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# Evaluating the state of Transit-Oriented Development in Norway

## The Node-Place-Design model and Form Syntax applied in the InterCity-Triangle in the Oslo Fjord region

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## ABSTRACT

Enhancing sustainable cities and mobility means is on the agenda in several countries. In Norway this manifests itself as targets on zero-increase in personal vehicle transport, making intergovernmental agreements between state and municipalities about city-growth, and conducting large investments to upgrade the interregional rail network named InterCity. The national policy on 'Land-Use Transport Integration' (LUTI) is a mean to reach sustainable cities and mobility. In this paper two distinct methods are combined to address LUTI. The methods of Node-Place-Design model and Form Syntax is integrated in a manner never done before on the railway network around the Oslo fjord region as case. InterCity and associated station areas represent the transport network and nodes used as case studies for testing and refining the evaluation method.

The result is an evaluation method shown to be operational through testing. This evaluation method is applicable on scales from regional urban planning as well as local urban design and provides a foundation for urban diagnostics and improvement strategies for the cities and railway station areas. Evaluating the entire InterCity-network provides the basis for introducing brand new typologies for railway station areas adapted on a Norwegian context. The state of LUTI between cities and station areas along the InterCity can be compared, and the cities' role in the network can be derived.

## KEYWORDS

Form Syntax, Node-Place-Design value model, TOD, TAD, Railway stations

## 1 INTRODUCTION

In Norway, there is a desire to increase the share of use for sustainable transport modes, for example by replacing travel by private car with public transport, walking and cycling. The aim is to reduce transport-related inequalities and achieve sustainability goals. The vision of zero growth in private car transport is a national goal (Samferdselsdepartementet, 2017). The national policy of Land-Use Transport Integration (LUTI) is playing a key role here. However, there is little focus on how to implement 'Transit-Oriented Development' (TOD) into practice in Norway.

According to Banister (2008), spatial planning is one of four ways to influence travel patterns and mobility to achieve sustainable mobility. 'Land-Use Transport Integration' (LUTI) is a concept to achieve this. There are several ways to implement LUTI. Internationally, the approach to implementing LUTI is often in the form of the concept 'Transit-Oriented Development' (TOD). At the same time, LUTI is difficult to quantify and evaluate. The Node-Place-Design model is a tool that can help us to understand the condition of LUTI in Norway when applied to transport corridors in Oslo and the Eastern Norway region.

This research explores the limitations and potential of the Node-Place-Design model. The model is adapted to the Norwegian context through investigating 31 railway station towns along the rail transport network defined by the InterCity triangle around the Oslo fjord region. This contributes to the discussion about LUTI in transport corridors and networks instead through individual studies of nodes. The strength of the LUTI model is how it describes an entire transport network and the nodes in it.

The main focus of this research is to reveal how the Node-Place-Design model is integrated with Form Syntax in a way that has not been done before. The result of the integration is a robust evaluation method where Form Syntax describes the local spatial conditions in the station towns through existing morphological conditions such as street networks, building forms & density and functional mix.

This research carries out an exhaustive analysis of the transport corridors which shows that most of the nodes in the network belong to a typology that describes 'imbalance.' The imbalance is attributed to a mismatch between node qualities, place qualities and design qualities at different places in the network. Moreover, our findings contribute to insight into how an integrated land use and transport planning can be evaluated comprehensively at system, node and local internal level in Norway.

The current policy of Land-Use Transport Integration is the prevailing view of how it should be planned in Norway. Different approaches for implementation have been proposed. Land-Use Transport Integration is a policy goal that is anchored down in the planning hierarchy through national expectations, national transport plans and state guidelines and must be exercised by regional and municipal planning authorities (Kommunal- og moderniseringsdepartementet, 2019; Kommunal- og moderniseringsdepartementet, 2014; Samferdselsdepartementet, 2017).

There is a knowledge gap between understanding the situation and implementing LUTI into practice. A framework is thus needed for evaluating the current state of LUTI in Norway. The TOD concept has such a framework. Therefore, the following question is at stake: How can various degrees of integrated land use and transport planning be evaluated along the InterCity Triangle around the Oslo fjord region?

The responsibility for LUTI lies on two levels in the Norwegian planning hierarchy; regional and municipal planning authorities. The regional planning authority is responsible for the regional transport system. The municipal authority is responsible for the nodes in the transport system. By using the Node-Place-Design model, these two levels can be evaluated. A shortcoming of this approach is that it does not say anything about the location of unbalanced relationships between transport, place and design internally in the node. With Form Syntax morphological conditions are mapped and unbalanced locations are made visible prioritization and improvement strategies. Within the TOD framework, 'Transit Joint Development' (TJD) as an approach to improvement strategies and implementation of LUTI at the local level.

Evaluating integrated land use and transport planning therefore consists of an evaluation at 3 levels: The entire transport system, the nodes and locally in the nodes. In this task, the planned Ringerriksbanen line has been excluded as this rail line is not implemented. On a local scale, the delimitation is given by the station area. In the Node-Place-Design model, this delimitation is given as a radius of 800 meters around the train station. For the Form Syntax method, an extended radius of 1500 meters has been used.

Densification and comprehensive hub development of railway stations are taken into consideration through national plans, guidelines and guidelines. In Transit-Oriented Development (TOD), the railway station has the largest improvement potentials because here the proximity between transport, necessary activities and attractions is greatest.

## 2 METHODS AND KNOWLEDGE DEVELOPED SO FAR

The cities of the world have major problems with air pollution, noise, high temperatures, few green areas, sedentary lifestyles, collisions, social inequality and lack of mobility (Nieuwenhuijsen & Khreis, 2019). Annually, this causes millions of deaths (Nieuwenhuijsen & Khreis, 2019; World Health Organization, 2018). These problems can be linked to the prevailing transport system built around private transport (Low, 2013; Banister, 2008)

According to Banister (2008), sustainable mobility is an alternative paradigm to the prevailing transport system. The intention in sustainable mobility is not to ban private cars, but rather to design cities that are accessible and offer choices, where the private car is not the prerequisite for this (Banister, 2008). In the search for sustainable mobility, Banister (2008) proposes 4 key elements. One of these concerns land use planning on the basis of how land use affects travel patterns and the choice of transport mode (Banister, 2008; Van Wee, 2011; Wegener & Fürst, 1999). As a result of this link, Land-use Transport Integration (LUTI) is an approach to achieving the goal of sustainable mobility.

Research has shown that the biggest challenge with LUTI is related to implementation (Tan, et al., 2014; Curtis, 2012; Tan, et al., 2014b). The implementation of LUTI often takes the form of the concept 'Transit-Oriented Development' (TOD), but due to shortcomings in implementation, the result is often less successful. Less successful TODs often end up in the group of development projects identified as 'Transit-Adjacent Development' (TAD) (Cervero, et al., 2002; Tumlin & Millard-Ball, 2003; Renne, 2009).

TOD has also been criticized at various levels. Tan, et al., (2014) highlight the challenges of implementing TOD as a result of institutional barriers. Tan, et al., (2014b) point to the implementation process for TOD as approximate. Chapman (2013) argues that TOD places too much emphasis on development in connection with railways and points out that other factors may have a greater influence on car use. Crane (2016) points out that we still have too little knowledge about and possibly how land use and design affect traffic.

In the following two subsections we present the knowledge developed up to so far based on research on the Node-Place value model and Space Syntax in relation to railway stations and their vicinity. At the same time, we present the methods we used in this research.

## 2.1 The Node-Place-Design value model

In the Node-Place-Design value model, qualities at the station area are quantified. The quantification takes place in the form of indicators that measure different qualities of the station area within the dimension node, place and design. The average sum of the indicators constitutes the node index, the place index and the design index (Bertolini, 1999; Vale, et al., 2018).

In the original Node-Place model, there were a total of 15 indicators, of which 9 concerned transport and 6 concerned place (Bertolini, 1999). Since then, the number of indicators has grown. In a review of studies with the Node-Place model, a set of a total of 94 different indicators has been identified (Lyu, et al., 2016). 24 of these belong to the node index, 53 to the place index and 17 to the design index.

Examples of indicators that belong to the *node* index are the number of different public transport modes in the station area; number of routes or lines by public transport; departure frequency by public transport; number of bicycle parking spaces; distance to CBD (Vale, 2015; Chorus & Bertolini, 2011).

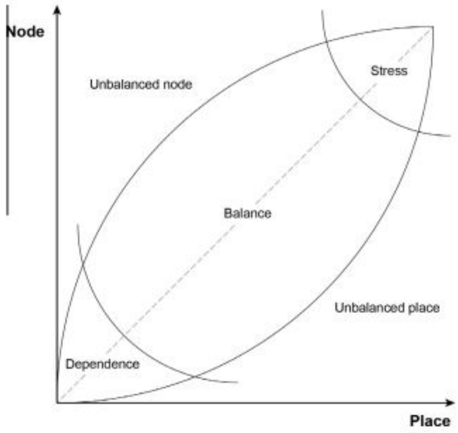


Figure 1: The original concept of the Node-Place model as described by Bertolini (1999) with the 5 different typologies.

The indicators in the *place* index originate from 'The 5ds' (Ewing & Cervero, 2010) with emphasis on density and function mix. The '5ds' stands for density, diversity of land use, design, distance to transit, and destination accessibility. Examples of indicators used for the place index are: number of inhabitants; amount of housing; number of employees in total and in different industries; diversity in land use; number and variation in destinations (Vale, 2015; Vale, et al., 2018).

The indicators in the *design* index are taken from 'The 5ds' (Ewing & Cervero, 2010) with emphasis on 'destination accessibility' and the variables for the number of intersections, street density. Variables such as 'PedShed ratio' and average quarterly length are also common indicators (Vale, 2015; Lyu, et al., 2016) with a documented effect on the choice of transport mode (Schlossberger & Brown, 2004; Cervero, et al., 1997).

Once the indices have been calculated, they are plotted in a graph where the different dimensions in the model are axes. In the original Node-Place model, there were only 2 axes with the place and node index. In the original model it was also defined 5 typologies according to which the station areas were classified. These typologies were 'balanced', 'dependent', 'stressed', 'unbalanced node' and 'unbalanced place' (Bertolini, 1999), Figure 1. These typologies belonged to different places on the graph as it reflected features in the composition of values for the place and node index. Balanced railway stations represent an equal node and place index. Dependent and stressed typologies also represent balanced stations, but with respectively low and high values. Unbalanced node or place represent cases where the node or place value, is significantly higher than the other. In recent studies, several other typologies have been introduced that takes into account the local context and to a greater extent describe the state of TOD in a node (Reussser, et al., 2008; Zemp, et al., 2011; Zhang, et al. al., 2019; Pezeshknejad, et al., 2020; Li, et al., 2019; Vale, 2015; Vale, et al., 2018).

In order to delimit and define new typologies in these studies, different cluster analyses are applied recognizing natural groupings in the distribution of the index values. It is therefore possible that several clusters arise in different transport networks because it becomes index-dependent, and consequently context-dependent.

The nodes in a transport system are described both as complementary to each other, and as being in a competitive relationship (Calthorpe, 1993; Bertolini, 1999). In addition, the railway station areas must be understood as both nodes in a transport network and places in cities and towns. The consequences of this duality are that the development of the station area may be different for the node's qualities and the site's qualities. The development implies thus that the railway station area is unbalanced between transport and place issues. One of the key issues in TOD is to resolve this imbalance (Dittmar & Poticha, 2004). But even though the station areas have a duality between node and place, there is also a dependency between these two dimensions. This dependency is conceptualized through "The Land-Use Transport Feedback Cycle"

The Land-Use Transport Feedback Cycle is based on presumptions about that there is an interaction between transport (node) and land use (place) with a background in both the social sciences, economics and mobility (Wegener & Fürst, 1999). The interaction can be roughly described in four conditions: (1) Spatial distribution of land use affects the location of human activity; (2) Spatial distribution of human activity affects the transport system; (3) Transport system gives rise to availability; (4) Accessibility through the transport system affects the distribution of land use (Wegener & Fürst, 1999). Depending on where a node is in the cycle, either land use drives increased accessibility in the node dimension or the transport system drives increased accessibility in the site dimension.

The phases of 'The Land-Use Transport Feedback Cycle' can be studied in light of different typologies and classifications for extended insight into the state of implementation of TOD in railway station areas. For example, a railway station area that is an unbalanced node, according to Bertolini (1999), will be in a phase of the cycle where accessibility through the transport system has not yet had a balancing effect on the development of land use. Similarly, an unbalanced location will lack satisfactory accessibility in the transport system. Seen in the context of the previously mentioned typologies, 'Undersupplied TOD' will be a parallel to unbalanced place and lack of accessibility in the transport system relative to place qualities (Pezeshknejad, et al., 2020; Bertolini, 1999). 'The Land-Use Transport Feedback Cycle' predicts that this imbalance will drive the development of the transport system towards a balanced situation (Wegener & Fürst, 1999). As with the original Node-Place model, 'The Land-Use Transport Feedback Cycle' also falls short in cases where TAD and TOD are to be differentiated between. Although site quality and design qualities are related through 'The

5Ds', design is not directly represented in 'The Land-Use Transport Feedback Cycle'. This makes it difficult to distinguish TOD and TAD from each other in the cycle.

## 2.2 Form Syntax with the application of Space Syntax and Urban morphology

'The Theory of Natural Movement Economic Process' has a high degree of predictability. It has gained strong empirical support with Space Syntax (van Nes and Yamu 2020). The structure of the street network has an influence on movement and attraction, which in turn is related to social, economic and cognitive factors (Hillier, et al., 1993).

'The Theory of the Urban Transformation Process' states that the structure of the street network influences degrees of building density and land use diversity (Ye & Van Nes, 2014; Ye & Van Nes, 2016). According to the theory, building density and functional diversity will be adjusted in line with the spatial integration of the street network. The theory is based on empirical experiments where analysis methods for building density and land use diversity are combined with Space Syntax (Ye & Van Nes, 2013; Ye & Van Nes, 2014).

Both theories explains that building density and land use is a consequence of the natural movement and attraction of the street network. Through the city's maturation process land use and densification are affected by the street and road network where the spatial integration is highest on different scale levels. According to both theories, most people gather at the most integrated streets, which shapes the opportunity to attract customers and potential for economic activity (Hillier, et al., 1993; Van Nes & Claudia 2021; Van Nes, 2021). As the structure of the street network is the most stable morphological element, this adaptation is a maturing process that takes time (Ye & Van Nes, 2016).

Seemingly, the structure of the street network is the independent variable. Over time the maturation processes of land use will consolidate along the highest integrated streets on various scale levels. However, this does not prevent land use, which are destinations, from disappearing from these places in the network in the relatively short term. These are short-term changes that change the movement pattern because a destination has been moved. However, it does not change the spatial structure of the street network. It only changes when the network itself changes (Carmona, et al., 2010).

The natural movement manifests itself as movement from one place to another in the network ('To-movement'), or movement through the network ('Through-movement') (Hillier et al 2005). Qualities in the street network include connectivity, permeability and integration (Hillier, et al., 1993). The qualities reflect reality through distances between places in the network, the number of changes of direction and the angle of the changes of direction.

Space syntax research have also been carried out on railway stations areas. According to Mulder-Kusumo (2005), the main factor for whether railway stations have a central location surrounded by compact socio-economic conditions is that it is spatially integrated into the local structure of the street network. Regional accessibility is less important. Paksukcharern (2003) has shown that a street network that continues inside and through a station building, is particularly important for the station's integration: As she writes ‘The main proposition for successfully creating a place out of a transport node such as a railway terminus is to embed its internal space into the local grid network so that the node itself becomes an integrated part of the local pedestrian movement system’ (Paksukcharern, 2003).

Space Syntax is able to quantify the spatial configuration of the street network. Spacematrix is able to quantify building density and morphology (Rådberg 1996). Land use diversity can be quantified through the Mixed-Use Index (MXI) analyses (Hoek, 2009). The combination of these analyses has turned out to give empirical support to the theory of the natural urban transformation process (van Nes et al 2012, Ye and van Nes 2013). Later on, this methodological combination is named Form Syntax (Ye, et al., 2016). Form Syntax is seen as a contribution to geodesign, which is a science in which geographical analyses are introduced into the urban design process (Ye, et al., 2016).

In Spacematrix, building density is studied through the ‘Floor Space Index’ (FSI), the ‘Ground Space Index’ (GSI), the ‘Open Space Index’ (OSI) and the ‘Levels’ (L) which is number of floors (Rådberg, 1996). By studying different relationships between the indices, different building typologies can be defined. Spacematrix is therefore a typo-morphological urban analysis (Rådberg, 1996). Some typologies are identified as suitable urban settlements because they contribute to more urbanity, while others have too low a density and a shape that is not suitable in urban environments. Examples of typologies that represent urban form are quarters with medium or high number of floors.

The Mixed-Use Index analyses the diversity of functions, categorized as either ‘housing’, ‘work’ or ‘amenity’. The Mixed-Use Index calculates the ratio between the 3 different categories. If 1 category is dominant with up to 100% share, it is not a question of diversity of functions, but of a ‘monofunctional’ area. Is there a relatively even distribution of the share between 2 categories, but little of the third is a question of a ‘bifunctionality’. If there is a relatively even distribution of shares between the categories, it is a question of a ‘multifunctional’ area (Van Nes, et al., 2012).

Through combining the results of Space Syntax, Spacematrix and Mixed-Use Index, new typologies for various degrees of urbanity can be defined. The typologies express the conditions of urban form associated with a location, and identify the locations where there are imbalances between various spatial and physical parameters. The results of a Form Syntax analysis can therefore enable targeted measures and resource use for urban development and transformation strategies. Based on the Form Syntax analyses of Dutch and Chinese new and old towns, Ye and van Nes (2014) made the following classifications on various degrees of urbanity in built environments: Highly urban areas, Medium urban areas, inn-between areas (high, middle and low values), low urban areas and suburban areas. The inn-between areas have the highest potentials for urban transformation.

In a TOD context, these delimited quarters and the property with low or unbalanced morphological qualities can be potential TJD. It can at least be understood as effective goals for focused investment and resource use in the development of TOD, or for shifting the station area upwards on the TAD-TOD spectrum.

It has been shown that urban design in line with ‘The 5 Ds’ can increase accessibility and choice and contribute to more people choosing public transport, walking and cycling over the private car (Cervero, et al., 1997; Ewing & Cervero, 2010). Among other things, positive correlations have been demonstrated with the number of blocks with 4 facades facing the street (as long as the length of the blocks is short) (Cervero, et al., 1997). The influence of the amount of intersections and street density and functional diversity is also probable (Cervero, et al., 1997; Ewing & Cervero, 2010).

Van Nes and Stolk’s research (2012) on 57 railway stations in the province of North Holland is the first example to combine the Node-Place model with Space Syntax. Monajem & Nosratian (2015), Pezeshknejad et al. (2020) and Li et al. (2019) have since further developed the Node-Place-Design model by including Space Syntax as an indicator. Monajem & Nosratian (2015) base four indicators on Space Syntax, two in the Node Index and two in the Place Index. Pezeshknejad, et al., (2020) and Li, et al., (2019) have based indicators in the design index on Space Syntax. Correlation analyses between indicators done in these studies coincide with the theories about the structure of the street network's role. Among other things, a correlation has been shown between population figures, jobs and the degree of integration in the street network (Pezeshknejad, et al., 2020). In fact, some of the indicators for Space Syntax are omitted in the most effective because the correlation was strong enough to shift the results (Pezeshknejad, et al., 2020). An alternative to Space Syntax in the model has been indicators based on walkability, such as the ‘PedShed Ratio’ (Vale, 2015; Lyu, et al., 2016; Vale, et al., 2018; Schlossberger & Brown, 2004).

By using Space Syntax, Spacematrix and Mixed-Use Index to calculate the indicators in the Node-Place-Design model, a two-way connection is created between this model and Form Syntax. Therefore, the use of the Node-Place-Design model and Form Syntax becoming a sequential and clearly two-part process where the two methods are connected parallelly and carried out simultaneously. It also strengthens the model’s explanatory power through a stronger academic connection to ‘The Theory of natural movement economic process’ and to ‘The Theory of Urban Transformation Process’.

## 2.3 Method used for Node-Place-Design Model and Form Syntax

In the study 25 different indicator has been used. The node index consists of 13, the place index of 8 and the design index by 4 (Table 1). As mention 94 different indicators has been identified as used in earlier studies (Lyu, et al., 2016). In this study indicators have been selected from the list of 94 indicators based on data availability and adjustment to the local context. In addition, the study aims at further develop the Node-Place-Design model by integration with Form Syntax. Therefor the methods making up Form syntax has also been introduced as indicators, either as completely new or replacing existing similar indicators. The indicators have been sourced within a buffer of 800 meters around the train station.

All indicators have been checked for normality, and most of the indicators are log-transformed as log (x+1) to increase the normality, as custom in related studies and described by Zhang et al. (2019). The indicators are normalized to values between 0 and 1. A few indicators exhibit large skewness, and to reduce this effect a clipping normalization has been used.

Each of the three indexes is calculated by summarizing the indicators and dividing by the number of indicators constituting the index.

Figure 2: Table of indicators used for the Node-Place-Design value model

Indicators used to calculate node, place and design indexes.

| Indicator description | Calculation |
|---|---|
| ***Node index*** | |
| Number of train routes from station | y1 = number of train routes offered at the station |
| Departure frequency with train during rush hour | y2 = number of trains departing from the station between time-intervals 07:00-09:00 and 15:00-17:00 at a representative workday and Saturday |
| Number of train stations within 45 minutes of travel | y3 = number of train stations reachable within 45 minutes by train, including transfer |
| Number of passengers departing by train during rush hour | y4 = number of passengers on trains departing the station during rush hour at a representative workday and Saturday (equal y2) |
| Number of bus routes departing from the station area | y5 = number of bus routes departing from bus stops within an 800 meter buffer zone |
| Departure frequency with bus during rush hour | y6 = number of buses departing during rush hour (equal y2) |
| Number of other public transport options during rush hour | y7 = Number of other public transport options offer at the station during rush hour (bus, tram, subway, ferry, airplane) |
| Number of car parking spaces | y8 = Number of car parking spaces in connection with the station |
| Number of car parking spaces reserved commuters | y9 = Number of car parking spaces reserved commuters in connection with the station |
| Number of bicycle routes | y10 = number of bicycle routes through or adjacent to the station area |
| Number of bicycle parking spaces | y11 = number of associated bicycle parking spaces at the station |
| Number of bicycle parking spaces in bike room | y12 = number of bicycle parking spaces in associated bike room at the station |
| Number of handicap parking spaces | y13 = Number of handicap parking spaces offered at the station |
| ***Place index*** | |
| Number of residents | x1 = number of residents within an 800 meter buffer zone |
| Number of workers | x2 = numbers of workers within 800 meters |
| Floor space for housing | x3 = amount of floor space area within 800 meters |
| Floor space for work | x4 = amount of floor space workplace area within 800 meters |
| Floor space for amenities | x5 = amount of floor space dedicated to service and amenities within 800 meters |
| Degree of functional mix | x6 = value by summarizing cell score (0 – 2) on degree of built environment urban form calculated with the Mixed-Use Index within 800 |

| | |
|---|---|
| Number of POIs | x7 = number of points of interest (retail, social infrastructure, entertainment, recreation) within 800 meters |
| Variety of POIs | x8 = numbers of categories (retail, social infrastructure, entertainment, recreation) of point of interest (POI) within 800 meters |
| ***Design index*** | |
| Pedshed ratio | w1 = pedestrian shed ratio |
| Intersection density | w2 = density of intersections per square meters |
| Accessible street network length | w3 = length of accessible street network in meters |
| Degree of urban form | w4 = value by summarizing cell score (0 – 2) on degree of built environment urban form calculated with the Spacematrix method within |

Most of the indicators for the node index concerning routes and frequencies has been collected manually from the itinerary and rout planners on the websites of the different service companies providing transit. The government-owned train company Vy is the source for indicators (y1, y2, y3). Bus companies operate in different regions. The InterCity-network crosses several regions with railway stations in all. Depending on the region the online itinerary of the current bus company has been applied for indicators (y5, y6). Bane Nor Eiendom is the real estate company operating the train stations. Each train station has its own website with information about transport services. This is the main source for indicators (y7, y8, y9, y11, y12, y13). Open Street Map has been used for indicator y10. For indicator y4 Norwegian Railway Directorate provide a sample of passenger number, which is kept confidential in the study. Indicator y13 has been clipped to a maximum value of 30.

The indicators for the place index consist of data and geodata provided from several sources which is implemented directly or combined. For indicator (x1, x2) Statistic Norway provide open data for residents and workers by census block. Census blocks do not comply with the 800-meter buffer zone around train stations. To accommodate the indicator x1 has been weighted with the amount of floor space housing within the 800-meter buffer. Indicator x2 is weighted by floor space workplace within 800 meters. The geodata for the indicators (x3, x4, x5) is collected from the GeoNorge initiative, the national website providing geodata. The source data is the building type code, the building ground space and the related floor space area of the building. The building type code describing the primary functional use of the building is grouped in to the three categories of the MXI analysis and summarized within the 800-meter buffer zone.
Data for indicators (x7, x8) was imported from Open Street Map to QGIS with the QGIS OSM Plugin. Numbers of POIs within the 800-meter buffer was summarized. Each type of POI was categorised in to one out of four types. The number of types of POIs within the buffer constitutes indicator x8. Indicator x1 is clipped to a minimum of 100 inhabitants. Indicators x3 and x5 are clipped at a maximum

The design index comprises four indicators. Indicator w1 is a pedshed ratio, which is the ratio between the station area and the area reach through the street network. For the station area, the 800-meter buffer is used. The network dataset provided in ArcGIS Pro is used together with the network analysis "Service Area" to calculate the area covered by the network. For indicator (w2, w3) the road network from the National Road Database is used. For w2 all intersections in the network are summarized with in the 800-meter buffer. For w3 the length of the network is summarized within the buffer.

Indicators (x6, w4) is a coupling between Form Syntax and Node-Place-Design mode as they are used in both methods. Indicator, x6 stems from MXI-analysis, and indicator w4 stems from Spacematrix. The basis for these analyses is the construction of a hexagonal grid with each hexagon being 10 000 square meters is placed. The grid centres around the train station and has a radius of 1500 meters. A hexagonal grid is chosen to avoid delineation along streets. The grade of the grid must be balanced between too fine and too coarse. In other Form Syntax studies, when building plots is not used, square grid cells of 22 500 square meters (150x150 meters) is often used for grid form and size, but to accommodate the smaller towns in this study, a finer grid is chosen (Ye & Van Nes, 2014).

For the indicator x6 the source data from indicators (x3, x4, x5) is reused and is collected from the GeoNorge initiative, the national website providing geodata. The floor space area of each of the three types of uses in the MXI analysis is summarized within each grid cell. The ratio of floor space area for the three different types of functions is the used in the analysis. If the grid cell is 90 % mono-functional the functional mix is "low" and the cell is given 0 points. A "medium"-functional cell has two functions with more then 10 %, but the third function is less then 10 %. This cell gets 1 point. In a multi-functional grid cell, all three types of functions have more than a 10 % share. This cell is defined as "high" and given 2 points. As an indicator in the Node-Place-Design model, all cells intersecting the 800-meter buffer around the train station is summarized.

For indicator w4 the Spacematrix method is applied. The cell is defined as one of the nine types of building forms in Spacematrix by summarizing for ground space area and floor space area, and then calculating the ratio. The cells are assigned as low, medium or high, corresponding to the classifications from Ye & Van Nes (2014). Low is quantified as 1 point, medium as 2 and high as 3 points. As with MXI, the indicator is the summarizing of the grid cells within the 800-meter buffer zone.

Space syntax is used as part of the Form syntax, but this method not included in the Node-Place-Design model. The method to classify and quantify grid cells follows Ye & Van Nes (2014). The segment with the highest integration is used to represent the cell in the current type of space syntax analysis. Two different types of analysis are run (Angular choice and segment integration), each with two subtypes for low and high metric radius. The analysis was conducted with ten intervals (the natural break method). Values in the lower third part of the intervals classified as "Low", the middle third as medium, and values in the top third of the intervals classified as high. When aggregated as shown in figure 3 the combinations define the end result as low, medium or high as described by Ye & Van Nes (2014),

| Space Syntax | The content of this classification |
|---|---|
| High value | High values in both metric and topological analyses;<br>One analysis with high value and the other with medium value |
| Medium value | Medium values in both metric and topological analyses;<br>One analysis with high value and the other with low value |
| Low value | Low values in both metric and topological analyses<br>One analysis with medium value and the other with low value |

Figure 3: Reclassification when aggregating different types of space syntax analysis (Ye & Van Nes, 2014)

When combining all three analyses in to Form Syntax there are 27 possible combinations, which in turn is reclassified to describe the urbanity of the area or grid cell. The reclassification scheme is shown in figure 4, and the application in this study in upper map of Figure 9, 11, and 14.

| Categories of urban areas | The division of values from space syntax, spacematrix and MXI | Examples |
|---|---|---|
| 1) Suburban areas | L/L/L, M/L/L, L/L/M, L/M/L |  |
| 2) Low urban areas | L/M/M, M/L/M, M/M/L |  |
| 3) In-between (low) areas | H/L/L, L/H/L, L/L/H |  |
| 4) In-between (middle) areas | H/M/L, M/H/L, L/M/H, H/L/M, L/H/M, M/L/H | |
| 5) In-between (high) areas | H/H/L, H/L/H, L/H/H | |
| 6) Middle urban areas | M/M/H, M/H/M, H/M/M, M/M/M |  |
| 7) highly urban areas | H/H/H, H/M/H, M/H/H, H/H/M |  |

L = Low values, M = Middle values, H = High values

Figure 4: Reclassifications scheme for Form Syntax from Ye & Van Nes (2013)

For clustering the built-in function in ArcGIS Pro is used.

## 3 THE RESULTS

On a regional scale, we first conducted the Node-Place-Design model analyses of all the 31 stations. This set the bases for selecting the cases for a local scale analysis with form syntax for three different railway station towns/villages.

## 3.1 The Node-Place-Design value analyses

Figure 5 shows the results from all the Node-place-design analyses with all the analysed stations. The results are based on the scatter plot of place and node indices originally from Bertolini (1999), with adding several new indicators, adding design index and running cluster analyses of all these indicators.

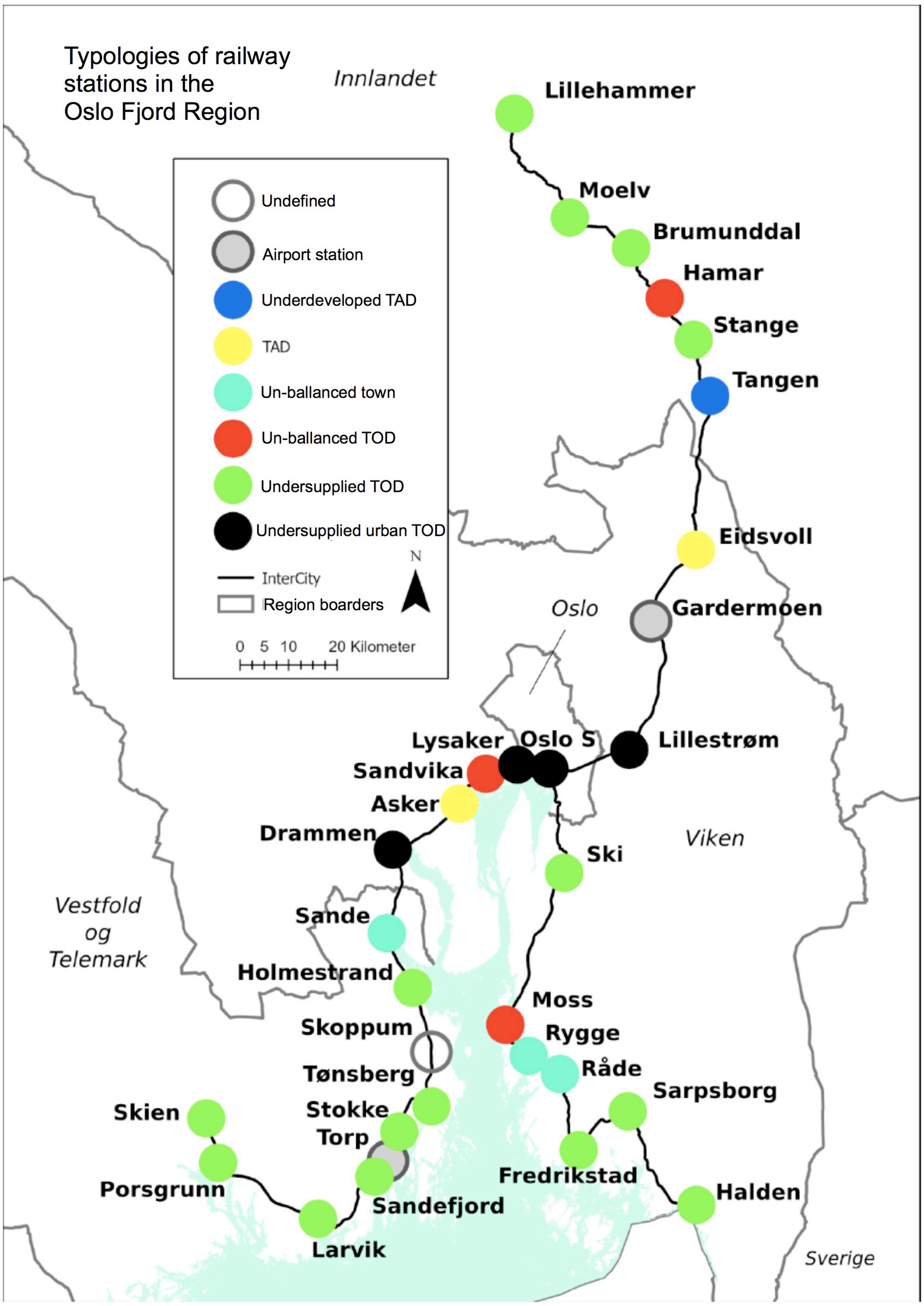


Figure 5: Typologies of railway stations in the InterCity triangle

Geographically, the station areas around Oslo again have the highest design index, except for Sandvika and Asker. As Sandvika is particularly high on the node and place index, it may seem as the design for integrating transport and place could be improved. Asker is relatively low on both the place and design index, which indicates the potential for better utilization of transport qualities.

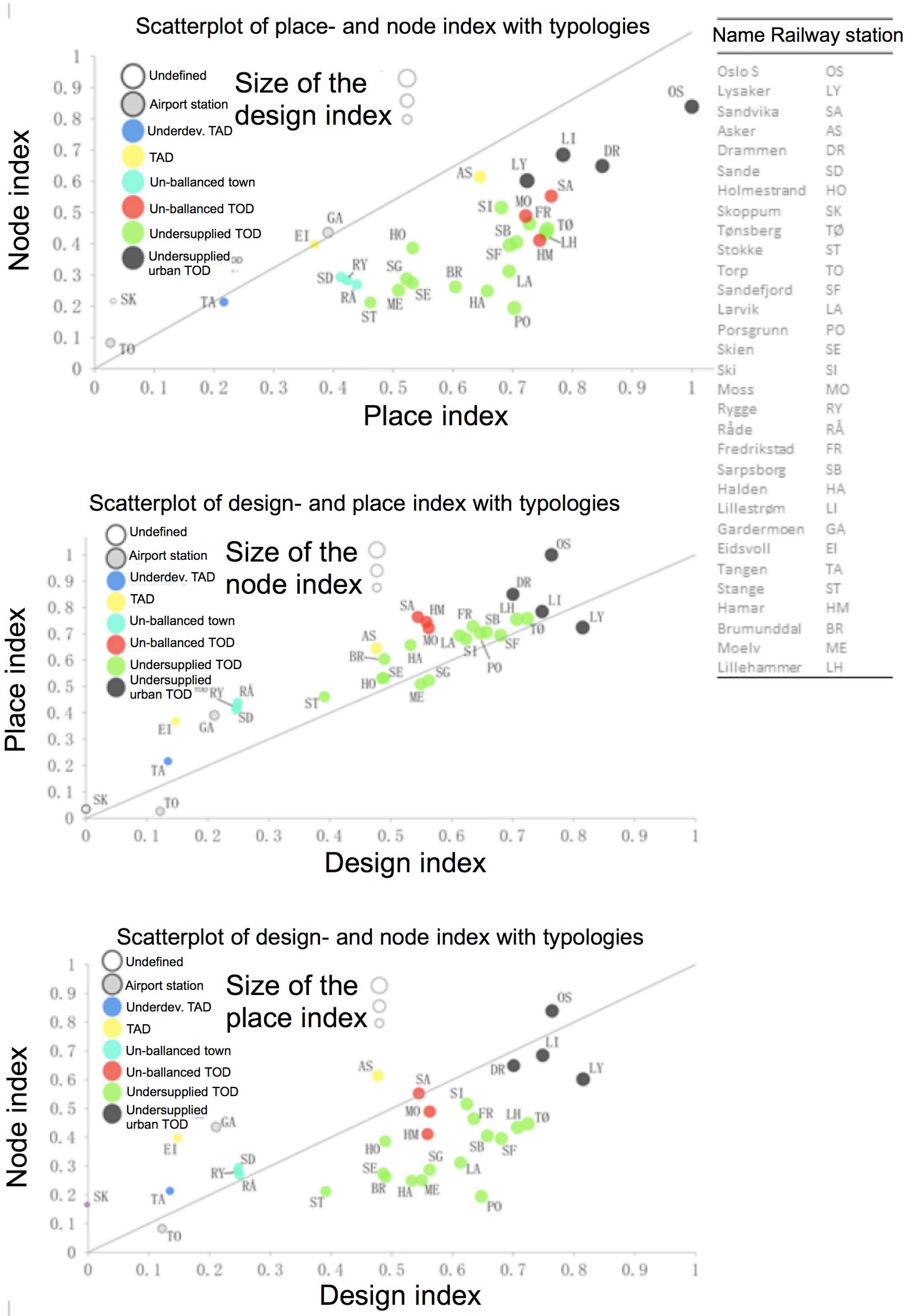


Figure 6: Scatterplots for identifying the Node-Place-Design Value for the InterCity stations in the Oslo Fjord region.

In order to classify the station areas along the InterCity railway lines, a cluster analysis has been performed as a basis for defining different typologies of railway stations. The built-in functions in ArcGIS pro for 'optimized pseude-F score' has been used together with a 'multivariable clustering' to find a suitable number of clusters based on the nature of the data. The approach uses K-means to calculate the clusters. The number of clusters that were most meaningful to use was 5 clusters with the highest local F-score of 50.5. The definition of the typologies is based on Vale, et al., (2018), but local adaptations are added in line with this research purpose. Figure 6 shows the results of all the cluster analyses, with the colours of the various types of railway stations that are shown in figure 5.

Cluster 1 consists of 3 railway station areas that has generally low values, but with a node index that is significantly higher than the place index. This may indicate a railway station area that is underdeveloped as a place. Cluster 2 contains 5 railway stations and has a significantly higher node index than the design index, and a slightly higher place index than the design index. This indicates that node qualities and place qualities are quite balanced, but that the integration between them is lacking. This appears to be 'balanced' in the original Node-Place model, but in reality it looks more like a TAD. We also see in the place and node graph that there are small differences between Sande, Rygge and Råde with Stokke and Moelv in cluster 3.

Cluster 3 consists of 9 railway stations where the node index is significantly lower than the other two indices. This indicates an 'unbalanced place' where an improvement of the transport supply can have an effect. There are large overlaps to cluster 4 in design and place graphs where Larvik, Porsgrunn and partly Halden stand out. The size of the symbols clearly illustrates that the difference between the clusters is due to node qualities, which are also seen in these station areas in the graphs where node indices are displayed along the axes.

The 10 railway stations in cluster 4 show approximately the same ratio between the indices as cluster 3, but with generally higher values. The design index is somewhat lower than the place index, which suggests that an improvement in the transport supply should take place in connection with an improvement of design factors such as improving walking opportunities. Asker stands out somewhat internally in the cluster with a marked overlap with cluster 3 in the design and place graph. Sandvika and Asker are also approaching cluster 5 in terms of node qualities, but Lillehammer and Tønsberg are closest in terms of place and design indices.

The 4 railway stations in cluster 5 are in better balance than clusters 3 and 4, but at the same time have similar tendencies with a lower node index. Lysaker is closest to cluster 4 in terms of node quality, but stands out with a high design index.

The overall impression of the clusters is that the node index is generally lower than the other indices. With regard to the placement of InterCity in phase 4 of the "Land-Use Transport Feedback Cycle", this is expected, but it is interesting to reveal where the discrepancies are. Cluster 1 is small in number and somewhat distorted as a result of methodological choices in this research for Skoppum's location. It is interesting to see that cluster 2 has a node index that is higher than the design index. The concentration of clusters 4 and 5 is clear around Oslo. One also sees a number of cases of cluster 4 elsewhere on the transport network, such as Lillehammer, Sandefjord, Moss and Fredrikstad.

## 3.2 The Form Syntax analyses of three station towns

Oslo central station not taken into account in the local scale analyses of the larger vicinity of railway stations. All spatial and morphological values from a form syntax analysis will show very high values in the vicinity of Oslo Central station. We choose the following 3 different stations for the Form-Syntax analysis: Eidsvoll, Råde and Porsgrunn.

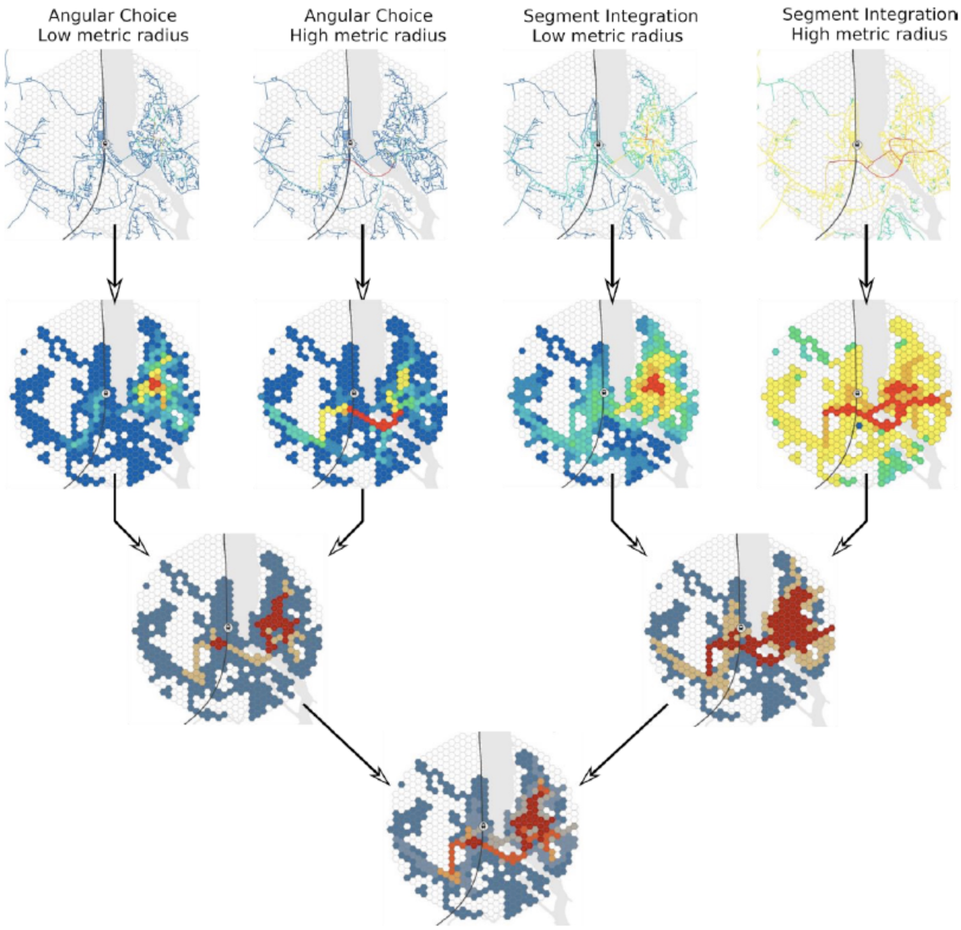


Figure 7: Aggregating the results from the various space syntax analyses in GIS.

Each case represents its own typology with associated characteristics and different challenges based on the Node-Place-Design model. Eidsvoll is defined with the typology 'TAD', and is highly relevant as a case study. It is defined as an 'unbalanced urban area' where future improvements in the transport supply must be met with corresponding improvements in the design dimension. Porsgrunn is defined as a ‘Undersupplied TOD’, where the transport supply is very skewed compared to both the place and design index. Porsgrunn is the station area with the greatest skew between node and place qualities.

Figure 7 shows how the values from the various space syntax analyses are put into one model. A grid is created through GIS where the results from the various space syntax analyses can be correlated with the results from the Spacematrix and MXI analyses. The results from the most recent space syntax analyses (angular segment integration and angular choice with both high and low metrical radii) are aggregated into the GIS map and aggregated. The segment lines with the highest values decides the value of the cell (van Nes et al 2012).

**Eidsvoll**

Eidsvoll is defined as a ‘TAD’ because the node quality appears much better than the design qualities. Through the Form Syntax analysis, it will be made clear that much of this is due to the railway station's location outside the centre of Eidsvoll on the other side of the river Vorma. Improvement strategies for Eidsvoll should prioritize connections as well as density adjacent to the railway station.

Figure 8 shows the results from the Form Syntax analyses of Eidsvoll. The town centre area on the east side of Vorma is relatively well integrated with the street network regards the space syntax analyses. There is also an integral main route that follows the main road over Vorma from east to west side and closer to the railway station. It clearly appears that the railway station to a small extent is connected to the street network. The pedestrian bridge over Vorma contributes to slightly improve the spatial integration of the railway station. However, the railway station area is not so well integrated like the area on the east side of the river. A challenge for Eidsvoll station is consequently that the spatial accessibility between the train station and town centre is poor. This affects the flow of movement between these two locations and are unfavourable in a TOD perspective. This contributes to the perception of Eidsvoll belonging under the typology ‘TAD’.

From the Spacematrix analysis, as much as 95.1% of the building forms in Eidsvoll can be classified as low point buildings, for example detached houses. This is the type of building that is least urban in terms of density. A somewhat low stripe and quarter building shapes has been registered in the centre of Eidsvoll. This amounts for 1.6% and 2.1% of the buildings. These values regard building form and typologies in Eidsvoll supports the impression regards the urban design dimensions. Likewise, the Space Syntax analysis also points to the Spacematrix analysis in the direction of TAD for Eidsvoll.

From the Mixed-Use Index analysis, approximately 60% of the area has a monofunctional residential land use. About 11% of the land use is for work purpose and 16.6% combined work and ‘amenities’. In total, monofunctional land use amounts for 70.8% in the MXI analyses. Correspondingly, there is 6.3% combined work and housing. In total, there are 5.9% multifunctional land use. It is clear that a number of different combinations of functional diversity have been consolidated in the centre of

Eidsvoll, while monofunctional housing purposes are dominating the peripheral zones. Also, around the train station there is some bifunctionality, but to a much lesser extent than in the town centre. Eidsvoll appears to be relatively diverse in land use, which is also reflected in the place index where the Mixed-Use Index is included as an indicator.

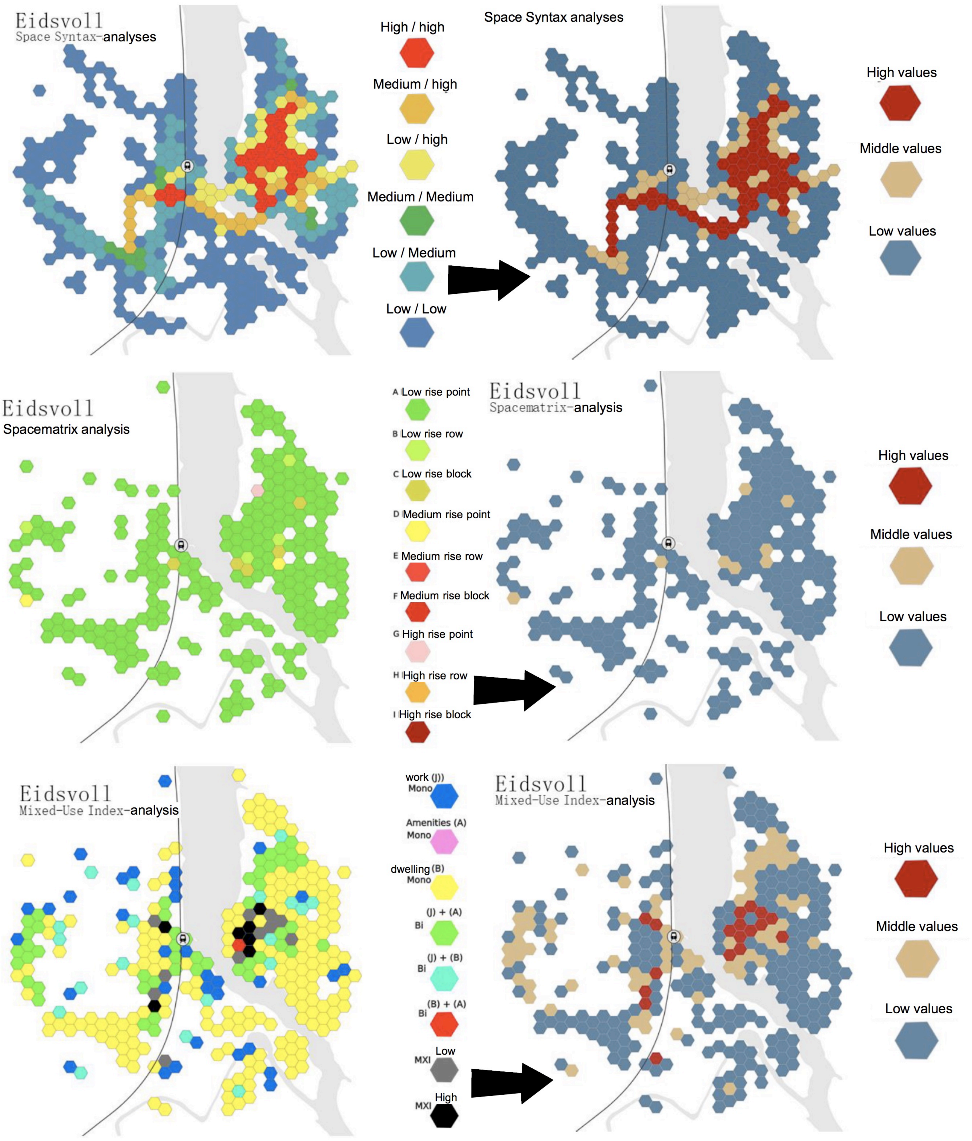


Figure 8: Various spatial analyses of Eidsvoll.

Regarding the Form Syntax analysis (Figure 9), Eidsvoll does not have any areas that are characterized as 'Highly urban areas'. Only a few areas in the town centre are 'Medium urban areas'. Otherwise, the centre consists mainly of 'inn-between areas'. The edge zone is dominated by 'Suburban areas'. The areas closest to the railway station are also mainly classified as 'suburban areas' or 'low urban areas'. There are also a few 'In-between (low) areas'. The results of the Form Syntax analysis clearly show that the areas closest to the railway station lack urbanity. This is where resources and investment should be directed to move upwards the TAD-TOD spectrum, and from the

TAD layer. The potential in terms of unbalanced morphological conditions is consolidated throughout the downtown area. Increased densification will balance out these conditions.

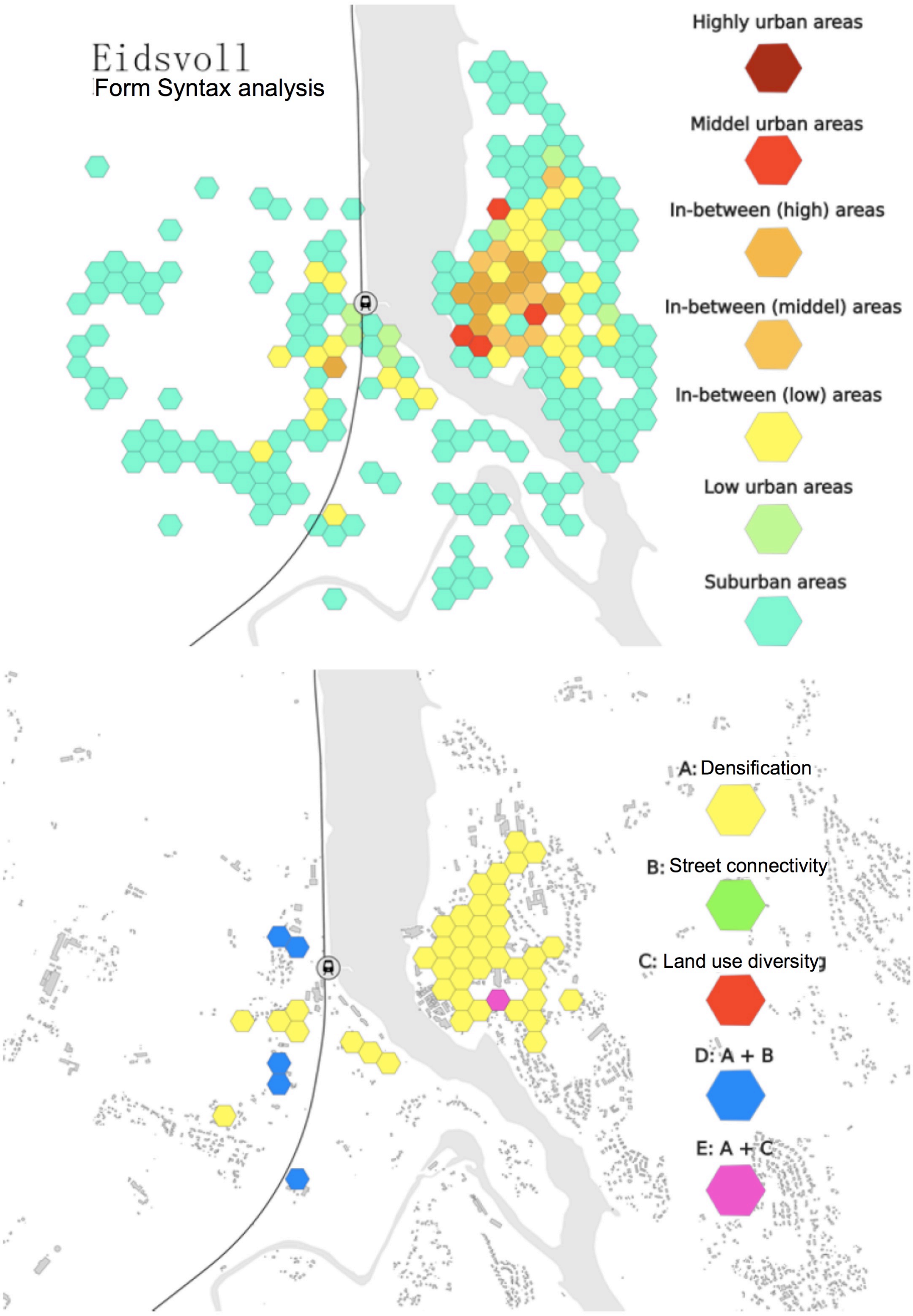


Figure 9: Form Syntax analyses of Eidsvoll.

Eidsvoll has thus a large densification potential. Approximately 96% of the buildings consists of single-family houses. At the same time, the street network proved to have relatively high qualities, while the diversity of functions also performs well. There are imbalances adjacent to the train station. Therefore, both densification and improvement of the street network connectivity must be enhanced.

This is seen in the context of most of the area here is classified as suburban. This sets the framework for improvement strategies with a view to achieving effective measures for improving the degree of urbanity of the unbalanced areas close to the railway station. Densification in correlation with TJD can be an improvement strategy that lifts Eidsvoll out of TAD and into TOD in a node-place-design value model.

**Råde**

Råde is defined as an 'Unbalanced settlement' because the site quality appears much better than the design qualities. Through the Form Syntax analysis, the morphological improvements suggestions of Råde are made to reveal future improvement of the node qualities and urban development in general. Among other things, a Form Syntax analysis shows the potential for densification along the settlement's integrated main street.

The Space Syntax analyses (Figure 10, top) shows that the highest integrated areas of Råde is on its main street. This is the street that generates the most natural movement to and through it. The intersection east of the street is also well connected and integrated into the street network as well as the main street. The railway station itself is located slightly south of the centre, on the outskirts of the village. The railway station has a medium good connection in this direction, but the station itself is poorly integrated into the local street and road structure. The space syntax analysis also shows that the degrees of street network integration is rapidly reducing from the main street. This indicates that there is little natural movement between places other than to, from and through the main street. The overall impression is that Råde has a highly integrated main street, but otherwise low spatial integrating of its remaining streets. This may explain some of the low design index. The railway station is poorly integrated with Råde centre and the accessibility to the station is low.

From the Spacematrix analysis, 91.5% of the building form are low-rise buildings, such as detached houses. Only 3% are low stripe building, and 5.6% is low rise urban block building. It is worth noting that just about all buildings that are connected to the main street are low-rise buildings. Other types of buildings are public buildings, such as a school at the railway station, or larger factory / commercial building northwest of Råde. The railway station itself is surrounded by several undeveloped areas, which in turn confirms that it is located at the edge of the settlement far from the dwelling areas. In terms of building morphologies or typologies and place index, Eidsvoll and Råde have similar values. The difference is that Råde has no tendencies to consolidate urban form towards an urban centre, whereas Eidsvoll has.

From the Mixed-Use Index analysis, 44.6% of the land use in Råde are monofunctional residential areas. 24.3% of the land use is for work purposes and 1% for 'amenities'. In total, mono-functionality accounts for approximately 70% of the land use. The main part of bi-functionality is the combination of work and housing (16.6%) and the combination of work and amenities (7.8%). 'Amenities' and housing together account for only 0.3% of the land use. In total, multifunctional land use of Råde is 5.4%. The distribution between mono-, bi- and multifunctionality is comparable to Eidsvoll, but Råde scores slightly better than Eidsvoll. The highest land use diversity is along Råde's main street and at the large intersection. Råde has a fairly diverse centre with a multifunctional land use. The settlement's centre is located in the middle between two larger zones for residential purposes. This means that the availability of services appears to be quite good in Råde.

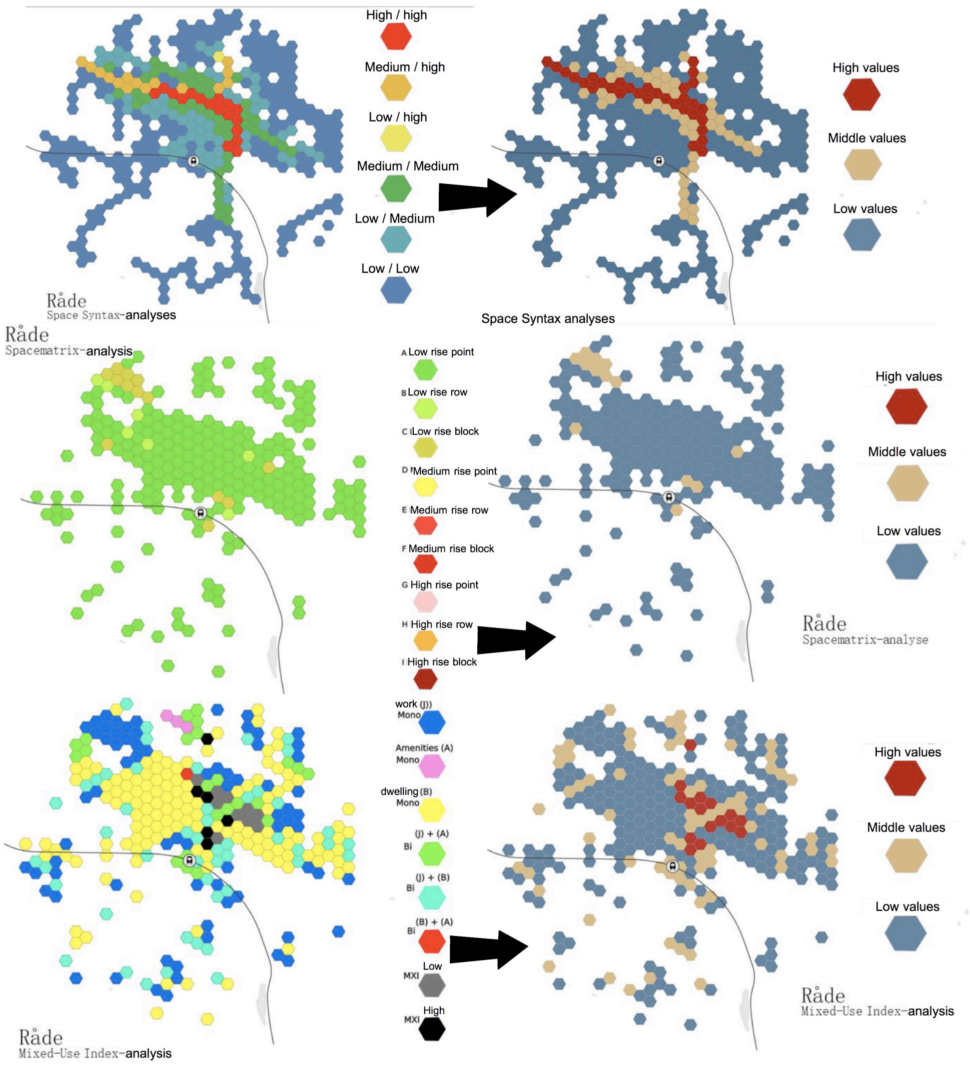


Figure 10: Various spatial analyses of Råde.

Regarding the Form syntax analysis (figure 11) Råde has no 'Highly urban areas' and only a 'Medium urban area.' On the other hand, there are several 'inn-between areas' of high and medium degrees. These are consolidated around the X-junction in the main street. Otherwise, the main street and the detour down towards the railway station are surrounded by 'suburban areas'. There is a positive tendency that there is a semi-urban connection between the main street and the train station. On the other side of the railway station, the areas are suburban or has no buildings at all. The accessibility along all the morphological elements is lacking. It will require commitment along all these dimensions to make this area accessible.

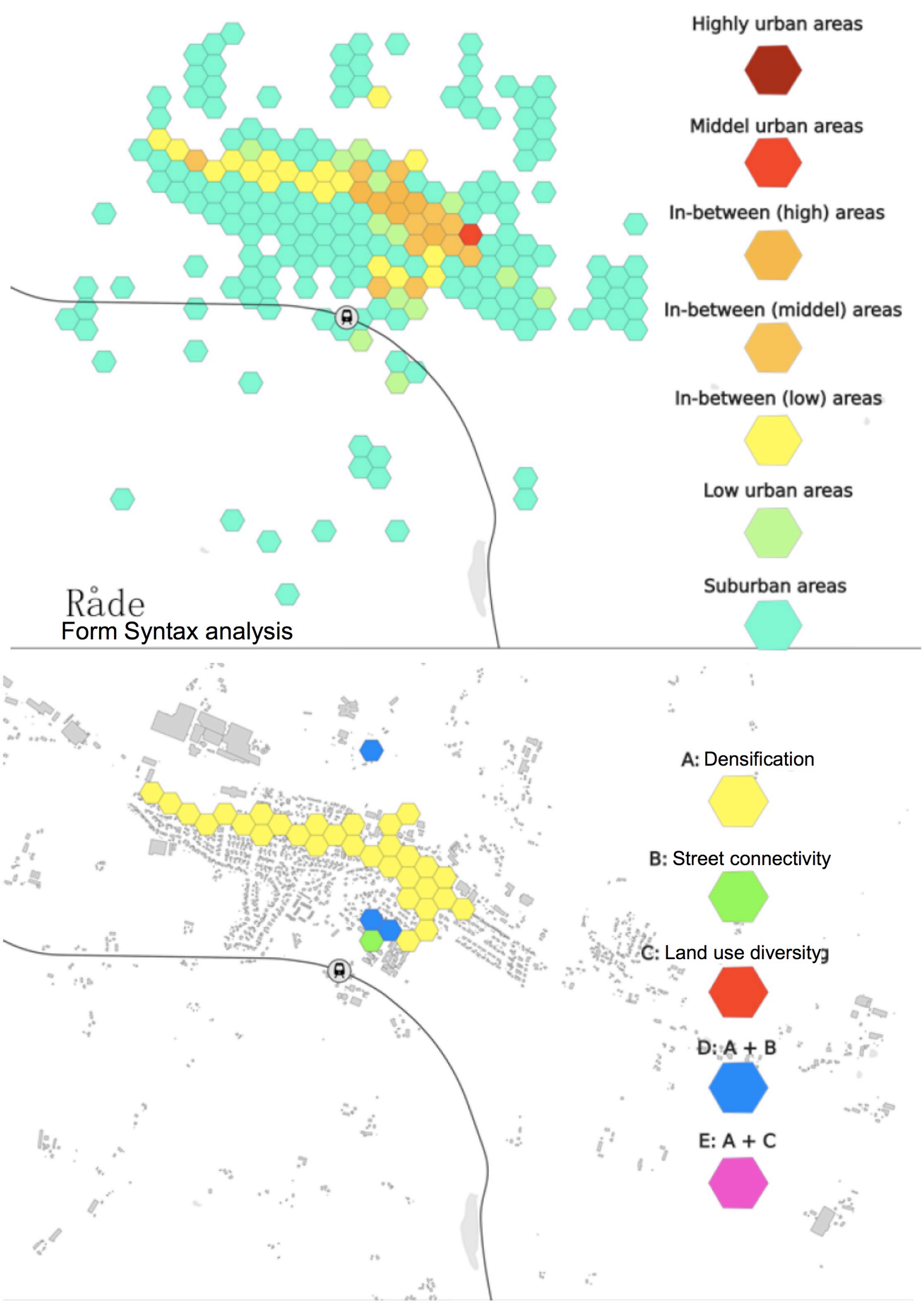


Figure 11: Form Syntax analyses of Råde.

The potential for urbanisation in Råde is present. Almost the entire main street turns out to be out of balance with regard to building form and density. Urbanisation and densification along the entire main street could boost development in Råde in a TOD perspective. An improvement strategy that includes densification along the main street and increased connection to the railway can be implemented as TJD, as it will be of interest to both the business community and the public transport provider. It requires to increase the connectivity of the main street towards the rest of the settlement. The potential for densification is also along the street between the centre and the train station. Improving accessibility around the railway station to the new densification areas and town centre contribute to reduce travel distances.

**Porsgrunn**

The town Porsgrunn is defined as an 'Undersupplied TOD' through the Node-Place-Design model analyses. This is the railway station area in the model where the difference between the node quality and the site qualities is greatest. The node index is the second lowest in the entire system, only higher than Torp station. In terms of place and design, Porsgrunn is comparable to Fredrikstad, Sarpsborg and Ski. Through the Form Syntax analysis, the site qualities in Porsgrunn are highlighted and show the areas that should be prioritized through improvement strategies in combination with increased capacity in the public transport supply.

From the space syntax analysis (figure 12), a well-integrated town centre appears in the integration analyses of the street network for Porsgrunn. The railway station itself is located on the edge of the area where the quality changes from medium to low. The railway station is located close to the integrated town centre. Areas of medium value are located with some distance from the centre in a southerly direction. This is in connection to a detached house area that has a network shaped street structure. It is also a small area by the station that is highly integrated through the walkway connection under the railway tracks connecting the east and west sides. Even if the station is not fully integrated in the centre, it is located close by. Compared to Eidsvoll and Råde, Porsgrunn scores higher on the various spatial analyses because the railway station and town centre are well integrated on the street network.

From the spacematrix analysis, Porsgrunn has a dense town centre between the railway station and down along the Porsgrunn river. Here there are several areas with medium-high stripes and urban blocks building types. This is, however, still only 1.8% of the building form. Porsgrunn has a gradual transition from urban forms to low-rise buildings. At the fringe of the town centre there are only low-rise buildings. Detached houses and other low-rise buildings accounts for as much as 79.6% of the buildings. The building density is low on the east side of the railway tracks.

According to the MXI analyses, Porsgrunn has a belt along the south side of the river with several bifunctional and multifunctional urban areas. At the same time the monofunctional land use for dwellings are 59.8%. North of the train station the rail tracks makes a clear boarder between monofunctional residential areas and multifunctional central urban areas. In total, 63.2% of Porsgrunn's land use is monofunctional, 24% is bifunctional and 12.7% is multifunctional. There are also some scattered bifunctionality areas consisting of work places and dwelling areas outside the town centre.

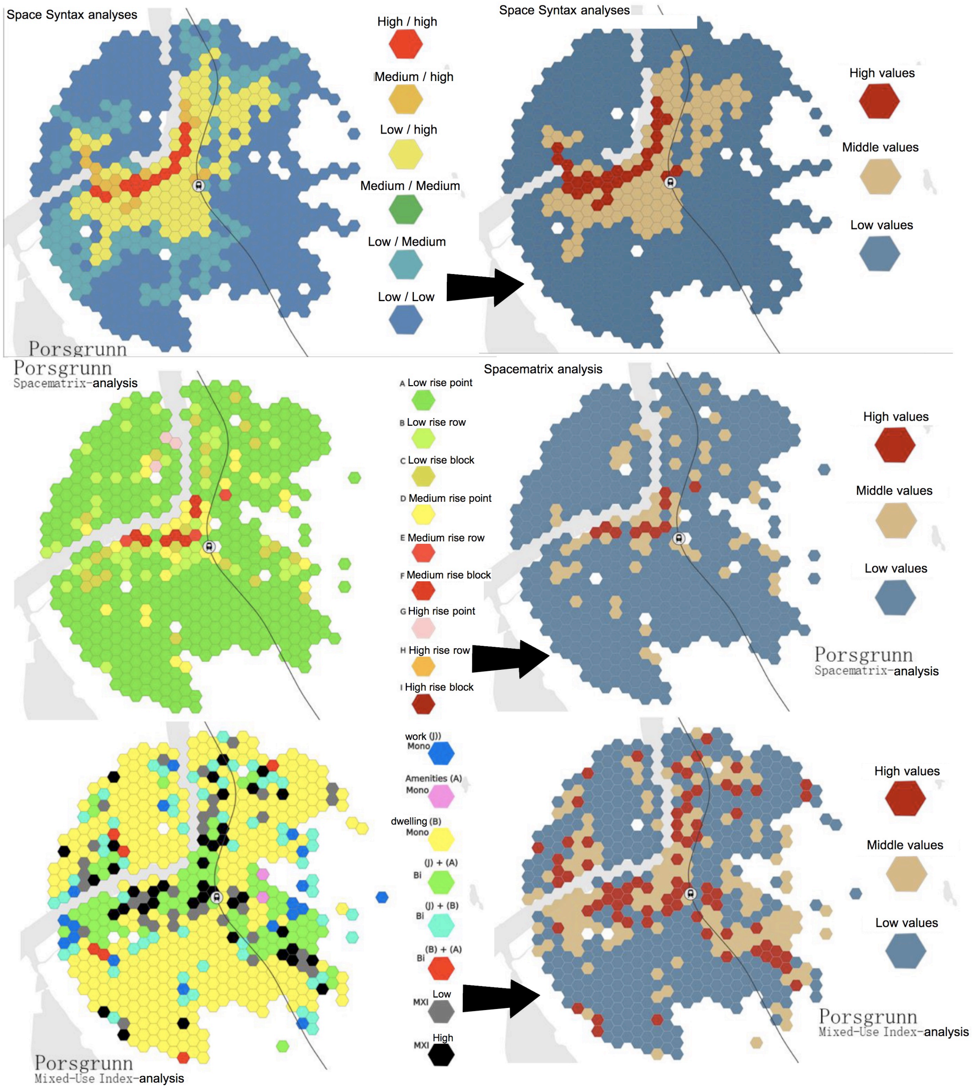


Figure 12: Various spatial analyses of Porsgrunn.

Figure 13 shows the Form Syntax analyses of Porsgrunn. Along the southeast side of the river, Porsgrunn has a centre with a large proportion of high or medium-high urban areas. The train station is located close to the centre in an ‘inn-between (high) area’. This indicates good accessibility between station and town centre, which can contribute to that more people will choose the train for transport. The transition between high urbanity and suburban is abrupt. From the analysis for improvement strategies, we see that unbalanced areas are located on this transition boarder.

The street network in the residential areas south of the town centre has high integration, offering great potentials for densification. A densification of the buildings can extend the town centre. Likewise, the densification potential is also present around the railway station. Improvement strategies for Porsgrunn should therefore focus on a densification of urban areas located close to the town centre, and involve public transport providers in urban development around the train station according to the TJD concept. This could improve Porsgrunn's already relatively high site qualities to also to a greater extent apply to the immediate area of the train station. Porsgrunn's greatest need is still increased supply on the transport side, but strategies to improve the site qualities around the station will be able to help facilitate this, among other things by increasing a sufficient high number of public transport users.

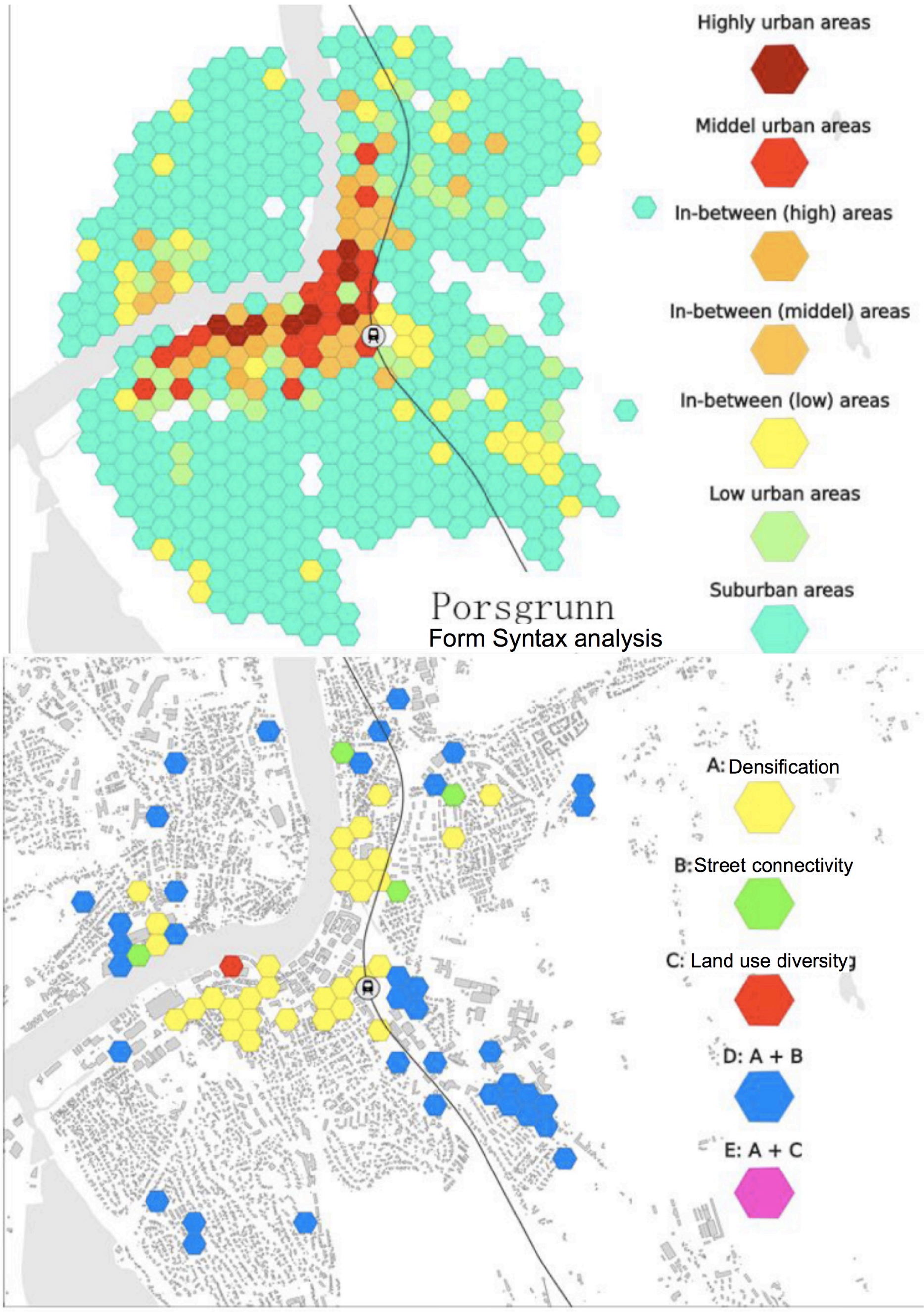


Figure 13: Form Syntax analyses of Porsgrunn.

In the business area southeast of the railway station, an imbalance has also been revealed with regard to weak street connections and urban form. Regards the results from the MXI analysis, this is a multifunctional area. However, poor street network integration contributes to a low number of people using the streets.

The overall impression is that Porsgrunn has very good place and design qualities in the downtown area along the river, but these values drop at the edge of this area. The railway station is located on the edge of the town centre area, and benefits from this. Simultaneous, the potential for densification is present at the station's back side and improvement strategies should address this.

## 4 DISCUSSIONS AND CONCLUSIONS

With the Node-Place-Design model, a context is provided through the node's typology for the selection of the three cases used in this research. With Form Syntax used in this context, site-specific knowledge is obtained about conditions within the node that can be seen in light of the typologies. Site-specific knowledge comes in the form of the cell's location and associated degree of urbanity. This shapes a basis for further investigations into properties and urban blocks that overlap with the cells and the development of improvement strategies. Raising quality internally in the cells will also raise the qualities of the node as a whole, which in turn will be reflected in the Node-Place-Design model. This will shift the node and conditions in the model. In this way, it is possible to check the quality of the effect of internal measures against the condition of the entire system.

For example, we see from the case studies that Eidsvoll is defined as 'TAD'. This can be explained that the railway station (transport) is not integrated with the town centre (place). High integration of the street network, high density building types and high mix of functions is present in the town centre, while these spatial and morphological features lack in the areas adjacent to the railway station. If these qualities are improved, Eidsvoll will make a shift in the Node-Place-Design model towards a TOD typology.

In this research, the Node-Place-Design model has been further developed through integration with Form Syntax. It shows that the Node-Place-Design model and Form Syntax complement each other. Through testing of these two methods on a Norwegian context, it has been shown to be operational and precise. Brand new typologies adapted to the Norwegian context have been described, here represented by the InterCity Triangle.

This integrated evaluation method contributes to solve several challenges. Firstly, it is shown as an operational evaluation method for the condition of the implementation of integrated land use and transport planning on several scale levels. It provides a basis for an understanding of the relationship between transport, place and design in all 3 levels of transport networks that have not previously been achieved. Increased understanding provides a new basis for allocating funds and prioritizing between projects, and investing within projects.

Secondly, through testing of the model, new knowledge is added about the state of integrated land use and transport planning in Norway at system, node and local levels. Information from various analyses is suitable as a knowledge base for future improvement strategies and planning activities of the InterCity network and associated station areas. Locations of new railway stations, strategies for transport and mobility, improvement strategies for densification or urban design are all examples where the results from this research will be relevant for.

Thirdly, the integrated method is shown to be suitable as a practical tool for future planning work. The methodology conveyed throughout the research is conducted in a detailed and easy-to-understand way. Collection and processing of available data can be easily replicated. The method is relatively simple, has professional ballast, gives results suitable for presentation, and provide a good basis for improvement strategies. Transport, place qualities and design, as well as the balance between them, are all tangible factors that everyone can relate to. It gives the method appeal as a priority tool for preparing a decision basis for planners at the regional and local level.

There are still possibilities for changing indicators and the data base in the node-place-design value index. Which indicators to use, as well as where and how the data can be obtained are all dependent on the choices made by the researcher. For example, city bikes and e-bikes for rent are an increasingly common transport service that contributes to increasing mobility. Extracting existing data to a greater extent and avoiding manual counting will streamline and reduce the chance of sources of error.

A complete application of Space Syntax in the model will also be a natural step in further development to improve the basis of the design index. Extra awareness of including the path networks inside and through a railway station building in the Space Syntax analyses can contribute to further knowledge of the role of a railway station and its vicinity.

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