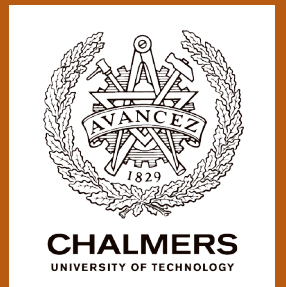


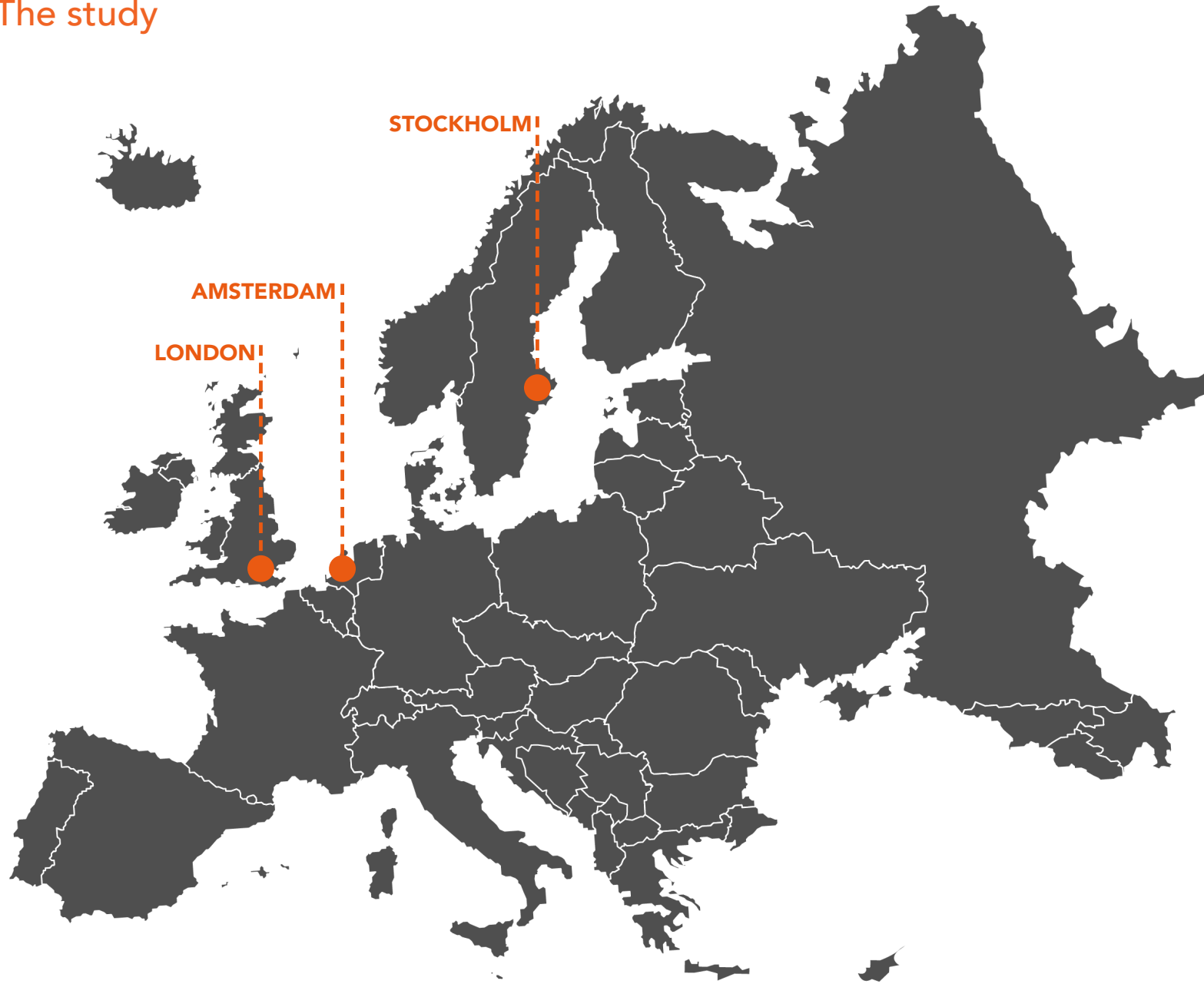
Methodology and results of an international observational study on pedestrian movement tracking anonymised Wi-Fi signals from mobile phones

Gianna Stavroulaki¹, Meta Berghauser Pont¹, Lars Marcus¹, Kailun Sun¹, Staffan Liljestrand²

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 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

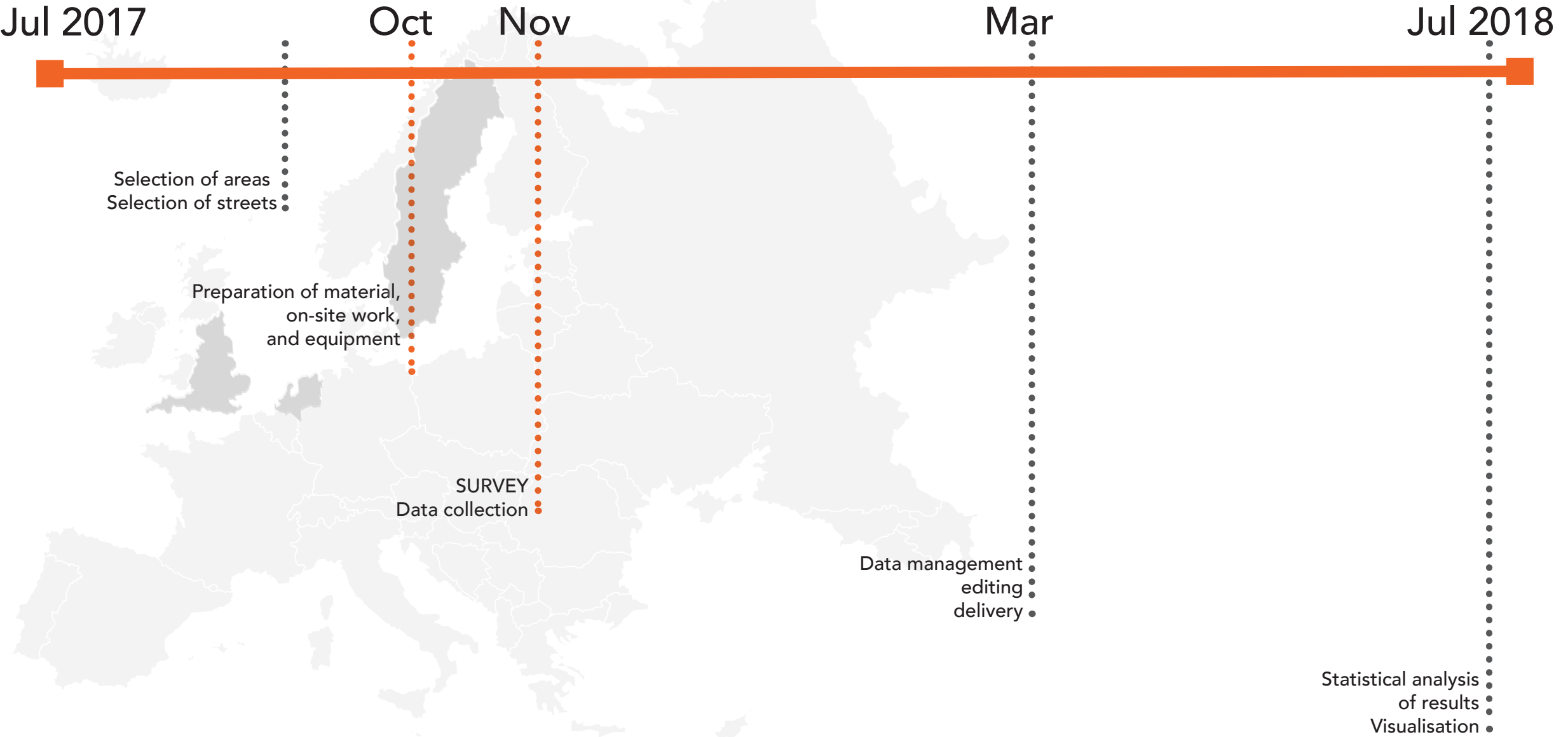
Antonio Sanna, Freelance, Architect

Bumbee Labs

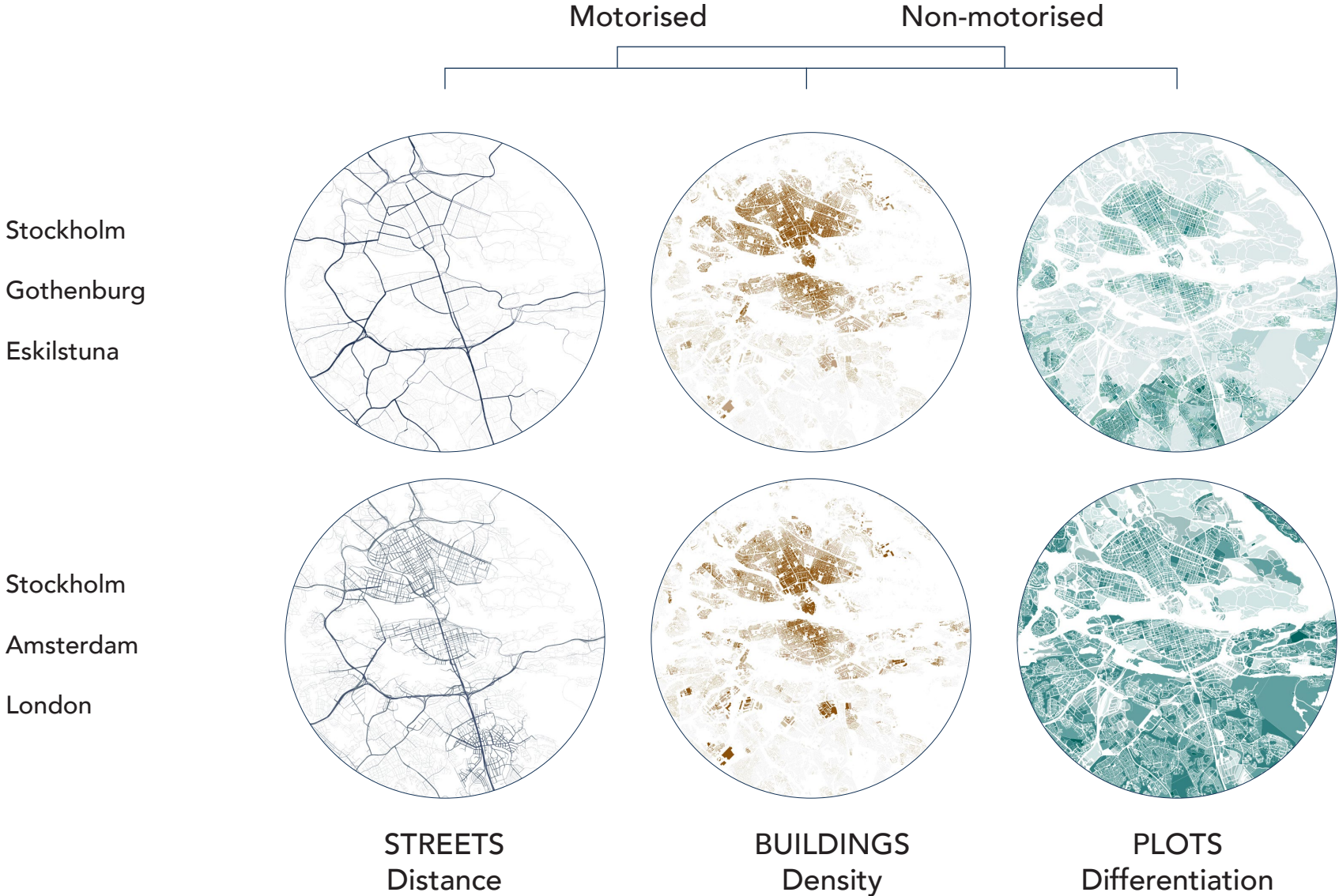
Ludvig Kratz, Data analyst

Christoffer Rydberg, Engineer

The study



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



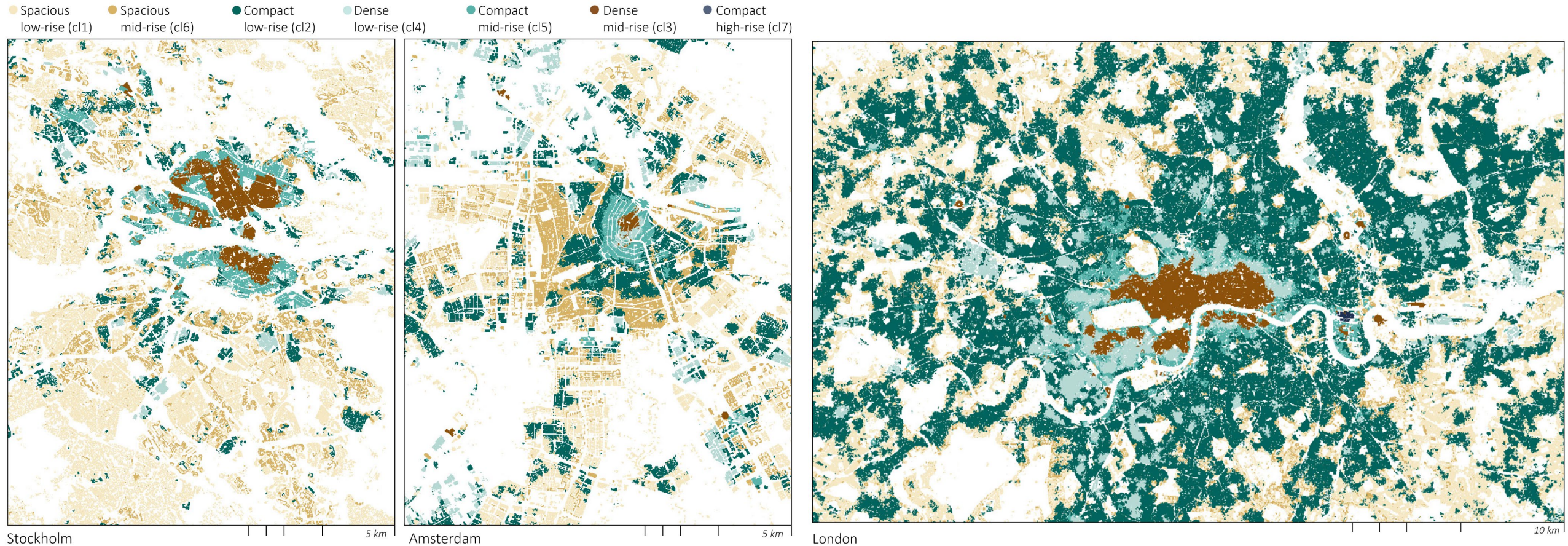
TYPOLOGIES of SPATIAL FORM
Density types
Centrality types
Differentiation types

RELATION TO URBAN PROCESSES



Sample selection

Areas_Variation in Density types



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

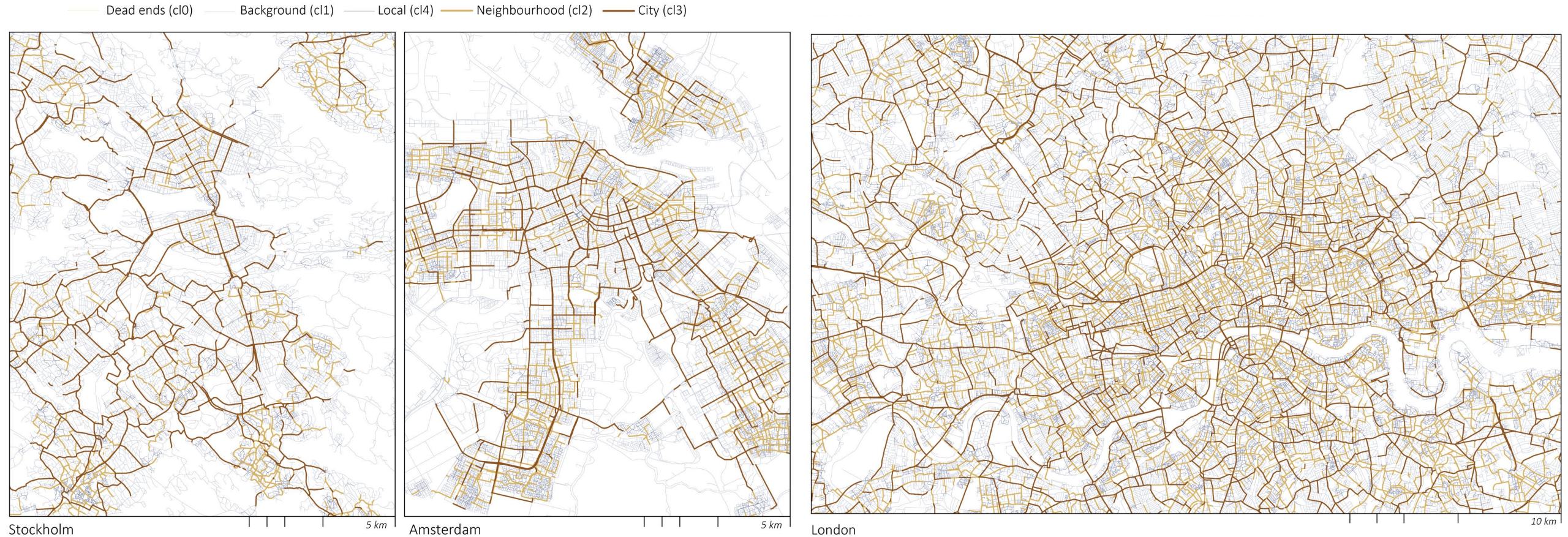
Berghauser Pont, M., Stavroulaki, G., Gil, J., Marcus, L., Serra, M., Hausleitner, B., Olsson, J., Abshirini, E., Dhanani, A. (2017a), 'Quantitative comparison of cities: Distribution of street and building types based on density and centrality measures'. Proceedings XI space syntax conference, Lisbon.

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



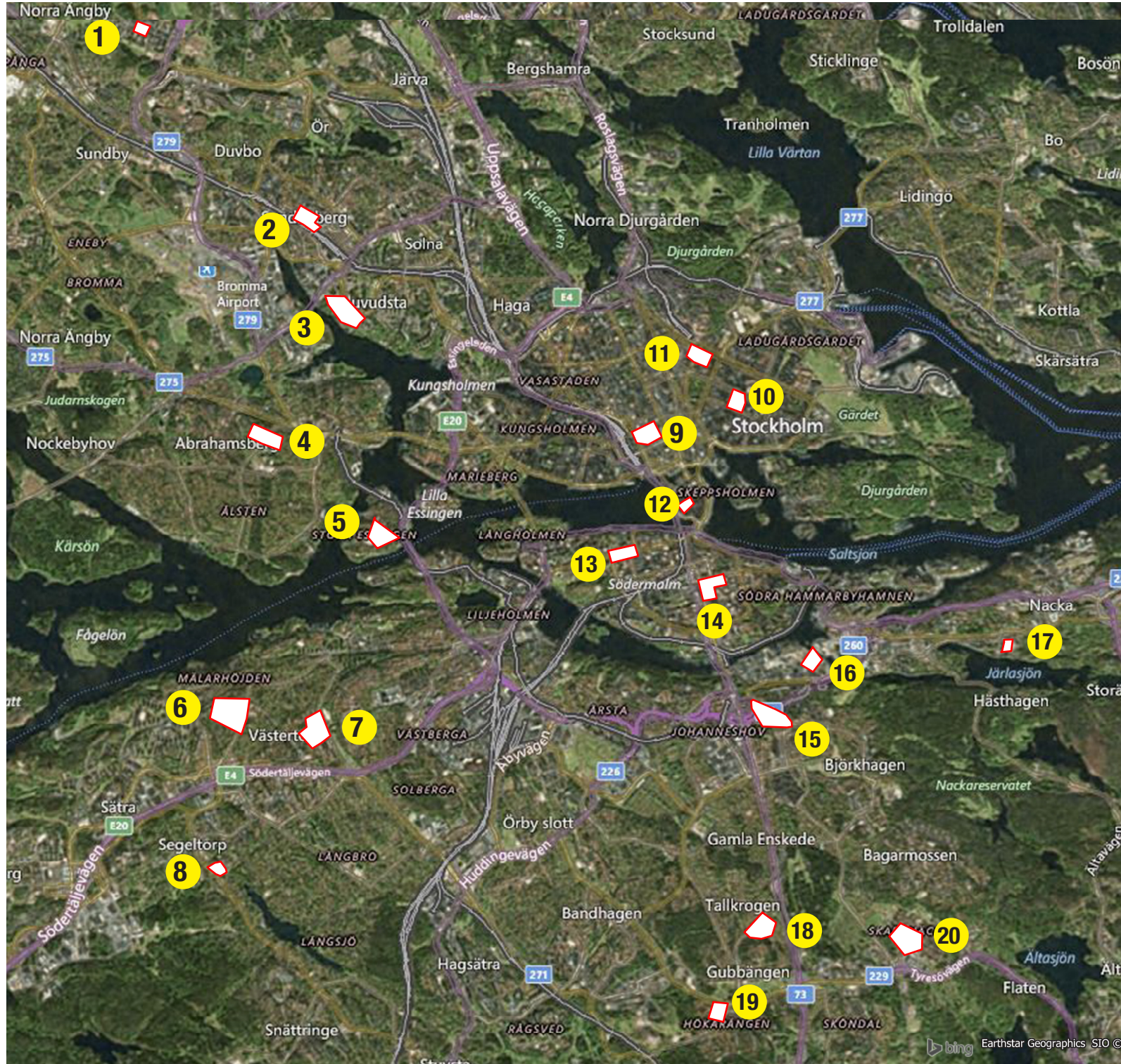
Distribution of street types in Amsterdam, Stockholm and London (types are based on network betweenness centrality in 10 scales from 500m to 5km)

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

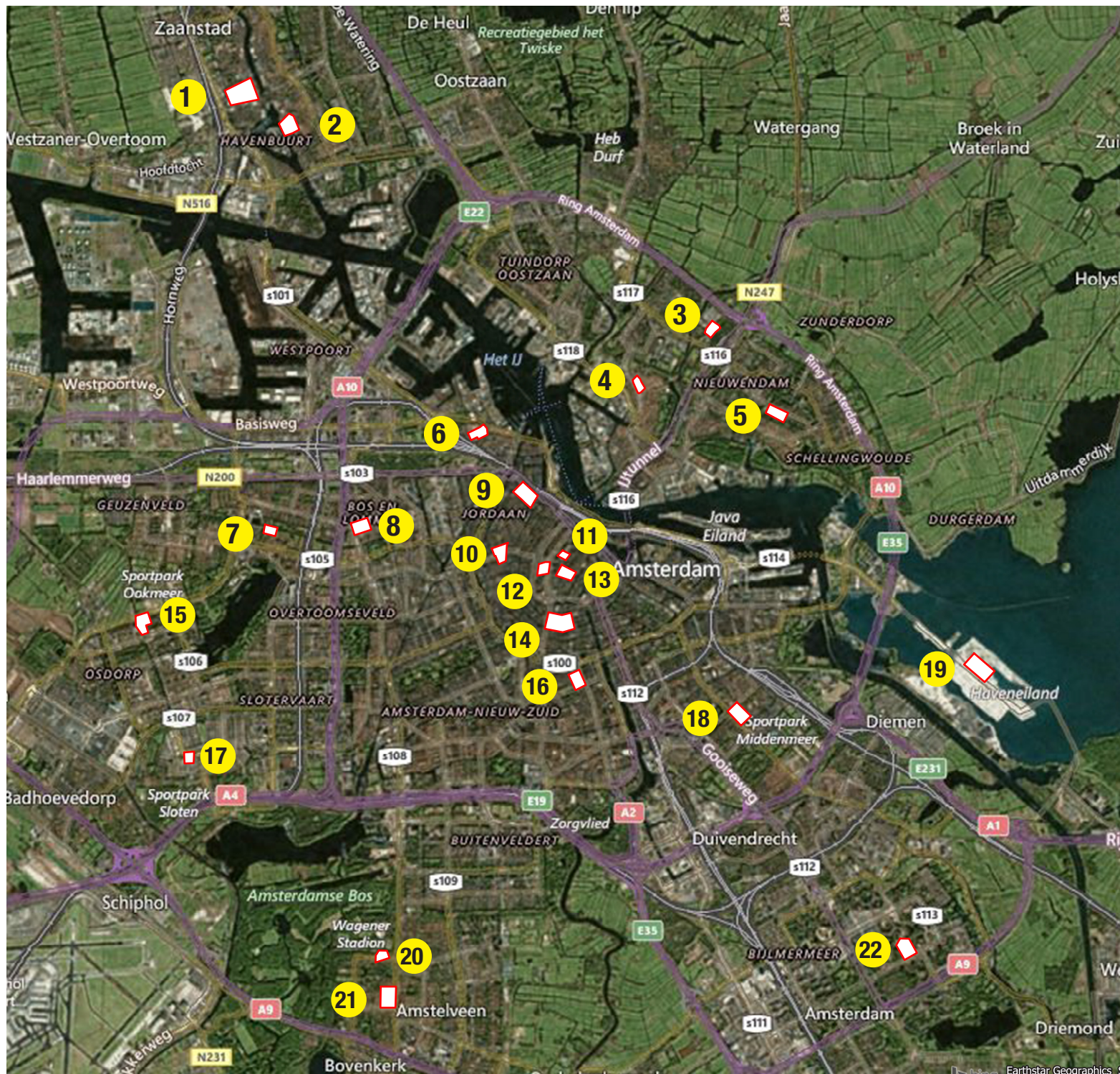


Stockholm

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

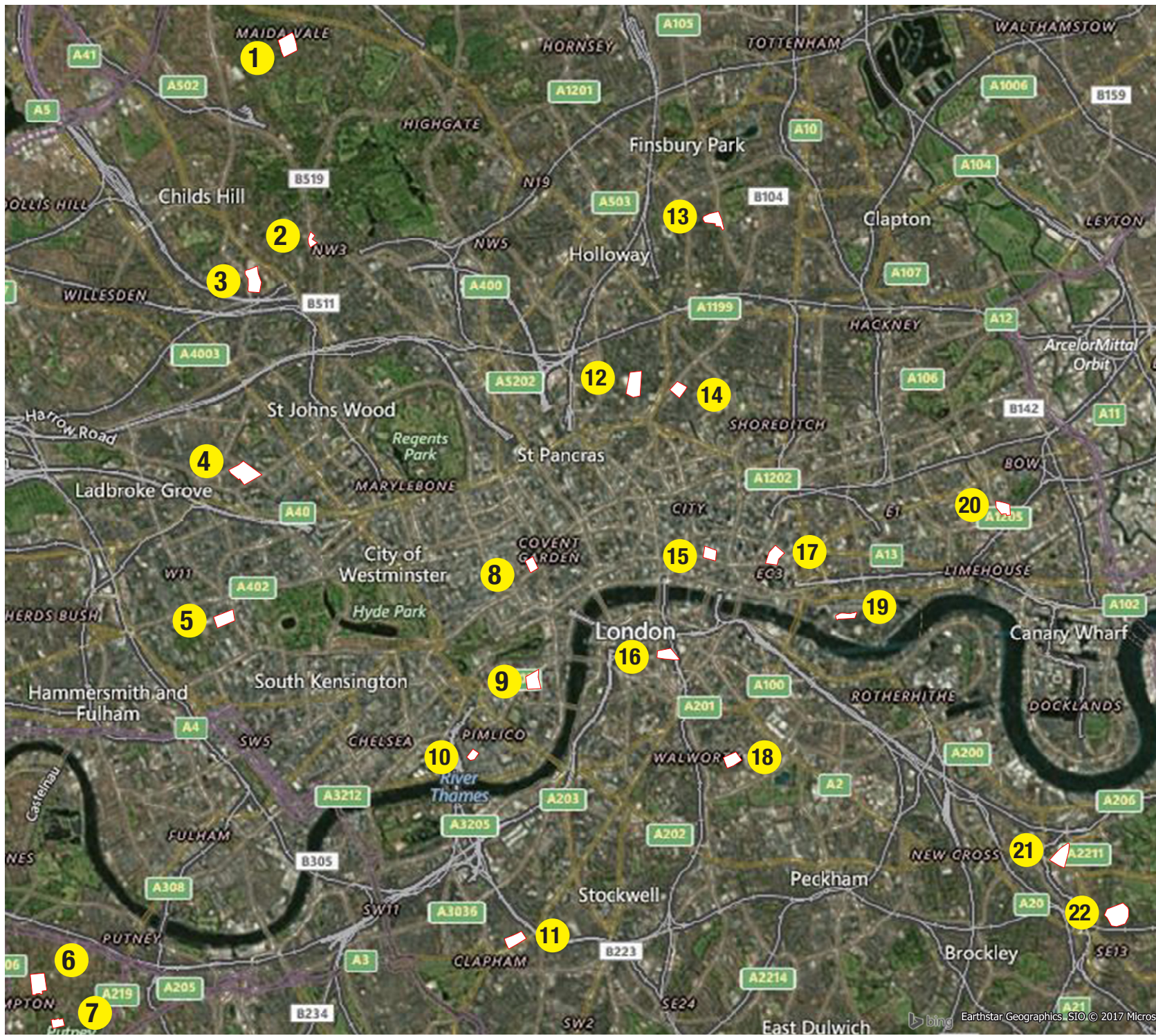


Amsterdam

Oct. 08-Oct.14

- ~~1~~ ~~Zaandam, Russische Buurt~~
- ~~2~~ ~~Zaandam, Poolenburg~~
- 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 (Merrow 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

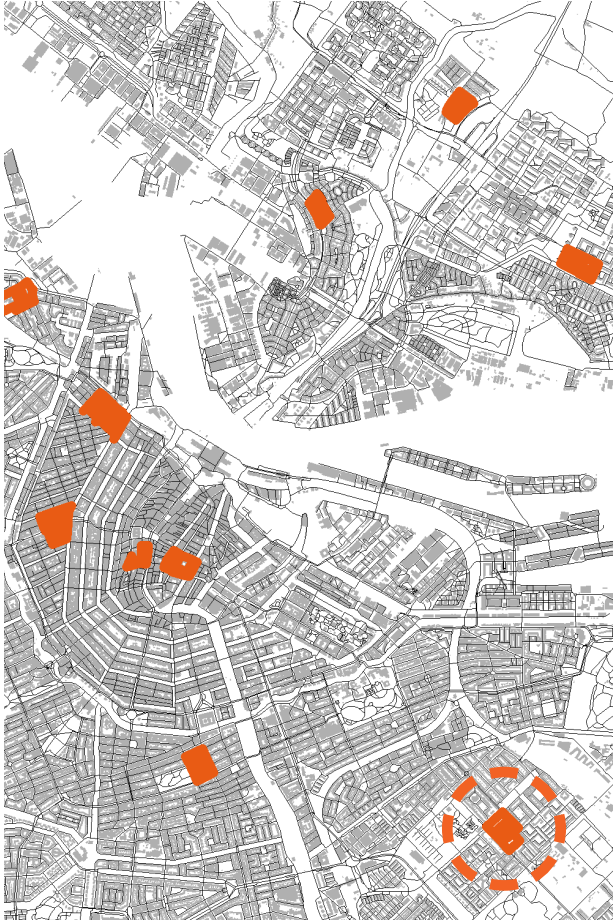


Noord, Kadoelen, Amsterdam
(spacious low-rise)



Sample

Examples of areas and street types

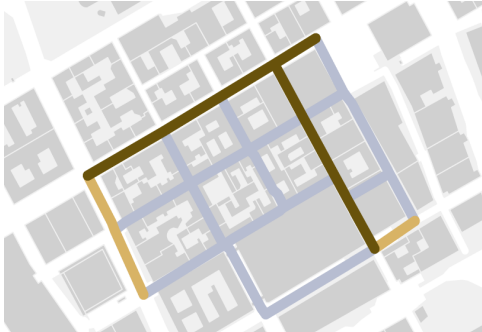


De Pijp, Amsterdam
(compact mid-rise)

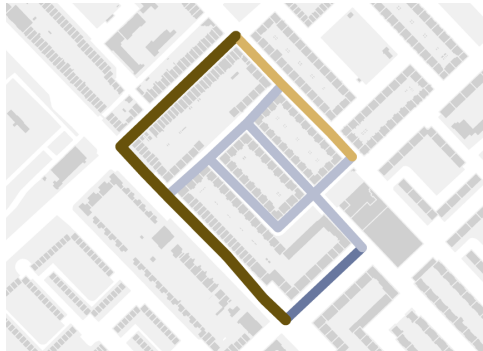


Sample

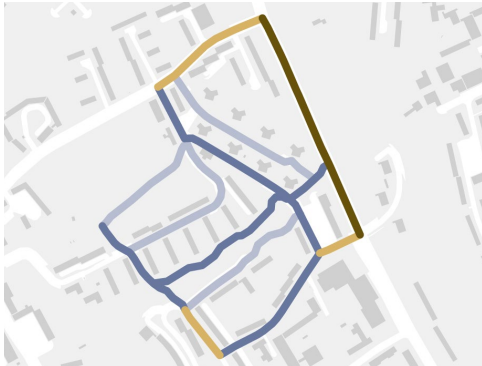
Examples of areas and street types



1.
Stockholm
Density type:
Dense mid-rise
Norrmalm



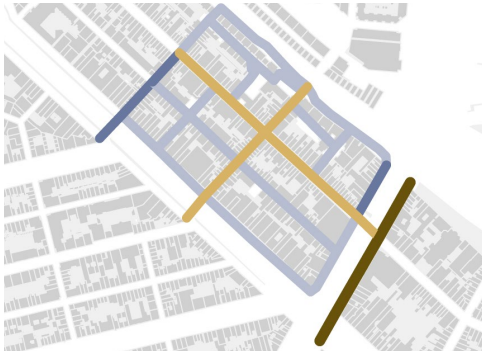
4.
Amsterdam
Density type:
Spacious low-rise
Watergraafsmeer



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.

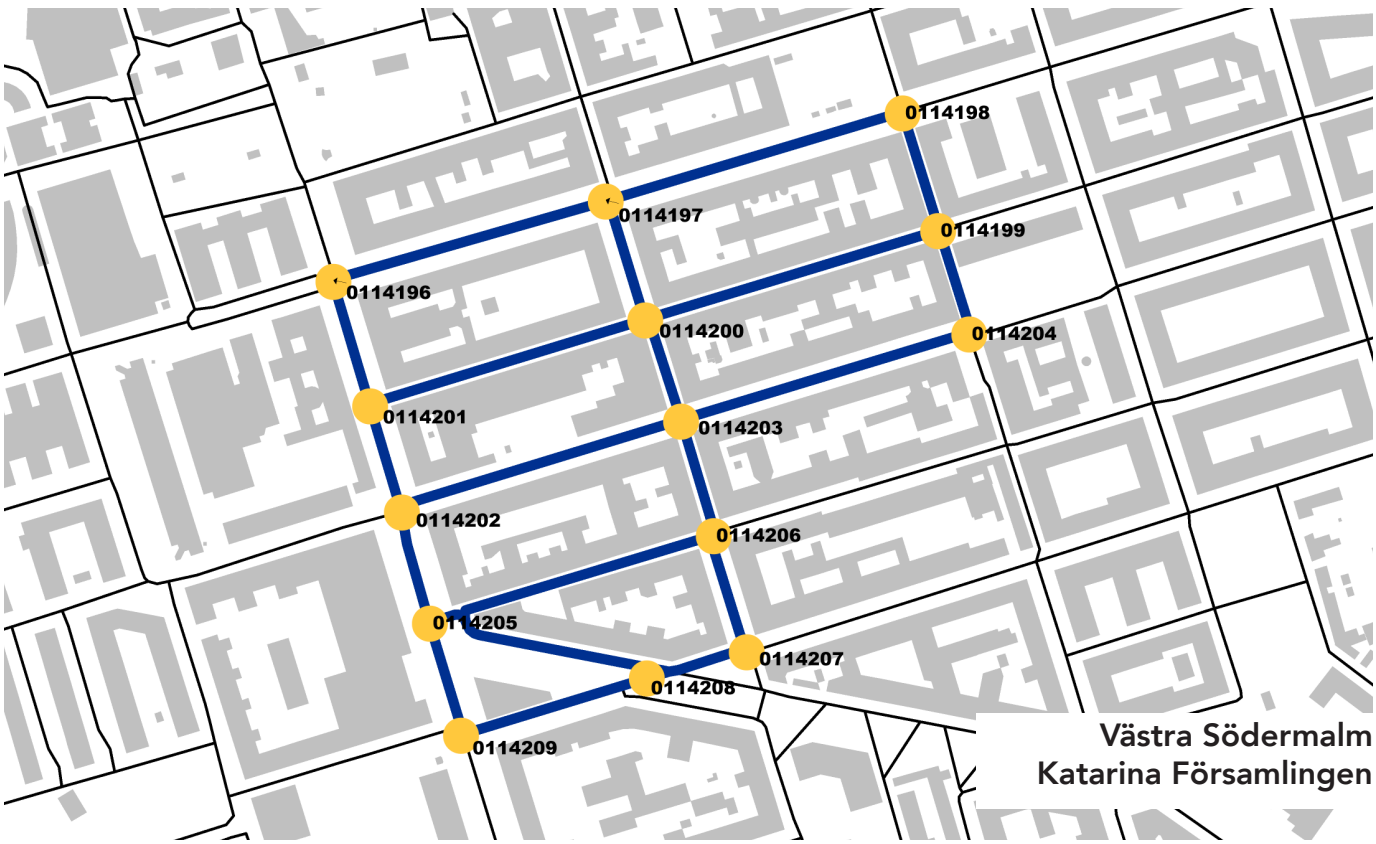


Method

'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*

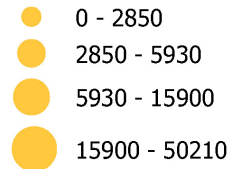
*the results can be aggregated in different ways, per city, per area, per density type, per centrality type

The results

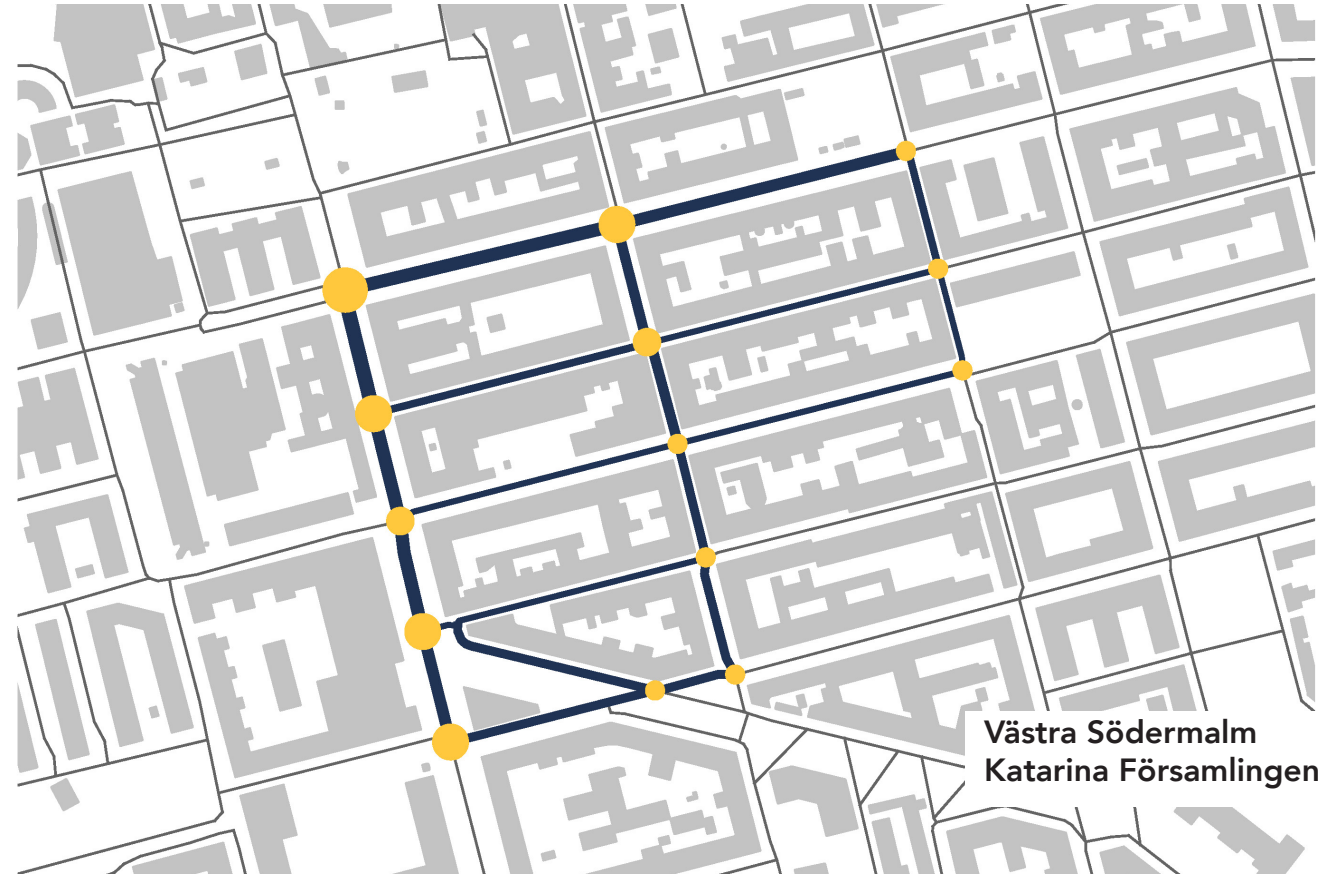
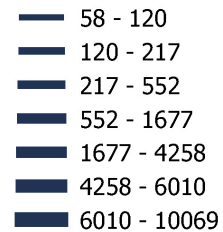
Extracted data

Flows and presence

Full-day presence



Full-day flows



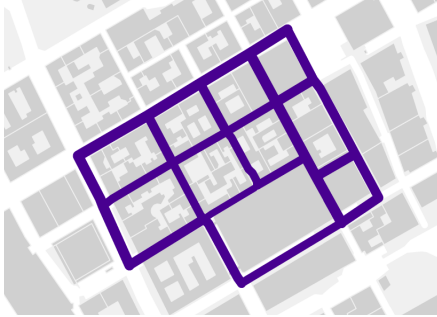
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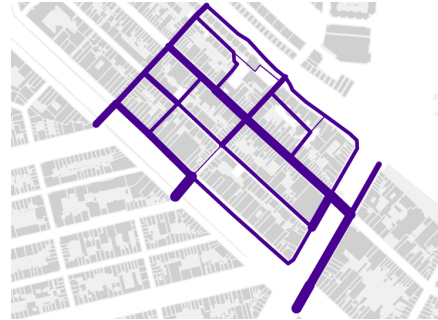
Results

Extracted data

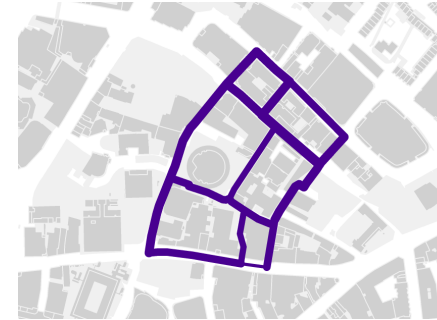
Full day flows



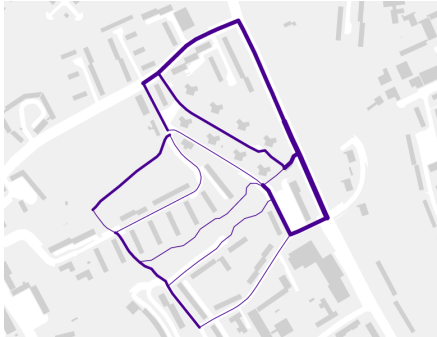
Stockholm
Density type:
Dense mid-rise
Norrmalm



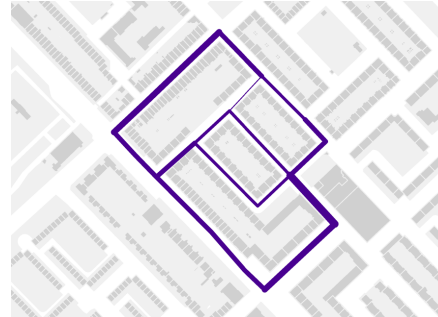
3.
Amsterdam
Density type:
Compact mid-rise
Haarlemmersbuurt



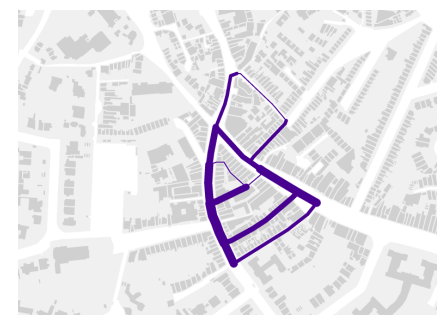
5.
London
Density type:
Dense mid-rise
Cornhill



2.
Stockholm
Density type:
Spacious mid-rise
Västertorp

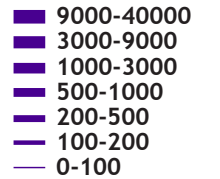


4.
Amsterdam
Density type:
Spacious low-rise
Watergraafsmeer



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

Full-day flows



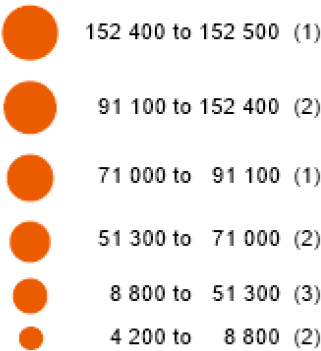
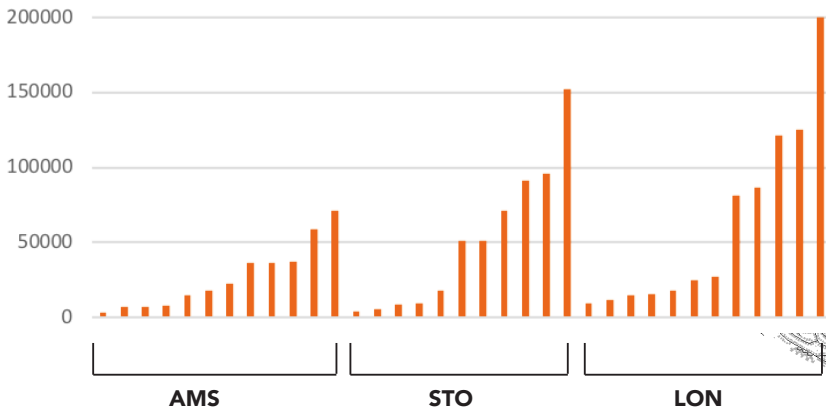
aggregate information:

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- > 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

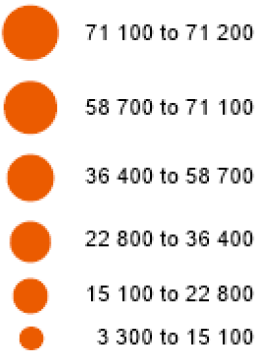
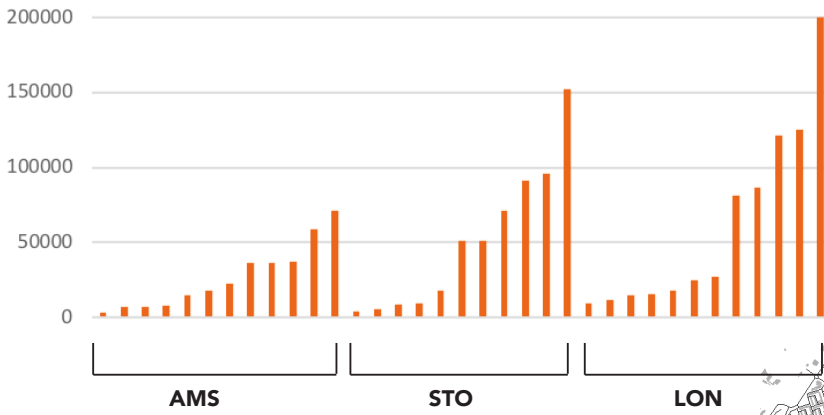
Full-day presence_Stockholm



Results

Extracted data

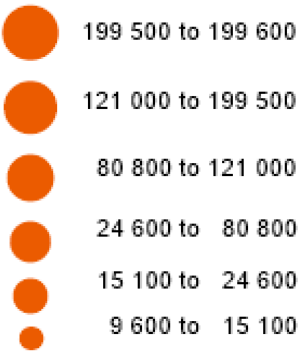
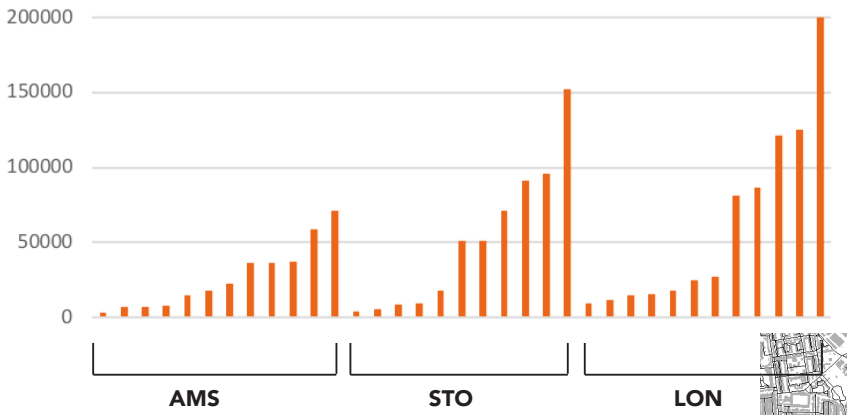
Full-day presence_Amsterdam



Results

Full-day presence_London

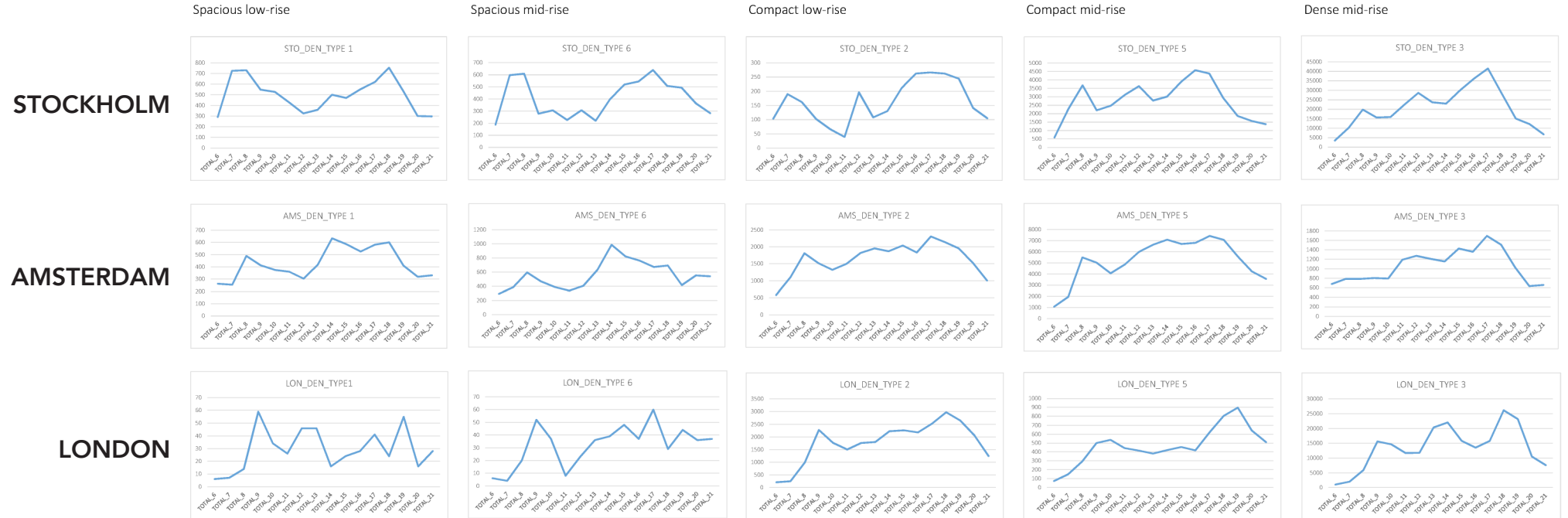
Extracted data



Results

Extracted data

Fluctuation of flow intensity



aggregate information:

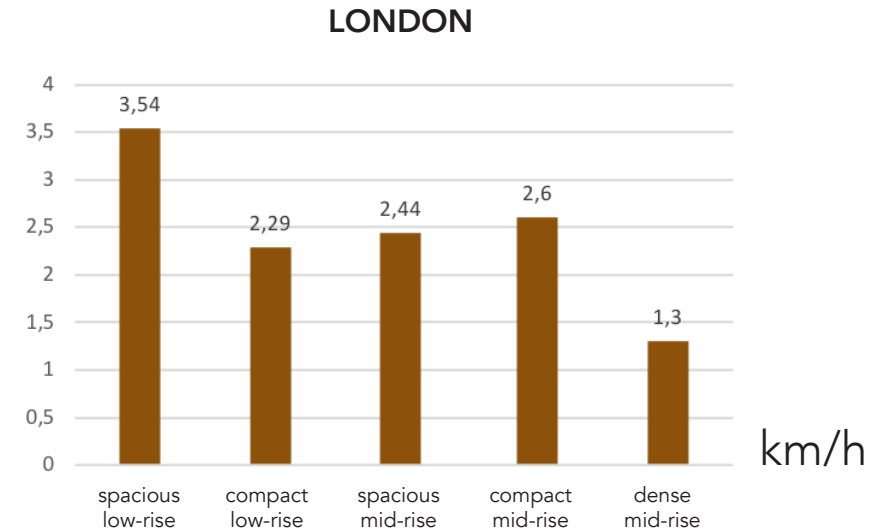
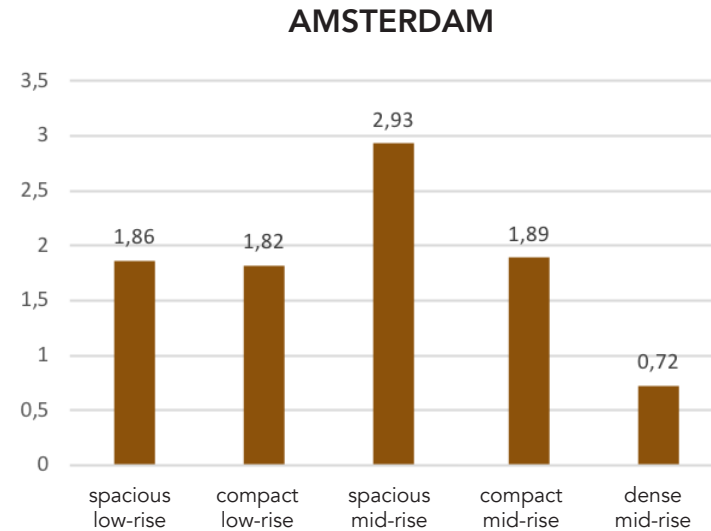
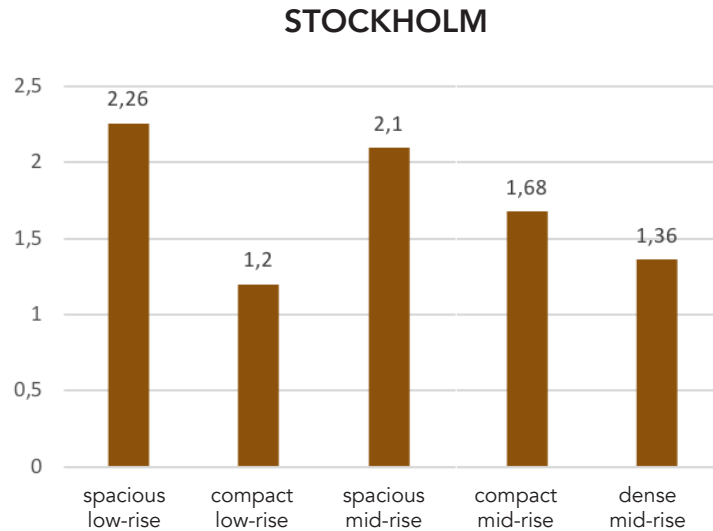
- > the pedestrian flow in each street on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the presence of people in every intersection on different time-frames (e.g. per hour, whole day, during lunch hours)
- > the overall presence of people in each area on different time-frames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

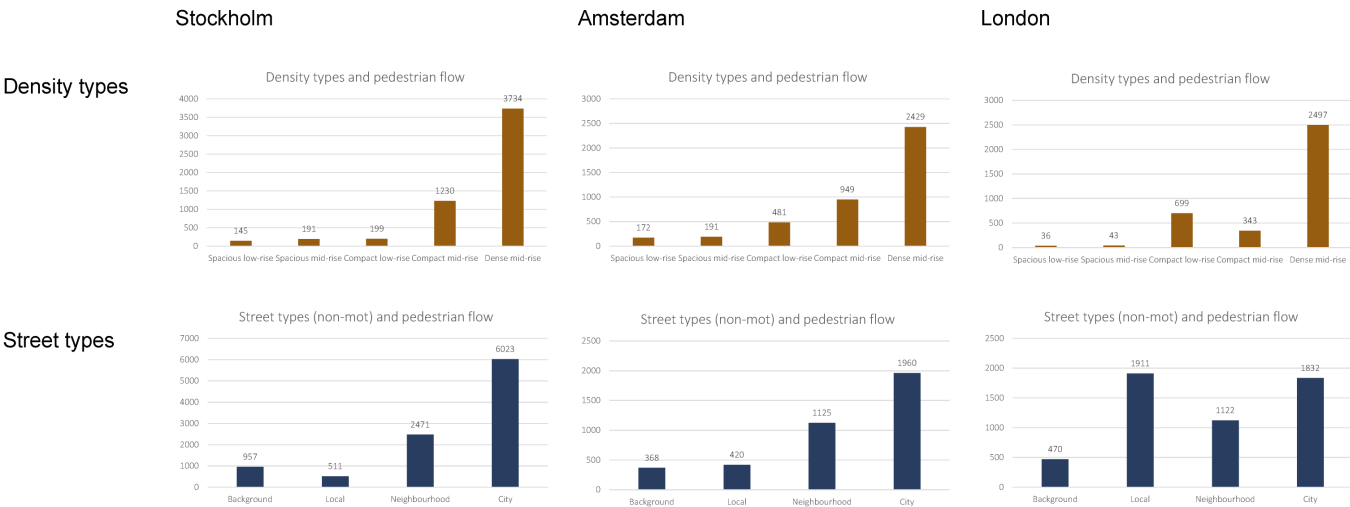
*the results can be aggregated in different ways, per city, per area, per density type, per centrality type

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



Berghauer 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

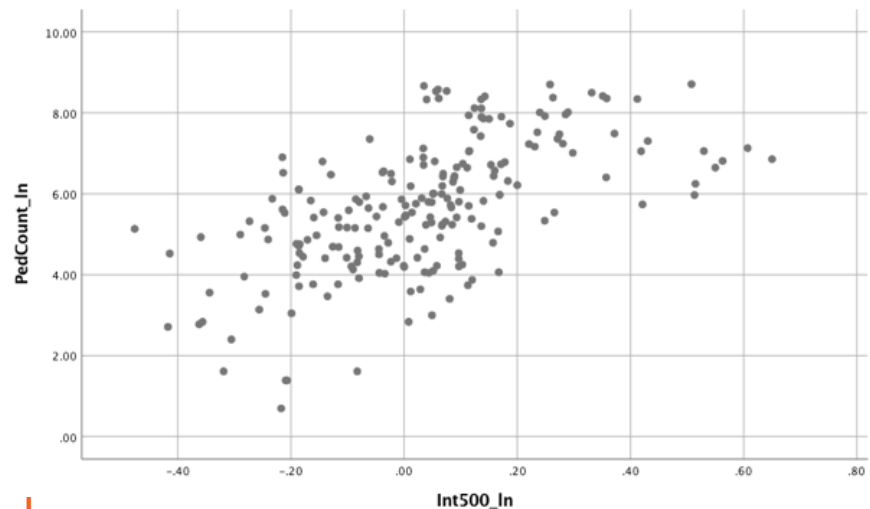
next steps

- > 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_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 ^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), InFSI_500, InInt_1000, InPlot500_In
b. Dependent Variable: PedCount_In

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), InFSI_500, InBet_500, InInt_1000, InPlot_500
b. Dependent Variable: PedCount_In

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), 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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