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. Bumbee 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 Designing 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  
Evgeniya 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

- 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

Motorised Non-motorised

Stockholm Gothenburg Eskilstuna

Stockholm Amsterdam London

STREETS BUILDINGS PLOTS
Distance Density Differentiation

TYPOLOGIES of SPATIAL FORM
Density types Centrality types Differentiation types

RELATION TO URBAN PROCESSES

www.smog.chalmers.se

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

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)


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 181)
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. Wapping (Mill St, Portland St)
19. Mile End (Pocock St, Hackney Rd)
20. Limehouse (Greenwich Rd)
21. Greenwich (Egerton Dr, A2, A206)
22. Lewisham (Walerand Rd)

London
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

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**

- **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”

#### Data Summary

- **STOCKHOLM:** 789,889 visit_ids/trips
- **AMSTERDAM:** 532,068 visit_ids/trips
- **LONDON:** 766,645 visit_ids/trips

#### Table Example

<table>
<thead>
<tr>
<th>visit_id</th>
<th>gate_id</th>
<th>timestamp</th>
<th>X</th>
<th>Y</th>
<th>gate/street intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>0114196</td>
<td>0114197</td>
<td>2017-05-05 06:00</td>
<td>675092.947832</td>
<td>6579125.31807</td>
<td>Västra Södermalm Katarina Församlingen</td>
</tr>
</tbody>
</table>

#### Map Example

- **gate_id**: 0114196-209
- **recorded street segment**: Västra Södermalm Katarina Församlingen
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/unynomised 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

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
Applications and next steps
Explaining pedestrian flows
Street centrality and Built density

<table>
<thead>
<tr>
<th>Density types</th>
<th>Street types</th>
<th>Combined effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>R2</td>
<td>Sig.</td>
<td>R2</td>
</tr>
<tr>
<td>Stockholm</td>
<td>0.133</td>
<td>0.000</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>0.183</td>
<td>0.000</td>
</tr>
<tr>
<td>London</td>
<td>0.386</td>
<td>0.000</td>
</tr>
</tbody>
</table>

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

next steps
> improve the statistical model
  (add spatial factor, add more variables e.g. attractions)
> add more data, cities
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The authors would like to thank Ann Legeby, Birgit Hausleitner, Jorge Gil, Alexander Hellervik for their input in various stages of this study.