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Movement and the connectivity of streets:
A closer look at route distribution and pedestrian density

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Abstract
Correlations between pedestrian movement and connectivity of streets have been frequently found in numerous studies. The configuration of the street network and its relation to observed movement patterns found in space syntax research is, of course, a significant part from them. With an attempt to further investigate the relation between urban form and movement behaviour, this study tests the correlation between configurational measures and a more detailed data on pedestrian movement. Observed in three residential neighbourhoods from Stockholm, the first part of data collected is the number of pedestrian per street segment (on a given moment). This so-called ‘snapshot’ data of the pedestrian density is tested with the configurational measures of the street network. The preliminary result shows a significant degree of correlation between pedestrian density and configuration. More importantly, another set of data on pedestrian movement is the data of 200 individual trips made in one of the three study areas (with highest average movement density). The detailed data on individual walking trips is obtained through random on-site tracking of pedestrians, and includes the route and the details of the trip character. This data is also tested in its correlation to configuration measures. An interesting result from this is the large difference in the degrees of correlation found for origin/destination segments and route-in-between segments. The result also shows that the degree of correlation also differs according to the character of the walking activity e.g. utilitarian, recreational, etc. Testing with data on movement containing more details of pedestrian behaviour, this study tries to investigate how urban form interacts with pedestrian movement in the aspect of street connectivity.

Keywords
Pedestrian movement, pedestrian behaviour, walkability.

1. Introduction
Correlations between pedestrian movement and built environment have been frequently found in numerous studies. Various studies from transportation and urban planning research and the recent walkability studies have found positive associations between movement and higher density (Cervero, 1996; Frank and Pivo, 1994; Messenger and Ewing, 1996), better street connectivity (Boarnet and Crane, 2001; Crane and Crepeau, 1998; Kitamura et al., 1997), and the presence of mixed land uses (Cervero, 1996; Moudon et al., 1997; Saelens et al., 2003). Theories and studies from the space syntax field have also provided significant findings and discussions on the relation between movement and urban form (Hillier et al., 1987; Hillier et al., 1993; Hillier and Iida, 2005).
This paper will investigate how aspects of movement behaviour relates to built form considering different types and parts of walking trips, and how movement behaviour aggregates into pedestrian presence on streets.

Numerous studies have shown strong correlation between configurational measures of urban form and observed movement pattern (Hillier and Iida, 2005), and measures such as integration has proven to have strength in predicting (or postdicting) the distribution of movement in urban system. However, from the space syntax theories, what also has significance for research on urban movement are the discussions and theories that try to investigate the effect of configuration on movement in detail.

Different terms regarding urban movement have been discussed in space syntax research in order to identify its relation to urban form and also to imply the complexity and variety in movement behaviour. The interrelation between attraction, configuration and movement, for instance, is discussed and natural movement theory includes the attempt to differentiate and define the direct and indirect effect of configuration on movement (Hillier et al., 1987; Hillier et al., 1993). Natural movement refers to the proportion of urban pedestrian movement defined by configuration itself, and it is argued that although not always quantitatively the largest component of movement in urban spaces, it is the most consistent and most pervasive type of movement (Hillier et al., 1993). The discussion of urban form as “movement interface” e.g. that of “inhabitants” and “strangers” that differ in the knowledge of the layout or the terms to-movement and through-movement (Hillier et al., 1987) also try to define the different movement behaviours regarding their relation to configuration.

Such attempts to differentiate and identify the nature of movement in its relation to urban form are crucial if we are to investigate the complex mechanism behind urban form and pedestrian movement. However, despite their value in conceptualizing the different aspects of urban form-movement relationship, the discussion and theories in existing research are not yet sufficiently supported by empirical evidence and largely remain as grounded hypotheses. This study investigates the different aspects of movement behaviour based on an empirical study with a detailed data on urban movement. The main aim is to test if there is difference in the relation to urban form factors according to the difference in pedestrian movement behaviour.

One aspect that is tested here is related to what is discussed in the terminology to- and through-movement. To-/through- movement defines the two aspects in the nature of human movement: the selection of a destination from an origin; and the selection of the intervening spaces that must be passed through to go from one to the other (Hillier and Iida, 2005). To-movement and through-movement, as defined for this study, is regarding which part of the movement process (i.e. destination/origin or route) urban form is influencing. This differentiation is examining the movement from the perspective of urban form, the street segments, rather than from the perspective of individual walking activity. For example, we examine and discuss a street segment or an urban area, and from perspective of that given environment discuss the pedestrian movement present on that location regarding whether it is a to-movement or a through-movement, (i.e. whether it has its origin/destination there or is passing through in its route).

Therefore, the concept of to-/through- movement here is a division of the process or parts within a walking trip and does not relate to the character of its entire trip as all walking trips consist of to-movement and through-movement. It is different from partitioning urban movement by its character of the walking activity/behaviour as the concept is used in some studies and from the division of movement by their purpose used in various studies on walkability, e.g. utilitarian walking, walking for transport, etc. (Lee and Moudon, 2006; Baran et al., 2008; Gehl, 2010). Such differentiation of movement based more on its behavioural aspect is the also examined in this study. In a previous study on the complexity behind movement behaviour, some classification of movement in such respect has been proposed, e.g. utilitarian walking behaviour, social walking behaviour, recreational walking behaviour (Choi, 2012) which will later be further discussed. Based on this division, in this study, it has been tested if relation to urban form differs according to such difference in movement behaviour as well. Therefore, two overall aspects will be investigated in this paper; first the relation...
between urban form and walking on the detailed levels or portions of trips consisting of to- and through- movement, and second, how this relates to different behavioural types of walking trips.

2. The Empirical Study

Studied areas
Three residential areas from Stockholm were selected for the empirical study. Two areas are located in the inner city of Stockholm and one is a suburban neighbourhood situated in the southern part of the city (See Figure 1). The two areas in the inner city are situated close to each other in the city centre, where one is a traditional urban area and the other is a more recently redeveloped area. The area with the traditional urban blocks will be referred to as the SoFo area. During the recent years the area has begun to function as a centre of creative and innovative fashion and retailing, which offers a wide selection of restaurants, bars, coffee shops, and art galleries. The area is shown to have a strong connection to the rest of the city in its configuration analysis, which characterizes the area as a part of the inner city of Stockholm, rather than as a localized sub-area (Marcus, 2000).

The other selected area in the inner city, Södrastation is a redeveloped area that is a highly fragmented and segregated from the rest of the island it is located in. Many of its spaces have highly localized usages, characterizing the area as of a rather domestic character. Lastly, Hökarängen, is a suburban neighbourhood planned in the 1940s, with mostly residential buildings widely spaced with green spaces and yards. While the population numbers are similar in the three selected areas, the population density in Hökarängen is significantly lower than the areas of the inner city.

Integration analyses at global level and district level show that SoFo and the Södrastation area are highly integrated with the whole city on an urban scale, as well as being highly connected at district level with their surroundings, whereas Hökarängen has the lowest integration at both levels (Figure 2). At local level, Södrastation appears to be less integrated than SoFo in some parts of the area, while Hökarängen has a fragmented structure with few integrated routes (Figure 3).

Figure 1: Map of the three studied neighbourhoods in Stockholm
Figure 2: Spatial integration analysis: global level (radius 30) (top), and district level (radius 9) (below) (Choi and Sardari Sayyar 2012)
Data on the amount of pedestrian – snapshot data

While majority of existing research have tested the movement patterns or density through data obtained by gate counts, this study tried a slightly different method in obtaining data on the amount of movement (or pedestrians). From the three residential neighbourhoods, the number of pedestrian per street segment (on a given moment) is collected. The data includes the number of walking person, seating person, and standing person (as well as the direction the walking person is moving). The count has been conducted 12 times in each segment and each area, including different times of day (morning/daytime/evening) and also weekdays/weekends. A sample of his so-called ‘snapshot’ data of the pedestrian density from each area is shown in Figure 4.
Figure 4: Snapshot data from the study areas showing the amount of pedestrians *(From top to bottom: SoFo / Södertalje / Hökarängen)*
The data on the amount of pedestrians have been tested in their correlation to integration measures and the results are shown in Table 1. However, more important purpose of this data in this study is for testing against dataset of individual movement trips which will be described in the next section. The correlation between pedestrian density and spatial integration shows fairly significant results for the entire data set as well as for SoFo and Södrastation, but not for Hökarängen, the suburban neighbourhood.

<table>
<thead>
<tr>
<th></th>
<th>INT(radius 2)</th>
<th>INT(radius 6)</th>
<th>INT(radius 12)</th>
<th>INT(radius 30)</th>
<th>INT(radius 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dataset</td>
<td>0.58</td>
<td>0.64</td>
<td>0.57</td>
<td>0.61</td>
<td>0.56</td>
</tr>
<tr>
<td>SoFo</td>
<td>0.45</td>
<td>0.57</td>
<td>0.62</td>
<td>0.42</td>
<td>0.55</td>
</tr>
<tr>
<td>Södrastation</td>
<td>0.49</td>
<td>0.73</td>
<td>0.64</td>
<td>0.78</td>
<td>0.77</td>
</tr>
<tr>
<td>Hökarängen</td>
<td>0.13</td>
<td>0.17</td>
<td>0.22</td>
<td>0.33</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Table 1: Correlation between pedestrian density and integration

Another set of data on movement in this study is the data of 200 individual trips made in the study area, SoFo. This detailed data on individual walking trips is obtained through random on-site tracking of pedestrians. For each individual trip, the data includes origin, route, and destination as well as other details regarding both the trip character and the pedestrian collected through direct observation. The reason for testing the individual trip data from SoFo is that, through a previous study, the area has shown to have not only highest amount of pedestrian density, but also most variety and most even distribution of different movement behaviours (Choi, 2012). The area has been investigated to have a relatively high share of non-locals visiting the area, compared to other parts of the city (Legeby, 2013).
**Configuration and attractions**

In this paper, for configuration of urban form, integration measures have been tested. Local, district level, and global measures have been calculated at different radii (2, 6, 12, 30, and 60). For testing the effect of attractions, a simple data on the number of non-residential use on each segment has been used. The amount of non-residential use present on the ground level of the buildings on each street segment (observed by their entrance point and their contribution to the walking environment) has been observed for this data. The data only contains amount of non-residential uses since for the studied area, the effect from the distribution of residential density is marginal. For the area SoFo, the analysis between integration and pedestrian density per street segment showed correlation value between approximately 0.4 and 0.6. Pedestrian density and amount of non-residential use showed correlation value of 0.57. An interesting result comes from correlation analysis between configuration and attractions in SoFo, with very low values (Table 2).

<table>
<thead>
<tr>
<th># of Attractions</th>
<th>R2</th>
<th>R6</th>
<th>R12</th>
<th>R30</th>
<th>R60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.12</td>
<td>0.00</td>
<td>-0.17</td>
<td>-0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

**Table 2: Analysis of spatial configuration and attractions**

**Individual movement (trip data) and urban form**

The route data of 200 individual movements in SoFo has been tested against integration and amount of attractions. For the 36 street segments within the area boundary, the data shows the number of individual trips (among 200 in total) that passed each given segment. The data also includes the detail on the number of trips that used the street segment each as origin, destination, or passing route. Therefore, this data may capture the aspect that is discussed by the concept of to- and through-movement. The results of correlation analysis for this data from 200 trips for the 36 street segments are as shown in Table 3.

<table>
<thead>
<tr>
<th>segment chosen as</th>
<th>INT R2</th>
<th>INT R6</th>
<th>INT R12</th>
<th>INT R30</th>
<th>INT R60</th>
<th>Attractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>origin</td>
<td>0.04</td>
<td>0.05</td>
<td>-0.02</td>
<td>-0.04</td>
<td>-0.01</td>
<td>0.39</td>
</tr>
<tr>
<td>destination</td>
<td>0.07</td>
<td>0.19</td>
<td>0.03</td>
<td>0.07</td>
<td>0.14</td>
<td>0.74</td>
</tr>
<tr>
<td>route</td>
<td>0.55</td>
<td>0.61</td>
<td>0.69</td>
<td>0.53</td>
<td>0.61</td>
<td>-0.16</td>
</tr>
<tr>
<td>total # of trips</td>
<td>0.50</td>
<td>0.58</td>
<td>0.59</td>
<td>0.46</td>
<td>0.56</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Table 3: Analysis of movement data and spatial integration/attractions**

As described in the previous section, there is no correlation found between configuration and attractions in this area. Considering this, the results of analysis presented in Table 3 shows a clear difference in the effect of configuration and attractions for to-movement and through-movement (processes). Integration has significant correlation values to the rate of being chosen as route (through-movement), while having no significant correlation to the rate of choice as origin or route (to-movement). To be clear again, this is when to- and through-movement is considered as the corresponding portions of individual trips, and not as kinds of movement; the portion of trips that move through a segment correlates, whereas the portion of trips that consists of leaving an origin or arriving at a destination does not. The amount of attractions has an opposite effect, showing significant correlation to to-movement, but not to through-movement.

The trip data of individual movements has also been tested in its correlation to pedestrian density, the snapshot data. The two types of data on pedestrian movement shows a high correlation value of 0.91 as shown in Table 4. Also, as in the case of analysis against configuration and attractions, the correlation values were significantly different when testing the details of trips data. It showed no significance in correlation for the rate of choice as origin or destination.
**Correlation (R) between trip data and pedestrian density per segment**

<table>
<thead>
<tr>
<th></th>
<th>As Origin</th>
<th>Destination</th>
<th>As Route</th>
<th>Total Trips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian density</td>
<td>0.04</td>
<td>0.06</td>
<td>0.89</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Table 4: Analysis of movement data and pedestrian density per segment

**Analysing different movement behaviours in their relation to urban form factors**

Since the data consisting of individual trips include the details on both the pedestrian and the activity for each movement, this study investigated whether movements of different character (in behaviour) are differently affected by (or use) urban form. A simple classification of movement that has been tested first is by sorting out trips that passed the area, having neither origin nor destination within the area, and therefore generally consisting of relatively longer distance. As shown in Table 5, these trips show significantly high correlation values when testing with integration measures. The values are mostly higher than when testing the entire trip dataset (see Table 3). Opposite to configuration measure, correlation value between area-passing trips and the amount of attractions was -0.26.

**Correlation (R) between amount of area-passing trips and integration**

<table>
<thead>
<tr>
<th></th>
<th>R2</th>
<th>R6</th>
<th>R12</th>
<th>R30</th>
<th>R60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate chosen as route</td>
<td>0.72</td>
<td>0.63</td>
<td>0.77</td>
<td>0.49</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Table 5: Analysis of area-passing trips and configuration

While the area-passing trips are having somewhat ‘non-local’ profile, a type of walking behaviour which involves mostly the ‘local’ or the inhabitants of the area was also investigated. This type of movement behaviour will be referred to as ‘utilitarian’ movement behaviour in this study. Utilitarian movement behaviour may be defined as having purpose involving the everyday life activities such as going between home and public transportation, going to the grocery store, taking the child to daycare or school, etc. These movements tend to have fixed origin and destination points, and efficiency in movement is the prioritized factor in making route choice. Since individual trips may each involve different aspects of behaviour or purposes and such cases do exist in the dataset, trips that are dominantly characterized solely by utilitarian behaviour have been sorted out. These trips are therefore conducted mostly by the inhabitants and also have all chosen (both metric and configurational) shortest route in the movement.

The other type of movement behaviour classified in comparison to utilitarian movement is ‘social’ movement behaviour and ‘recreational’ movement behaviour. Social movement behaviour often involves pleasure-walking purpose and seeks interaction with other people and activities. This type of movement have more flexibility in moving and sojourning and the destination for these movement can better be described as flowing or continuous rather than as a fixed location. Recreational movement behaviour is similar to social movement behaviour that it does not prioritize efficiency in movement in route choice and that destination also tend to be flexible and flowing. However, this type has been defined to differentiate the type of behaviour that prioritize certain land-use such as green spaces and tend to avoid environment with high movement density, opposite from social movement behaviour (Choi, 2012).

When testing the different dataset of trips defined by the movement behaviour that is dominantly characterizing them, the results in correlation analysis against configuration and attractions showed significantly different pattern for the three behaviour types – utilitarian, social, and recreational. For example, utilitarian movement data showed similar result with the result for the entire data set: only route showing significant value with integration, and the origin and destination showing significant value with amount of attractions. For the social movement behaviour data, significant correlation value was found only between origin/destination and attractions. Recreational movement behaviour data did not have any significant correlation value for either integration and amount of attractions.
3. Concluding discussion

The results from the empirical study provide implications regarding the details behind the complex relationship between urban form and movement. The dataset from individual movement allowed the testing of the varying influence of urban form on different process of movement (to-movement and through-movement). From this study it is suggested that to-movement is related to the presence of attractions while through-movement is related more to the configuration of urban form. Again, here, the terms that divide these two movements correspond to the parts within an individual’s walking trip.

Another interesting result is that the origin and destination segments simply do not seem to gain much pedestrian presence in comparison to the segments the trips pass through, and the segments chosen as routes follow integration whereas the origin/destination pair do not. I.e. although the individual route data (as total) correlated highly to pedestrian density data, the significant presence of pedestrian amount generated on the segments are neither the by start nor the end of the trip.

One of the main purpose of this study was to test the different movement behaviour defined through a qualitative study on movement conducted previously (Choi, 2012) in order to see if their different relation to urban form could also be statistically shown. The results have shown to have significant difference between the movement behaviours. It suggests that major factors of urban form influencing movement behaviour such as configuration and attractions may vary in the degree they affect the movement according to the character of the movement behaviour. What needs to be noted is that the type of movement where this pattern is found most dominantly is in utilitarian walking behaviour. It appears that the other identified types of movement do not follow this pattern in that they do not show a strong correlation to integration either in route or in origin/destination. This points to how the pattern-generating movement that correlates with configuration is of a particular kind whereas other forms of movement relates to the environment in other ways, that can be related to configuration but if it is, it remains to be investigated how it is so.

In order to acquire better understanding of how urban form affects pedestrian movement, it is important to acknowledge the differences both in the way built environment factors affect movement and also the differences in how the movements themselves operate. This study, although limited in the amount of data and statistical testing, was an attempt to investigate into these differences. Further investigation may be done by testing the detailed data on individual trips with regard to the different aspects of walking, and also by testing them against more various measures of configuration, attraction, and density.
References


