The walkability potential matrix – a new method for measuring sustainable destination configurations in town and city centres

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Abstract
The object of this present study is to reveal the spatial configuration of 55 Norwegian towns and cities related to degree of walkability potentials. The aim is to investigate to what extent the street or road profile affect the walkability potentials in the town centres based on the distribution of roads in comparison of streets based on street names. The focus is on the town centres, because they tend to have the largest walkability potentials. For this, the last part of the street or road names is used to identifying whether it is a balanced street or a road encouraging car use. Likewise, the number of X and T junctions is counted in the town centre. Correlations between T and X junctions were made, and correlations between road and streets were made for the town centre of all 55 Norwegian towns and cities.

The results show that the higher number of X-junctions in correlation with T-junctions, the shorter urban blocks, implying higher degree of walkability potentials in the town centres. Likewise, the higher numbers of streets in correlation with roads in a town centre, the higher degree of facilitation of pedestrian friendly pathways. Three different clusters are identified in the statistical analyses, in which comply with the reputations the various town and city centres have regards walking attractiveness or private car dependency. The higher number of X-junctions in correlation with T-junctions, the more integrated the town centre is on a local as well as global scale. Likewise, the higher number of streets in correlation with roads, the more integrated the town centre is. Finally, the more the town or city centres have an orthogonal grid structure consisting of streets, the higher integration and thus higher walkability potentials.

The method is a first step to have an operational and easy applicable tool to measure degrees of walkability potentials in town and city centres.

Keywords: walkability potentials, street names, street profiles, junction type, urban centres.

Introduction – measuring attractive walkable town and city centres

Town and city centres are regional attractors and attractive destinations where a diversity of functions is clustered, and the building densities are higher than the surroundings. During the last 30 years, town and city centres are perceived to be beneficial for encouraging sustainable transport means such as providing an efficient public transport and facilities for walking (Banister 2008, Murgante et al 2023, van Nes 2021a). But how can the physical and spatial framework of walking friendliness be measured? Often it is believed that high building density and high degree of land use diversity encourage short walking distances and hence more people in streets (Ewing and Cervero 2010). Therefore, densification of the built mass and intensification of land use diversity if often used as a strategy for making sustainable town and city centres. However, the spatial configuration of the mobility network is often forgotten in the sustainable city debate (van Nes 2021a). The application of various space syntax analyses on a wide range of cities world-wide highlight that town and city centres have high spatial to- and through movement in relation to the whole town or city (Hillier et al 2007). However, the degree of walkability of the mobility network is difficult to identify with only the space syntax method. Therefor the aim of this contribution is to present a different approach to measure walkability potentials in town and city centres, based on street profiles and junction type. To what extend play street profiles and junction type for the walkability potential in town and city centres? How can street profiles be measured or quantified?

Most Norwegian towns and cities have small urban centres surrounded by many single-family houses. Oslo, the largest city of Norway, has three large local centres (van Nes 2003) and they are surrounded by sub-urban neighbourhoods consisting of flats, row houses and single-family homes. Bergen is the second and Trondheim is the third largest city in Norway, and both cities have one small urban centre surrounded by sub-urban neighbourhoods consisting of mostly single-family homes, and some flats and row houses. Since the 1960s, urban growth in Norway has been much planned around the private car. The effects are the emergence of low-density urban sprawl, location of large out of town car-based shopping malls, and acceptance of new land use plans facilitating single-family houses in the countryside and into the forest (Aarsæther, Falleth, Nyseth, & Kristiansen 2012).

There exist several reports where researchers have been trying to measure various sustainability indicators for Norwegian towns and cities. The sustainability indicators have been to measure the populations' distance to nature or parks, population density on build up land, distance to kindergarten, primary school, grocery shops and daily travel behaviour. What is missing are various means for identifying the spatial framework for making walking attractive instead of using the private car for distances lesser than 1,5 km.

As space syntax research has shown, streets with high to- as well as through movement potentials on a local scale, combined with well-integrated main routes running through them tend to be lively neighbourhoods with high walkability potentials (Kråkenes et al 2022, Bolset et al 2022, van Nes 2021 a and b). Often these neighbourhoods have short urban blocks, tend to have high building densities and a large variation of functions inside buildings (Ye and van Nes 2014, van Nes 2021c, Berge et al 2022). Often town and city centres score high on these spatial analyses. Therefore, space syntax analyses are conducted of all 55 Norwegian cities and towns. The results from the space syntax analyses in the town and city centres are tested on junction type, based on Stephen Marshall's work (2005), and path type, based on Job Eldijk's method (2014) on classifying streets regards their functions or users. The number of X and T junctions is counted and correlated with one another. Furthermore, the total number of roads and highways in correlation to all other streets is investigated in the city and town centres based on pathnames. The reason for focusing on the centres, is that the walkability potentials are largest there and the various spatial structures of these centres gives an indication of the degree of private car dependency.

The first part of this paper will present the state of the art of current sustainability policies and practice in Norway. The second part will present the scope of this inquiry with the method used, whereas the third part present the results from the various spatial analyses and the statistics. An outline for a walkability potential matrix is presented. The fourth part discuss the findings, and the fifth part reflects over the usefulness of the walkability potential matrix.

Sustainability parameters, planning policies, and practice

Norway has a short urban history. Before the industrial revolution, Norway had a strong farming culture (van Nes 2022). There were a few towns along the coastal areas with small urban centres. These centres are still existing. During the industrial revolution, around 1850 in Norway, some new towns grew up where the large factories were located whereas others expanded around the old historic cores. In general, most Norwegian towns up to 1960 were small and compact, and developed according to the pedestrian, bus and in some cases trams.

After 1961, everyone was allowed to buy a private car in Norway. Since then, Norwegian built environments are transformed and planned around the private car. Except from the large cities, Norwegian towns are extremely private car dependent. During the last decade, there exist national policies to make towns and cities more sustainable by improving public transport, implement high parking fees, reduce parking facilities, implementing bicycle lanes, implement road payments etc. However, little of this can be seen in Norwegian small and medium sized towns (Kråkenes et al 2022).

During the last 30 years, the consideration of the environment has put some influence on the planning of Norwegian towns and cities. The focus is on finding good solutions for pedestrians and cyclists, increasing the building density within existing built-up land, and providing large investments in new solutions for public transport in the large cities in Norway. The concept of sustainability was first incorporated in planning in the national policy documents in 1993 and then substituted by governmental planning guidelines in 2014.

The problem of measuring sustainability parameters in Norway

So far, it seems that the large cities are better at implementing sustainable planning measurements than the smaller towns of Norway (Kråkenes et al 2022). This problem is revealed by comparative case studies of large as well as small sized Norwegian towns and cities the last decades. The report 'Byer og Miljø' (Cities and Environment) focus on the state of the environment and sustainable development in the 13 largest municipalities in Norway. The total population in these 13 municipalities represents 36% of Norway's total population (Kommunal- og Moderniseringsdepartementet 2016).

Based on their parameters, the results in this report show that the largest cities in Norway score higher on environmental status and sustainable development than the average values for all towns in Norway. For example, the report shows that smaller towns have a larger built-up area per inhabitant compared to the larger cities. In 2012, Oslo had the lowest built-up area with 224 m2 per inhabitant but has the highest density of buildings within the built-up area. Conversely, Tromsø city, with a significantly high density of buildings per inhabitant, had the lowest density of buildings in the period 2011-2012 with 50%. Overall, the density of buildings within the conurbation boundary of these 13 municipalities was 72%, while it was on a national average 43%. The results in this report clearly show that cities with high density of buildings are also the cities that are most able to live up to the authorities' targets for densification. Densification refers to the part of new housing that is established within existing urban boundaries (Haagensen 2015, p.20-22).

The report's indictor of walkability potentials is based on metrical distances from homes to grocery shops, schools, and kindergartens. Oslo scores highest with 90% on the indicator 'residents living with less than 500 meters away from a grocery store' in the municipality. Stavanger city is second on this list where 75% of the residents is living close to a grocery store. Most inhabitants in the largest cities have a short distance from home to a grocery store. These distances seem to increase the lower the population is in a town. This trend can also be seen by comparing the average from these 13 towns and cities with the average for the country (Haagensen, 2015, p.51). Likewise, regards distance from home to primary school, Oslo has the largest number of children living lesser than 500 meters betweeen their homes and primary school. In 2014, 96 % of the children had a short distance between home and primary school. The national average is lower than the average of these 13 cities, which is 63% versus 85%. Thus, the lower population density in a city, the longer distances between home and primary schools (Haagensen, 2015, p.55).

A report from the Institute of Transport Economics about land use and transport development for climate-friendly and attractive cities shows that there are clear correlations between densification and car dependence. Densifying in and around the existing town and city centre reduce private car dependency, reduces urban sprawl into the countryside, gives positive impact on the attractiveness of cities by contributing to high variation of services and land uses, contributing to lively and vibrant urban areas. Improved public transport services results in reduced car use. Furthermore, densification and transformation in the city centre contribute to increased accessibility, a provision of a variation of jobs, and increased attractiveness for the establishment of advanced businesses that requires highly skilled and specialized employees (Tennøy, Øksenholt, Tønnesen and Hagen 2017, p. 19).

Another important finding from this report was that the compact urban centres in the large cities provided at least as good access to public outdoor areas as the low-density towns. Arrangements for public transport, cycling and walking in combination with restrictive measures to regulate car traffic contributed to many of the same effects. At the same time, the report shows that restrictions on car traffic in heavily car-based cities are experienced as a significant disadvantage for those who work or live in areas where one is heavily dependent on the private car for daily activities (Tennøy, Øksenholt, Tønnesen, and Hagen 2017, p. 19).

Current trend in Norwegian towns and cities

Through restrictive municipal plans and strong agreements with governmental institutions, the large cities have shown ability to act in line with national policies and guidelines. Since 2014, the objective of the national transport plan is zero growth in private car transport. However, the small and medium-sized cities in Norway are lagging behind regards enhancing compact town centres and avoiding urban sprawl (Kråkenes et al 2022). For example, the town Notodden decided to reduce 180 acres of virgin land in favour of one hundred new detached residential plots in 2015. This is happening at the same time as state planning guidelines emphasize densification and transformation in already built-up areas. Four years later, Notodden's out of town shopping centre was granted permission to expand for car-based retail. At the same time, the regional plans discourage these kinds of developments for preventing deterioration of existing old town centres and increased passenger car traffic (Kråkenes et al 2022). The following features is taking place in most Norwegian towns during the last 20 years (Kråkenes et al 2022):

• Large car-based shopping centres are established outside the city and town centres,
• Agriculture and natural resources are being demolished through implementing new buildings on nature land,
• Important urban functions, such as homes, workplaces, etc. are established far from each other,
• The proportion of dwellings that require space, energy and resources is high, such as for the establishment of detached single-family houses,
• The car is given high priority as a means of transport in the cityscape despite increased government investment in more climate- and environment-friendly modes of transport such as walking, cycling and public transport,
• Important downtown streets and main squares are dominated by car parking spaces,
• Large new residential areas are established at a long distance from the city centre, which contributes to increased private car dependency and long travel journeys between work, school, leisure activities and shopping.

Thus, there is a large gap between national and regional planning policies and local implementation practice.

Relevant writings on walkability in an international context
It is believed that a town centre with good walkability facilities can contribute to lesser use of the private car and encourage densification strategies inside and around the existing town centre. The recent used concept 'the 15 minutes cities' indicated that everything should be accessible within 15 minutes walking within the city centres and from public transport stops. The concepts short travel time, high building density, high land use diversity and proximity of everything are used to describe the '15 minutes city' (Murgante et al 2023). Except from Oslo, most Norwegian town centres can be crossed within 15 minutes of walking.

There exist a large body of literature on measuring walkability potentials. In the study of Cervero and Kockelman (1997) the authors found out that compact neighbourhoods with a synergy of high building density, mixture of functions and pedestrian friendly design encourage reduction of vehicle trips. The authors propose a concept of 3Ds (density, diversity, and design), where the definitions of density and diversity is well defined. However, when it comes to the definition of design, it is defined to consist of sidewalks, tree rows, and providing facilities for pedestrian and cyclists. The study is slightly touching upon street profiles. However, the underlying spatial configuration of the mobility network is lacking. The authors are aware of that short block lengths encourage walking.

Later, Erwing and Cervero (2010) changed the 3Ds to 5Ds, now standing for density, diversity of land use, design, distance to transit, and destination accessibility. Still the concept of design is vague, and the issue of street profiles and street network configuration is lacking. The distances between homes and transit are now considered. In research on evaluating the state of transit-oriented development in the InterCity-Triangle of the Oslo fjord region, density and degree of function mixture was considered and correlated with space syntax analyses and strong correlations between them were found (Myklebust et al 2022). However, the street profiles were not considered in this research.

In another research, Moudon et al (2006) attempt to make operational definitions of walkable neighbourhoods. The authors also claim that higher residential density, smaller street blocks, presence of sidewalks, and finer mixes of uses promote high degree of neighbourhood walkability. Closeness of shops and retail have the largest impact of walking.

The concept 'walking the last mile' is used for understanding the various parameters for making walking attractive from the public transport stop to a destination (Braun et al 2022). However, what kind of spatial structure can enhance the initiative that people choose to move on foot or by car? There must be something more the built environment can offer rather than short metric distances or good pavement surfaces. Does the spatial structure and profile on the path network really matter? How can they be combined in one method?

In 2014 Job van Eldijk developed a method for street profiles based on street functions or street or road users (Eldijk 2014). He divides the mobility network in the following four categories: 1) pedestrian and bicycle streets, 2) balanced streets, 3) vehicle dominated roads, and 4) vehicle only roads. The purpose of the analysis is to examine how the street and road network is used by the various road user groups, and who dominates street use.

As research has shown, traditional town centres and neighbourhoods tend to have a high number of balanced streets. These streets are constituted by buildings entrances adjacent to the pavements and the buildings tend to have 'active frontages' oriented towards the pavements (Olsen et al 2022, Berge et al 2022, Meinert et al 2019). Modern neighbourhoods tend to have mostly vehicle dominated roads and separate pedestrian and bicycle paths (Stedal et al 2022, Kråkenes et al 2022). Buildings tend to lack entrances and windows on ground floor level along the roads.

Based on earlier space syntax research, urban centres with both high local and global integration, and the main routes need to be well connected to the neighbourhood seems to be well frequented by pedestrians (de Koning et al 2020a,b, van Nes & Yamu 2020, van Nes 2021a,b,c). Seemingly, urban environments with short urban blocks and a high number of X-junctions tend to have high spatial integration values (Shi and van Nes 2009). On a micro scale level, the street profiles seem to enhance walking (Meinert et al 2019). That means that buildings need to face streets with active frontages (Rønneberg Nordhov et al 2019), and a balanced street with both access for cars and pedestrians, or spatially well-integrated streets for pedestrians only (Berge et al 2022). Seemingly, encouraging sustainable mobility means that it is not enough to have high building density and high degree of land use diversity. It is the structure of the street and road network that influence the degree of density and land use diversity (van Nes et al 2012, Ye and van Nes 2014, de Koning et al 2021a,b, van Nes 2021b).

Method for developing the walkability potential matrix
For the town and city centres, the total number of T and X junctions are counted based on Stephen Marchall's work from 2005 (p.96-98). For junctions consisting of five arms and more, are registered as X-junction. A correlation is made between the total number of T and X junctions in relation to the total number of junctions. When the value is close to 1, the higher number of X junctions.

A correlation is made between roads and streets versus the total number of paths. For this, the last part of the street or road names is used to identify whether it is a balanced street that enhance walkability or a road encouraging car use. Based on Eldijk's classification system on street function, a separation of category 1) and 2) from category 3) and 4) is made based on the last part of path names. The first two categories are pedestrian friendly streets, whereas the last two part are roads designed for vehicles.

A path's name consists of mostly two parts. One part is a particular name given to the specific path for identification of a particular place and wayfinding, whereas the other part indicates the type of path (street, road, avenue etc). The 'particular name' part can be named after persons, things, animals, objects from the nature, unique shapes, places, or hierarchy of pathways (for example: Main Street, or in Norwegian 'Storgata'). The focus on this inquiry concerns the second part of the name, which often indicates for the type of users and the type of path.

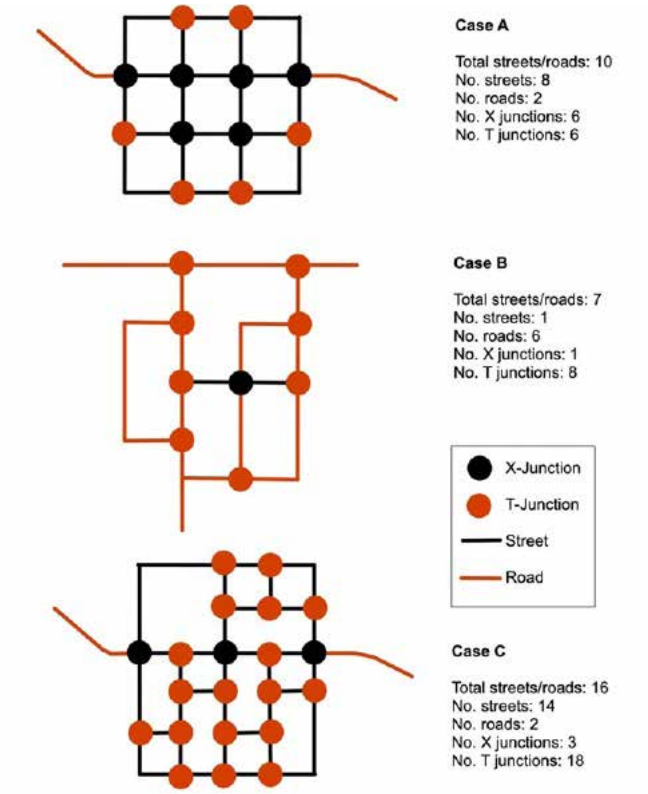

Figure 1: Three types of town centres based on path type and junction type.

In many northern European build environments, the balanced streets tend to have names ending on 'street' whereas the vehicle dominated roads ends on 'road'. In Norway the word 'gate' is used for 'street' and 'vei' for road. In this inquiry, all the paths with the name ending on 'vei, veg, veien, and vegen are registered as 'roads' in all 55 town and city centres. The names of the motor- and highways in Norway tend also to end on road ('vei', 'veg', 'veien' or 'vegen'). The remaining streets we classify as balanced or pedestrianized. A check was made with google street view. There are some exceptions, but the number is very low. For example, one of Oslo's main shopping streets is named 'Bogstadveien'. In the past it was a road leading from Oslo's city centre towards Bogstad farm. Through city growth, the road was urbanised and have today a balanced street profile.

In historic city centres, there exist a small number of paths with names that not always are ending on street (gate in Norwegian). Examples are 'smau' (pedestrian dominated path), 'almenning' (balanced street), 'aveny' (balanced street) or 'kroken' (balanced street). Therefore, they are all put into the category 'street' because they are pedestrian friendly streets. A correlation is made between the categories 'roads' and 'streets.' When the value is close to 1, the higher number of streets in correlations to road a city or town centre has.

Space syntax analyses are conducted of all 55 Norwegian towns and cities in 2022 with purpose to ascertain how various Norwegian towns and cities perform spatially. In sum, all these analyses indicate to some extend walkability potentials in these centres. All axial maps are hand drawn. It was possible to correlate the spatial data with data regards car ownership and building activities from the CBS of Norway for 47 towns and cities. For the larger cities, data about travel behaviour for public transport was gained for 6 cities. However, the resolution of all these data is too rough for correlations with the space syntax variables.

Regards the space syntax analyses, various normalised angular integration (NAIN), and normalised angular choice (NACH) analyses with both 500 (local) and 5000 (global) radii are conducted. The NAIN analyses show the to-movement potentials, whereas the NACH analyses show the trough-movement potentials of the street and road network. In addition, the angular step depth analyses taken from all the main routes are used for revealing how the main routes are connected to the local streets of the various neighbourhoods (van Nes 2021c).

These space syntax variables are used to test the results from the walkability potential matrix.

Hypotheses
As world-wide space syntax research has shown, streets with high through- and to- movement potentials on a local scale has the highest number of pedestrians in and along streets. Regards the theory of the natural movement (Hillier et al 1993), the higher level of through movement potentials on a local scale, the higher walkability potentials. At the same time, these locally integrated streets need to be well-connected to the main route network, in which is identified by calculating the through movement potentials on a city scale (de Koning and van Nes 2019).

On the scale of the town and city centres, one hypothesis is that the higher number of X-junctions in correlation with T-junctions, the shorter urban blocks, the more locally integrated the neighbourhood is, and the higher walkability potentials. Seemingly, the more the town or city centres have an orthogonal path network structure, the higher integration and thus higher walkability potentials. Another hypothesis is that the higher numbers of streets in correlation with roads in a town centre, the more integrated the urban area is and the higher walkability friendliness. Streets tend to have pavements and buildings located in a row with active frontages faces towards the pavements and streets. Conversely, roads tend to have free standing buildings that have frontages that are turned away from the streets. The entrances are often located on the side or the back side of the buildings.

Most town centres in Norway tend either to have an orthogonal street grid structure with a high number of streets and X junctions, or a road network structure consisting of mostly roads and T-junctions. The hybrid variant is a town centre having a street network with high number of streets with a high number of T-junctions. Figure 1 shows a diagram of three types of town centre.

Case A has an orthogonal grid structure with a high number of X-Junctions and high number of streets. Examples of these types of town centres are Kristiansand and Sarpsborg centres. Case B has a high number of T-junctions and roads. Examples on these kinds of town centres are Alta, Sandvika and Karasjok. Case C has high number of streets and seems to have an orthogonal grid structure but has a high number of T-junctions. Examples of this case are Arendal and Kragerø centre.

Developing the walkability potential matrix and statistical testing
The walkability potential matrix consists of identifying the degree of walkability potentials of town and city centres based on correlating junction and path type. The 4-star diagrams are used to visualise how each town scores. In the regression analyses, the mean values for all space syntax analyses are used for the whole city or town, and for only the town centre. The reason for correlating the findings from junction and path type with space syntax analyses is to reveal how the walkability potential matrix affects the degree of to- and through movement potentials in town and city centres.

Findings
The space syntax analyses of all 55 cities shows that the main centre appears to have the highest degree of through as well as to-movement potentials on town or city level. Figure 2 shows the to-movement potentials (NAIN) of twelve towns and cities centres of different sizes in Norway. Often it is difficult to see on a space syntax map to what extend a city centre is vehicle dominated or pedestrian friendly. The six cases on the top are towns with a high degree of private car dependency. The centres consist of car-based shopping centres surrounded by parking lots. Likewise, these town centres consist of mostly roads and has a high number of T-junctions, in line with case B in figure 1.

The six cases below have an orthogonal street network consisting of a high number of X-junctions and high number of streets, in line with case A in figure 1. These town and city centres have linear shopping streets with a high variation of individual shops easily accessible on foot. However, nothing can be said about the degree of walking friendliness of the streets of these towns based on the various space syntax analyses.

If it is so that local integration matters for enhancing walkability, figure 3 shows the NAIN and NACH analyses with a low metrical radius (500 meters), and street function analyses of three different Norwegian town centres. Trondheim centre has a high number of T-junctions but consists of mostly streets. The local to-movement as well as through-movement potentials are high. Moreover, most of the streets are balanced. Trondheim centre is known to have a high number of people frequenting streets and is also very bicycle friendly. Conversely, Alta centre consists of roads and has a high number of T-junctions. These roads are vehicle dominated. The local to-movement potentials are low, and it has average values on the local through movement potentials. The shopping centre is turned away from the roads and is surrounded by large parking lots. Kristiansand has a high number of X-junctions and a high number of streets. It has a high number of balanced streets, with a high number of pedestrians frequenting the streets.

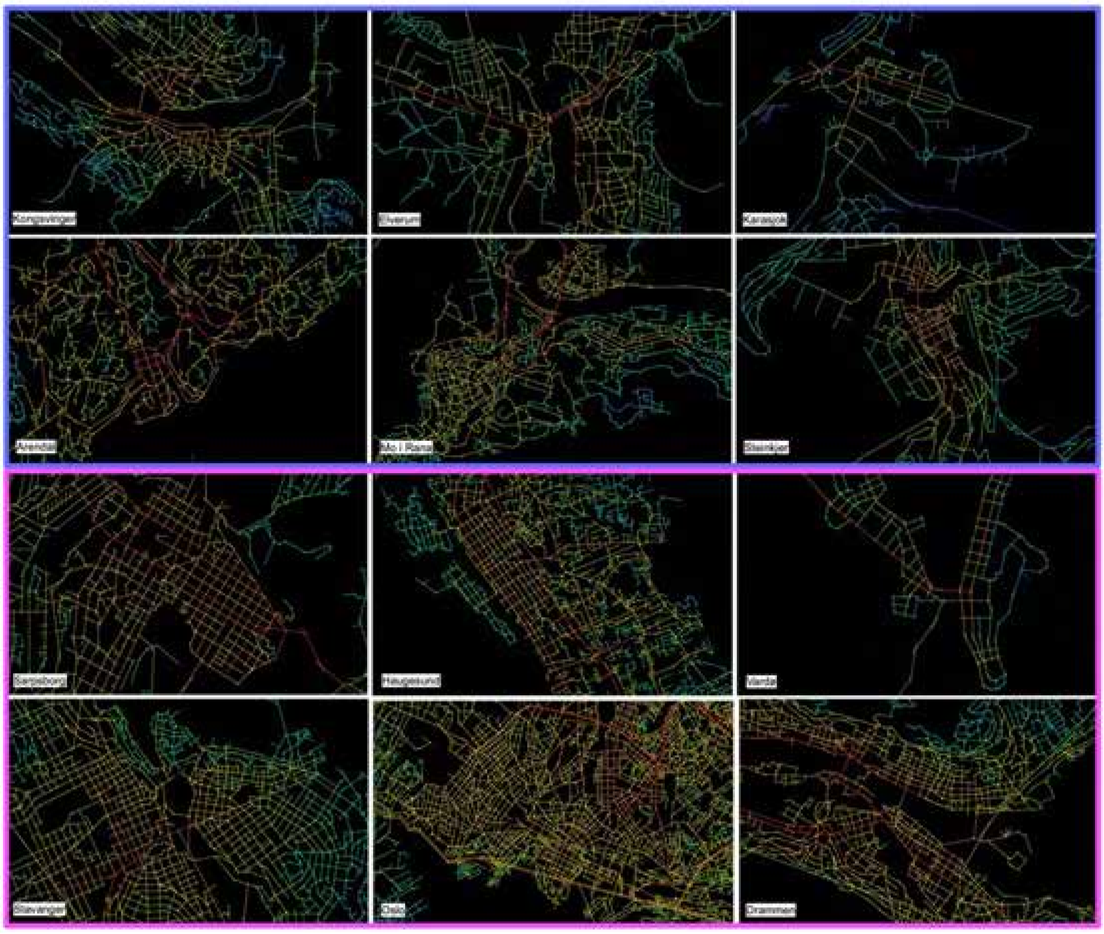

Figure 2: NAIN analyses with high radius of 12 Norwegian town and city centre. The six cases on the top have high number of T-junctions and consist of mostly roads, whereas the six cases below have high number of X-junctions and consists mostly of streets.

From the space syntax and the street function analyses it is not clear to what extend the level of the walkability potentials are in the town and city centres. Therefore, a closer view on junction and path type is revealed in the next chapter.

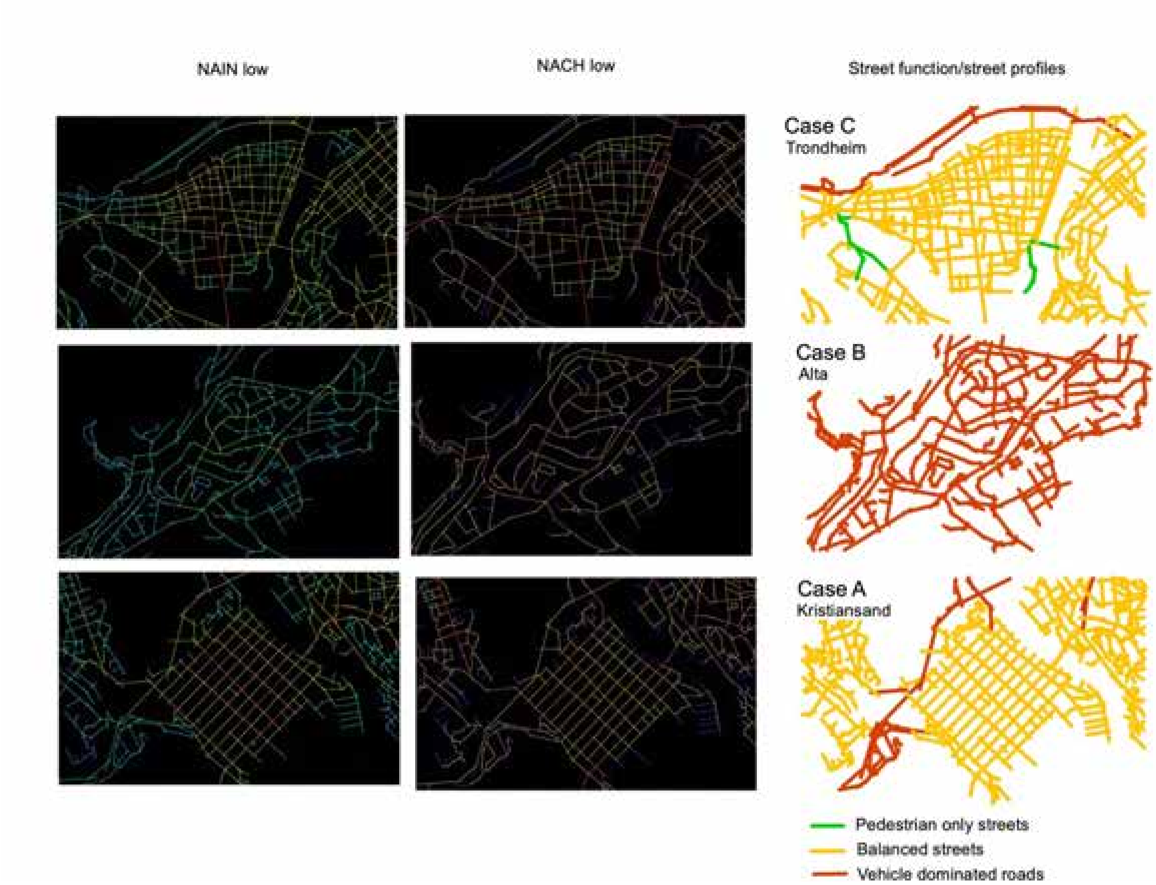

Figure 3: Space syntax and street function analyses of Trondheim (top), Alta (middle) and Kristiansand (below).

The correlation between path and junction types
A 4-star diagram can visualise how each town and city perform in relation to others regards the junction and path types. First, the correlation is shown between T-junctions and X junctions in relation to the total number of junctions, and the correlation between street and roads in relation to the total number of paths. The centres are grouped into large, medium, and small sized cities or towns.

Figure 4 shows a 4-star diagram of Norway's 6 largest cities. Kristiansand (green line) has the lowest number of T junctions due to that the centre consist of a strict orthogonal street network with mostly X-junctions. Trondheim's centre (blue line) consists of mostly streets with mostly T-junctions. Oslo (red line) scores average on all analyses.

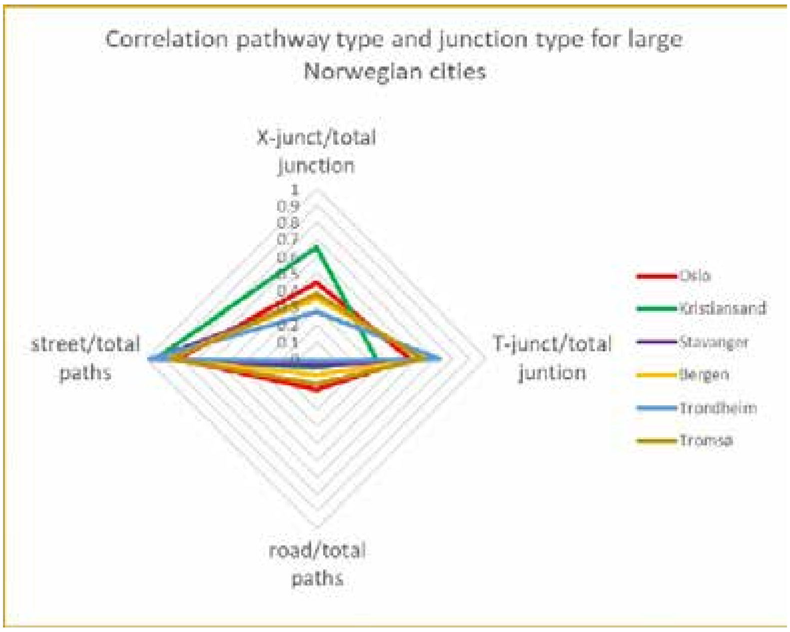

Figure 4: a 4-star diagram of Norway's 6 largest cities showing the correlation between streets, roads, X-junctions, and T-junctions.

Figure 5 shows a 4-star diagram of the medium sized town centres. Alta centre (red line) scores high on the number of T-junctions and roads, whereas Halden centre (blue line) scores high on the number of streets, and Sarpsborg centre (dark purple line) high on the number of X-junctions.

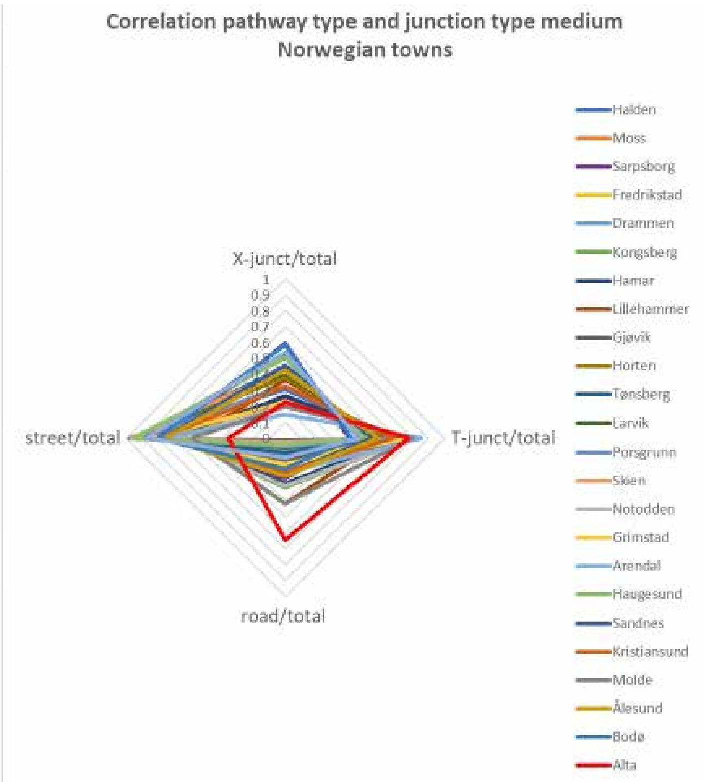

Figure 5: a 4-star diagram of Norway's medium sized towns showing the correlation between streets, roads, X-junctions, and T-junctions.

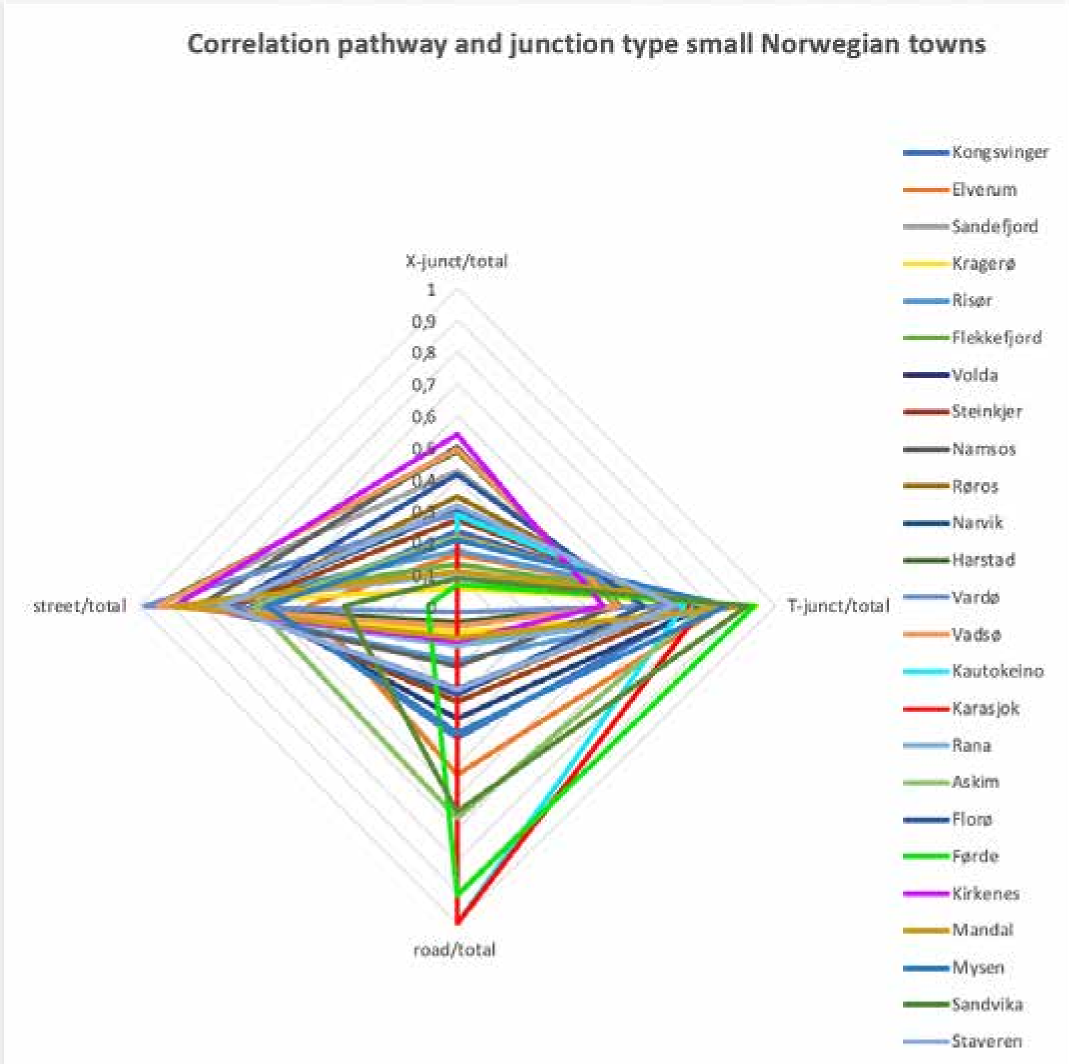

Figure 6: a 4-star diagram of Norway's small sized towns showing the correlation between streets, roads, X-junctions, and T-junctions.

Figure 6 shows the correlations of the centres of small Norwegian towns. The old coastal towns with an orthogonal street grid structure scores high on the X-junction and the percentage of streets. Conversely, the two Sami towns Karasjok (red line) and Kautokeino (turquoise line) consists of only roads. Likewise, the centres of the new towns, such as Førde (green line) and Sandvika (dark green line) have high number of roads and T-junctions. The small southern Norwegian town Kragerø (Yellow line) has a high number of streets and high number of T-junctions. The northern Norwegian coastal town Kirkenes (purple line) and Vadsø (orange line) has the highest number of X-junctions.

Figure 7 shows a scatterplot with the correlation between junction type and path type, and three different examples of town centres. The scatterplot represents the walkability potential matrix. On the Y axis, the closer a centre is to number 1, the higher percentage of streets in correlation to total number of paths. On the X axis, the close a centre is to number 1, the higher percentage of X-junctions in relation to the total number of junctions in a centre.

Three clusters can be seen in the scatterplot, in which comply with the three cases shown in figure 1. The town and city centres with orthogonal street grid are clustered together on the upper right corner in the scatterplot. Kristiansand centre has the highest number of X-junctions and streets. In the other cluster, town centres that has a small orthogonal grid in it centres, high number of streets, but has a high number of T-junctions in relation to X-junctions. The towns Kragerø, Rana and Flekkefjord are examples of this. On the lower right part of the scatterplot the towns Elverum, Alta, Sandvika, Førde, Karasjok and Kautokeino are located. These towns have mostly roads and T-junctions.

The town centres that are located on the upper right in the scatterplot are case A towns, whereas towns centres located on the lower left in the scatterplot are case B towns. The case C towns are those who are located on the upper right in the scatterplot.

In many ways the scatterplot shown in figure 7 is a walkability potential matrix based on only junction and path type. The three clusters shown in the scatterplot comply with the reputation these towns have. Town centres in cluster A are known to be pedestrian friendly, town centres in cluster C are car-based, whereas towns in case B are also pedestrian friendly due to the high number of balanced streets. These streets are constituted by buildings that are oriented towards the streets with entrances and windows.

Below in figure 7 a four-star diagram is shown with the three most extreme cases representing each cluster. The shape and the location of the diamond indicate the type of town. The green diamond is on located on the upper left and consist of a high number of streets and T-junctions. These towns have robust centres enhancing pedestrian-based shopping streets and has a high level of walkability, in which indicate high level of sustainable transportation modes.

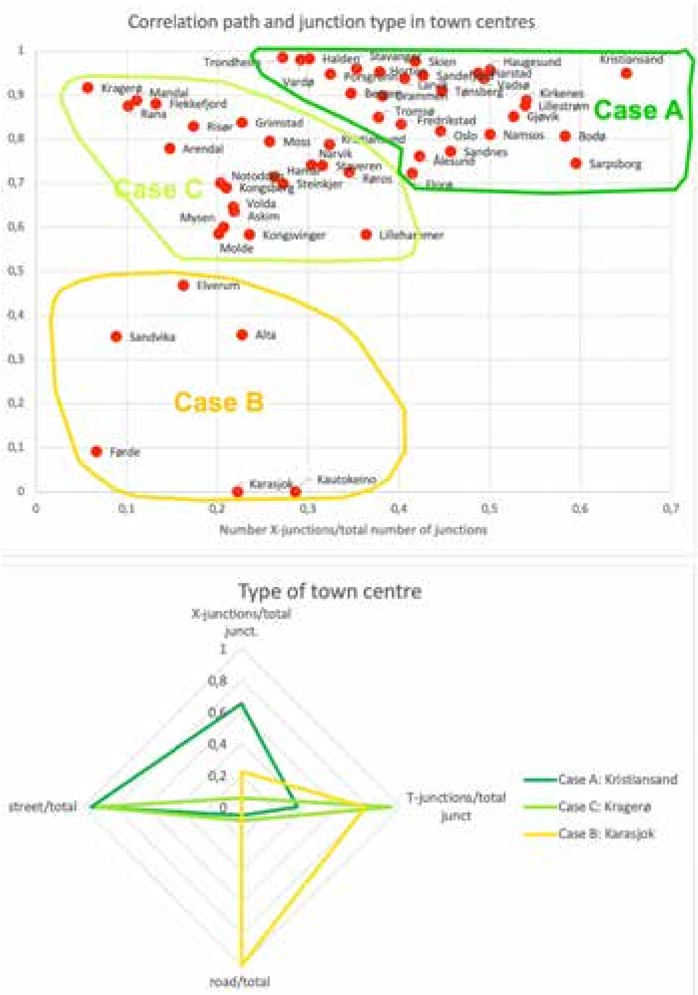

Figure 7: Top: The walkability potential matrix - Scatterplot showing the correlation between junction and path type. Bottom: 4-star diagram showing examples of three different towns representative for each cluster.

The light green diamond is flat and stretched out on the horizontal levels. The towns belonging to this category are small old town centres that either are squeezed between small hills or narrow valleys or along a coastal line. The biggest threat of these towns are the establishment and expansions of out-of-town shopping malls. Often these shopping malls are causing town centre decline due to that shops move out to these car-based shopping malls. Therefore, these town centres are very woundable when expanding due to population growth.

The yellow diamond is located on the lover right in the diagram. Towns belonging to this category are villages that recently got the status as town due to their regional position or population growth, or they are new towns. Their centres are developed around a T-junction, and everything is dimensioned around private car usage. Traffic safety, road capacity rules from the road engineer handbooks have steered the development of these town centres.

The next is to reveal to what extend the number of various junction and path types correlates with space syntax variables through regression analyses.

Regression analyses between junction type and space syntax
To what extend do these three types of town and city centres score on the spatial configuration of the street and road network? The axial map does not make any difference between path as well as junction type. Scatterplots were made for revealing the regression (R2) between space syntax analyses and path and junction types for all 55 town and city centres. The strongest correlations were found with the local NAIN and NACH analyses with a radius of 500 meters.

The correlation coefficient between the junction type and local NACH is R2 = 0,3701 and local NAIN is R2 = 0,3325 for all town and city centres. Thus, high number of X-junctions matters for generating high integration with high local to- and through-movement potentials. As research has shown, central urban areas with high local integration are attractive for pedestrians and contributes to low energy use for transport (de Koning et al 2020b).

Figure 8 shows a scatterplot with a differentiation between the size of the cities and towns. Regards the local to-movement potentials (mean NAIN low), the medium sized towns have the highest correlation with the percentage of X-junctions. Conversely, the larger the town or city, the stronger the correlation is between the percentage of X-junctions and local through movement potentials (mean NACH low). Seemingly, large towns and cities has a well-integrated main route network well-connected to adjacent larger neighbourhoods than the medium and small towns. Many of the small towns that just got the town status have a centre that is consisting of mostly roads with several T-junctions. Most of them are small villages that has expanded.

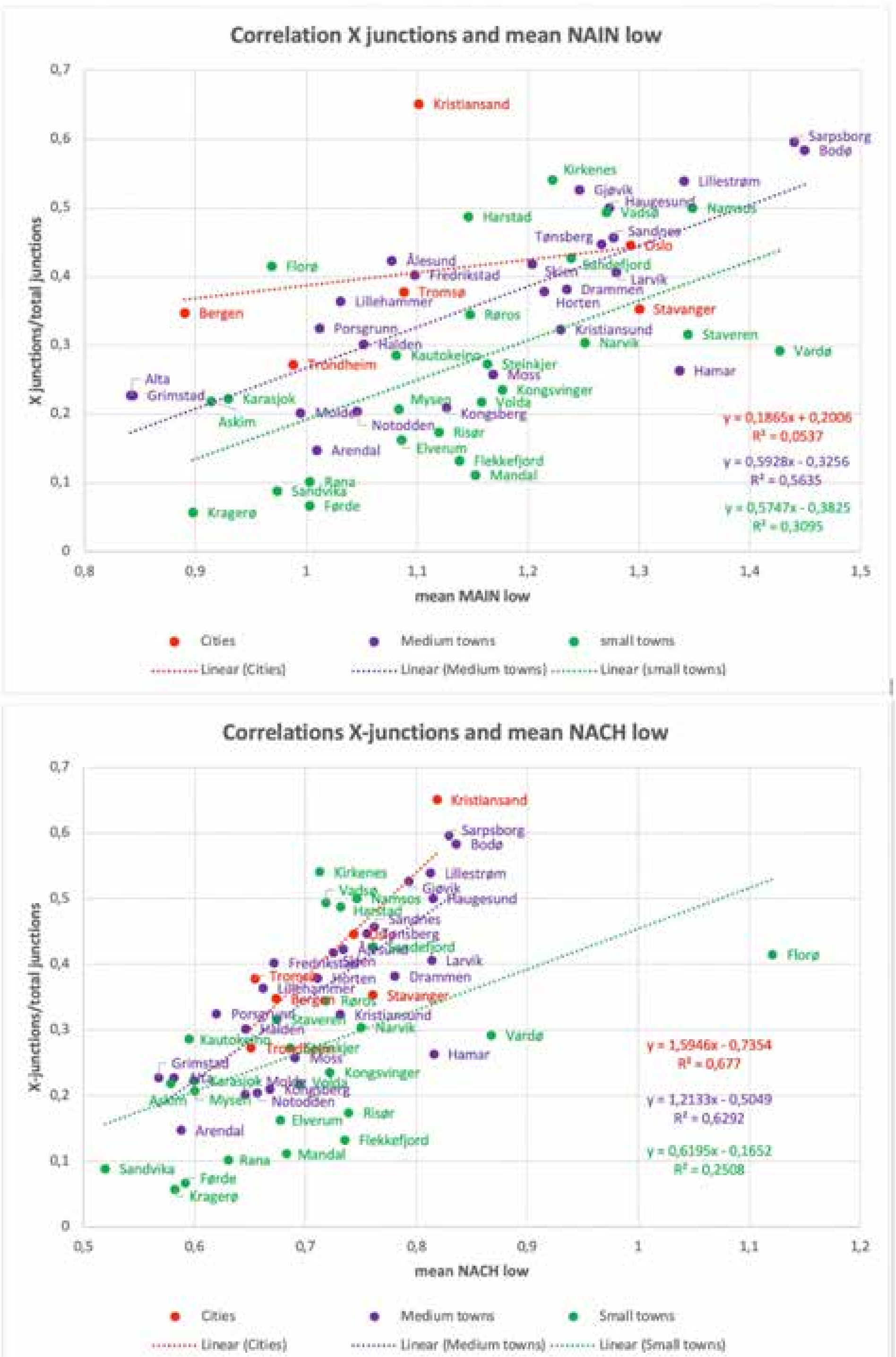

Figure 8: Regression analyses of X junctions and local mean NAIN and NACH with a differentiation of the town and city size.

Regression analyses between path type and space syntax

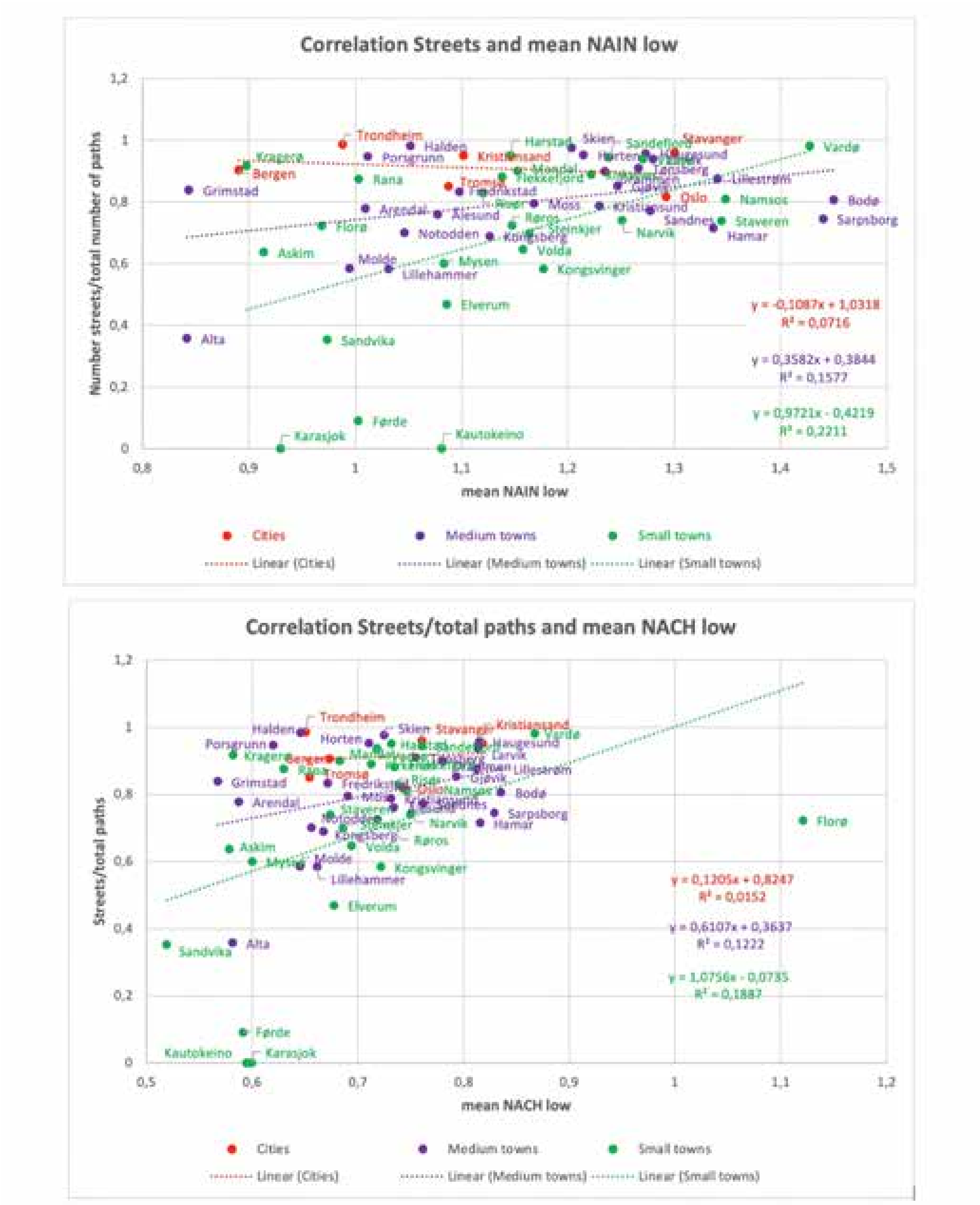

Figure 9: Regression analyses of percentage of streets and local mean NAIN and NACH with a differentiation of the town and city size.

Regards the correlation coefficient between the percentage of streets in relation to roads with local to- and through movement potentials for all towns and cities, they are slightly lower than the X-junctions. The correlation coefficient between the path type and local NACH is R2 = 0,1627 and local NAIN is R2 = 0,13 for all town and city centres. When making a differentiation between the sizes of the city and towns, as shown in figure 9, the small towns show the strongest correlation between the percentage of streets and local to- and through movement. The smallest towns have the largest variation of all three cases. Thus, the percentages of streets in relation to roads seems to matter to some extend in the various local integration analyses.

Discussion

As the results of all the 55 Norwegian town and city centres show, a high number of X-Junctions in correlation with T-junctions combined with a high number of streets in correlation to roads contribute to high degree of walkability potentials. Often town centres with an orthogonal street grid, have many X-junctions and tend to have short urban blocks. All streets in these towns and cities have pavements or are pedestrianised. In the streets with car accessibility, there is a balanced use between pedestrians and car drivers. In most cases, the buildings tend to be faced towards the streets with active frontages.

Conversely, town centres with high number of roads in relation to streets tend to be dominated by T-junctions. The urban blocks tend to be large, in which increase walking distances. Even though most of the roads have pavements, it is still vehicles dominating these roads. Buildings are mostly turned away from roads, in which makes walking as a boring experience. Town centres with these spatial features tend to have a car-based shopping centre and few people frequenting streets on foot. Often a random chosen small area is reserved for a square with some benches to sit, often named 'torget' (the square).

Figure 10 shows some google street view images of four different town and city centres. The two cases on the top are car dominated towns with a car-based shopping centre surrounded by parking lots. The buildings are turned away from the roads, in which reduce the perception of safety and attractiveness for walking. The two cases below are from city centres that are dominated by streets. Whereas Kristiansand centre consists of mostly X-junctions and Trondheim centre consists of mostly T-junctions, the centres consist of mostly streets with pavements. All buildings have active frontages oriented towards the streets.

Figure 10: Google Street view images of the car dominated roads in the centres in Alta and Mo i Rana, and the balanced streets in the centres of Kristiansand and Trondheim.

The percentage of X-junctions have the strongest correlation with the degree of local to- and through movement potentials. High number of X-junctions contributes to short urban blocks and high local integration, in which creates short movement routes and high degree of land use mixture. A high percentage of streets in relation to roads contribute to make the path network attractive for walking, due to that the buildings along streets tend to have active frontages with many entrances orientated towards the streets. This stimulates the senses and gives a nice walking experience. Moreover, the location pattern of shops tends to have a linear pattern. The variation of shops tends to be high in these kinds of centre, in relation to the centres that are dominated by roads and T-junctions. Conversely, the location pattern of shops tends to be clustered in a car-based shopping centre in towns dominated by roads and T-junctions. Most shops are from branches and offers few opportunities for individual shops.

Conclusions – the walkability potential matrix measures the destiny configuration
A first step to enhance sustainable mobility means is to focus on the path network in city and town centres. It is not enough with high density of buildings and high degree of land use diversity. The spatial structure and the profile of the path network also matters. Metric or topological distances do to some extend matters for enhancing walkability but must be seen together with the path type and the junction type. The first one is about making walking is comfortable, safe, and enjoyable (stimulating the senses during walking), whereas the second one is about the degree of routes choices (dealing with monotony versus variation). Seemingly, the spatial framework for the so-called '15 minutes cities' or for 'walking the last mile' indicates the following spatial parameters:

- High number of X junctions in relation to T Junctions,
- High number of streets in relation to roads,
- High global as well as local to- and through movement potentials regards the spatial configuration.

All these parameters together contribute to enhancing potentials for walking friendly town and city centres. A street with buildings faced towards it, short urban blocks and large choice of routes makes walking far more attractive than a road with adjacent building turned away from it and large urban blocks with few route choices. These parameters needed to be incorporated into the 'design' part of the 5Ds proposed by Ewing and Cervero (2010). Or a 6th 'D' needs to be added, such as for example 'destination configuration'.

How can the walkability potential matrix be applied into current planning and urban design practice? In general, all present urban planning and design activities must start from to build on information about the town or city where the intervention takes place. Those responsible for planning must be able to obtain this information. A regrettable fact is that many planners and urban designers do not distinguish between qualifications for preparing plans and qualifications for obtaining relevant information and analysing such information for planning. The aim of this contribution focus on the latter.

Over the past decades, knowledge has been developed both for obtaining and analysing information that has given both planners and urban designers far better tools than before to carry out analyses of urban structure and its characteristics for space use than before. However, it is still a long way to go from research into planning practice.

The use of the walkability potential matrix will give indications of how attractive it is to be a pedestrian in the various street profiles. This attractiveness is also affected by light, sunlight etc. This is probably one of the reasons why small urban blocks are more attractive than large urban blocks. Large parts of Norway lie at the same latitude as Greenland, where several streets have shade with snow and ice on the ground for about 6 months per year. When implementing high density of houses in central urban areas in line with the central authorities' recommendations in neighbourhoods consisting of large urban blocks with new roads with buildings turned away from it, contribute to pedestrian unfriendly streets.

The walkability potential matrix is needed to assess the formulation of policies at a higher level than at a municipality level. This is needed to make policies for a good street network suitable and attractive for pedestrians. Moreover, this method can be used to make a screening for new planning proposal for neighbourhoods to test to what extend the path network contributes to high degree of walkability. The biggest challenge is to upgrade and change the road engineer's path network dimension 'bible' containing rigid road standards requirements mostly suitable for vehicle dominated roads in the Norwegian countryside. Requirements for street dimensions in an urban context is lacking in this book. Likewise, requirements must be set for new buildings in land use plans, such as enhancing active frontages with windows and doors facing towards streets on ground floor level.

Even though the focus in this inquiry focused only on junction and path types, the next step is to obtain information about the characteristics of streetscapes and buildings in terms of attractive pedestrian movement routes and its relation to shadow and sunlight analyses. Likewise, the next challenge is to obtain detailed travel behaviour data from each town and city for correlating the results with the walkability potential matrix. What is clear is that the weather conditions do not influence a town or city's walkability potentials. Some of the towns are in areas with rough climate and weather conditions. Moreover, the walkability potential matrix needs also to be tested on town and city centres from other countries.

Most streets in Norwegian town and city centres came into being before the explosion of private car ownership. Therefore, most building entrances and windows on ground floor level are oriented towards the streets. Therefore, a note of warning must be given to current urban planners and designers: When giving a new pathway a name ending on 'street', it is not a guarantee for that it will facilitate pedestrian movement. Seemingly, the path needs pavements, building with entrances and windows (active frontages) oriented towards the path on ground floor level for making walking attractive, safe, and enjoyable.

For generating walking friendly and sustainable town and city centres in Norway, the largest challenges need to be put on the road engineers. The current road planning manuals need updates regards requirements for street profiles with good urban qualities. The road engineer needs to look further outside the road or street's boarder and incorporate the adjacent buildings to a street when intervening in built environments (van Nes 2021b). Likewise, the rigid planning standards on maximum noise is based on models based on origin and destination traffic models. All these requirements create anti-urban urban centres, in which make walking boring. In addition, the challenge for urban planners is to put requirements on building facades and street profiles in land use plans. The adjacent buildings to streets need active frontages with doors and windows on the ground floor facing streets for making walking safe and enjoyable. Streets with blind walls and buildings turned away from streets are perceived as boring, dull, and unsafe.

At present, villages with a regional central position are expanding in Norway. Recently, many of them are getting a town status. Often these village have a tiny old centre consisting of one or two streets. When the number of inhabitants is growing, often large new neighbourhoods containing single-family houses are spread out into the countryside around these small centres. This creates long travelling distances along roads that are boring to walk on, which again are contributing to that these centres are planned around the private car. Again, this contributes to the establishment of car-based shopping centres adjacent to these tiny old centres. Therefore, the largest challenge is to introduce street planning and traditional balanced street profiles for creating short and attractive walking distances in town and city centres.

The next step is to try out the walkability potential matrix on other cities outside Norway. The historic and the local context need to be considered regards identifying the path type from path names. In Norway the last part of street names correlates with Eldijk's street profiles classification. Hopefully, the walkability potential matrix can contribute to refine the 'design' concept from the 5Ds or to add a 6th D named 'destination configuration.'

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