Urban form and daily travel; non-motorised transport in Trondheim examined by combining space syntax and GIS-based methods

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Abstract

During recent years, approaches ranging from preventive medicine to carbon emission cut have shed critical light on our car-dependant societies and pointed out a need for focusing on non-motorised transportation. This paper is based on a research project related to future development of the Brøset-area in the city of Trondheim, Norway, and presents methods of analyses as well as results concerning urban form correlates of daily travel, particularly focusing on walking and biking. By comparing the results of space syntax analyses with empirical data of peoples’ daily travel routes, this research project illustrates the potential of the recently developed space syntax parameters “choice” and “angular change”. Further on, by combining space syntax methods with GIS within the frame of the Place Syntax software, we illustrate how complex aspects of urban form such as peoples’ accessibility to daily destination can be analysed and made operational to real planning and design. Finally, we are carrying out a statistical modelling looking for correlations between daily travels of 5000 peoples in Trondheim and a set of urban form variables that according to recent research should be decisive to daily travel behaviour. Thanks to extensive surveys provided by the local authorities of Trondheim, socio-economic and others confounding factors are also taken into account. In addition to present useful methods of analyses, our study shed light on how different aspect of urban physiognomy influences amount of non-motorised daily transportation as well as peoples travel routes.

Keywords: urban form; space syntax; travel behaviour; walking; biking.
1 Introduction

Non-motorised transportation is the oldest and most basic form of transport and compared to other modes of transportation it is advantageous for numerous reasons; it has positive impact on health, it causes no pollution, it requires no fuel but normal nutrition, it has negligible amount of accidents (unless being exposed for motorised vehicles!), and last but not least: non-motorised transport are the modes of transport associated with cities that are attractive in terms of culture, retail and diversity of urban daily life. Litman (2009) criticises that transportation seems to be ranked by speed; the faster the transport the more important it is. He argues that the situation is the opposite where it comes to urban life; due to “amount of exposure” to street environment caused by the low speed of walking, walking is superior to other modes of transportation when it comes to provide potential for commerce and activity in the cities. Despite the advantages mentioned above, non-motorised transportation is a field with short history of research or scholarly knowledge. Even today, most planning and design concerned with transportation is about catering for obstacle-free movement for the private car and supplementing this with public transportation in the situations where private cars are not useful. Interest in non-motorised transportation has been about handling conflicts against motorised transport, rather than about walking and cycling’s potential for replacing and reducing amount of motorised transportation. However, based on approaches ranging from preventive medicine (Brennan Ramirez et al. 2006) to pollution and carbon emission cut, criticism of our car-dependant societies has increased and non-motorised transportation has become of larger interest. This interest is a background for the ongoing research project “Brøset, towards carbon neutral settlements” in the city of Trondheim, Norway, - a research project on which this paper is based.

After describing the overall methodology, this paper consists of three main parts. The first part explains some new space syntax based tools for modelling and analysing urban form, the second compares results of these analyses with empirical data of peoples’ real travels, whereas the third part presents methods and some results from a statistical study of urban form correlates to modes of daily travel. By this, we hope to contribute to methodological development within this research field of urban form and transportation as well as to provide some explicit knowledge about urban form and non-motorised transportation.

2 Background

2.1 Urban form and transportation

A basic issue within the evolving interest in non-motorised transport is what makes people walk and cycle, - or seen from an architectural or urban design point of view: how do we plan and design cities where people walk and cycle more than what is usual in cities planned and built during the last century? A consequence of non-motorised transportation being a new field of scholarly interest is that the knowledge is rapidly developing rather than being well established and fixed. This implies
that statements of relevant research are diverse and some time contradictory. Cervero & Kockelman (1997) examined how walking is related to “the 3Ds: Density, diversity, and design”, whereas Lee & Moudon (2006) argue that “several of the variables commonly believed to be important for walking were not significant” and entitled their paper “The 3Ds+R” where they have replaced “diversity and design” from Cervero and Kockerman’s paper by “destination and distance” and where the added “R” represents “route to destinations”. They characterise “route” by the parameters “block size” / “length of sidewalks” and by “directness” to important destinations such as grocery stores, schools and eating/drinking-places. Before going into the methodology and details of the research on urban form and transportation, it is important to remember that non-motorised transportation is not one phenomenon. As pointed out by for instance Schlossberg et al. (2006), biking and walking must in many cases be handled as two phenomenons. This is due to basic differences of the two; cycling distances can be much longer that walking distances whereas walking is far more robust than cycling concerning the quality of pavement/street-surface, steep terrain and the geometry of curves and crossings. Going more into detail, there are also different perspectives on cycling Haake (2009) and Forester (1992) argue that separate cycling lanes are unsafe and that cyclists should operate in the traffic almost as if they were motor vehicles, whereas Pucher and Buehler (2009) point out that cyclists are of very different kinds and that very different kinds of layout are therefore needed. In our ongoing research we examine differences between modes of non-motorised transport, whereas in this paper we only focus on a selection of overall results.

Regardless of the fact that non-motorised transportation is of different kinds, there are some aspects related to urban planning and urban form that most researchers consider important (Thomsen and Manum, 2009). Among these are “population density”, “land-use mix”, accessibility to daily destinations such as school or retail, and basic features of the “street-network” such as “street connectivity” or “grid-density”. (Brennan Ramirez et al. (2006), Lee and Moudon (2006) and Schlossberg et al. (2006)). This paper deals in particular with modelling and analysing the parameters of the street-network that according to research should be relevant for amount of non-motorised transportation.

2.2 Space syntax as a tool for studying urban form and modes of transportation

Space syntax is a field of architectural research where useful methods for studying spatial configurations have been derived from a consistent theoretical framework. Fundamental in the development of space syntax is the work of Bill Hillier and Julienne Hanson at the Bartlett, University College London (Hillier and Hanson (1984), Hanson (1998) and Hillier (1996)). Extensive studies have shown that analyses by space syntax methods correlate convincingly to numerous aspects of complex phenomenon taking place in urban space, phenomenon ranging from amount of different kinds of traffic, location of retail or frequency of burglary. Pedestrian movements but also cycling are modes of transport where space syntax methods are particularly useful (Hiller (1996, p.164), Hillier and Iida (2005) and Raford, Chiaradia and Gil (2007)).
Concerning space syntax theory and methods, this paper focuses on the application and development carried out in our research project. For those not being familiar to space syntax, some further reading would be useful. About historical development as well as recent state of space syntax research, see for instance Hillier and Vaughan (2007). For a summary of basic theory and methods, see for instance Manum (2006, p.66–81). If being interested in particular issues or details of the extensive amount and variety of research carried out within the field of space syntax, see the proceedings of the biannual space syntax symposia where the two most recent are http://www.spacesyntaxistanbul.itu.edu.tr/papers.htm or http://www.sss7.org/Proceedings.html.

A basic kind of space syntax analyses is the “axial-line analyses” that consist in analysing “axial-maps” where urban space is modelled by straight lines that either are connected or not connected. Until recently, “axial-line” has been the kind of spatial syntax modelling and “integration” has been the space syntax parameter usually applied in space syntax analyses of urban space in the cases where movement or traffic are the issues of interest. Integration calculated within different “radii” has shown to correlate to different kinds of movement (van Nes, 2002). This is partly due to the fact that space syntax integration captures distance as “number of changing direction of movement” and not as metric distance. For car traffic, “global integration” is the usually applied parameter (calculating “axial steps” between all axial lines in a particular model). For pedestrian movements, “local integration” shows the highest correlation (calculating axial steps only between axial lines that are within distance of 3 or 5 intersections from each other). Additional to “integration”, the parameter called “choice” has been developed. Whereas “integration” describes the distance (in terms of axial steps) from one element to all others, “choice” (also termed “betweenness”) describes to what extent a particular line is part of the shortest route between other elements (Hillier and Iida (2005), Turner (2007) and Hillier (2009)). In parallel to the introduction of the parameter “choice” there have been developed space syntax tools that handle “spatial distance” in a more advanced way than what is the case for axial-lines (being either connected or not). Turner (2001, 2005 and 2007) has developed the parameter “angular change” in combination with “segment-analyses”. In segment analyses, the basic spatial element is the straight line from one intersection/junction to the next and the space syntax distance between intersecting elements (line-segments) are calculated in accordance to the angle between the lines. According to Raford et al. (2007) space syntax analyses calculating “segment angular change” correspond well to bicycle traffic. More explicitly, they found that continuity in terms of “angular minimisation” is essential for a good bicycle-route.

The space syntax analyses in the research described in this paper includes calculating both “integration” (radius 6) with an axial map and “choice” with a segment map. Basic space syntax is about “configurational properties” of space, - leaving out all other properties of space for instance land use. As we will describe more closely in the section about methods, our research do not consist only in such basic space syntax analyses but also includes analyses that combine space syntax and GIS. This is a part of our research where the consultants Tobias Nordström and Alexander Ståhle (Spacescape, Sweden) have contributed substantially.
2.3 The Place Syntax tool and “attraction accessibility”

Place Syntax combines the space syntax concepts for modelling urban space as cognitive environment, i.e. topological axial line distance, with conventional descriptions of attractions / destinations into a “combined accessibility analysis model” which is the Place Syntax software. Axial distance correlates better with observed pedestrian movement than walking distance in meters or with straight-line distance in meters. By introducing the axial line as a distance unit in detailed GIS-based attraction-accessibility analysis the Place Syntax tool capture essential features of urban form as cognitive environments. The Place Syntax tool is particularly useful for predicting movement in urban areas where the distributions of densities and buildings are uneven.

2.4 The research project

The research project “Brøset, towards carbon neutral settlement” is about urban development of the Brøset area in the city of Trondheim and is funded by the Norwegian Research Council. It is chaired by NTNU, The Norwegian University of Science and Technology and is carried out by an interdisciplinary group of researchers, from departments of industrial ecology, architecture and planning, engineering as well as from social sciences. There is also a close co-operation with Trondheim municipality, who is in charge of planning the Brøset area. More explicitly, this paper is based on the transport-part of the Brøset research project, a part that focuses on examining urban form’s potential for reducing carbon emissions from transportation. Some basic issues in this respect are how to reduce the amount of transportation and by what means transport is carried out. We have particularly focused on urban forms potential for increasing the share of daily travel carried out by non-motorised transportation. More information about the Brøset-project, including more details about the “transport and urban form”-part of the research project, can be found at [http://brozed.wordpress.com/](http://brozed.wordpress.com/).

After examining what features of urban form that according to research should be relevant for the amount of non-motorised transportation, we have carried out three kinds of studies. The first was to interview people about their daily travel. This included registering the actual routes of peoples’ main daily travel. The second was to carry out a series of space syntax and GIS analyses of parameters that according to research should be important for walking and biking. This is the part of work done in collaboration with the consultants Spacescape. Finally, we are carrying out a statistical study looking for correlates between numerous urban form parameters and peoples’ actual travel behaviour. Some of the results of these studies can be found at the Brøset web-site referred above. Based on these studies, we have the possibility of comparing analyses and empirical data. The next sections describe this more in detail.
3 Methods

3.1 The space syntax and GIS-analyses

An important part of our research has been carried out in collaboration with the consultants Spacescape (Sweden) and with the local authorities of Trondheim. Thanks to the Trondheim municipality’s GIS-data that includes detailed information about 5000 peoples’ daily travel and Spacescape’s competence in analyses combining space syntax and GIS, our research project has been an arena for developing spatial analyses by means of the software Place Syntax (Ståhle, Marcus and Karlström, 2005). Based on Trondheim municipality’s GIS-road-map and “orthophoto” in high resolution, Spacescape made a detailed axial-map of all streets and paths for walking- and biking in the entire city of Trondheim. Then, they carried out space syntax analyses as well as Place Syntax analyses combining space syntax and GIS-data. The aim of the space syntax analyses was to reveal potential (and problems) of the street-network, whereas the aim of the Place Syntax analyses was to calculate a series of parameters describing accessibility to destinations that according to research should be important for people choice of mode of transport. The space syntax analyses consisted in analyses of the street network in itself, calculated by “axial integration” with a radius of 6 axial steps to capture pedestrian movement potential as well as “segment angular choice” with a radius of 5 000 metres to capture bicycle routes. The Place Syntax analyses examined accessibility to density of residents and to strategic destinations such as schools, kindergartens and workplaces. In these Place Syntax analyses distance was measured in airline distance as well as network distance in metres and axial steps (changes of direction).

3.2 Comparing analyses, intended bicycle routes and real bicycle routes

The field of planning and transportation mostly deals with how “mode” and “amount” of transportation relate to residential density and location of workplaces and other “destinations”. Trondheim municipality’s data about peoples’ daily travel was obtained thanks to a survey carried out in 2001-2003 (Vågane, 2006). In Trondheim as well as in most other cities, we know little about actual routes that people choose. Therefore, we have carried out a survey identifying peoples’ “actual routes” of travel. We did one questionnaire-based survey where the respondents were people working in or nearby Trondheim city centre, - asking for where they lived, how they travelled and which route they choose from home to work (Knudsen, Gabrielsen and Håland, 2008). The results were drawn on a map, giving a “squid-like-image” describing real bicycle routes to (and from) the centre of Trondheim (see figure 2). We did a similar study at the Brøset area, visiting people at home and registering their route of travel to work, study or other “main daily destination” (Karlsnes, Straume and Manum, 2009). These “actual route maps” provide empirical data that is useful for being compared with “intended bicycle routes” as described by “bicycle route map” of the local authorities of Trondheim. The “intended routes” (the red lines in figure 1) are of numerous kinds: some are well designed separate bicycle lanes, some are streets suited for cycling due to
little car traffic, and some are streets or paths that by different reasons are not much used by cyclists. By comparing “actual route maps” with “intended bicycle routes” we can provide information about the usefulness of the intended bicycle routes in Trondheim.

Space syntax analysis is a way of revealing “potential performance” of the urban space (Marcus, 2000). To what extent this potential is managed depends on numerous issues on street level such as amount of car traffic, quality of the road-surface, obstacles in terms of crossings, slope and other issues not captured by the space syntax model (the axial- or the segment-map) or the space syntax calculation. In our case, where we have modelled a segment-map of bicycle-route-network and calculated space syntax parameters that should be relevant for cycling (Raford et al., 2007), the results should illustrate the potential for bicycle traffic along the line-segments in the model. By comparing these results with “intended route map” and with “actual route map”, we should be able to shed light on the applicability of the space syntax analyses.

3.3 Statistical analyses of urban form correlates to modes of transportation

In addition to comparing analyses and empirical data as described in previous section, we are doing a statistical analysis looking for correlations between the accessibility-parameters as found by the Place Syntax analyses and extensive empirical data of Trondheim population’s real daily travel. The first part of our work presented here focus on daily choice of travel modes to go to work over the year while we are currently working on single and chained trips to a dozen of destinations.

In order to examine patterns in details, we have chosen to integrate numerous urban form measures at a rather disaggregated level. Socio-economic data are also used at a disaggregated level. The methodology, inspired by Lee and Moudon (2006), who also handled a large set of urban form measures, consists in variable screening and grouping before logit multinomial regression. Two analyses are performed independently for socio-economic / travel characteristics measures (1st Model), and urban form measures (2nd Model) alone which are then put together to build a third complete model and derive their respective influences (Stead’s methodology, 2001).

Based on the transport survey data, we computed our dependant variable describing daily travel habits to work with four modalities: walking 3 days a week or more (11.8%), cycling 3 days a week or more (24%), using public transport 3 days a week or more (8.9%) and driving 3 days a week or more (55.3%). Origins (home) and destination (work) addresses were recorded on a “Grunnkrets” level. Grunnkrets are small administrative area-units of Trondheim. Consequently, people living in the same Grunnkrets were assigned to the same address (the geometrical average address of the Grunnkrets), implying that their urban environment is assumed to be identical. This approximation constitutes an uncertainty that will be reduced when data registered at parcel level will be available, hopefully during 2010. Travel duration and distance from home to work were integrated as travel characteristics. Travels performed within one Grunnkrets, which is the case for people working and living within in one Grunnkrets, were set with constant values based on Grunnkrets average size and correlation optimization; typically 200 meters.
Socio-economic measures concern gender, age, occupation, incomes, household size and cars accessibility. Several variables attached to work description were collected (total worked hours per week, work schedule, workplace or type of parking). Urban form data were extracted from MapInfo using Place Syntax and space syntax (previously described) and were provided at both parcel and Grunnkrets levels. Measures characterize both workplace location and home place location and are mostly distances in meters and axial steps to a panel of destinations, number of accessible daily destinations, densities, block sizes or lengths of lane types (some are log-transformed). A handful of computed indicators to characterize spatial accessibility (integration and choice previously described) or building morphology are also integrated. Finally, 199 variables are used to characterize a location: 147 from network measures and 52 from airline measures. It should be noticed that we put airline and network measures in competition together in the same model. As we are interested in different transportation modes which have each a specific distance scale we used five size of buffer regarding network measures (1 km, 1 km and 6 Axial Steps, 3 km, 3 km and 6 Axial Steps, 5 km) and two regarding airline measures (1 km, 3 km). Moreover we introduced the distance in axial steps to a closest destination and used it also to define new type of buffers.

Complete urban form characteristics for both workplace and home place were available for 2000 respondents as well as few socio-economic data were missing. Regarding travels to work analysis, we took into account only people who were working more than 30 hours per week and were therefore going to work every day. Finally 980 respondents constitute the sample. Environmental missing data were mostly concerning people living in remote suburbs who were much more subject to car travels independently from district characteristics.

To build the first model socio-economic variables were forced in the model while travel characteristics variables were selected through a backward stepwise process (entrance with p value under 0.1 and exit with p value higher than 0.1).

To build the second model we tested first variables for their bivariate association with the dependant variable (Pearson coefficient). Due to the very large sample size only those significant at the 0.01 level were further considered. Secondly we grouped variables on the basis of bivariate inter-correlation coefficients. We considered the different categories of variables (distances, number of accessible daily destinations, areas, densities, length, slope, time, spatial accessibility indicators...) independently and we focused for each variable category on competition between buffer sizes, network and airline measurements and finally variables within the same category. Variables with inter-correlation coefficient higher than 0.7 were put together and represented by an unique variable chosen for its stronger correlation with the dependant variable. Finally we checked remaining variables for any unexpected correlation until no more correlation higher than 0.9 were found. Number of daily destinations, densities, length of lane types, block size and slope were more often close related than expected. Then we performed the logit multinomial regression including intercept and backward stepwise modelling. Variables enter and stay in the model with p value under 0.1. To build the third model travel characteristic and socio-economic variables coming from the first model were forced into the model while applying the same backward stepwise modelling process for the environmental variables selected after the grouping process.
4 Results

4.1 Theory and practice; results from comparing space syntax analyses, intended cycle-routes and peoples’ real cycling.

Figure 1 shows the results of the space syntax analyses calculating “segment angular choice” of Trondheim, whereas the red lines show “intended bicycle routes” (according to the planning authorities of Trondheim) on the same map. What we see, is that the space syntax analyses, which is a purely mathematical calculation of configurational properties of the street- and path-network, corresponds very well to “intended bicycle routes” as well as to where people cycle. Looking more closely, we see several places in Trondheim where the three maps do not correspond.

Point 1 in figure 2 is Fjordgata, a street much used by cyclist but neither marked by the intended cycling routes (red lines in figure 1) nor captured by the space syntax analyses (figure 1). The reason for cycling in Fjordgata is its location at north edge of the city centre, implying that there are no crossing streets from north into street. Therefore, different from the Olav Trygvassons gate that according to space syntax analyses and municipal intentions should be the cycle-route, Fjordgata provide an “obstacle-free” cycle distance of about 500 meters. Since this kind of information is not present in the space syntax modelling or analyses, it is not surprising that space syntax results do not capture it. Concerning intended routes, the results show that intentions about people choice of route are of little use if not knowing and taking into account people’s reasons for selecting their routes.

At the point marked 2, neither the space syntax nor the intended route corresponds to actual cycling. The reason is that the terrain is very steep. This is not captured by the space syntax analyses since slope is not a feature present in the analyses. Concerning intended routes, these must be based on understanding of peoples’ preferences. Crossing streets as well as slopes are examples of features highly important for peoples’ cycle routes without necessarily being taken into account when planning formal bicycle routes.

Point 3 is Erling Skakkes gate, a street where space syntax analyses and real cycling correspond but that is not present in the “intended routes”. This street being preferred by cyclist shows the importance of route directness / least angular change, - a feature that is capture by the space syntax analyses but not taken into account by the planning of formal bicycle routes.

Point 4 shows how the heavily trafficked Elgeseter gate is not chosen by cyclist. Instead, they choose parallel streets since these are as direct to their destination. This phenomenon of choosing parallel streets in cases of heavy traffic is captured in the intended bicycle routes but only partly in the space syntax analyses.

In conclusion, our study shows that space syntax analyses in terms of least angle segment analyses within a metric radius is a very useful tool for predicting bicycle routes. However, no analyses can capture features not being present in the input. Therefore, since slopes and heavy traffic are obstacles that influence cycling habits but not captured by space syntax analyses, these parameters need to be taking into account by other means than space syntax tools.
4.2 Combing space syntax and GIS analyses of Trondheim and an example of applying these analyses in real urban planning of the Brøset area.

An essential part of our analyses has been to provide knowledge about accessibility from residents (based on GIS-data about real residents located at real addresses) to the “destinations” relevant for non-motorised transportation. Figure 3 is a map showing accessibility to schools, in the sense that the scale from red to blue represents good to low access. Access is measured as number of schools within 1 km distance along walking/cycling network. The figure shows that the accessibility from the Brøset area to schools is not good. Figure 4 illustrate the space syntax spatial integration of the street-network (lines coloured red to blue, red being much integrated), density of residents (area coloured red to blue, red implying many people within short distance). Finally, the dots show the location of grocery shops (large dots are several shops, large shops, shopping centres, whereas small dots are small single shops). The figure show that the area around Brøset is characterised by low residential density, the street network is not well integrated and there are few grocery shops. The table in figure 5 shows accessibility from the Brøset area compared to the centre of Trondheim and to Trondheim on average. In the results presented in this figure, accessibility is calculated in different ways (distance to destinations, supply of destinations and spatial integration). The accessibility value is then compared with the average value of all areas within 5 km from the city centre. What we see is that schools and retail are not easily accessible from the Brøset area. According to Lee and Moudon (2006), access to school and retail are among the most important parameters for achieving a high rate of walking and cycling. Therefore, aiming at “carbon neutral settlement” at Brøset, the area’s accessibility to these destinations should be improved. This can be done by including school and shops in the Brøset-project or by adding/improving the walking and biking street/path-network so that the access from Brøset to existing destinations in the surrounding areas becomes better.

Concerning the bicycle route-network, figure 5 show that the “intersection-density” or “grid density” is very low around Brøset. This implies that the street network should be completed by adding new streets or paths and by upgrading some of the existing ones. An explicit proposal for doing so is shown in figure 5.

These proposals concerning accessibility and street-network are results of the research by Spacescape (2009) and will be guidelines for further planning and design of the Brøset area. The methods of analyses shown here will be applied in order to evaluate the proposal for urban design in the urban development project at Brøset.
Figure 1. Space syntax analyses illustrating "continuity" of the bicycle network ("segment angular change, choice, buffer radius 5000 meters") Yellow: high continuity, blue: low continuity. Red lines show bicycle routes as intended by the local authorities of Trondheim. (Spacescape, 2009)

Figure 2. Real cycling routes to (and from) Trondheim city centre. Coloured dots show the workplaces where the survey was carried out. Corresponding coloured lines show the respondents actual cycling routes from home. (Numbers mark points commented in the main text.)
Figure 3. Accessibility to schools (kinder gardens, primary schools, high schools and universities within 1 km distance along walking/cycling-street-network). (Spacescape, 2009)

Figure 4. Spatial integration (radius 6) of streets (red being highly integrated), density of residents from each point (orange/red implying many people within short distance) and the location of grocery shops (large dots are several shops, large shops, shopping centres, whereas small dots are small single shops). (Spacescape, 2009)
Figure 5. Accessibility to difference destinations, from Brøset compared to city centre and to Trondheim within 5 km from the city centre on average. (Spacescape, 2009)

Figure 6. Proposal for improved bicycle-network in the Bøset area. Blue: important existing routes Cyan: new routes. (Spacescape, 2009)
4.3 Statistical analyses of urban form correlates to modes of transportation

This statistical analysis provided a lot of interesting results. We will present the main patterns and focus on results related to distance measurements and spatial accessibility concepts as described in the methodology section.

The few socio-economic variables we forced in the model are significant, especially and not surprisingly the car availability, the number of cars owned by the household and the total number of persons in the household with a p value < 0.001. Car availability and number of cars play a similar role and strongly decrease the probability to walk and cycle relatively to drive and even more strongly the probability to use public transportation. The total number of persons per household has a more equivocal influence: the more people in a household, the less probable they will walk but the more probable they will cycle relatively to drive. An explanation could be the Norwegian habit to drop off their children to nursery or school on the way to work either by bike or by car rather than walk with. Incomes per person as well as total household incomes appear to be not significant and show no clear patterns about walking and cycling. This may due to the high average income in Norway where everybody can afford a car. The relative price of gasoline is also lower than in others countries. Concerning travel variables, driving time and distance from home to work, grouped together, are the second most important factor, after car accessibility, to explain people travel habits in the 3rd model.

Finally the first model shows a $R^2 = 0.430$ (Nagelkerke) while 2nd model has a $R^2$ equal to 0.325 (Nagelkerke) and 3rd model has a $R^2$ equal to 0.609 (Nagelkerke). Accordingly to Stead (2001), this means that urban form characteristics can explain directly between 18% and 32% of the variance of the dependant variable (people travel habits to work) whereas socio-economic and distance to work together can explain between 28% and 43%.

<table>
<thead>
<tr>
<th>3rd Model</th>
<th>Khi-2</th>
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<tbody>
<tr>
<td>Number of destinations within 3km Air (around Work)</td>
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<td>,005</td>
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<tr>
<td>Number of Nurseries within 1km_Air (around Work)</td>
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<tr>
<td>Time to City Center by Bus (from Work)</td>
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<td>,000</td>
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<tr>
<td>Number of High Prox. destinations within 3km 6 Axial Steps (around Work)</td>
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<td>,019</td>
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<tr>
<td>Closest green area (from Home)</td>
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<tr>
<td>Average block size within 1km 6 Ax (around Home)</td>
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<td>,015</td>
</tr>
<tr>
<td>Closest cycle lane (from Work)</td>
<td>10,9</td>
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<tr>
<td>Maximal Spatial Integration (for Work)</td>
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<td>Sloppy kilometers within 3km 6Axial steps (around Work)</td>
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<tr>
<td>Length bus lanes within 3km_Air (around Work)</td>
<td>10,9</td>
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Table 1. 3rd Model: highly significant urban form variables (p value <0.05)
Not surprisingly, employment densities, population density around home and average block size appear to be important factors and follow patterns pointed out by previous research (Saelens, (2003), Lee and Moudon (2006) and Milakis et al. (2008)). The time distance (by bus) from work to city center is also one of the key factors while some other factors are a bit strange. For instance the higher the total number of steep kilometers, the more probable people will walk, cycle or use bus compared to drive. This paradox may be explained by the specific topography of Trondheim where a high number reflects a strategic location in the “valley” close to the city center.

Coming back to the Brøset project, it is interesting to compare the Brøset area to an average Grunnkrets of Trondheim and to the city center, considering urban form characteristics. For instance, what are the differences in probabilities for a person to walk, cycle or use public transport on a daily basis relatively to drive to work depending on his residence location, all others parameters being equal? If we take into account only the most significant urban form characteristics around home location (p value <0.05), we retain: closest distance to a green area, average block size within 1 km and 6 axial steps, density of employment within 3 km and density of population within 3 km and 6 axial steps. Moreover, we assumed that urban form characteristics explain 25% (in fact 18% to 30% as described previously) of the individual people’s choice. Results are presented on the figure 7 below, where probabilities for city center are arbitrary set to 1 for the example.

![Figure 7. Relative probability to walk / cycle / use public transport to work depending on residence location](image)

If, for instance, a resident in the city center has the same probability to walk or cycle as drive daily to work; in Brøset he has respectively 47% and 60% less chances to walk or cycle than drive (independently from socio-economic factors, distance to work and work location). Regarding
walking this is near the same for a resident in an average Grunnkrets of Trondheim whereas regarding cycling he has few more chances to daily cycle to work than in Brøset. These are preliminary results but they point out the real effect of accessibility problems (described in the part 4.2) on people choices and that the carbon neutral objective for the Brøset project is a challenge.

Another important result is the influence of the “workplace maximal spatial integration”, which is a way to characterize the accessibility. Within our sample this factor ranges from 1 (minimal integration) to 2.2 (maximal integration). Figure 8 illustrates the strong link between “maximal spatial integration at work” and share of non-motorised transportation for daily travels to work. Moreover, accounting for others confounding factors (after multinomial logit regression), an increase by 1 of maximal spatial integration at work increases walking and cycling probabilities relatively to driving probability respectively 18 and 5 times. In our case spatial integration seems to be a better way to measure accessibility than choice which was much less correlated with the dependant variables. Accordingly to Hillier (2009), this may be due to the local scale being more important than global scale concerning non-motorised transportation (see 2.2). It’s also interesting to notice that spatial integration of the work location seems to be more important than the spatial integration of the home location to explain people travel habits. The reason may be that average block size can better explain people choices than spatial integration around home.

Figure 8. Maximal Spatial Integration (radius 6) at work and share of non-motorised transportation

Nevertheless, results from grouping process are as interesting as the final results. Concerning distances to the closest daily destination we looked first for correlation between network distances measured in meters, axial steps or axial steps*meters. Strong correlation was found for both home and work location. Regarding home location, distances in axial steps were much more correlated with the dependant variable while for the work location the pattern was less clear and few distances in meters were kept depending on the destination. Finally, for short distances, distances in axial
steps explain people’s daily choices of transportation to work much more than distances in network meters do. Consequently, in our case, when it comes to measure closest distance to daily destinations, axial steps should be preferred. Further work is needed to examine this pattern for longer distances. For instance, it could be done by comparing correlation with people’s daily choices of travel mode, for home to work distances depending on measures in network meters or in axial steps. Results are expected to be complex and methods for computing these two parameters in a “single distance indicator” would be useful. Further elaborations on space syntax based parameters, which capture human cognition of distance much better than merely metric distance does, will improve correlates with travel habits (Hillier, 2009). The one we have tried in this work, meters multiplied by axial steps, doesn’t appear as a good one as was less correlated with the dependant variable than the simple network meters, and far less than only axial steps.

Subsequently, axial steps are relevant way to define buffers especially those of high proximity and to account for people subjective perception of distances in buffer definition. In fact concerning number of accessible daily destinations, we looked first for competition between buffer sizes. For each destination, measures corresponding to the five network buffer size were highly correlated to one another and two measures instead of five were sufficient. Concerning home location, two profiles were revealed. Some “high proximity daily destinations” (bus stops, nursery, sport equipments, parks and stops) were highly correlated with the dependant variable for the 3 km and 6 axial steps buffer, whereas “medium proximity daily destination” (school, gymnasium, universities, works, groceries, and eating and drinking places) were much more correlated at the 3 km buffer size. Variables within those groups were also strongly correlated to each other. This structure was still present but less clear for airline measures. Regarding the work location those two groups merged in one became one for network measurements and the 3 km and 6 axial steps buffer was the best for all facilities. Once again this was less visible for airline measures.

Consequently, everyday destinations (on the way to work) can be split in two groups: high subjective proximity destinations (best correlation for a buffer size < 3 kilometres and 6 axial steps) and medium subjective proximity destinations (best correlation for a buffer size > 3 kilometres and 6 axial steps). For all variables taken into account, three kilometres appears to be a threshold distance to characterize home location as well as work location when it comes to explain travel habits. Regarding small buffers, by adding an axial steps constraint to a classic distance constraint (in network meters) to our buffer, we improved the explanation of the dependant variable a lot. Even though 3 km seems to be a surprising long distance, the 3 km and 6 axial steps buffer is often the best scale to capture high proximity equipment variation within an area among the buffer sizes we tested. This is partly explained by the 3 kilometres and 6 axial steps buffer size which is closer to the 1km or 1 km and 6 axial steps than the 3 kilometres buffers. Axial steps constraint is the limiting factor. This means that we might have missed the optimum distance constraint (between 1 and 3 network kilometres). Concerning the axial steps constraint we used only 6 as a default setting. However, now that the importance of this factor on buffer sizes definitions is identified we should look at these issues more in detail, for instance with constraints of 6, 8, 10 or 12 axial steps for buffers definition.
Finally, our results have confirmed the superiority of network meters on airline meters to capture people distances appreciations. Network measurements are more efficient than airline measurements for almost all the variables. Lee and Moudon (2006), for instance, has found different patterns (about number of accessible destinations) when it comes to explain people walking distances. Their result might be due to a too small buffer size definition which falsely emphasized airline buffers significance compared to network buffers. Still, number of accessible destinations within buffer defined with airline meters can stay in the final model, even if they are less correlated with the dependant variable, because they are not highly correlated with any other measures contrary to most of the number of accessible destinations within buffer defined with networks meters.

5 Conclusion

Our research has consisted in comparing a wide range of information concerning urban form and peoples’ daily travel in the city of Trondheim, aiming at providing general knowledge as well as to contribute in planning the urban development at the Brøset area in Trondheim.

By comparing space syntax analyses with peoples’ real travels, we have illustrated how the parameter “segment angular choice” convincingly corresponds to the complex phenomenon of which specific route people chose to cycle. At several places in Trondheim we see that this space syntax analysis capture cyclists’ preference for continuous and “angle-minimized” routes much better than the intended bicycle routes of Trondheim do. This illustrates how space syntax provides powerful tools for planning well functioning bicycle route network. Our guideline for planning and design of the Brøset area is an example in this respect.

The Place Syntax analyses provided a large set of data about urban form characteristics. According to our statistical analysis, some of them such as employment and population around home and maximal spatial integration at work location are very significant to explain daily travel to work habits. Furthermore, the statistical analysis indicate that axial steps are the parameter that best correlates short distances (to the closest daily destination) to daily travel to work habits; far better than metric distance or distance computed as metric distance multiplied by axial steps distance. Axial steps are also revealed as essential component for origin and destination areas description. By adding an axial steps constraint to a classic metric constraint for buffer definition we improved significantly measurements correlation with daily travel to work habits. Finally, our statistical analysis shows that the space syntax and Place Syntax analyses not only correlate to choice of travel routes but also explain choice of travel modes, which is a step further toward sustainable planning. From the work carried out so far, we see several subjects that we look forward to examine more closely. One is to look at non work trips as well as chained trips; a second is to optimize the Place Syntax analysis by going further into distance measuring, buffers defining and the computing of accessibility indicators. We also look forward to apply our model of analyses on results of the ongoing transport survey that is based an exact addresses (parcel) rather than aggregate areas. This will surely improve the ability to explain peoples’ travel habits.
A basis for the development of space syntax theory and methodology is the comparisons of empirical data and calculations with new parameters. Our result that spatial integration explain work-surroundings’ influence on travel habits well, whereas density and average block size are better for explaining the influence of home surroundings, is an issue that should be examined more closely. This result might have parallels to the finding of Raford et al. (2007) that individual’s routes and aggregated routes correspond differently to configurational aspects of the urban space. Furthermore, our results indicate that Hillier’s concept of to-movement (to be distinguished from “through-movement”, Hillier and Iida (2005, p. 556)) can be distinguished into “to-” and “from-movements”, - in the sense that travel-mode between A and B depends on A or B being the starting point. Our methodological framework of combining space syntax and GIS data within the Place Syntax tool is well suited for elaborating these issues.

In conclusion, Trondheim’s extensive GIS based information about the city, its residents and their travels has provided a unique basis not only for carrying out analyses that are operational for actual planning but also for developing the Place Syntax tool. Our study has been carried out on GIS-data made for general purposes. Providing GIS data aiming more specifically at being basis for this kind of analyses should substantially improve knowledge about urban form’s influence on daily travels. Such knowledge would benefit other and more overall issues such as reducing carbon emissions and improving health.
References

Brennan Ramirez L K et al. (2006) “Indicators of Activity-Friendly Communities, An Evidence-Based Consensus Process” American Journal of Preventive Medicine, Vol. 36, No. 6, p.515-524


Hillier B (1996) Space is the Machine, Cambridge

Hillier B (2009) “Studying cities to learn about minds: some implications of space syntax for spatial cognition” Environment and Planning B: Planning and Design (online publication, 2 October 2009)


Saelens B E, Sallis J F and Frank L.D (2003) Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures, Annals of Behavioral Medicine, vol. 25, p.80-91


van Nes A (2002) Road Building and Urban Change, Ås

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