AESOP Annual Congress, Gothenburg, 2018 July 10-14

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

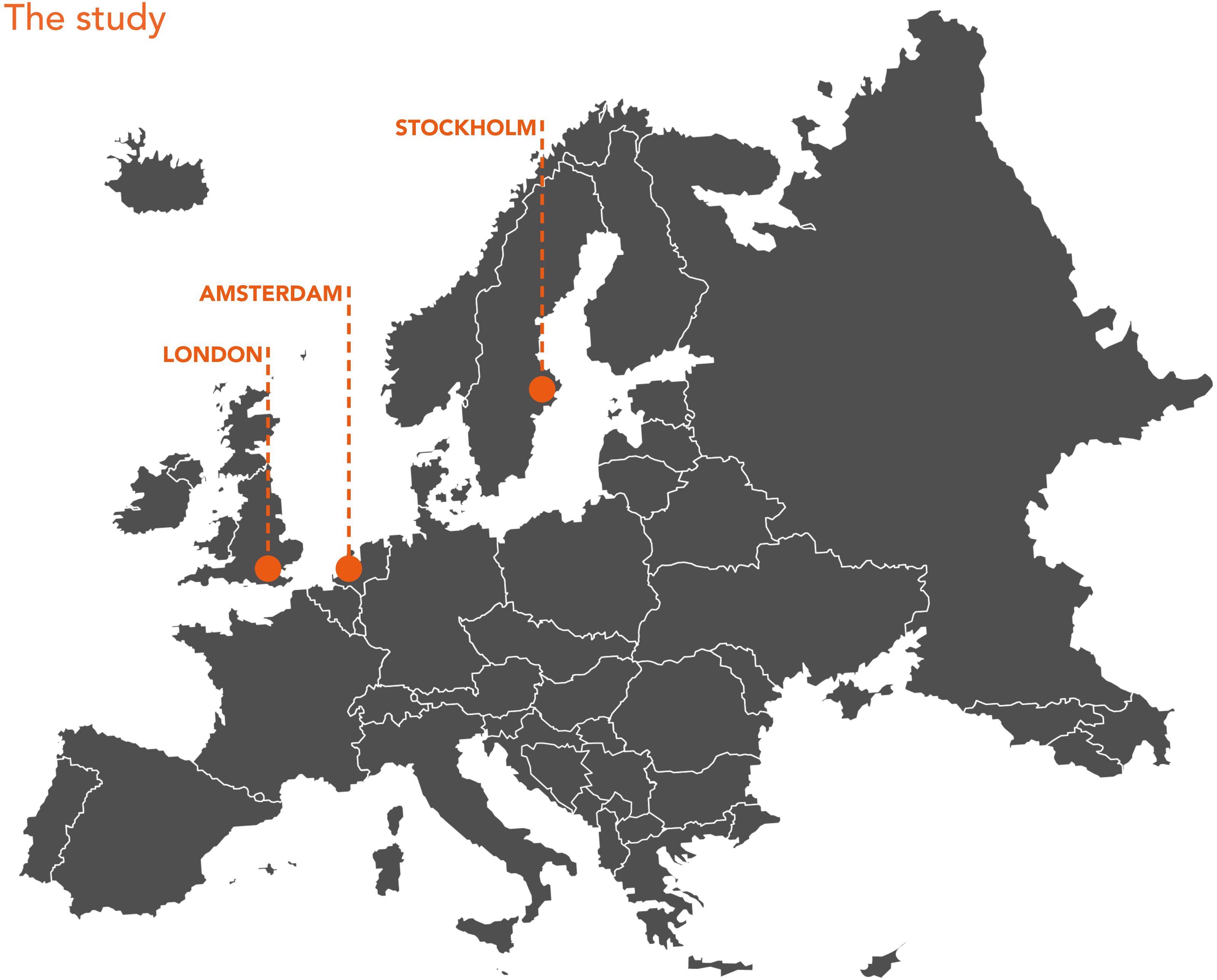
Gianna Stavroulaki[1], Meta Berghauser Pont[1], Lars Marcus[1], Kailun Sun[1], Staffan Liljestrand[2]

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

2. Bumbee Labs, Consultancy firm, Stockholm

CHALMERS
UNIVERSITY OF TECHNOLOGY

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 Desing 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

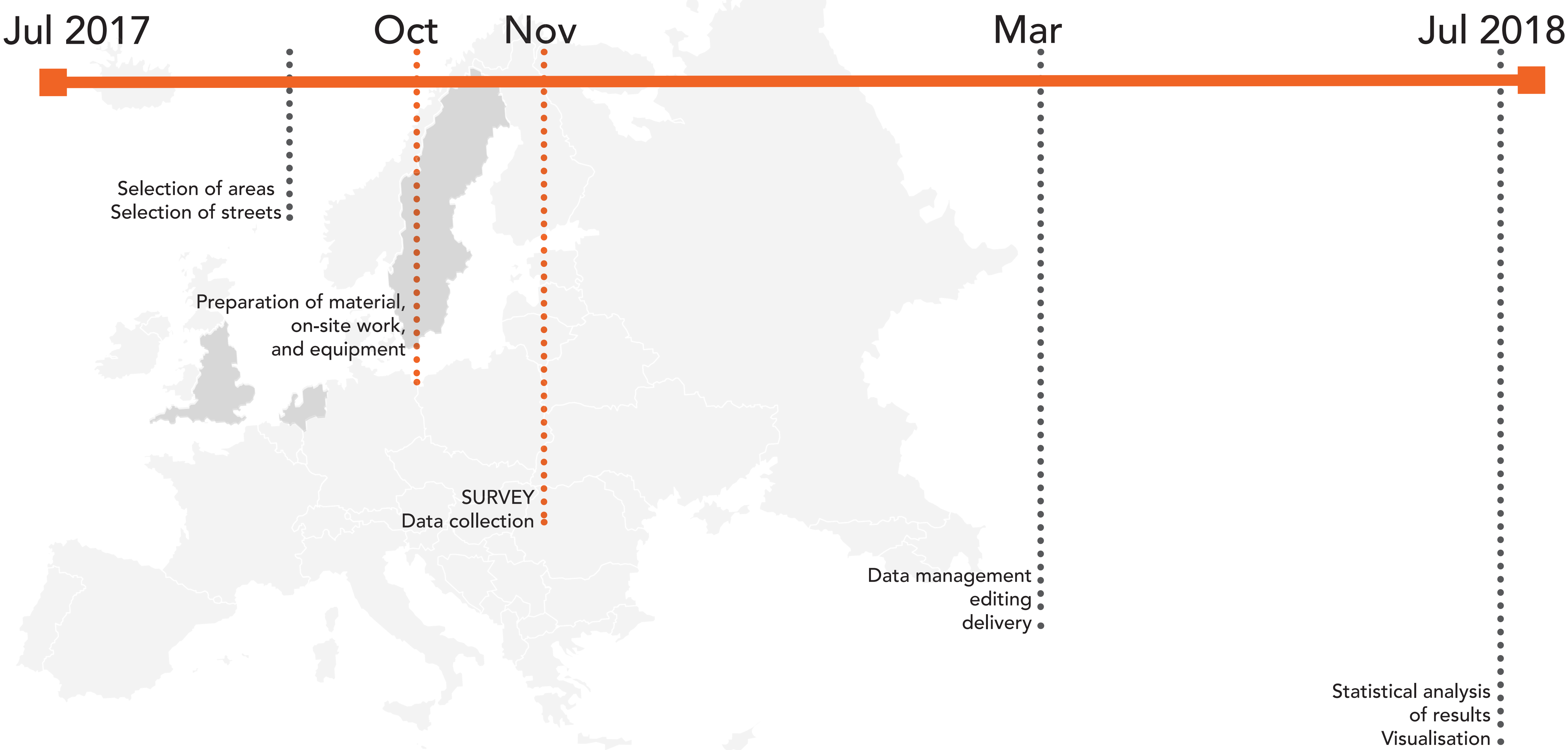
MON to FRI

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



Jul 2017
Oct
Nov
Mar
Jul 2018
Selection of areas
Selection of streets
Preparation of material,
on-site work,
and equipment
SURVEY
Data collection
Data management
editing
delivery
Statistical analysis
of results
Visualisation

The context
International Spatial Morphology Lab

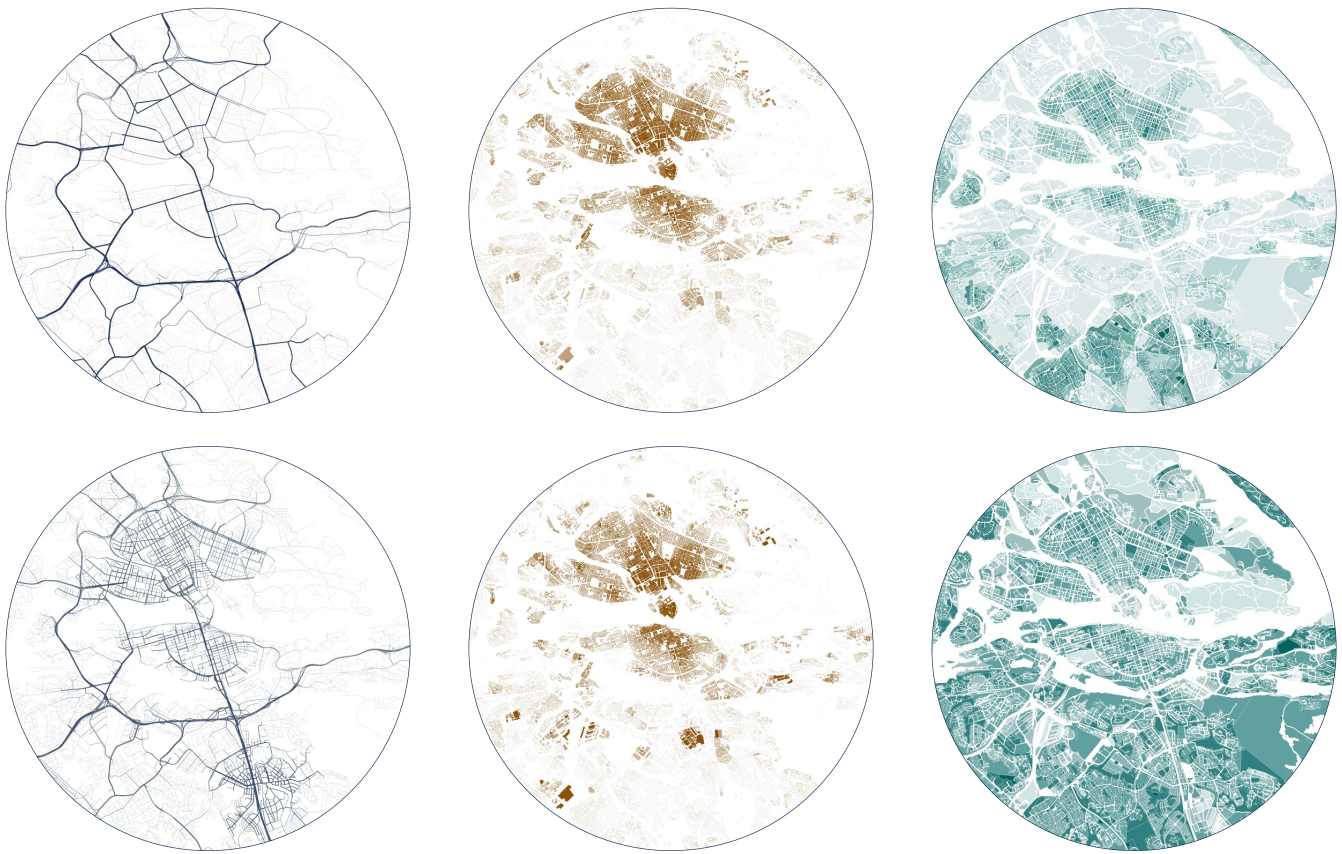
www.smog.chalmers.se

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

Motorised Non-motorised

Stockholm
Gothenburg
Eskilstuna

Stockholm
Amsterdam
London



STREETS
Distance

BUILDINGS
Density

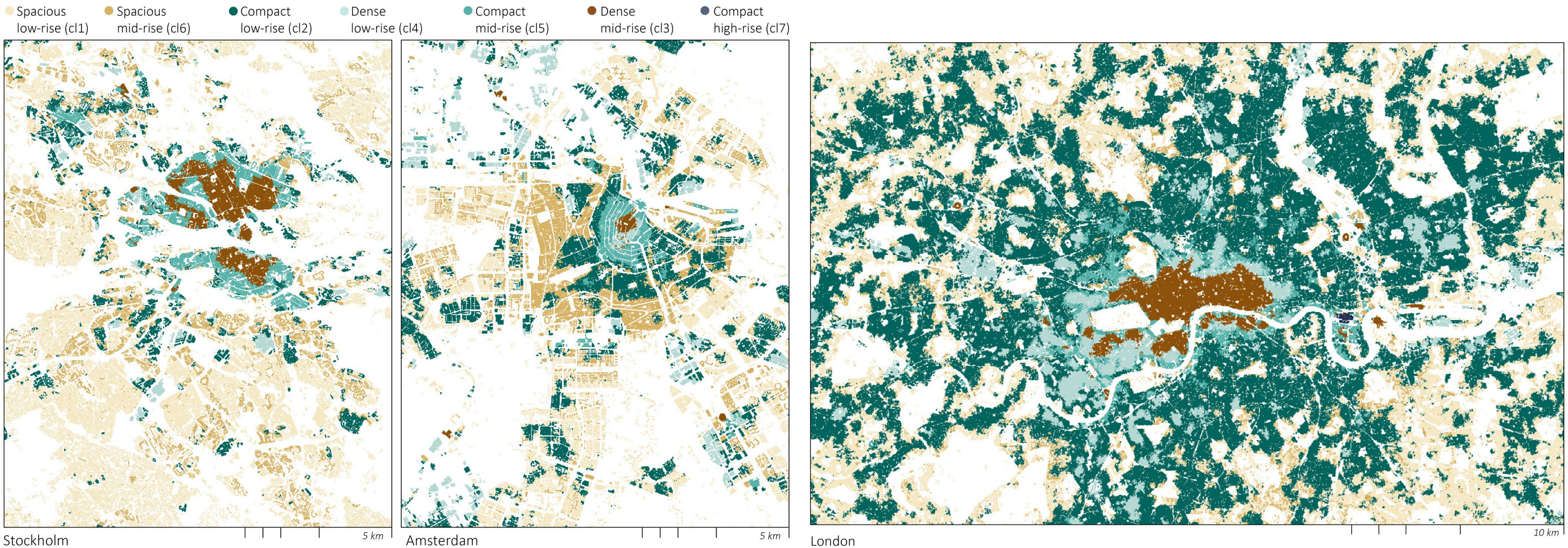
PLOTS
Differentiation

TYPOLOGIES of SPATIAL FORM
Density types
Centrality types
Differentiation types

RELATION TO URBAN PROCESSES

Sample selection

Areas_Variation in Density types

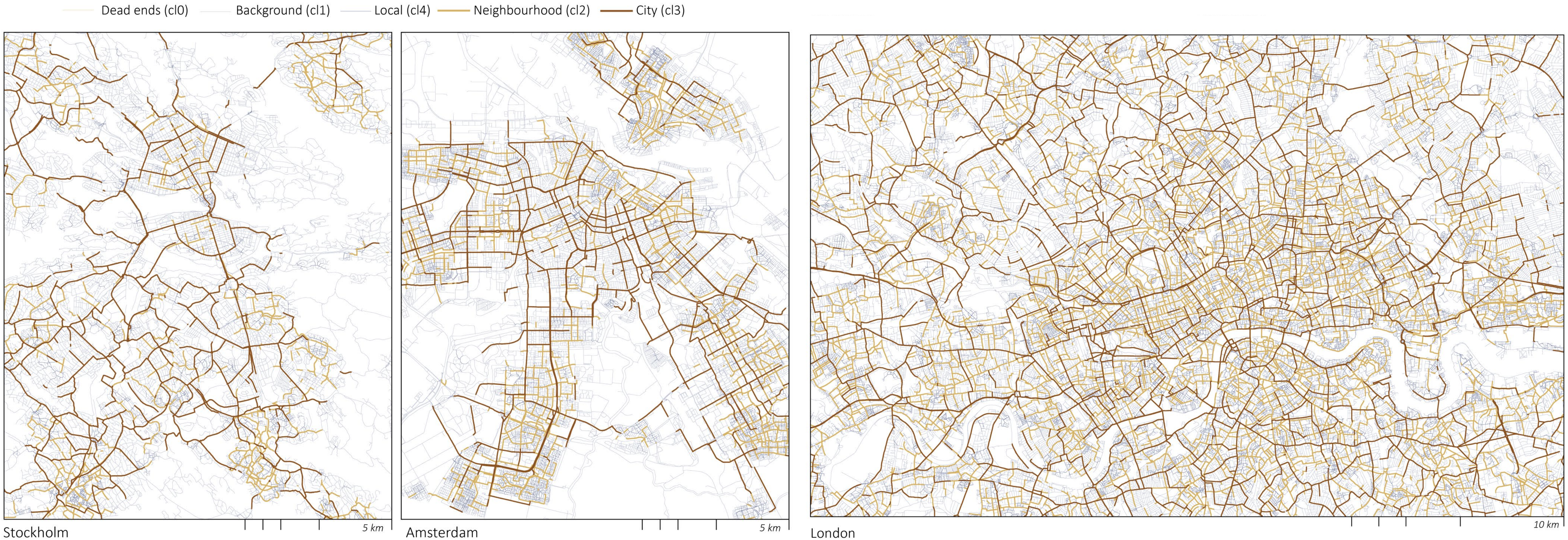


Distribution of built density types in Amsterdam, Stockholm and London (types are based on Accessible FSI, GSI in 500m)

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



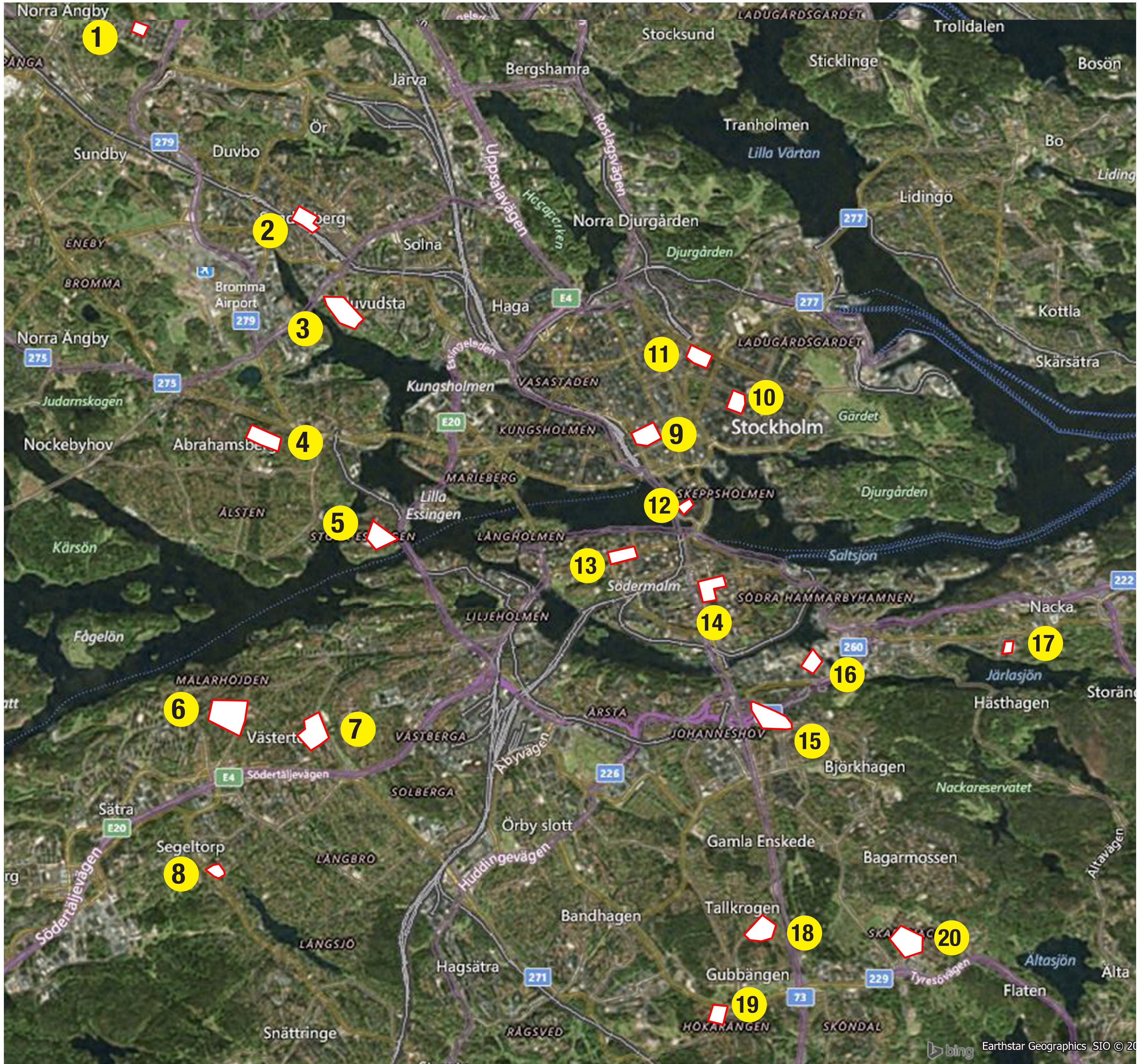
Distribution of street types in Amsterdam, Stockholm and Lodon (types are based on network betweeness centrality in 10 scales from 500m to 5km)

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.

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
Study areas

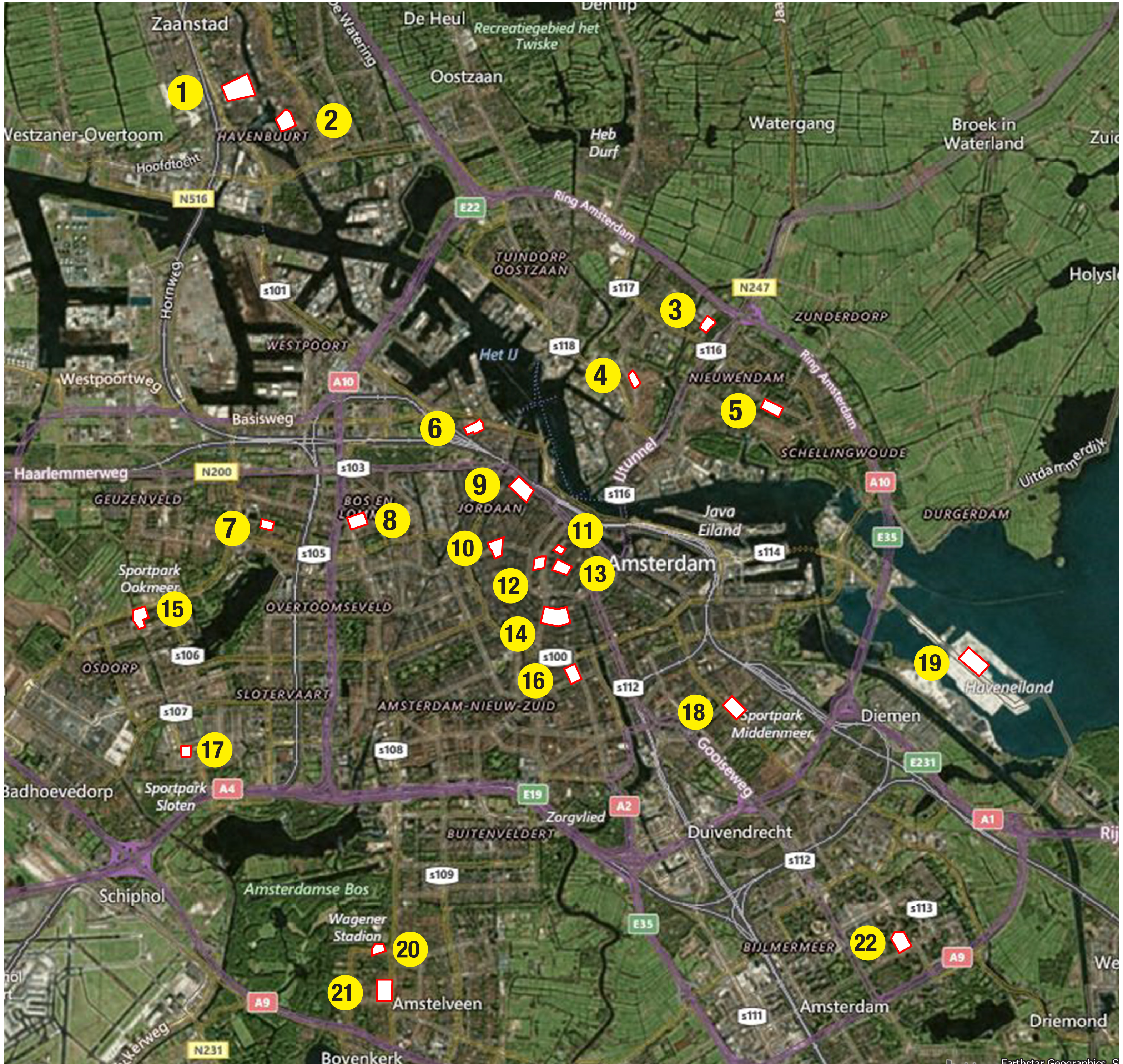


Stockholm

Oct. 01-Oct.07

1 ~~Rinkeby~~
2 Sundbyberg
3 Jungfrudansen
4 Stora Mossen
5 Stora Essingen
6 Mälarhöjden
7 Västertorp
8 Segeltorp
9 Norrmalm
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

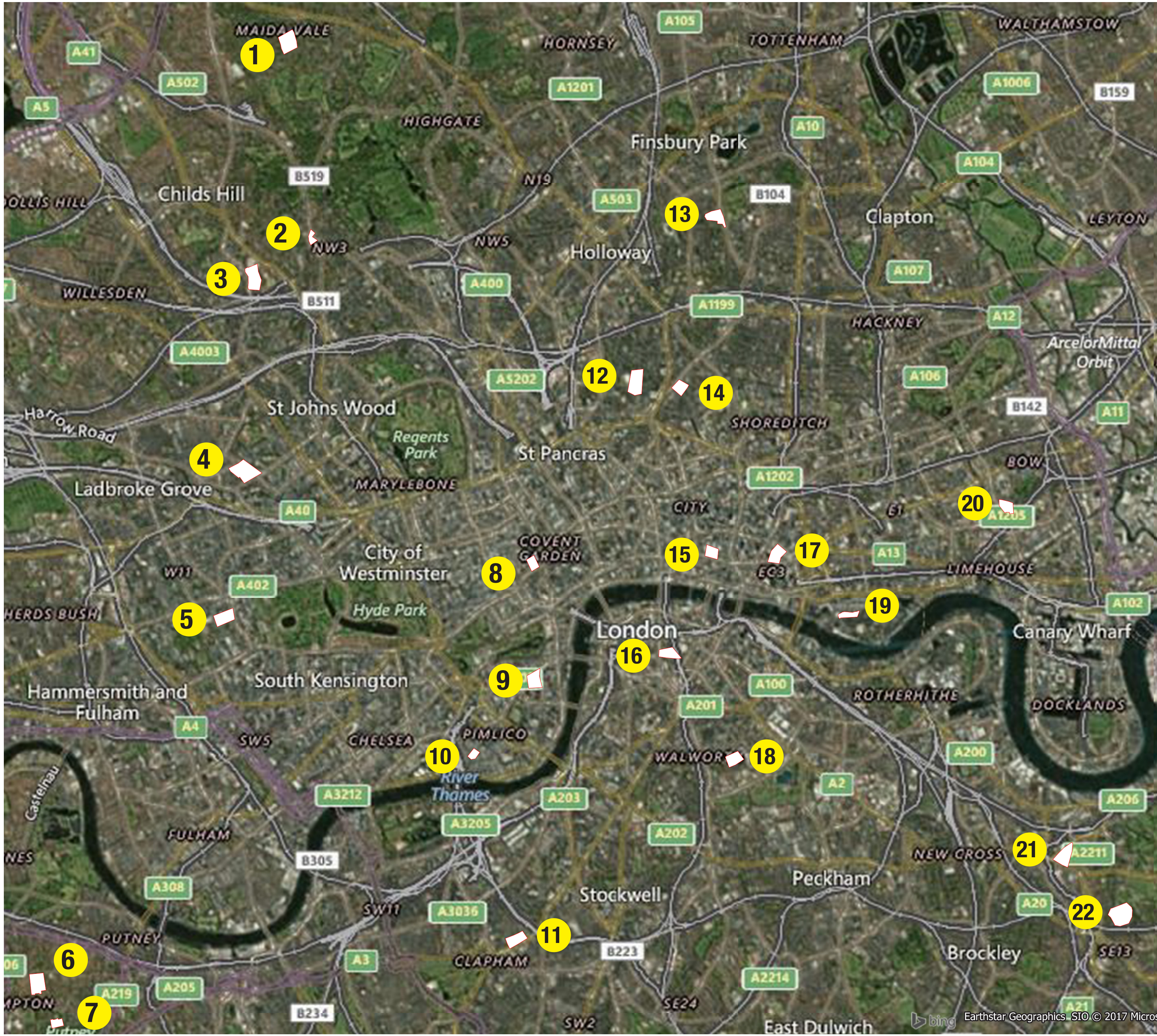
Sample
Study areas



Amsterdam
Oct. 08-Oct.14

1. ~~Zaandam, Russische Buurt~~
2. ~~Zaandam, Poelenburg~~
3. Noord, Kadoelen
4. Noord (Kamperfoelieweg 200)
5. Noord, Nieuwendam
6. Spaarndammer en zeeheldenbuurt
7. Slotermeer-noordoost
8. Bos en Lommer
9. Haarlemmerbuurt
10. Jordaan
11. ~~De Wallen (Warmoesstraat 163)~~
12. Burgwallen Nieuwe Zijde
13. De Wallen (Oudezijds Voorburgwal 181)
14. ~~Grachtengordel (Herengracht 498)~~
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

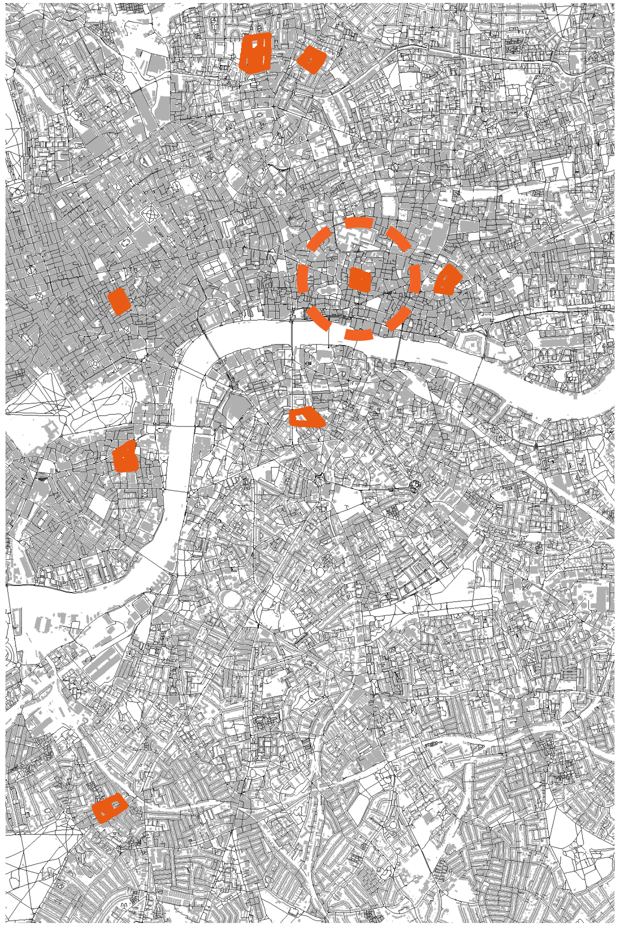


London
Oct. 15-Oct.21

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 Walworth (Merrow St, Portland St)~~
~~19 Wapping (Kennet St)~~
~~20 Mile End (Eric St, Joseph St.)~~
~~21 Greenwich (Egerton Dr, A2, A206)~~
~~22 Lewisham (Waleran Rd)~~

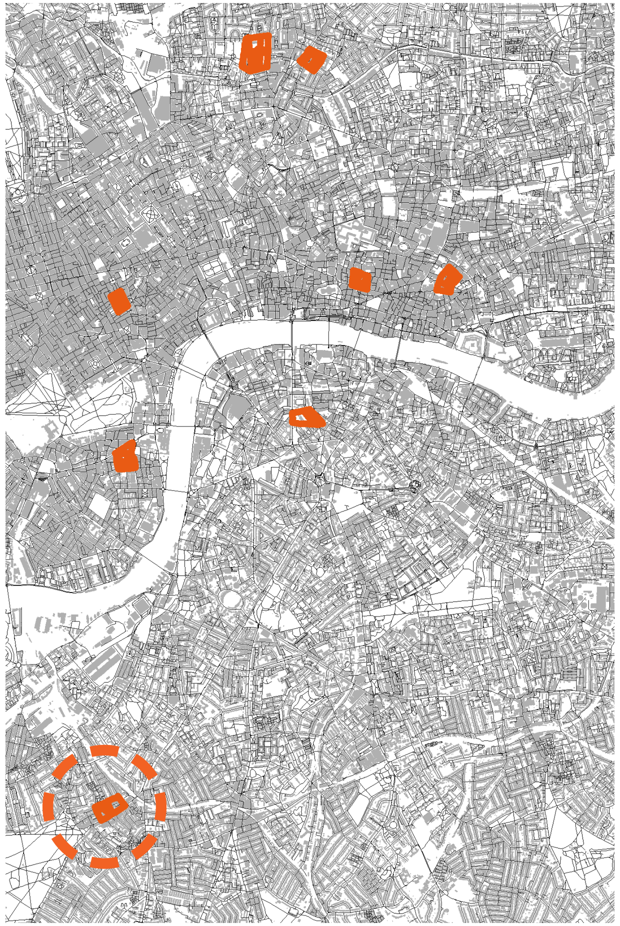
Sample

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)

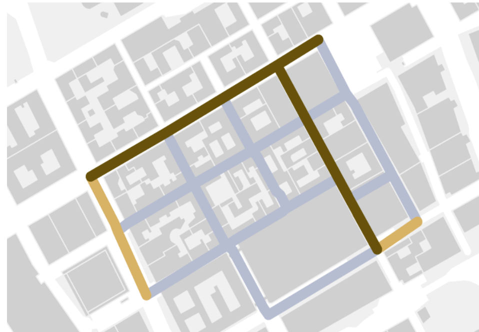
Sample

Examples of areas and street types

De Pijp, Amsterdam
(compact mid-rise)

Sample

Examples of areas and street types

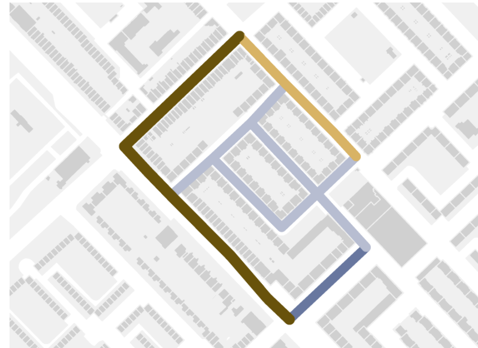


1.
Stockholm
Density type:
Dense mid-rise
Norrmalm

2.
Stockholm
Density type:
Spacious mid-rise
Västertorp

3.
Amsterdam
Density type:
Compact mid-rise
Haarlemmersbuurt

city
neighborhood
very local
background



4.
Amsterdam
Density type:
Spacious low-rise
Watergraafsmeer

5.
London
Density type:
Dense mid-rise
Cornhill

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

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).

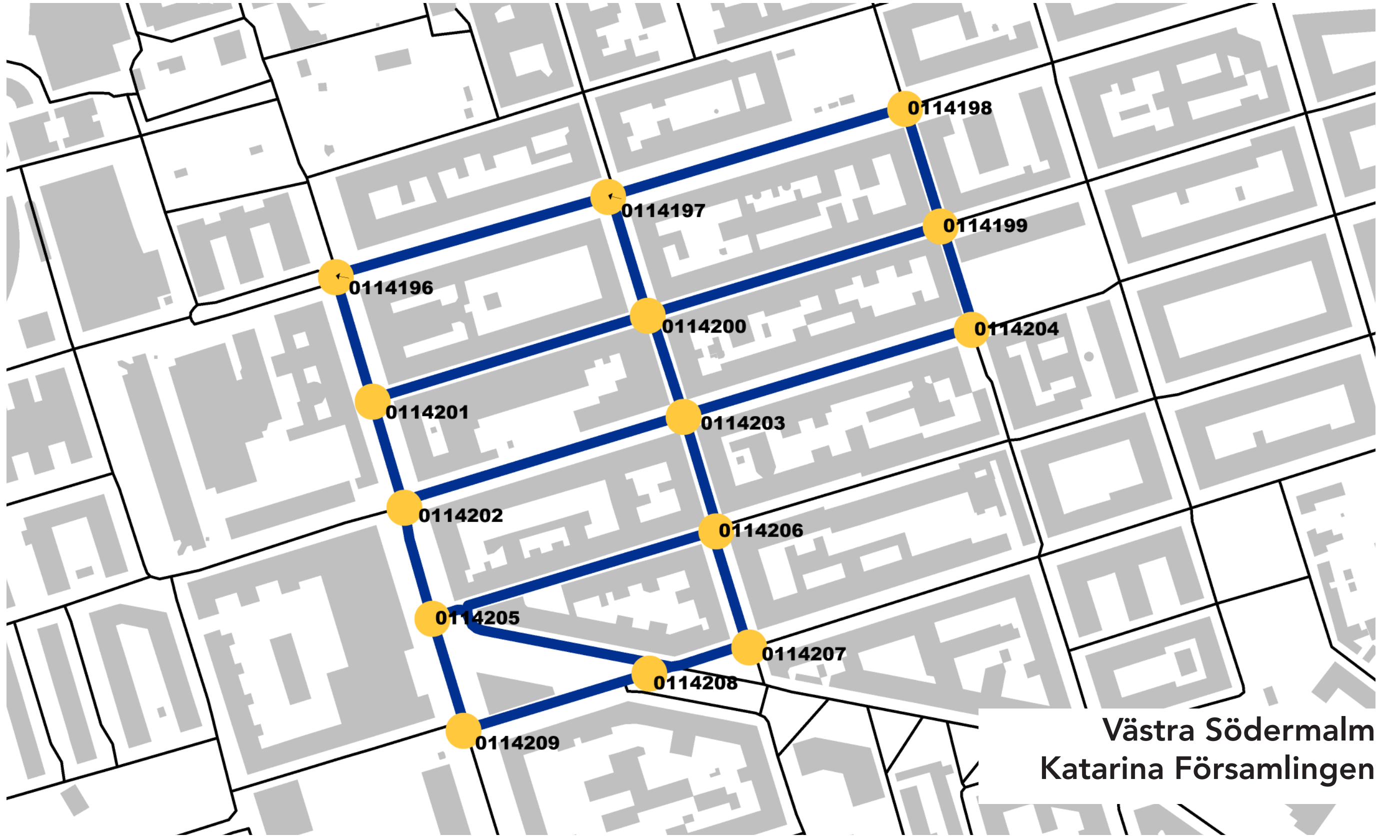
> Each sample includes a timestamp, a RSSI (Received Signal Strength Indication) and an anonymized indicator. The RSSI gives us a the distance of the phone from the antenna.

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. he 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.*

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:

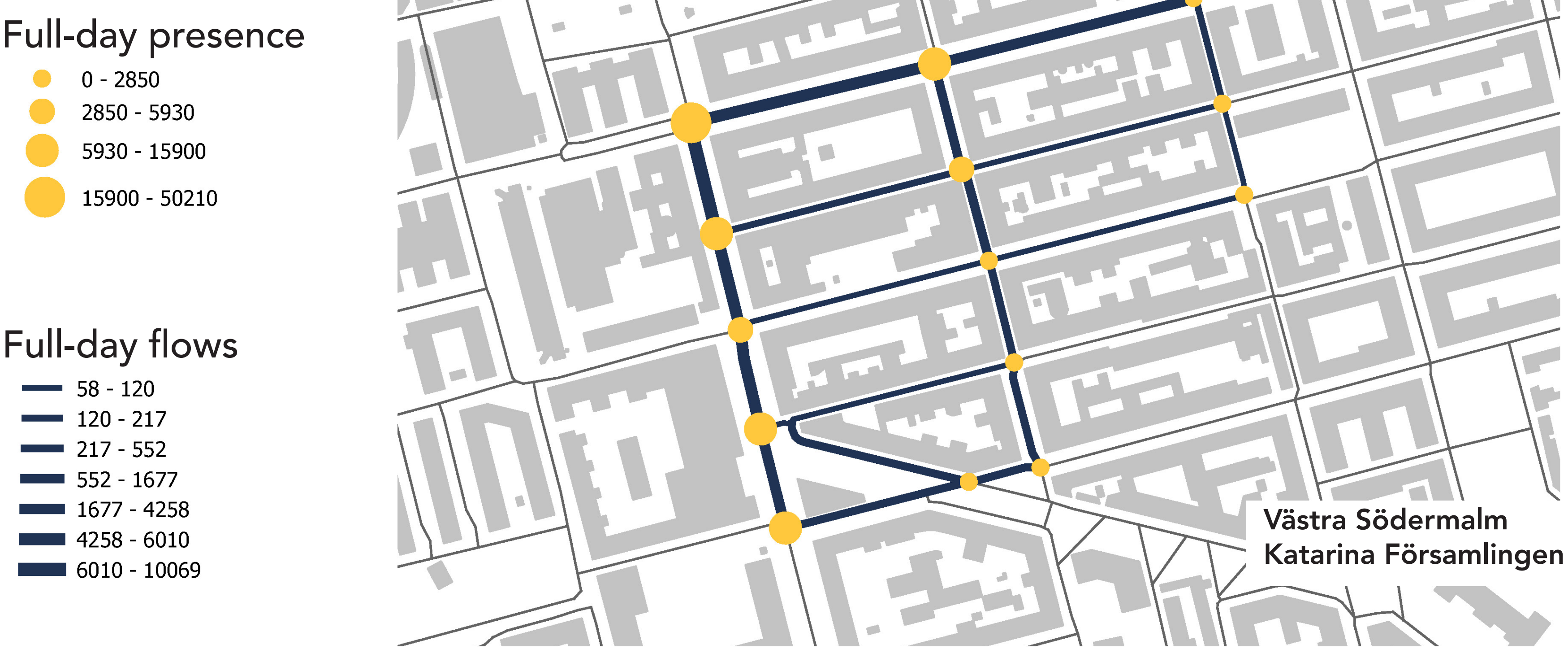
> the unique path of each phone/unonymised pedestrian
> the direction of movement
> the speed of movement
> the duration of each trip through the area

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

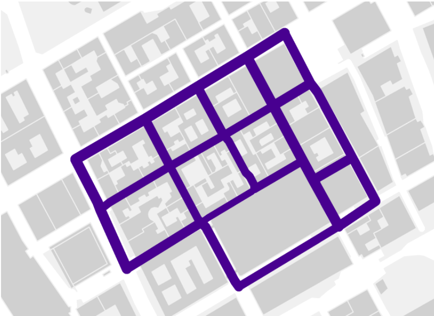


aggregate information:

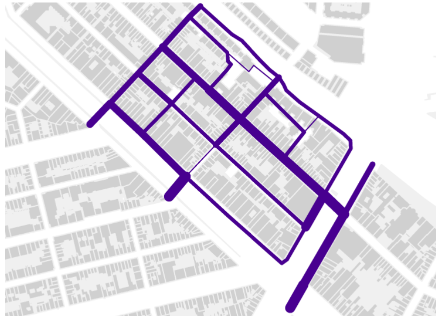
> the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
> the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
> the overall presence of people in each area on different time-frames (e.g. 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

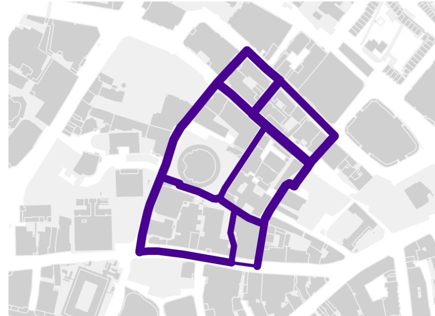
Extracted data
Full day flows



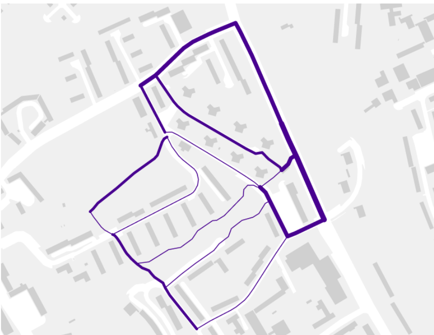
Stockholm
Density type:
Dense mid-rise
Norrmalm



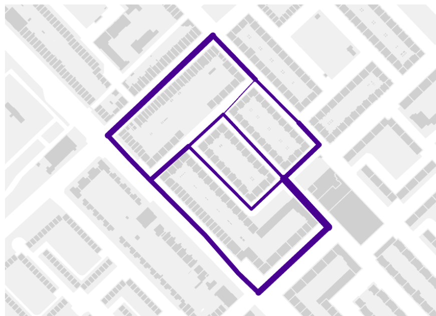
3.
Amsterdam
Density type:
Compact mid-rise
Haarlemmersbuurt



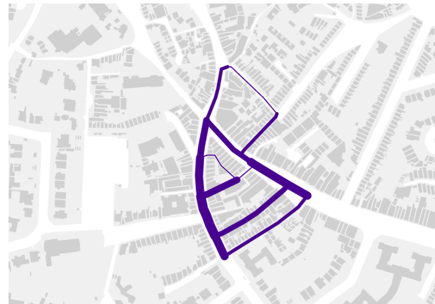
5.
London
Density type:
Dense mid-rise
Cornhill



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

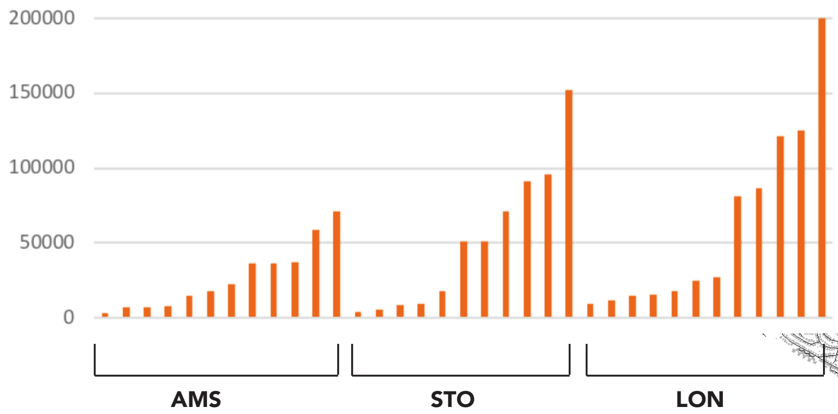
- 9000-40000
- 3000-9000
- 1000-3000
- 500-1000
- 200-500
- 100-200
- 0-100

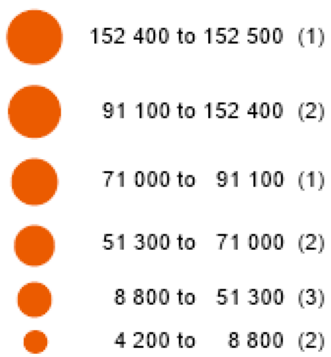
aggregate information:

> 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

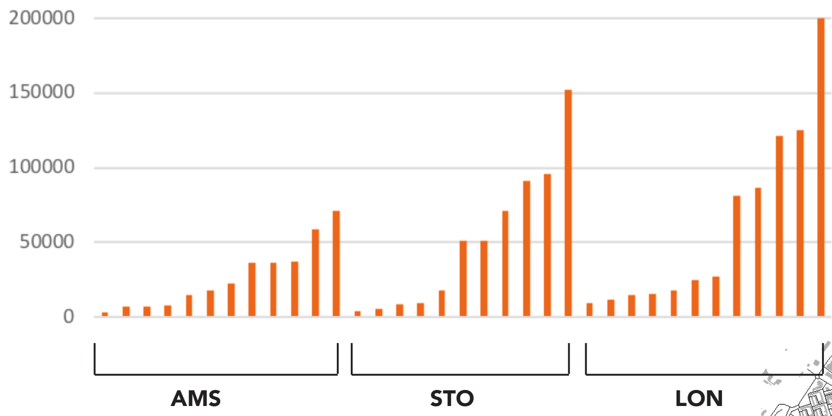




Results

Extracted data

Full-day presence_Amsterdam



71 100 to 71 200

58 700 to 71 100

36 400 to 58 700

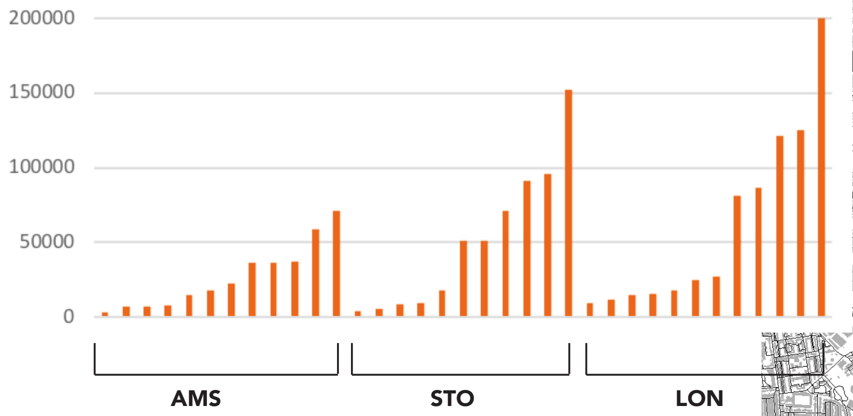
22 800 to 36 400

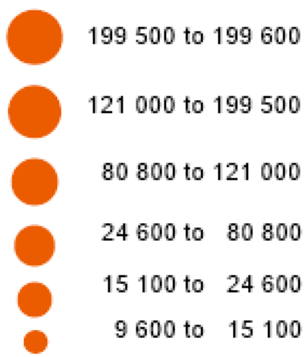
15 100 to 22 800

3 300 to 15 100

Results

Full-day presence_London
Extracted data





Results

Extracted data

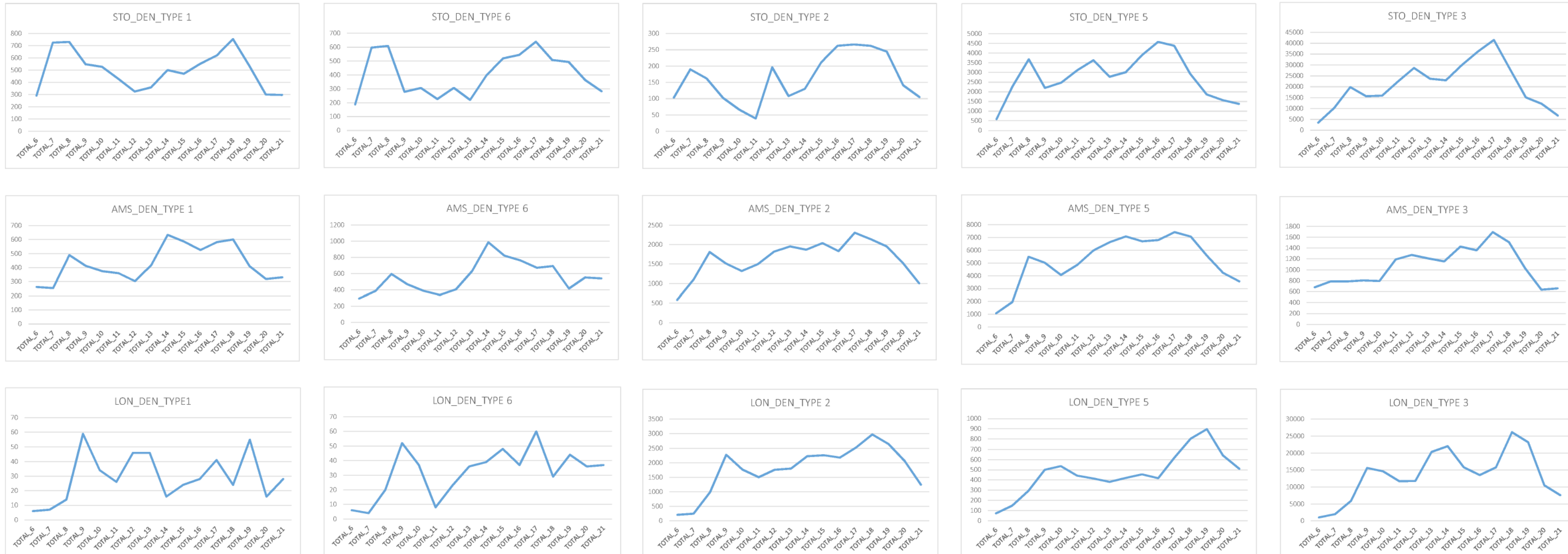
Fluctuation of flow intensity

Spacious low-rise | Spacious mid-rise | Compact low-rise | Compact mid-rise | Dense mid-rise

STOCKHOLM

AMSTERDAM

LONDON

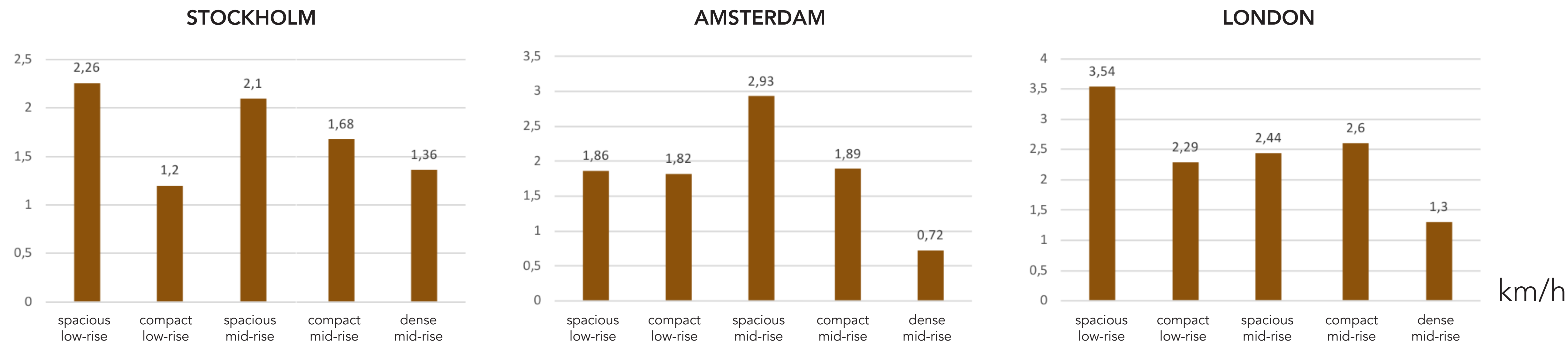


aggregate information:

> 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

Applications and next steps

Explaining pedestrian flows

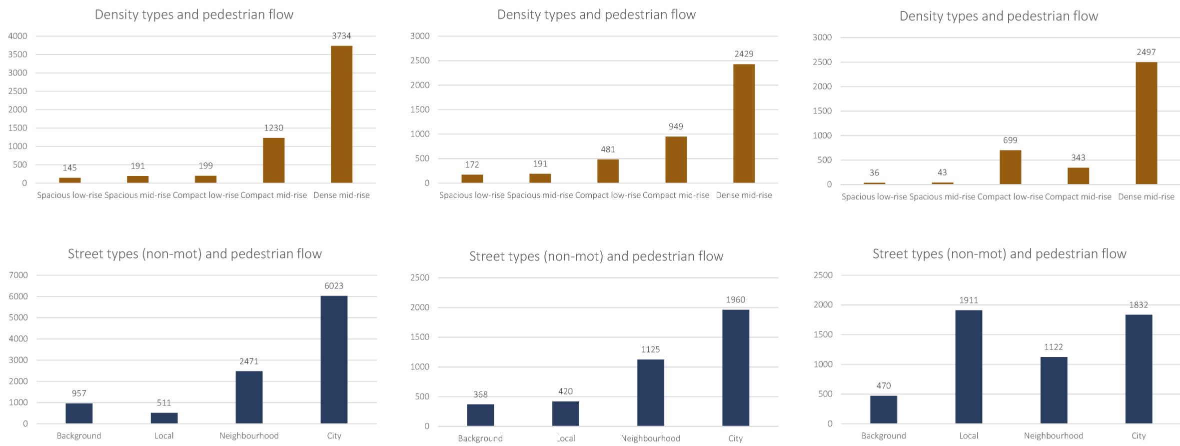
Street centrality and Built density

	ANOVA					
	Density types		Street types		Combined effects	
	R2	Sig.	R2	Sig.	R2	Sig.
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

Stockholm Amsterdam London

Density types

Street types



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*

next steps

> improve the statistical methods (spatial statistics)

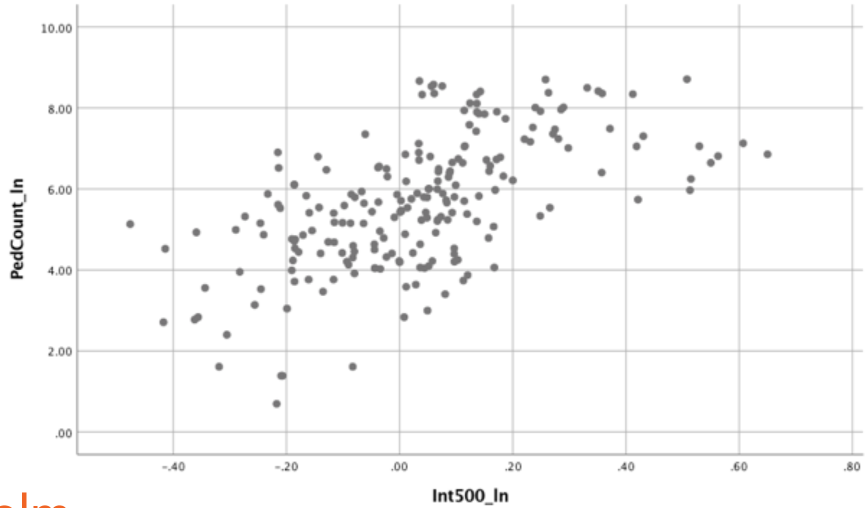
> add more variables e.g. attractions)

> 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[a]	.352	.349	1.29424

a. Predictors: (Constant), Int500m_ln

b. Dependent Variable: PedCount_ln

N. 214

next steps

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

> add more data, cities

Stockholm

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.723[a]	.523	.515	1.14282	1.466

a. Predictors: (Constant), lnFSI_500, lnInt_1000, lnPlot500_ln

b. Dependent Variable: PedCount_ln

London

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.780[a]	.608	.600	1.27918	1.457

a. Predictors: (Constant), lnFSI_500, lnBet_500, lnInt_1000, lnPlot_500

b. Dependent Variable: PedCount_ln

Amsterdam

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.654[a]	.428	.419	1.14858	1.804

a. Predictors: (Constant), lnFSI_500,lnBet4000, lnInt1000, lnPlot_500

b. Dependent Variable: PedCount_ln

AESOP Annual Congress, Gothenburg, 2018 July 10-14

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

Gianna Stavroulaki[1], Meta Berghauser Pont[1], Lars Marcus[1], Kailun Sun[1], Staffan Liljestrand[2]

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

2. Bumbee Labs, Consultancy firm, Stockholm

The authors would like to thank
Ann Legeby, Birgit Hausleitner, Jorge Gil, Alexander Hellervik
for their input in various stages of this study

CHALMERS
UNIVERSITY OF TECHNOLOGY