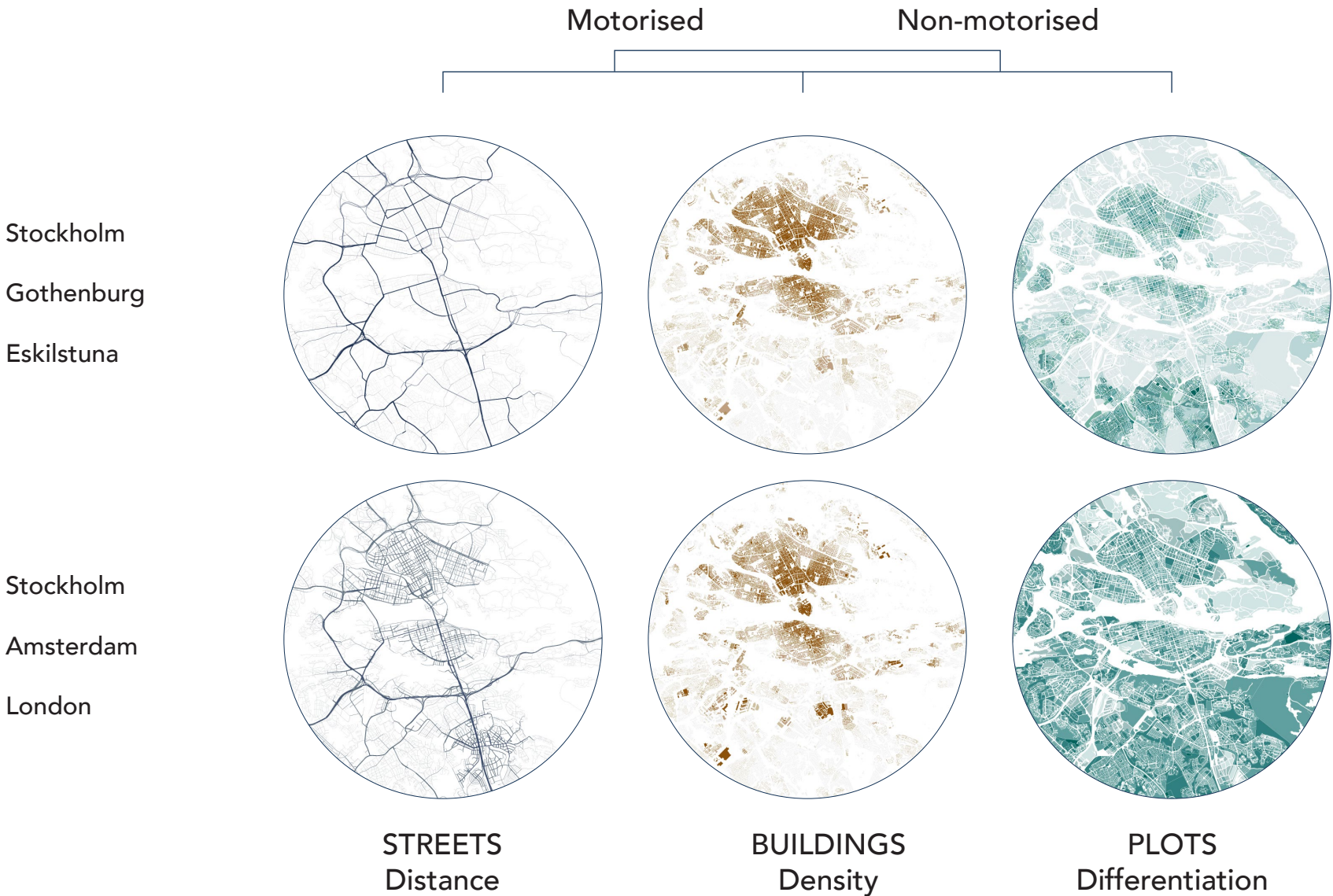
Ludvig Kratz, Data analyst  
Christoffer Rydberg, Engineer



The study



in collaboration with  
KTH, Stockholm, Sweden  
TU Delft, the Netherlands  
UCL, London, UK



TYPOLOGIES of SPATIAL FORM  
Density types  
Centrality types  
Differentiation types

RELATION TO URBAN PROCESSES

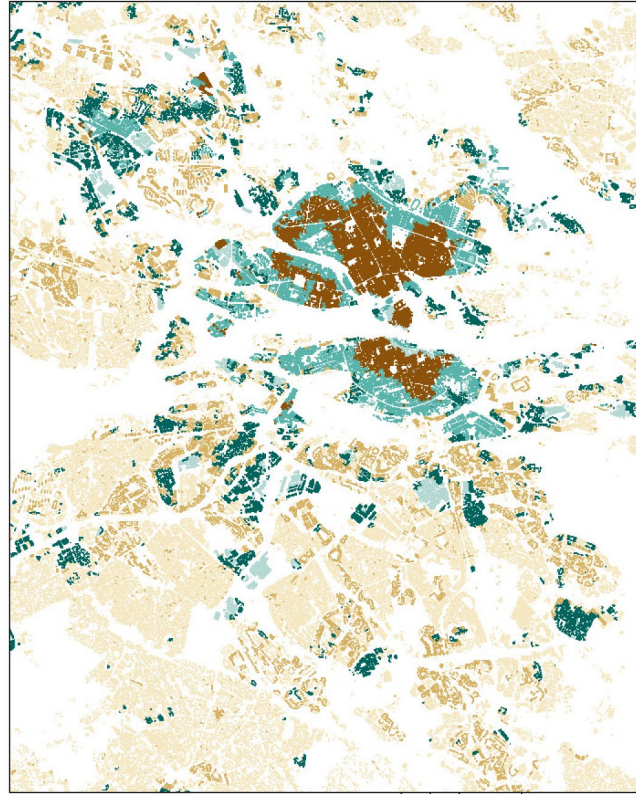




## Sample selection

### Areas\_Variation in Density types

Spacious low-rise (cl1)   Spacious mid-rise (cl6)   Compact low-rise (cl2)   Dense low-rise (cl4)   Compact mid-rise (cl5)   Dense mid-rise (cl3)   Compact high-rise (cl7)



Stockholm



Amsterdam



London

Distribution of built density types in Amsterdam, Stockholm and London (types are based on Accessible FSI, GSI in 500m)

**Berghauser Pont, M., Stavroulaki, G., Gil, J., Marcus, L., Serra, M., Hausleitner, B., Olsson, J., Abshirini, E., Dhanani, A. (2017a),** 'Quantitative comparison of cities: Distribution of street and building types based on density and centrality measures'. Proceedings XI space syntax conference, Lisbon.

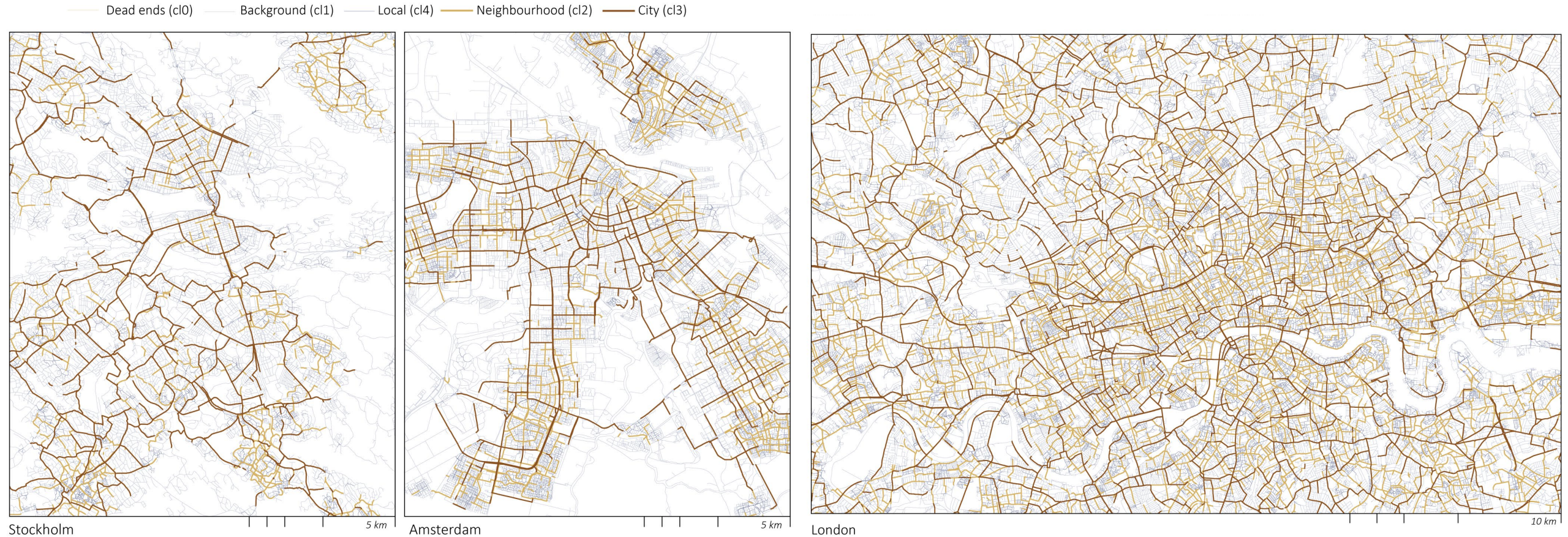
**Berghauser Pont, M., Stavroulaki, G., Sun, K., Abshirini, E., Olsson, J., Marcus, L. (2017b),** 'Quantitative comparison of the distribution of densities in three Swedish cities'. Proceedings 24th International Seminar on Urban Form, Valencia.

**Berghauser Pont, M., Stavroulaki, G., Marcus, L., (2018),** 'Development of Urban Types, based on Network Centrality and Built Density, and their Impact on Pedestrian Movement', Environment and Planning B, *under review*



## Sample selection

### Streets\_Variation in Density types



Distribution of street types in Amsterdam, Stockholm and London (types are based on network betweenness centrality in 10 scales from 500m to 5km)

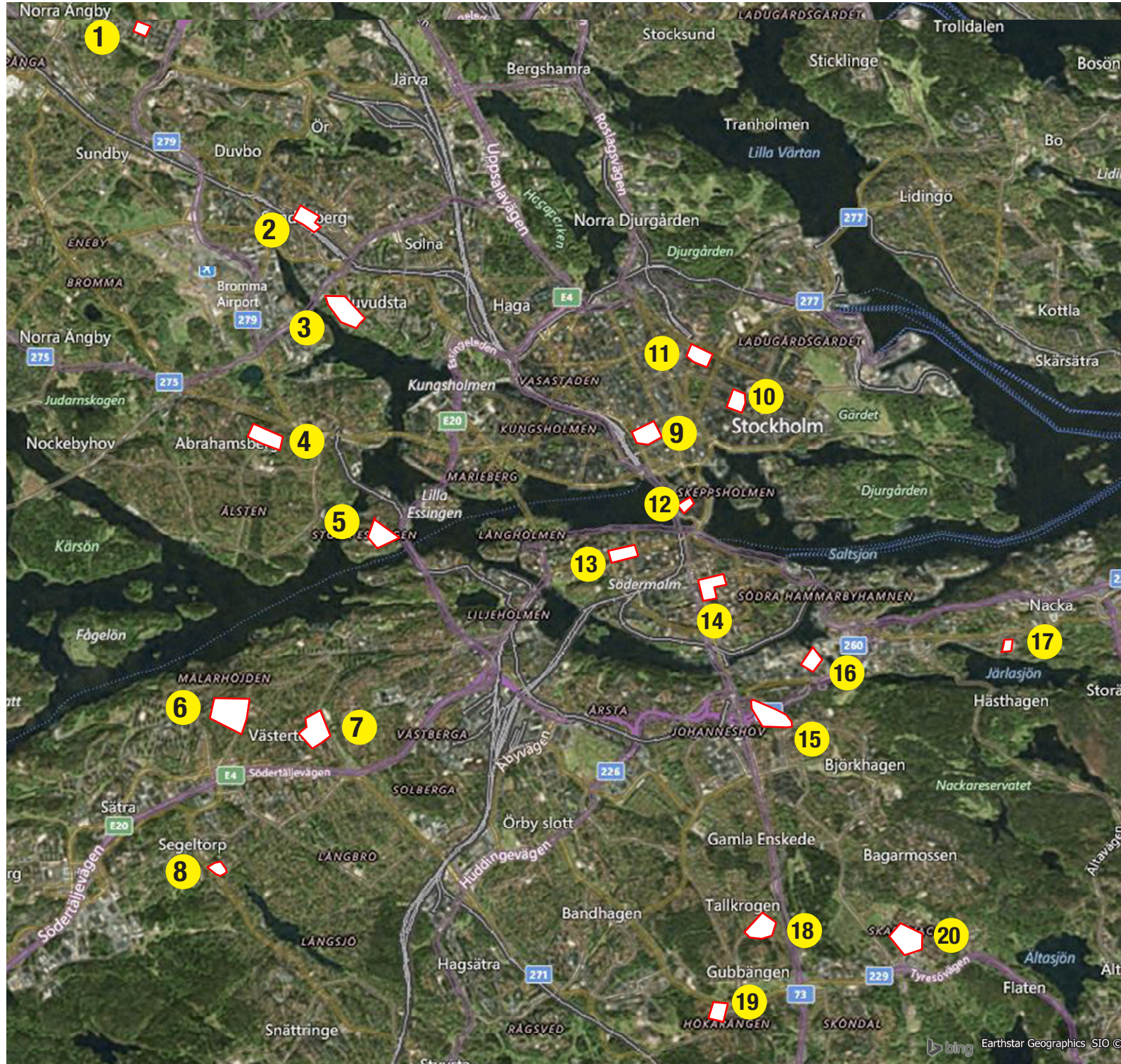
**Berghauser Pont, M., Stavroulaki, G., Gil, J., Marcus, L., Serra, M., Hausleitner, B., Olsson, J., Abshirini, E., Dhanani, A. (2017a),** 'Quantitative comparison of cities: Distribution of street and building types based on density and centrality measures'. Proceedings XI space syntax conference, Lisbon.

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**Berghauser Pont, M., Stavroulaki, G., Marcus, L., (2018),** 'Development of Urban Types, based on Network Centrality and Built Density, and their Impact on Pedestrian Movement', Environment and Planning B, *under review*



## Sample Study areas



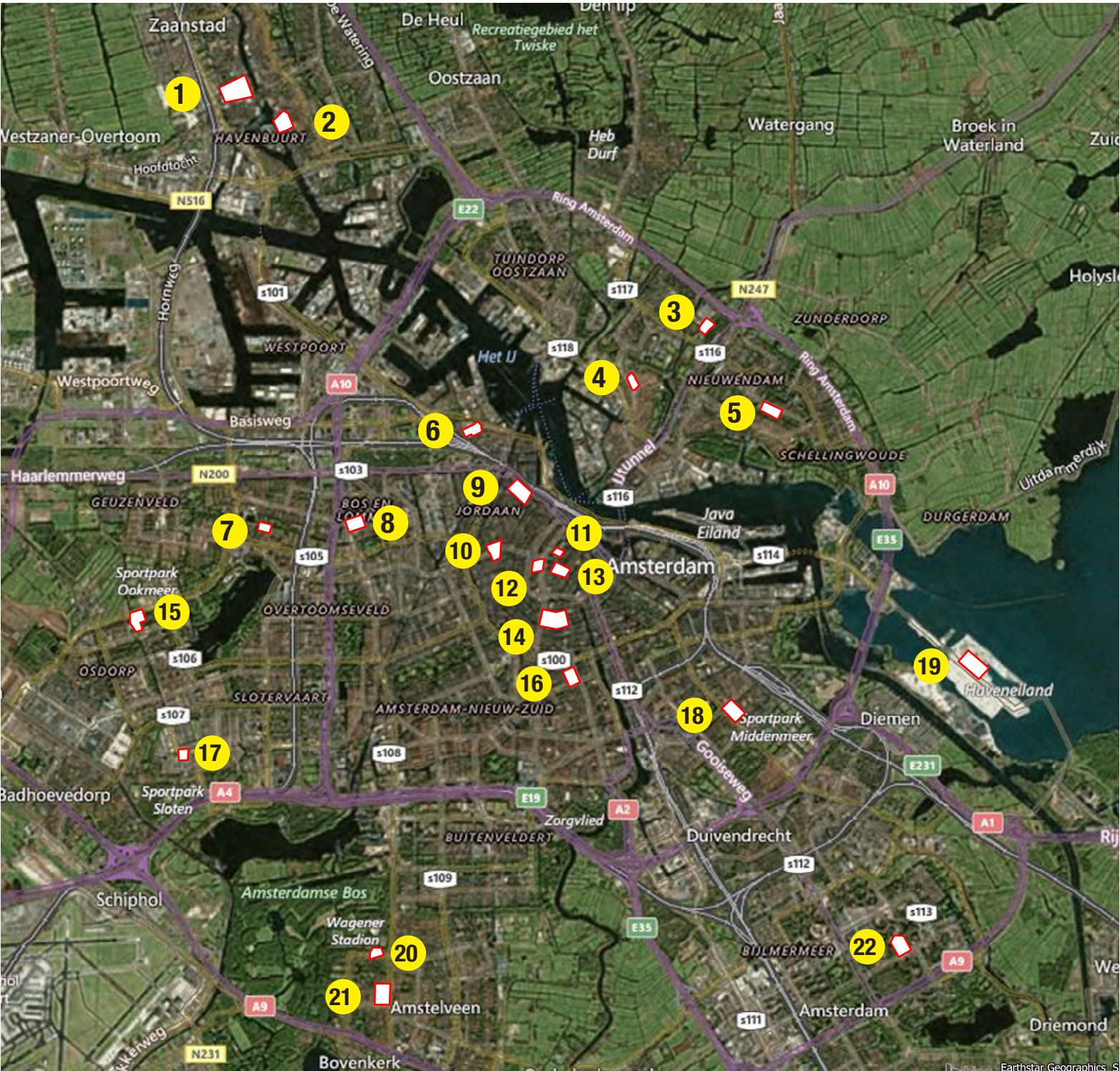
## Stockholm

Oct. 01-Oct.07

- 1 Rinkeby
- 2 Sundbyberg
- 3 Jungfrudansen
- 4 Stora Mossen
- 5 Stora Essingen
- 6 Mälarhöjden
- 7 Västertorp
- 8 Segeltorp
- 9 Normalm
- 10 Östermalm (Sibyllegatan 18)
- 11 Östermalm (Rådmansgatan 4-10)
- 12 Galma Stan
- 13 Centrala Södermalm, Maria Församlingen
- 14 Västra Södermalm, Katarina Församlingen
- 15 Hammarby Höjden
- 16 Hammarby Sjöstad
- 17 Järlasjö
- 18 Tallkrogen
- 19 Hökarängen
- 20 Skarpnäck



Sample  
Study areas

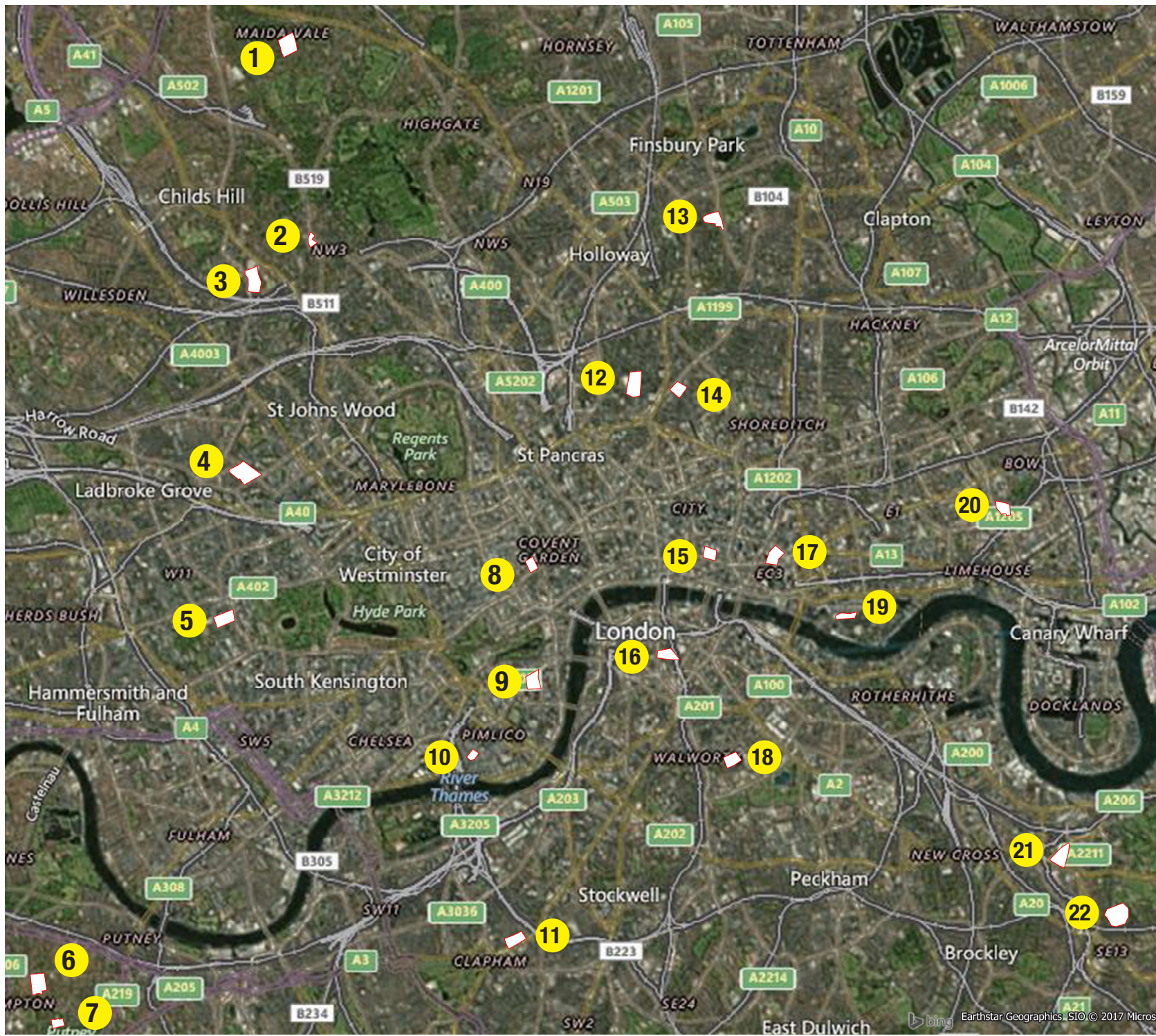


Amsterdam  
Oct. 08-Oct.14

- ~~1~~ Zaanstad, Russische Buurt
- ~~2~~ Zaanstad, Poelenburg
- 3 Noord, Kadoelen
- 4 Noord (Kamperfoelieweg 200)
- 5 Noord, Nieuwendam
- 6 Spaarndammer en zeeheldenbuurt
- 7 Sloterveer-noordoost
- 8 Bos en Lommer
- 9 Haarlemmerbuurt
- 10 Jordaan
- ~~11~~ De Wallen (Willemsstraat 163)
- 12 Burgwallen Nieuwe Zijde
- 13 De Wallen (Oudezijds Voorburgwal 181)
- ~~14~~ Grachtengordel (Herengracht 499)
- 15 Osdorp-oost
- 16 De Pijp (Govert Flinckstraat 286)
- 17 Nieuw Sloten
- 18 Watergraafsmeer (Middenweg 163)
- 19 IJburg West
- 20 Amstelveen, Patrimonium (Amsterdamseweg 405)
- 21 Amstelveen, Elsrijk (C v Montpensierln 33)
- 22 Zuidoost (Karspeldreef 1085)



Sample  
Study areas



- # London

Oct. 15-Oct.21
- 1

Hampstead garden suburb  
(Thornton W, Litchfield W)
- 2

Hampstead station area
- 3

West Hampstead (Lymington Rd)
- 4

Maida Hill (Sutherland Ave.)
- 5

Notting Hill (Peel st, Sheffield Terrace)
- 6

Putney (Putney health, Putney park ln)
- 7

Putney (Hawkesbury Rd)
- 8

Soho (Greek St., Dean St.)
- 9

Westminster (Victoria St.  
Great Peter St.)
- 10

~~Pimlico (Lupus St., Sussex St.)~~
- 11

Clapham (Clapham High St. Cresset St)
- 12

Barnsbury (Barnsbury Rd)
- 13

Highbury East
- 14

Hoxton (Packington St, A104)
- 15

Cornhill (Wood St, Lothbury)
- 16

Newington (Pocock St, Webber St)
- 17

Cornhill (Houndsditch, Leaden Hall St.)
- 18

~~Warworth (Merrrow St, Portland St)~~
- 19

~~Wapping (Kinner St)~~
- 20

~~Mile End (Eric St, Joseph St)~~
- 21

~~Greenwich (Egerton Dr, A2, A206)~~
- 22

~~Lewisham (Walerand Rd)~~



## Sample

### Examples of areas and street types



Cornhill, London  
(dense mid-rise)





## Sample

Examples of areas and street types



Clapham, London  
dense low-rise





## Sample

Examples of areas and street types



Noord, Kadoelen, Amsterdam  
(spacious low-rise)





## Sample

Examples of areas and street types



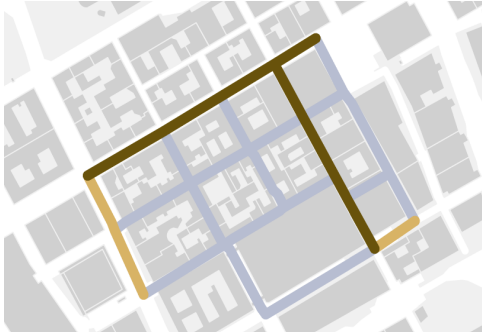
De Pijp, Amsterdam  
(compact mid-rise)



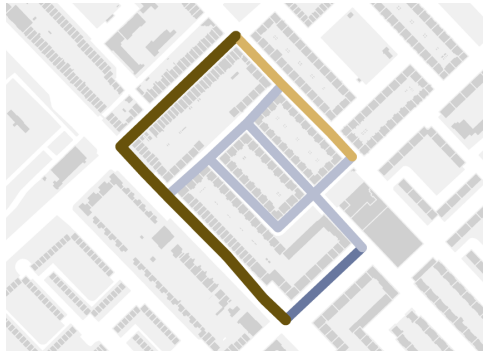


Sample

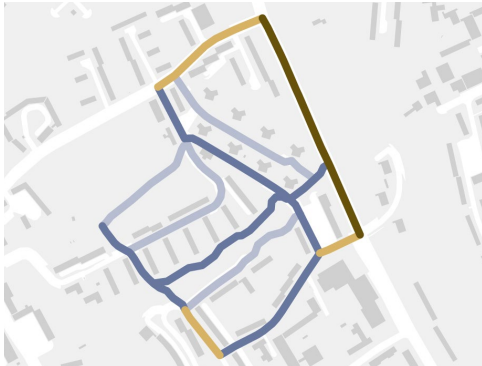
Examples of areas and street types



1.  
Stockholm  
Density type:  
Dense mid-rise  
Norrmalm



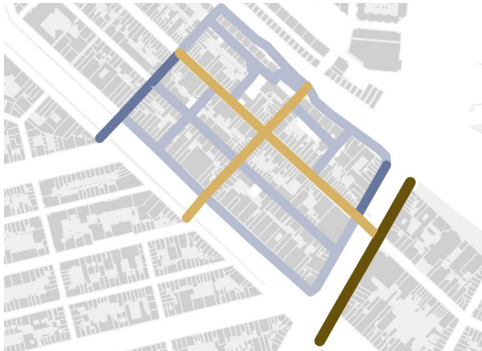
4.  
Amsterdam  
Density type:  
Spacious low-rise  
Watergraafsmeer



2.  
Stockholm  
Density type:  
Spacious mid-rise  
Västertorp



5.  
London  
Density type:  
Dense mid-rise  
Cornhill



3.  
Amsterdam  
Density type:  
Compact mid-rise  
Haarlemmersbuurt



6.  
London  
Density type:  
Compact low-rise  
Hampstead station

city  
neighborhood  
very local  
background



## Method

### Devices

#### > Contents:

wi-fi router (receiver)  
4G modem (sender)  
battery

#### 'Raw' data:

> collected samples of wi-fi signals  
when phones are searching for wi-fi  
networks (wi-fi probe requests).

> Each sample includes a timestamp,  
a RSSI (Received Signal Strength  
Indication) and an anonymized  
indicator. The RSSI gives us a the  
distance of the phone from the  
antenna.



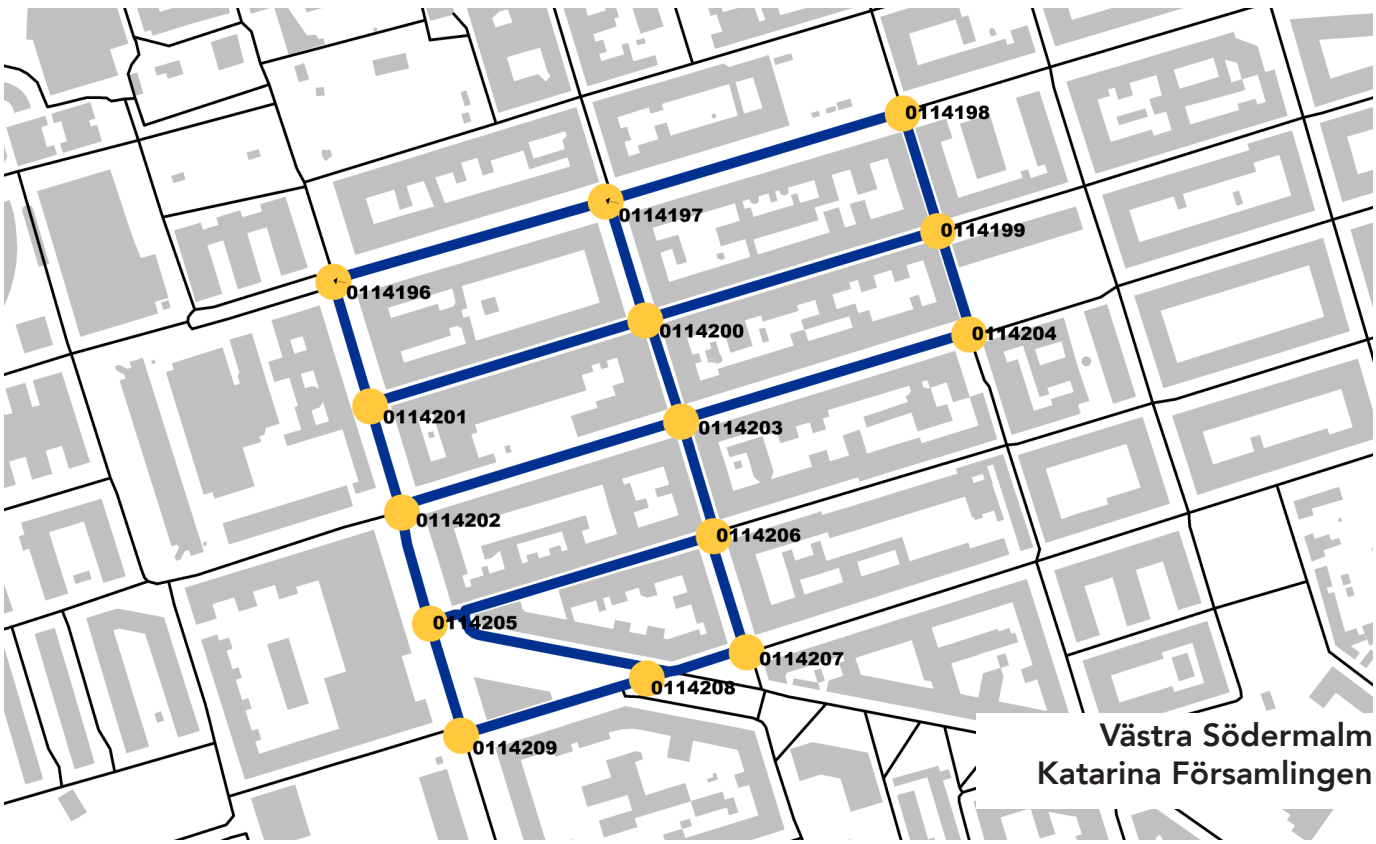


Method

'Raw' data

STOCKHOLM: 789.889 visit\_ids/trips  
AMSTERDAM: 532.068 visit\_ids/trips  
LONDON: 766.645 visit\_ids/trips

|    | A        | B       | C                | D                 | E                 |
|----|----------|---------|------------------|-------------------|-------------------|
| 1  | visit_id | gate_id | timestamp        | X                 | Y                 |
| 2  | 0114_1   | 114197  | 2017-10-05 06:00 | 675092.947832     | 6579125.31807     |
| 3  | 0114_1   | 114198  | 2017-10-05 06:02 | 675270.5775479999 | 6579181.03863     |
| 4  | 0114_2   | 114196  | 2017-10-05 06:02 | 674922.099638     | 6579073.26476     |
| 5  | 0114_2   | 114197  | 2017-10-05 06:03 | 675092.947832     | 6579125.31807     |
| 6  | 0114_3   | 114197  | 2017-10-05 06:03 | 675092.947832     | 6579125.31807     |
| 7  | 0114_3   | 114196  | 2017-10-05 06:03 | 674922.099638     | 6579073.26476     |
| 8  | 0114_4   | 114205  | 2017-10-05 06:05 | 674986.373212     | 6578857.9952      |
| 9  | 0114_4   | 114201  | 2017-10-05 06:05 | 674947.89521      | 6579001.07808     |
| 10 | 0114_4   | 114196  | 2017-10-05 06:05 | 674922.099638     | 6579073.26476     |
| 11 | 0114_5   | 114209  | 2017-10-05 06:06 | 675002.666861     | 6578792.841519999 |
| 12 | 0114_5   | 114205  | 2017-10-05 06:06 | 674986.373212     | 6578857.9952      |
| 13 | 0114_6   | 114196  | 2017-10-05 06:01 | 674922.099638     | 6579073.26476     |
| 14 | 0114_6   | 114201  | 2017-10-05 06:09 | 674947.89521      | 6579001.07808     |
| 15 | 0114_6   | 114200  | 2017-10-05 06:11 | 675117.7263859999 | 6579048.06709     |
| 16 | 0114_7   | 114203  | 2017-10-05 06:08 | 675136.4088229999 | 6578994.175969999 |
| 17 | 0114_7   | 114197  | 2017-10-05 06:09 | 675092.947832     | 6579125.31807     |
| 18 | 0114_7   | 114200  | 2017-10-05 06:09 | 675117.7263859999 | 6579048.06709     |
| 19 | 0114_7   | 114196  | 2017-10-05 06:10 | 674922.099638     | 6579073.26476     |
| 20 | 0114_8   | 114201  | 2017-10-05 06:11 | 674947.89521      | 6579001.07808     |
| 21 | 0114_8   | 114196  | 2017-10-05 06:12 | 674922.099638     | 6579073.26476     |
| 22 | 0114_9   | 114196  | 2017-10-05 06:02 | 674922.099638     | 6579073.26476     |
| 23 | 0114_9   | 114197  | 2017-10-05 06:03 | 675092.947832     | 6579125.31807     |
| 24 | 0114_9   | 114198  | 2017-10-05 06:03 | 675270.5775479999 | 6579181.03863     |
| 25 | 0114_9   | 114200  | 2017-10-05 06:17 | 675117.7263859999 | 6579048.06709     |
| 26 | 0114_9   | 114196  | 2017-10-05 06:17 | 674922.099638     | 6579073.26476     |
| 27 | 0114_10  | 114197  | 2017-10-05 06:17 | 675092.947832     | 6579125.31807     |



visit\_id = unique id of a smart phone/ unonymised pedestrian  
gate\_id = unique id of the street intersection where a device was placed  
timestamp = exact time when the "visit\_id" was recorded at the "gate\_id"

● gate/street intersection  
— recorded street segment  
0114196-209 gate\_id



## Method

### 'Raw' data\_Editing

- > Cleaning data from non-moving wifi signals and other 'noise' (e.g. wifi printers)
- > Calibrating (scaling) data. A scaling factor was used for each city to account for the fact that not all people passing had enabled wi-fi. the scaling factor was based on previous studies and reference manual counts
- > Extrapolating data in case of malfunctioning devices
- > Extrapolating data in case of not fully measured pedestrian paths, due to no probe-request within the measured zone\*

\* *How often a phone searches for a wi-fi network differs a lot, from as low as two times a minute to sixty times a minute. The average rate is seven to fifteen times a minute. The rate depends on a lot of factors, such as distance to wi-fi network, usage of the device etc.*





## Results

### Extracted data

from the raw data:

visit\_id = unique id of a smart phone/pedestrian

gate\_id = unique id of the street intersection where a device was placed

timestamp = exact time when the "visit\_id" was recorded at the "gate\_id"

we can extract disaggregate and aggregate information on pedestrian movement through each area:

disaggregate information:

- > the unique path of each phone/unonymised pedestrian
- > the direction of movement
- > the speed of movement
- > the duration of each trip through the area

aggregate information:

- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the overall presence of people in each area on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the fluctuation of movement intensity during the day, from 6:00 to 22:00\*
- > the average speed of movement\*

\*the results can be aggregated in different ways, per city, per area, per density type, per centrality type

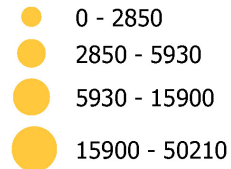


## The results

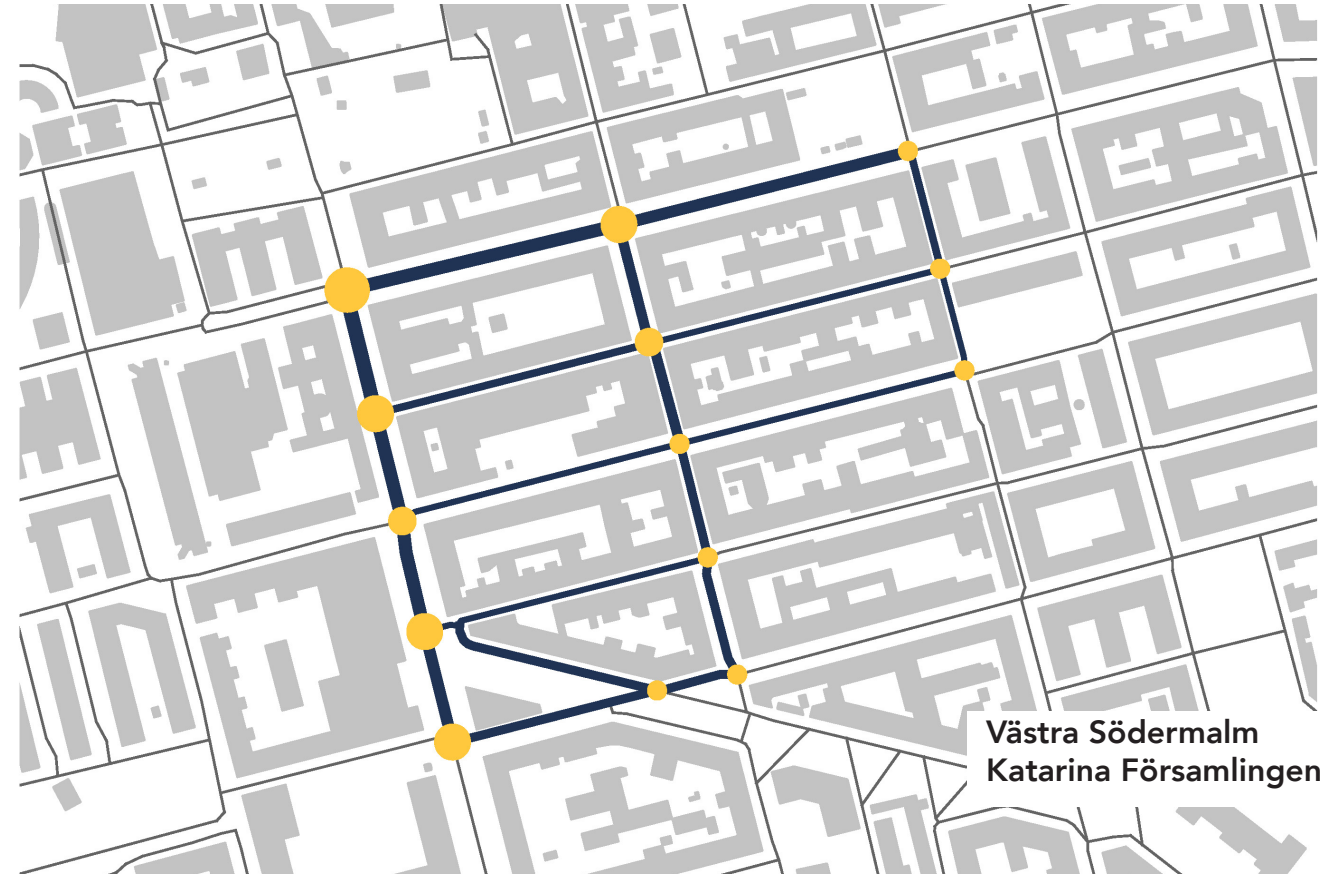
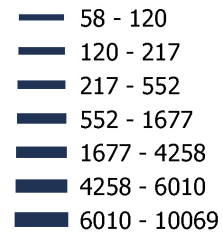
Extracted data

Flows and presence

### Full-day presence



### Full-day flows



### aggregate information:

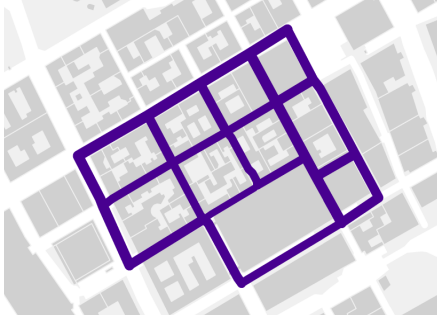
- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
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- > the fluctuation of movement intensity during the day, from 6:00 to 22:00
- > the average speed of movement



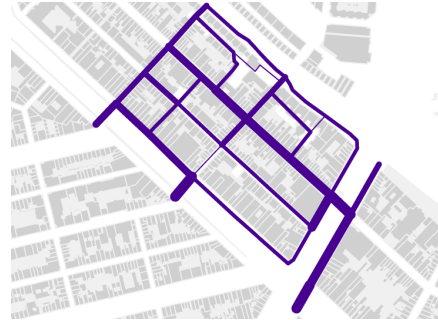
## Results

Extracted data

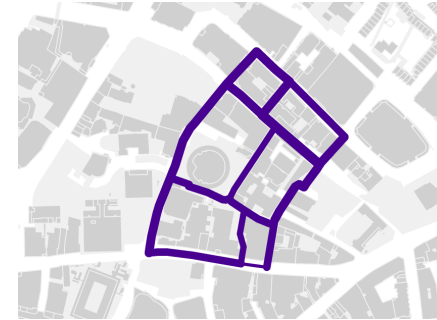
Full day flows



Stockholm  
Density type:  
Dense mid-rise  
Norrmalm



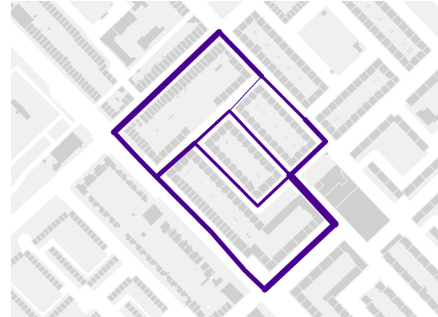
3.  
Amsterdam  
Density type:  
Compact mid-rise  
Haarlemmersbuurt



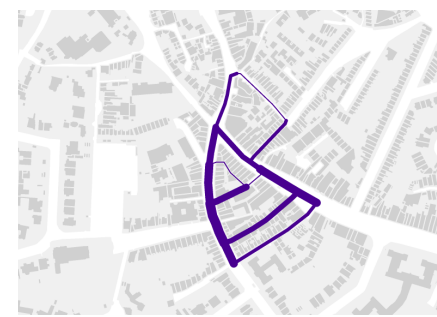
5.  
London  
Density type:  
Dense mid-rise  
Cornhill



2.  
Stockholm  
Density type:  
Spacious mid-rise  
Västertorp

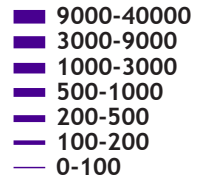


4.  
Amsterdam  
Density type:  
Spacious low-rise  
Watergraafsmeer



6.  
London  
Density type:  
Compact low-rise  
Hampstead station

### Full-day flows



### aggregate information:

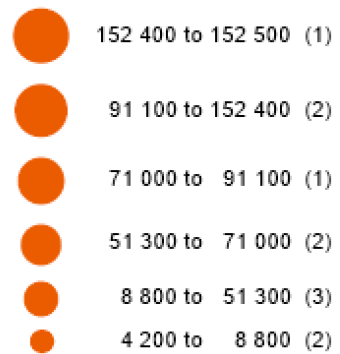
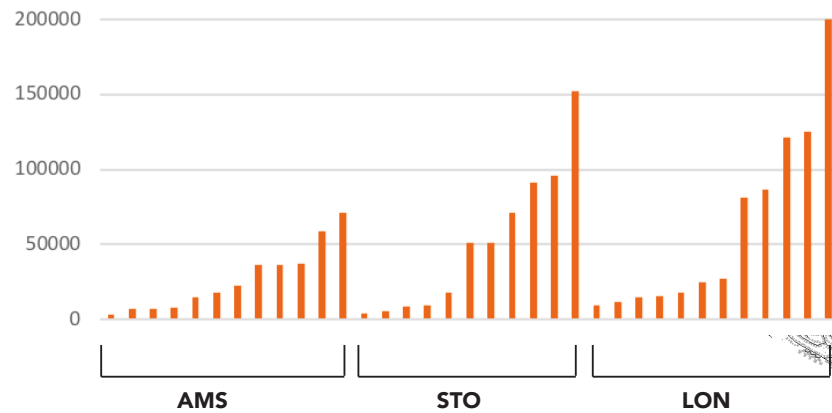
- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the overall presence of people in each area on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the fluctuation of movement intensity during the day, from 6:00 to 22:00
- > the average speed of movement



## Results

## Extracted data

Full-day presence\_Stockholm

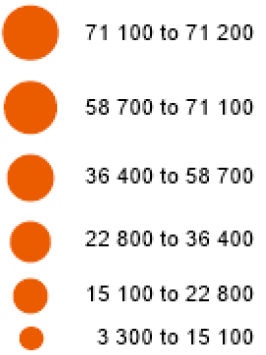
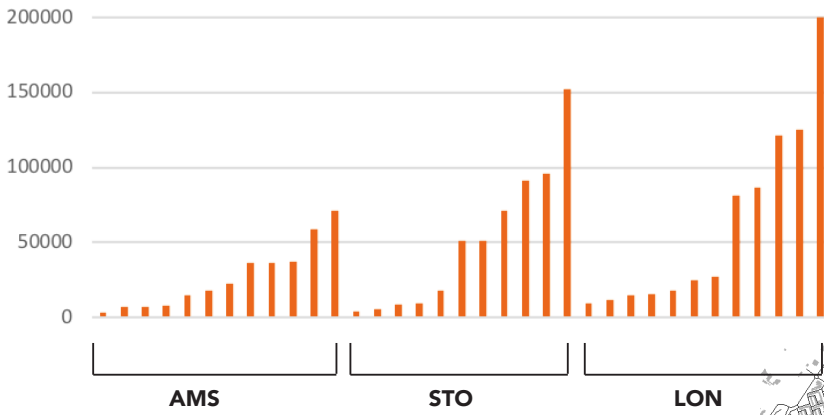




Results

Extracted data

Full-day presence\_Amsterdam

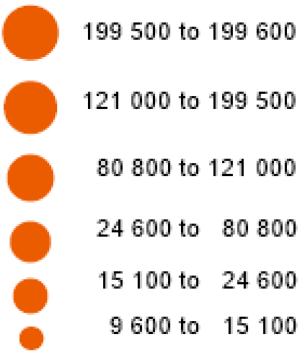
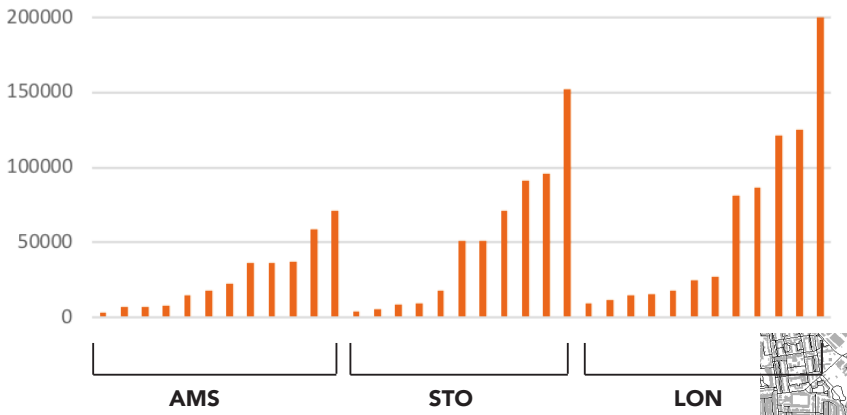




Results

Full-day presence\_London

Extracted data

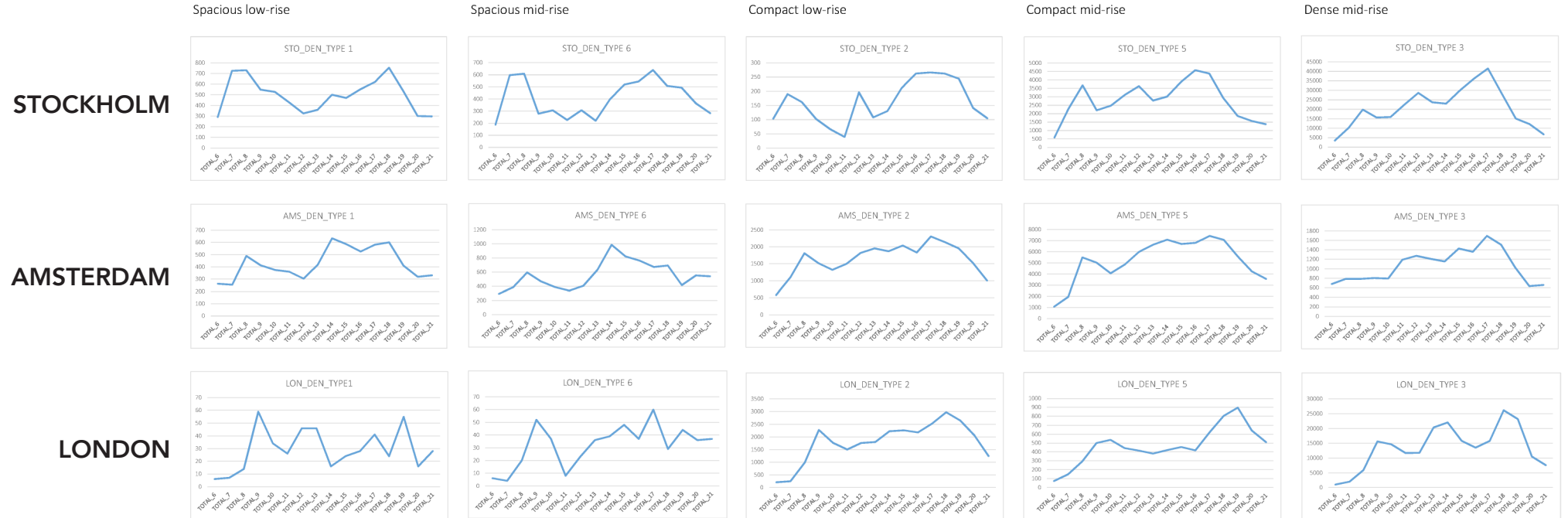




# Results

Extracted data

Fluctuation of flow intensity



aggregate information:

- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the overall presence of people in each area on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the fluctuation of movement intensity during the day, from 6:00 to 22:00\*
- > the average speed of movement\*

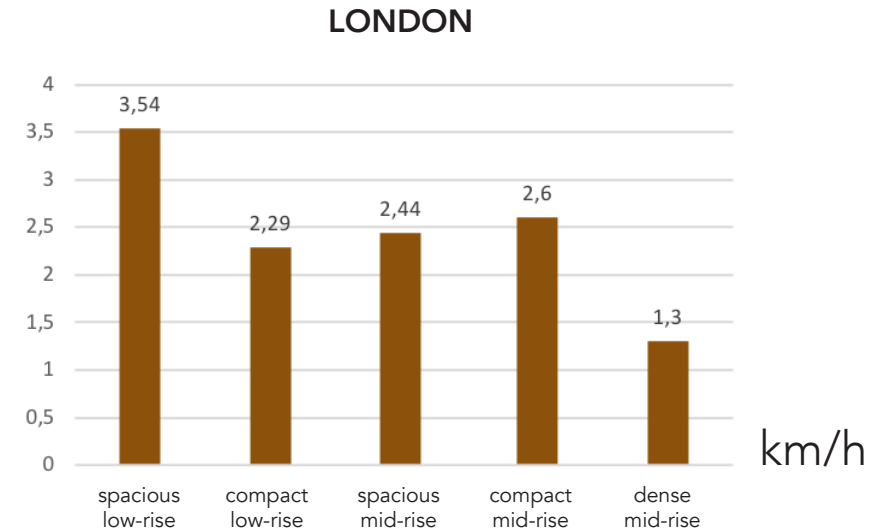
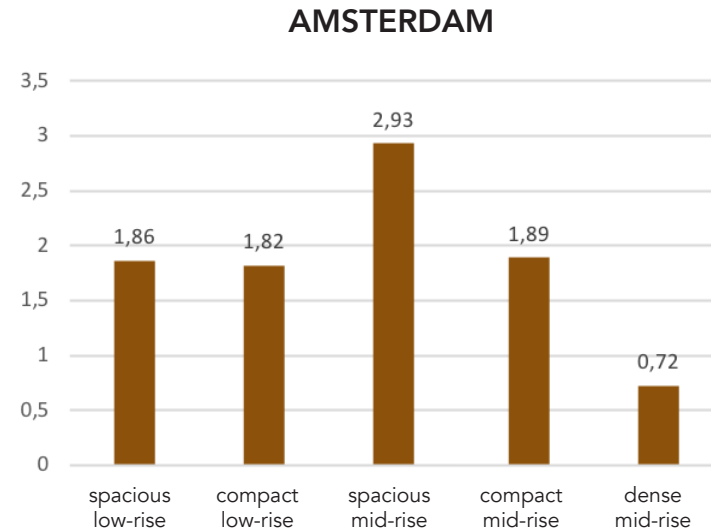
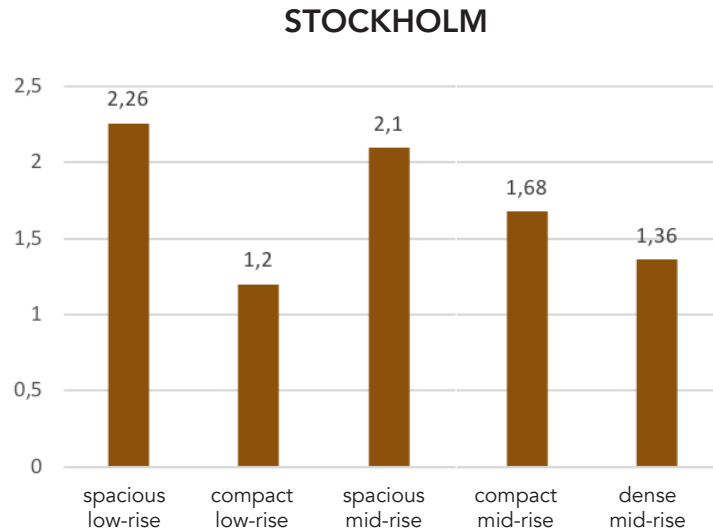
\*the results can be aggregated in different ways, per city, per area, per density type, per centrality type



## Results

Extracted data

Average speed of movement



### aggregate information:

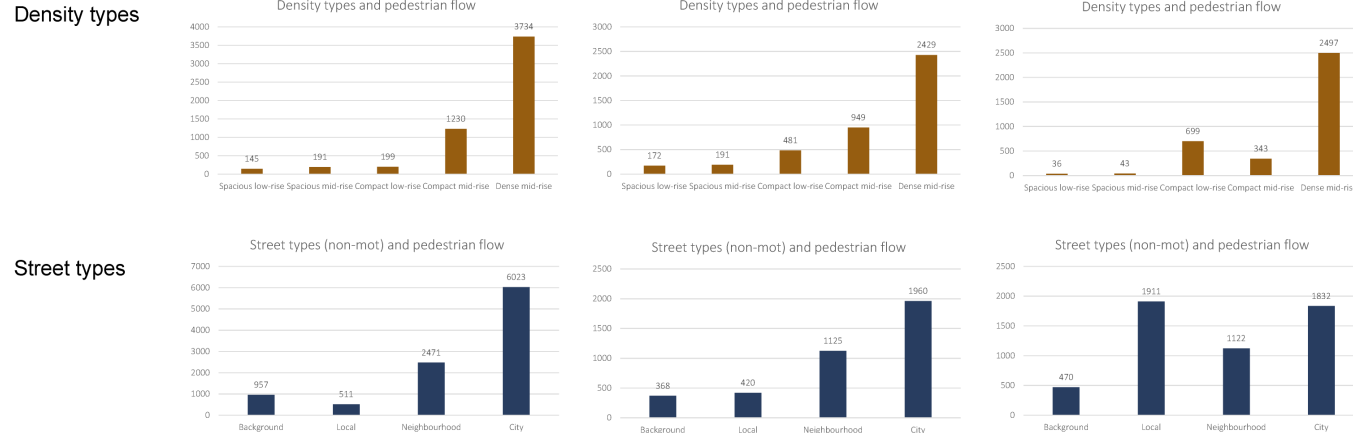
- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the overall presence of people in each area on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the fluctuation of movement intensity during the day, from 6:00 to 22:00\*
- > the average speed of movement\*

\*the results can be aggregated in different ways, per city, per area, per density type, per centrality type



## Street centrality and Built density

|           |       |       |       |       |       |       |
|-----------|-------|-------|-------|-------|-------|-------|
| Stockholm | 0.133 | 0.000 | 0.174 | 0.000 | 0.453 | 0.000 |
| Amsterdam | 0.183 | 0.000 | 0.161 | 0.000 | 0.547 | 0.000 |
| London    | 0.386 | 0.000 | 0.095 | 0.000 | 0.525 | 0.000 |



**Berghauser Pont, M., Stavroulaki, G., Marcus, L., (2018), 'Development of Urban Types, based on Network Centrality and Built Density, and their Impact on Pedestrian Movement', Environment and Planning B, *under review***

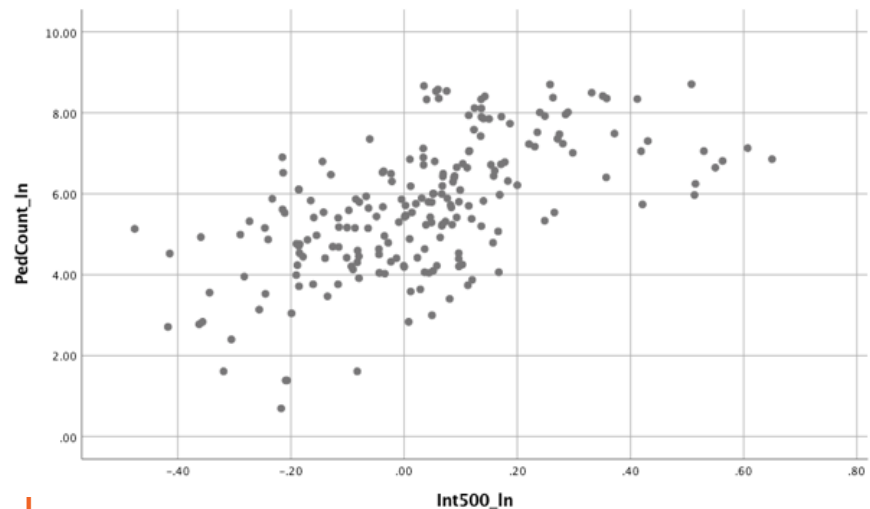
- > improve the statistical methods (spatial statistics)
- > add more variables e.g. attractions
- > add more data, cities





Applications

Explaining pedestrian flows  
Street centrality and Built density



Stockholm

| Model                                 | R                 | R Square | Adjusted R Square | Std. Error of the Estimate |
|---------------------------------------|-------------------|----------|-------------------|----------------------------|
| 1                                     | .593 <sup>a</sup> | .352     | .349              | 1.29424                    |
| a. Predictors: (Constant), Int500m_In |                   |          |                   |                            |
| b. Dependent Variable: PedCount_In    |                   |          |                   |                            |
| N. 214                                |                   |          |                   |                            |

next steps

- > improve the statistical model  
(add spatial factor, add more variables e.g. attractions)
- > add more data, cities

Stockholm

| Model Summary <sup>b</sup> |                   |          |                   |                            |               |
|----------------------------|-------------------|----------|-------------------|----------------------------|---------------|
| Model                      | R                 | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
| 1                          | .723 <sup>a</sup> | .523     | .515              | 1.14282                    | 1.466         |

a. Predictors: (Constant), InFSI\_500, InInt\_1000, InPlot500\_In  
b. Dependent Variable: PedCount\_In

London

| Model Summary <sup>b</sup> |                   |          |                   |                            |               |
|----------------------------|-------------------|----------|-------------------|----------------------------|---------------|
| Model                      | R                 | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
| 1                          | .780 <sup>a</sup> | .608     | .600              | 1.27918                    | 1.457         |

a. Predictors: (Constant), InFSI\_500, InBet\_500, InInt\_1000, InPlot\_500  
b. Dependent Variable: PedCount\_In

Amsterdam

| Model Summary <sup>b</sup> |                   |          |                   |                            |               |
|----------------------------|-------------------|----------|-------------------|----------------------------|---------------|
| Model                      | R                 | R Square | Adjusted R Square | Std. Error of the Estimate | Durbin-Watson |
| 1                          | .654 <sup>a</sup> | .428     | .419              | 1.14858                    | 1.804         |

a. Predictors: (Constant), InFSI\_500, InBet4000, InInt1000, InPlot\_500  
b. Dependent Variable: PedCount\_In

# Methodology and results of an international observational study on pedestrian movement tracking anonymised Wi-Fi signals from mobile phones

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