

## INTEGRATING BICYCLE NETWORK ANALYSIS IN URBAN DESIGN: Improving bikeability in Trondheim by combining space syntax and GIS-methods using the place syntax tool

028

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### Abstract

*By approaches ranging from preventive medicine to carbon emission cut, fundamental problems of our car-dependant societies have been pointed out. In this context, bicycling represents a still unexploited capacity of transportation. Based on the research project Brøset, Towards Carbon Neutral Settlements in Trondheim, Norway, this paper presents space syntax based analyses of bikeability of street networks by means of the Place Syntax Tool. In addition to present the methods and compare analyses with real peoples' bicycle routes, we show results from applying these methods in actual urban design. In conclusion, the analyses capture streets networks' potential for containing useful bicycle routes and are highly useful for evaluating urban design proposals that include street network layout. By this, we hope to contribute to the further methodological development of space syntax tools as well as to provide explicit knowledge about urban form and non-motorised transportation.*

**Keywords:** bikeability, bicycle routes, street network, space syntax, place syntax tool

**Theme:** Green Urbanism and Sustainable Developments

## Introduction

By approaches ranging from preventive medicine to carbon emission cut, fundamental problems of our car-dependant societies have been pointed out. For numerous reasons, non-motorised daily travel, or more explicitly walking and bicycling, are extremely advantageous modes of transport when it comes to sustainable urban development; they have huge positive impact on health, they cause no pollution, they require no fuel apart from normal nutrition, they cause few accidents and they do not require expensive infrastructure.

The crucial question concerning 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 our cities so that people walk and cycle more than what is usual in cities planned during the last century? Peoples' modes of daily travel are closely related to accessibility from home to daily destinations. For a particular household to travel non-motorised, their total of daily destinations must be conveniently accessible by walking or bicycling. Besides workplace, important daily destinations in this respect are kindergartens, schools, shops, local service and parks/recreation areas. Accessibility is closely related to distance along routes that are considered safe and by others means useful. However, concerning walking and biking, space syntax research as well as research from far outside the field of space syntax have pointed out that distance is more than metric length; street network properties such as *street connectivity*, *route directness*, *block size / intersection density* and *angular change* are decisive for walking and biking routes (Cervero et al. 2003; Brennan Ramirez et al. 2006; Lee and Moudon 2006; Schlossberg et al. 2006; Thomsen and Manum 2009). In this paper, we particularly deal with street network layout and accessibility to destinations that according to research should be important for increasing the share of non-motorised transport being the preferred mode of peoples' daily travel. Even though we have paid particular attention to bicycling, the issue of providing street networks that give people accessibility to their total of daily destinations within acceptable distance on safe and useful routes is as relevant for walking as it is for bicycling.

The empirical background for this paper is the research project *Brøset, towards carbon neutral settlements*. Brøset is a former mental hospital and green-field area in Trondheim, Norway, where urban development now is being planned. The aim of the research project, which has been a collaboration between the local authorities in Trondheim, consultants and The Norwegian University of Science and Technology (NTNU), has been to provide guidelines for the design process of a new urban development where carbon emissions should be far below what now usually is the case in Norway. The site for the new urban development is 35 hectare, located about 3 km from the historical centre of Trondheim. Due to the history of being a mental hospital, the area has by purpose been disconnected from the surrounding city. The planning process has been chaired by the local authorities in Trondheim and has been carried out as an urban design competition where four teams have been working in parallel. Based on the four design proposals, the local authorities are now developing the formal master plan for the area.

This paper first presents the space syntax based methods that we applied for analysing bikeability of street networks and includes a comparison of these analyses and real peoples bicycle routes. Then we show some results from the analyses of the Brøset area, providing guidelines for urban design and evaluating the design proposals made by the design teams.

## Space syntax and bikeability

Our study is based on space syntax methodology, a field of architectural research that is about configurational aspects of space, i.e. how spaces are positioned in relation to each. Results from space syntax analyses correlate to several complex phenomenon taking place in urban space, phenomenon such as amount and kinds of traffic, real estate value, location of retail and frequency of burglary. Compared to car driving, walking and bicycling are more flexible concerning route choice; often allowing for moving directly towards your destination, simply in the street that you actually see, and they are rarely obstructed by conjunctions. For these reasons, pedestrian movements and bicycling are modes of transport where space syntax methods are particularly useful (Hiller 1996, 164; Hillier and Iida 2005; Raford et al. 2007).

Until the last decade, space syntax modelling of urban spaces / streetscapes were based on the *axial line analyses*, consisting in analysing *axial maps* where streets and other accessible urban spaces are modelled by straight lines representing views and peoples' potential movement, and where *axial lines* are either connected or not. The measurement *spatial integration* is calculated within different radii (radius in the meaning number of change of direction between two lines) has shown to correlate well with different kinds of movement (van Nes 2002). For car traffic, *global integration* is a useful parameter (calculating axial steps between all axial lines in a particular model). For pedestrian movements, *local integration* is more useful. Additional to *integration*, recent years' development of space syntax methodology includes the parameter *choice*. Whereas *integration* describes the distance in terms of axial steps from one element (or one street) to all others, *choice* (in mathematical graph theory termed *betweenness*) describes to what extent a particular line-segment is part of the shortest route between other elements (Hillier and Iida 2005; Turner 2007; Hillier 2012). In parallel to the introduction of the parameter choice, space syntax tools have been developed in order to handle spatial distances in a more refined ways than axial lines being either connected at an intersection or not (Figueiredo and Amorin 2005). For this purpose the parameter *angular change* in combination with *segment analyses* has been developed (Turner 2001, 2005 and 2007). In these analyses, the basic spatial element is the straight line from one intersection/junction to the next and the space syntax distance between two connected line-segments are calculated in accordance with the angle between the lines; the spatial distance between two line segments being 0 (zero) in the cases where there are no angular change, i.e. continuing straight ahead at an intersection, and 1 when it is 90 degrees. Space syntax analyses calculating *segment angular change* correlate very well to bicycle traffic (Raford et al. 2007). More explicitly, continuity in terms of *angular minimisation* or *least angular change* is essential for attractive bicycle-routes. This is well known by cyclists; on bike, in order not to loose speed, you try hard to "smooth" sharp corners on the route. Therefore, as we will come back to, this kind of analyses is very useful for predicting bikeability of a street network. Concerning the different kinds of space syntax analyses mentioned above, our research includes calculating *space syntax integration* based on an *axial map* as well as calculating choice (or *route directness*) based on *segment maps*.

## Methodological approach, combining space syntax and GIS

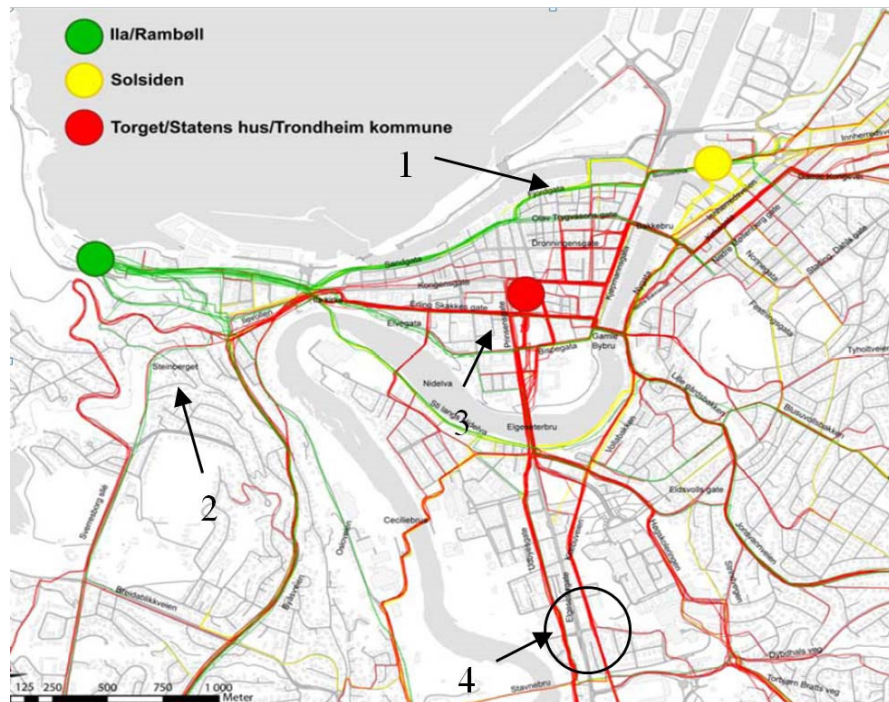
Basic space syntax is about configurational properties of space, leaving out other spatial properties. Therefore, in order to capture wider aspects of street networks and urban form, our methodological approach has been to combine space syntax analyses and GIS (Geographic Information Systems). This we have done by means of the Place Syntax Tool, a software developed at the Royal Technical University in Stockholm (KTH), Sweden. The Place Syntax Tool combines space syntax concepts for modelling urban space, i.e. topological axial line distances, with GIS-based descriptions of attractions / destinations into a combined accessibility analysis model (Ståhle et al. 2005). By introducing the axial line as a distance-unit in a GIS-based

“attraction-accessibility analysis” we capture essential features of urban form as complex cognitive environments. Thanks to Trondheim municipality’s GIS-data that includes detailed information about 5000 peoples’ daily travel habits, our research project has been an arena for developing and testing spatial analyses and for providing knowledge about the relations between urban form and daily travel patterns. Based on Trondheim municipality’s GIS-map and ortho-photos in high resolution, we made a detailed axial-map of all streets and paths for walking- and biking in the entire city of Trondheim. Then, applying the Place Syntax Tool, we carried out space syntax analyses of the street network as well as more advanced analyses examining combinations of space syntax and GIS-data. The aim of the space syntax analyses was to reveal potentials (and problems) of the street-network. The space syntax analyses consisted in calculating axial integration with a radius of 6 axial steps (in order to capture pedestrian movement potential) and segment angular choice with a radius of 5000 metres (in order to capture bicycle routes). The aim of the combined space syntax and GIS analyses was to examine parameters describing accessibility to destinations, parameters that according to research should be important for people choice of mode of daily transport. By the Place Syntax Tool, we examined accessibility to peoples’ daily destinations such as schools, kindergartens, shops and workplaces. As mentioned above, we have captured distance by combining GIS and space syntax methods; combining metric distance along the street network and perceived spatial distance as measured by space syntax axial steps.

### **Results: comparing results of space syntax analysis with peoples’ real bicycle routes**

In the following, we present results from comparing space syntax analyses of the bicycle route network, peoples’ actual bicycle routes and official or intended bicycle routes as planned by the local authorities.

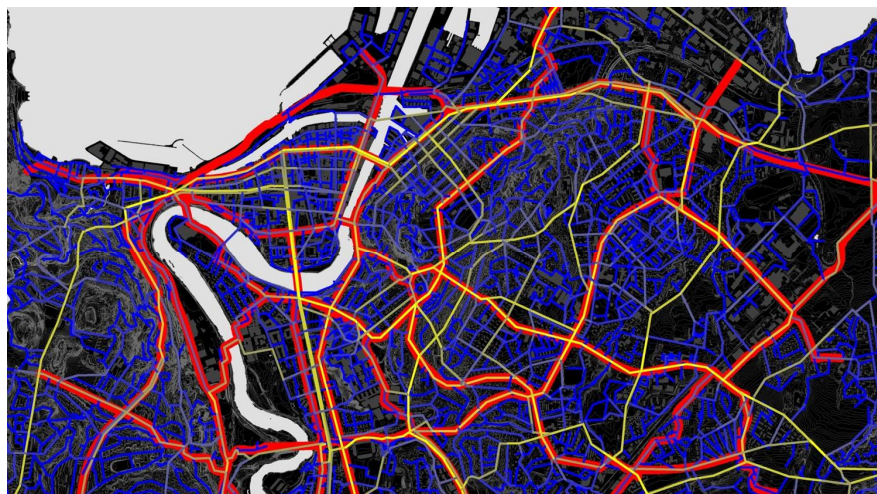
In Trondheim as well as in many other cities, there exist much data about amount of traffic at specific points, data found by counting or assumed by calculations. Something that we often know less about is which specific routes individual people actually choose. In order to examine this, we carried out surveys identifying peoples’ actual bicycle routes to work. We did a questionnaire-based survey where the respondents were people working in or nearby Trondheim city centre, - asking where they lived, how they travelled to work and which route they chose from home to work. The respondents drew their route by hand directly on a paper-map. Then, we drew these individual routes manually one by one on computer, resulting in squid-like images describing real bicycle routes to (and from) the centre of Trondheim (see fig. 1). 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 et al. 2009). These actual route maps provide empirical data that is useful for being compared with the space syntax analyses and with intended bicycle routes as described by formal bicycle route map of the local authorities of Trondheim.



**Figure 1:** 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/to home.

Comments:

- 1: Fjordgata, no crossings from north.
- 2: Steinberget, steep slope.
- 3: The importance of visual continuity (as also captured by the space syntax analysis, fig.2).
- 4: Bicyclists choose parallel routes when such exist and there is heavy traffic in main street.



**Figure 2** Comparing results from space syntax analysis with official/intended bicycle routes. The space syntax analysis is "segment angular change, choice, buffer radius 5000 meters", measuring *route directness* of the bicycle network. (Blue = low, wide yellow = high) The additional red lines mark formal bicycle routes as officially planned by the local authorities of Trondheim.

Space syntax analysis of street network is a way of revealing potential performance of urban space (Marcus 2000). To what extent the potential for non-motorised transportation is exploited (or realised) depends on numerous issues on street level such as amount of cars, obstacles in terms of crossing traffic, slope, street surface quality, lightening by night, views/scenery and other issues not captured by the space syntax model (this being axial- or segment-map). 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 of the analysis should illustrate the potential for bicycle traffic along the line-segments in the model, see fig. 2. By comparing these results with intended route map and with actual route map, we can examine the applicability of the space syntax analyses.

The line segment colours ranging from yellow to dark blue in fig. 2 show the results of the space syntax analyses calculating *choice* (or *route directness*) of Trondheim, whereas the red lines in the same figure show intended bicycle routes (according to the planning authorities of Trondheim) on the same map. The intended routes are of numerous kinds: some are well designed separate bicycle lanes, some are mixed-use streets that are suited for cycling due to little car traffic, and some are streets or paths that in reality, for different reasons, are not much used by cyclists. What we see, is that the space syntax analyses, which is a purely mathematical calculation of some configurational properties of the street- and path-network, corresponds very well to intended bicycle routes as well as to where people cycle in real. However, looking more closely, we see several places where the three maps do not correspond and that are worth some comments.

Point 1 in fig. 1 is Fjordgata, a street much used by cyclist but neither marked on the intended cycling routes (red lines in fig. 2) nor captured by the space syntax analyses (blue to yellow lines in fig. 2). (Please note that the word *gate*, or *gata* as in *Fjordgata*, is a Norwegian word that means *street* and not *gate* in English.) The reason for bicycling in Fjordgata is this street's location at the north edge of the city centre, implying that no streets from north cross into Fjordgata. Therefore, different from Olav Trygvassons gate that according to the space syntax analysis as well as municipal intentions should be the bicycle route, Fjordgata provides an obstacle-free bicycle distance of about 500 meters. Since the time consuming effect of intersections is an issue not included in the space syntax modelling or analyses, it is not surprising that space syntax results do not capture it. Concerning intended or official bicycle routes, the results show that crossing-free routes are highly preferred by cyclist and that the local authorities' choice of Olav Trygvassons gate being the main bicycle route should be questioned.

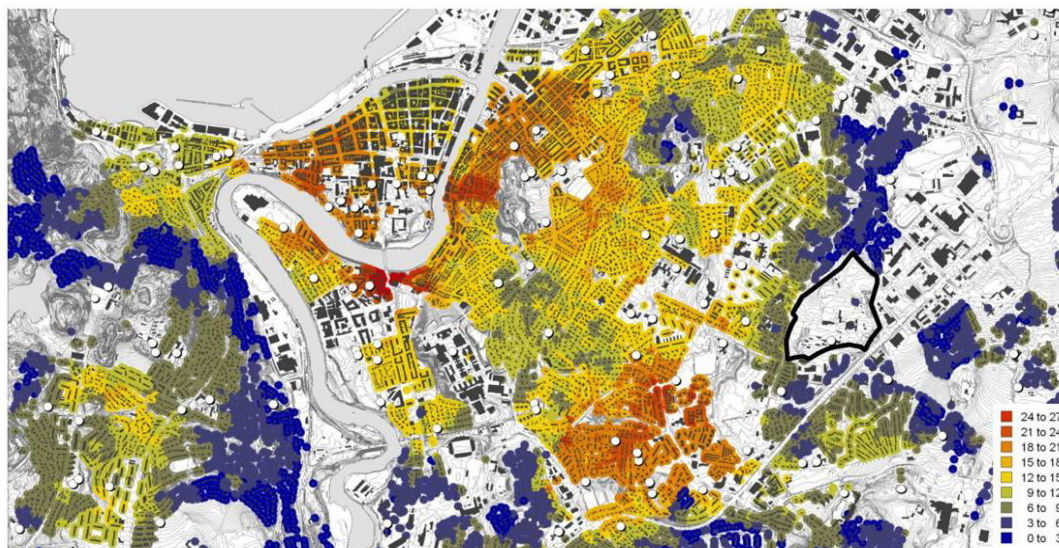
In conclusion, the comparison of the analyses and real peoples' route choice on bicycle illustrates how this kind of spatial analyses are very useful for grasping the bike route potential of a street network. For understanding the relation between urban form and real bike flows in more detail, further properties on a place level, such as the amount of car traffic, the number and kinds of crossing streets and bike lane quality, need to be taken into account. By further development of software, several of these additional and decisive properties can easily be included in the same kind of analyses that we have applied here.

## Analysing existing situation in the brøset area and providing guidelines for design

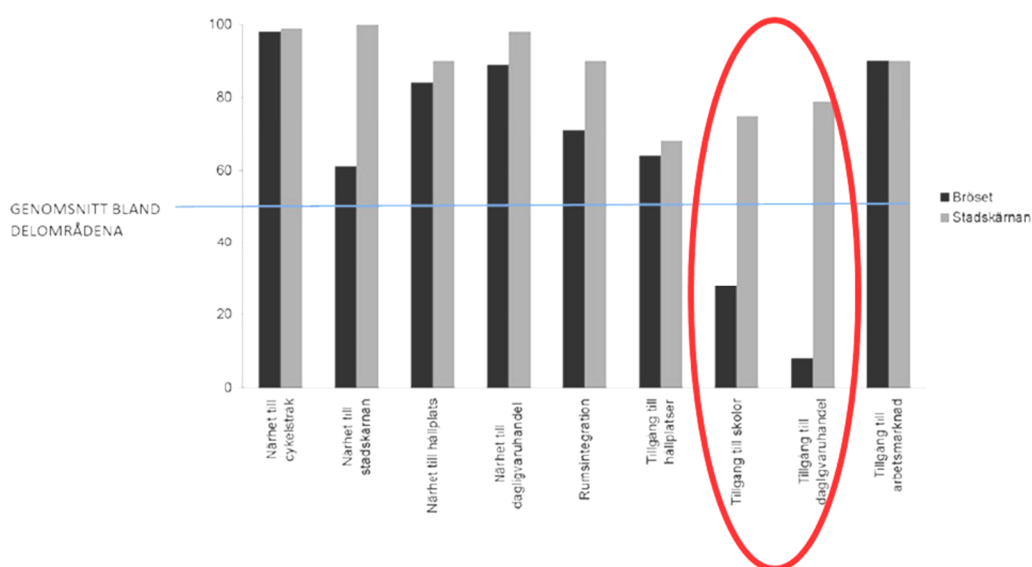
The aim of our research has been to provide design-guidelines about how to reduce carbon emission from transport at Brøset by means of urban planning and urban form. A main focus has been to increase non-motorised daily travel, and in order to achieve this, there are two important and interrelated issues. One is to cater for a street network that supports walking and biking. The other is to locate dwellings as well as peoples' daily destinations in relation to this street network so that walking or bicycling becomes the favourable mode of transport for a higher share of the population. In order to reduce private car driving also for those travelling longer than walking or bicycling distances and for those that for other reasons cannot walk or cycle, it is important to ensure close access to bus (or tram) stops on good public transport routes.

Concerning accessibility in the Brøset area, this is of several kinds. One is about accessibility for the new residents at Brøset, from their home to their daily destination. The second is about accessible density of residents; to what extent do the Brøset area, after the new urban development is built, provide the accessible density of residents that is needed for local destinations (shops, service, schools) to survive without car based travel from more distant areas. The third is about the new Brøset's influence on its surrounding area. A Brøset project that includes well designed walking/bicycling-routes as well as *destinations* that now are lacking in the area, has huge potential in improving the accessibility to daily destinations also for existing population in the Brøset area. The Brøset project also has great potential in improving accessibility between the surrounding areas that now are poorly interconnected. Concerning reduction of carbon emission from transport, the effects of the latter might be as large as what might be achieved within the new settlement at Brøset.

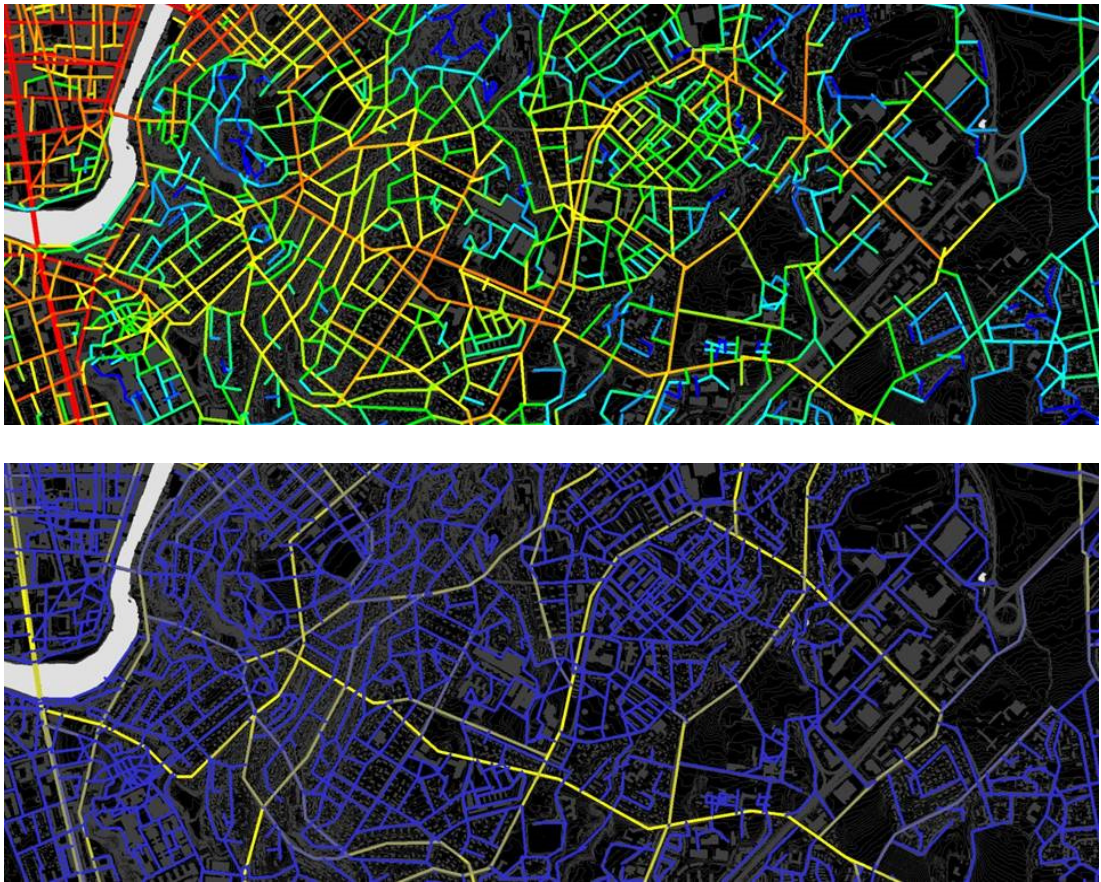
Fig. 3 shows accessibility to schools, where the scale from red to blue represents high to low accessibility. This *accessible density* of schools is measured as number of schools within 1 km and 6 axial steps along potential walking/cycling routes. What we see, is that accessibility to schools is very poor in the Brøset area. Fig. 5 illustrates the space syntax integration of the street-network (lines coloured red to blue, red being much integrated) and route directness of existing situation. The figure shows that the street network around Brøset has low intersection density and is not well integrated. Fig. 4 shows accessibility from Brøset to a selection of destination compared to the same accessibilities from the centre of Trondheim. The accessibility is also compared with the average of other areas of Trondheim within 5 km from the city centre. What we see, is that schools and retail are poorly accessible from Brøset. Accessibility to school and retail are among the most important parameters for achieving a high rate of walking and cycling (Lee and Moudon 2006). Therefore, aiming at "carbon neutral settlement" at Brøset, the area's accessibility to these destinations should be significantly improved. This can be done by including school and shops in the Brøset-project or by improving the street network for walking and bicycling so that access from Brøset to schools and shops in the surrounding areas becomes better.



**Figure 3:** Accessibility to schools, measured as number of schools (kindergardens, primary schools, high schools and universities) within 1 km distance along walking/cycling-street-network.

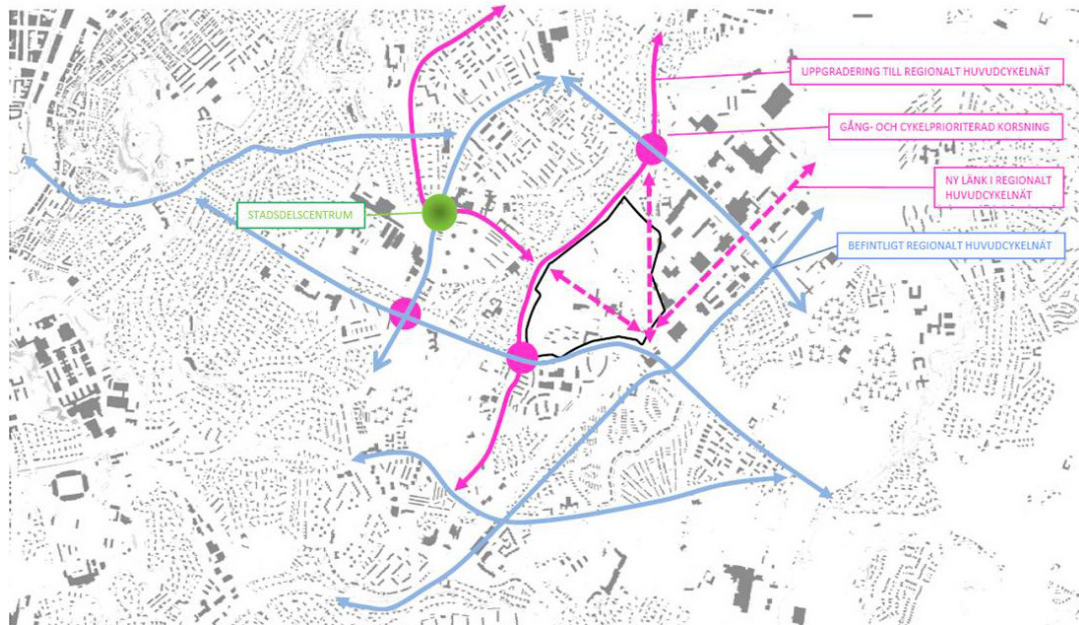


**Figure 4:** Accessibility to a selection of destinations, from Brøset compared to city centre and to Trondheim within 5 km from the city centre on average. Grey: from Brøset. Black: from Trondheim historic centre. Blue line: city of Trondheim on average. The red marking points out how accessibility to schools and shops is very poor in the Brøset area.



**Figure 5:** Results of space syntax analyses of existing situation. Space syntax *integration* (top) and space syntax *choice / route directness* (bottom).

Concerning the bicycle route-network, fig. 5 shows that the intersection density is low in the Brøset area. This implies that the street network should be completed by adding new streets or paths and by upgrading some of the existing ones. Our proposal for doing so is shown in fig.6, where blue lines are existing routes, continuous red lines are existing routes that should be upgraded and dotted lines are new routes that should be added. These proposals concerning accessibility and street network layout are results from our research that have been guidelines for the parallel design proposals as well as for the further planning and design of the Brøset area.



**Figure 6:** Our proposal for improving the bicycle-network in the Brøset area.

Blue: important and well working existing routes

Cyan, continuous line: existing routes that should be upgraded.

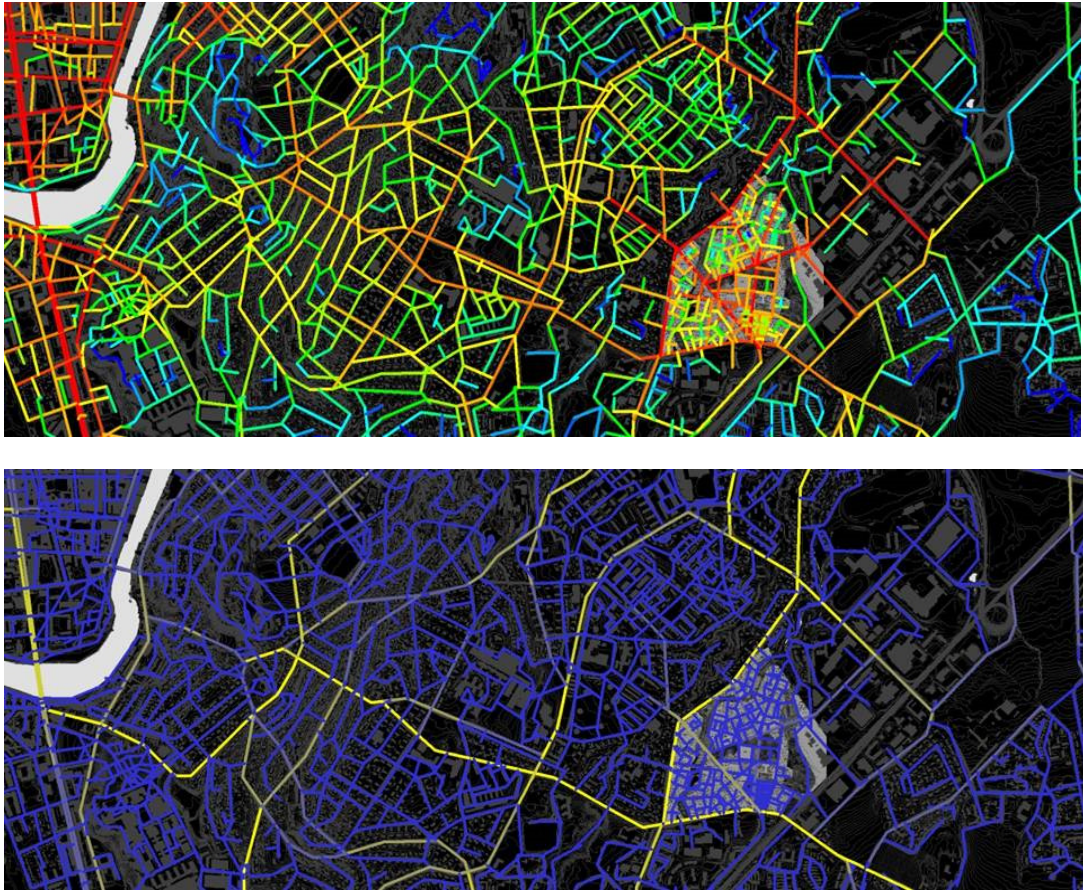
Cyan, dotted line: new routes that should be made.

Green dot: the local centre Valentinlyst, 500 meters north-west of Brøset.

## Comparing and evaluating the design proposals

In order to evaluate the four proposals from the parallel commissioning process for urban design at Brøset, we applied the methods of analyses presented above. We modelled the four urban design proposals into the GIS-model of entire Trondheim; each of the proposals were modelled by their particular street-layouts and by their number and locations of dwellings (implying an assumed number of residents) as well as the location of other functions. By the Place Syntax Tool software we analysed the four proposals. Here, we will point out some of the results. Most interesting is the comparison of the proposal from team SLA with the proposal from team CODE. These two proposals have quite similar number of dwellings (CODE having 1200 dwellings whereas SLA has 1500 dwellings) but are very different in terms of the street networks. Fig. 7 and fig. 8 shows the space syntax analyses of the CODE and the SLA proposal, respectively. What we see, is that the SLA proposal is a labyrinth and disconnected from surrounding streets, whereas the CODE proposal is the total opposite. In the CODE project, the inhabitants have easy access to the surroundings, including to the shops and the local service centre Valentinlyst about 500 meters north-west of Brøset (see green dot in figure 6). The CODE project also provides easy access to Valentinlyst by foot or bike for all those living south west of Brøset, an area that now is poorly connected to Brøset as well as to Valentinlyst.

As for bicycle route network, the CODE project is the only containing a bicycle route likely to be important within Brøset as well as connecting the surrounding areas. Concerning density and locations of residents, the CODE project is the one where the accessible density of residents best corresponds to the spatial hierarchy of the street layout. Such correspondence indicates that the proposed main streets have the potential of becoming places where retail and other activities likely will be located and work well due to sufficient supply of customers. Besides this, the CODE proposal is the one that most consciously provides a wide range of attractions within the site, aiming at reducing the inhabitants' need for travelling to remote places for recreation.



**Figure 7:** Space syntax analysis of the Team CODE project, space syntax *integration* (top) and space syntax *choice / route directness* (bottom).

Our proposal, after analysing and comparing the four design proposal for the new settlement at Brøset, is that the project should be developed based on CODE's well connected street network and that some higher number of dwellings should be examined. Concerning other issues, the plan could be improved by more conscious positioning of different densities of buildings in relation to the hierarchy of spatial integration in street network. This should include to examine how functions requiring "consumers" (such as shops and service, maybe also schools) could be easy accessible by being located along well integrated streets at the west edge of the Brøset-area (see fig. 5, 7 and 8) and not only in the centre of the Brøset-area (which is the place where all proposals have located these functions). Based on the four design proposals, from which only the CODE and SLA projects are presented here, the planning department of Trondheim local authorities are now working out a master plan for the Brøset area.



**Figure 8:** Space syntax analysis of the Team SLA project, space syntax *integration* (top) and space syntax *choice / route directness* (bottom).

## Conclusion

In this research, aiming at understanding how urban planning and urban form can help increasing bicycling, we have examined several issues related to urban form and peoples' mode of daily travel. One of these issues is configurational properties of the street network, or to be more precise: accessibility properties of the *bicycle route network*, where bicycle routes include all streets, lanes and paths where cycling is possible, allowed and fairly safe.

According to earlier research, space syntax analyses calculating *choice* rather than *integration* are useful for analysing street network properties relevant for biking. In order to properly capture bikeability, our analysis has calculated *choice* or "*network betweenness*" within a certain *metric distance*. In parallel to this theoretical analysis of the street network, we have carried out surveys mapping individual peoples' actual bicycle routes. By comparing the results of our analyses with peoples' real bicycle routes and also with the officially signed bicycle routes as planned by the local authorities, we have evaluated the applicability of the space syntax analysis. The result is that the space syntax analysis using the *Place Syntax software* convincingly identifies the potential for bicycling in a street network, clearly pointing out the most bikeable routes in the network.

Based on these results, we have applied our methods in more detailed analysis of the Brøset site in Trondheim and suggested guidelines for improving the street layout of the site, as shown in fig. 6. Then, after four design teams had made their urban design proposals, we analysed and

evaluated the proposals and provided input for the further design done by the local authorities. In accordance with the aim of promoting biking as the preferred mode of daily transport, the analysis has provided important input to the planning and urban design process.

The nature of architects' design practice is to argue that the design proposal, when realised, will be nice and solve its tasks. To what extent this is likely to really happen, is usually not thoroughly examined. By our research we try to improve this. By comparing empiric data with analyses using recently developed tools combining space syntax- and GIS-based methods, we have shown the usability of some specific methods and provided information to the actual design-process of the Brøset settlement. The methods described in this paper are powerful tools for shedding light on presumable effects of alternative urban design proposals. Some of our results, such as pointing out the potential in connecting Trondheim in east-west direction by means of the Brøset project, are not exploited in the on-going planning and design. This is a bit surprising, since our and others' research clearly indicate huge positive effect of such better connected street networks. Other results, such as the need for improving accessibility to schools and retail in the Brøset are, are now included in the proceeding master plan carried out by the local authorities in Trondheim. In conclusion, we hope that our input to the planning process and our specific proposals for design of the Brøset settlement can be some of the many steps required on the travel towards more sustainable urban development. As shown in the previous paragraphs, the methods developed through our research are useful tools for analysing and discussing basic issues of planning and urban development.

Our results from comparing the space syntax analysis with empirical data of real bicycling show the applicability of the analyses in revealing street networks' potential for bicycling. As shown in this paper, such analyses are highly useful for proposing improvement of the street network as well as for evaluating and comparing alternative urban design proposals. By this, we hope to contribute to the further methodological development of space syntax tools as well to provide some explicit knowledge about urban form and non-motorised transportation in general and bikeability in particular.

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