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Accessible density; a condition for sustainable urban development

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Abstract

This paper is based on the research project *Brøset, towards carbon neutral settlements*, in Trondheim, Norway and presents the concept *accessible density* as an approach for examining how, by means of planning and urban design, to increase walking and biking as mode of daily travel. Different from conventional density that illustrates number of elements in relation to area, *accessible density* does not point out where numerous elements are located but to what extent any selection of elements/destinations/attractions are accessible from any particular point. In many questions related to urban planning, *accessible density* is far more useful than only density. In this paper, we present the methodology of examining *accessible density* by combining GIS and space syntax methods and show how the methods have been applied in developing and evaluating urban design proposals.

Introduction

Some density of people is essential for urban life in general and for sustainable urban life in particular. In order to provide the population needed for a grocery shop to be reached by a sufficient number of customers, a school to be reached by a sufficient number of pupils or workplaces to have the required amount of labour, a certain density of people is needed in the surrounding area. In countries where most households own a private car, low density of people makes private car the only option for daily travel. For these reasons, the issue of density is present in most discussion on attractive urban life and sustainable urban development. Density of people is commonly considered as the number of people per area. However, such density is a very simplified parameter for grasping the real peoples' access to their daily destinations. As we will elaborate in this paper, the concept of *accessible density* is far more useful. For a shop to have the needed amount of customers within a distance allowing for sustainable transport, the question is not how many people that lives in a certain geographical area, but how many people that in reality have convenient access to the shop without having to drive a private car. Before explaining this concept of *accessible density* more in detail, we will briefly describe the research project on which this paper is based.

This paper presents methods and results from the research project *Brøset, Towards Carbon Neutral Settlements*. This research project has examined how to develop a previous hospital and green field area in Trondheim into an attractive neighbourhood where energy consumption and carbon emissions are far less than what now is common in Norway. An important issue of our research has been how, by means of planning and urban design, to increase the share of walking and biking in peoples' daily transport. In addition to being sustainable due to almost no energy consumption, emissions and pollution, walking and biking are advantageous for attractive urban life, perceived safety, mixed used neighbourhoods and for health.

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? Mode of daily transport is closely related to accessibility from home to daily destinations. For a particular household to travel non-motorised, their total of daily destinations must be accessible by walking or bicycling without too much bother. Besides workplace, important daily destinations in this respect are kindergartens, schools, shops, local service and parks/recreation areas. Accessibility is closely related to distance and land use mix. However, concerning walking and biking, distance is more than metric length; also street network properties such as *street connectivity*, *route directness*, *block size / intersection density* and *angular change* are decisive for real as well as for perceived travel distances. (Brennan Ramirez et al. (2006); Cervero (2003); Lee and Moudon (2006); Schlossberg et al. (2006); Thomsen and Manum (2009)) In the research presented in this paper, we have particularly dealt with street network layouts and accessibility to destinations that according to research should be important for non-motorised transport being the preferred modes of peoples' daily travel. Even though we have paid particular attention to bicycling, the issue of accessibility to daily destinations within a certain acceptable distance on safe and useful routes is as relevant for walking as it is for bicycling.

Methodological approach, the concept of *accessible density*

Different from conventional density, which illustrates number of elements in relation to area (the element being residents, shops, schools or whatever), *accessible density* do not point out where elements are located but to what extent selected elements are accessible from any particular point. In our research we have examined *accessible density* by combining GIS-analyses with distance measurements according to space syntax methodology. This is done with the Place Syntax Tool developed at The Royal Technical University in Stockholm, Sweden. (Ståhle, Marcus and Karlström, 2005). Fig. 1 illustrates the difference between density and accessible density; fig. 1 left shows density of residents in Stockholm, whereas fig. 1 right shows accessible amount of residents within a defined distance. Concerning urban life and activities accessibility density gives a more accurate picture than density in terms of number per area. Analyses of accessible density can be based on different kinds of distance measurements; simply metric distance (along the street-network), distance in terms of *space syntax axial steps*, which we will come back to, or any combination of the two, the latter often being most useful. What distance and what measurement to apply in a particular analysis, depends on the subject of interest and is a question also worth future research. For evaluating alternative locations of playgrounds for small children, the buffer distance should be shorter than when examining accessibility to grocery shops or high schools. As illustrated in fig. 1, the pattern of *accessible density* can be very different from that of density. In many questions related to urban planning *accessible density* is far more useful than only density.

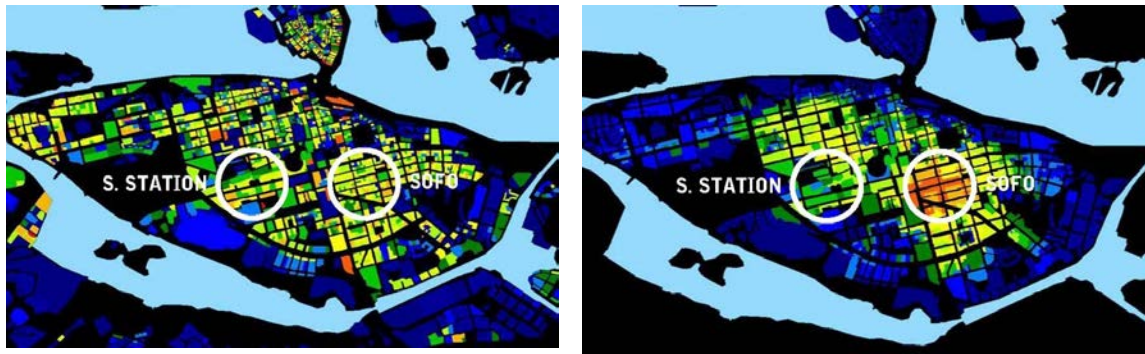


Figure 1

Left: *density* of residents in Stockholm

Right: *accessibly density* of residents in Stockholm (measured within 1km walking distance)

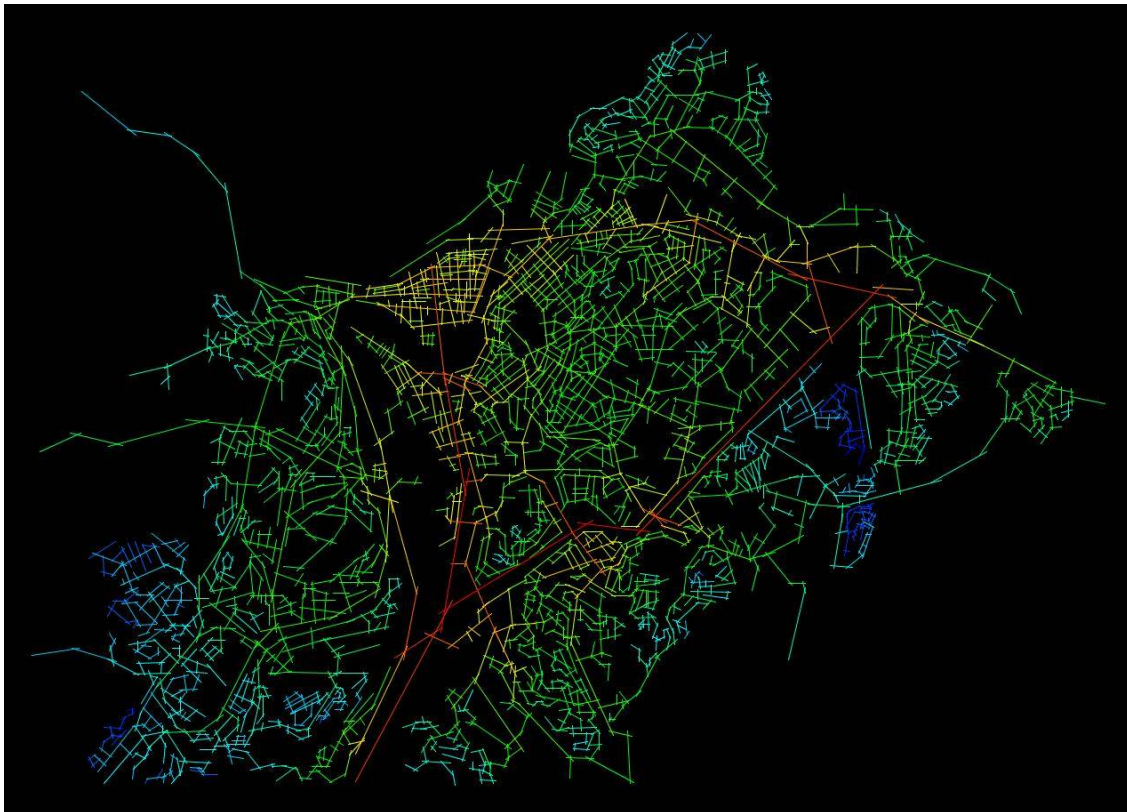


Figure 2

Space syntax axial map of Trondheim

(Here coloured in accordance with *space syntax global integration*, software: AGRAPH)

As just described, our distance measurements are based on methods from *space syntax*, a field of architectural research that is about configurational aspects of space, i.e. how spaces are positioned in relation to each other, and that leans on combinatorics / graph theory in mathematics. Fundamental in the development of space syntax theories and methods are the works of Bill Hillier and Julienne Hanson at The Bartlett, University College London (Hillier and Hanson (1984); Hanson (1998); Hillier (1996)). Results from space syntax analyses correlate to numerous 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. Pedestrian movements and bicycling are modes of transport where space syntax methods are particularly useful (Hillier (1996, p.164); Hillier and Iida (2005); Raford et. al. (2007)). For more information about *space syntax* theory than what is given in this chapter, see for instance Hillier and Vaughan (2007) or, for a brief overview of theory and methods, see Manum (2006, p.66–81).

A basic kind of space syntax methodology is the so-called *axial-line analyses* that consist in analysing *axial-maps* where streets and other accessible urban spaces are modelled by straight lines representing views and peoples' potential movement. Fig. 3 shows an axial map of Trondheim where the axial line is coloured in accordance with *space syntax integration*, illustrating the distance in terms of number of crossings (or number of change of directions) between each particular line and all other lines. Integration calculated within different radii (radius in the meaning number of change of direction between two lines) has shown to correlate 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, as shown in fig. 2. For pedestrian movements, *local integration* is more useful. *Local integration* means calculating axial steps only between axial lines that are within a certain number of intersections (or changes of direction) from each other. 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 (2009)). 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 Turner (2001, 2005 and 2007) has developed the parameter *angular change* in combination with *segment analyses*.

In our research we have combined 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 by means of the software Place Syntax Tool (Ståhle, Marcus and Karlström, 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. 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, similarly to the map in fig. 2. Then, applying the Place Syntax software, we carried out space syntax analyses of the

street network as well as more advanced analyses combining 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 5 000 metres (in order to capture bicycle routes). By the Place Syntax software, we examined accessibility to strategic destinations such as schools, kindergartens and workplaces. For more details about the methods, see Manum and Voisin (2010).

The urban planning / urban design project at Brøset

In order to increase non-motorised daily travel, there are two important and interrelated issues. One is to cater for a well designed street network. The other is to locate dwellings as well as peoples' daily destinations so in relation to this street network that walking or bicycling becomes the favourable mode of transport for a high share of the population.

Before looking at our analyses of the Brøset-area, it is interesting to compare today's accessibility to daily destinations in Trondheim with Trondheim's historical urban development. In fig. 4 we see the historical development of Trondheim; black showing built areas. Fig. 5 shows today's accessibility from residences (addresses in Trondheim where people live) to a selection of daily destination that according to research should be important for peoples' mode of daily travel. The destinations are bus stops, schools and grocery stores within a distance of maximum 1 km network distance and maximum 6 axial steps. This measurement of accessibility represents easy access by walking.. Comparing the maps, we see that the parts of town developed before 1940, i.e. before car traffic becoming a main criteria for urban planning, are the parts of town that still today by far have the best accessibility to destination that according to research are important for managing daily life without driving a private car. In brief, if we aim at attractive post-car urbanism, many lessons about density, street-grid layout and mixed use can easily be learned from pre-car urbanism.

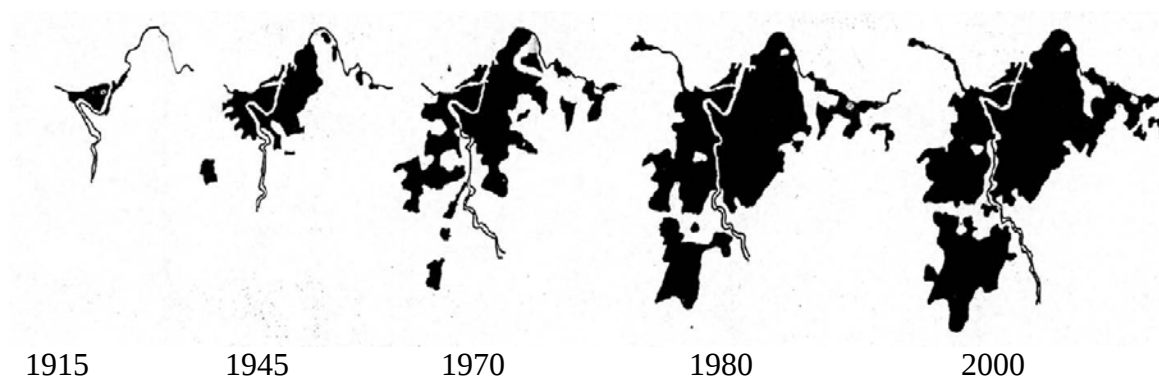


Figure 4

The historical development of the urban fabric of Trondheim

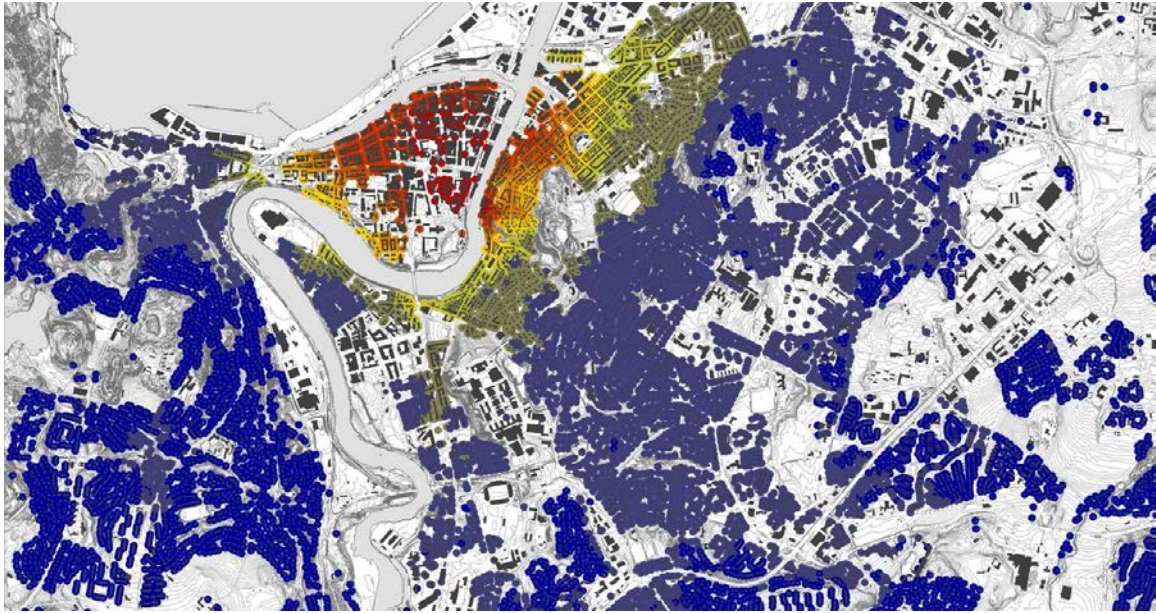


Figure 5

Accessibility to bus stops, schools and grocery shops.

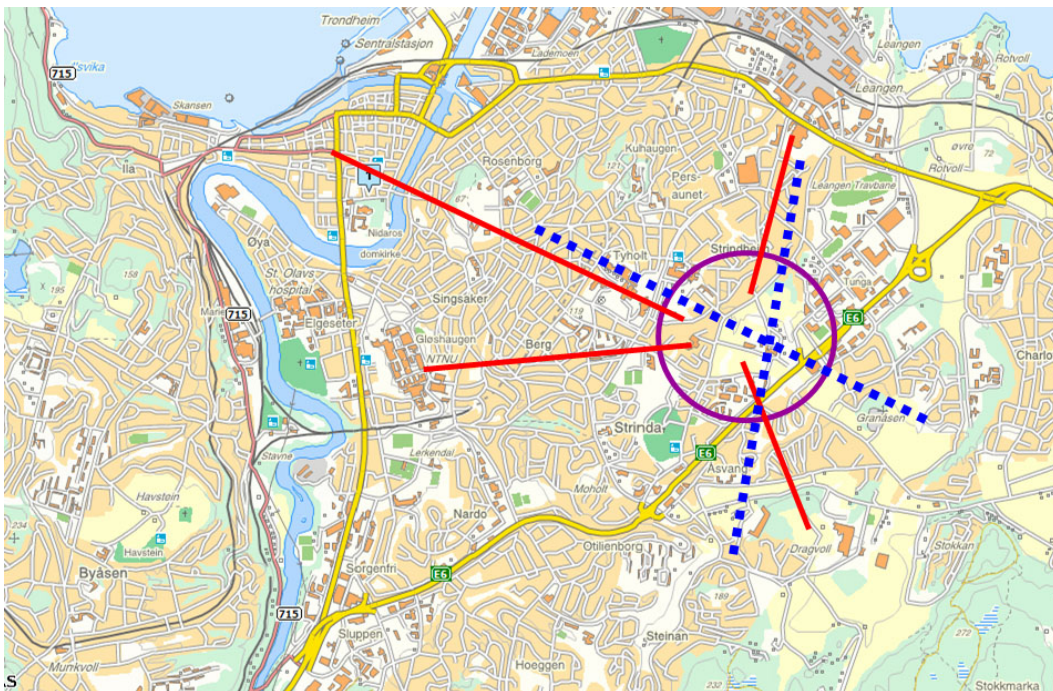


Figure 6

Important connections in the Brøset area

Red lines: connecting Brøset to important destinations.

Blue dotted line: Brøset's potential for connecting its existing surroundings which now are poorly interconnected. .

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 destinations (red lines on fig.6). 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 parts of town. 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, areas that now are separated by the Brøset-site. (See blue lines on fig.6) 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.

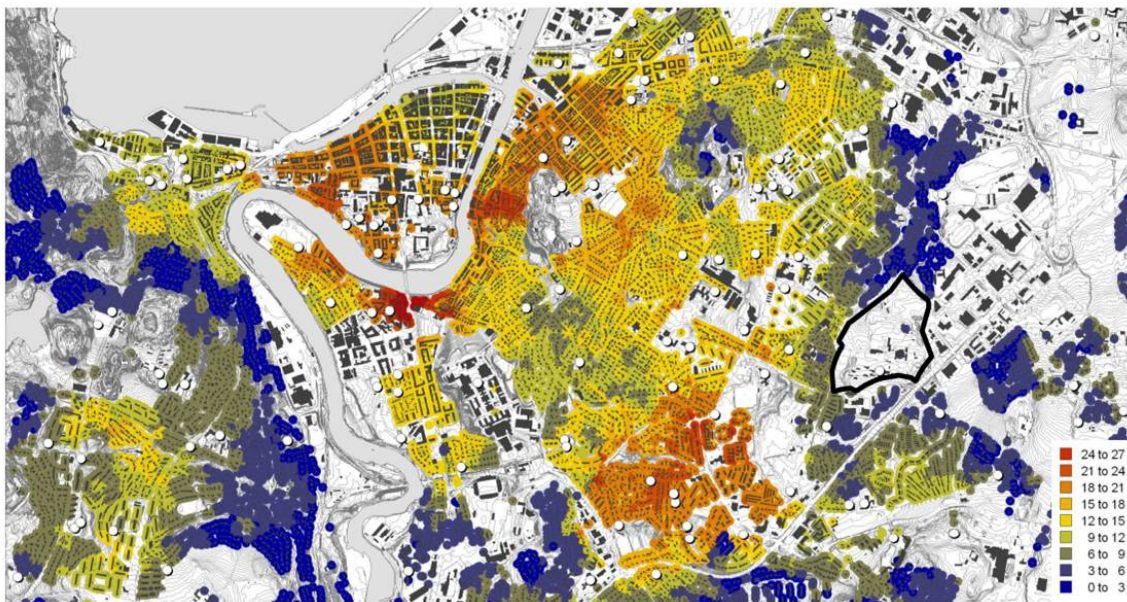


Figure 7

Accessible density of schools

Kinder gardens, primary schools, secondary schools, high schools and universities within 1km and 6 space syntax axial steps.

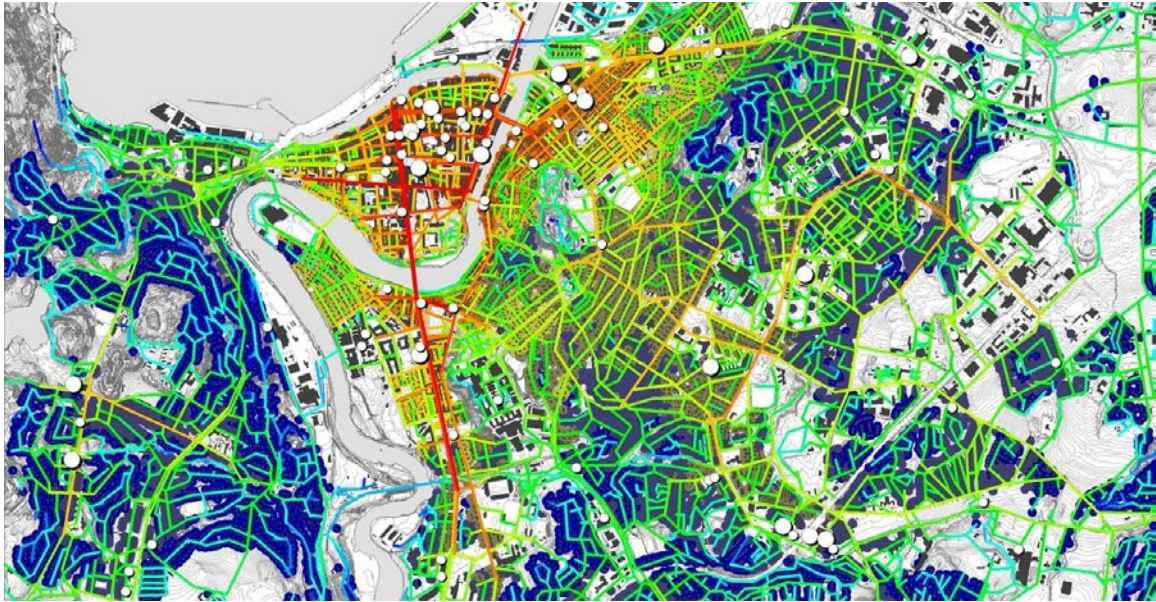


Figure 8

Accessible density of residents (coloured areas) within 1km distance and 6 space syntax axial steps. Spatial accessibility of street network measured as space syntax integration with 6 axial steps (coloured lines).

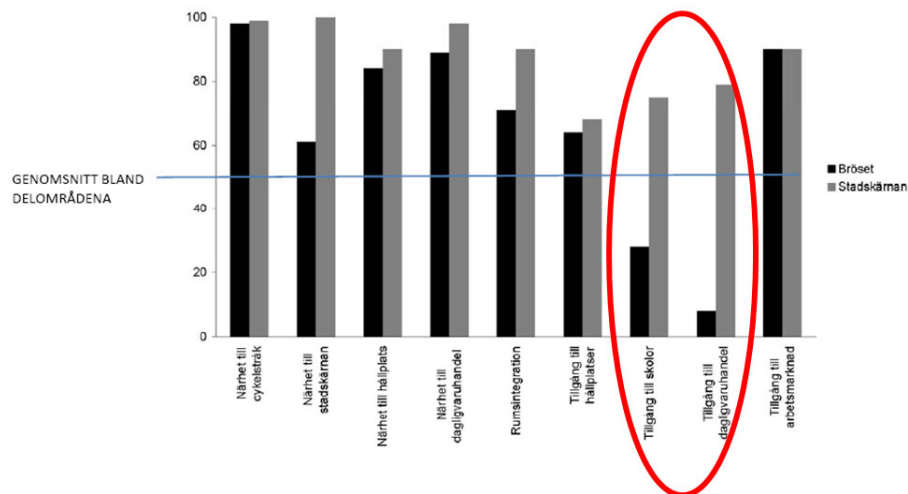


Figure 9

Accessibility to a selection of destinations.

grey: from Brøset

black: from Trondheim historic centre

blue line: city of Trondheim on average.

Conclusion: At Brøset, accessibility to schools and shops is poor. This should be improved, either by including these functions/programs in the Brøset project or by improving the accessibility from Brøset to these functions located in the surrounding area.

Fig. 7 shows our results concerning accessibility to schools, where the scale from red to blue represents high to low accessibility. Accessible density of schools is measured as number of schools within 1 km and 6 axial steps along walking/cycling network. What we see, is that accessibility to schools is poor in the Brøset area, implying that without consciously including this issue in the planning and design of the Brøset area, children living at Brøset will very likely be transported to schools by their parents in private cars. Fig. 8 illustrates the *space syntax integration* of the street-network (lines coloured red to blue, red being much integrated) and the *accessible density of residents* (areas coloured red to blue, red implying many people living 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 shows that the area around Brøset is characterised by low accessible density of residents, the street network is not well integrated and there are few grocery shops. Fig. 9 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 the Brøset. 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 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.

Concerning the bicycle route-network, the *intersection density* in the Brøset area is low: this is disadvantageous for walking and bicycling (se fig 12 a), implying that the street network should be completed by adding new streets or paths and by upgrading existing ones. Our proposal for doing so is shown in fig. B16, 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 planning and design of the Brøset area.

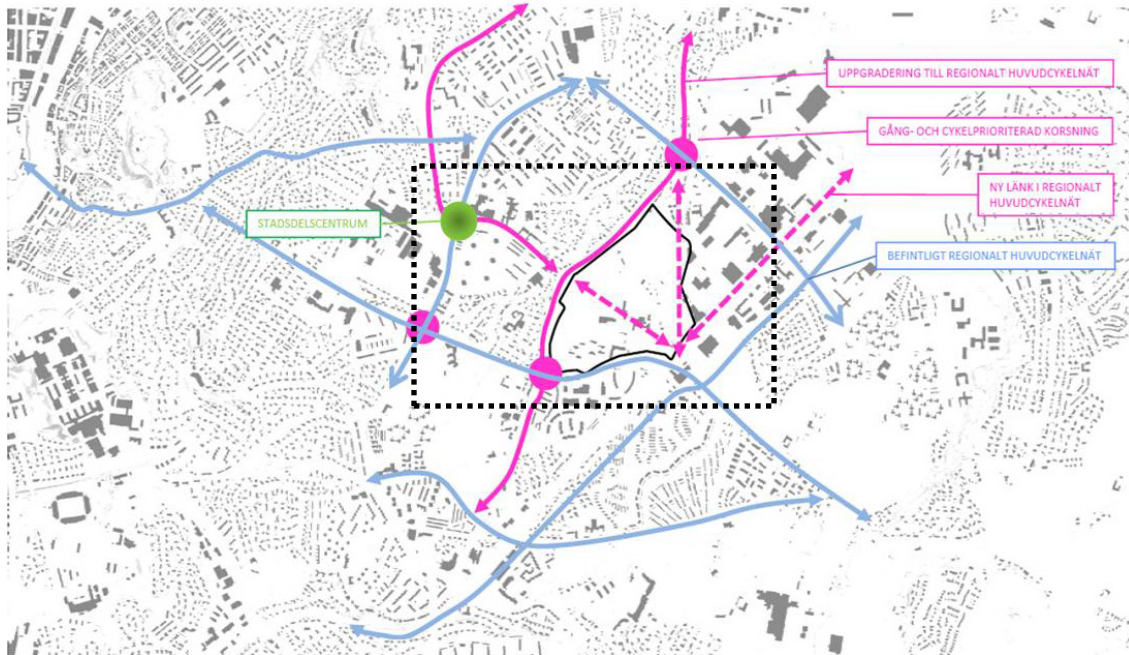


Figure 10

Proposal for improving the bicycle route network in the Brøset area.

Cyan: existing routes that should be upgraded / improved.

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

Blue: existing lines that works well in current state.

Black dotted rectangle: reference for map on fig.11

Evaluation of proposal for master plan for the Brøset area

Based on urban design proposals made by four interdisciplinary design teams working in parallel, the planning department of Trondheim local authorities has worked out a master plan for the Brøset area Fig. 11 shows this plan whereas fig. 12 a, b and fig. 13 a, b show the results from calculating *space syntax integration* and *space syntax choice / route directness*, respectively. In terms of differentiating building densities in accordance to hierarchy of the street network's centrality (i.e. properties capturing the *space syntax* parameter *integration*) the plan is well figured out. The plan improves the connectivity of the area by connecting Brøset to the local service centre at Valentinlyst (see green dot at upper left at fig. 10). Other issues are less convincing, among these is the lack of direct route for walking and biking across the Brøset-area in the northwest-southeast direction as (top-left to bottom-right diagonal in fig. 11, see also the proposal in fig 10). One of the four urban design proposal, the one from team CODE (see fig.13) includes such a connection, a proposal that according to our analyses should have very positive effect both in terms of improving the bicycle route network (fig. 13 b) and by improving the spatial integration of the street network, likely supporting urban life activities (fig.13 a). Such a connection would have improved the accessibility by foot or bicycle towards Valentinlyst and Trondheim city centre for all those living in the areas east of Brøset. Instead, the proposed main street inside the Brøset-area is given geometry typical for recent decennials' suburban road systems and is linked to the car-prioritised road-system at the north-east of Brøset (see fig. 11). This main street is planned to be a main bus route. In order to reduce car-travel it is important to cater for well working public transport. Nevertheless, making this approach by bus becoming the only access to Brøset from east is disadvantageous for walking and bicycling. In the current layout, the main street inside the Brøset area is so well designed for car traffic that legislative restrictions in terms of gates and signs will likely be required in order to avoid intensive use of private car in the area. The alternative, which does not seem to have been seriously examined, would have been to design a street system that gives priority to accessibility for walking and biking AND that works also for a bus-route.

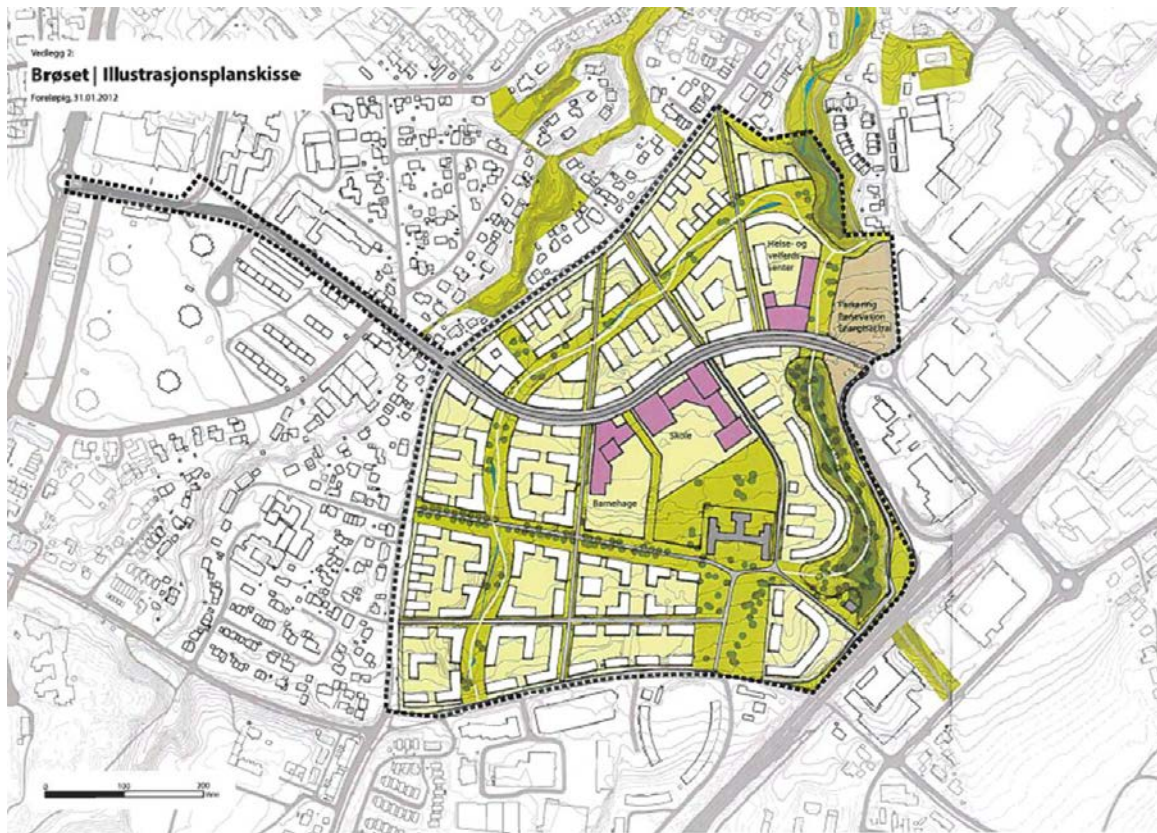


Figure 11

Proposed master plan for Brøset, by local planning authorities in Trondheim.

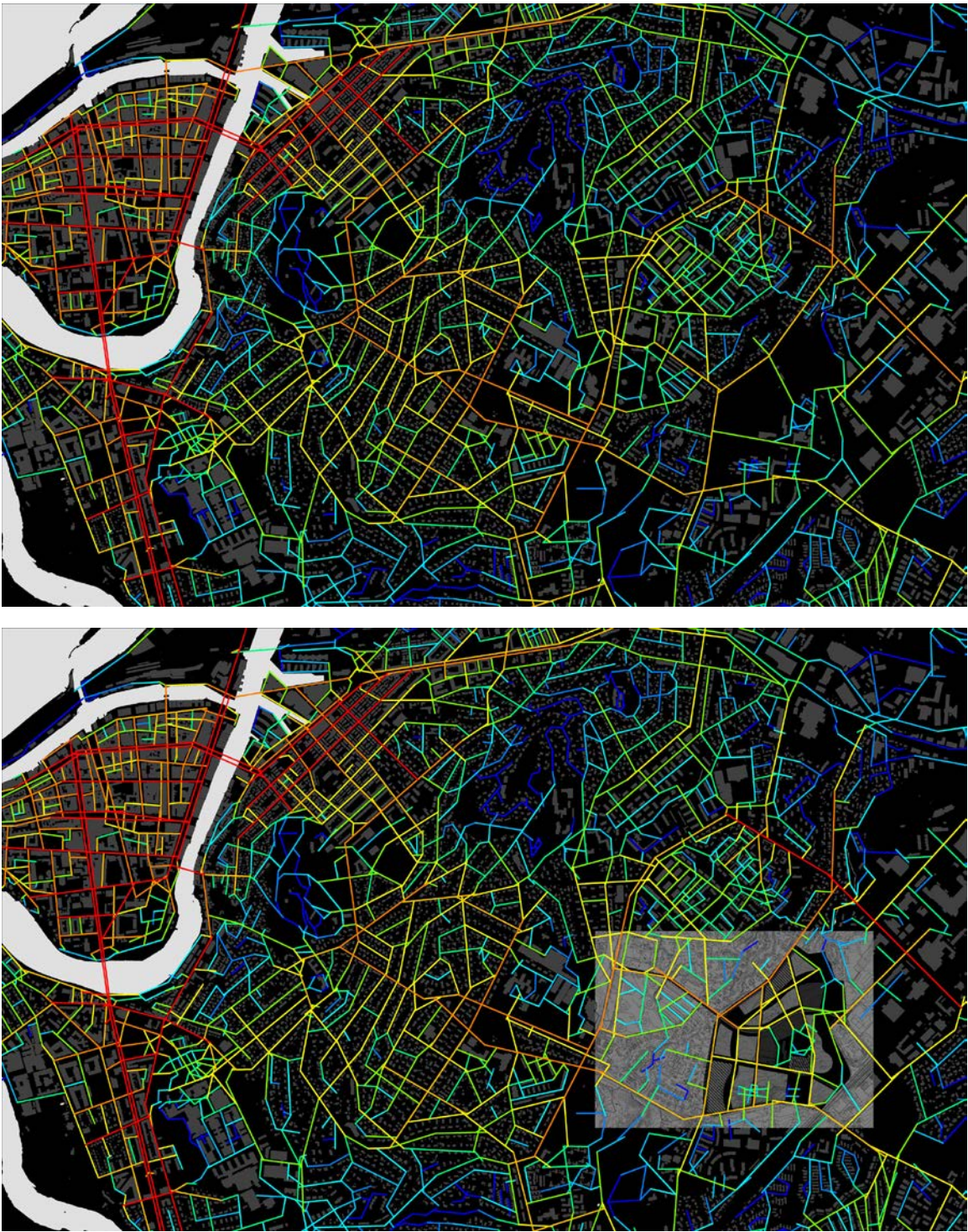


Figure 12 a, b

Space syntax integration

a (top) : existing situation.

b (bottom): proposal for master plan

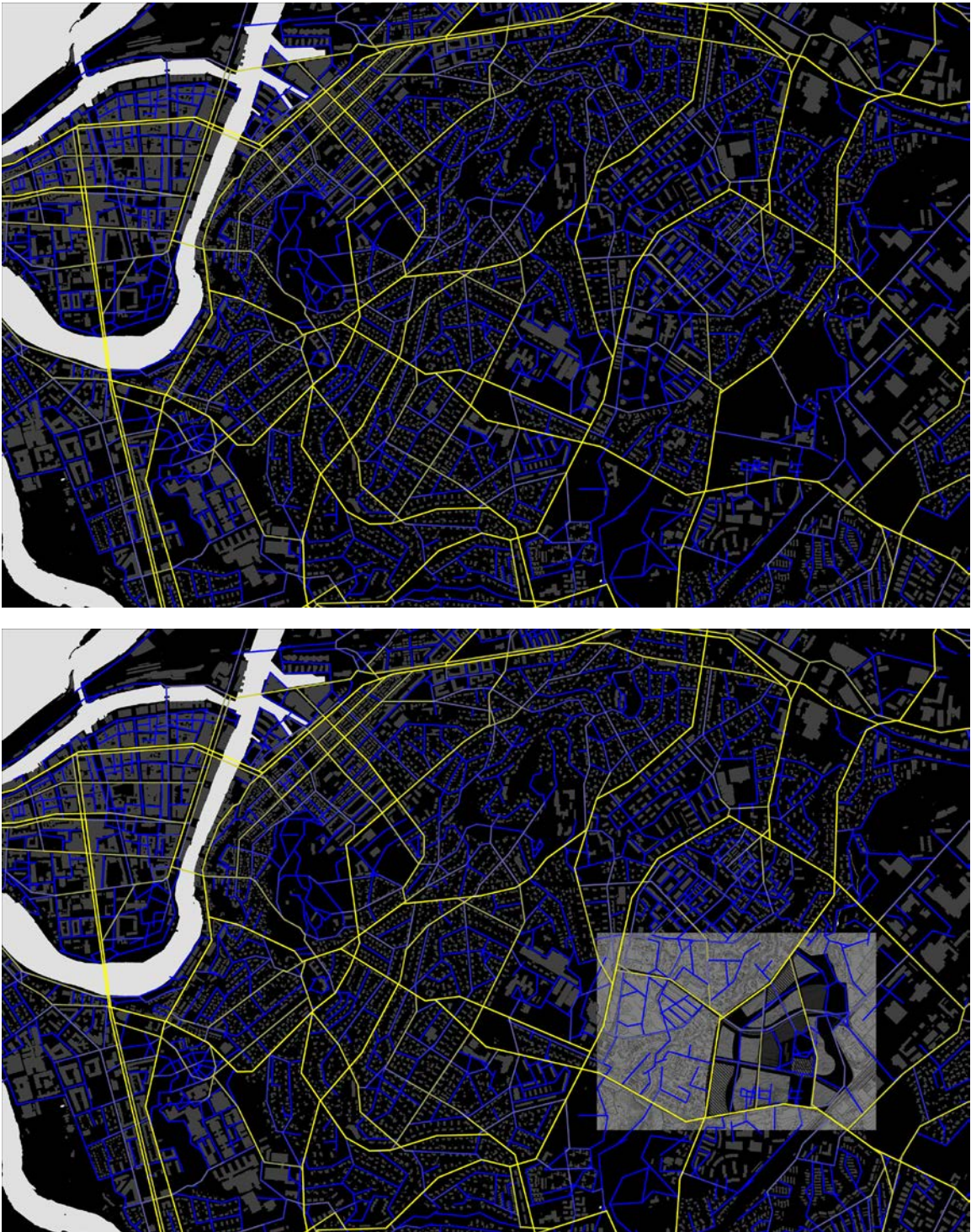


Figure 13 a, b

Space syntax choice / route directness

a (top) : existing situation.

b (bottom): proposal for master plan

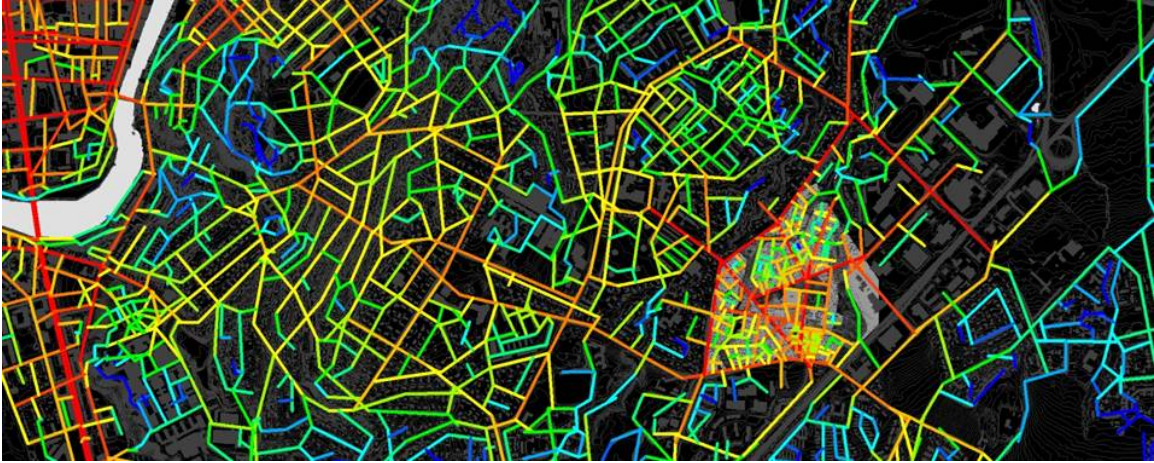


Figure 14 a, b

Space syntax analyses of the proposal of team CODE (one of four design teams)

a (top) : integration

b (bottom): choice / route directness

Accessible density due to a new bicycle route, an example

In order to show the usability of the methods described in this chapter, we finally present an analysis of the Tempe area south of Trondheim City Centre. In this area, there will soon be large urban developments including numerous work places. Towards west, on the other side of the river Nidelva, is the hill Byåsen, a residential area now poorly connected to the Tempe-area. In this area, large road projects are under planning and construction. At an earlier stage, the road proposal included plans for improved bicycle routes between Byåsen and Tempe. This has later been cancelled due to likely having little effect. (SVV, 2010 p.9) Norwegian Bicyclist Organisation (SLF) has questioned this conclusion and proposed a direct bicycle-route that includes a bike/pedestrian-bridge across Nidelva (fig. 15). Autumn 2012, this bridge was given students of architecture at NTNU as the task for their design course. In order to exemplify the applicability of the methods and to give some input to the students as well as to SLF, we put the proposal of SLF into our GIS-model of Trondheim and examined its likely effect by applying the Place Syntax tool. Fig. 16 a and b shows the *route directness* of the bicycle-route network without and with the new route. What we see, is that the route will likely be a very important link in the total bicycle-route network in this part of Trondheim. Fig. 17 a and b shows the accessible area within 3 km bicycle distance from Tempe, before and after the new route, whereas figure 18 a and b shows the *accessible densities of residents*. Concerning actual numbers of people, the new route would increase the number of people having access to Tempe within 3 km with about 8 000 people, from 32 to 40 000. Adding the potential in constructing new dwellings in the areas that by this proposal becomes within walking and biking distance from Tempe, the number will be even higher. Our results indicate that the conclusion of SVV (the Norwegian Public Roads Administration) is far from correct and that investing a share of the huge road-construction budget for Tempe in a new direct connection Byåsen-Tempe likely will have huge positive effect in terms of reducing car traffic and for strengthen the urban development of the Tempe area.



Figure 15

Proposal for new bicycle routes
(green lines)

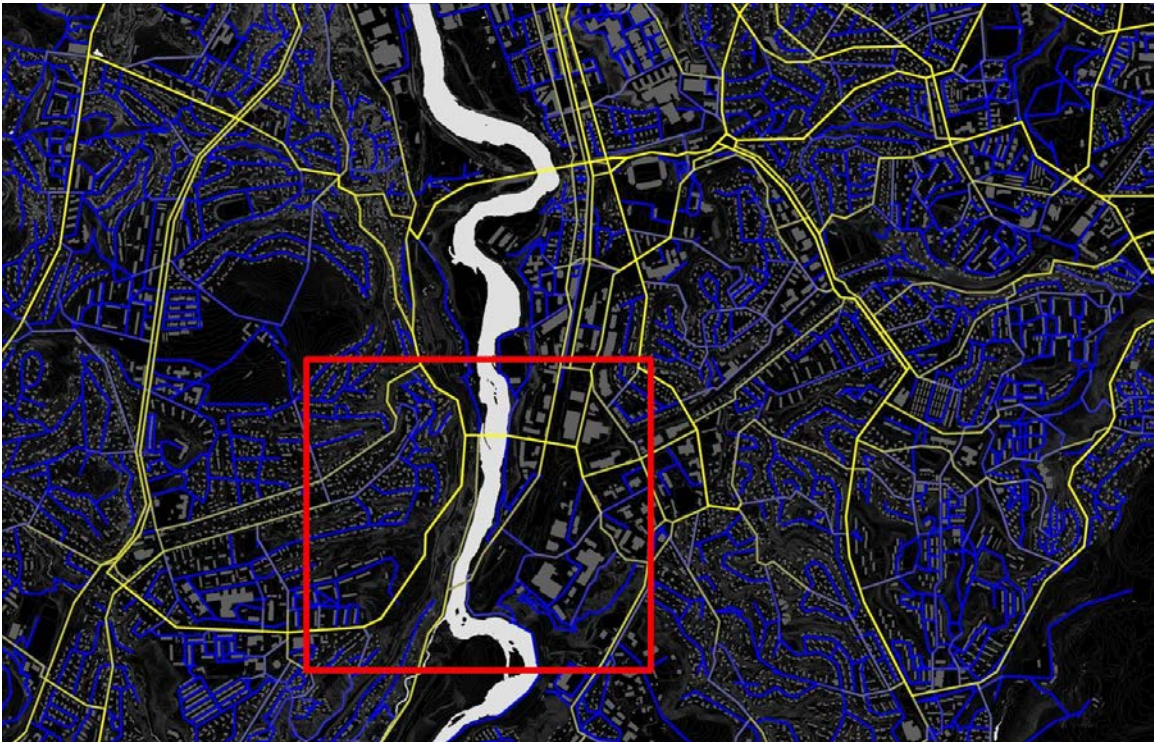
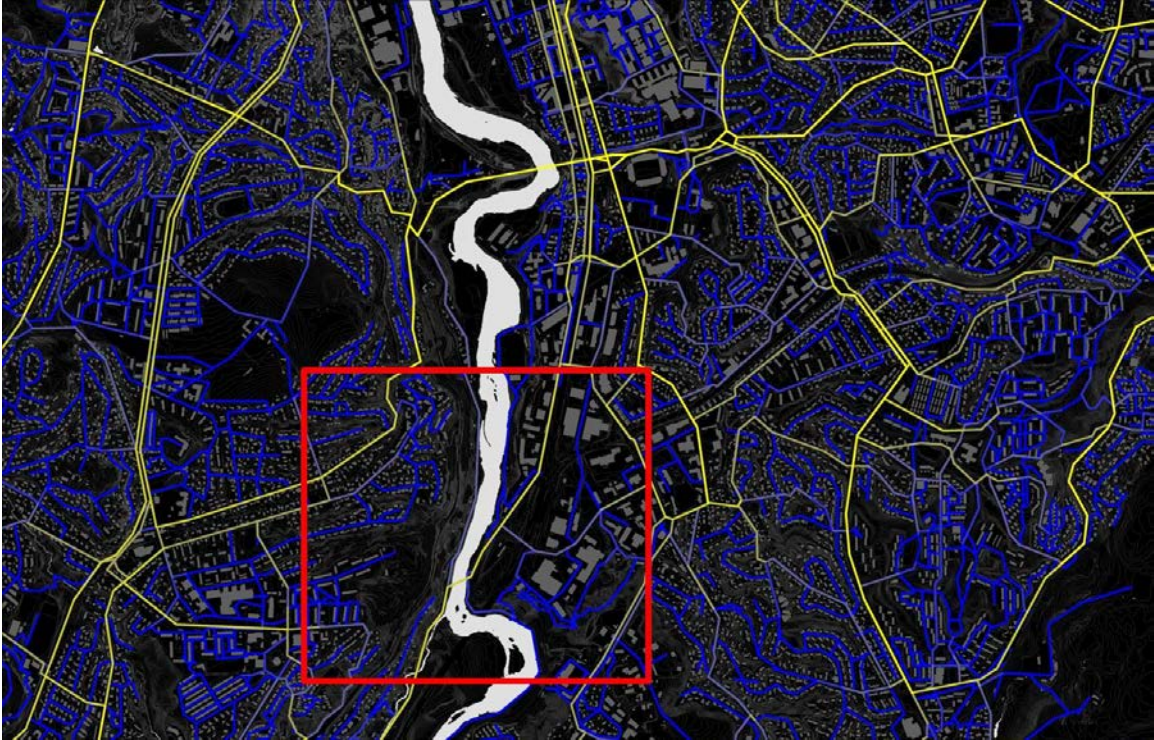


Figure 16 a, b

Space syntax choice

a (top): existing situation

b (bottom): with proposed new bicycle routes

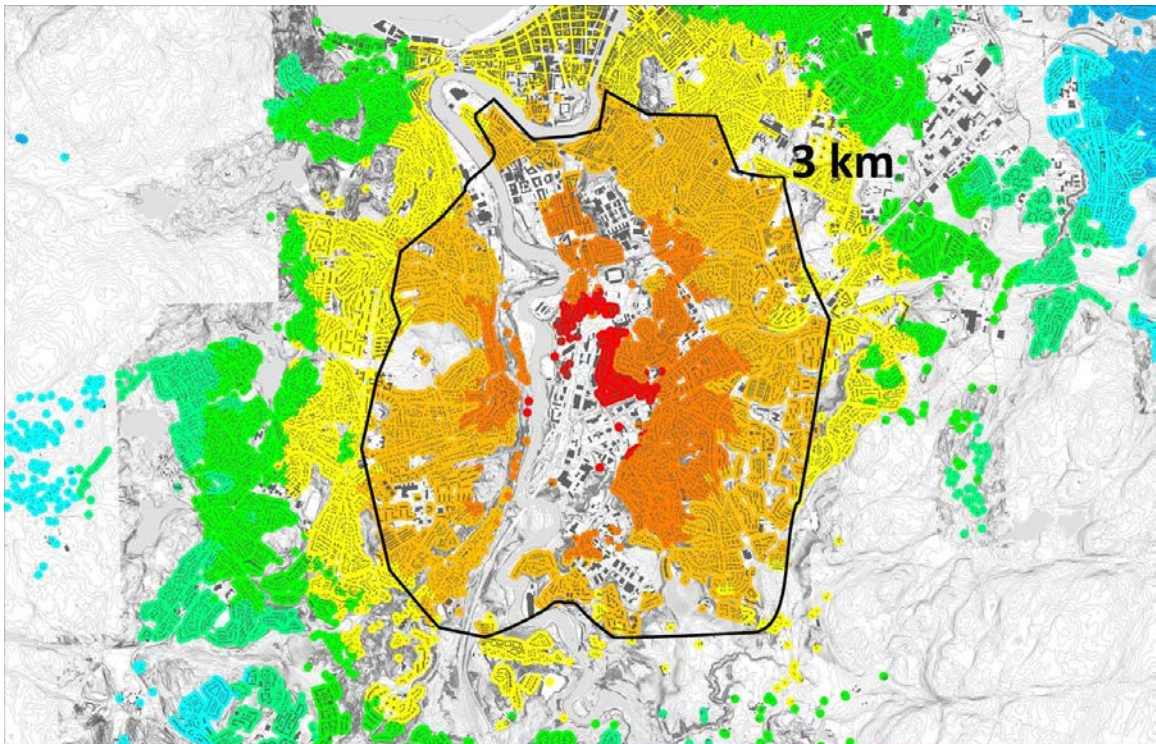
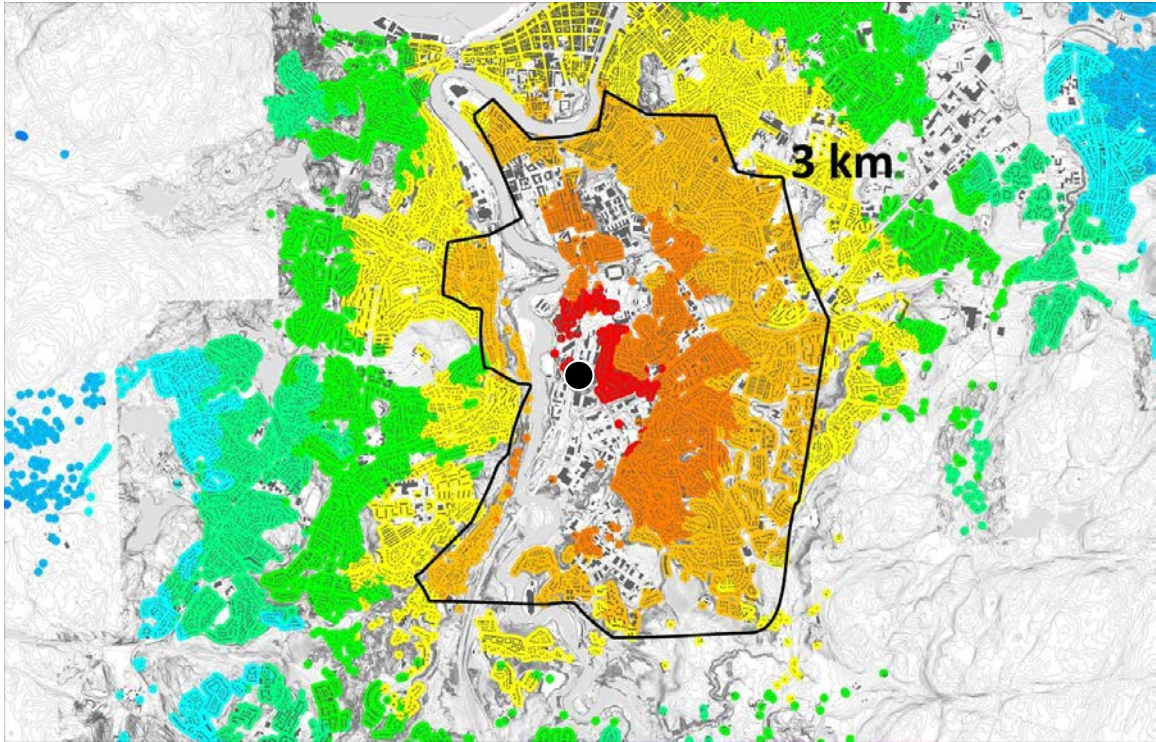


Figure 17 a, b

Bicycle distance on bicycle routes from Tempe (black line = 3km distance)

a (top): existing situation

b (bottom): with proposed new bicycle routes

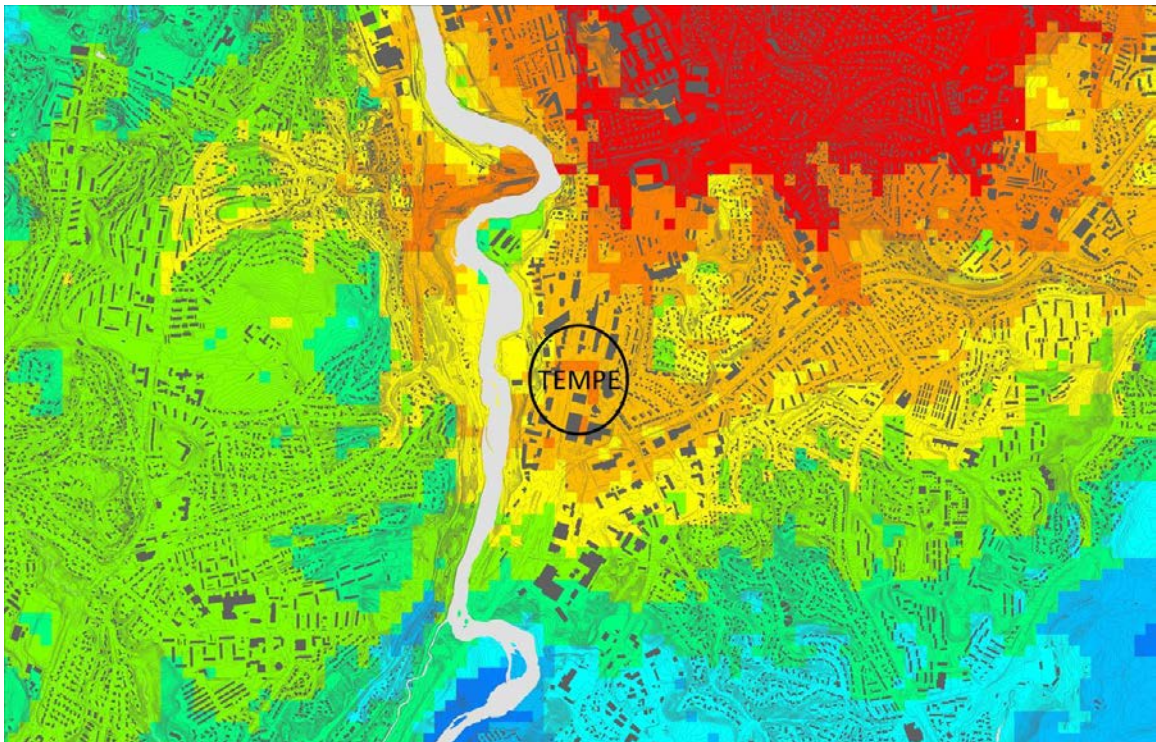
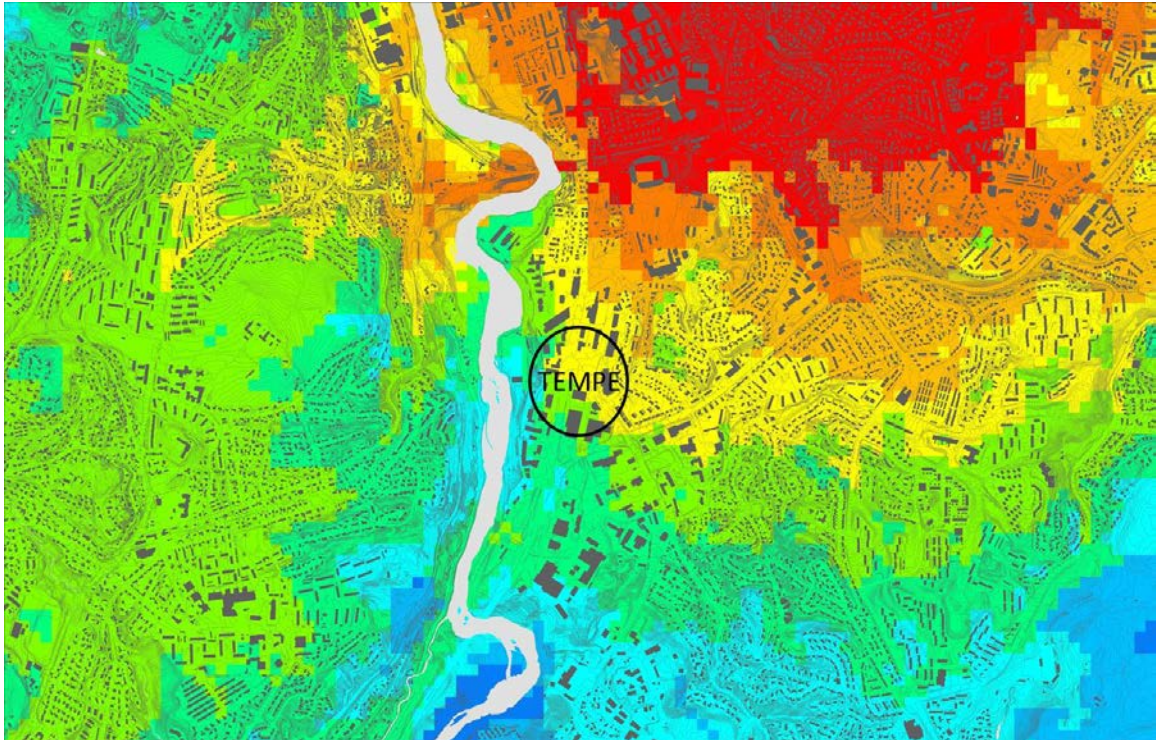


Figure 18 a, b

Accessible density of residents

a (top) : existing situation

b (bottom): with proposed new bicycle routes

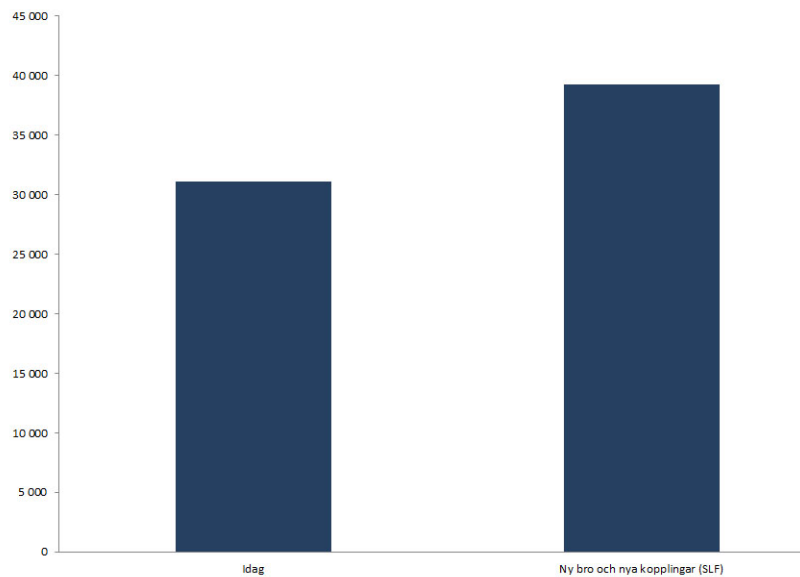


Figure 19

Accessible density of residents in numbers: people living within 3 km bicycle distance from Tempe, now about 32 000 (left) and with proposed new routes about 40 000 (right).

Conclusion

Real peoples' accessibility to a supply of daily destination is a crucial condition for sustainable urban development. In this paper, we show how the concept *accessible density*, examined by combining GIS- and space syntax methods using the Place Syntax Tool, is a highly useful approach for grasping this issue. The method is a powerful tool for shedding light on presumable effects of alternative urban design proposals and for supporting urban design processes aiming at mixed used neighbourhoods and car traffic reduction.

Concerning our input to the urban design processes, some of our proposals have been followed in detail while others have not. The potential in connecting Trondheim in east-west direction by means of the Brøset project is a proposal from our research that is not exploited in the further planning and design. This is a bit surprising, since our and others' research indicate that such more connected street networks have huge positive effect on walkability and bikeability. Other results, such as the need for improving accessibility to schools and retail in the Brøset area as well as the unexploited urban potential in constructing higher density of buildings along the spatially most integrated streets, are now included in the proceeding work on the master plan carried out by the local authorities.

We hope that our methodological development, as well as our evaluation of urban design proposal and our specific proposals can be some of the many steps required towards more sustainable urban development.

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