Marianne Gro Lindau

Master's thesis

Identifying Densification Potential in Urban Areas

NTNU
Norwegian University of Science and Technology
Faculty of Architecture and Fine Art
Department of Urban Design and Planning

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Identifying densification potential in urban areas.

Development of a GIS-based methodology.

Master's thesis in Physical Planning

Trondheim, June 2015

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Marianne Gro Lindau

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Contemporary urban planning has a challenging task of ensuring densification that contributes to the preservation or establishment of high quality neighbourhoods. This task is not made easier by the fact that there exists considerable confusing as to what density implies, how we best can measure it and what higher densities will look like. This master thesis has attempted to address this problem through a GIS (geographical information systems) framework. The focus of the thesis has been to experiment with possibilities within GIS and attempt to find a way to identify development potential within existing city limits. The result is a proposal for a GIS-based analysis methodology that can identify densification potential in urban areas.

The thesis presents the first iteration in the development of the analysis methodology. The research question is: "How can GIS tools be utilized to identify urban areas with densification potential?" A central issue is determining which variables should be included in the analysis and how well GIS tools are able to represent and analyse these variables.

The thesis was developed in three parts. Firstly, it included research into existing densification literature and into the current use of GIS within Norwegian densification planning, based on interviews with planners and GIS experts. Secondly, it included experimentation with different analyses tools in the GIS software (ArcGIS and CityEngine) related to the needs in urban planning. And thirdly, a proposal for a new densification analysis methodology was developed. This last part included among other things the proposal for and construction of a new spatial dataset containing homogenous urban zones.

STIKKORD:	VEILEDER:
GIS, fortetting, densification, urban planning, byplanlegging, by- og regionplanlegging, fysisk planlegging, geografiske informasjonssystemer, fortettingspotensiale, urban design, density, tare, homogenous zones	Prof. Yngve Karl Frøyen
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NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET
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ERKLÆRING

Jeg erklærer med dette at jeg har fulgt gjeldende instruks for utarbeidelse av masteroppgaven ved Fakultet for arkitektur og billedkunst, NTNU

Bergen, 07.06.15

Preface

This is a master thesis written in the field of Physical Planning at NTNU, Trondheim in the spring semester of 2015.

Many people have helped me write this thesis and I am truly grateful for all their advice, criticisms, encouragements and inspiring discussions. My supervisor at NTNU, Prof. Yngve Karl Frøyen has not only been a great discussion partner and advisor during the thesis development, but he has also been an inspiring teacher throughout my master studies in Physical Planning.

I was fortunate enough to participate in the Asplan Viak Programme for students, which meant that I was given an office space and several additional advisors in Asplan Viak Bergen. I would like to thank Fredrik Boge, Torhild Wiklund, Øyvind Sundfjord and Fredrik Barth for the weekly thesis discussion sessions and the countless questions answered with enthusiasm, and not even a hint of exasperation, during these five months of writing. The "enthusiasm and not exasperation" part can also be said for all the other people that have shared their knowledge freely in Asplan Viak. Thank you for that!

I would also like to thank all my informants in the municipalities of Trondheim, Oslo and Bergen, and in Asplan Viak Oslo, who took the time to let me interview them so that I could benefit from their insight and experience in densification planning and geographical analysis. The thesis would have been much less interesting without their input.

Finally, I would like to thank ESRI and Geodata for thinking of the ESRI Young Scholar Award, giving the award to me this year and sending me to San Diego based on a not quite finished thesis draft. That is truly a compliment and a confidence boost for me personally.

Bergen, June 8th 2015

Marianne Gro Lindau

The front-page photo is from a competition contribution (May 2015) created by Asplan Viak and MAD Architects for the development of three harbour lots in Bergen. The photo portrays the Møhlenpris design, where the idea for the middle square in part was inspired by the Betweenness analysis described in the thesis.

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Abbreviations

ABC-Method	Dutch Urban Planning Methodology
AR5	Arealressurskart – (Norw. landcover map dataset)
ArcGIS	The ESRI GIS software platform
ArchiCAD	BIM software
ArcMap	Main component of ArcGIS
ATP-modellen	Norwegian GIS tool, plug-in to ArcMap
BIBSYS	Norwegian library search engine
BRA	Bruksareal (Norwegian GFA)
BTA	Swedish GFA
BYA	Bebygd areal (Norwegian building footprint)
CGA	Computer Generated Architecture
daa	Decare
DSR	Design Science Research
ESRI	GIS Software Company
FAR	Floor Area Ratio
FKB	Felles kartdatabase (Norwegian map dataset)
FSI	Floor Space Index
GFA	Gross Floor Area
GIS	Geographic Information Systems
GSI	Ground Space Index
haa	Hectare
IS	Information Systems
IT	Information Technology
KPA	Kommuneplanens arealdel (Norwegian master plan)
L	Building height measured in number of floors
MAUP	Modifiable Area Unit Problem
MCA	Multiple Criteria Analysis
N	Network density
NTNU	Norges teknisk-naturvitenskaplige universitet
OSR	Spaciousness
QGIS	Opensource GIS software
SIB	Studentsamskibnaden i Bergen
SSB	Statistisk sentralbyrå (Statistics Norway)
TU Delft	Delft University of Technology
US	United States
2D	2-Dimensional
3D	3-Dimensional

Note:

All English translations are my own, unless otherwise stated.

Appendix A is a map of the case area containing place names referenced in the text.

Summary

Contemporary urban planning has a challenging task of ensuring densification that contributes to the preservation or establishment of high quality neighbourhoods. This task is not made easier by the fact that there exists considerable confusion as to what density implies, how we best can measure it and what higher densities will look like. This master thesis attempts to address this problem through a GIS (geographical information systems) framework. The focus of the thesis work was to experiment with possibilities within GIS and attempt to find a way to identify development potential within existing city limits. The result is a proposal for a GIS-based analysis methodology that can identify densification potential in urban areas.

The thesis presents the first iteration in the development of the analysis methodology. The research question is: "How can GIS tools be utilized to identify urban areas with densification potential?" A central issue is determining which variables should be included in a densification analysis and how well GIS tools are able to represent and analyse these variables.

The thesis was developed in three parts. Firstly, it included research into existing densification literature and into the current use of GIS within Norwegian densification planning, based on interviews with planners and GIS experts. Secondly, it included experimentation with different analyses tools in the GIS software (ArcGIS and CityEngine) related to the needs in urban planning. And thirdly, a proposal for a new densification analysis methodology was developed. This last part included among other things the proposal for and construction of a new spatial dataset containing homogenous urban zones.

The goal is to attempt to improve the use of GIS within the field of urban planning. Norwegian densification planning currently uses GIS mainly for visualization purposes and for theoretical calculations of densification potential. The calculations of densification potential are largely based on the discrepancy between actual population densities and political goals, rather than spatial factors. Ideas for how to improve the current methods were found by comparing Norwegian densification analysis to more advanced international counterparts.

The case area is located in Bergen, Norway, and includes the city centre and some surrounding districts.

Introduction

We are faced with a challenge. Our cities are already built and we are running out of space, but more people are just pouring in. Densification is the buzzword, but exactly what this entails remains unclear. We want to keep our history and our sunlight, but we need to be able to breathe as well. This master thesis offers a suggestion as to how we can approach this problem. The subject matter is densification planning and it will be approached within a GIS (geographical information systems) framework. More specifically, my research question is: "*How can GIS tools be utilized to identify urban areas with densification potential?"*

The decision to choose this research question stems from my interest in both GIS as its own field, and in the intersection between GIS and urban planning. I will examine whether it is possible to utilize more of the possibilities in the software than what already is the case. Densification planning is an interesting focus because it is a relatively new subfield within urban planning, where analysis and planning techniques may still need development.

Throughout my research, I have worked under the assumption that there is enough space within existing city limits for all new development for decades to come. The goal of the thesis has been to find a way to identify this space. The result is a proposal for a GIS-based methodology for the identification of densification potential in Norwegian urban areas. GIS is a very powerful toolbox for urban planning. Most of the issues we have to consider have a spatial component, and GIS is able to structure and simplify the vast complexity of information that is the city. Norwegian urban planning can benefit from looking abroad, where planners have developed quite advanced techniques using GIS. These have been a great inspiration for the methodology presented here.

Figure 1 – Built environment in Bergen

Background

The 20th century saw a massive expansion of cities, and a resulting drop in both building and population density. Various factors explain this development, but in particular the introduction of the car as a mode of transportation available to the general population, and the popularity of the garden city and the modernist approach to architecture and urban planning were influential. In Norway, economic growth and the expansion of the welfare state allowed many to build single-family homes with private gardens on the outskirts of the cities. The dream of owning a garden villa still seems to drive the continuing sprawl of Norwegian cities, though the villa largely has been replaced by row housing ("rekkehus") in new developments.

Figure 2 – Typical Norwegian residential area. Bergen. © Digitale Medier 1881

At the same time Norwegian cities are growing in population and are expected to continue to grow substantially over the next few decades (SSB, 2014a). According to an SSB (Statistics Norway) prognosis, the biggest population growth will occur in and around the larger cities. For example Bergen, with a current population of about 275 000, is estimated to increase its population with 20,5% by 2040, to about 332 000 inhabitants (SSB, 2014a). Similar population growths are expected in Oslo, Trondheim and Stavanger as well (see table 1 below).

Table 1 – Middle prognosis of population growth by 2040 (SSB, 2014a). Current population as of 01.01.2015.

City	Population 2015	Population 2040	Increase	% Increase
Oslo	647 676	828 820	181 144	28,0
Bergen	275 112	331 571	56 459	20,5
Trondheim	184 960	220 195	35 235	19,1
Stavanger	132 102	145 619	13 517	10,2

Political goals and the need for densification

The government document "National Expectations for Regional and Municipal Planning" contains guidelines for all plans subject to the Norwegian Planning and Building Act. It specifically mentions densification as an "expectation" in this way:

> "Urban municipalities will emphasize densification and transformation in the urban centres and in connection to public transportation hubs, and they will contribute to the prevention of urban sprawl. Densification and transformation will be achieved with quality, and without reducing the quality of the surrounding area or lead to increased pollution"[1] (Miljøverndepartementet, 2011:18).

The document places densification in the context of shortages of agricultural land. Today only 3 % of the country is agricultural land, and much of this is located in urban areas. Every year agricultural land is claimed for urban expansion. Quite often this is some of the most fertile land for food production in the country (Miljøverndepartementet, 2011). Furthermore, densification is seen as a way to reduce the distances to services and functions, and through this reduce overall transportation needs, particularly for motorized transportation. The promotion of public health ("folkehelse") is another "expectation", which is related to urban structure. A densification goal should in this context be to reduce distances between the home and daily activities to such an extent that walking or cycling become practical alternatives to car travel. A related practical consideration is the ability of senior citizens to function in society even when they cannot drive anymore.

[1]By- og tettstedskommuner vektlegger fortetting og transformasjon i sentrum og rundt kollektivknutepunkter og bidrar til å forhindre byspredning. Fortetting og omforming skjer med kvalitet og uten at det forringer omgivelsene eller fører til økt forurensning.

Figure 3 – Nesttun in Bergen. This is an important public transportation hub.
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The national expectations also requires the counties and municipalities to take climate change seriously, and to reduce energy consumption and pollution through planning (Miljøverndepartementet, 2011). Aud Tennøy (2011) argues that densification may reduce motorized transportation needs and increase the use of environmentally friendly modes of transportation. However, this is not always the case. Research has demonstrated that the positive effect of densification on car-based transport depends on the location in question and its distance to the city centre and to public transportation hubs (Tennøy, 2011). Densification on the city fringes can actually increase transportation needs, because such areas tend to be very car-dependent (Tennøy, 2011).

The correct placement of businesses in relation to the city centre and other areas with a well-developed public transportation system is another important means to reduce car-based travel in a city (Strømmen, 2001). This is because different types of businesses generate different types and amount of transport, depending on the number of employees, number of visitors and amount of freight transport. Locating businesses with many employees and a high number of visitors close to public transportation hubs will have a positive impact in the overall amount of car travel in a city (Strømmen, 2001). It is therefore necessary to have a proper understanding of densification as a complex phenomenon, and it is important to keep the difference between residential densification and densification of businesses and services in mind.

In general, public transportation and other services, both public and private, will benefit from an increase in density, because this will strengthen their population basis. Densification in urban areas will increase the use of public transportation (Norheim and Ruud, 2007). Causes for this are, firstly, that denser cities have fewer parking spaces, and secondly that distances to daily activities are reduced. The public transportation system will in particular benefit if new structures are located close to existing routes and hubs (Norheim and Ruud, 2007).

The above strengthens the argument that it is necessary to densify Norwegian cities. Nevertheless, there are negative aspects of increased urban densities, which may prompt scepticism. New development can reduce neighbours' access to sun light, view and green space. If executed without regulations and careful consideration of potential consequences, densification can reduce the quality of life for residents. If done correctly, however, densification can increase quality of life, either by laying the foundation for better services, or through compensations, like the development of new parks and other public goods. I will not delve too deep into the discussion of whether we should densify, but rather focus on the issue of how to ensure a qualitatively good densification.

Figure 4 – Example of negative densification that does not consider context. New Jersey. (Campoli and MacLean, 2007)

Densification today

The densification of Norwegian cities today is the result of different developments. One is the political goal to densify based on environmental and sustainability considerations, another is the ideal of urbanity promoted by architects and city planners, and a third is changing market conditions (Guttu and Schmidt, 2008). The market has seen a shift in life style and desire for centrally located housing, and developers see opportunities for profits in the increased building intensity allowed on their properties (Guttu and Schmidt, 2008).

The master plan of the municipality of Bergen (2010) states that residential development has been the biggest contributor to the city's expansion for the last 30 years (Bergen kommune, 2010). Even though housing construction in the central city area has increased significantly, the outer districts of the city still experience the biggest population growth (Bergen kommune, 2010). The master plan sets the goal that 60% of new residential developments will occur through densification. At the same time, the plan offers few specific indications for how or where this densification will take place. It only provides detailed information of new development areas in the periphery.

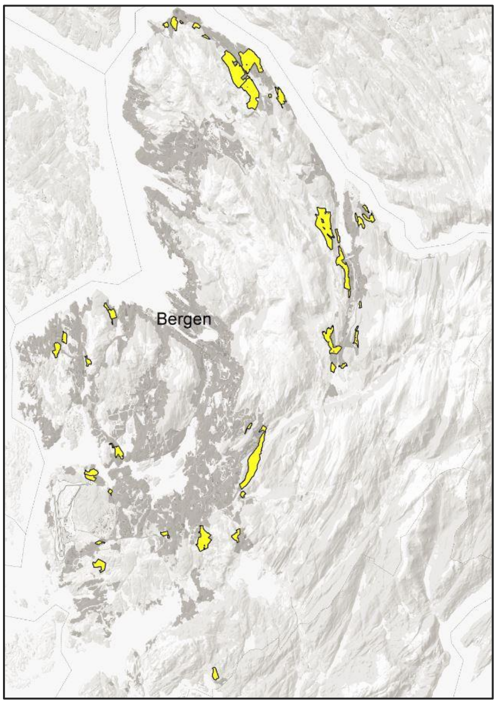


Figure 5 – New land for residential development in Bergen approved in the current master plan.

At first glance, densification may seem difficult to achieve, in particular as city municipalities continue the course of urban sprawl by assigning large areas to residential development on the city fringes. However, another picture emerges when we look to Trondheim, where about 80% of new residential development has occurred within existing city limits during the 2000s (Trondheim kommune, 2012:6). This corresponds with the densification goals in the municipal master plan. Svein Åge Relling[2] at the Municipality of Trondheim expresses concerns that these numbers seemingly are not coming across to politicians, as they have just allowed a massive expansion of residential land on the city's edge. These new areas constitutes far more than what is necessary for expected development in the coming years. At the same time, density levels within the existing urban area are still quite low, meaning that there should be plenty of possibilities for further developments here. This abundance of available land for development indicates that the municipality is granting the control of the city's growth and development to private developers.

Room for improvement?

This continuing land consumption and the resulting scarcity of available land makes research into the capacity and different qualities of space necessary (Berghauser Pont and Haupt, 2010). The change in the planning process from one driven by public master plans, to an increasingly project-based planning driven by private initiative, is thus relevant to densification planning. It consitutes a shift from *government* to *governance*, where planning takes place through negotiations between public and private actors (Berghauser Pont and Haupt, 2010). A method for densification planning will have to consider these conditions.

Trondheim's master plan gives minimum requirements for density in terms of the number of dwellings per decare. This is arguably a limited form of regulation, as it can be interpreted in a number of ways, and as a consequence leaves the job of ensuring good quality to the developer and the individual municipal caseworker.

As mentioned, the topic of densification remains somewhat contested. The scepticism may at least in part be explained historically with reference to the poor living conditions that resulted from the massive crowding of the cities during the Industrial Revolution in the 19th century. Few regulations at the time resulted in overcrowding in dark and poorly sanitized conditions, where disease was frequent and people in general suffered under low standards of living. In the last decades of the 19th century, building regulations intended to address these poor living conditions began to emerge with a focus on limiting density (Berghauser Pont and Haupt, 2010). Reinhard Baumeister and Joseph Stübben in Germany, for example, introduced regulations on the maximum number of floors, and stipulated that the heights of buildings should not exceed the width of the street (Berghauser Pont and Haupt, 2010). They were the

[2] Interviewed in Trondheim on December 2, 2014.

first to systematically address density in their analyses of urban problems (Berghauser Pont and Haupt, 2010). Today the situation has turned upside-down, as planning authorities pose *minimum* levels of density on new development.

A limited definition of density used to regulate new development seems like a haphazard way of planning, in particular because what is meant by *density* is often misunderstood. The definitions commonly used, e.g. population density or dwelling density, do not properly correspond to a certain physical form. A high-rise development can have the same population and dwelling density as a historical inner city, but their urban qualities vary substantially. It is a challenge to conduct a conversation about density and be certain that the participants argue from the same mental image of what is actually being discussed. This indicates that there is a need for methods that can both help analyse and visualize density in contemporary urban planning.

Ås tettsted, videreføring av dagens tetthet med enebolig i felt krever 3200 daa og dobbelt så høyt årlig CO2-utslipp

Figure 6 –Land required for new development using existing density. © Asplan Viak

Konsentrert utbygging på 400 daa med rekkehus/leilighet. Samme antall boenheter

Figure 7 – Land required for new development with increased density. © Asplan Viak

Research question

My thesis will attempt to answer the following research question:

How can GIS tools be utilized to identify urban areas with densification potential?[3]

Here, I defined *GIS tools* as any GIS software, including the analysis techniques within them that exist on today's market. However, I focused on software that I am already familiar with, namely ESRI's ArcGIS platform. I have used this software package both during my GIS studies and during my master studies in urban planning. The thesis work also included work with CityEngine. This is a 3D modelling tool specifically developed for urban planning. It makes it possible to model entire cities in 3D and perform various analyses. GIS tools are already used both in planning in general and in densification planning as well, but I am interested to find out whether the full potential of the software and methodology is being utilized.

Density as a concept in urban planning is defined in many different ways. At a basic level, density refers to the physical form of the city, which in turn affects many factors that are relevant in urban planning. Often definitions of density emphasize these related factors, so that density is measured in terms of population or dwelling density, not in "physical" values like building heights. How to most accurately define density will be a central part of the thesis development.

Densification potential is defined as the ability to fit new buildings in areas that are already developed. This may include agricultural fields surrounded by existing urban structure. By definition, densification takes place within existing city limits, meaning that the city grows inwards, not outwards. As such, development that expands the city limits is not densification. Densification may also include the demolition of existing buildings in order to construct buildings with a better utilization of space. Different forms of densification is more thoroughly discussed in the theory chapter.

Urban areas is in this thesis defined as areas within Norwegian cities, i.e. areas within the built or functional city limits, not necessarily the municipal boundaries.

To clarify, the thesis focus is on methodology, but within a densification planning framework. It has therefore been necessary to examine densification planning in general and to evaluate

[3] Hvordan kan GIS-verktøy utnyttes til å identifisere områder i by med fortettingspotensiale?

how densification planning best can be conducted. Furthermore, I have focused on GIS as a methodology, even though there may be other useful methodologies available. Within the broad field of GIS I have focused on ESRI software.

Research sub-questions

I have formulated four sub-questions to make the thesis goal more concrete. They are listed below.

1. How are GIS tools utilized in densification planning today?
2. Which spatial variables/ criteria must be met in order to achieve good densification?
    a. Which variables/ criteria decide where we <u>can</u> densify?
    b. Which variables/ criteria decide where we <u>should</u> densify?
    c. Which variables/ criteria decide <u>how</u> to densify?
3. How well suited are GIS tools to portray and analyse these variables?
4. Can GIS tools be utilized better in densification planning than what they are today? In which case, how?

The first sub-question entails finding out as much as possible about contemporary densification planning, both in Norway and internationally. Norwegian planning may be able to benefit from the experience of countries with a more extensive urban tradition that consequently have more experience with densification planning, like for example the Netherlands.

The second sub-question relates to the variables used in the analysis, which can be divided into three group. Where we *can* densify and where we *should* densify are two different questions. The first answers where densification is at all possible, based on technical or quantitative issues. The second is more concerned with issues stemming from political goals, e.g. sustainability and the protection of agricultural land. Here issues like distance to public transportation hubs or services' need of a larger population basis are considered. The third question, *how* to densify, requires yet another set of variables. These variables are used in the actual design of a densification proposal.

The last two research sub-questions are concerned with the evaluation of the software's suitability and potential within densification planning. The goal of the thesis is to find a way to identify densification potential, through the development of a GIS-based methodology, suited for Norwegian urban areas. This method will not comprise aspects of densification, which do not relate to GIS. It will be necessary to combine it with other tools, such as negotiations and techniques that can help create a constructive public debate, issues that are beyond the scope of my thesis.

The case area - Bergen

I initially set out to use the entire Municipality of Bergen as a case, but I quickly realized that the available map data did not allow for such a comprehensive approach. Since I had to produce some of the necessary datasets myself, I had to reduce the case area to the city centre and some of the surrounding area. The total size is about 35 km^2, or 1/16th of the municipality. It includes the entire area that is being considered for “centre”- expansion in the master plan currently under development. The boundary of the case area was drawn along “breaks” in the urban structure, in order to minimize the number of homogenous areas cut in half. I included some sections of the City Mountains, with the boundary drawn roughly at the mountaintops.

I chose Bergen as my case mainly for convenience. I have been writing in Bergen, so it was convenient to be able to visit areas I was evaluating on the map. I was also able to take advantage of the local knowledge of my advisors in Asplan Viak Bergen. Added to this, a methodology developed for Bergen, is likely to be suitable for other larger Norwegian cities, with only minor adjustments. Should the method be applied to smaller cities, it may have to be re-evaluated and possibly modified somewhat more.

Figure 8 – Area of study (red line)

Theory

There is quite an extensive literature on the subject of density and densification in urban planning. I have only been able to scratch the surface, since the thesis' focus is on methodology. The goal with the literature study has therefore been to get an overview of the current discussions and status of the field to use in the practical work of the thesis. Thankfully, I was able to find papers that already attempt to sum up the various studies on the subject, relieving me of this task (Churchman, 1999, Boyko and Cooper, 2011). It should be noted that their research is limited to studies written in English, and therefore are skewed towards Anglo-Saxon urban planning.

The central issue under discussion in most of the field is how to define and measure density, and related to this, how to communicate an idea of what density means. It is an important discussion, because density in urban planning is a very complex phenomenon, which is difficult to distil into common mental images. The word "densification" can mean wildly different things for different people. The challenge is to communicate that an "increase in density" does not necessarily translate to high-rise building structures, and that it does not necessarily equal a reduction in quality of life. Density as a term has nothing to do with quality. It is a number, a number that is assigned too much power compared to qualitative descriptions of the built environment. This is an important consideration related to the use of GIS in densification planning, as it increases the importance of visualization.

Higher densities, good or bad? – a matter of subjective opinion

Another central discussion is which degree of density is preferable. Opinions differ greatly in this regard, also among noted urban planning thinkers. Raymond Unwin, on the one hand, argued that 12 dwellings per acre (3 dwellings per decare) should be the maximum to avoid overcrowding (Berghauser Pont and Haupt, 2010). Jane Jacobs, on the other hand, argued that the minimum density needed was 100 dwellings per acre (17.5 dwellings per decare) to achieve a well-functioning city with social and economic vitality (Berghauser Pont and Haupt, 2010). The huge gap between these two indicate that optimal density levels are a matter of personal preference, not scientific fact. It is something that should be decided politically. It is therefore beyond the scope of this thesis to explore this debate too deeply.

What is considered high density depends on context.

> “Every aspect of high density has both advantages and disadvantages, but whether an advantage or disadvantage applies in a given situation depends on context in its most inclusive sense. Furthermore, all of these advantages and disadvantages are on some level theoretical – they represent possibilities or potentials, not certainties or inevitabilities”(Churchman, 1999:399).

Evaluating whether a project maximizes the advantages and minimizes the disadvantages of higher density is not straightforward because:

> “1. there is no clear cut agreement among professionals and researchers as to what is an advantage and what is a disadvantage of high density; 2. for residents and users of an environment, one person’s advantage may be another person’s disadvantage; 3. at least some of the factors are not under the control of planners or politicians, including subjective interpretations by residents and user; and 4. subjective intervening variables that relate to the concepts of perceived density and crowding”(Churchman, 1999:402).

Berghauser Pont and Haupt argue that “Attempts to describe the ‘best densities’ or the ‘good city’ have a long history, but all tend towards highly prescriptive recommendations based on the subjective leanings of individual authors in specific contexts”(Berghauser Pont and Haupt, 2010:201). Arza Churchman has another valid point, which argues that “no one solution will meet the needs of every situation, context, person, or group. Therefore, a variety of solutions (different types of settlements, neighborhoods, housing, and transportation) are essential to meet the needs between and within countries, regions, and towns”(Churchman, 1999:408). A too homogenous urban structure is therefore a problem. It may be a valid argument that the average Norwegian desires a single family home in the suburbs, but the percentage of these kinds of housing is already very high. A diversification of the housing structure by introducing denser, urban neighbourhoods should therefore be an enrichment to the cities.

It seems endemic to the debate on density that the term is given too much significance, either in the positive or in the negative direction relating to the urban landscape. In large parts of the 20th century, density was tainted by the bad experience of over-crowding in the newly industrialized cities at the end of the 19th century. The debate was dominated by the goal of limiting density to ensure quality of life. As a result, the density grew so low that it became a problem for the urban system and for human life “in-between the buildings”. Many of the problems associated with high density may instead be caused by a function of variables, such as population size compared to available resources, building types, location within the city, socio-economic status, or noise, heat and pollution, rather than the actual density itself (Churchman, 1999).

In recent decades, the debate has shifted towards the positive aspects related to density. Densification has commenced in Norwegian cities, though it seems that the term now to some extent has been put on a pedestal. As long as developers invoke it in their projects, they are given a mark of quality, which they often do not deserve. The report “Fortett med vett”(Guttu and Schmidt, 2008) published by NIBR (Norwegian Institute for Urban and Regional Research) examined 27 new residential densification projects in Norwegian cities, and found only three they deemed to be “best-practise” cases. The main problems were that the projects did not “give back” to the city, but were simply free riders on already available public goods like parks, that they were too dense and that they did not sufficiently care for the outdoor open spaces, neither public nor private (Guttu and Schmidt, 2008). This suggests a problem with how density is interpreted and regulated.

Defining density

Boyko and Cooper (2011) examined 75 density studies and found numerous different ways to define density. My research has found that Norwegian planners usually use population density or dwelling density in their analyses of densification potential, although floor space density (“BRA/areal”) can sometimes be used as a supplement. Population and dwelling density can be converted interchangeably if one assumes an average number of persons per dwelling. These density types can be measured in different ways. One can measure the number of people in a given area, or one can measure the number of people that can be reached within a certain distance or travel time along the street network (for example within 1 km).

Other conventional ways to measure density are as land use intensity, coverage/ open space ratio, building height and spaciousness (Berghauser Pont and Haupt, 2010). These last ones are all related to physical form. It is also possible to combine the measures in one way or another. Boyko and Cooper (2011) research found that by far most planners used population and dwelling density. Yet some measured the density of shops, infrastructure, transit stops or even waste. Boyko (2014) argues that it is necessary to also consider such densities in order to create liveable cities. Researchers coming from the urban morphology and space syntax fields are promoting a new way to measure density based on location accessibility rather than on finite area density (Ståhle, 2008). The argument is that this measurement removes the Modifiable Area Unit Problem (MAUP), which is a problem when defining density for urban areas (Ståhle, 2008). The MAUP is a fundamental problem of geographical analysis, which refers to the fact that the definition of the area unit of analysis can manipulate the analysis results. Area units can for example be a voting district or a raster cell. Location accessibility calculates the amount of available floor space within a certain radius from each point location. The argument is that this measure gives a better idea of people's perception of density, rather than the administrator's perception of density per area unit (Ståhle, 2008). While this certainly is an interesting way to consider density, the need to set a radius still seems to retain the original problem.

Another example of the combination of different types of density is found in Toronto.

> "A basic premise of Toronto's redevelopment plan is that when the nature of the changed urban form is determined, residential uses cannot be treated separately from employment uses. Thus, a new measure of density was proposed: gross reurbanization density. Gross reurbanisation density is defined as the number of residents and employed persons per hectare, regardless of the relative predominance of members of each group"(Churchman, 1999:397).

This same measurement is used in Norway, but is here called "activity density" (Asplan Viak, 2014).

The problem with population and dwelling density

Berghauser Pont and Haupt (2010) argue that both population and dwelling density are imprecise measurements of the actual built environment in an area. They refer to, among other places, the Vondelparkbuurt and the Jordaan areas in Amsterdam when demonstrating this. These areas have a very similar built environments, with similar building typology and similar building heights. Over time, they have had significantly different population densities, however. This is because the dwellings in the Vondelparkbuurt originally where much larger than dwellings in the Jordaan. The Vondelparkbuurt was built for affluent families, whereas the Jordaan was for the working class. The Jordaan therefore had a larger number of much smaller dwellings that housed a very high number of people. The average number of floor space per person was significantly smaller in the Jordaan, than in the Vondelparkbuurt. Over time this changed, as the small dwellings in the Jordaan were combined into larger apartments, and buildings in the Vondelparkbuurt increasingly were used as office space instead of dwellings. Therefore, the population densities and dwelling densities changed, while the built environment remained the same. (Berghauser Pont and Haupt, 2010)

The average amount of floor space per person has increased significantly in Norway over the last hundred years. Changes in family constellations and larger homes are causes of this development. When considering the appropriate level of physical densification in an area, one should therefore be sceptical to rely on such insecure measurements as population density and dwelling density. Berghauser Pont and Haupt have developed an alternative multivariate definition of density based on physical structures (see below). Nevertheless, population density is an important number in relation to the calculation of capacity of infrastructure and amenities, so it should not be left out of development projects. Rather a combination of different measurements seems to be in order.

Spacematrix – A multivariate definition of density

Meta Berghauser Pont and Per Haupt created the Spacematrix/Spacemate method as an attempt to develop a useful definition of density with an "effective relation to urban form" (Berghauser Pont and Haupt, 2010:14). The result is the Spacematrix, a multivariate density concept, and they promote "the establishment of a science of density"(Berghauser Pont and Haupt, 2010:14).

They write this about what a definition of density should entail: "Such a definition should relate density to potential urban form (type of urban environment) and other performances" (Berghauser Pont and Haupt, 2010:16). Performances are exemplified as daylight access, parking, privacy and potential building types. Furthermore, a method for densification planning must be able to deal with the challenges in today's urban planning, that is, it must be practical for a project-driven urban development (Berghauser Pont and Haupt, 2010). It must also be able to address the increased urban spatial consumption (Berghauser Pont and Haupt, 2010).

They use the work of geographer M.R.G. Conzen, founder of the English school of morphology as a framework to understand the basic components of the built environment. His approach is called typomorphology. Conzen developed a "manual to analyze the physical urban plan on different levels of scale" (Berghauser Pont and Haupt, 2010:18). Berghauser Pont and Haupt combine Conzen's method with the deductive, quantitative research method of Leslie Martin and Lionel March at the Centre for land use and built form studies at Cambridge. Their method includes variables like available land, existing buildings and the streets serving them (Berghauser Pont and Haupt, 2010). Their method based urban fabric types on street network and building types:

Network types + building types → urban fabric types

The building types can be divided into:

a) Pavilion (point), Street (strip) and court (block) development
b) Low-rise, mid-rise and high-rise

The network types are divided into:

Tiny European blocks (x<5.000 m2), small blocks (x<10.000 m2), medium sized blocks (x<20.000 m2), and large blocks (x>20.000 m2).

Turning back to their definition of density, they emphasise that the definition of numerator and denominator in the density fraction (Ex. GFA/hectare) are important to consider carefully (Berghauser Pont and Haupt, 2010). The denominator refers to the total area included in the calculation, where the boundaries are set. For example, whether or not streets are included. This measure varies a great deal between countries when density is measured (Berghauser Pont and Haupt, 2010, Boyko and Cooper, 2011).

Through the evaluation of different definitions of density, Berghauser Pont and Haupt found that none of them individually could give a good indication of urban form. It is necessary to combine them. They propose a multivariate measure of density as the most appropriate way to accurately assess urban form. They have named their method "the Spacematrix". The Spacematrix includes three core indicators: Floor Space Index (FSI), Ground Space Index (GSI), and Network Density (N). These can be used to calculate other derived indicators, all of which are relevant to assess urban form.

The Floor Space Index (FSI) is a measure of land use intensity. It compares the total floor space to the lot (or plan) size. This is similar to the Norwegian "Utnyttingsgrad" or the American FAR index (Floor Area Ratio), which expresses building bulk in relation to lot size (Berghauser Pont and Haupt, 2010). A note for Norwegian users is that the FSI only includes indoor floor space, not the area occupied by parking or verandas.

$FSI_x = F_x / A_x$ (2) where

F_x = gross floor area (m^2)
A_x = area of aggregation x (m^2)
x = aggregation (lot (l), island (i), fabric (f), or district (d))

This index uses the unit square metres per square metres (m^2/m^2).

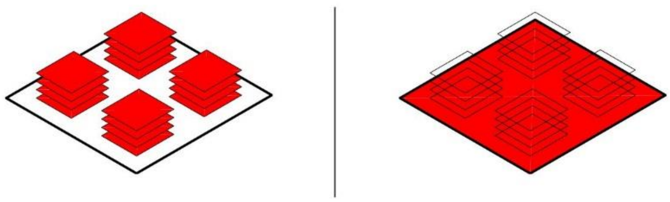


Figure 9 - Calculation of floor space index (Berghauser Pont and Haupt, 2010).

This index expresses form better than population density and dwelling density, but it still cannot distinguish sufficiently between different spatial layouts, for example areas with high-rise buildings compared to historical block structures.

Figure 4 – Bijlmermeer. Outside Amsterdam.

Figure 5 – The historical centre of Amsterdam.

The Ground Space Index (GSI) measures the coverage of an area. It is the relationship between built and non-built land. The index uses the building footprint to see how much open land remains in the area measured. This index would to a greater extent be able to separate Bijlmermeer with the centre of Amsterdam as seen in the photos above.

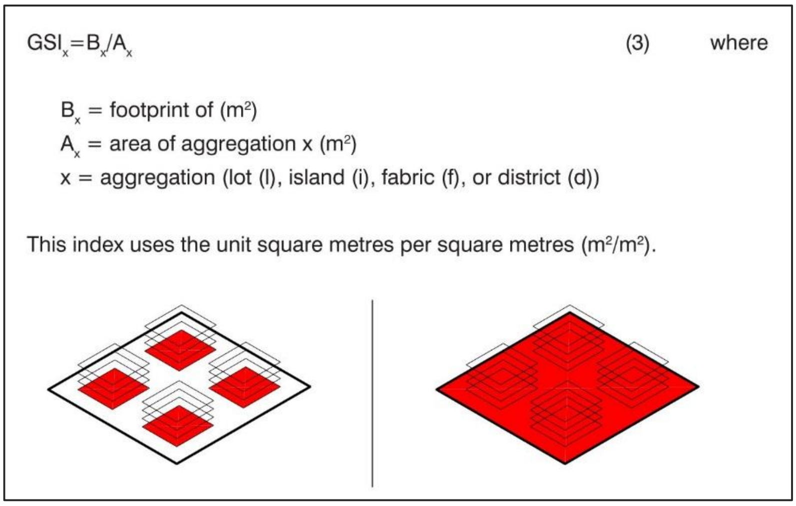


Figure 12 - Calculation of ground space index (Berghauser Pont and Haupt, 2010).

Finally, the Network density (N) assesses the amount of street network per area. It is calculated using the total length of the street centre lines divided by total area in square meters. This measure is needed because the two above indicators do not provide a reference to scale/ size. The size of the blocks are an important characteristic to urban form. The street network and the block shapes/ islands are very resistant to change once they are made (Berghauser Pont and Haupt, 2010). The width of the streets and the compactness of the blocks is very important to urban form.

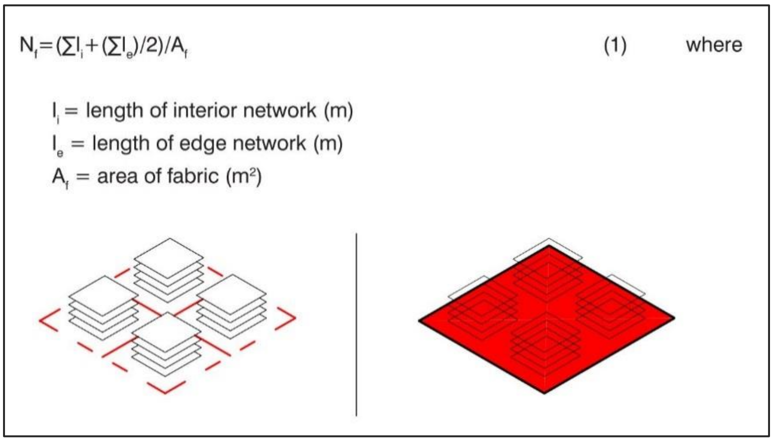


Figure 13 - Calculation of network density (Berghauser Pont and Haupt, 2010).

These three indicators are constructed with four variables: base land area (A), network length (l), gross floor area (F), and building footprint (B).

The base land area (A) is calculated by first dividing the urban area into subdivisions based on morphological characteristics. This division can either be done by hand, or by creating algorithms consisting of variables like changes in density gradient, boundary elements (barriers, cadastral borders, networks), and degree of homogeneity. There is no limit set on size of the areas, nor differences in relative size of the areas. Berghauser Pont and Haupt argue that this is acceptable, because the homogeneity of the area is what is important to the analysis. The placement of the boundaries of the areas are very important to the result.

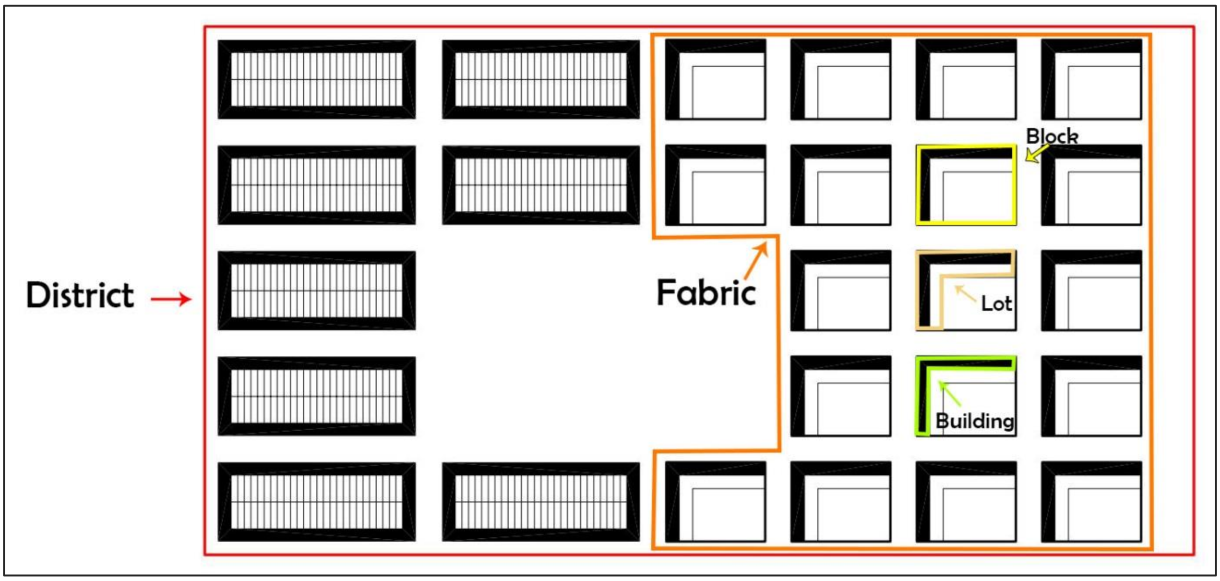


Figure 14 –Relationship between the different scale area units (Spacematrix).

The level of scale must be considered (Berghauser Pont and Haupt, 2010). Are we for example working on the level of the building footprint, the lot, the block or the urban fabric? The elements included or excluded in each of these scales are important to consider. Is for example non-built land included in the block, will the boundary be set at the street edge, or in the middle of the street? These decisions will affect the result. The authors set the boundary of the block at the street edge, the boundaries of the fabric are set in the middle of the access streets, and where there are no streets they are set at the lot boundaries. In addition to this, a further scale level is called "district". This is an aggregate of several fabrics, but it also includes parks and other non-built land, and are defined as the Dutch "neighbourhood" (buurt). The boundaries are circulation streets rather than access streets.

The network length (l) is as mentioned the length of the streets in the area. In the urban fabric scale, which is the focus of the authors analysis, the access streets are counted. In addition, an explicit choice of modalities must be made. Pedestrian streets, for example, can be included.

The only criteria is consistency across the analysis. The internal streets in the area are all included, whereas the length of the external streets, those that mark the boundaries of the area, are divided by 2.

The gross floor area (F) is floor space defined by the Dutch standard. This does not include outdoor area, such as area of a balcony. Underground area is included.

The building footprint (B) is measured as the ground area of the building. The Norwegian BYA (“bebygd areal”) is comparable.

After the three main indicators have been defined, we can derive other indicators that can also be of use in the assessment of urban form. The first is building height (L), which is defined as the number of floors. The second is spaciousness (OSR), which is defined as the amount of non-built land divided by the gross floor area (F). This gives an indication of the pressure on non-built land, i.e. the number of people who will share it. The third derived indicator is tare (T). This is the difference of the base land area between two levels of scale. It is the left over area that is not included at the lower level of scale, but is included in the higher level, for instance the area of the street in relation to the block level and the fabric level. The forth indicator is mesh and profile width (w and b). This formula calculated mesh: w= 2/Network density. It gives a measure of mesh size. When this is combined with the tare (T), the profile width (b) can be calculated.

$b=2*(1\text{-root}(1-T_f))/N_f$

or, combined with (7):

$b=2*(1\text{-root}(GSI_f/GSI_l))/N_f$

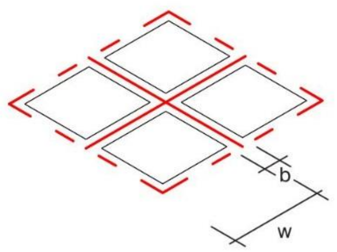


Figure 15 - Calculation of mesh and profile width (Berghauser Pont and Haupt, 2010).

The Spacematrix is a 3D-diagram with the three core density indicators; FSI, GSI and N. FSI is the z-axis, GSI is the x-axis and N is the y-axis. This diagram makes it possible to give a graphical representation of the "density fingerprint" of an urban area (Berghauser Pont and Haupt, 2010).

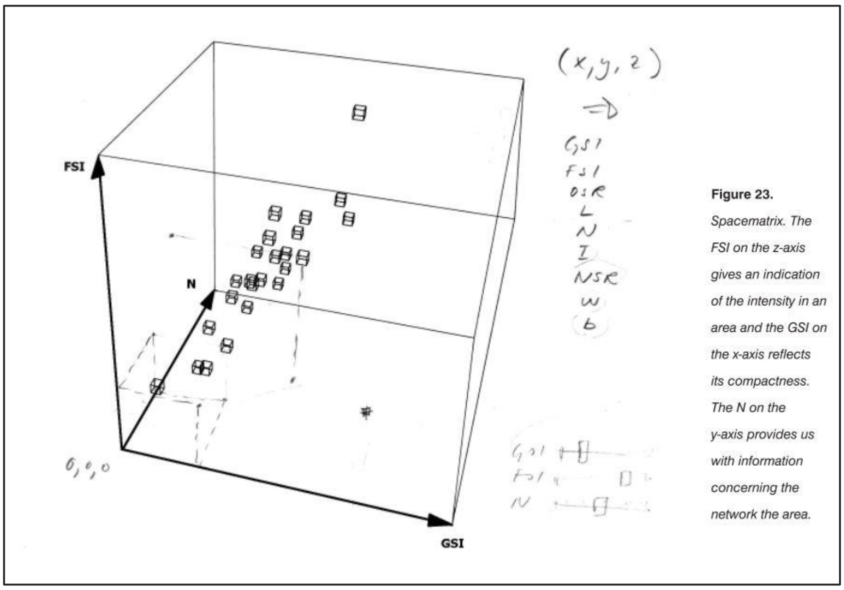


Figure 16 - The Spacematrix. (Berghauser Pont and Haupt, 2010).

The authors notes that such a graphical representation (3D) is difficult to use in practise. They have therefore developed other graphical representations of the indicators, the most used of which is the "Spacemate". This a 2D-diagram where FSI and GSI make up the x- and y-axis, and where L and OSR are gradients. The density fingerprints of the area being analysed are plotted on the diagram. In this way, the density fingerprints of different scales in the same area can be compared.

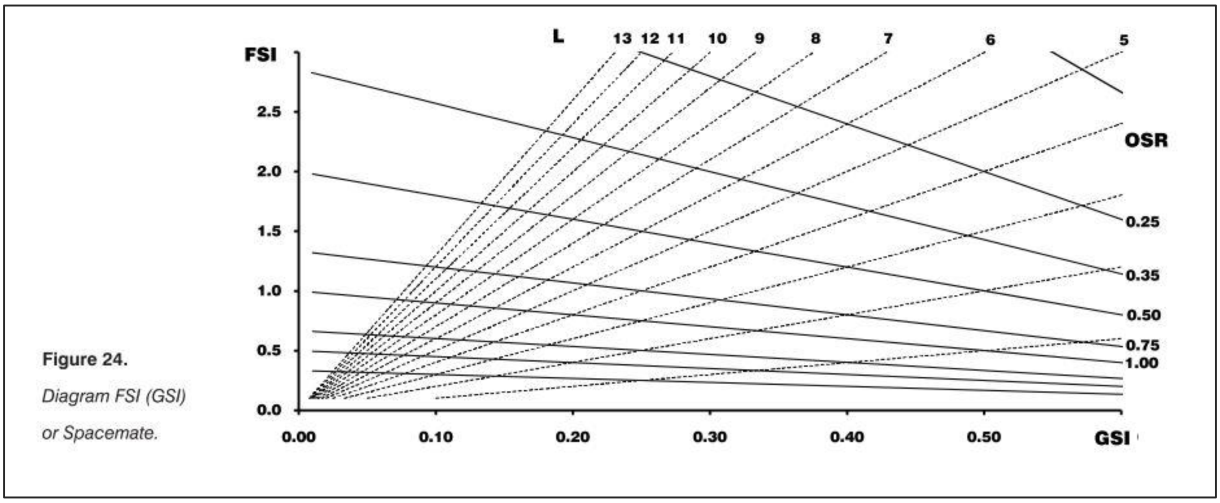


Figure 17 - The spacemate. (Berghauser Pont and Haupt, 2010).

Using fixed FSI and GSI levels one can still produce an infinite array of solutions, but when real world constraints, such as lighting, privacy and access are considered, the number of available options shrink to more manageable levels (Berghauser Pont and Haupt, 2010).

This way of measuring density using a multivariate approach is interesting. It is my argument that the current use of "områdeutnyttelse" (FSI) in Norwegian densification planning today, needs to be supplemented with at least equivalent parameters to GSI or OSR. There is a need for some number, that can safeguard the urban open space. As planner Silje Hoftun[4] says concerning the use of a fixed "områdeutnyttelse" in the planning regulations in Oslo: "The second you write a number [on the degree of densification] that is the only thing people see. They forget the qualitative regulations".[5] Even though another number will certainly not remove this problem, it might increase the status of open space. It will also help describe the desired urban form to a greater extent, while still keeping the complexity of the method on a reasonable level.

[4] Interviewed in Oslo on the 30th of January, 2015.
[5] «Med én gang man skriver et tall [på grad av fortetting] er det det eneste folk ser, de glemmer de kvalitative bestemmelsene.»

The process of densification

Densification is the process of increasing the building mass in an area. It means that the city "grows inwards" and uses its available land more efficiently. There are many different ways to accomplish this. Infill is the most common approach, where available space between existing buildings is utilized. Villa areas most often experience infill through "eplehagefortetting" (garden densification), where another villa is constructed in another villa's garden. This is common in Norway. Often the children of the property owners build a new house next to their parents. There is usually little controversy associated with this type of densification. More urban areas can see buildings "filled in" for example on free lots, within blocks, or in existing green space. This last one can be controversial, particularly if there is a short supply on green space from the outset.

Figure 18 –Leftover space (Schmidt, 2001)

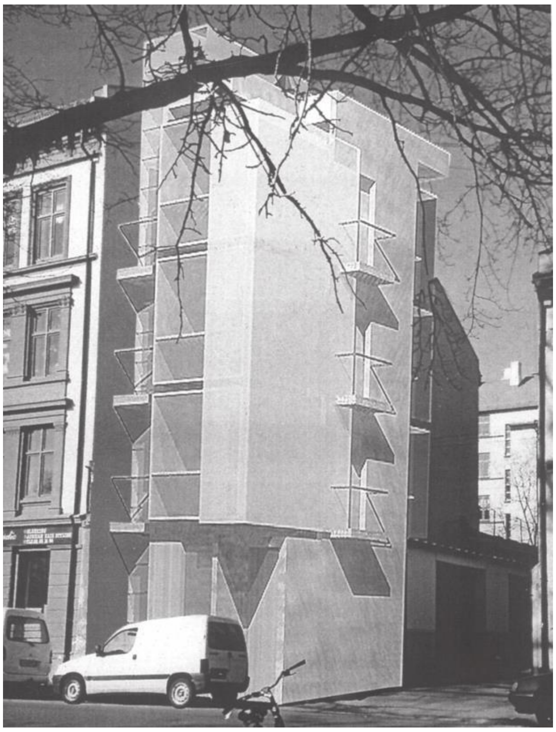


Figure 19 –Example of infill on leftover space (Schmidt, 2001)

Another way to densify is to add floor space to existing buildings, for example by adding new floors, thereby increasing their height. Densification can also take place through change of use of existing buildings, for example by furnishing an attic. Then again, densification can mean to demolish existing buildings and build larger buildings in their place. This last one can also be very controversial, depending on the area. The transformation of industrial brown fields is generally preferred to densification in existing residential areas, particularly nowadays, as traditional industries are being outsourced from Norway and other western countries. Moving activity that demands a lot of space out of the city centre, thereby allowing intensified land use in its place is another current solution. In particular, the relocation of freight terminals both for road, rail and sea transport will allow for significant intensification in Norwegian city centres. This would demand new land on the outskirts of the cities, however, and therefore it can be discussed whether such developments actually qualify as densification, or rather is an attempt to reduce overall transportation. Realistically, this solution will allow for much higher densities, than if the new buildings are built on the city limit.

Finally, it may also be possible to "claim" new land, for example by building a "lid" over roads to free up new land for development, or by filling in water. The creation of new land "Dutch style" is frequently suggested in the larger Norwegian cities at the moment (Smith-Sivertsen, 2015, Teknisk Ukeblad, 2014). The creation of new land in connection to the city centres solves many challenges associated with densification.

Figure 20 – Suggestion for new land creation in Bergen. Fortunen arkitekter 2014.

Densification for quality of life

As mentioned, the evaluation of density is very subjective. However, I will attempt to analyse densification potential, and will therefore have to make some choices concerning what is required for densification to be successful. The literature has suggested many different variables, which may be used to evaluate this potential. As Boyko and Cooper (2011) states, proximity is the most crucial attribute that characterizes a city. Proximity entails certain by-products, which have to be accepted if one is to live in a city. The garden villa can exist on the periphery of a city, but it does not make a city.

Good densification has to ensure that people's basic physiological needs are met. Daylight, sunshine, and clean air are necessary. Equally, people need to be protected from noise, smog and other pollution, and they need access to green space. Finnish researchers Kyttä et al. (2013) discovered that people tend to value green space the highest when asked to rank their favourite places. Their research is presented below. In addition, some degree of privacy both at home and outdoors is important. The protection of privacy is particularly important in high-density areas. Crowding causes stress and must therefore be compensated by private enclaves where people can withdraw to relax (Uytenhaak, 2008).

> "In principle, density must not come at the expense of the enjoyment of the home. In fact, the quality of the dwelling, the residential building and the surrounding public space should provide compensation for the density that has been reached. Natural light penetration, access, views, privacy and the quality of the (semi-) public space are therefore always important pieces of our puzzles"(Uytenhaak, 2008:35).

Day light is perhaps the most frequent factor mentioned in the literature, and is perhaps the one that is most frequently associated with density. In terms of urban planning the need for day light is addressed through street width and building heights. Building depth is also an important factor related to light penetration, but this is in the realm of the architect, not the urban planner. Adequate daylight is context dependent, and varies according to latitude and climate. Open spaces in Spain will benefit from shadow, while open spaces in Norway demand sun light if people are to spend time in them.

Berghauser Pont and Haupt (2010) argue that it is necessary to be aware of the difference between performance of density (for example OSR values) and the evaluation of this performance, which is context dependent.

> "In all cases, the investigation into the relation between density and performance should always focus on the conditional character of density for the performance of the urban landscape. In some cases this conditionality is rather direct and obvious (for example user intensity), in other cases more concealed (daylight access), sometimes controversial and tainted by vested interests (crime and happiness), and in some others probably not worth the effort to pursue (infertility). The amount of daylight, for instance, is pretty straightforward. Even if weather, pollution and interior decoration affect the final daylight penetration, the urban layout plays an important role in conditioning the access of daylight. In many other cases, density might participate as a minor condition in a complex set of physical, social and psychological factors. In such cases there is a danger of assigning this minor factor an exaggerated role, and even regarding it as a simple cause (for instance: high-rise living causes depression…"(Berghauser Pont and Haupt, 2010:205)

They divide the variables associated with density into three groups (Berghauser Pont and Haupt, 2010):

1. Variables from urban physics: daylight access, sunlight, wind, air pollution, energy consumption.
2. Variables from urban practise: user intensity, parking, the ratio between public and private land, commercial exposure ("kundegrunnlag").
3. Variables associated with perception: urbanity, privacy, circulation convenience.

A note on how Berghauser Pont and Haupt evaluate urbanity. They focus on the physical-spatial properties of the environment, and therefore define urbanity in terms of FSI, network ratio, exposure ratio and connectivity ratio. All of these relate to user intensity, the number of people in the streets. They refer to Eduardo Lozano's ideas of user intensity thresholds. At certain population densities, the number of people is sufficient to generate interactions needed to make certain functions viable (Berghauser Pont and Haupt, 2010). More people, means greater richness of life. Network ratio evaluates the amount of street available to share the user intensity. Exposure ratio concerns the facades and possible points of interactions (like entrances). Connectivity ratio of the street network, looks at the number of crossings per area, which also says something about the possibility of interaction. Smaller blocks and a higher network ratio increases interaction.

Accessibility is another variable connected to good density. As mentioned, densification in the periphery may increase car dependency, compared to densification in the centre or in connection to public transportation hubs.

Mixed use is another variable frequently mentioned in the literature. The mix of functions, such as residential, employment and shops in the same area, reduces the necessity to travel outside of the neighbourhood. How this applies to densification potential is another matter, however. If the goal is to calculate the number of new inhabitants in an area, mixed use must be considered as a part of the tare and amenities. How many work places (measured as floor space for businesses) to locate in an area, will affect the appropriate number of dwellings.

Finally, the ideas of the Swedish firm Spacescape are interesting to consider in connection to the variable discussion for the analysis. They claim that they can predict price variation for dwellings with more than 90% accuracy based on certain spatial variables (Ståhle, 2011). These variables would then provide a measure of spatial quality, which can be used in the analysis to evaluate good densification. They have seven spatial variables in addition to one socio-economic control variable. The seven variables are:

1. Distance to the city centre.
2. Distance to public transportation stop (metro, tram)
3. Access to the pedestrian street network
4. Access to urban functions (culture, shops, restaurants)
5. Access to parks
6. Distance to water
7. Urban closed block building structure ("kvartalstruktur")

Method

This chapter is a short description of the work methods used in the development of the thesis, including a study of available literature and interviews with planners and GIS experts. The methodological development has followed the Design Science Research workflow of iterative product development (Vaishnavi and Kuechler, 2004).

Study of available literature

The literature studied includes books, journal articles, web pages, videos, doctoral and master theses, various reports, as well as government documents (instruction manuals and spatial plan documents). There are not many books written on the subject of densification planning. Most of them are American and deal with sprawl repair and smart growth in the spirit of New Urbanism. Of particular interest were reports describing actual planning processes. A Swedish report from the Stockholm region, presented below, has been a very central source for the development of the methodology. The literature has been found through library and web searches in BIBSYS, Google scholar and various journal and academic databases. The most productive results usually came through references in relevant literature.

Interviews

Since the Norwegian literature on the subject is very limited, it was valuable to talk directly to the densification planners themselves. I have been able to interview ten planners and GIS experts in the three largest Norwegian cities - Trondheim, Bergen and Oslo.

The formality of the interviews and their rendition in the thesis had to be limited, because of the time frame of the project. Some master theses are written solely on the basis of interviews, but my intention was to use the interviews as background research and inspiration for the methodology development. Methodological considerations, like how to secure a representative selection of informants was limited, which means that I cannot claim to present a complete picture of how this type of planning is conducted in Norway today. The goal was rather to get a general idea of how professionals operate and think, so that the methodology development would be relevant to the practical planning situation.

The interviews were conducted as informal semi-structured interviews. Questions were prepared in advance, but the conversations were allowed to develop in other relevant directions. The interview guide centred on questions related to how the informants worked with densification planning, such as: Which tools do they use? How do they conduct analyses of densification potential? Which variables do they use in the analyses?

Design Science Research

The actual methodological development in the thesis followed the workflow in a method called Design Science Research (DSR). DSR stems from the field of Information Systems (IS) and is in particularly used in Engineering and Computer Science (Vaishnavi and Kuechler, 2004).

> "Design science research involves the creation of new knowledge through design of novel or innovative artifacts … and analysis of the use and/or performance of such artifacts along with reflection and abstraction – to improve and understand the behavior of aspects of Information Systems. Such artifacts include – but certainly are not limited to – algorithms …, human/computer interfaces, and system design methodologies or languages" (Vaishnavi and Kuechler, 2004:1).

In other words, the method includes the development of a product, evaluation of its performance, and a conclusion as to how the product can be improved.

There are five phases in the DSR methodology (Vaishnavi and Kuechler, 2004):

1. Awareness of Problem
2. Artefact design / Suggestion
3. Development
4. Evaluation
5. Conclusion

The method involves the creation of a new product that does not already exist, where the knowledge of how to create such a product is not known beforehand. This implies the acquisition of new knowledge and that learning takes place throughout the process (Vaishnavi and Kuechler, 2004).

The process starts with the awareness that there is a problem. This corresponds to the first step in my project outline described below, where I found issues that can be improved in the way GIS is used in densification planning today. The second phase, "Suggestion", is closely connected to the first one and includes a suggestion for a tentative design of the product. The product in this context is the GIS-based method for densification planning. According to DSR, the suggestion is envisioned “on paper” in a creative process linking back to an understanding of the problem (Vaishnavi and Kuechler, 2004). In my project outline, this phase blends into the third DSR phase of “Development”, where the design is developed in practise. The nature of my “product” makes this blending of the two phases (Suggestion and Development) more practical.

The fourth phase involves the testing and evaluation of the new product. Here I tested the GIS method on the case area in Bergen. The DSR evaluation requires that all deviations from expectations are noted, and hypotheses are made about their causes. These hypotheses are then used iteratively in a new suggestion of tentative design. The aforementioned phases are repeated until the product performs to satisfaction, or the attempt is discarded. The final phase of “conclusion” focuses on communicating the knowledge contribution gained in the process. Here the new knowledge itself is evaluated, for example as being “firm” or as having “loose ends”. (Vaishnavi and Kuechler, 2004)

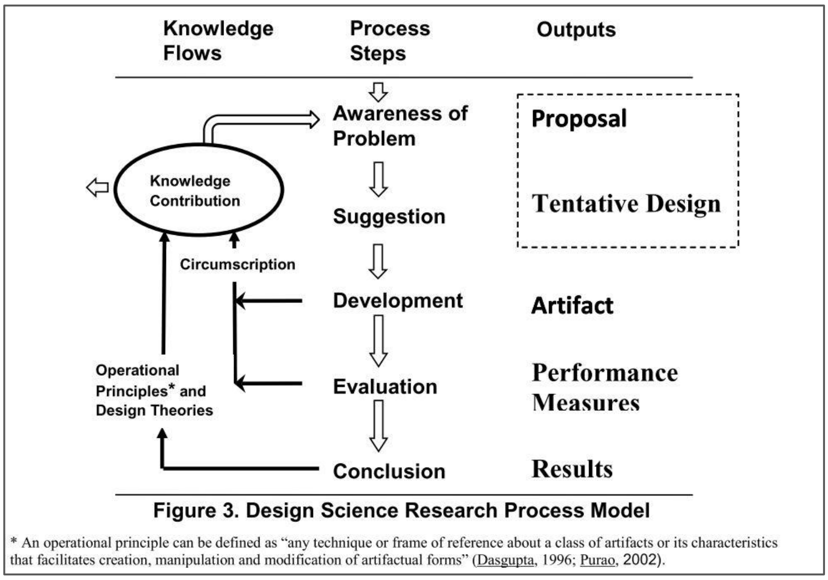


Figure 21 – The DSR Process Model (Vaishnavi and Kuechler, 2004:7)

The DSR process runs in a loop until a satisfactory product is created. The time frame of the thesis project only allowed for one iteration. Therefore, suggestions for future improvements constitute an important part of the thesis. This meant that I did not enter the fifth phase “Conclusion” during the thesis work.

Project outline

This project outline describes how the thesis was developed. Some of the steps coincided or alternated at times, particularly during the experimentation and product development phase.

1. Overview of the field by answering the first research sub-question. ("How are GIS tools utilized in densification planning today?") Techniques included the literature study and the interviews.
2. Evaluation of which variables should be included in the analysis based on the findings in phase 1. Selection of variables based on CAN, SHOULD and HOW.
3. Overview of possibilities in GIS for urban planning. Experimentation with the possibilities for how to represent and operationalize the variables in GIS. Here a discussion of available data sources was appropriate.
4. Development of a proposal for a GIS-based densification methodology.
5. Tested the method on a case (Bergen).
6. Evaluation of the product with suggestions for further refinement.

Results and Analysis

This chapter presents answers to the research questions and describes the proposed analysis methodology.

How are GIS tools utilized in densification planning today?

To answer this question I have studied available literature and talked to planners and GIS-engineers in the largest Norwegian cities. I am able to answer the question to a certain extent. I have studied cases from various countries, which show that there is a significant amount of GIS use in densification planning. I do not, however, have a full overview on an international level. Therefore, I have decided to rephrase the research sub-question to focus on Norwegian conditions. Since I have talked to planners in the largest cities, where the specialist communities are most extensive, I should be able to say something concrete about the current state of GIS use in Norwegian densification planning today. The international examples will then be useful as comparison to the Norwegian cases, and may provide inspiration for improvement.

Hence, the sub-question is rephrased in this way: **How are GIS tools utilized in densification planning in Norway today?**

After talking to GIS-engineers and planners in the municipalities of Trondheim, Bergen and Oslo, and GIS engineers in Asplan Viak Bergen and Oslo I am able to answer the above question[6]. Densification planning is conducted at two planning scales, and GIS is mainly used in one of them, the regional and master plan scale. Here GIS is mostly used to evaluate the theoretical densification potential. This is done by comparing the existing density (for instance population or number of dwellings) to a theoretical increase in density, based on either a political goal or on the unused potential in existing plans. The densification potential is calculated as the difference between the political goal density and the existing density. This method does not look in detail at the physical potential, i.e. where there is room to construct new buildings. The logic behind this abstract thinking seems to relate to what Gunnar Berglund[7] concluded for the Oslo and Akershus regional plan that: “in theory, endless density is possible”. The theoretical limits to how densely we can build and how tall the buildings can be are practically non-existent. In the end, we have to choose a desired level of density. The

[6] The appendices include a list of names of informants and discussion partners.
[7] Interviewed in Oslo on January 30th 2015.

identification of the realistic potential is left for the second level, the detailed development plan level. The GIS engineers are largely absent from planning at this level. GIS is not really utilized here. The architects are in charge of the process, and they prefer other methods and tools, such as Adobe Illustrator or model work. Stein Furru[8], urban planner in the Municipality of Bergen, worked on the area plan for the densification zone in Wergeland, where they experimented with how much new floor space it was possible to add. The planners added as many buildings as they though responsible, but were not able to reach the political density goal. This suggests that the abstract general calculations of densification potential need to become more "realistic" if they are to be useful.

The calculations at the general level include only a few variables. These include simplified land use, distance to the city centre and access to public transportation. There is no standardized set of variables or a standardized method of analysing densification potential currently in use.

Density measurements

Density in measured in several different ways. The measurement chosen in reality depends on the preferences of the individual planner or GIS engineer. There is no standardized way of measurement in use, which makes detailed comparisons between cities difficult. Population and work place density per area, dwelling density per area and floor space or building footprint per area are all used (all of them mostly presented as per decare). The Municipality of Bergen measures area per person (m2/person) among other measurements. The measures are also combined, so that several different density maps are created for the same project. This seems to be a way of dealing with the inaccuracies and arbitrariness of the different measurements. Population and work place density are possible to combine into an "activity density" indicator, which is useful in mixed-use areas.

When measuring floor space as BRA, both BRA per decare or BRA as a percentage of the area size are possibilities. When using percentage this can either be calculated as "utnyttingsgrad" (degree of intensity) or as "områdeutnyttelse" (area intensity). "Utnyttingsgrad" of a property is a well-known term to municipal caseworkers, but the problem with this measure for a density analysis is that it does not differentiate which amenities or "tare" are included. For density measurements "områdeutnyttelse" is better, because it detaches from the property borders and can be used on areas defined for the sole

[8] Interviewed in Bergen on the 10th of February 2015.

purpose of the density analysis. This brings us to one of the main challenges experienced by all the informants: how to define the area unit to be used in the analysis.

Modifiable Area Unit Problem (MAUP)

In addition to the numerator in the density calculation varying (for example population), the denominator (the area definition) also varies, even within projects. The MAUP is a significant challenge for density analyses, and one that the informants have all tried to cope with in different ways. Svein Heggelund[9] at the Municipality of Bergen for instance has created several density maps using different area units for the development of the new master plan, the most detailed of which is the administrative statistical unit "grunnkrets". He also uses an aggregate of this, the "levekårssoner", which combines the "grunnkretser" into aggregate zones containing approximately 5000 inhabitants. Finally, Heggelund has also made maps using the district level ("bydel"). All of these zones include both built and unbuilt land, which affects the density measurements negatively. To decrease this problem Heggelund uses the urban area polygons defined by SSB (Statistics Norway) to erase the unbuilt land.

Trondheim uses their so-called "planning zones". They generally correspond to the school districts, and therefore do not take internal physical homogeneity into consideration. Svein Åge Relling[10] and his colleagues view this as a weakness in the analysis results. The same is the case in Bergen. They are not satisfied with the current division of analysis areas. In Trondheim, the tare functions that are not relevant for development are deducted from each planning zone's total area. The tare includes roads, green space, public services ("offentlig formål"), institution land and areas currently under development. Whether or not green space and heritage sites ("kulturminne / kulturmiljø") should be included in the analysis is an ongoing discussion in Trondheim.

The master plan land use zones are in Norwegian densification analyses frequently chosen as the area units of analysis. They are useful, because they are generally smaller and more homogenous than the various administrative zones. The problem with the master plan zones is that their level of detail varies from municipality to municipality and even within municipalities. In addition, the zones are not detailed enough, so that density and urban form can vary significantly within one zone. Furthermore, they are not consistent in terms of which tare is included or excluded. Gunnar Berglund at Asplan Viak Oslo noted that it is possible to

[9] Interviewed in Bergen on the 10th of February 2015.
[10] Interviewed in Trondheim on the 2nd of December 2014.

clip these land use polygons with the street network, thus creating smaller “block” polygons, which are more likely to be homogenous.

Øyvind Dalen and Gunnar Berglund[11] at Asplan Viak Oslo are the informants with the most extensive experience with GIS analyses of densification potential. Dalen has led a project to develop a methodology for the identification of densification potential (presented below). Dalen and Berglund emphasize the problem of how to determine where to draw the boundary of each area unit. Particularly which tare should be included. This is difficult to standardize. It is very easy to manipulate the results by drawing the boundary in a certain way. Dalen and Berglund have found a way to mitigate the problem by including photos of reference areas together with their analysis results.

Figure 22 – Reference photo, 12 dwellings per decare (Asplan Viak, 2013).

They find aerial images of areas, preferably within the same city as the particular project, that have the desired density. This is a way to deal with the problem of describing what a certain density may look like. Non-planners will find it easier to understand comparisons to areas they know personally. The reference areas aid interpretation of the analysis results. It is in addition important to explain properly how the analysis is conducted; which amenities are included, where the boundaries are drawn and so on.

Another possible way to mitigate the MAUP is to make a raster map and use a cell buffer to calculate the intensity “utnyttingsgrad” within the buffer for each cell (see figure below). This

[11] Interviewed in Oslo January 30th 2015

is the same principle as Alexander Ståhle's location accessibility density described below. The necessity to set a buffer radius does seem to retain the original MAUP, however.

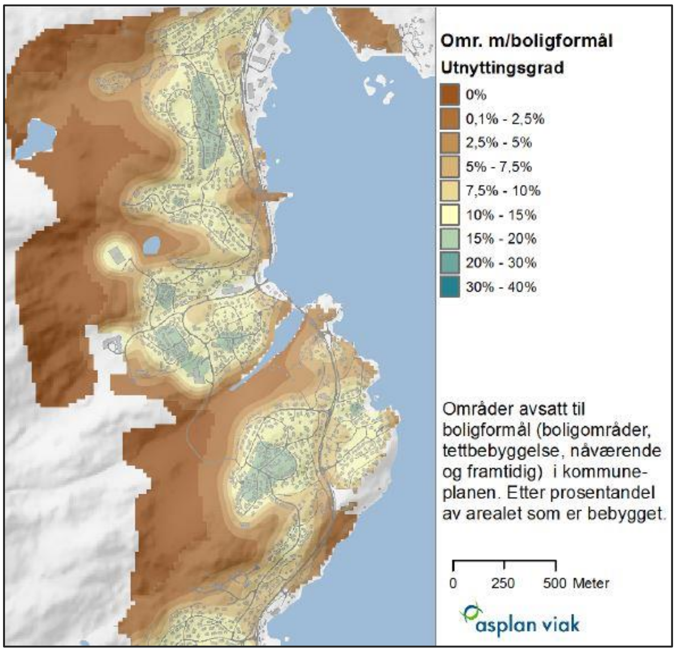


Figure 23 –Density map over Harstad using search radius (150m) around cells "Area intensity". BRA/area size(Asplan Viak, 2015)

Buffers are themselves also used as the unit of analysis, particularly when examining densification potential around public transportation hubs. 1000m is often the radius chosen, either in straight lines distance or as distance along the street network.

Variables determining densification potential

The Norwegian GIS analyses only include a few variables. Centrality is the main one, which refers to distance to the centre or to public transportation hubs. Existing land use, such as residential area, green space, etc. is another variable. I have also found reference to the use of topography and building typology to a certain extent. Property sizes have been used to get an idea of development potential. Finally, existing plans and current planning processes are often included in the analysis, where the unused development potential in the plans are included in the calculations.

Developing scenarios that outline which variables to include in an analysis is a useful technique to produce alternatives for discussions. One scenario may include all land types in the density analysis, while another excludes agricultural land or green space for example.

How the analyses are used in practical planning

The results of the density analyses are used to write regulations for the master plan, which are then copied downwards in the planning hierarchy. The regulations are simple minimum or maximum density numbers, together with qualitative descriptions prescribing “good solutions” in various degrees of detail. The actual design and implementation of these regulations is left for private developers. As an example, the Municipality of Trondheim defines densification as the number of dwellings per decare, and as minimum intensity, so that also non-residential structures are included. The current master plan defines minimum levels of density for different areas in the city (Trondheim kommune, 2013). The city centre has a minimum residential density of ten dwellings per decare. District centres and areas along the main public transport corridors have been given a minimum density of six dwellings per decare. Three dwellings per decare is the general rule for the rest of the existing residential areas. New development areas will have a minimum density of six dwellings per decare. Business development in areas with a well-developed public transportation system must have a minimum intensity of 140% BRA.

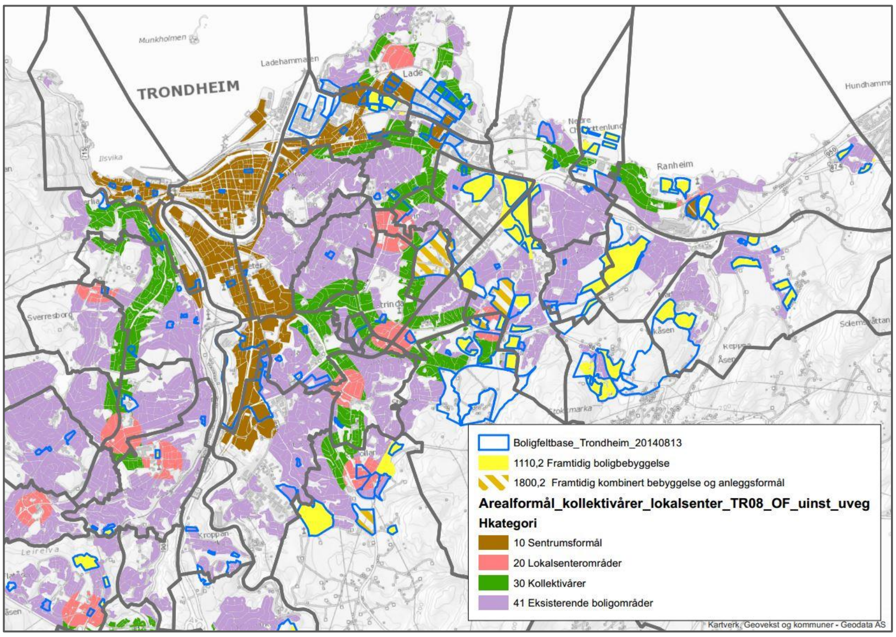


Figure 24 – Map showing zones (coloured polygons) with different density-requirements in Trondheim. In addition, the blue lines indicate areas were residential development is currently planned. The grey lines indicate the planning zones. (Relling, 2014)

As mentioned, there is in fact a significant densification taking place in Trondheim, which constitutes 80% of total residential development in the 2000s. According to Relling[12], this process is developer driven. Densification planning therefore occurs incrementally and not as the result of strategic densification plans. Developers wish to maximize utilization of their properties. The job of the city planners is therefore to restrain them, in order to secure good urban qualities.

At the same time the politicians have approved massive new areas for residential development on the city fringes. As Relling has understood it, the motivation for this, at least in part, was a political wish to keep housing prices down. This urban expansion is a cause for concern within the municipal administration. These new areas are much larger than what is actually needed for expected development in the coming years. This could result in a halt in densification. Relling questioned if the problem could be communication; that the actual numbers were not coming across to politicians.

Software and map data

The interviewed GIS engineers all use ArcGIS and more or less the same analysis toolkit within the software. They all use Excel as an addition to perform calculations or simply to manage the data, either before or after analysing the data with GIS.

A source of weakness for the densification analysis is often a lack of sufficient map data. The use of master plan zones are a result of the lack of map data thematically identifying different urban area types. The lack of standardized and updated data makes the job of data preparation much larger when conducting the analyses of densification potential.

To sum up, the GIS analyses of theoretical potential for densification calculated at the general level may be completely detached from the actual potential revealed at the detailed level. This is a weakness of the current analyses. The question is whether it is possible to improve them by including more variables, or if this will make the job too complex. Dalen and Berglund[13] emphasize that local knowledge is needed to interpret their analyses, particularly related to ongoing planning processes and developments, local limitations and opportunities. Dalen pointed out that there are many different ways to conduct the analyses, and that it is a problem that their method does not address the issue of quality, i.e. how to achieve a good densification.

[12] Interviewed in Trondheim on December 2, 2014.
[13] Interviewed in Oslo January 30th 2015

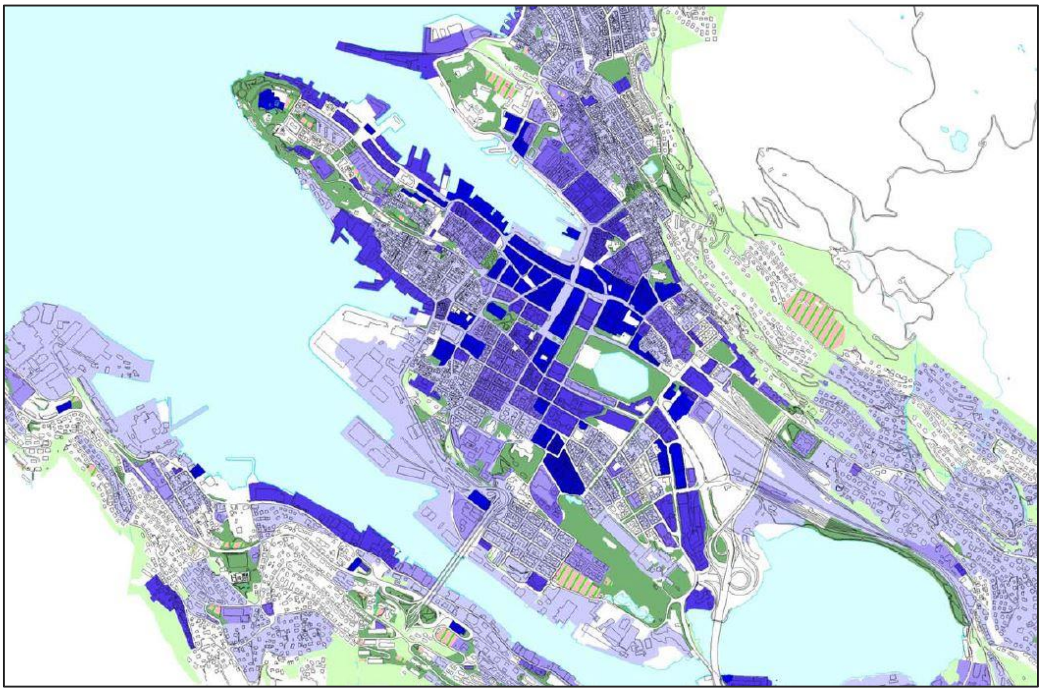


Figure 25 – Work place density (Bergen kommune et al., 2004)

Available map data

This section presents my findings related to the available map data sources that are useful for the analysis of densification potential. The extent to which the capabilities in the GIS software can be utilized depends on the quality of available data sources. This section will describe some of the main Norwegian spatial and statistical data sources available. Some of them are freely available for download for student. The rest I have had to be granted access to from the municipality and other public institutions, or I was able to access data via Asplan Viak.

Basic map data (FKB)

FKB ("Felles kartdatabase") is the Norwegian basic map database, which includes buildings, road networks, technical installations and contour lines among other objects. They include all the geographical objects needed to construct a topographic map. The building dataset includes simplified information about building type, which to some extent can be used to determine land use in an area, but it cannot show different functions in a mixed-use building.

FKB has 3D functionality. The building database varies with regards to how detailed the buildings are rendered and how well the 3D rendition works in practise. The larger cities will have a high level of detail, at least in the city centre. The quality of this data is not optimal for 3D, however. There are many errors in the dataset, which are invisible in a 2D setting, but which become apparent when viewing the data in 3D. This means that in order to build a 3D model of a city we have a significant amount of errors to edit manually.

Municipal master plan (KPA) map data

These data are often used to determine land use in geographical analyses. The degree of detail of the data varies from municipality to municipality. The Bergen municipal master plan, for example, does not give a detailed representation of land use within the existing built area. They simply classify the entire area as the general land use type “building and construction” (“bygge- og anleggsområde”). This means that the master plan data cannot be used to describe and calculate existing land use. Other municipalities differentiate land use to a greater extent, for instance as residential zones, business zones or public services. These detailed zones are still not ideal for a density analysis, however, because they will usually have both high density and low density areas within the same zone (Asplan Viak, 2014).

Land resource data (AR5)

The AR5 dataset is an alternative, but it is not better suited for a density analysis. This is a dataset constructed to map agricultural land use and land resources. It includes polygons for built-up land and infrastructure. It does not include detailed land use information within the built-up land category, unfortunately. AR5’s classification scheme does not distinguish between different types of built-up land use, such as residential land, industrial land or sports fields.

Cadastre data (Matrikkelen)

Cadastral data includes information about real properties and property borders, buildings and address information. This database gives more information about building types and activities than the FKB data does. It stores information about the number of dwelling units in each building, and what floor they are on. Information about building activities is simplified to only show the main activity in a building (determined using the amount of floor space per activity), which constitutes a problem when dealing with buildings that have multiple functions. This means that buildings with retail on the ground floor and dwellings on the upper floors are only registered as retail buildings (Asplan Viak, 2014). This particular type of mixed use can be identified by checking for the existence of dwelling units in the building, but this solution does not solve the problem when a building has more than one non-residential function.

Floor space (BRA) is registered, but this data can be faulty, particularly for older buildings. The quality of the cadastral data depends on the resources each municipality has spent on them over the years. The Municipality of Trondheim, for instance, has improved the building database significantly in recent years. Only a small percentage of buildings still have a faulty registration. The Municipality of Bergen has a high degree of accuracy when it comes to floor space information for buildings that are included in property tax calculations. Other buildings, like garages and outhouses can have a quite faulty registration.

The cadastral data must in any case be cleaned before use, because they contain “tiltaksdata” (building changes), which can result in floor space being counted twice. The cadastral data are more difficult to access because of privacy restrictions, but can be obtained from the municipalities themselves or from the Norwegian Mapping Authority (Statens kartverk).

Elveg

This is a dataset containing the centre lines of all drivable roads longer than 50 m, forest roads, and pedestrian and bicycle roads. It is constructed with topology, so that network analysis is possible.

Population data

The Norwegian Public Road Administration (Statens vegvesen) develops a dataset with population data. It consists of point map data of each person connected to an address. The dataset combines data from Folkeregisteret (National Registry) and Matrikkelen.

Population data is a challenge, particularly in university cities, because students do not normally change their place of residence in the National Registry. The centre of Bergen has a very large percentage of students and therefore the population data here is particularly unreliable. There are around 27.000 students in Bergen. 4000 of these live in public student accommodation (SIB), and may therefore be traced from SIB’s records. The other 23.000, however, are living in accommodation on the private market, often in shared apartments (“kollektiv”), and are not listed in a public registry. Because of this, it is very difficult and time consuming to locate them. Not even the municipality has a complete overview of how many people live in each part of the city.

Persons registered in the National Registry can more easily be counted. When people change residence in Norway, the central registry is usually changed as well. The registry cannot give information about apartments that are used as commuter dwellings, however. The city centre in Bergen has a lot of these as well.

Because of the inaccuracies of the population data, it is more reliable to use the number of dwellings as a density measure in the centre of Bergen. This information is found in the cadastral data. Using this data for density measurements, one has to be aware that the number of inhabitants per dwelling may vary from the national average, which is 2.2 persons per dwelling (SSB, 2011). There are many shared apartments where people live very densely. Then again there are many single occupancy apartments, and many commuter apartments which are empty for shorter or longer periods of time. These last two factors contribute to decrease the average number of persons per dwelling. An Asplan Viak project found that the city centre of Bergen had an average of 1.55 persons per dwelling, calculated from the estimated population and the registered number of dwellings (Asplan Viak, 2003).

Business registry

Work place density can be calculated using the business registry combined with cadastral address data (Matrikkelen). The business registry dataset is developed by Statistics Norway (SSB). It gives information about the type of business and the number of employees registered. The business registry can therefore be used to determine land use, especially in mixed-use areas. The data is stored as points that are georeferenced on the business's official address. A significant amount of the data registered is outdated and faulty, meaning that the dataset has to be cleaned before use. For instance, some companies have many locations of operation, but all employees are registered on the main address. This is particularly a problem for large companies. Sole proprietorships are often inaccurately registered, as well.

Lack of national datasets for urban analysis

It is apparent that Norway lacks a suitable standardized map dataset for urban land use. We need a standardized dataset, which at least differentiates between general land uses, such as residential land use, public services, green space and mixed use. Ideally, such a dataset should also contain information about building typologies. There is a long tradition for registering information about agricultural land, but it seems that the shift in societal importance to urban development has not yet caught up with the administration of map data. Since the cities are only gaining in importance, this must entail additional resources for the collection of necessary map data based on urban needs. Swedish datasets could be an inspiration for how the Norwegian version could be constructed. Of particular importance to urban planning would be that FKB and/or cadastral data should include information about the number of floors in each building, and the main functions on each floor.

"Analyse av arealbruk i byområder" (Land use analysis for urban areas) – A Norwegian analysis of densification potential

This is a Norwegian approach to the examination of densification potential. It was conducted by Asplan Viak (led by Øyvind Dalen[14]), with the goal to contribute to increased knowledge about development of land use, land need and densification potential in six Norwegian urban areas of varying sizes. The report was written as a methodological description of how an analysis of densification and transformation potential can be conducted (Asplan Viak, 2014). The analysis examined the following three themes:

I. Status of planned housing construction, along with numbers on the need for new housing and new building land according to the prognoses for population growth.
II. Regulated residential land reserves in existing plans, in connection to public transportation hubs and within existing city limits.
III. Densification potential close to public transportation hubs.

The six urban areas examined were Moss, Hamar, Tønsberg, Sandnes, Nesttun (Bergen), and Ranheim (Trondheim).

The data used in the analysis:

- *Municipal master plan map data*
- *Land resource data (AR5)*
- *The population dataset developed by Statens vegvesen*
- *The business registry developed by SSB*
- *Cadastral data (Matrikkelen)*
- *Infrastructure data (FKB)*
- *Elveg*

The ATP-model

The analysis was based on the ATP-model. This is a Norwegian GIS-based tool for land use and transportation planning developed by Asplan Viak (Asplan Viak, 2014). It is used both for analysis and visualization purposes. It is based on the ArcGIS Network Analyst tool, and

[14] Interviewed in Oslo January 30th 2015

combines this with population data, travel statistics, etc. Accessibility analyses, service areas and distance analyses are some of the possibilities within the tool.

Calculation of density

This analysis used population and employee density as density measures. The population and employee numbers were found for each master plan zone considered to have development potential. Density in each zone was calculated using the number of inhabitants and/or employees times 1000, divided by each zone's area in m2. When both inhabitants and employees are used in the calculation we get a measure of the level of activity in the area (Asplan Viak, 2014). Each zone was then classified according to distance from the nearest public transportation hub.

Densification potential

The densification potential estimate was based on existing residential and work place density (Asplan Viak, 2014). The analysis was restricted to areas within 1.2 km of a public transportation hub. Areas were included in the analysis depending on their master plan land use type. Large parking areas, green space, and industrial land are examples of land use types deemed to have densification potential (Asplan Viak, 2014).

The total area is reduced by 50% to account for land needed for infrastructure, green space, social infrastructure, etc. (Asplan Viak, 2014). The following parameters were used in the analysis, according to distance from the public transportation hub:

- Buildable land: 50% (only half the area available was included to account for tare)
- Mix of residential and business function:
  - 0 - 300 m: 50% residential / 50% business
  - 300 - 600 m: 70% residential / 30% business
  - 600 - 1200 m: 90% residential / 10% business
- Number of inhabitants per housing unit: 2
- Number of employees per decare: 50

The areas were divided into three distance zones: 0-300m, 300-600m, 600-1200m.

Two scenarios for densification were calculated:

1. Densification based on existing local conditions. Average population density within each distance zone. This gives a variation of three to eleven inhabitants per decare.

2. Densification based on an urban closed block building structure (using the example of Hamar). This gives an average of 30 inhabitants per decare.

There are some choices made in this analysis that are not clearly explained. For instance, it is not quite clear how Asplan Viak divided the number of decare available to residential development and the number of decare for work place development within the distance zones. The division itself seems to stem from an idea that buildings should be mono-functional. I am not certain that this is a good way to calculate densification potential.

The method relies mostly on existing population numbers, and provides a seemingly arbitrary analysis of where development can take place. Asplan Viak does not go into detail about which criteria they use to choose the possible development areas. In some places they identify residential areas with single-family homes with development potential, other places they do not. This kind of controversial densification needs a better criterial foundation. In addition, the analysis lacks an evaluation about what can be done with the existing building structure.

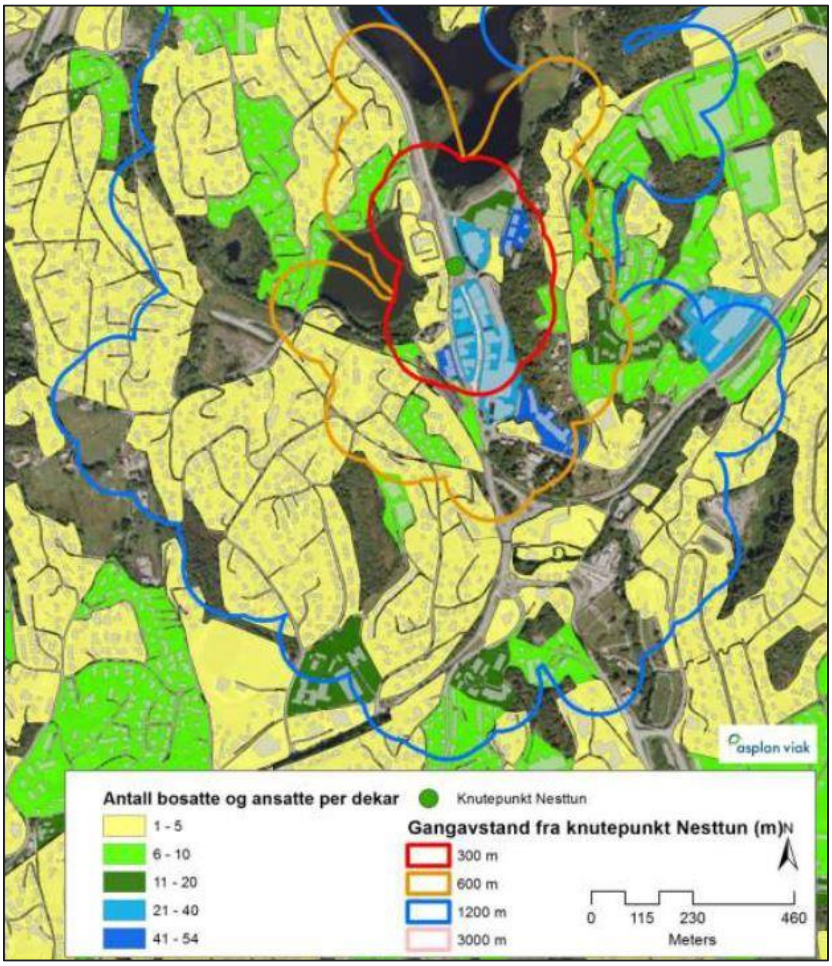


Figure 26 - Map showing zones indicating walking distance from hub. (Asplan Viak, 2014)

Densification analyses in other countries

Norwegian urban planning is not as developed as that of other European countries that have a longer urban tradition. It is therefore likely that we will find solutions to our challenges in the experiences of others. I have been able to find literature describing methods related to densification planning from various countries. It has been important to me to find sources from different nationalities, so that though I may not be able to provide an account of the full field of research, I have still gotten some understanding of the current debates in each country by studying one contribution. There is a wide variety of examples of how GIS is utilized in densification planning, ranging from classic overlay suitability analysis to predictive analysis of urban growth with cellular automata (Stevens et al., 2007). Below I present the most interesting examples I have come across.

"Compact sprawl – exploring public open space and contradictions in urban density." (Sweden)

Alexander Ståhle's doctoral thesis is a treatment of the concept of urban density, how to measure it, and how to densify suburbia, through the eyes of urban morphology. The thesis is particularly interesting to me because the author seeks to take advantage of GIS as a central tool in the densification planning process. A central argument in the thesis is the difference in how a user experiences density and how the administrator measures density. He argues that the traditional way of measuring density per area, is not how a user will experiences the density. The traveling user experiences the accessibility to density (to floor space) instead. "Every location is a result of its accessibilities"(Ståhle, 2008:46).

Sweden is very interesting as a case for Norwegian planning, because the societies are so similar, and Sweden has come further in terms of urban planning and densification than Norway. Swedish suburban densification started in the 1980s (Ståhle, 2008). According to Ståhle, Sweden has now already completed most of the possible brown-field and parking lot densification. "The pressure on the inner rather dispersed "green" suburbs is too strong"(Ståhle, 2008:216). Norway is still a step behind and can benefit from Swedish experiences.

Open spaces of quality is a central focus in the thesis, as well as new ways of measuring and understanding them. Ståhle describes the sociotope map as a Swedish innovation, which seeks to measure the quality of open spaces in the city, through the direct use value different groups in society place on them. He argues that open space, quite often green space, is not simply that. There is a wide range of quality. One should therefore not measure open space simply as square meters, but in terms of its direct use value. Densification may reduce the overall square meters of open space, but this may be compensated, and one can actually improve the access to open space, if the remaining spaces increase in quality. “It could be that less green space can be restructured and better distributed spatially”(Ståhle, 2008:145).

Figure 27-Snip of the Sociotope map of Kista, a district in Stockholm (created 2004) The blue letters indicate type of use value. *http://www.stockholm.se/TrafikStadsplanering/Stadsutveckling/Stadsplanering/Sociotopkarta/Sociotopkartor/ downloaded 04.02.15*

Ambi-territory is another concept he introduces which is closely associated with the quality of open space. He calls this “suburban no-man’s land”, which is characterized as an area with ambiguous ownership, public or private. This confusion makes potential users avoid these spaces, because they do not feel comfortable in them. A way to improve the quality of these spaces is to remove the ambiguity and clearly demarcate them as public or private territory.

He takes advantage of GIS to identify such possible areas, by looking at distance from private buildings (surveillance), roads and entrances (spatial integration/ public movement).

Ståhle also researches how inhabitants experience their access to green space and other open spaces in relation to what kind of built environment they live in. The results are surprising.

> "The results point out that the dense inner city areas with relatively low green and open surface area experiences measure higher accessibility than the two post-war suburbs, which have many times higher green and open surface area. Hence there exists 'more green space (in the life world of people), but denser cities (in the system world of planners)'. The explanation is the differences in use value and accessibility. The results clearly imply that there are structural deficiencies in the post-war areas."(Ståhle, 2008:164)

The attractiveness of an open space increases the more "use value" it has, for example usable for both relaxing, picnic, walking and so on. The accessibility depends on ease of access (distance, orientation), but one can also say that an open space's accessibility in general improves when the space has several uses.

Ståhle's thesis culminates in an experiment that aims to develop different scenarios for densification of two case areas in the Stockholm suburbs. These scenarios are evaluated according to accessibility to open space and other parameters of quality (see figure 28), compared to the existing situation.

	Location measure	Result object	Unit	Associated area measure
A	Axial line integration	Axial line	integration value	-
B	Entrance density	Axial line	entrances/100 m	-
C	Floor area accessibility	Address point	sqm	Floor Area Ratio
D	Ambiterritory	Open space	sqm	-
E	Public open space proximity	Address point	meter	-
F	Public open space accessibility	Address point	weighted sqm	Share of Open Space
G	Location spaciousness	Address point	-	Open Space Ratio
H	Location compactness	Address point	-	Spatial Compactness Ratio

Fig. 2. Components and units for the eight location measures, and associated area density measure.

Figure 28 – Location measures used to evaluate possible densification scenarios (Ståhle, 2008).

The four scenarios represent different combinations of increased street network and increased building heights. It was important that no existing buildings or infrastructure be torn down (Ståhle, 2008). The experiment was simplified in the sense that the only consideration was to place the buildings close to existing infrastructure where possible given topographical limitations. They did not consider ecological, social, economical or traffic issues. Finally, the scenarios were evaluated according to their attractiveness for powerful agents, such as residents, developers, and the municipality. This gave an idea of the realistic options.

	Developers	Municipality	Architect community	Nature conservation NGOs	Culture conservation NGOs	Existing Residents	Existing businesses	To-tal
New urbanism	++	-	0	--	--	--	+	-4
New regularism	+	--	+	-	--	-	+	-3
New conservatism	-	+	+	+	++	0	-	2
New modernism	++	+	++	+	-	-	-	4

Fig. 20. Powerful agents of Swedish big city planning politics, and their expected attitude towards the different densification strategies in modernist suburbia. ++ means 'very positive' and - - means 'very negative'. The table was created together with the municipal planner reference group.

Figure 29 –Table showing powerful agents attitude to the four scenarios. New urbanism had a denser street network, but no taller buildings, new regularism had both taller buildings and a denser street network, new conservatism had neither denser street network or taller buildings, and new modernism had taller buildings, but not a denser street network(Ståhle, 2008).

Alexander Ståhle and the firm Spacescape do a lot of interesting work on densification potential using GIS. They are particularly strong when it comes to visualization and the communication of results. Below are maps from an analysis of development potential in the Kirseberg district in Malmö. They look at spatial integration of the street network, citywide and locally, existing density in terms of residents, employees and services, green spaces and access to public transport.

TVÅ TÄTHETSANALYSER

Den övre kartbilden visar befolkningstätrheten inom stadsdelar och den undre kartbilden visar den tillgängliga tätheten från varje fastighet. Den tillgängliga tätheten visar hur stadsstrukturen fungerar, tex serviceutbu-det. Områdestäthet är ett adminstrativt mått.

Figure 30 – Figure showing different ways to measure density. Area based or location-accessibility based(Spacescape, 2014b).

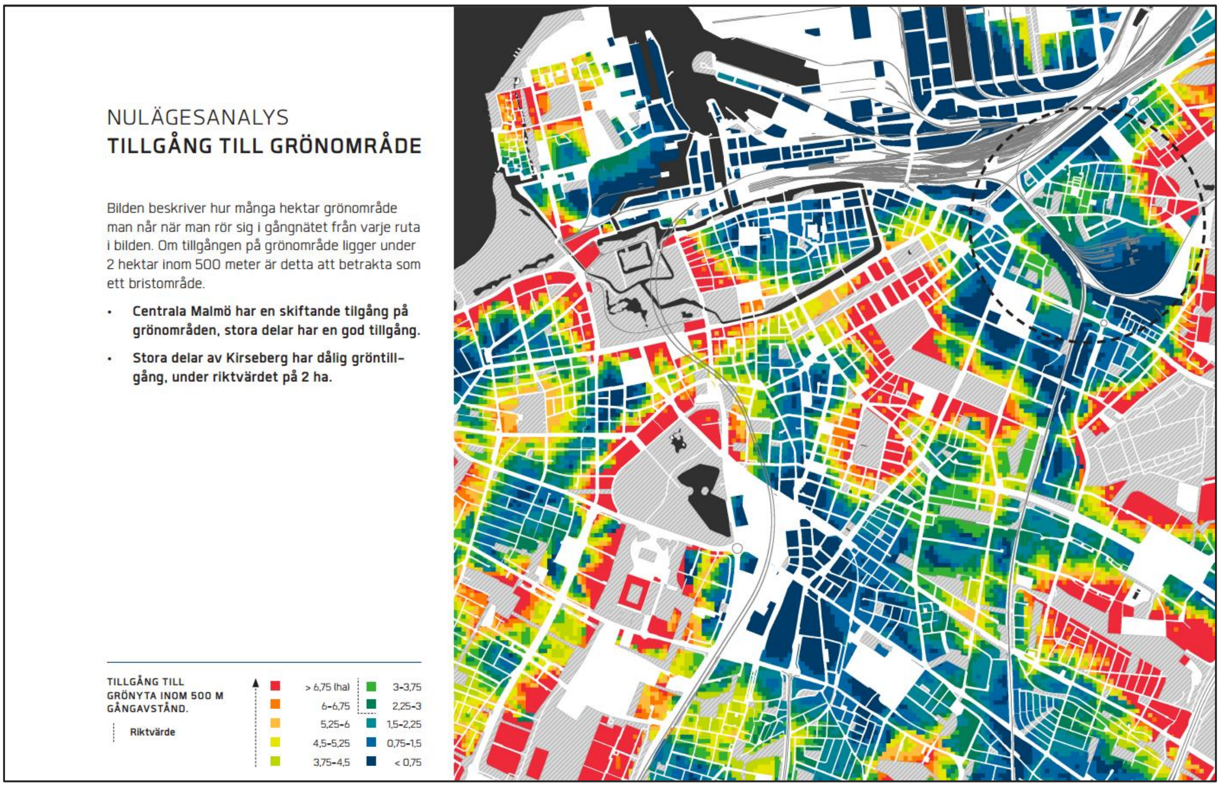


Figure 31 – Accessibility to green space. Area of green space within 500 m. (Spacescape, 2014b)

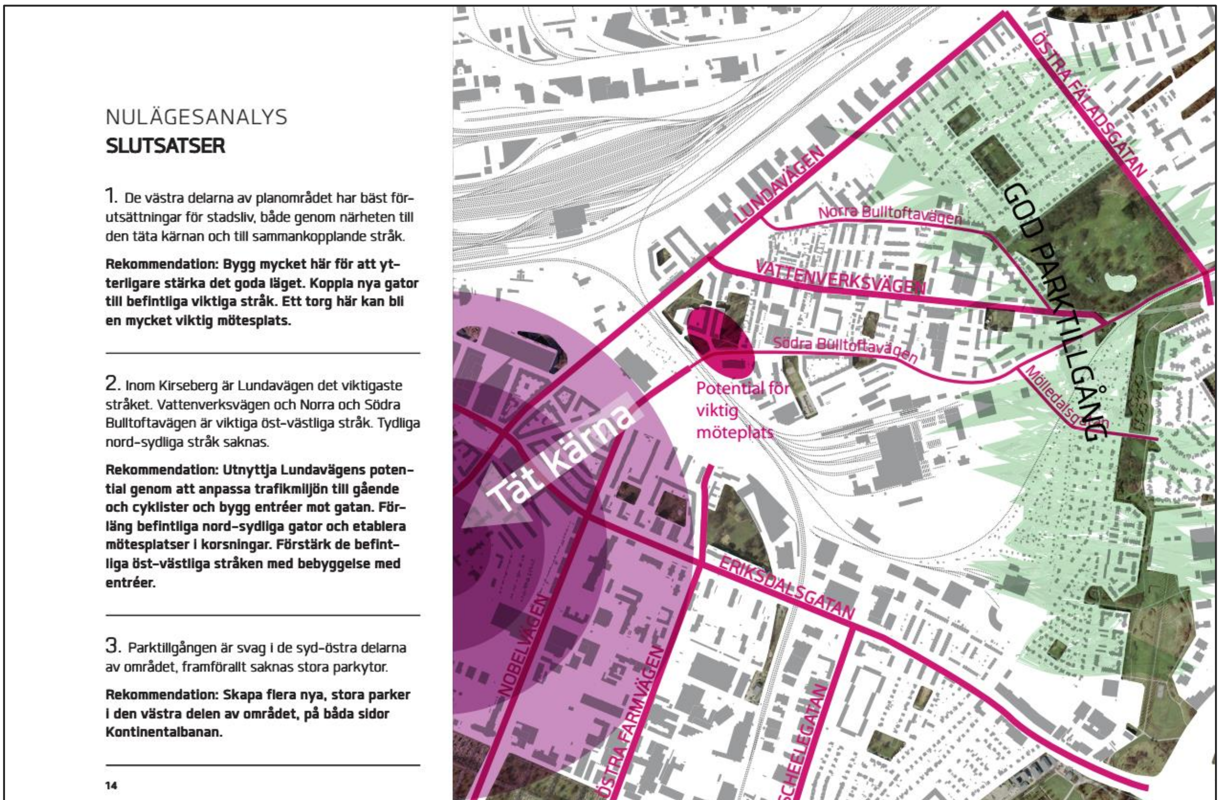


Figure 32 –Maps showing conclusions based on GIS analyses of spatial integration of street network, density and accessibility to green spaces. (Spacescape, 2014b)

Tätare Stockholm – A Swedish analysis of densification potential (Sweden)

Regionplanekontoret in the Stockholm region published this report in 2009. Spacescape, which includes Alexander Ståhle, contributed to writing the report. It presents the method and results of an analysis of densification potential in the Stockholm region. The report was made as a basis for the development of the city master plan and the regional development plan. The Stockholm region is predicted to see a population growth of between 300 000 and 500 000 people by 2030 (Regionplanekontoret, 2009). The region aims to house most of these through densification. The strategy is to develop several regional urban cores, as well as urban cores within Stockholm city. These areas are intended to become attractive and dense urban environments (Regionplanekontoret, 2009).

The report uses a method that evaluates densification potential by looking at the prerequisites for city development in a broad analysis. The results show that the potential is very big in the identified core areas, but that it may be necessary with a radical new way of thinking to be able to tap into this potential (Regionplanekontoret, 2009). According to the researchers, it is not possible to identify the densification potential using a single analysis or measurement. Densification takes place when several factors coincide (Regionplanekontoret, 2009). The researchers use a model for analysis called “The Densification Rose”. It consists of four main factors that must be present for densification attempts to be successful: densification need, densification pressure, densification room, and densification freedom. Densification need refers to the development needed to achieve a desirable city structure. Densification pressure takes the demands of the market into consideration. Densification room deals with buildable space available, and densification freedom looks at the legal and political restraints that may inhibit development. The report calls this a kind of risk analysis, which evaluates the likelihood of success for densification attempts in each area.

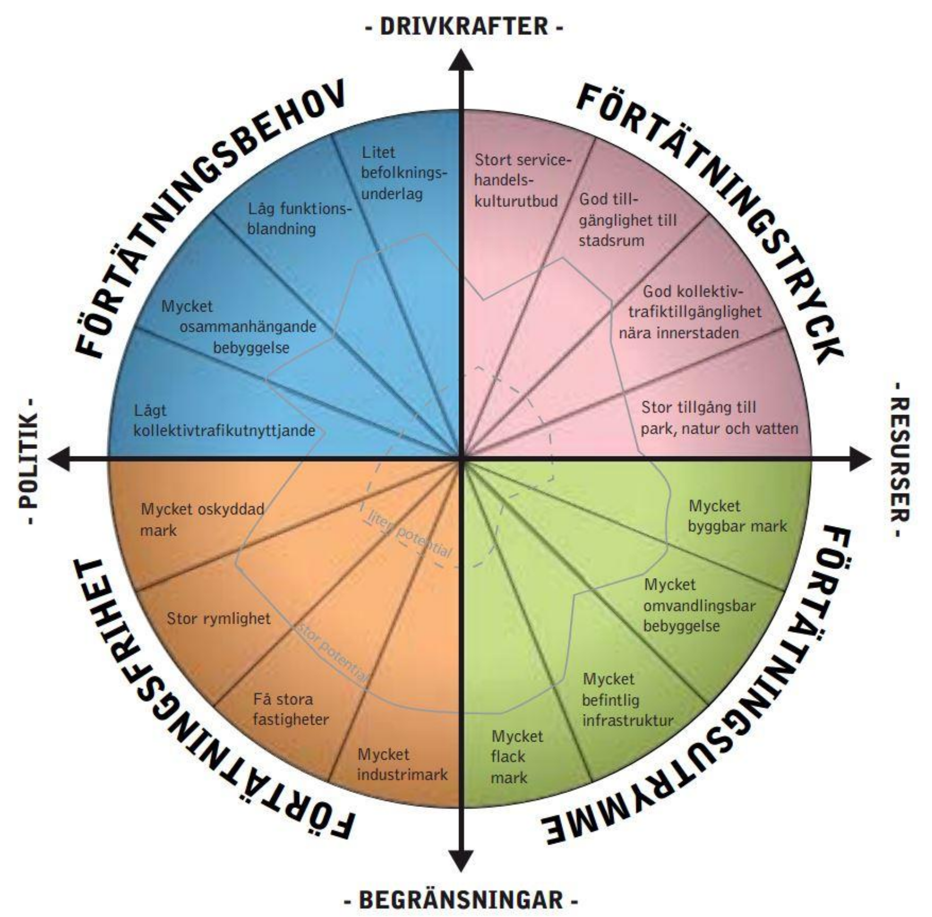


Figure 33 - The densification rose. © Spacescape 2008

Figure 33 shows the Densification Rose with strategic variables for urban development that were included in the analysis. These variables are listed below, along with information about how they were operationalized.

Table 2 – Variables used in the densification rose analysis.

Main factors	**Strategic variables**	**Measure**
Densification need	Utilization of existing public transportation	BTA (Swedish floor space) within 500 m walk from rail transport stop.
	Cohesion of building structure	Area of land located between 100 and 500 m between buildings.
	Level of mixed use	Percentage area with more than 75% or less than 25% residential use.
	Population base for services	Population within 1000 m from all addresses.

Densification pressure	Service, retail, and cultural offer	Number per hectare.
	Access to urban space (connectivity)	Average urban space integration for all axial lines. (space syntax)
	Access to public transportation (also regional)	Walking distance to rail transport stop from all addresses, plus distance to city centre (or travel time).
	Access to parks, nature, and water	Total area of green space within 1000 m, and total area within 500 m to shore line.
Densification room	Buildable land available	Percentage of open land and non-built industrial land minus land closer than 65m to high way, 25m from public road, 10 m from access road and 7.5 from street.
	Existing building structure's ability to increase density	Map of urban typology.
	Existing infrastructure	Percentage of land within 50 m of a road or street.
	Topography (flat vs. steep terrain)	Percentage of land that slopes less than 20%.
Densification freedom	Amount of industrial land	Percentage of industrial land.
	Amount of protected land (restrictions on land use)	Percentage of land without restrictions on land use.
	Spaciousness of area (amount of green space per person)	Available green space per person from all addresses.
	Property sizes (number of property owners affected, the fewer the better)	Number of properties per hectare.

The factors are given a value scale from zero to one, where one indicates maximum densification potential.

The GIS model is based on three spatial types: buildings, green space (using existing maps of valuable green structure), and urban space network (the network of roads, streets and pedestrian roads). The urban network is analysed using Space Syntax Methodology, which both measures walking distances and ease of orientation in the network (Regionplanekontoret, 2009). It is also particularly concerned with the connectivity of the street, and urban space, network.

Building typology and urban types can be used as generalized indicators of densification space (Regionplanekontoret, 2009). Here they take advantage of an already existing classification of Swedish urban typology, Rådbergs "Svenska stadstyper" (Rådberg and Friberg, 2001). This defines typologies into low open building structure, low dense building structure, preindustrial city, etc. The authors also propose that size and distribution of facility and housing structures together with year of construction may be used to classify areas. In addition, they use the "Spacemate"–model to define the urban environments.

The report classifies the whole Stockholm region using these methods. The result is a thematic map divided into nine classes of urban typology. These are high, medium and low closed building structures, high and medium open building structures, dense low-rise housing ("småhusbebyggelse"), dispersed low-rise housing, very dispersed low-rise housing, and industrial land.

To identify the densification room within these urban typologies they add two limiting rules, based on realistic building processes and basic housing qualities, such as natural lighting, accessibility, apartment floor plans, stairwells, fire regulations and usable outdoor areas (Regionplanekontoret, 2009).

1. Maximum density – max. 8 floors building height, max. 50% built area, min. spaciousness is 0.1.
2. Maximum level of change – max. 50% change in building height, built area and spaciousness.

These rules are meant to makes sure that the development will not be too extreme.

Four densification scenarios are examined:

i. Infill – New buildings are placed on available land according to the existing building structure.
ii. Lifting – Existing buildings are modified to an increased height of on average 50%.
iii. Renew – New 50% taller buildings are built according to the existing building structure.

iv. Transform – 10-20% of existing buildings are demolished, new 50% taller buildings replace them in a new structure.

The first three scenarios preserve existing buildings. The forth demolishes 10-20%, so the majority is still preserved. The small percentage being demolished makes it more likely that this can be achieved through market mechanisms, and on a voluntary basis. The evaluation of the four scenarios calculate the increased utilization of the areas based on the urban typologies. The results show that the increase in utilization is low in areas with low-rise housing. It is easier to increase utilization in areas that already have a higher density (Regionplanekontoret, 2009).

Additional sources of data used in the GIS analysis

a) Standardized terrain maps depicting the built environment, industry, forests and water.
b) Cadastre building data with number of inhabitants, floor space (BTA), year of construction.
c) Business registry showing type of business (service, retail, culture, restaurants) and number of employees.
d) Map of stops for rail-based public transport.
e) Road network

These data types are mostly available in Norway as well. An issue is the emphasis on rail vs. bus transportation. Most Norwegian cities have a public transportation system based on bus travel. Only Oslo has a well-developed system of trams, subways and trains. Even though Stockholm also has busses to supplement the rail-based transport, the Swedish planners do not think these are important enough to be included in the analysis. This may be because of the regional scale of the analysis. A similar analysis for Bergen, for example, will have to include busses. The light rail service area is still very limited. Busses make up the bulk of the public transportation system.

The Stockholm methodology

Firstly, existing density is described in this way:

The Floor Space Index (FSI) of each urban core is calculated.

The FSI of built land in each urban core is calculated.

These two measures are shown as graphs.

Secondly, a map of accessible building density was created. They used total floor space within 1000 m along the road network of each address point to create the map. This measure also indicates the effectiveness of the area's street network, when compared to a map showing regular building density. This gives a measure of how an urban area functions, particularly in dispersed areas with a lot of barriers (Regionplanekontoret, 2009). One can get a graph visualizing this by dividing the average accessible floor space by the FSI value of the area (Regionplanekontoret, 2009).

This map can be complemented with a map showing accessible population density in the same way (Regionplanekontoret, 2009). The total number of people within 1000 m of each address along the street network, gives a measure of population basis for services. The service area analysis in ArcMap is applicable for this analysis.

Thirdly, one map is created for each of the variables in the densification rose. These are described below.

Densification need

The four variables listed under densification need in table 2 is used in this analysis. Swedish political goals regarding densification are: high utilization of the public transport system, a high percentage of cohesive building structure (sammenhengende bebyggelse), a high level of mixed use, and a large population basis for services (Regionplanekontoret, 2009).

Densification pressure

It is assumed that a high densification pressure results from a large offer of services, retail and culture, good access to urban space, good access to regional public transportation, and good availability of parks, nature and water. Access to public transportation is calculated both with the average distance to a public transport stop, multiplied by the number of direction changes on the way (ease of orientation), and by measuring the straight line distance or travel time to the inner city. Parks and nature are operationalized as total area of public green space (offentlige grøntområder) within 1000m of addresses. Access to water is found by creating a 500 m buffer to all water fronts. The Stockholm analysis shows that access to these amenities is not linked to density (Regionplanekontoret, 2009). Some very dense areas have large portions of green space, which one can assume increases their attractiveness and the densification pressure in these areas (Regionplanekontoret, 2009).

Densification room

The more buildable land available the better. Whether or not to build on green space depends on the amount of it available in the area. The existing building structure is also a factor. Due to among other things the need for sun light and accessibility different urban typologies have varying abilities to densify (Regionplanekontoret, 2009). It is easier to densify open "building-in-parks" areas, than closed block structures (Regionplanekontoret, 2009). Costs of development decrease substantially if one is able to use existing infrastructure, such as roads, water works and electrical installations (Regionplanekontoret, 2009).

Densification freedom

The variables that could increase densification freedom are: large areas of industrial land, that the land is owned by fewer owners, the area is very spacious, and that little of the land has restrictions on use.

When all of these maps have been created, the variables within each main category are added up for each of the urban core areas. The results are normalised to a value between 0 and 1 and plotted into the densification rose. This will give a graphical representation of what the opportunities and challenges for densification in each area are.

The report finishes by examining two of the cores and applying the densification scenarios "Infill" and "Transformation" to each of them. A map showing a possible development under each scenario is created for each core (see figure 100). This makes it possible to give approximate numbers for new utilization, and through this give a number for population growth under each scenario. The transformation scenario will provide housing to more than twice that which the infill scenario can achieve. If we use the prognosis predicting 200 000 new inhabitants in Stockholm city by 2030, the infill-scenario will suffice for the predicted population growth until 2033, while the transformation scenario will manage until 2066 (Regionplanekontoret, 2009).

According to the authors, the Transformation scenario relies on a strong political vision about the dense, mixed-use city, with support in the market and in public opinion. The Infill scenario has weaker driving forces and greater limitations (Regionplanekontoret, 2009). Overcoming limitations will require an active dialogue between the actors, and a combination of public and private investments, such as new streets and parks (Regionplanekontoret, 2009). These new amenities will only be introduced in the Transformation scenario, Infill will only see new buildings in available space.

An interesting fact that will be useful for an analysis of green space is the authors' evaluation of the amount of green space necessary per person. By comparing the inner and outer city, they concluded that there should be a minimum of 10m2 of public green space per person in an urban area (Regionplanekontoret, 2009). Less than this will put a too heavy strain on available parks and nature.

Sprawl retrofit: sustainable urban form in unsustainable places (USA)

Emily Talen suggests a method for evaluating the potential for suburban retrofit or sprawl repair. The method evaluates places with a "potential to catalyse sustainable urbanism" that are called "nodes"(Talen, 2011:953). The nodes are assessed using different dimensions of urban form. This means that local conditions are the starting point of the analysis. Talen defines sustainable urban form in terms of compact building forms, walkability, well-designed public spaces, and mixed-use. The influence of New Urbanism is evident in these ideals.

The dimensions she lists as most important in the analysis are accessibility, connectivity, density, diversity, and nodality (Talen, 2011). Accessibility refers to the ease of access, particularly pedestrian, to services in the neighbourhood. Connectivity looks at points of connection and contact, both between people and resources. The argument goes that higher "levels of interaction between residents and the environment, society and cultural and economic activity…improve neighbourhood stability in the long term" (Talen, 2011:955). Connectivity is valid both at the local level, particularly through the street network, and at the regional scale. The goal is to maximize opportunities for interaction. Cul-de-sacs and large blocks are quite negative in this context. Density is self-explanatory, though the author does not make it clear what the exact relationship between density and sustainability is. Diversity refers both to mixed land-use and to a diverse population, in terms of social factors like income and ethnicity. Nodality, finally, is concerned with building a polycentric urban area.

Talen asks if retrofitting should focus on areas that have a higher score on one or more of these dimensions, or if the worst sprawl areas should be targeted first. She evaluates different types of areas; neighbourhood centres, light rail stations, areas heavy on asphalt and parking lots, and shopping centre nodes close to public facilities like parks and schools. The evaluation used spatial measures of the five dimensions in a GIS analysis. The results suggest that areas with a high score on one of the variables can be a good starting point for sprawl repair. This gives the planner something to work with (Talen, 2011).

Spatial measures used:

Density – population per square miles, in block groups

Diversity – Housing-type diversity (f.ex. single-family house, 5-9 units in a building, etc) (Simpson diversity index)

Connectivity – street centrelines and intersections per area of tract

Accessibility – Number of residential parcels within 500ft of retail, divided by area of tract

According to Talen, retrofitting involves three strategies. These are rule change, which refers to adjusting regulations, targeted public investments to strengthen public places, and economic incentives to stimulate private investment (Talen, 2011). Creating good public spaces may stimulate private investment (Talen, 2011).

Talen argues that this kind of method provides a degree of objectivity when evaluating investment priorities. It also provides tools for more effective policy intervention, which delivers many alternatives for future development (Talen, 2011).

The article is written in an American context within the sprawl retrofit debate. This is coloured by the limited public planning in the US, and may therefore not apply directly to a Norwegian planning context. However, Norwegian planning is similar in the respect that the actual implementation of plans are left to private developers. This suggests that we may be able to utilize the same methods.

Towards contextually sensitive urban densification: Location-based softGIS knowledge revealing perceived residential environmental quality. (Finland)

Densification as a concept generally holds negative connotations, because people are afraid that it entails the loss of environmental qualities in their surrounding area. This article describes the findings in a survey, where people were asked about the environmental qualities important to them. The article refers to a study in Brisbane that found a complex relationship between urban densification and liveability. "In addition to the well-known concerns, residents welcomed the potential improvements in infrastructure, local amenities and public transport services. Therefore, densification projects need to understand and embrace local experiences and ways of living, and neighbourhood plans should be contextually sensitive."(Kyttä et al., 2013:30-31)

Kyttä et al. refers to the above article by Emily Talen when writing this: “Talen (2011) has introduced a locally sensitive approach to the suburban retrofit, which recognizes the varying potentials the urban structure provides for sustainable densification. A careful GIS-based analysis of the overlaying, register-based data on accessibility, density, diversity, connectivity and nodality reveals strategically promising nodes for development. This localized analysis helps define local structural strengths and weaknesses and provides a variety of alternatives for further development. According to our view, the location-based experiential knowledge of residents described in this paper could also comprise an additional layer of contextually sensitive information for the planner.”(Kyttä et al., 2013:31)

The article mentions “Affordance theory”. “…which affordances out of an endless number of perceived physical features can potentially be perceived as meaningful by inhabitants.” (Kyttä et al., 2013:32). This has to do with people’s perception of the world and objects within it, and their possibilities for action and emotional reactions (Kyttä et al., 2013).

The authors, from Aalto University in Finland, describe the softGIS software they have developed as a tool to receive public feedback on “environmental quality factors” in an urban planning setting in Finland. These factors are divided into four main themes: functional possibilities, social life, appearance, and atmosphere. The sub-factors within these themes were chosen based on a previous Finnish study to get locally valid categories. The software is an internet based discussion forum with a mapping function. Respondents place points in the map and describe the locations’ significance to them. It collects “experiential knowledge” concerning urban environments (Kyttä et al., 2013). This data can in itself be used as a layer in an overlay analysis identifying areas for densification. It bears distinct resemblance to the Swedish sociotope map.

In addition, the article describes an analysis they conducted that systematically studied the urban structural characteristics of the locations marked by respondents. They drew a buffer around each point location and calculated the amount of green space and the housing density within the buffers. Afterwards they analysed the results in a logistic regression analysis to find the probability of a positive or negative evaluation of each location depending on the amount of green space and level of housing density.

One of the findings the article mentions is that improvements in aesthetic quality and in the transportation network for pedestrians and bicyclists could be successful compensations in urban densification projects. Another was the importance respondents placed on green space.

By far the most positive locations were set in green surroundings. A surprising result was that sub-urban respondents identified positive green space much further away from home than urban respondents, even though Finnish suburbia mostly consist of apartment buildings surrounded by forest (Kyttä et al., 2013). According to Kyttä et al. this suggests that the quality of green space is more important than the quantity. “Therefore, green areas that are not perceived as highly meaningful or attractive for recreation may be potential sites for infill projects” (Kyttä et al., 2013:43). This corresponds to the findings of Alexander Ståhle.

The authors conclude by praising softGIS, and methods like it, as alternatives to traditional public participation, such as public meetings. It is a good way to get positive experiential information, which is rarely obtained from traditional planning participation (Kyttä et al., 2013).

GIS-based geo-environmental evaluation of urban land-use planning (China)

Dai, Lee and Zhang (2001) present a geo-environmental GIS analysis for development potential for Lanzhou City in China. The analysis is a multiple criteria weighted analysis, which produces suitability maps for different types of development; high-rises, multi-storey buildings, low-rises, waste disposal and natural conservation. They include topography, geology, ground-water conditions, and geological hazards in their evaluation (Dai et al., 2001). They worked with raster maps of 20x20m cells. The figure below shows how they conducted their analysis.

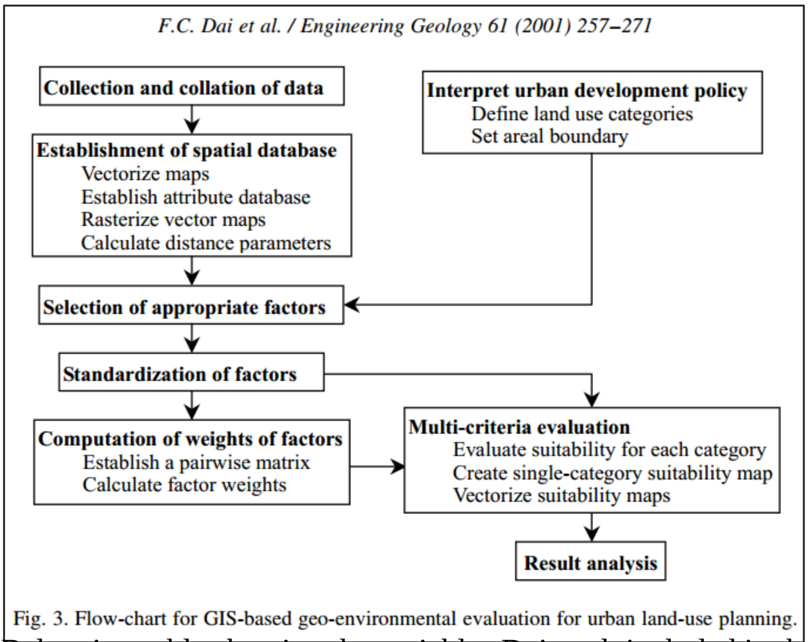


Figure 34 –Diagram of methodology (Dai et al., 2001)

Below is a table showing the variables Dai et al. included in the analysis. Much of the data used in the analysis required fieldwork to collect it.

Selection of factors for suitability evaluation					
Factors	Urban land-use categories				
	High-rise building	Multi-storey building	Low-rise building	Waste disposal	Natural conservation
Topography					
Slope	Δ	Δ	Δ	Δ	Δ
Elevation	Δ	Δ	Δ	Δ	Δ
Ground conditions					
Surficial geology			Δ	Δ	
Formation combination				Δ	
Lithology of bearing layer	Δ	Δ			
Groundwater					
Depth to groundwater table	Δ	Δ		Δ	
Corrosive potential of groundwater	Δ	Δ		Δ	
Groundwater rise	Δ	Δ	Δ	Δ	
Geologic hazards					
Distance to debris flow	Δ	Δ	Δ	Δ	Δ
Distance to landsliding	Δ	Δ	Δ	Δ	Δ
Liquefaction potential	Δ	Δ	Δ	Δ	
Distance to fault	Δ	Δ	Δ	Δ	

Figure 35 – The table showing the variables selected for the analysis. (Dai et al., 2001)

To calculate the weights used for each variable they used the analytic hierarchy process (AHP). This is a “multi-objective, multi-criteria decision-making approach that employs a pair-wise comparison procedure to arrive at a scale of preference among a set of alternatives”(Dai et al., 2001:263). This may be a technique that could be used to determine the appropriate weights for my overlay analysis.

Examples of densification planning without the use of GIS

It is necessary to be familiar with densification analysis techniques that do not use GIS. They will be useful controls with which to compare the GIS methods. I will briefly present three different sources below.

Architect Gerrit Mosebach at the Municipality of Oslo

Gerrit Mosebach has an extensive background as an urban planner and has worked a lot with densification initiatives. He does not himself work with GIS. Instead, he prefers Adobe Illustrator and similar software. Mosebach thinks GIS analyses are useful, but that they are more registration tools, than analysis tools. To him an analysis is more than a registration of facts. It includes an interpretation of the registered data. He does not think that GIS can be used to interpret the information in order to propose a concrete new development, at least not through calculations. This needs qualitative analyses. He emphasizes the importance of visiting the areas and talking to the inhabitants and the business leaders, to identify the actual development potential. Ideally, the plans of the property owners in the area should be examined, what they plan to do with their land. The quality of the existing built environment should be evaluated. Is it economical to demolish existing buildings? What is the "Gjenbruksverdi" (value of "reuse") of the buildings? What are the driving forces in the community? Is there a need to densify, how is the market, the property prices?

Evaluate the Driving forces,

User interests,

Project goals

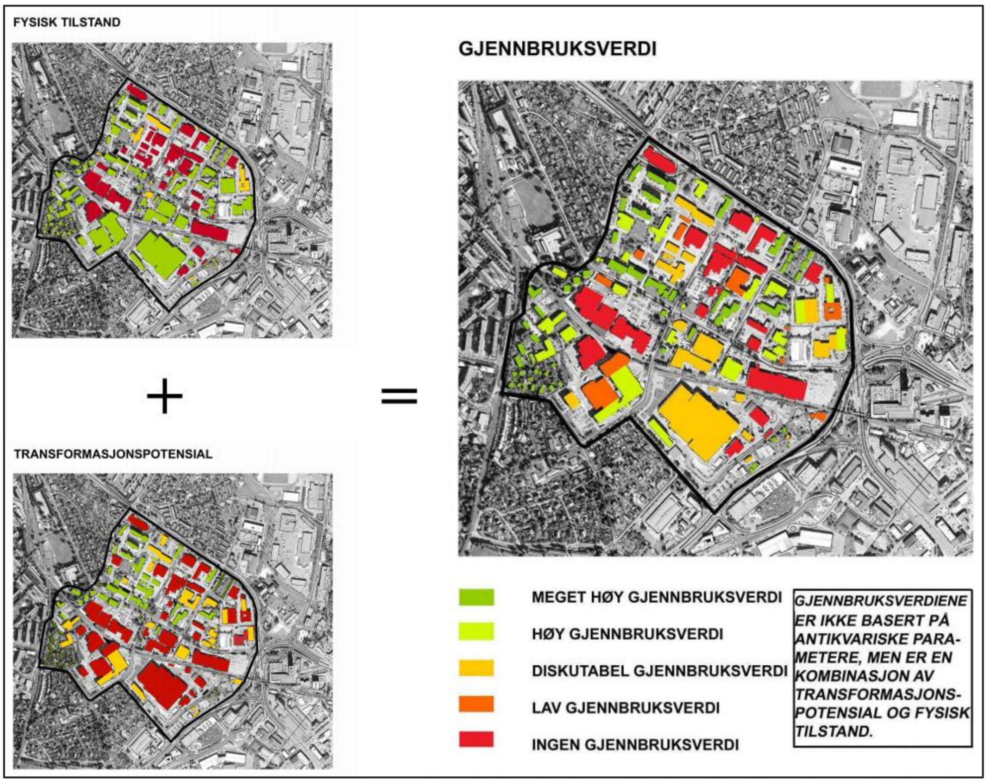


Figure 36 - Maps showing the conditions of buildings, and the transformation potential of each building into dwellings. Created by visual evaluation in the field. The combination of the two gives each building's value for reuse. (Mosebach, 2002)

Mosebach recommends the use of "Realistisk byanalyse" (realistic city analysis) to examine the physical structure of an area, but he notes that this method also has its weaknesses. In particular, that it does not examine the driving forces behind development, such as the market and the user interests in the area. It does not examine the three variables mentioned above.

Realistic city analysis focuses on physical structures; the cadastral structure, morphology, functions and axes. It is a descriptive method, which aims to provide an informative basis on which one can discuss future changes in a city (Ellefsen and Tvilde, 1991). The method has a strong emphasis on history and how historical structures and events can be found referenced in existing structures. This approach can be useful when considering HOW densification should take place.

Realistic city analysis has a classification scheme for built environments that contains ten classes. These include: lineær, gren, kam, lamell, allmenning, plass, mark, rutenett, institusjon, and havn. I will not translate these to English, but say that they are similar to the classification scheme used by Martin and March (pavilion, street and court), only more detailed.

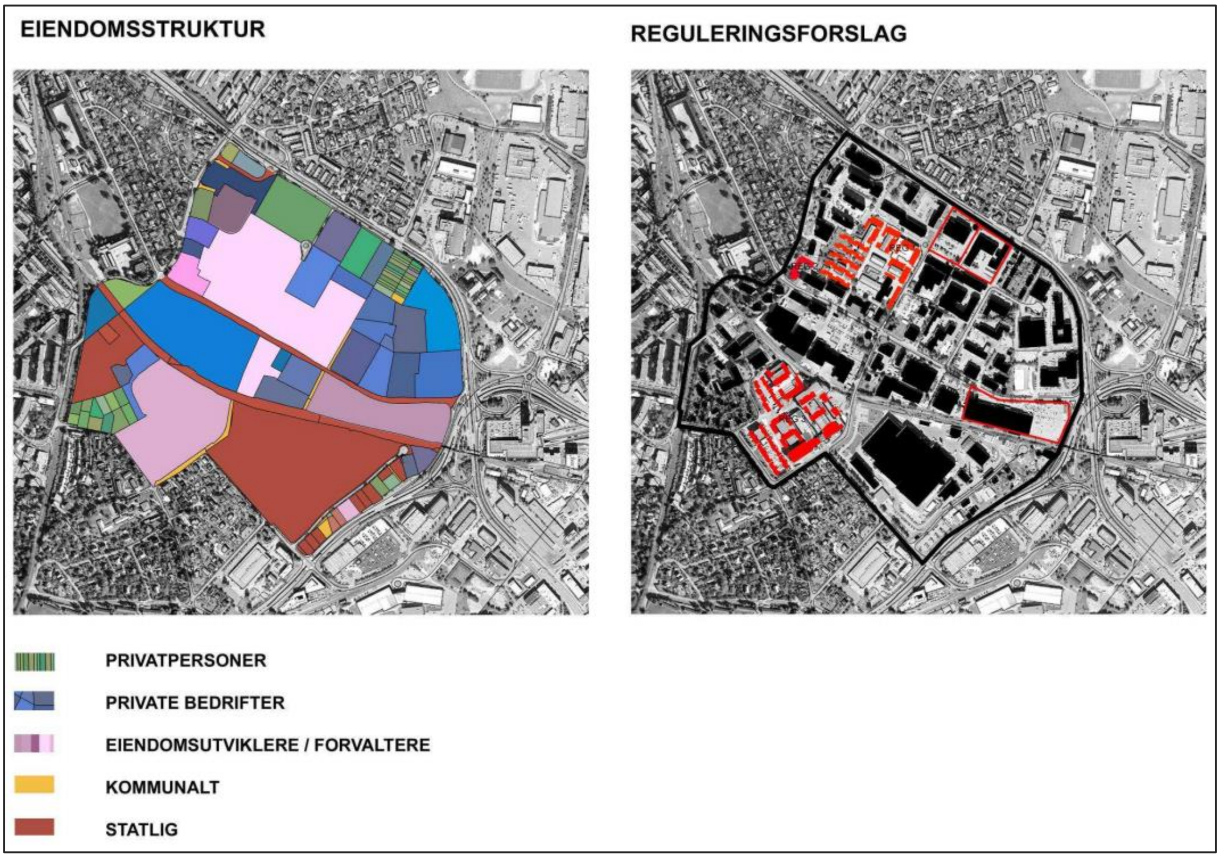
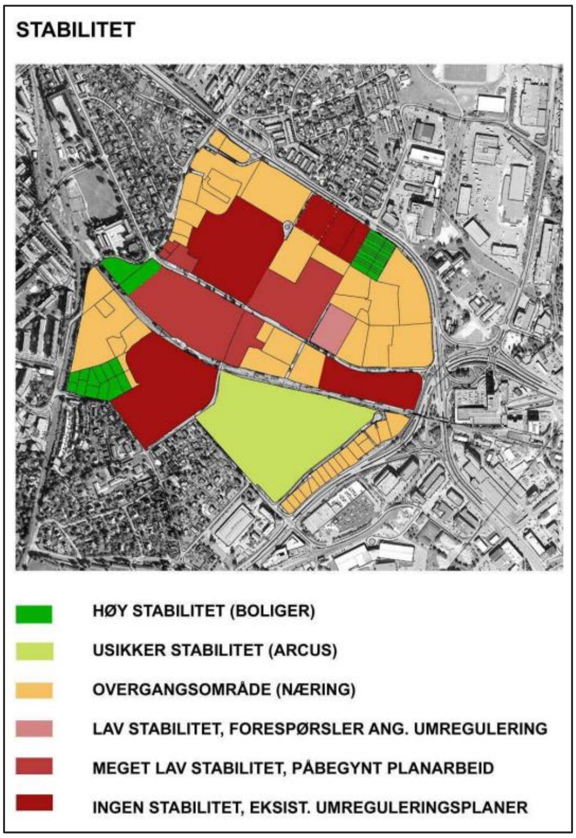


Figure 37 –Map showing property structure and map showing sites currently under planning. (Mosebach, 2002)

Mental mapping, Kevin Lynch style, is important for Mosebach. “Barnetråkk” (children’s places) is a simplified mental map. He emphasizes the necessity to include the inhabitants in the planning area, and gain an understanding of their concerns and wishes, otherwise the implementation of the plans will likely fail. Participation is key for a successful planning process! NIMBY can change to PIMBY (Please in my back yard). "Neighbours and the city antiquarian are strong opposing forces against development"(Mosebach, 2015).

Other tips he had were stability maps. They shows areas, like villa areas, as very stable, i.e. unlikely to change, while areas currently being planned as more unstable, easier to develop. Comparative methodology is also useful. Show existing examples of the planned development.



A map showing property prices can be mapped using data from www.finn.no. Digitize all houses for sale over a period of time, for example two weeks. In addition, it is important to remember that areas are very different. It is very important to treat a residential villa area different from a brown-field transformation area. Finally, the analysis should result in a map showing the recommended development. How the analyses are interpreted.

Figure 38 –Map showing stability and thus ease of change. Derived from maps in the previous figure. (Mosebach, 2002)

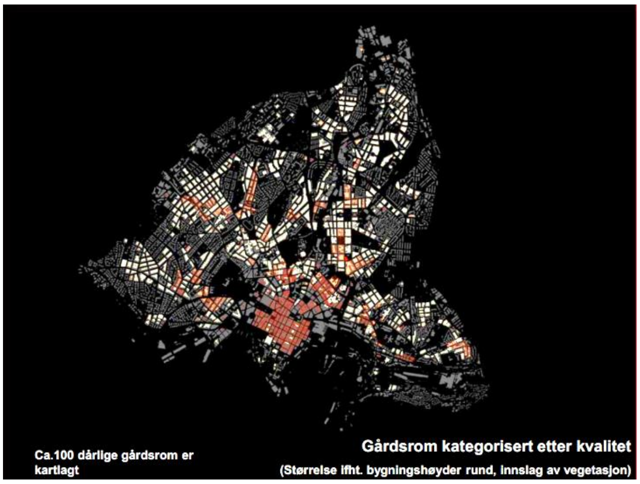


Figure 39 - Map of poor quality courtyards. Size compared to building heights, and greenery. (Mosebach, 2005)

Spacematrix (The Netherlands)

Berghauser Pont and Haupt (2010) conclude their book by describing projects, where they have utilized their method in practice. According to the authors, these projects showed them where to most effectively implement the method in the planning process. “It has also made us aware of the shortcomings and pitfalls of the method due to its complexity and a certain discomfort felt by professionals to use a quantitative method to discuss spatial qualities”(Berghauser Pont and Haupt, 2010:237).

Prescriptive use of Spacemate

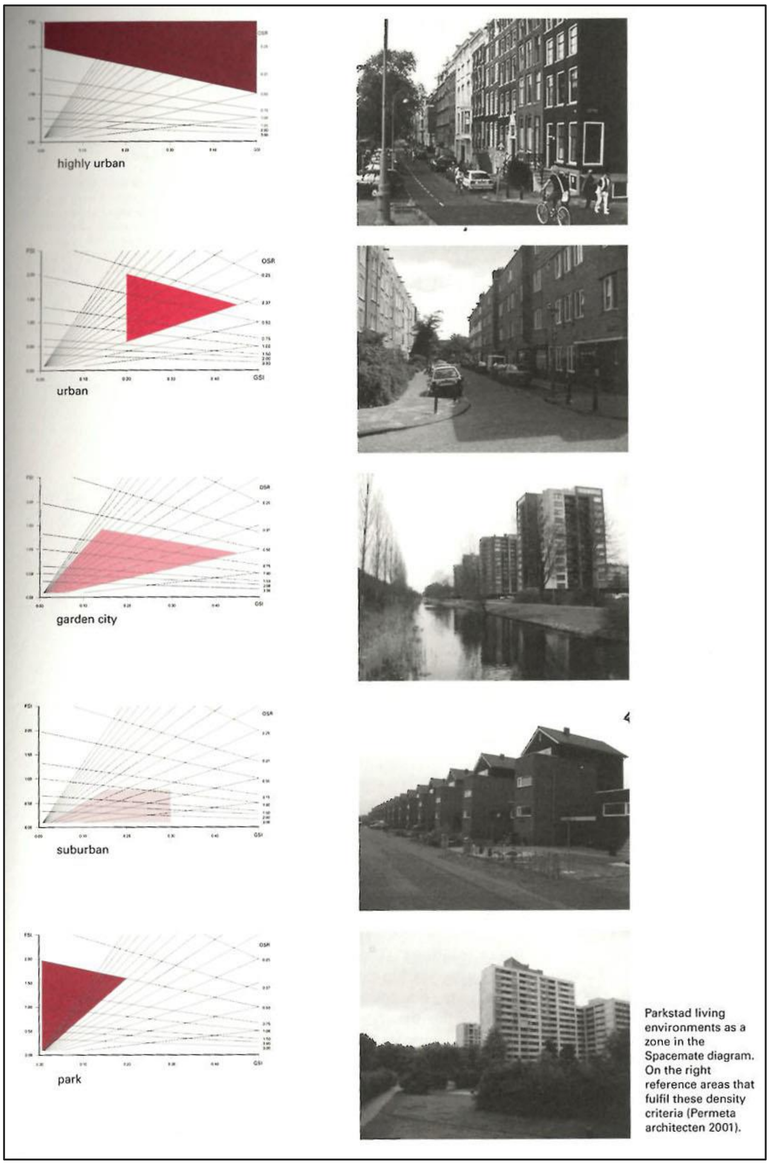


Figure 40 – Examples of the density area types defined in the Spacemate graph. (Berghauser Pont and Haupt, 2010)

The first project took place in Parkstadt, an Amsterdam suburb, and tried the Spacemate method prescriptively. The first attempt defined ten different area types with individual “classes” of allowed density (a defined zone in the Spacemate graph). The zone was defined using min and max FSI, and degree of GSI, which related to a defined OSR value. The evaluation of the project in hindsight showed that the result was unsatisfactory (Berghauser Pont and Haupt, 2010). The different area types were not developed within the limits defined in the spacemate graph. The caseworkers giving building permits did not feel comfortable using the Spacemate criteria, and were too reluctant to say no to projects that did not adhere to the guidelines. They needed more concrete guidelines. The openness of the first guidelines were unfamiliar to them.

The second attempt reduced the area types to three. In addition, scale and base land area were more precisely defined. When operating in a situation where negotiation and economic optimization is the order of the day, it is necessary to agree upon a clear set of definitions (Berghauser Pont and Haupt, 2010). Furthermore, the authors argue that using network density and the performance indicators in the guidelines would have enriched the characterization of the different living environments.

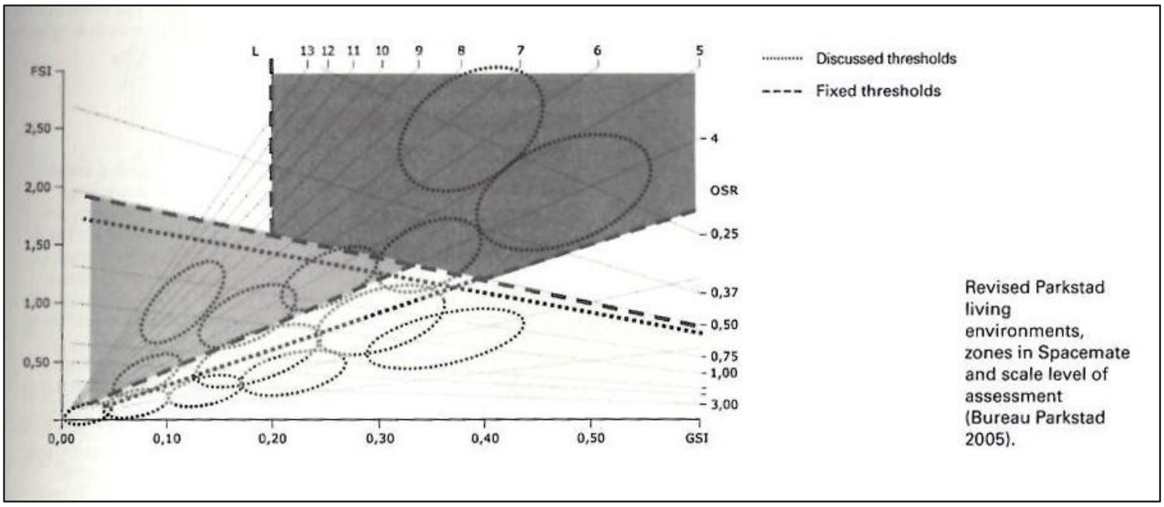


Figure 41 –Second attempt to define prescriptive density area types. Number reduced to three. (Berghauser Pont and Haupt, 2010)

Descriptive use of Spacemate

As shown in the figure below the Spacemate indicators can also be used to describe an existing area in terms of urban form. In this project in Zuidoostlob the goal was to identify different existing urban types and explore their potential for transformation into mixed urban areas. The optimal mix in mixed-use areas was set to 1:1 (residents vs. workplaces). The question they tried to answer was how to achieve the necessary GSI and mix in three different scenarios. The result was an evaluation of which area could most easily be transformed to comply with the level of mixed-use desired.

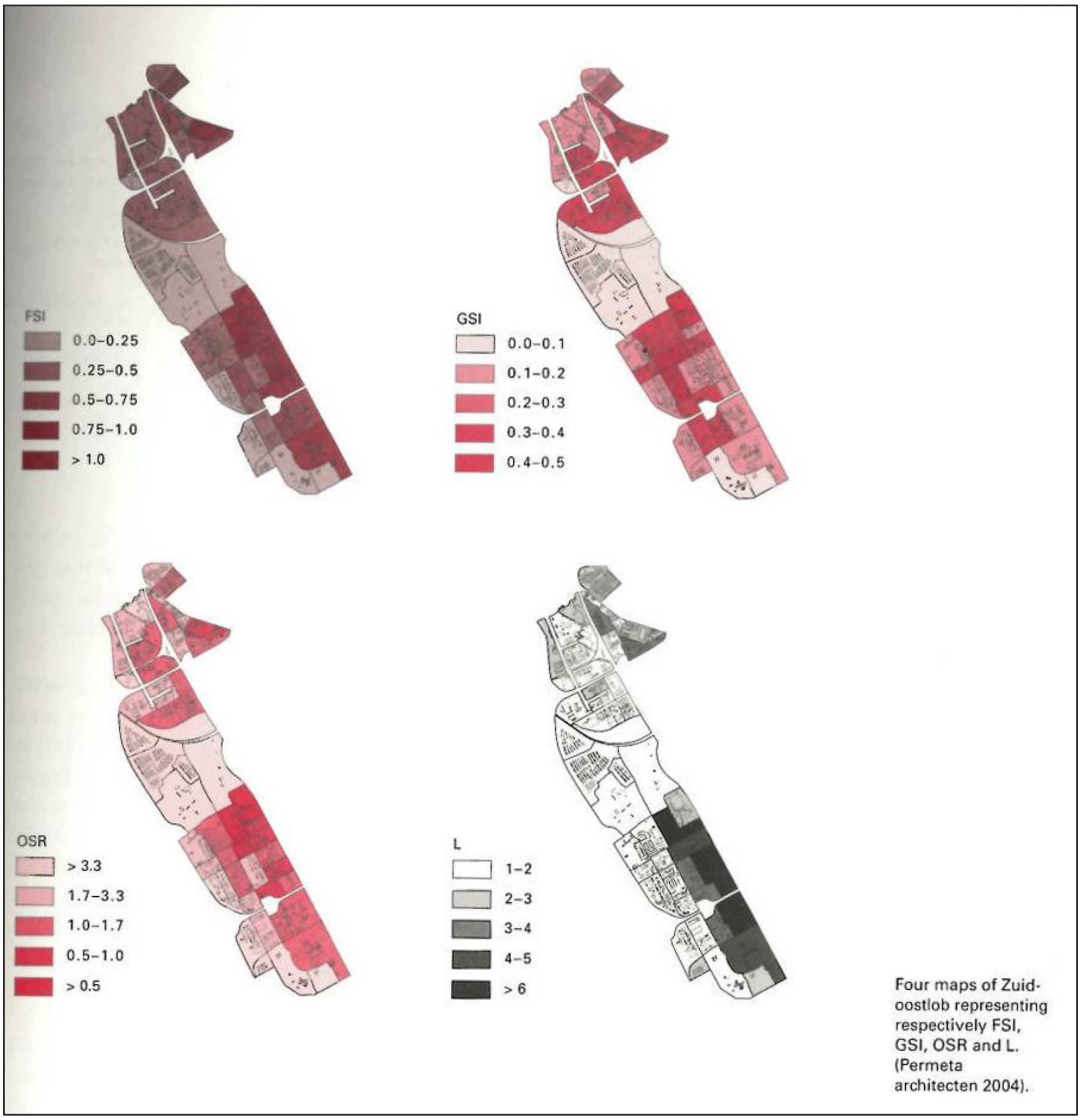


Figure 42 –Descriptive use of the spacemate indexes in an existing area (Berghauser Pont and Haupt, 2010)

Explorative use of Spacemate

A third possibility is to use the Spacemate in a feasibility study, to explore an area's potential for development.

Their conclusion from the practical projects was that too many overlapping zones in the Spacemate graph results in little variation between different environments. Furthermore, it is important to clearly define scale and demarcation of plan area, so that the caseworkers can use the indicator values confidently. To include network density in a prescriptive case could have defined the urban form better, but could also make the method too complex. The lack of an assessment procedure for the guidelines was a problem. The Spacemate method can best be used in early stages of the planning and design process. It can help determine criteria to later build the designs on.

Left Overs

I mention this report because it could be a possible criticism of a GIS-based method. It describes 153 areas in the centre of Bergen that the authors have identified as having residential infill potential and/or the potential to become parks or "green lungs" (Vabø and Beckstrøm Fuglseth, 2004). The method they used was to physically walk around the city and to register the sites manually. In this way, they could evaluate each site's potential in terms of actual use and neighbouring structures. It could possibly be argued that this is the best way of identifying densification potential. Perhaps the spatial analyses possible in GIS cannot evaluate each sites potential to a detailed enough extent?

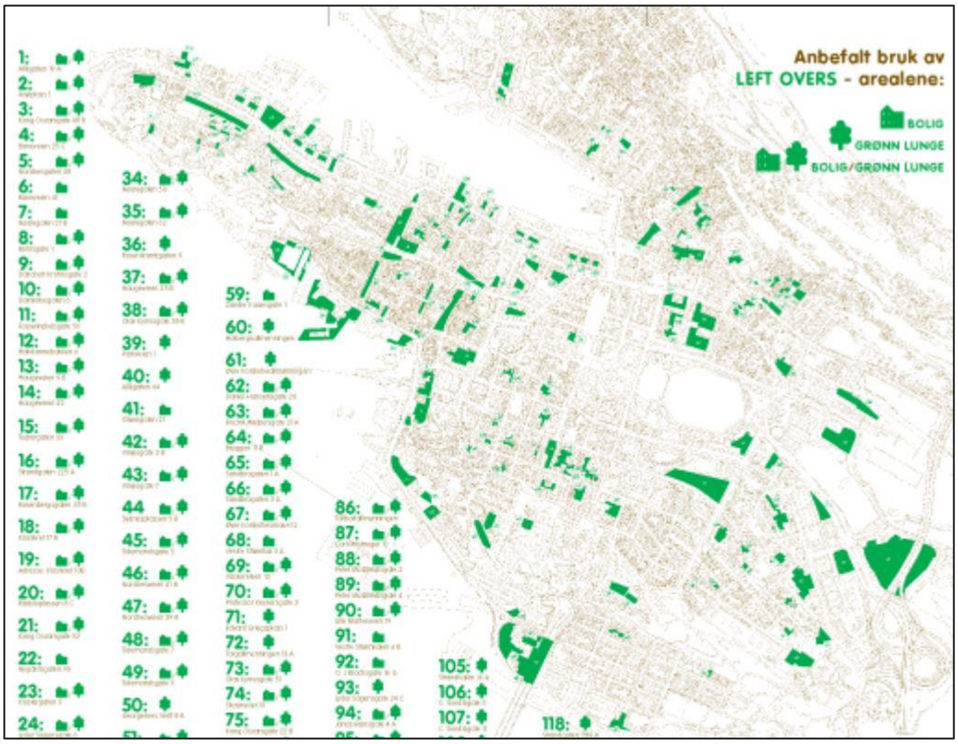


Figure 43 – Map of areas in Bergen with infill potential. (Vabø and Beckstrøm Fuglseth, 2004)

Discussion

The general impression I am left with after having studied both the Norwegian and international cases, is that the Norwegian analysis techniques are less developed and can benefit from looking abroad. The Norwegian GIS analyses are too abstract and could benefit from approaching the architect's techniques applied at the detailed level. They will benefit from a greater degree of practical realism. Mosebach[15]'s approach is more suitable to evaluate the actual densification potential, in particular in terms of user interests and political feasibility. His approach is to a large extent the architectural classical "stedsanalyse" (analysis of place?). Ideally, the two approaches should be combined. This is what Spacescape and Alexander Ståhle are doing. They are linking GIS to architectural understanding of place.

The Norwegian densification methodology is much less detailed than the Stockholm analysis. In Stockholm, green space was a distinct theme. The Swedish planners did not, however, mention the amount of land set aside for social infrastructure. They might have included it, but not felt the need to describe this in the report. They only reported the number of new inhabitants the scenarios could accommodate. They did not say anything about new work places, or the number of new schools and nurseries that could be accommodated. If this was not considered, it would be a weakness in the Swedish analysis. Problematic about the Norwegian analysis was that it did not say anything concrete about the amount of parks, or new green space needed, particularly since this tends to be one of the major concerns when densification is discussed.

The Norwegian analysis is very abstract compared to the international examples. It does not provide concrete alternatives to how densification can take place within the examined areas. They only provide a rough number estimate on how many new inhabitants and work places can fit in an area. A single number is a haphazard way of giving guidelines for densification.

There is also a difference between the Norwegian approach and the international in terms of the research behind the methodologies and the scientific focus. The Norwegians focus mainly on transportation and sustainability issues, while the international examples also include the issue of urbanity in their analyses. The issue of open space is practically non-existent in the Norwegian case. Green space is not placed on the pedestal in Norway, in the same way as they do in Sweden. At least not urban green space. Might this be because Norwegian associate recreation mainly with exiting the city all together, for example to the Bergen city mountains?

[15] Interviewed in Oslo January 30th 2015

Furthermore, the issue of the street network, its connectivity and spatial integration is not considered in the Norwegian case. The Norwegian analyses do not concern themselves with urban form.

While it may be that a GIS methodology may never fully replace the architectural detailed analysis of an area, GIS may still be useful to reduce the workload at the detailed level. It may also very well be implemented as an instrument aiding decision making of which areas should be planned further in detail. The use of graphs like the Spacemate, seems to be a useful supplement to the GIS analyses. Some data are better represented in graphs, than with maps.

Presentation and evaluation of the proposed methodology

The practical part of the thesis has included experimentation with GIS functionality and has resulted in a suggestion for an analysis methodology that can be used in densification planning. The first iteration of the methodology is presented and evaluated below. Suggestions for improvements are also discussed in coherence with the Design Science Research method of product development.

The initial idea for the structure of the methodology was a two phase workflow (see figure 44), where the first phase consists of a multiple criteria evaluation in the form of an overlay analysis. Two overlay maps are produced; one showing where densification "CAN" take place, the other where densification "SHOULD" take place. In these maps, each variable is represented by a raster layer, which is given a weight that determines the variable's impact on the analysis result relative to the other variables. The second phase of the workflow selects one or more areas with densification potential identified in the multiple criteria evaluation and continues the analysis on a more detailed scale. Here a different set of variables is used that will determine "HOW" densification should take place. One or more proposals for how these areas can be densified are developed according to different scenarios. This will give quite accurate estimates on the amount of new floor space possible. In addition, the visualization of the densification alternatives is very useful for the decision makers and general public. As will be explained below the final version of the methodology is somewhat modified.

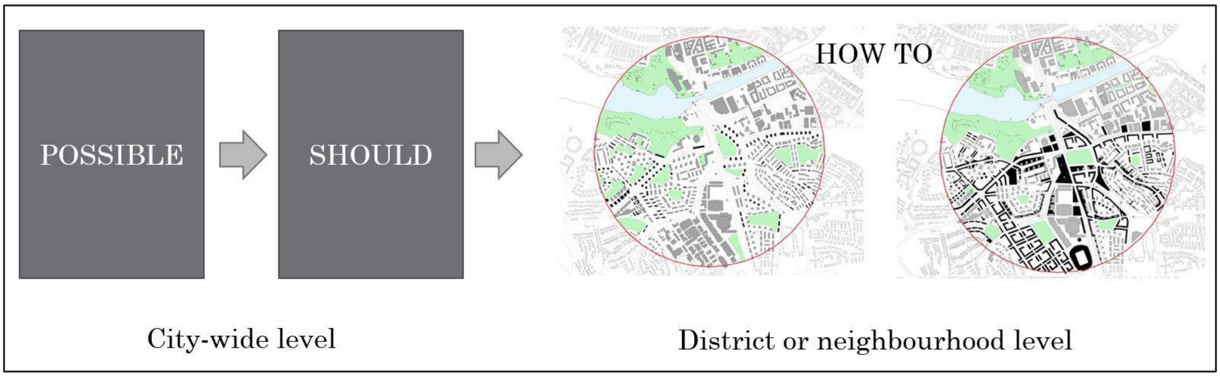


Figure 44 – Initial idea for the structure of the densification analysis methodology, including the production of three map types (CAN, SHOULD, and HOW). The "HOW TO" maps have been created by Spacescape (Spacescape, 2014a).

I have actually ended up working differently than I thought in the beginning. Instead of planning the product development and following a strict routine, I have started in one end with a variable I thought should be part of the analysis and experimented how to operationalize it using GIS. In doing so I have been more creative, I think. And I have kept the options open for as long as possible on how to do things. I have in this way also been able to reflect over problems when they arise in the analysis, instead of doing so before I even begin the practical GIS work. This does mean that I have not made a thorough study of the possibilies in general in GIS, but I have evaluated the use of GIS for each variable that became a part of the analysis. I think this was a good approach on this first iteration of the product development. A stricter regime can come later.

A general note on the possibilities within GIS. GIS is used in a variety of different professional fields. The possibilities are vast and it seems imagination is the limit. CityEngine is a big news for the field of urban planning, the use of web GIS to engage people in the planning process another.

Part 1: Preliminary density analysis and analysis of urban structure

The method starts with a preliminary analysis of the existing urban structure with existing densities. Usually this implies density analyses of population and dwelling density in the Norwegian context. An improved GIS method for the evaluation of densification potential should consider the physical structures in the city, not only look at abstract numbers of existing population density compared to a political goal. It should ideally evaluate exactly where it is possible to fit new buildings. The Spacematrix density measures have potential to improve these preliminary analyses. This means that we need to construct the base land areas for the analysis.

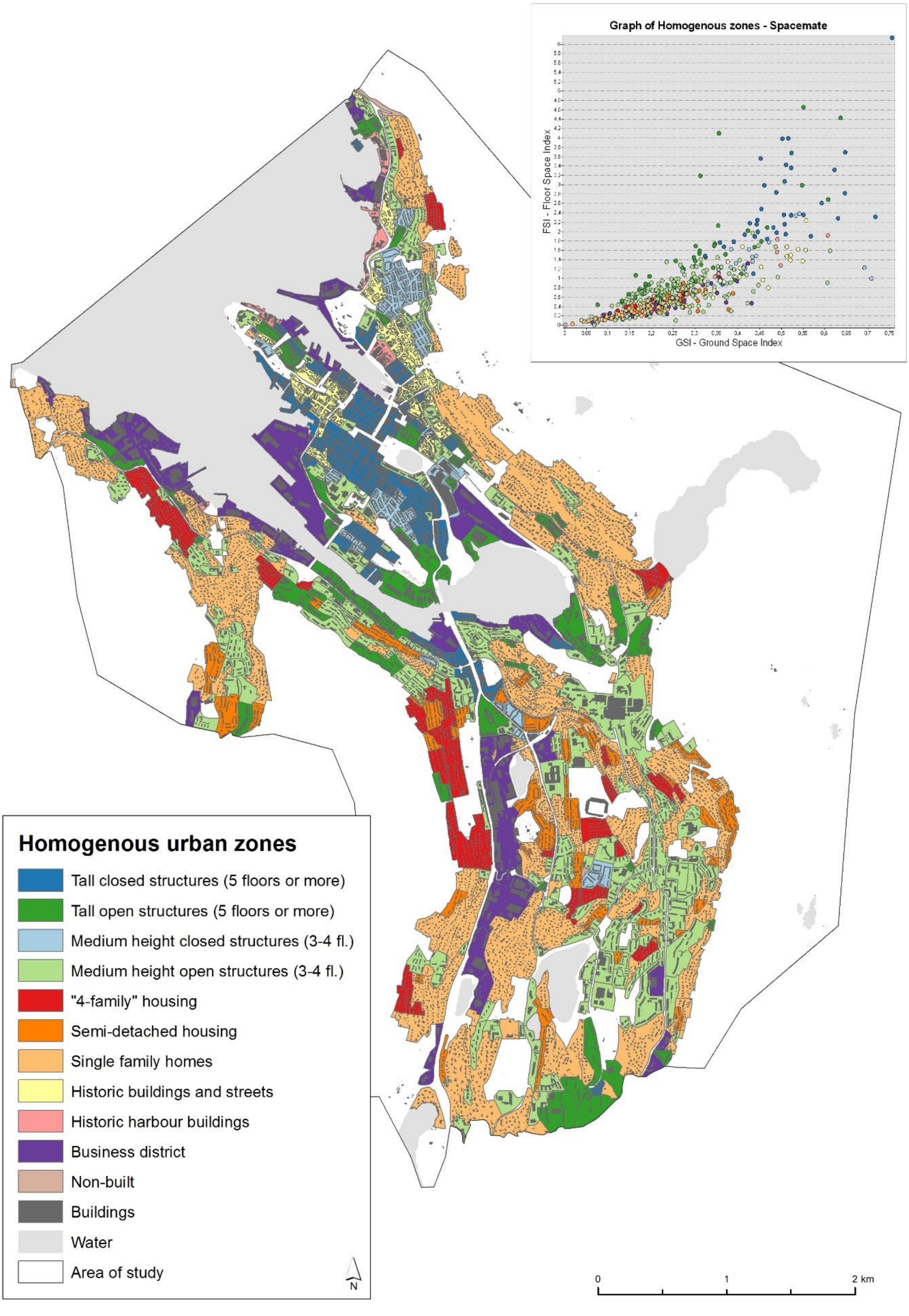


Figure 45 – Map of the homogenous zones dataset that was produced for the densification analysis.

Homogenous zones and tare

The analysis started with the production of a dataset showing the “Base Land Area” as described by Berghauser and Pont (2010), or the “Homogenous zones”, as I have named the dataset. Dividing the urban fabric into homogenous zones seems to be the best way to avoid MAUP, and it will also bring a better understanding of the urban structure in general. This is a good starting point for the densification analysis. I decided to construct the dataset from scratch, after having reviewed and discarded other available datasets as insufficient for the analysis. These included the AR5 dataset, master plan map data and various thematic datasets produced for Bergen in recent years.

It is a problem for the applicability of the methodology that such a dataset is not generally available in Norway, and that it is very time consuming to produce. However, once it is made it will remain valid for a long time, and it is easily updated using cadastral data to review new buildings’ impact on the homogeneity of the existing zones. I spent 2.5 weeks producing the dataset, which can be a problem in terms of time restraints, when considering that I only looked at a subsection of the city, albeit the most complex part of it. It would probably take 6 to 7 weeks to produce the dataset for the whole municipality. Berghauser Pont and Haupt suggest that an algorithm could be made to produce the dataset automatically. I decided not to do this for the first iteration, since I lacked experience with this type of data. Having now produced a satisfactory dataset manually, it could be possible to compare it to a second iteration of the dataset, which tests an automatic or semi-automatic algorithm.

Below I will describe the production of the dataset and the considerations I had to make along the way.

The fabric scale suits Norwegian cities

Berghauser Pont and Haupt’s method of dividing the urban structure into different scales (lot, island (block), fabric and district) is a practical approach, well suited for GIS. I began to experiment with the lots and continued to the block scale, which worked well in the historical centre of Bergen. I used the street polygons to clip out block polygons for the analysis. These had to be edited manually to some extent, but it was generally a very efficient technique. I encountered problems when continuing into the larger city, however. The 20th century city of large villa areas and modernist suburbia does not conform to the block structure street network. Particularly the villa areas have more of a tree-like street network. These areas cannot be defined using the street edges. I found that the block-level is therefore better avoided in the Norwegian context, and that one should rather start directly with the fabric level. The villa areas correspond better to the fabric concept, which includes the streets in the base land area. The fabric scale also works well in the city centre. I found it was not necessary to define blocks, as long as the fabric truly is homogenous in structure.

The digitizing of the zones is very time consuming and often requires a lot of individual evaluation. It is often not clear exactly where the boundaries between zones should go. It is relatively straightforward in areas that have been developed in a short amount of time, but gets trickier when an area has seen development over many decades, so that the buildings vary wildly in typology.

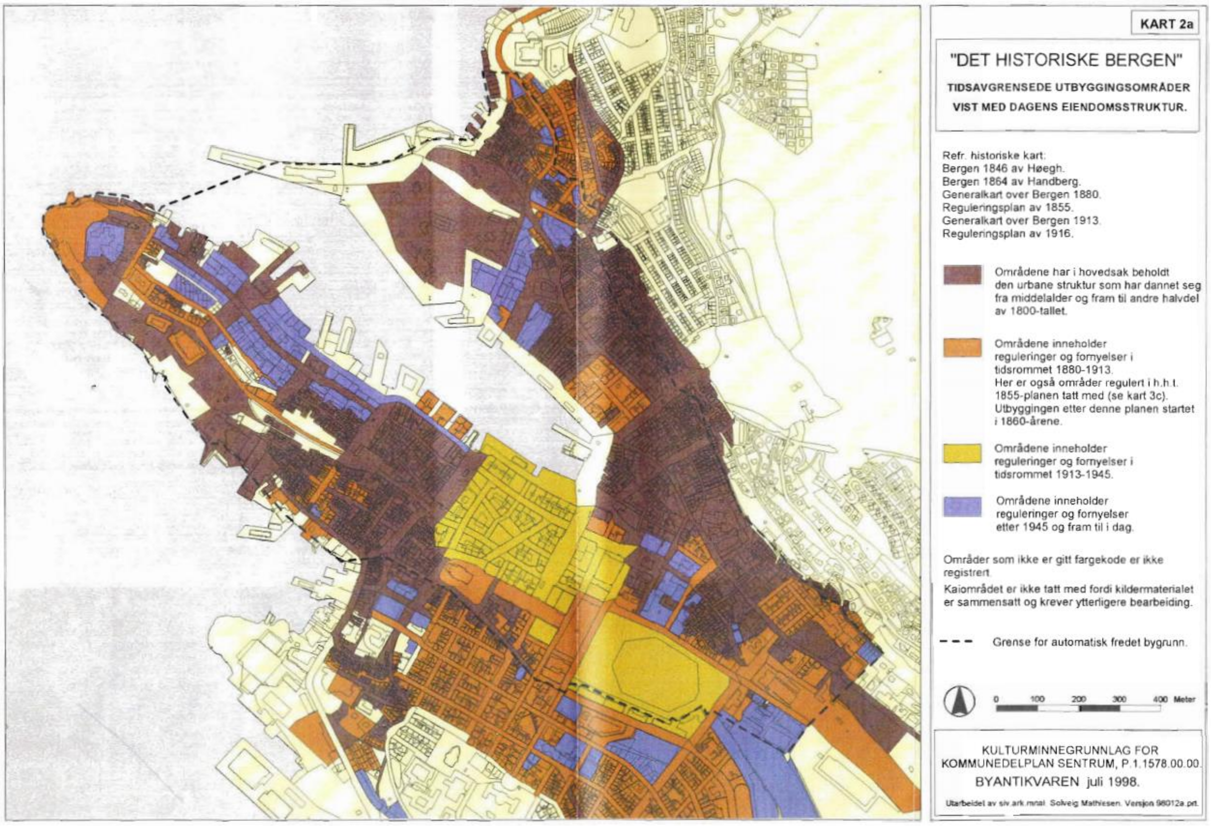


Figure 46 – Maps showing historic development areas in the centre of Bergen. Was useful when defining the fabric zones (Byantikvaren i Bergen kommune, 1999)

This means that it is necessary to carefully draft guidelines for how the divisions should be made in order for datasets to be comparable across projects and cities. One necessary guideline has to define how detailed the zones should be. One or two buildings that stand out from the surrounding area, should not get their own zones. Three or four buildings might. I have been relatively detailed in my dataset of the study area, but evaluating it afterwards, it seems I could have dissolved some of the smaller zones in their surrounding areas. It is in the end a matter of time restraints. A rule could be that areas smaller than 2 daa should not be defined as a separate zone.

An issue, which I have not encountered because of the choice of case is ‘how to define the city limits’. If the goal is densification then the city must grow inwards, not outwards. A densification analysis must therefore be able to determine where the outer city limits are drawn. In my case, I could take advantage of the “Byfjellgrense” (the regulated mountain boundary), which clearly separates the urban structure from the city mountains. If I were to analyse the entire municipality I would have to find another boundary in many cases. The SSB “tettstedsavgrensning” (urban area polygons) generated automatically using a certain buffer distance from the FKB building polygons can be a good option. This dataset is used by several of my informants.

Tare

Tare is mentioned in the theory chapter and is part of the Spacematrix method. Within the area of study there is a lot of unbuilt land that should not be a part of the density measurements of the urban structure, for instance the city mountains, and some unbuilt land within the urban structure that should not be a part of the density measurements of the fabric level. This is unbuilt land that may be located next to a fabric, but that does not belong exclusively to it, and which therefore will give a skewed density measure of the fabric if included in it. An example is a large park, which is used by the whole district or city. The park’s area belongs in a density measurement of the district, but does not belong in a density measurement of the smaller fabric located next to it. Including it in the measurement would give an inaccurate impression of the fabric’s density and urban structure.

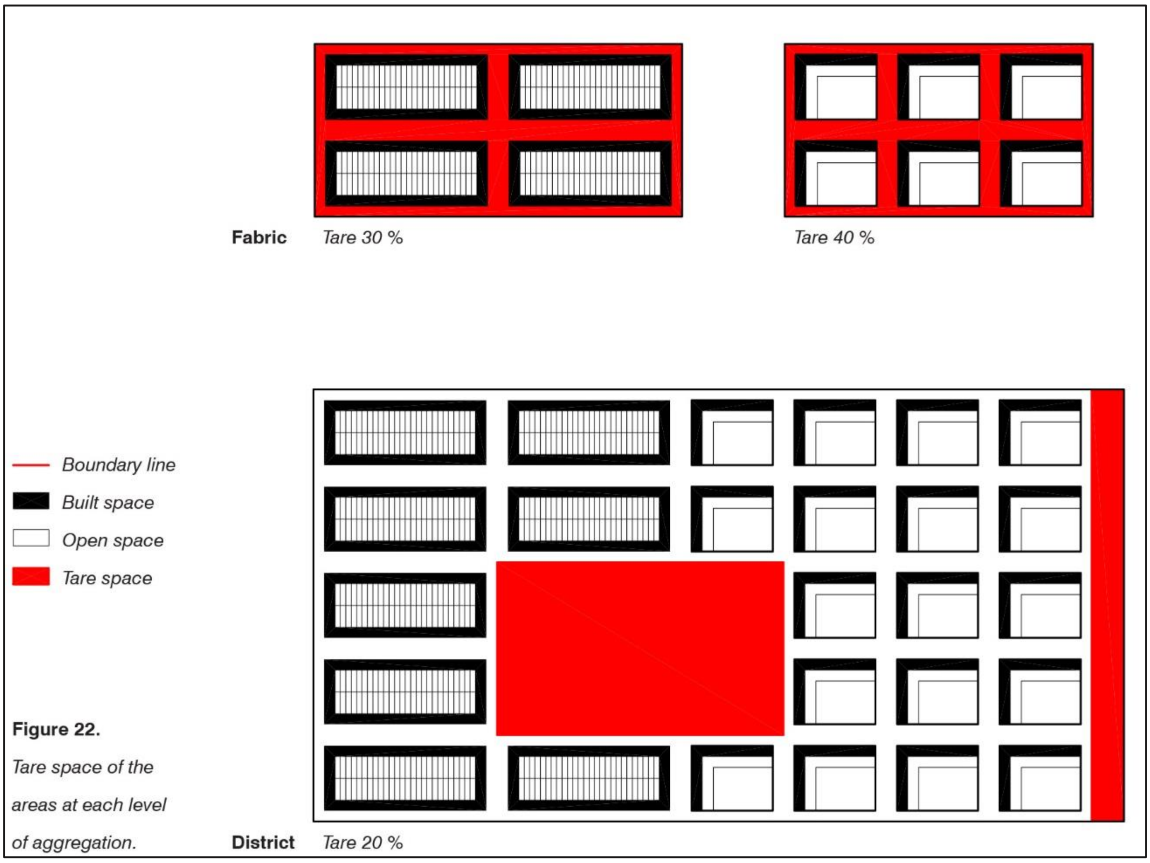


Figure 47 –Figure explaining the relationship between tare and different scale area units. (Berghauser Pont and Haupt, 2009)

The “tare” concept is used by both Dutch sources (Berghauser Pont and Haupt, 2010, Uytenhaak, 2008), but they define it differently. Berghauser Pont and Haupt generally use it for parking spaces and other such physical space, whereas Uytenhaak includes public amenities, like schools in the tare. Since the GIS method is meant to analyse the built environment as a whole, it would be wrong to leave out buildings with certain functions. I am not only seeking to analyse the density of residential buildings. Therefore, schools and churches and other types of buildings are all part of the fabric, leaving the tare in my analysis to consist of unbuilt land with various functions. An analysis of densification potential should look at the existing built environment no matter what activity is currently occupying the buildings.

Defining the tare in a separate dataset helps to increase one’s understanding of the urban structure. The historic city centre has a higher percentage of tare than the newer areas, which instead have lower densities. The tare mediates the consequences of high densities. Areas with very high built intensity can still be good residential areas as long as they have large parks and urban spaces in the vicinity.

The unbuilt area functions included in the tare dataset have been chosen because of their public character and their availability to the whole district or even the whole city. They include:

-The City Mountains (Byfjellene), defined by the regulated boundary (Byfjellsgrensen)

-Protected nature areas

-Large public spaces (Allmenninger og andre store plasser)

-Large parks

-Large sports fields

-Cemeteries

-Large bodies of water

-Railroad tracks

-Light rail tracks

-Circulation streets – use street polygons (FKB)

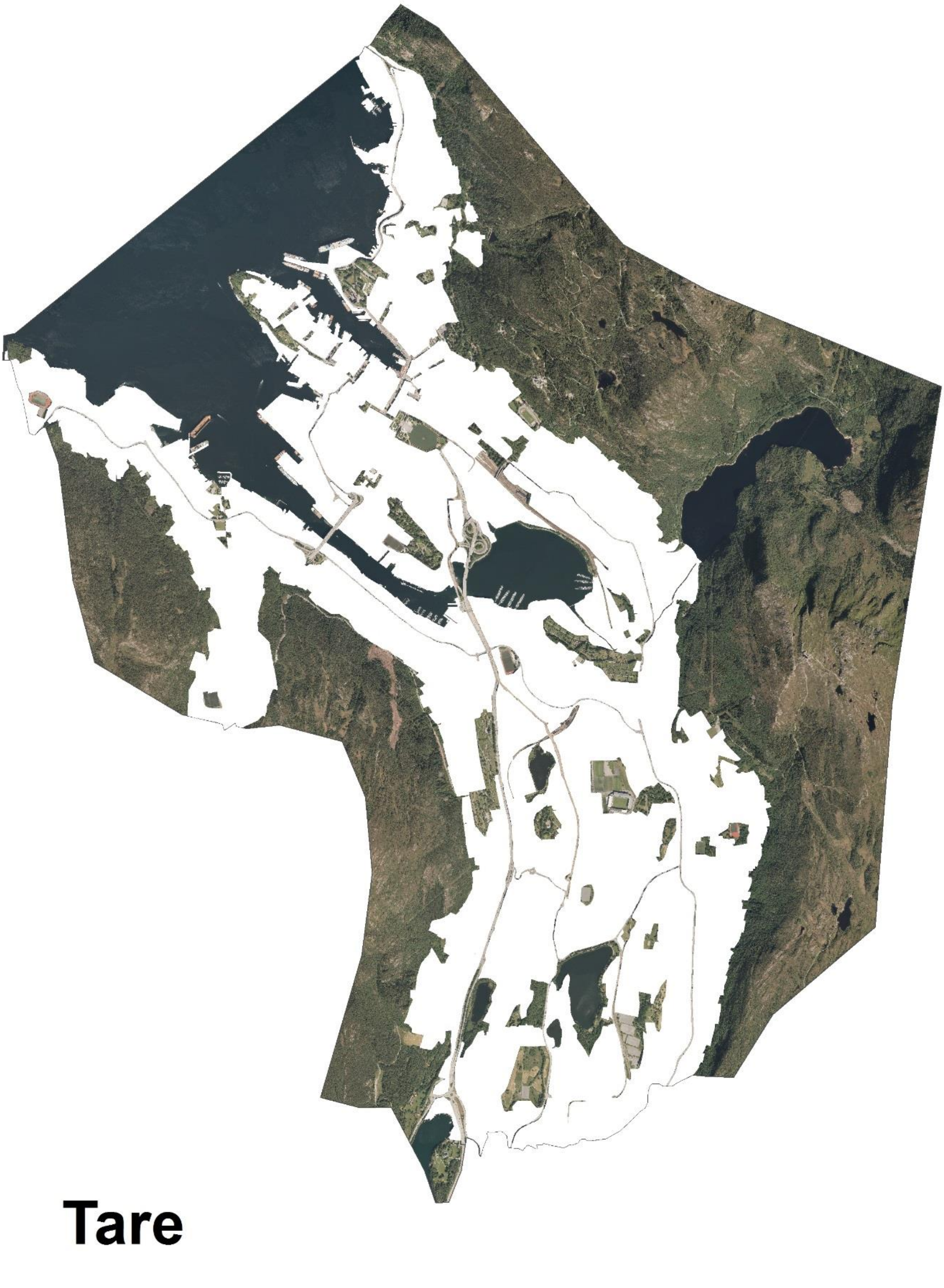


Figure 48 –Map of the tare (district scale) dataset (everything in the orthophoto is part of the tare).

Classification

I followed the Swedish classification described in the (Regionplanekontoret, 2009) Stockholm report when classifying the homogenous zones. This is because it is a tested dataset in a society similar to the Norwegian, and it treats the typologies similar to Berghauser Pont and Haupt and the realistic city analysis approach. An added bonus was that I was then able to use the "flexibility in the built environment" values calculated in the Stockholm analysis.

I examined whether the Swedish classes correspond to Norwegian typologies. In two cases, I did not find a equivalent Norwegian typology, so I refrained from using them. I also found that some dominant Norwegian typologies were not included in the Swedish classes. I evaluated these to be so distinct in terms of density that they needed their own classes.

Table 3 –How the classification I have used corresponds to the Swedish classification. Dark blue rows are new classes not present in the Swedish classification.

Swedish classes	**English translation**	**Norwegian classes**
Open building structure		
Gles småhusbebyggelse	Single family homes (1-2 floors)	Villabebyggelse
Tät småhusbebyggelse	Denser single family homes (1-2 floors)	(not relevant)
Medelhög öppen bebyggelse	Medium height open structures (3-4 floors)	Mellomhøy åpen bebyggelse
Hög öppen bebyggelse	Tall open structures (5 floors or more)	Høy åpen bebyggelse
Closed building structure		
Låg sluten bebyggelse	Low closed structure (1-2 floors)	(not relevant)
Medelhög sluten bebyggelse	Medium height closed structures (3 - 4 floors)	Mellomhøy sluttet bebyggelse
Hög sluten bebyggelse	Tall closed structures (5 floors or more)	Høy sluttet bebyggelse
Verksamhetsområdet	Business district	Næringsbebyggelse
	Row houses (1-2 floors)	Rekkehus
	Historic buildings in medieval street network.	Historisk tre-/murbebyggelse i middelalderstruktur

	Historic trade buildings on the harbour	Sjøboder
	“4-family” housing (2 floors)	4-familiehus
	Unbuilt	Ubebygd

It was not always easy to classify the different areas, particularly those that are characterized by their mix of different typologies. There are many areas which could probably have been placed just as correctly in another class, but which I eventually placed in a class based on their characteristics in terms of densification potential. This is particularly the case with business buildings, which are located in areas defined as centre areas in the master plan (KPA). These are areas that are possible to densify, but where the buildings are often only 1 to 2 floors. I have classified these cases as “mellomhøy åpen bebyggelse” (medium height open building structure), because they in terms of their densification potential have more in common with this class than with the lower height classes.

It is not necessarily the buildings’ age that determines the class, but the street and lot structure as well. A more recent building on a historic lot in a historic street will still be considered as part of the historic class. Many of the brick buildings in the historic class are the same age as the buildings in the “closed block classes”, but again, it is the volumes and overall structure that are important.

Classifying the areas as “open” or “closed” is not always clear-cut. Not all areas fall neatly into the traditional block structure (“kvartalstruktur”) or the modernist house-in-park structure. If in doubt, it is decided based on whether or not the buildings contribute to the creation of a street “wall”. Is it a street with a defined space (“romlighet”) or a road?

It is important to note that the class given to the homogenous zones indicates the general trend of the area. It does not necessarily apply to all buildings within the zone. For instance, I have a rather large fabric in the rectangular block structure in the centre “Høyden” (dark blue in the map). Here the general trend is a mix of buildings, mostly 4 to 5 floors, but there are also lower and taller buildings. I have chosen to give this area the class of the 5 floors and high class because of there in general are more tall buildings. At the same time there are whole blocks with 3 to 4 floors, which might actually belong in the “middle high” class. I have chosen to keep them together because of the general feel of homogeneity in the fabric.

Production of the tare dataset

For the area of study, these types of functions are included in the tare:

-The City Mountains (Byfjellene), defined by the legal boundary (Byfjellsgrensen).

-Protected nature areas

-Large public spaces (Allmenninger og andre store plasser) (x > 1.5 daa)

-Large parks (x > 5 daa)

-Large sports fields (x > 10 daa)

-Cemeteries

-Large bodies of water (x > 1 daa)

-Railroad tracks

-Light rail tracks

-Circulation streets – use street polygons (FKB)

Concerning streets

Berghauser Pont and Haupt define three types of streets in their analysis:

Internal streets

Access streets

Circulation streets

These street categories are related to function and to a certain extent size. They correspond somewhat to the Norwegian categories “Hovedveg”, “Samleveg”, “Adkomstveg”, “Privat veg”. Circulation streets are streets that connect different parts of the city, or different cities with each other. In the Norwegian context circulation streets are both “Hovedveg” and “Samleveg”. They are part of the district tare, and are not included in the homogenous zones. The FKB dataset unfortunately does not include these categories in an attribute. Instead, one can say that “Fylkesveg”, “Europaveg”, “Riksveg” and “Statlig veg” correspond to the circulation street category. Access streets are generally “kommuneveg”, but some of the “fylkesveger” also belong in the access street category. Street width is an indicator here, but more important is that many houses have their direct access onto the street. I therefore choose to delete some of these roads from the tare layer, since I value them as part of the fabric of the areas. They should be included in the density measurement for the fabrics. In the end, it comes down to an evaluation of whether or not the roads ought to be included in the density analysis of the surrounding area.

Internal streets are included in the fabric. Most “privat veg” belong here, and also the access streets in tree-like street networks.

Figure 49 – Block type street network vs. tree-like street network of typical Norwegian villa areas.

Unbuilt areas NOT included in the tare includes small squares and parks, play grounds, parking, small lakes, small football fields, and access streets. These are functionally a part of the fabric and should be included in the fabric density measurement.

It is not always clear whether green space should be included in the tare or not. I finally decided that green space which does not have a distinct function, but is rather “left over space”, for instance in very steep terrain, should be included in the fabric, not the tare. The tare is only unbuilt land with a clear function used by more people than the immediate neighbours. Protected nature sites also belong in the tare.

A note on boundary placement: If the tare, for instance a park, borders an access street with a fabric on the other side of the street, the boundary between the tare and the fabric will be set in the street centreline.

Production of the homogenous zones dataset

Data needed: orthophoto, Google Earth 3D view and Street View, building polygons representing building footprint (FKB bygg flate), cadastral net and street centerlines (Elveg, or most accurate), tare dataset.

The building polygons (FKB) have the attribute "building type" (bygningstype), which is useful to some extent. I placed the building polygons over the orthophoto and gave them different colours according to their defined building types. This gives an indication of which buildings belong in the same zone, but the categories cannot always be trusted to give a proper understanding of the built environment. As an example, the categories are often related to the number of floors a building has, but does not differentiate whether floors are underground or not. So a building can be registered as a 3-4 floor building, but in reality has only 2 floors above ground, which is important in an analysis of urban structure.

Boundary placement

As a rule, the fabric boundaries are drawn in the access street centrelines. Internal area streets are included in the fabric area, while larger circulation streets are not. If a zone borders a circulation street the border is drawn at the street edge. Concretely at the border of the street polygon (part of the tare dataset).

If no road or tare is present, then use a natural boundary or the cadastral boundary, which ever is the most logical boundary of the homogenous zone.

The street centreline dataset (Elveg?) often has a very poor quality. Ideally, the centre line should be constructed based on the street edges, but they are in reality mostly digitized by free hand. I did not have time to construct a better dataset, but judged the inaccuracy to not make a significant impact on the analysis results.

Division into zones

The level of detail of the zones should be more or less consistent. 1 or 2 buildings which are significantly different from their surroundings should still be included in the larger zone.

Both the building typology and the street network type contribute to the division of the zones. The unbuilt areas are assigned to the zones according to actual use. If it is unclear which zone an area should belong to the boundary is drawn in the middle, dividing the area between the neighbouring zones.

Tip! Produce the tare dataset first, and use this, the water polygons, street centrelines and the cadastral mesh as snapping layers when digitizing the homogenous zones. If you select the objects part of the boundary of a zone before digitizing (so that you only snap the line to the selected elements) you will be much more efficient (ArcGIS).

Evaluation

Evaluating the tare and homogenous zones datasets after some use, I am very happy with their utility in the densification analysis. In addition to providing an accurate basis for the density analyses, they can be used to operationalize several variables for the overlay analysis. The dataset has proven to be useful not only for the densification analysis itself, but has also sparked an interest among colleagues in other fields such as landscape architecture and heritage protection.

Still, I have found certain weaknesses, which I would rectify in the next iteration of the datasets. Firstly, it may be that the classification of the homogenous zones is too specific for Bergen. It should be tested on other cities. Secondly, I would remove some of the objects included in the tare, such as the parks belonging to public buildings (the botanical gardens) and the football stadium. After some consideration, I have concluded that they belong in the fabric.

Thirdly, I have not managed perfect consistency in terms of how detailed the homogenous zones area. Some of the smaller zones could probably just as well have been part of the larger neighbouring zone. The next iteration should follow some clear rules about this from the outset. Examining a realistic city analysis of Bergen (Ellefsen and Tvilde, 1991), I realised that some homogenous zones divided by a tare actually belong in the same zone. An example is a built environment organised around a square. They should have been part of the same fabric even though an access street or a square runs between them. On the other hand, I do not think this error affects the density analysis itself. It may be a problem for an architectural analysis of the urban area, but not for an analysis of densification potential.

Fourth, the Spacemate graph for the homogenous zones shows that many of the classes are well defined, but the high and medium height “open structure” classes cover large parts of the graph. This suggests that these classes could have been refined further. For instance, into the strip and pavilion typologies from Berghauser Pont and Haupt. If scale was included in this classification, we would probably be able to define the typologies even better. An example is the “Haukeland sykehus” (hospital) area. This is a pavilion typology, but the buildings are so large that they constitute whole blocks by themselves. On the other hand, I already have 10 different classes. It is already bordering too many.

I went back and forth on the “4-familiehus” class, and whether or not it should be a part of the “rekkehus” or “mellomhøy åpen bebyggelse” classes. In the end, none of the others fit perfectly and the typology was so widespread in the area of study that I decide to keep the class, at least for the first iteration.

Fifth, to increase efficiency I should check if it is possible to use the “bygningstype” attributes in an automatic algorithm to produce the homogenous zones. If accurate, this would save a lot of time. Sixth, considering my argument that function should not matter, it could be argued that the “næringsbebyggelse” (business buildings) - class should be made a part of the “mellomhøy åpen bebyggelse”. In terms of densification, potential there is not really that big a difference between these two classes.

Measuring density

Having produced the homogenous zones dataset, it is an easy task to produce very accurate density maps. As mentioned, I use the multivariate Spacemate density measures (FSI/GSI) because they most accurately describe the physical form of the urban area.

Production

Data used:

FKB Building polygons representing the building footprints.

Matrikkeldata – buildings with information on BRA per building.

Homogenous zones

The FKB Building polygons dataset is not one hundred percent accurate. Some houses have the roof, while others have the foot print as basis for the building polygon. Particularly the villas use the roofs, which means that they will get a larger GSI than what they have in reality. The difference is not very large however. In the city centre of Bergen the data tends to use the building footprint, giving better results.

Use spatial join to connect the zones with the building data. Sum the total amount of BRA per zone, and the total area of the building footprints per zone. Calculate the FSI, GSI and OSR values in a new field in the attribute table. The FSI and GSI values can be used with the "Create Graph" function in the attribute table to create a Spacemate graph (seen in figure 45).

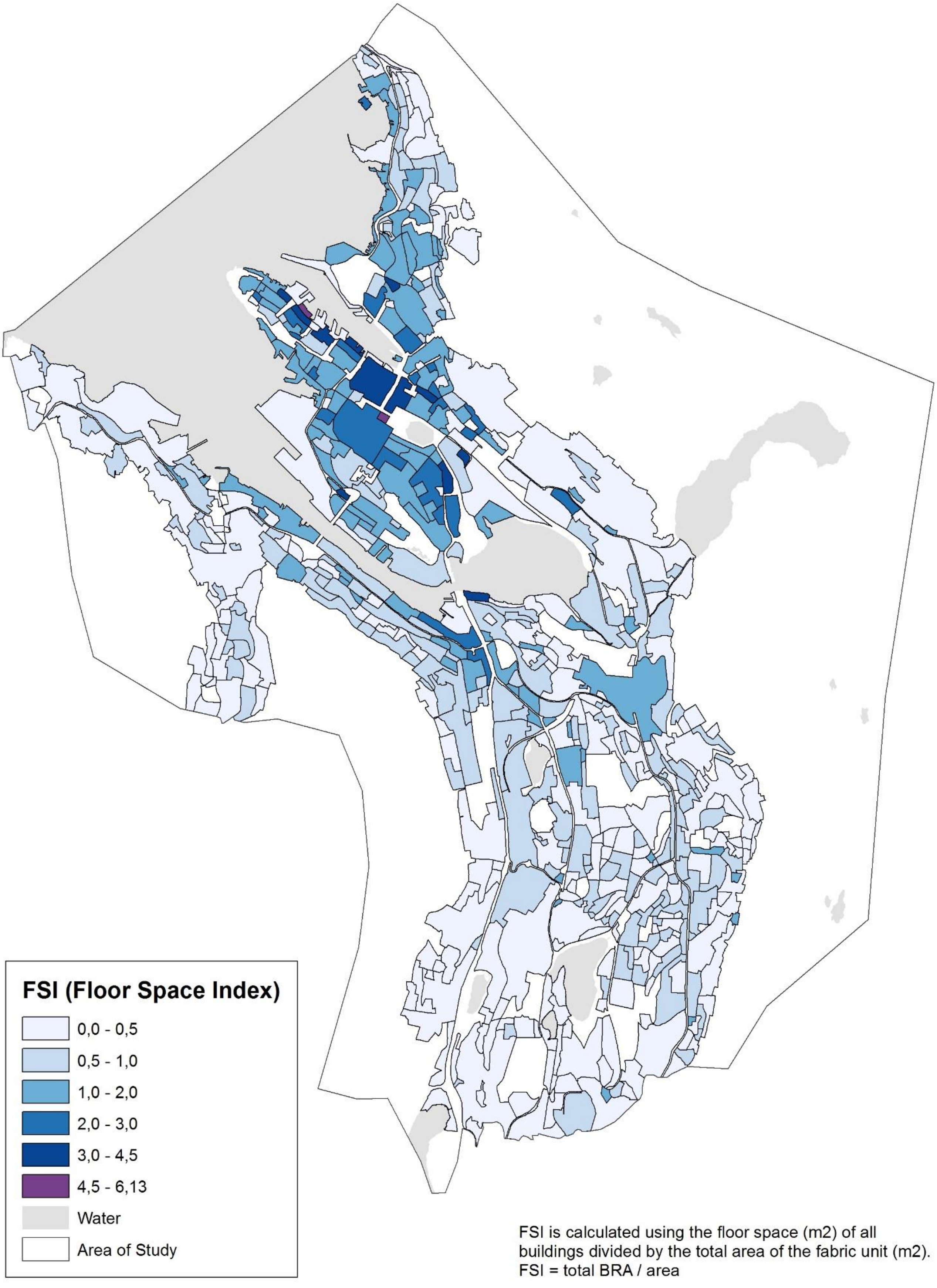


Figure 50 – FSI values of the homogenous zones.

The FSI map in figure 50 is a familiar way to visualize density in a map. Having the homogenous zones gives a more accurate description of the built environment, than a map using administrative zones is able to. The map below (figure 51) shows the same calculation of FSI value, but based on the “grunnkrets” units normally used in Norwegian density analyses instead of the homogenous zones. There is a significant difference in the values given to different areas. The same trends can be seen, but the homogenous zones are able to distinguish nuances better. The “grunnkrets” units were constructed in 1980 for use in statistical analyses of various kinds (SSB, 2014b). Coherence of the building structure is here one of the criteria used to construct them. They should also be homogenous in terms of nature type, business category and communications. The problem with the “grunnkrets” units for use in an analysis of urban structure is that they cannot change as reality changes, though this means they become more and more inaccurate as time passes. They are constructed as statistical units and changing them would make comparisons across time impossible.

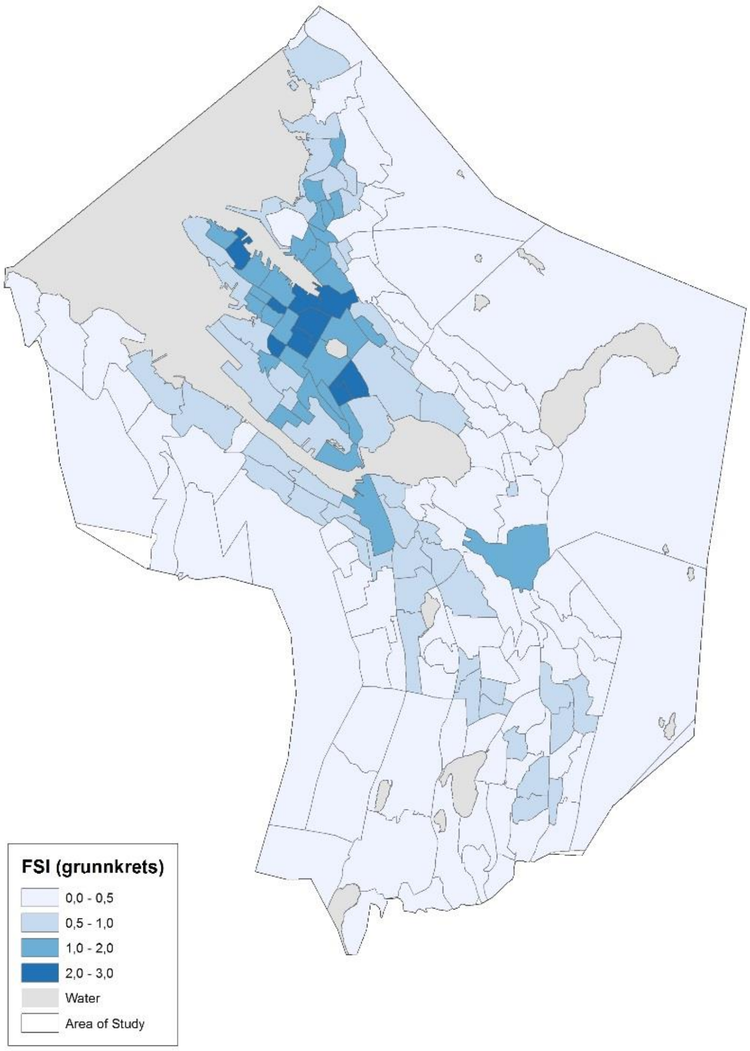


Figure 51 – FSI values of the area unit “grunnkrets”(base unit), normally used in Norwegian density analyses.

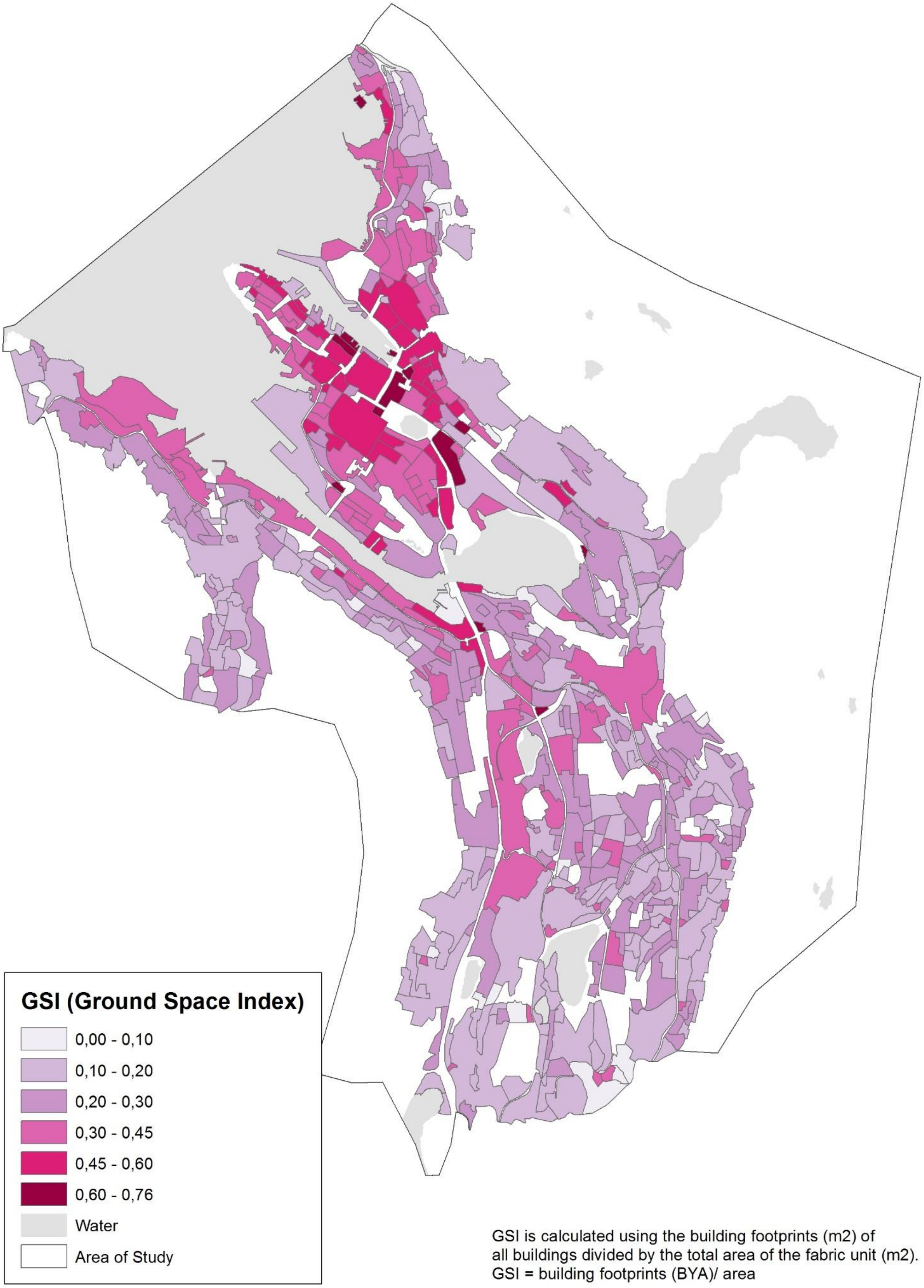


Figure 52 –GSI values of the homogenous zones.

Now to a comparison of the FSI map to the usual density measures of population density and dwelling density. Producing a population density map of Bergen is difficult, because as mentioned the data material is lacking. It is therefore recommended to use dwelling density, because these data are more reliable. Using this data one can calculate approximate population numbers from studies showing the average number of persons per dwelling in different parts of the city. The dwelling density map shows a different city than the FSI map. It gives the impression that business districts have very low densities, though the FSI maps shows some of them to have the highest densities by far. Very low density areas, such as the high-rises south in Fantoft seem to be some of the densest in the city. This gives little realism to the actual densification potential in the area.

When we consider the FSI map together with the GSI map a more nuanced image appears. The bulk of the floor space is in the city centre, but further out we see a less efficient use of space, where lower buildings spread out and consume more land with larger building footprints. Analysing two maps in this way is complicated. The spaciousness (OSR) map is therefore a very interesting alternative. The OSR value is a combination of the FSI and GSI values, and could be argued to give the most accurate idea of experienced density. This map can be used to evaluate which areas already have too little open space, which would exclude them from densification unless one at the same time provides new open spaces, such as new parks or squares.

By studying the spaciousness map, we see that the high-rise area in Fantoft has similar amounts of open space as the villa areas surrounding it. This could indicate that the area can accommodate new development, which could potentially be quite large, like the existing typology. The interpretation of the map is easier with some local knowledge, to determine how dense a certain OSR value actually feels in reality.

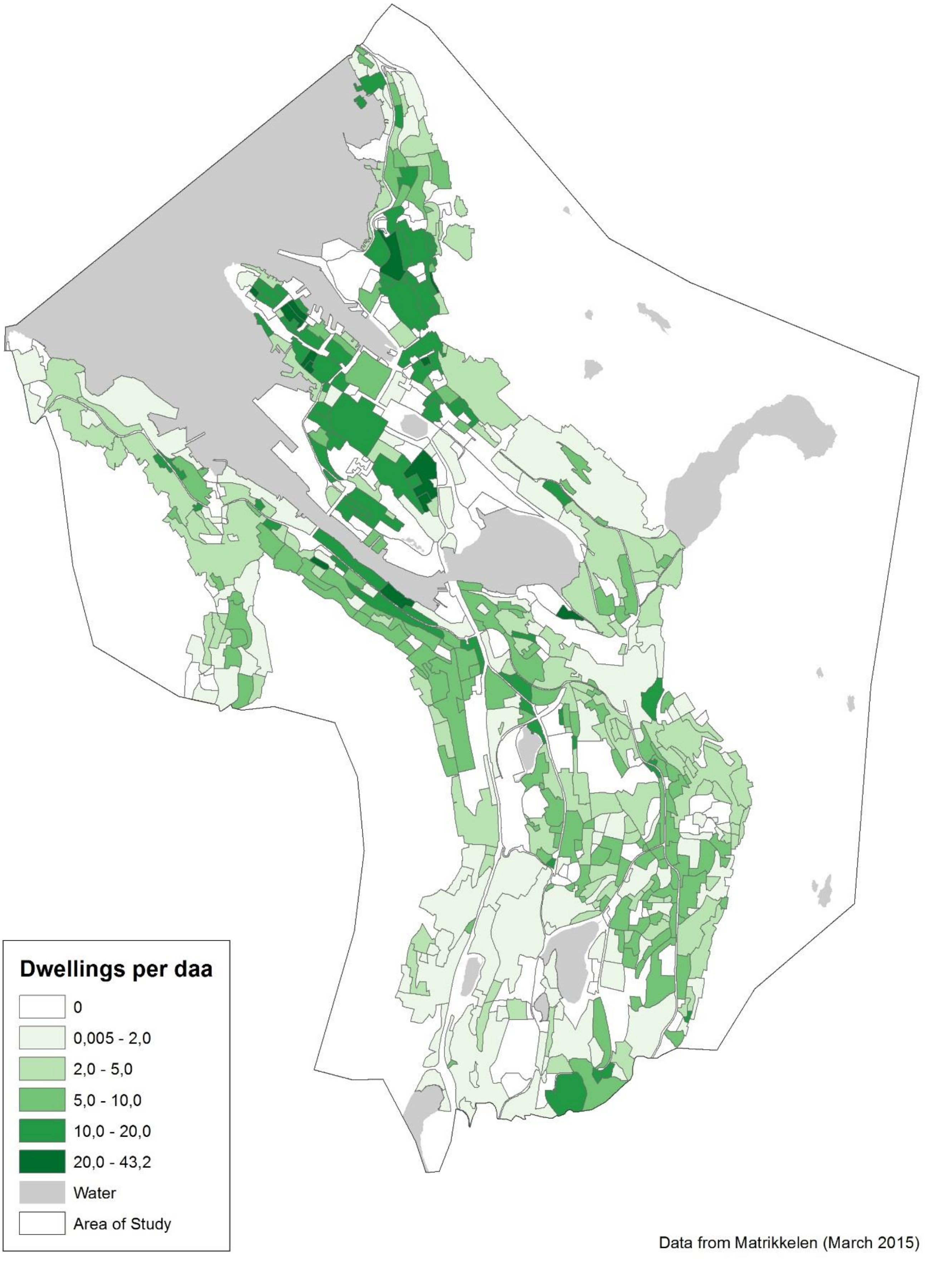


Figure 53 – Dwellings per decare in each homogenous zone.

I decided to use the Spacemate approach, rather than the Spacematrix, since simplicity is an issue. Introducing a new concept is difficult enough itself, without having to accustom people to read 3D graphs. Therefore, I did not put priority on using the Network Density variable. The production of such a map is rather time consuming, so it will have to wait until the second iteration. It is nevertheless valuable to be reminded of the issue of scale.

I have named Spaciousness "Romslighet" in Norwegian. The term "Romlighet" is already taken by the landscape architects and has a very concrete meaning.

Evaluation

I believe that these density measurements are more useful than population density and dwelling density when determining densification potential. It will be difficult to introduce these new concepts, but it will be worth the effort in my opinion. Particularly the spaciousness measure should be adopted. GSI in itself may not be that interesting, but Spaciousness combined with the current Norwegian FSI ("utnyttelsesgrad") measure could be practical to introduce. It would mitigate the problem Silje Hoftun[16] mentioned, where only quantitative density regulations are heeded, while the qualitative regulations are forgotten. Giving open space its own quantitative regulation would increase its impact on plans.

[16] Interviewed in Oslo January 30th 2015

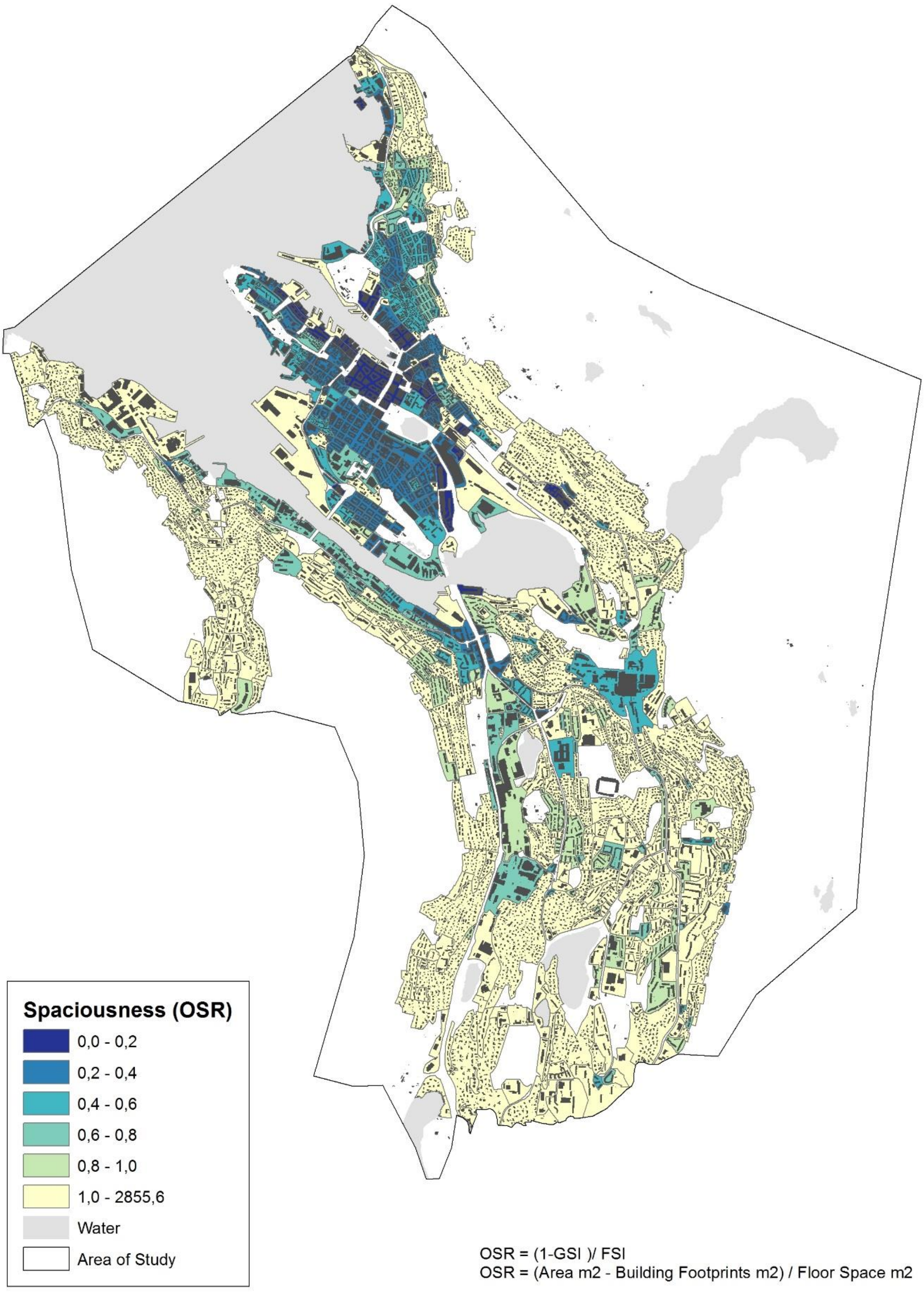


Figure 54 – Spaciousness values for the homogenous zones. ("Romslighet")

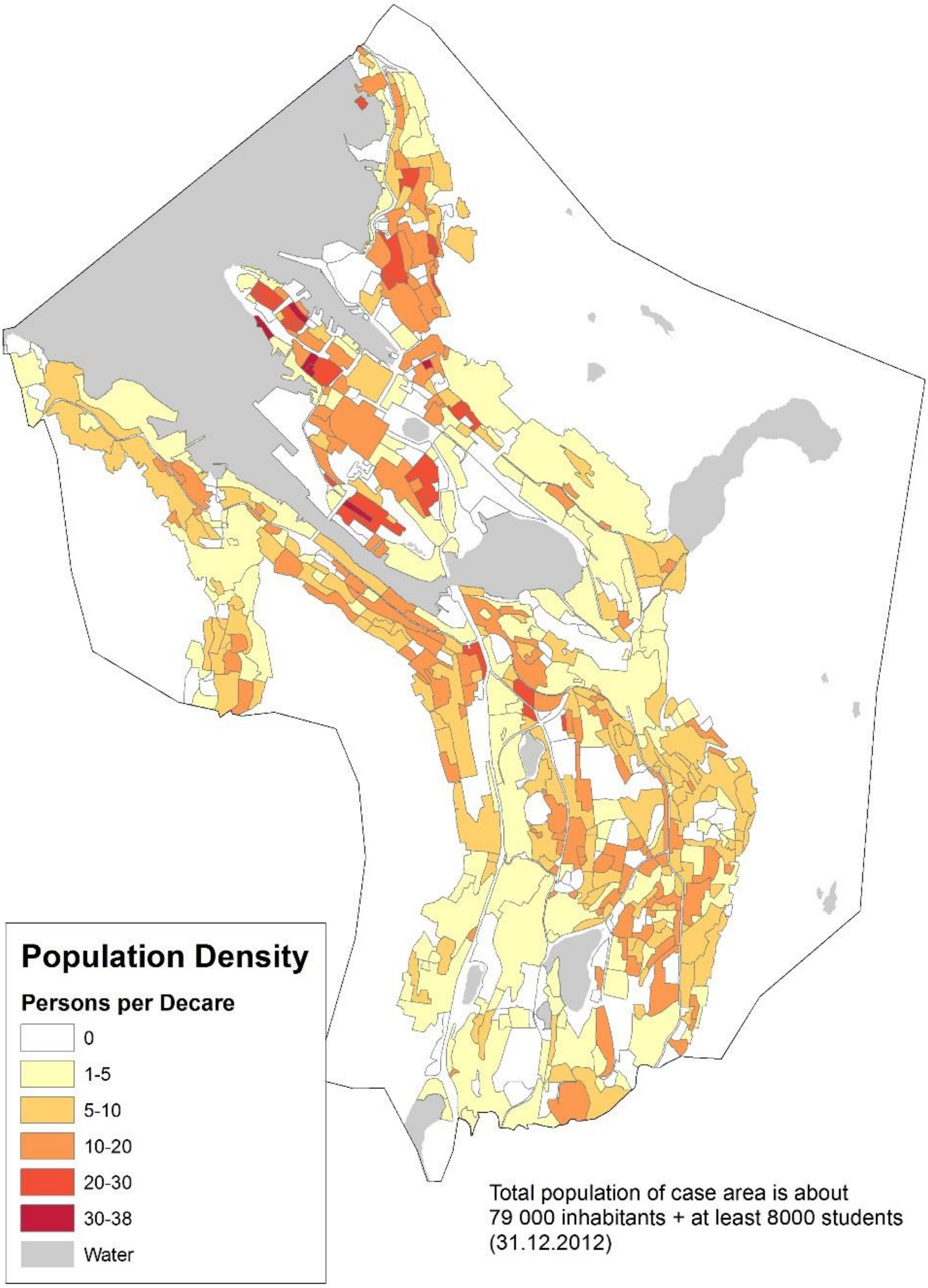


Figure 55 – Approximate population density using National Registry data. The unregistered students are not included in the density calculations.

Part 2: Overlay analysis – densification potential at the citywide scale

The next part of the methodology consists of an overlay analysis conducted at the citywide or regional scale. The overlay will identify areas where densification should take place based on a defined set of variables. The Stockholm analysis has been a great inspiration for the development of this part of the methodology. Most of the variables included there are also included here. I have modified the method somewhat, where Regionplanekontoret use the Densification Rose, I have combined the variables in a traditional overlay analysis. I have also defined and operationalized the variables somewhat differently. Sometimes this was because they needed to be modified to suit Norwegian conditions, other times because I felt a different definition was in order, or because I wanted to test a different analysis technique.

Variables

A major issue in the method development has been which variables should be included in the overlay analysis. It is time to answer the second research sub-question:

> Which spatial variables/ criteria must be met in order to achieve good densification?
>
> a. Which variables/ criteria decide where we can densify?
> b. Which variables/ criteria decide where we should densify?
> c. Which variables/ criteria decide how to densify?

I quickly realised starting with the "can" variables, that there really are no such things. There are no absolute variables that can determine that development is not physically possible. Land can be claimed in the sea and mountains can be torn down. Faced with this realization one quickly thinks that surely there are some variables that make realistic development impossible, for instance rockslide danger zones. But considering this variable, it really comes down to a matter of economics and landscape concerns, which is the realm of the "should" variables. A risk of rockslides can to some extent be mediated by taking measures to secure the slope. At some point, this does not become feasible, but at which point that happens is very difficult to determine. We do not have access to maps showing these "impossible" zone, only maps showing zones where one has to evaluate the risks further in each case. We cannot use these maps to say that development in general is impossible at the citywide scale.

Figure 56 –Proof that steep slopes and mountainsides do not rule out development. Positano, Italy and Taktshang Monastery, Bhutan (Photo source: Google)

This realisation led me to conclude that creating three different maps of densification potential, one for “can”, one for “should” and one for “how”, was not the most practical approach. Instead, it is better to change the initial method design to the production of two maps:

1. A citywide “here we SHOULD densify”- map.
2. A local more detailed “here’s HOW to densify” – map.

Both these maps can be fashioned according to different scenarios. The scenarios for the first map are created through the choice of which variables that are included and what weight they are given. The second map’s scenarios are based on the amount of densification and how far the new development departs from the existing context. The scenarios developed by Regionplanekontoret in the Stockholm analysis are examples of this. The current chapter will present the development of the first map; the SHOULD overlay.

Variables for the SHOULD map

Numerous variables are described as relevant to densification in the literature and in the interviews. I evaluated the variables according to whether they indicate where we should densify or indicate how to densify. Some variables fit somewhere in the middle between these two categories. Many of the variables are repeated by different sources, though sometimes defined slightly different. The analysis cannot practically include all the different variables, so a choice had to be made. I found that the set of variables in the Stockholm analysis contained a fairly good cross-section of the variables, which would work well for a Norwegian methodology. Not all of them fit the case area however, something I will discuss further below.

Table 4 – Variables for the overlay analysis

Variable	Stockholm densification category
Topography	Densification room
Unbuilt land	Densification room
Access to existing infrastructure	Densification room
Flexibility in the built environment	Densification room
Distance to city centre	Densification pressure
Mixed use – number of functions	Densification pressure
Access to public transportation	Densification pressure
Access to green space	Densification pressure
Access to water	Densification pressure
Industrial land	Densification freedom
Protected land	Densification freedom
Spaciousness	Densification freedom
Complexity of ownership	Densification freedom
Utilization of existing public transport	Densification need

To prepare the variables for the overlay analysis they are operationalized into raster maps, where the cells are given values between 0 and 1 in terms of their densification potential. Some variables have a binary value scale (0 – 1), and others have a continuous value scale.

The rasters are produced using a raster template as “snap-raster” to ensure that the cells line up. The cells are 2 x 2 m in size. This works well on an 35 km2 area of study. Should the analysis be applied to a larger area, the cell size may need to be bigger due to computer processing restraints.

Overview of data needed for the overlay analysis

Table 5 – Datasets needed for the construction of the overlay analysis

Case area polygon
Snap raster (Template raster based on the case area polygon.)
The homogenous zones dataset
Tare dataset
FKB Building polygons
FKB Water polygons (delete lakes smaller than 1 decare and all rivers)
FKB Road polygons
FKB Contour lines or Lidar data
FKB Water lines (used to create the elevation raster)
FKB Road lines (used to create the elevation raster)
Road network dataset (preferably pedestrian)
Public transportation stops as point feature class (Only high frequency rail and bus lines.)
City centre represented as a point feature class
Business registry as point data ("Bedriftsregisterdata")
Master plan map data
Green space map data
Protected land map data
Cadastral data – polygons ("Matrikkelenheter")
Cadastral data – building points ("Bygg i Matrikkelen") with information about floor space and building function
Cadastral data – address points ("Adressepunkt i Matrikkelen")
Excel file - number of owners per property (see page 168)
Excel file – number of part owners per housing cooperative (see page 168)
Population data as points ("Befolkningsdata")

Topography

The topography raster layer has a binary value scale, where 0 (red in map) is given to cells that are either steeper than 100% or between 33% and 100% incline with a north-east aspect (0 – 90 degrees). The cells with value 1 (green in map) is therefore considered to have potential for development in terms of the topography variable.

Production of topography raster

Data needed: Contour lines, Case area polygons, Snap raster, water polygons, water lines, road polygons, road lines.

Create an elevation raster using FKB høydekurver (contour lines) or laser data. Same cell size as overlay raster.

Use this to create a "Slope" raster and an "Aspect" raster. Use "Reclassify" to set all cells in the Slope raster steeper than 100 % (45 degrees) to 0, the rest to 1.

Create another raster with the Slope and Reclassify where all cells steeper than 33% are given the value 1, the rest 0. Then use Reclassify with the Aspect raster to create a raster where the cells facing North-east are given the value 1.

Multiply these last two rasters together using the Raster calculator (raster algebra) to create a raster where the cells that face north and have more than 33% slope are 1, the rest 0. Reclassify this raster so that the values are switched.

Add the resulting raster to the slope reclass using the raster calculator. The result is the finished product.

The Stockholm analysis used a maximum slope of 20% to evaluate densification potential. In Norway, a slope of 1:3 (33.3%) has traditionally been used as a recommended limit for development of residential villa areas (Fylkesplanen for Sogn og Fjordane 1980-83). Bjørneboe set a slope of 1:3 as the maximum for single family homes (Bjørneboe, 2000). However, he set 1:1 as the maximum for terrace houses ("terrassehus"). This incline means that outdoor stairs are no longer possible, and a problem with terrace houses (Norwegian typology) is their profound impact on the landscape. A slope of 1:3 is considered the maximum for outdoor areas ("leke- og uteoppholdsareal"), among other places in the Municipality of Bergen's master plan from 2010 (Bergen kommune, 2010). The landscape architects operate with 1:2 as the maximum for where it is difficult to make plants grow.

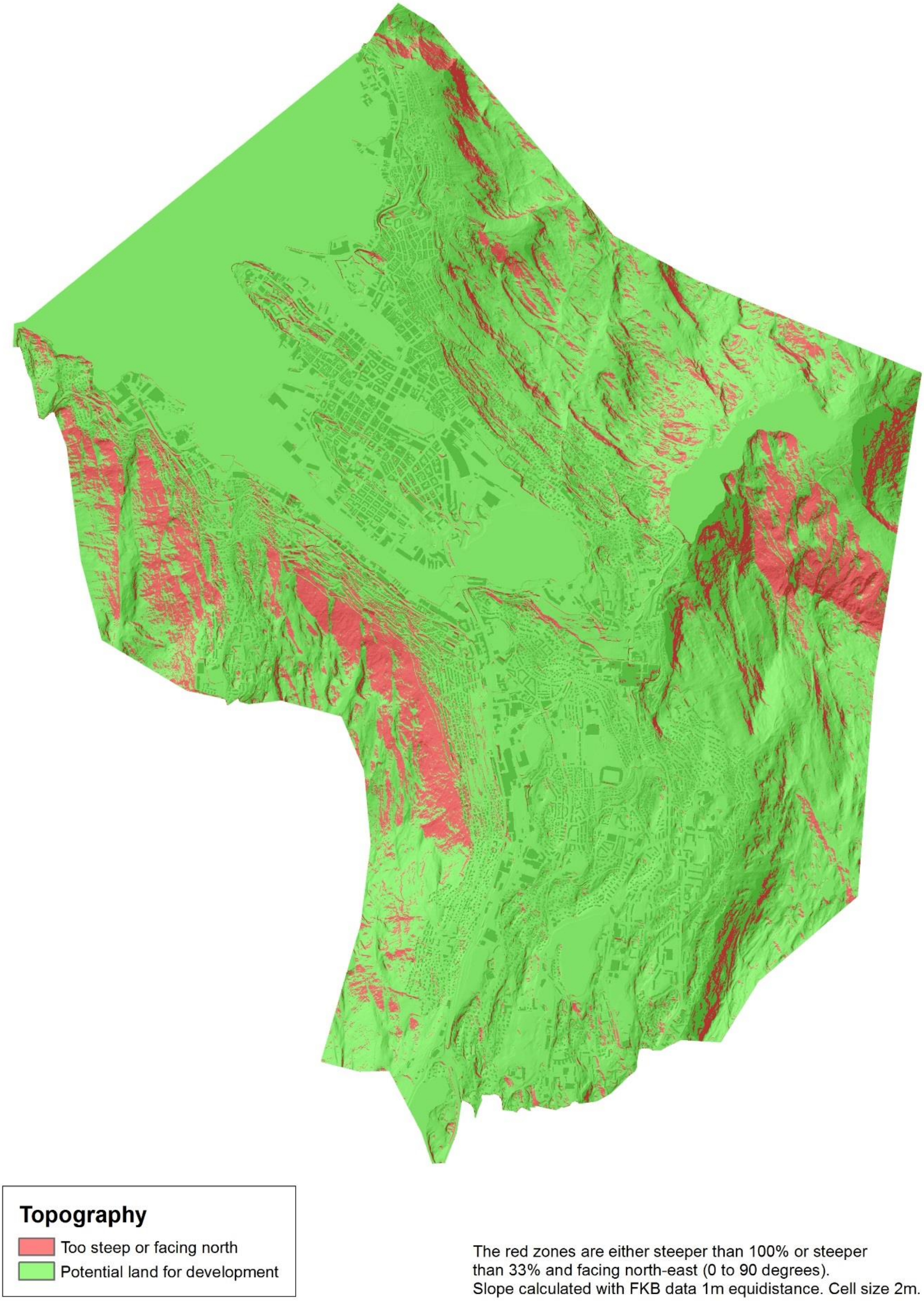


Figure 57 – Map showing the topography variable used in the overlay analysis.

Talking to engineers, landscape architects and architects in Asplan Viak it became clear that it is not possible to set a clear limit to how steep the terrain can be to allow densification. In Bergen today, it is often the lots with very steep terrain that are densified. A 1 decare lot with an elevation difference of 10 meters is actually a great location for developers, because they are able to cut into the terrain and build very tall and dense buildings, while keeping below the maximum heights in the area. This strategy does not work well for lots facing north, however.

With the housing prices as high as they currently are the extra costs this terrain modification entails seems not to deter developers (Christian Irgens, architect). Bergen has a much more varied topography than Stockholm and many existing buildings are located in steeper terrain than 20%. The Swedish measure will therefore not work well in this area. A different limit must be set. The problem is, as mentioned, that we do not currently operate with a specific limit, at least not one that is one single variable.

Steep slopes are attractive as sites for densification, but they become problematic when they are large enough, in particular related to falling rocks. High mountainsides may not be suitable for development. The smaller slope areas are not attractive when they face north. Figure 58 shows the degrees of aspect not suitable for residential development.

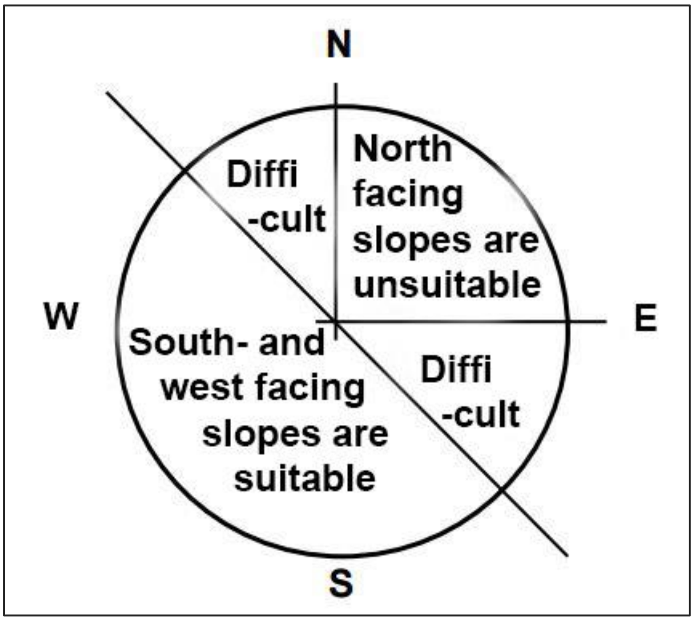


Figure 58 –Figure showing which degree of aspect to the northeast is problematic for slope development. (Christophersen, 2014)

An interesting by-product from this discussion could be a separate map showing densification potential in slopes. This map would show only the areas with a slope of more than 1:3 within the existing urban area, minus those that face to the northeast. Areas that are identified and are not already developed may be good candidates for densification.

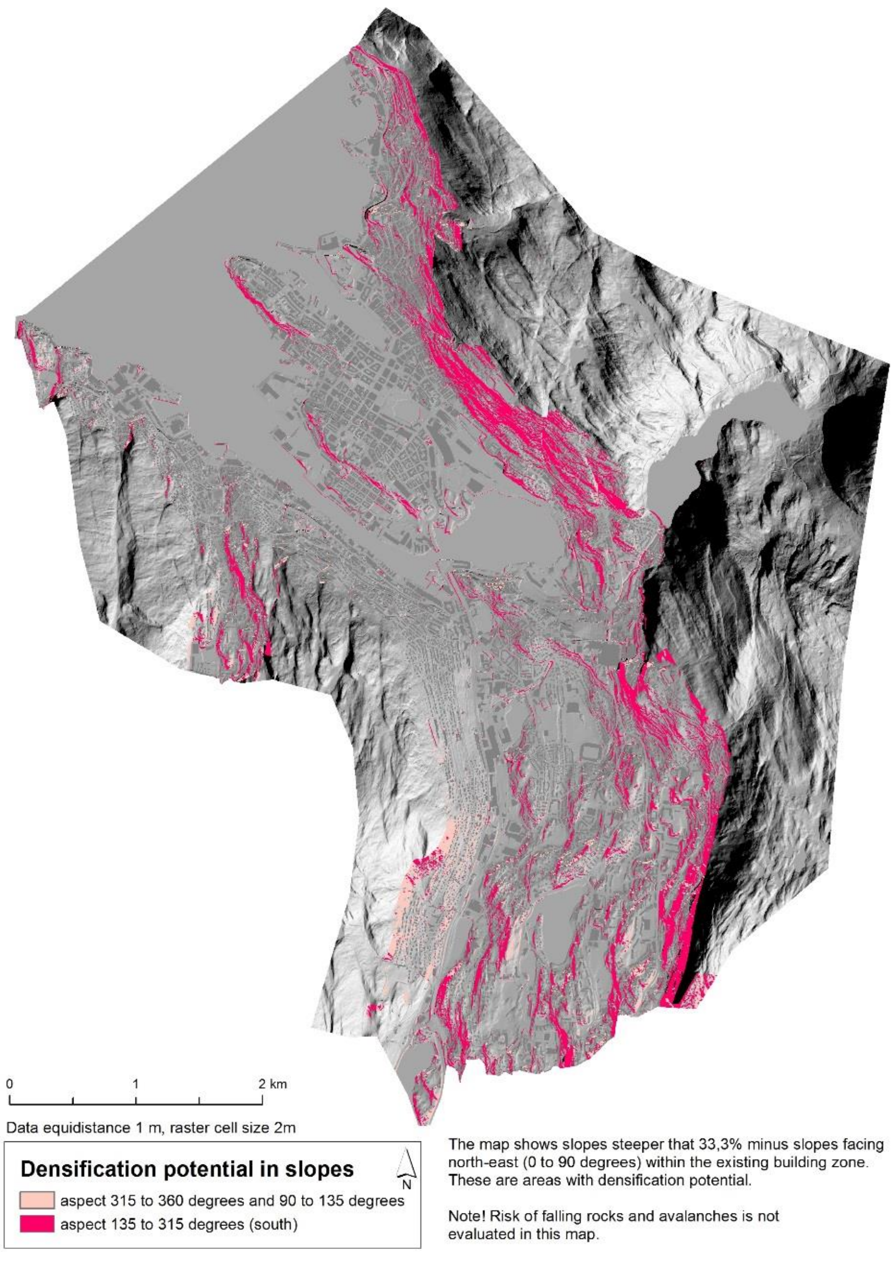


Figure 59 –Map showing steep slopes with good aspect value. These may possibly have densification potential.

A major issue with topography in development projects is risk of rockslides and avalanches. Where there is available data on areas with proven danger these could very well be included

as zero value cells in the raster. For the area of study, such data is not available. This is also the case for large parts of Norway. What we do have is polygon data showing potential of risk, meaning that the actual risks must be evaluated in each individual development project. Not even the Bergen master plan (KPA) have danger zones for rockslides. This means that the danger of falling rocks cannot be included in the topography layer. The analysis will therefore contain a weakness, which must be made clear to anyone interpreting the results.

One could argue that the topography variable should be removed from the analysis all together. The issue of landslide and avalanche risk is an important point, but it is one that seems to be too complex to include in the analysis. To exclude topography as a variable completely seems problematic, however. It is necessary to evaluate the effect of the mountains around the built zone. It is not easy to continue the urban structure much higher than the existing urban structure already has climbed up the mountainsides. When the slope is 1:1 it is difficult to stand. This suggests that large areas cannot be developed, but that smaller lots with this slope that are surrounded by flatter landscape can be developed.

Evaluation

The topography variable is tricky to operationalize because of the complexity of evaluating development potential. Such a general analysis as this will not be able to evaluate each lot for suitability. This evaluation must come later, when lots are analysed in detail. The risk of rockslides and avalanches must be considered. I decided to keep the variable in the analysis because it does at least clear out some truly unsuitable sites.

This operationalization of the topography variable is developed to suit conditions in Bergen. Cities with different topography and housing markets should operationalize the variable to fit their situation.

Unbuilt land

This variable is much easier to operationalize than the previous one. It is easier and less expensive to add new buildings without demolishing existing buildings, so the presence of a lot of unbuilt land in an area gives it greater densification potential. Unbuilt land can have important functions, such as parks. Parks and other green space are less costly to develop if allowed. This is why parks need extra protection, which this variable cannot give them. Bear in mind that the variable does not show that these unbuilt areas have varying degrees of availability for new development. Roads are not included in the unbuilt category.

Production

Data needed: Case area polygon, Snap raster, buildings polygons, road polygons, water polygons.

“Erase” the case area polygon using the building polygons, water polygons and street polygons. Give the remaining polygons the value 1 in a new raster value attribute. Use “Feature to raster” to convert the polygons to a raster. Remember to use the template raster as snap-raster. The NoData cells must then be reclassified to 0.

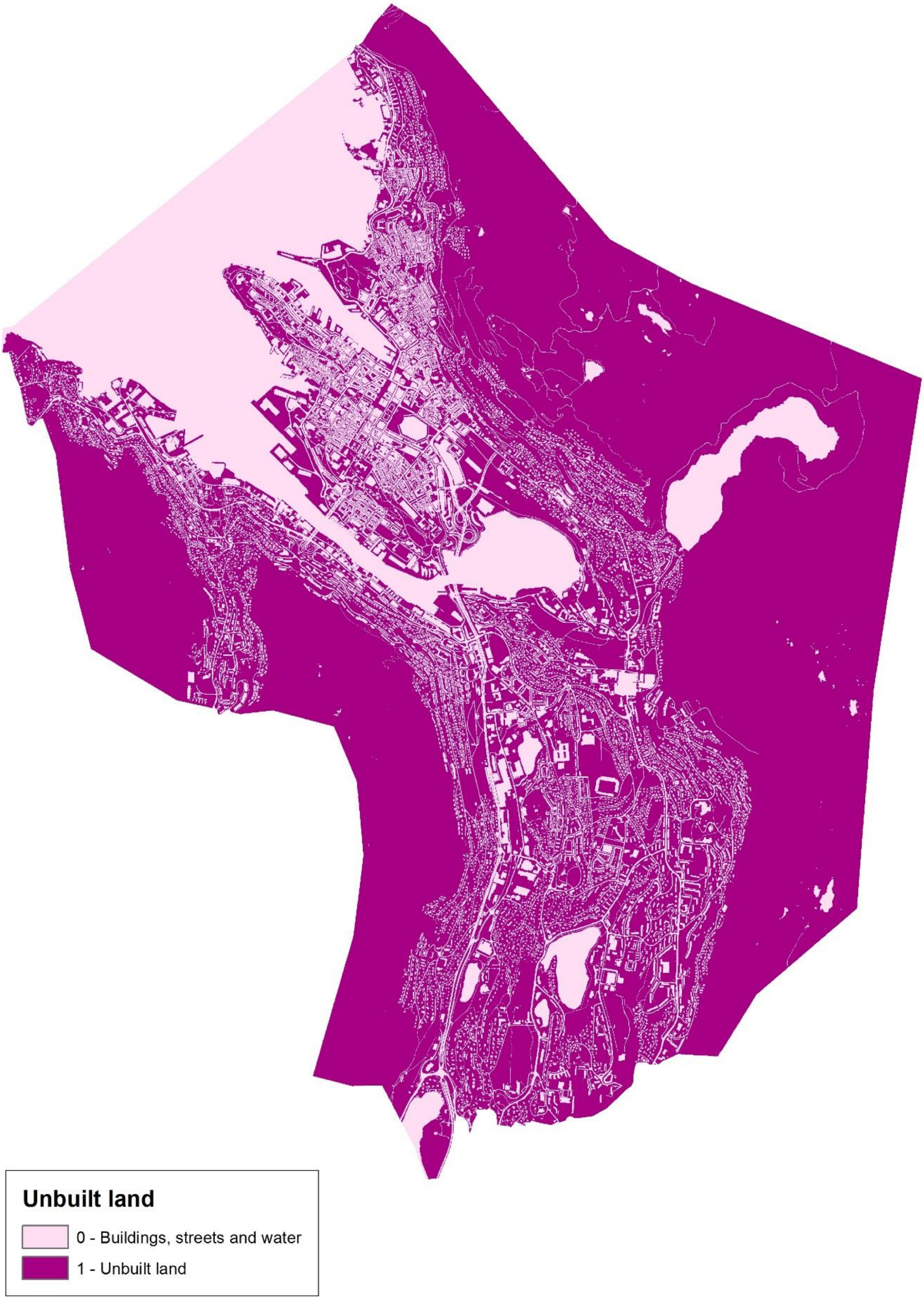


Figure 60 – Map showing the unbuilt land variable.

Access to existing infrastructure

This variable indicates costs related to new development in an area. If one can take advantage of existing infrastructure, such as roads, electricity and piping, the costs will go down. Ideally, we should produce a map that shows where existing infrastructure is available and whether or not it has available capacity. This information is unfortunately so complicated to represent in a map that it is not feasible to gather it for this analysis. Therefore, a simplified version is necessary, which takes advantage of available map data. The Stockholm analysis has operationalized the variable by using a buffer of 50 m on the street polygons. Existing roads are therefore included in the analysis, and where there are roads one will usually find piping and electricity, at least within the urban area. The raster map has included road buffers along the Svartediket and on the city mountains. Here piping and electricity nets are not present, so one could argue that the roads outside the urban structure should be deleted from the analysis. I have chosen to include them as a test to see how much they will impact the analysis.

The availability of schools and nursery facilities can be viewed as part of the infrastructure, but they are not included in the analysis. In the area of study, there is a shortage of nurseries, but available capacity in the schools. These numbers are not practical to include in the analysis at this point. Should a school run out of capacity it can be expanded, or a new school can be built. The number of new nurseries or schools necessary should rather be evaluated at the detailed local scale in part 3 of the methodology, not on the citywide scale of the overlay analysis.

The buffer distance of 50 m is copied from the Stockholm analysis. It has not been justified in the literature and may be somewhat arbitrary. A 100 m buffer would probably include some land without infrastructure, so this seems too much. A buffer distance less than 50 m would include very little land, and would mean that the variable had very little impact in the analysis.

Production

Data needed: case area polygon, snap raster, road polygons, water polygons.

Use the FKB street polygons, include all road types except forest roads. I also deleted some irrelevant objects in the dataset: “traktorveg” and some very large parking lots (“parkeringsområde”).

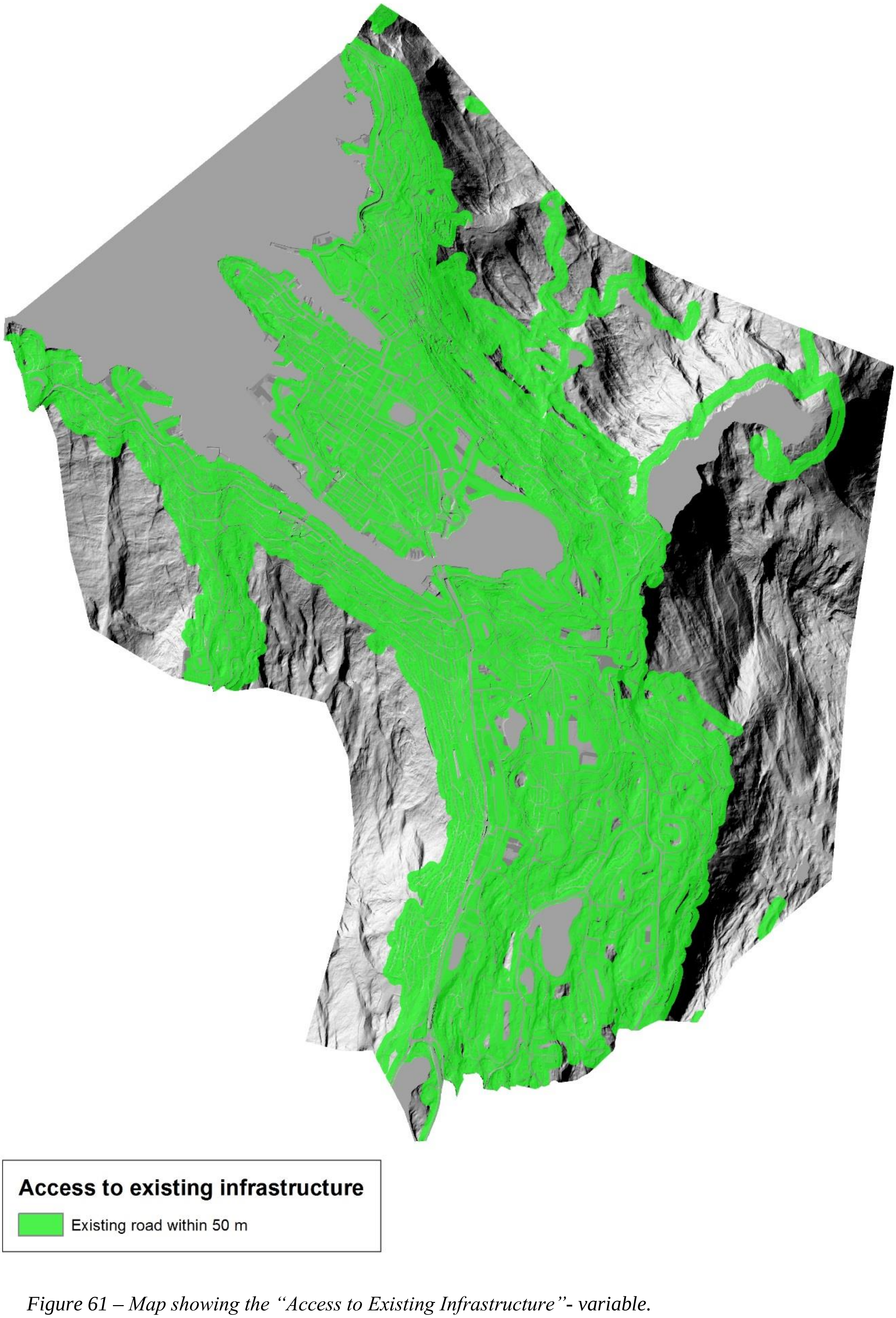


Figure 61 – Map showing the "Access to Existing Infrastructure"- variable.

Create 50 m buffers outside of the road polygons, not including the road area. By excluding the road area this will get a lower value in the overlay, letting it stand out from the surroundings. Use the water polygons to clip away water from the buffers. Give the remaining polygons the value 1 in a raster value attribute. Use Feature to Raster to convert. Use the snap raster. The NoData cells must be converted to 0.

Flexibility of the built environment

The flexibility variable is included to evaluate the difficulty of further development within an existing building typology. As argued by Regionplanekontoret (2009), there are varying degrees of transformation potential within the physical structures of different typologies due to among other things demands for sunlight and access to outdoor areas. Closed block structures are generally less able to accommodate infill than open pavilion structures (Regionplanekontoret, 2009).

This variable has great advantage of the homogenous zones dataset. Since the classification used is comparable to the one used in the Stockholm analysis, I am able to use their research into the development potential of the classified typologies. Through experimentation with the different typologies based on different densification scenarios, they calculated the number of potential new dwellings within each typology. The number of new dwellings in each of the four scenarios were calculated and an average index derived for each typology class.

Table 6 – Scenarios used in the flexibility experiments (Regionplanekontoret, 2009).

Scenario	Urban structure	Development	Building heights	Action
1. Infill	Keep existing structure	New buildings	Same heights as existing	Preserve exist. buildings
2. Lift	Keep existing structure	Add floors	+50% building heighs	Preserve exist. buildings
3. Renew	Keep existing structure	New buildings	+50% building heights	Preserve exist. buildings
4. Transform	New structure (street network)	New buildings	+50% building heights	Demolish 10 - 20 %

The scenarios are meant to be realistic and respectful of context, so that only a percentage increase in density from the existing structure was calculated. The idea is to respect the current building environment as much as possible. This means that residential areas dominated by single-family homes will get a low value, because even though there is a lot of available space, the density is so low to begin with, that a new density cannot be very high.

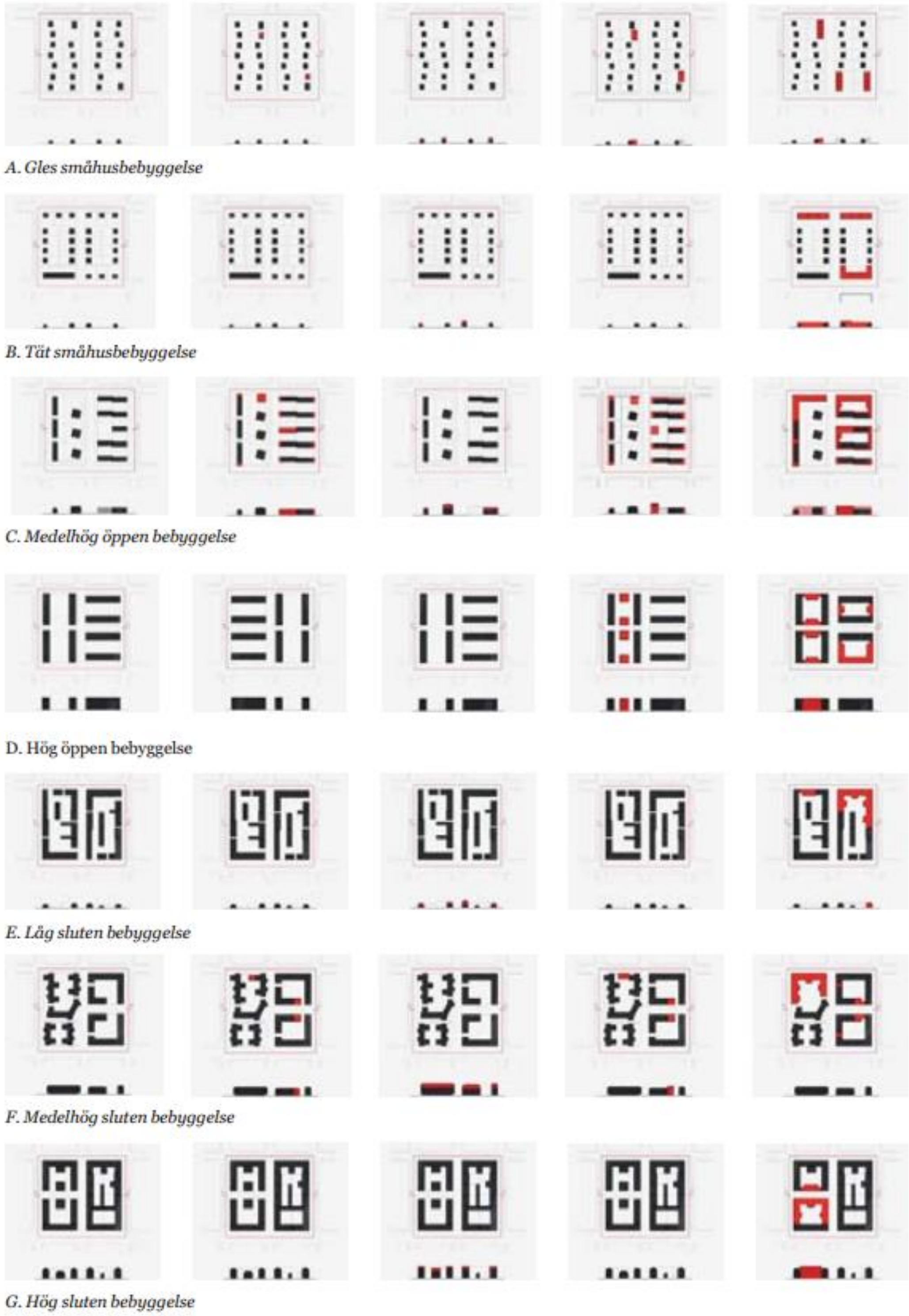


Figure 62 – Exploration of densification potential in the Swedish building structure classes. (Regionplanekontoret, 2009:34)

Tabell 4. Bebyggelsetypernas genomsnittliga förtätningsutrymme och ungefärlig ökning av exploateringstal.

Bebyggelsetyp	*Viktat genomsnittligt förtätningsutrymme*	*Ungefärlig ökning av exploateringstal*
Gles småhusbebyggelse	26 procent	0,03
Tät småhusbebyggelse	17 procent	0,04
Medelhög öppen bebyggelse	55 procent	0,2
Hög öppen bebyggelse	10 procent	0,1
Låg sluten bebyggelse	7 procent	0,02
Medelhög sluten bebyggelse	14 procent	0,05
Hög sluten bebyggelse	5 procent	0,1

Figure 63 – Values given to the Swedish classes for possible approximate increase in density (Regionplanekontoret, 2009:36) .

It is a weakness in my analysis that I have not been able to conduct a similar experiment based on the Norwegian classes. A second iteration of the method should include a similar evaluation of Norwegian typologies. I have attempted to match the Swedish classes as closely as possible to the Norwegian built environment, so that I am able to rely on the flexibility values. For the Norwegian classes that do not correspond to a Swedish class, I have given an approximate value based on the Swedish Flexibility index. For instance, I have judged the "rekkehus" and "4-familiehus"- classes to be relatively similar in terms of flexibility and somewhere in the middle between the Swedish "tät småhusbebyggelse" and "låg sluten bebyggelse". They have therefore been given the average values of these two classes. The historical typology classes are much less flexible than "rekkehus" and "4-familiehus", both because they are already so dense, and because the streets are very narrow. There is very little unbuilt land within this typology. Because of this, I evaluate them as having very little to no flexibility and have given them values accordingly. The "høy åpen bebyggelse" class has been given the same value as "mellomhøy åpen bebyggelse", because I judge it in terms of flexibility to be comparable to this class rather than the Swedish "Hög öppen bebyggelse", which is generally denser. At least within the current area of study.

Table 7 – Flexibility values for the Norwegian classes used in the overlay analysis.

Norwegian classes	**Value for flexibility**
Villabebyggelse	0.26
Rekkehus	0.12
4-familiehus	0.12
Historisk tre-/murbebyggelse	0.01
Sjøboder	0.01
Mellomhøy åpen bebyggelse	0.55
Høy åpen bebyggelse	0.55
Mellomhøy sluttet bebyggelse	0.14
Høy sluttet bebyggelse	0.05
Næringsbebyggelse	0.55
Ubebygd	1.00

A problem with the Swedish experimentation is that the courtyards in Bergen's closed blocks in general are much smaller than those used in the experiment. This makes it more difficult to achieve densification of quality, since there is already so little open space to start with. This issue is dealt with in the spaciousness variable, however.

Business areas ("næringsbebyggelse") are kept out of the Swedish analysis. I will include them here, since these are areas that are often identified with densification potential in Norway. This might be different in Sweden, because according to Ståhle (2008) the old industries have already moved out of the city and the sites have been transformed. I consider the business areas to be similar to the "mellomhøy åpen bebyggelse" class and give them the same flexibility index. Even though they in general might have more unbuilt space, this is again a matter of spaciousness. I also include the docks, a bus depot and freight terminals in the "næringsbebyggelse" category.

Production

Data needed: Case area polygon, Snap raster, homogenous zones

Use the homogenous zones dataset and assign flexibility values to the zones. Feature to raster to convert. Water and other irrelevant areas are set to 0.

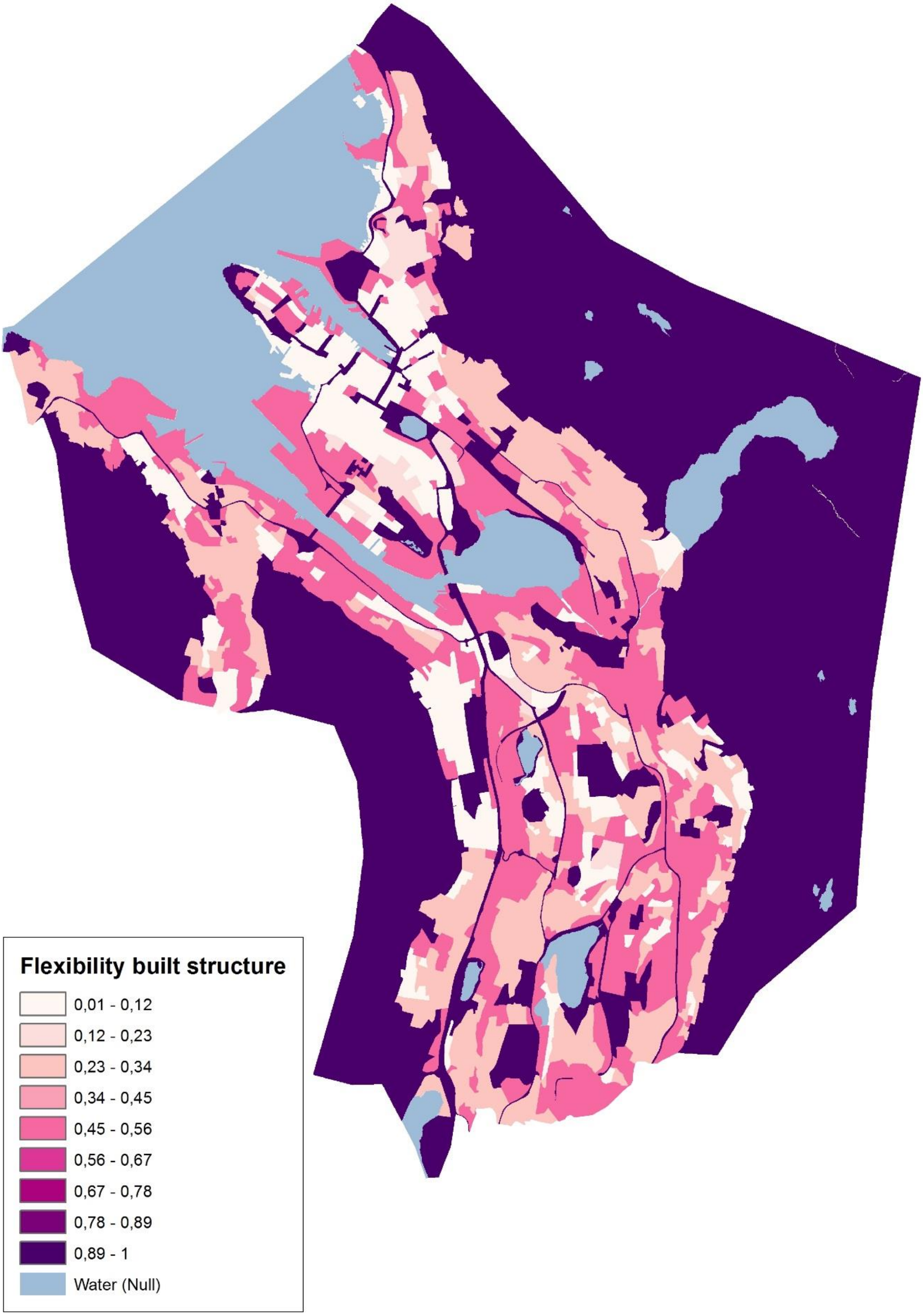


Figure 64- Map of the "Flexibility in the built environment" – variable.

Distance to the city centre

Distance to the city centre is an attraction variable, which evaluates densification pressure. It also relates to the sustainable transportation issue. The shorter the distance to the city centre the more likely that sustainable modes of transport, like walking or cycling, will be chosen. In much of the literature, it is referred to as "centrality", and is present as a central factor in most of the sources.

Distances can in GIS be measured either as linear distances or as distances along a network. Because of the sustainable transport issue, I chose to measure the distances along the pedestrian network. This means that areas outside the existing street network will not be given a value, and will therefore appear in the overlay as having zero densification potential for this variable. I decided to use the network distance in this case because the only areas excluded from the network were the City Mountains, where development would not be densification, but a continuation of sprawl. Should the method be used in another area, with a lot of unbuilt land not connected to the street network one should rather use a linear distance measure with the aid of a buffer analysis. The linear distance measure is unreliable in an area like Bergen with great variations in the topography. Here the street network zigzags up the mountain sides, making the actual walking distance much longer than the linear distance would suggest.

It could be possible to combine the use of network distance and linear distance. For example, the linear distance could be calculated from the edge of the network using the network value at the edge as a point of reference.

The distance values must be converted to values between 0 and 1 to work in the overlay analysis. This is a variable that works best as a relative value to the area of study, and is therefore not really comparable between studies. Converting the values can therefore by done using this formula:

1 – (length / maximum length in dataset)

Production

Data needed: Case area polygon, snap raster, point representing the city centre, the street network dataset, preferably for pedestrian traffic. If a pedestrian network is not available, make sure to remove those road segments where pedestrians cannot travel, like highways.

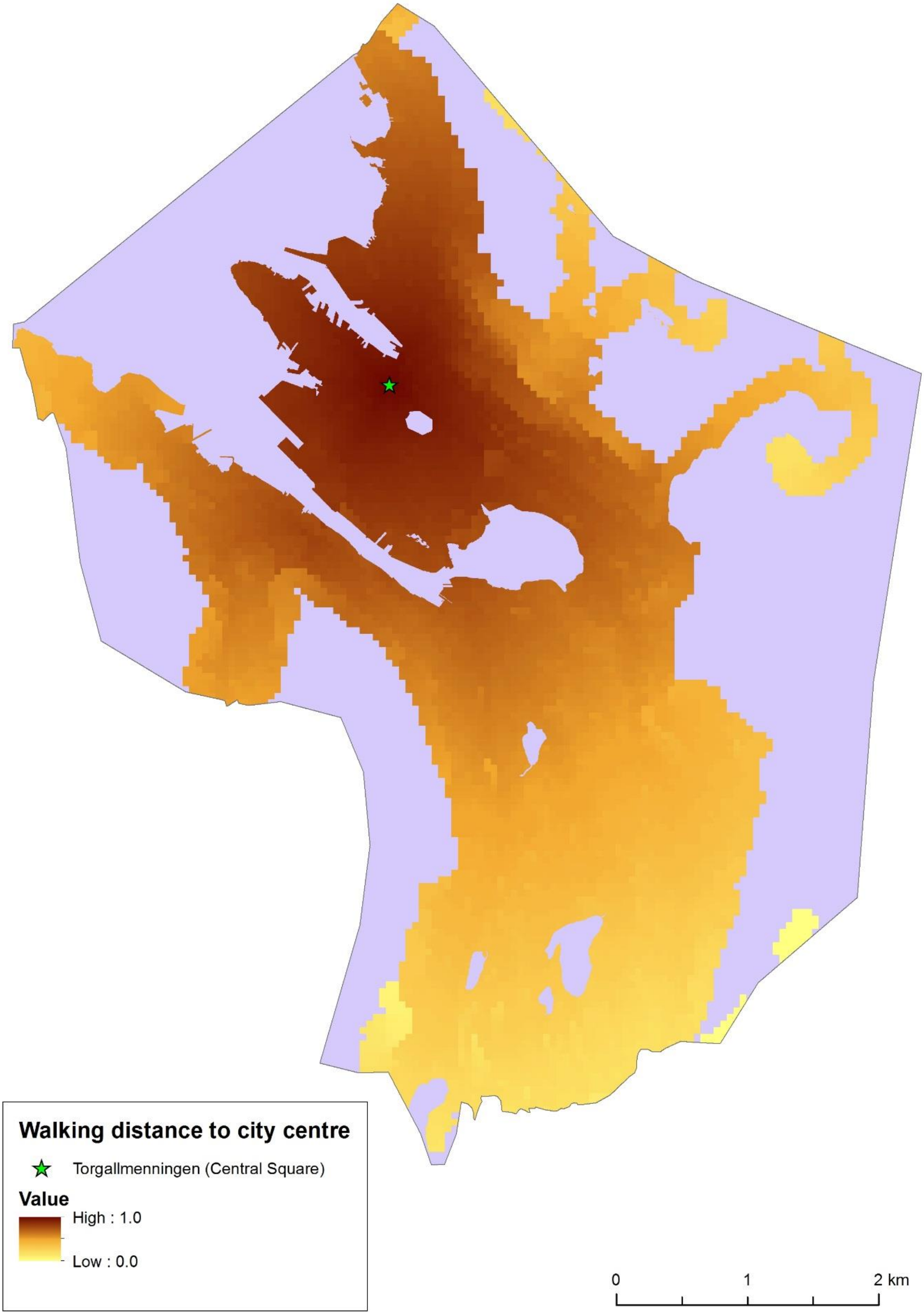


Figure 65 – Map showing the "Distance to city centre" – variable.

Indicate the city centre with a point feature class. In Bergen, this is “Torgallmenningen”. This is the location of the highest amount of activity and it is also one of the two main public transportation hubs in the centre. Create Fishnet point and polygon feature classes for 50 x 50 m cells aligned to the snap raster. Use the points as input in a Network Analyst - OD Cost Matrix.

Analysis settings:

Impedance: Length (Meters)

Default Cutoff Value: None

Destinations to find: All

Output Shape Type: None

Network Locations:

Search tolerance: 100 Meters

Join the resulting “Lines” to the loaded origin points (Fishnet points). The lines have a length attribute, which will be used as distance value. OriginID is key. Export to a new feature class.

Use a Spatial Join to join this new layer with the Fishnet polygons.

“Union” this layer with the FKB water polygons. Set the distance values of the “water polygon cells” to <NULL> (Use Python in the field calculator, write “None”). Create a new attribute for the distance index to be used in the overlay analysis. Use the formula described above with the values in the length attribute.

Feature to Raster. Remember to use the snap raster. The NoData cells must be converted to 0.

Mixed use – number of functions

The level of mixed use and presence of different functions is a very important aspect of urbanity and the quality of an urban area. UN Habitat says this about the need for mixed use: "The purpose of mixed land-use is to create local jobs, promote the local economy, reduce car dependency, encourage pedestrian and cyclist traffic, reduce landscape fragmentation, provide closer public services and support mixed communities"(UN Habitat, 2014:5). That people are able to find the functions they need within a short distance from their home reduces transport. Proximity to different functions is a city's raison d'être. According to Regionplanekontoret (2009) a high number of functions in an area makes the area more attractive and increases the densification pressure.

Because of the complexity of cities, mixed use is not an easy thing to measure. I have mostly found literature, where mixed use is measured according to size of a land use type or amount of floor space per function. These studies usually have a simplified categorization of functions. UN Habitat has defined a sufficient level of mixed use as: "At least 40 percent of floor space should be allocated for economic use in any neighbourhood" (2014:1). Going more in detail they say that the goal should be a mix of about 40% dwelling, 10% public services and 50% employment in any neighbourhood. The Swedish analysis measures the percentage of dwelling floor space relative to the percentage of floor space for other land uses. Manaugh and Kreider (Manaugh and Kreider, 2013) has developed a definition of mixed use using GIS, where they measure the amount and distribution of a simplified set of function types found in Canadian master plans. These are all simplified operationalisations, seeking to makes analysis possible with available map data. I have decided to test a more detailed operationalization of the variable that seems more logical to me.

If we wish to evaluate daily needs and daily travel outside of the home it would be useful to see the number of different daily functions that can be found within walking distance. In this case, the amount of floor space might not be the most relevant measure. Consider the difference between a post office and a storage facility, for example. A post office consumes only a fraction of the floor space of the storage facility, but is much more important as a daily function, and generates a lot more traffic. It has a higher intensity of visitors, as Kathrine Strømmen would say. The ideal analysis of mixed use should be able to compare areas based on the number of different daily functions that are available, both work, groceries, schools, entertainment and services. An alternative measure of mixed-use could therefore count the number of different function types within an area. I wish to test this in my method.

The consideration of amount of floor space for different functions has its merit, which this new definition cannot provide. The suggested definition would not differentiate between the offer in one lonely clothing store and 15 clothing stores in the same shopping centre. The same thing applies for cultural offers, restaurants and bar. The greater the number of restaurants and bars in an area, the higher the attraction.

The mixed use definition using number of function types is still not able to capture reality completely, but captures something left out of the mixed use definition based on amount of floor space. Ideally, the two measures should be combined. The Swedish analysis does combine two such variables. In addition to the mixed-use variable measuring amount of floor space, Regionplanekontoret (2009) has also included a variable defined as "the offer of retail, culture and services". It is measured as the total number of destinations per hectare. Here they do not differentiate between different types of functions, however. It is likely that the two definitions will yield more or less the same result. Areas with many different types of functions will also have many different destinations per hectare. I did not have the time to test this relationship thoroughly now, but it should be considered for the second iteration.

The map below is based on the Swedish mixed-use definition and shows the division of functions quite well. It should not be used in the overlay analysis, however, because it is biased towards single land uses. The problem is MAUP (the modifiable area unit problem). The homogenous zones are more likely to contain only one type of function, precisely because of their homogeneity. Therefore, they are not ideal for an analysis of mixed use.

The Swedish mixed use analysis uses square cells as units of analysis. They are to some extent better than the homogenous zones, but will still give a somewhat arbitrary result. A general weakness with using polygons in this type of analysis, is that areas close to the boundary between two polygons with different land use get a low score on mixed use. A house in a residential area lying next to the boundary of a shopping district will experience a high service-level, and should therefore get a better mixed use score than a house on the opposite side of the same residential area that borders to the mountainside.

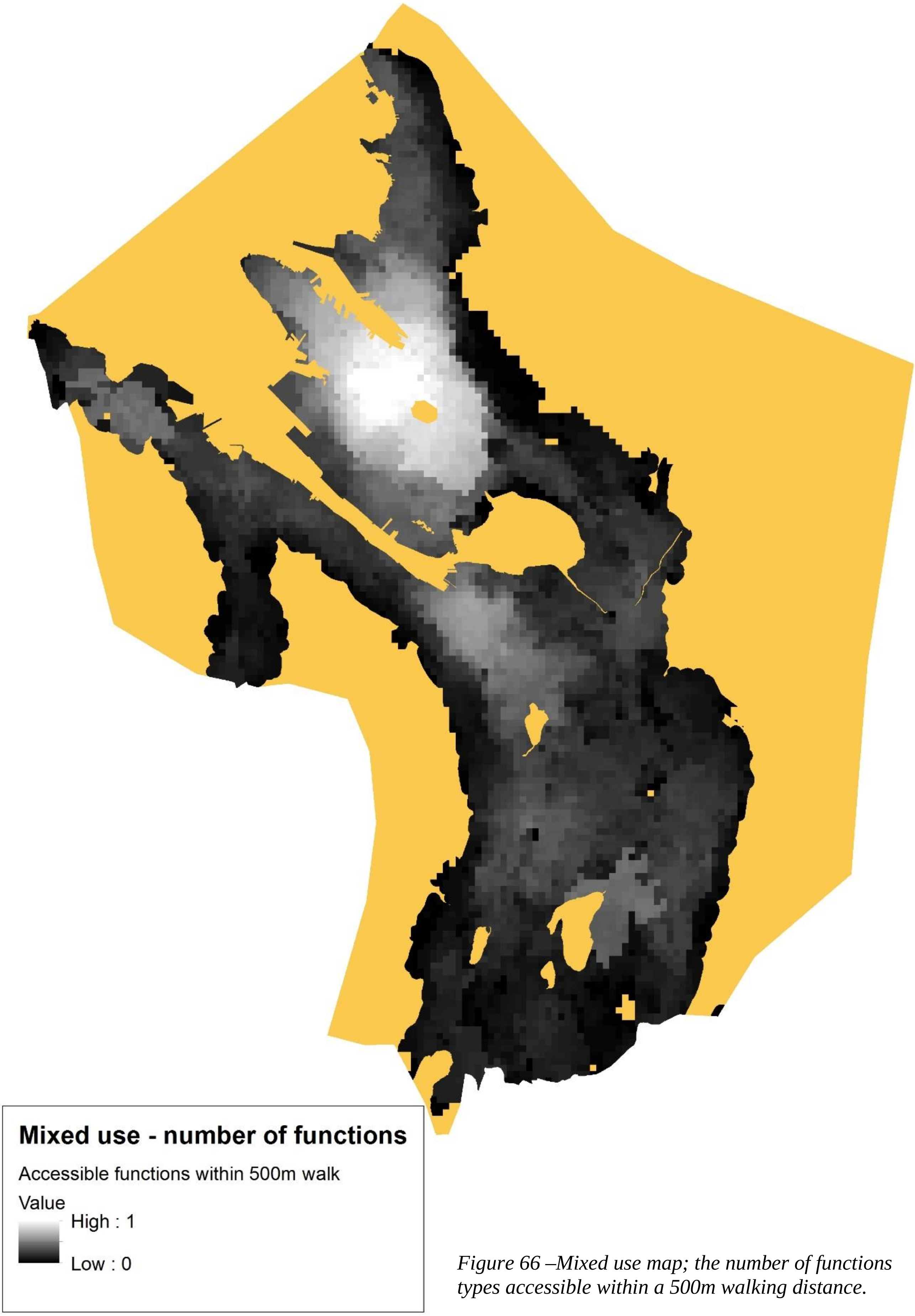


Figure 66 –Mixed use map; the number of functions types accessible within a 500m walking distance.

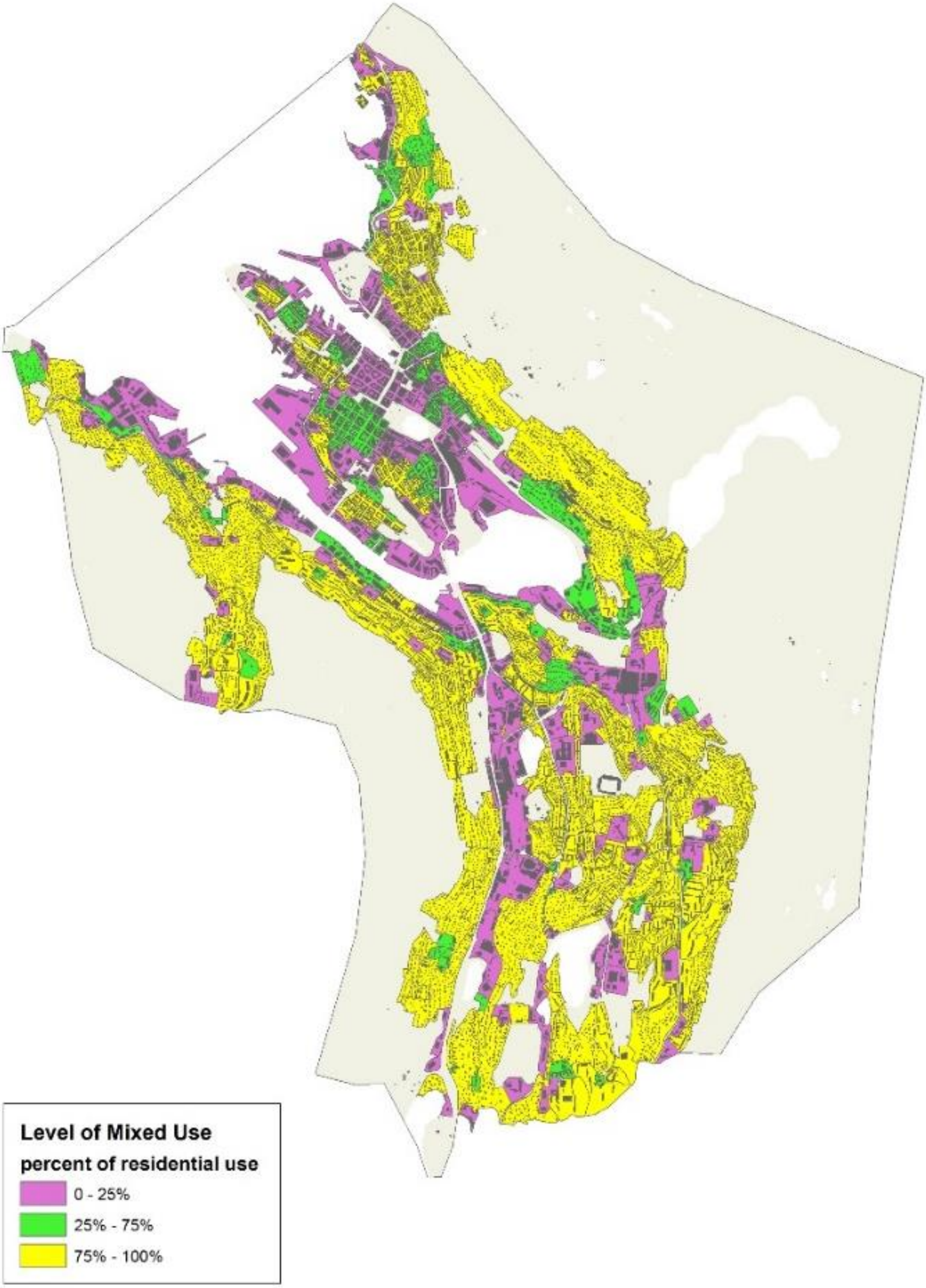

Level of Mixed Use
percent of residential use
0 - 25%
25% - 75%
75% - 100%

Figure 67 –Mixed use using the Swedish definition on the homogenous zones. Only very few of the zones satisfy this criteria for a sufficient level of mixed use. The zones are biased towards single-use.

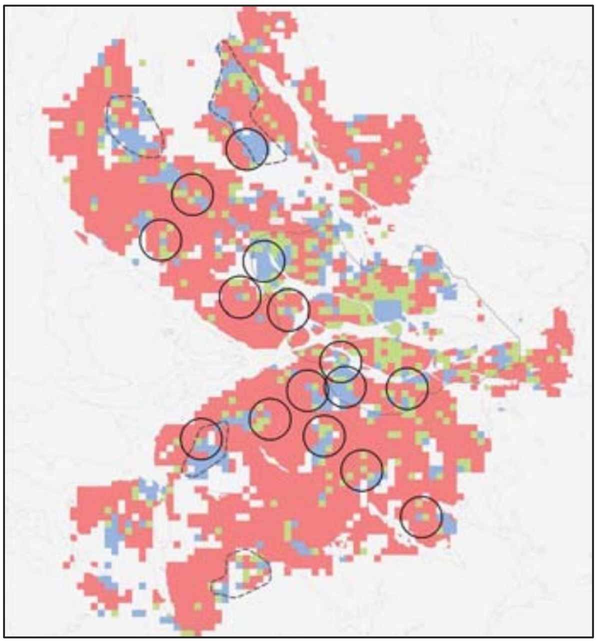


Figure 68 – Snip showing Mixed-use map (Regionplanekontoret, 2009).

In the case of mixed use, I agree with Ståhle that it is a more valid measurement to evaluate accessibility, instead of using discrete analysis zones. To measure the level of mixed-use within a distance buffer around a house, gives a much better idea of the house's perception of mixed-use in the surrounding area.

The initial conclusion in the mixed use discussion was to have both versions of the mixed use variable and possibly weigh them 0.5 each. After having produced both maps however I found that the variable of mixed use amount did not function well on the case area. The area of study was too small, which gave the resulting overlay map illogical values. The variable works better at the district or regional level. The map below show the produced raster of the mixed use amount variable. To get a reasonable looking map I had to use a search radius of 200m. This is a bit compared to the theory of acceptable walking distances. The conclusion is that this variable will work better on a regional or citywide scale and then with a larger search radius of 500 or 1000 m.

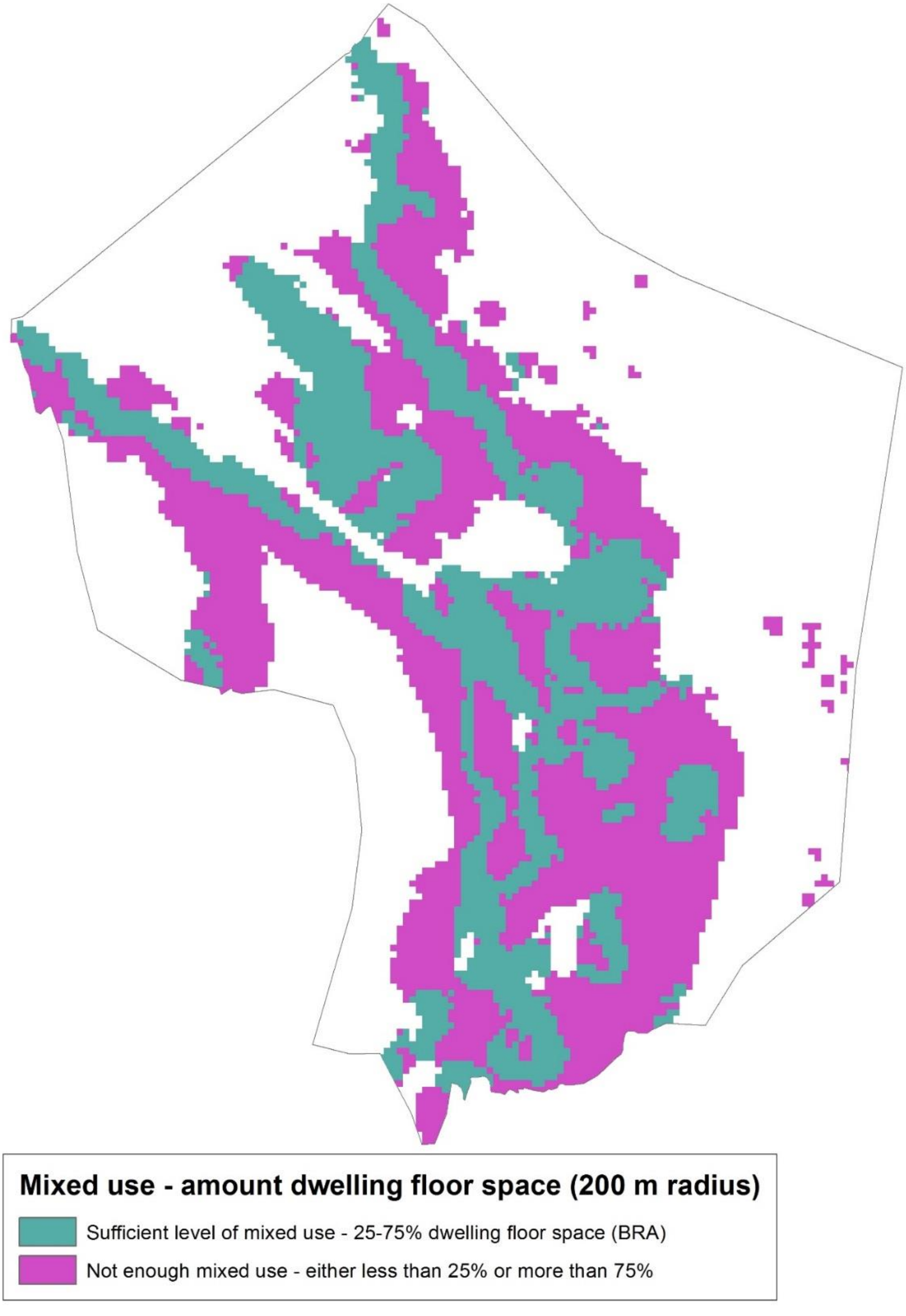


Figure 69 - Mixed use as amount of floor space. Not used in the overlay analysis.

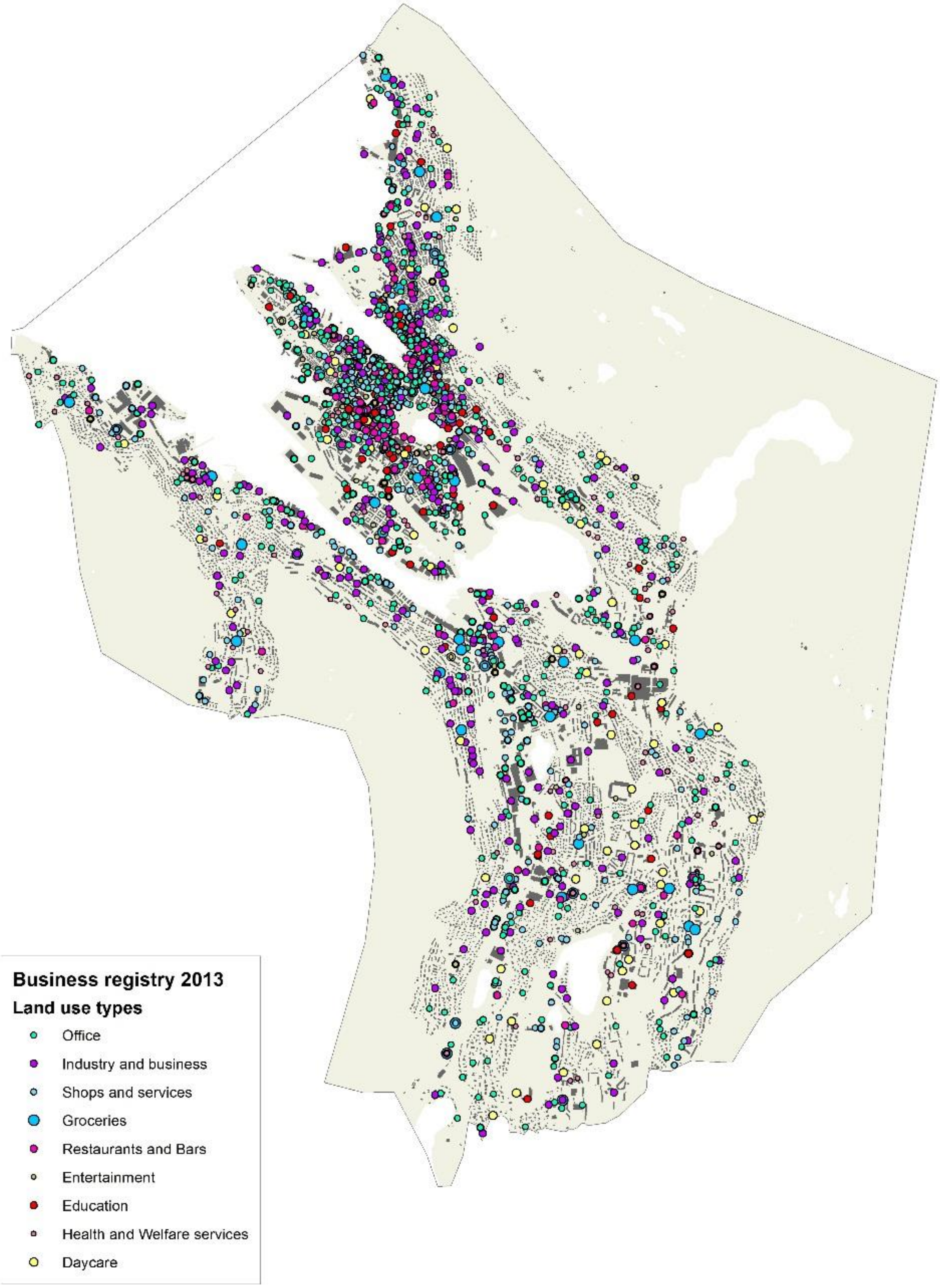


Figure 70 –Map showing the business registry point dataset using a simplified classification for visualization purposes.

Classification of functions for the mixed-use analysis.

The spectrum of different functions in a city is very complex and difficult to represent accurately in an analysis of mixed use. The different analyses I have come across in my research have all had different classifications, and mostly they have been very simple, only including two to a few different classes. I did not consider any of them perfectly suited for my analysis and therefore have attempted to develop my own classification using the NACE classification scheme used on the Norwegian “bedriftsregisteret” (business registry). This classification is, though not a perfect match, quite well suited for a mixed-use analysis. It has 21 broader categories and over 1000 sub-classes of functions.

I considered using only the 21 main categories, but because of the nature of the analysis this would mean that the differences between areas in the result map would be very small. If I on the other hand were to use all the sub-classes in the analysis this would drown out the more important functions needed for daily life and that are therefore more significant in terms of transport generation. Two different kinds of car salesmen, should not count equally to a school and a grocery store, for instance. Because of this, I decided to use the 21 broader NACE categories, but to use some sub-classes that I considered important to show as distinct categories, such as day care and grocery stores. Though not all daily functions are given their own class (hairdressers, for instance), this classification should nevertheless be able to give a good representation of mixed use. Using the NACE as a basis is also quite simple, and makes the analysis possible to replicate throughout Norway. The categories included in the mixed-use analysis can all be seen in table 8 below (green colour). There is a total number of 85 different classes.

Table 8 – Classification of mixed use based on the Norwegian NACE registry of business types. The table shows the categories of business and service types included in the mixed use analysis. Industry is here one category, while shops have been given classes according to the type of merchandise sold.

A Jordbruk, skogbruk og fiske			
B Bergverksdrift og utvinning			
C Industri			
D Elektrisitets-, gass-, damp- og varmtvannsforsyning			
E Vannforsyning, avløps- og renovasjonsvirksomhet			
F Bygge- og anleggsvirksomhet			
G Varehandel, reparasjon av motorvogner			
	45 Handel med og reparasjon av motorvogner		
	46 Agentur- og engroshandel, unntatt med motorvogner		
	47 Detaljhandel, unntatt med motorvogner		
		47.1 Butikkhandel med bredt vareutvalg	
			47.11 Butikkhandel med bredt vareutvalg med hovedvekt på nærings- og nytelsesmidler
			47.19 Butikkhandel med bredt vareutvalg ellers
		47.2 Butikkhandel med nærings- og nytelsesmidler i spesialforretninger	
			47.21 Butikkhandel med frukt og grønnsaker
			47.22 Butikkhandel med kjøtt og kjøttvarer
			47.23 Butikkhandel med fisk, skalldyr og bløtdyr
			47.24 Butikkhandel med bakervarer, konditorvarer og sukkervarer
			47.25 Butikkhandel med drikkevarer
			47.26 Butikkhandel med tobakksvarer
			47.29 Butikkhandel med nærings- og nytelsesmidler ellers
		47.3 Detaljhandel med drivstoff til motorvogner	
		47.4 Butikkhandel med IKT-utstyr i spesialforretninger	
			47.41 Butikkhandel med datamaskiner og utstyr til datamaskiner
			47.42 Butikkhandel md telekommunikasjonsutstyr
			47.43 Butikkhandel med audio- og videoutstyr
		47.5 Butikkhandel med andre husholdningsvarer i spesialforretninger	
			47.51 Butikkhandel med tekstiler og utstyrsvarer
			47.52 Butikkhandel med jernvarer, fargevarer og glass
			47.53 Butikkhandel med tapeter, gulvtepper og gardiner
			47.54 Butikkhandel med elektriske husholdningsapparater
			47.59 Butikkhandel med møbler, belysningsutstyr og andre innredningsartikler
		47.6 Butikkhandel med bøker, musikkartikler og andre fritidsartikler i spesialforretninger	
			47.61 Butikkhandel med bøker
			47.62 Butikkhandel med aviser og papirvarer
			47.63 Butikkhandel med innspillinger av musikk og video
			47.64 Butikkhandel med sportsutstyr
			47.65 Butikkhandel med spill og leker
		47.7 Annen butikkhandel i spesialforretninger	
			47.71 Butikkhandel med klær
			47.72 Butikkhandel med skotøy og lærvarer
			47.73 Butikkhandel med apotekvarer
			47.74 Butikkhandel med medisinske og ortopediske artikler
			47.75 Butikkhandel med kosmetikk og toalettartikler
			47.76 Butikkhandel med blomster og planter, kjæledyr og fôrvarer til kjæledyr
			47.77 Butikkhandel med ur, gull- og sølvvarer
			47.78 Annen butikkhandel med andre nye varer i spesialforretninger
			47.79 Butikkhandel med brukte varer
		47.8 Torghandel	
H Transport og lagring			
I Overnatting- og serveringsvirksomhet			
	55 Overnattingsvirksomhet		
	56 Serveringsvirksomhet		
		56.1 Restaurantvirksomhet	
		56.2 Cateringvirksomhet og kantiner drevet som selvstending virksomhet	
		56.3 Drift av barer	
J Informasjon og kommunikasjon			
K Finansierings- og forsikringsvirksomhet			
L Omsetning og drift av fast eiendom			
M Faglig, vitenskapelig og teknisk tjenesteyting			
N Forretningsmessig tjenesteyting			
O Offentlig administrasjon og forsvar, og trygdeordninger underlagt offentlig forvaltning			
P Undervisning			
	85 Undervisning		
		85.1 Førskoleundervisning	
		85.2 Grunnskoleundervisning	
		85.3 Undervisning på videregående skoles nivå	
		85.4 Undervisning i høyere utdanning	
		85.5 Annen undervisning	
			85.51 Undervisning innen idrett og rekreasjon
			85.52 Undervisning innen kultur

			85.53 Trafikkskoleundervisning	
			85.59 Annen undervisning ikke nevnt annet sted (85.202 og 85.203 inkluderes her)	
		85.6 Tjenester tilknyttet undervisning		
Q Helse- og sosialtjenester				
	86 Helsetjenester			
		86.1 Sykehustjenester		
		86.2 Lege- og tannlegetjenester		
		86.9 Andre helsetjenester		
	87 Pleie- og omsorgstjenester i institusjon			
	88 Sosiale omsorgstjenester uten botilbud			
		88.1 Sosialtjenester uten botilbud for eldre og funksjonshemmede		
		88.9 Andre sosialtjenester uten botilbud		
			88.91 Sosialtjenester uten botilbud for barn og ungdom	
				88.911 Barnehager (88.912 inkluderes her)
				88.913 Skolefritidsordninger
				88.914 Fritidsklubber for barn og ungdom
			88.99 Andre sosialtjenester uten botilbud ikke nevnt annet sted	
R Kulturell virksomhet, underholdning og fritidsaktiviteter				
	90 Kunstnerisk virksomhet, underholdning og fritidsaktiviteter			
	91 Drift av biblioteker, arkiver, museer og annen kulturvirksomhet			
		91.01 Drift av biblioteker og arkiver		
		91.02 Drift av museer		
		91.03 Drift av historiske steder og bygninger og lignende severdigheter		
		91.04 Drift av botaniske og zoologiske hager og naturreservater		
	92 Lotteri og totalisatorspill			
	93 Sports- og fritidsaktiviteter og drift av fornøyelsesetablissementer			
		93.1 Sportsaktiviteter		
			93.11 Drift av idrettsanlegg	
			93.12 Idrettslag og -klubber	
			93.13 Treningssentre	
			93.19 Andre sportsaktiviteter	
		93.2 Fritidsaktiviteter og drift av fornøyelsesetablissementer		
			93.21 Drift av fornøyelses- og temaparker	
			93.29 Andre fritidsaktiviteter	
S Annen tjenesteyting				
T Lønnet arbeid i private husholdninger				
U Internasjonale organisasjoner og organer				

I considered aggregating some of the main categories into an “industry”-class and an “office”-class, but eventually decided that it is a good thing to keep them separate to show the diversity of businesses and therefore employment opportunities available. Though these functions are not usually visited by the average person on the day to day, they are employment options, which increases the likelihood that a person may find a relevant job within the area.

Kathrine Strømmen (Strømmen, 2001) used a classification based on the NACE and also considered the functions with regards to their transport generative properties. In addition, she used their “ABC”-location to classify them further. For instance, the retail category contains both IKEA, located in a C area where most customers travel by car, and smaller design furniture store in the city centre that attracts softer traffic. She separates these two business into different categories, while the NACE places them together. I decided not to use Strømmen’s classification, because it has a complexity far beyond what I need for my analysis. Lack of these details should not greatly affect my analysis results, which are simply a sum of the number of different functions in an area.

Production

Data: Case area polygon, snap raster, pedestrian network, business registry point data, fishnet 50 x 50m points and polygons. The fishnet may need a different unit than 50 m depending on the scale of the analysis. The issue is computer processing power.

Preparing the data

The Business registry point dataset has errors that are important to be aware of (described above). It is important to clean the data as much as possible before the analysis. All the errors will not be possible to remove, so there will be a certain degree of inaccuracy in the analysis results. It is prudent to be aware of this when interpreting the map, but this inaccuracy should not affect the general trends in the results.

During the cleaning, I deleted some of the objects in the business registry dataset. These includes:

"Enkeltmannsforetak", removed because they are often not functions that are generally public, but I have kept dentists, doctors, hairdressers and others that are likely to be public.

Objects with postbox addresses, if any.

NACE code 47.9 «Detaljhandel utenom utsalgsted» has been deleted.

The remaining objects are assigned to their class in a new attribute to be used in the network analysis.

Step by step

The approach is to use network analyst OD cost matrix with fishnet points to count the number of different types of functions within a given search radius.

Load Locations Origins – Use the fishnet points

Object ID as sort field

Search tolerance 100m (This will leave some points as "Not located", but these can be given the neighbours' values manually later (for areas within the urban structure, like parks). The short Search tolerance is to avoid that "false" locations are given to the points on the mountains.

Load Locations Destinations – Use business registry points.

Sort field: the new classification attribute

Name: the new classification attribute

Search tolerance: 200 m (make sure all the points snap)

OD Cost matrix properties - Analysis settings: Impedance: Length (Meters)

Default cutoff value: 500

Destinations to find: All

Output shape type: None

Network locations: Search tolerance: 100m

I tested using both 1000m and 500m as search radius. Though 1000 m is an acceptable walking distance, the 500 m cut-off produced a more detailed map, where the centre areas stood out better. It corresponded better to the actual built environment. The American source I have referenced (Talen, 2011) uses 5 minutes walking distance as the cut-off in these types of accessibility analyses. 500 m corresponds to 6 minutes walking distance (walking speed 5 kmh). Spacescape uses both 1000m and 500m.

Solve

Open "Lines" attribute table.

Use "Summarize" on Name Field including Origin ID field (choose minimum). The resulting table gives you each function type connected to each fishnet point.

Use "Summarize" again, this time on the new table's "Minimum_OriginID" field. This table gives you the total number of different function types for each fishnet point.

Join "Origins" to the last table using OriginID/ MinOriginID as key.

Export the data into a new feature class. The data you want to continue using is in the field "Count_Min_OriginID".

Check the data. Are there some points without functions that should have them? Because of the short search tolerance some points within the urban structure, but further away from the road network than 100m will not have been given values. This will for example be the case for points in the middle of large parks. There were not many of these points within the area of study, so it was practical to manually give these points the same values as their neighbours.

Calculate a new attribute value to be used in the overlay analysis. I have used a relative scale only valid for the area of study, but it could be possible to make a scale comparable across studies by setting the maximum value as the maximum number of classes in the classification (85 classes). The maximum value within the case area was 79.

Overlay value = Number of functions within search distance / Max. number of functions.

“Erase” the points using the water polygons to remove the points within water.

The point data must now be converted to a raster. The fishnet points have corresponding square polygons, which are a useful stepping stone to a raster dataset.

Spatial join the fishnet points to the fishnet polygons. Make sure that the polygons without points or those having points without functions have 0 (zero) in the overlay value field.

“Feature to raster” using the overlay value field as input, remember the snap raster. The resulting raster dataset will be used in the overlay analysis.

If some cells need to be reclassed to NoData at this stage “extract by mask” can be useful.

Evaluation

I have proposed a different measure of mixed use than I found in the literature. It was an interesting thought experiment and it seems to give an accurate rendition of reality, so it was in that sense a success. It is somewhat more complicated than the other definitions however. For the overlay analysis for the current area of study I prefer my definition. The map in figure 67 shows the distribution of functions within the area of study. Though some areas have a lot of yellow, they are not far from purple areas, meaning that there is some degree of mixed-use on the district level. The goal should not be to make every area the same degree of mixed-use. A variation is positive, as long as one can still access daily needs without resorting to car-based transport.

A weakness using the business registry is that not all types of functions are included. Green space and playgrounds are examples of this. These types of functions will have to be included some other way, which they are: in the “Access to green space” variable.

Access to public transportation

This is another variable included in the densification pressure category in the Swedish analysis. Access to high frequency public transportation is a quality that makes an area more attractive. The frequency should be at least 10 min intervals throughout the day. Regionplanekontoret (2009) measured the distance to rail-based public transportation from all addresses in their analysis. I used a somewhat different operationalization. For one thing, restricting the analysis to only rail-based transportation does not suit the Bergen situation. Here it is better to use the “stamrute”-net. This includes the light rail line, but also a small number of high frequency bus lines, comparable in frequency to the light rail. The other bus lines have lower frequencies, meaning that they are not able to compete significantly with the private car in terms of relative travel time.

Production

Data needed: Pedestrian network, point feature class with public transportation stops on the “stamrute”-bus net + light rail stops, case area polygon, snap raster

Use Network Analyst - Service Area with the point feature class. In Analysis settings set Default Breaks to 500 m. Polygon generation: Detailed, Trim polygon 100m, Merge by break value, Disks.

Export the resulting polygons to a new feature class. The polygons should be cleaned up a bit using clip, erase and dissolve. Erase water and polygon segments outside of the area of study. Dissolve the polygons so they do not overlap (if merge-setting not used).

Union the polygons with the area of study polygon.

Add new attribute, where the service area polygons are given the value 1. The rest of the area of study is given the value 0.

Feature to raster using the new attribute as input values. Use the snap raster.

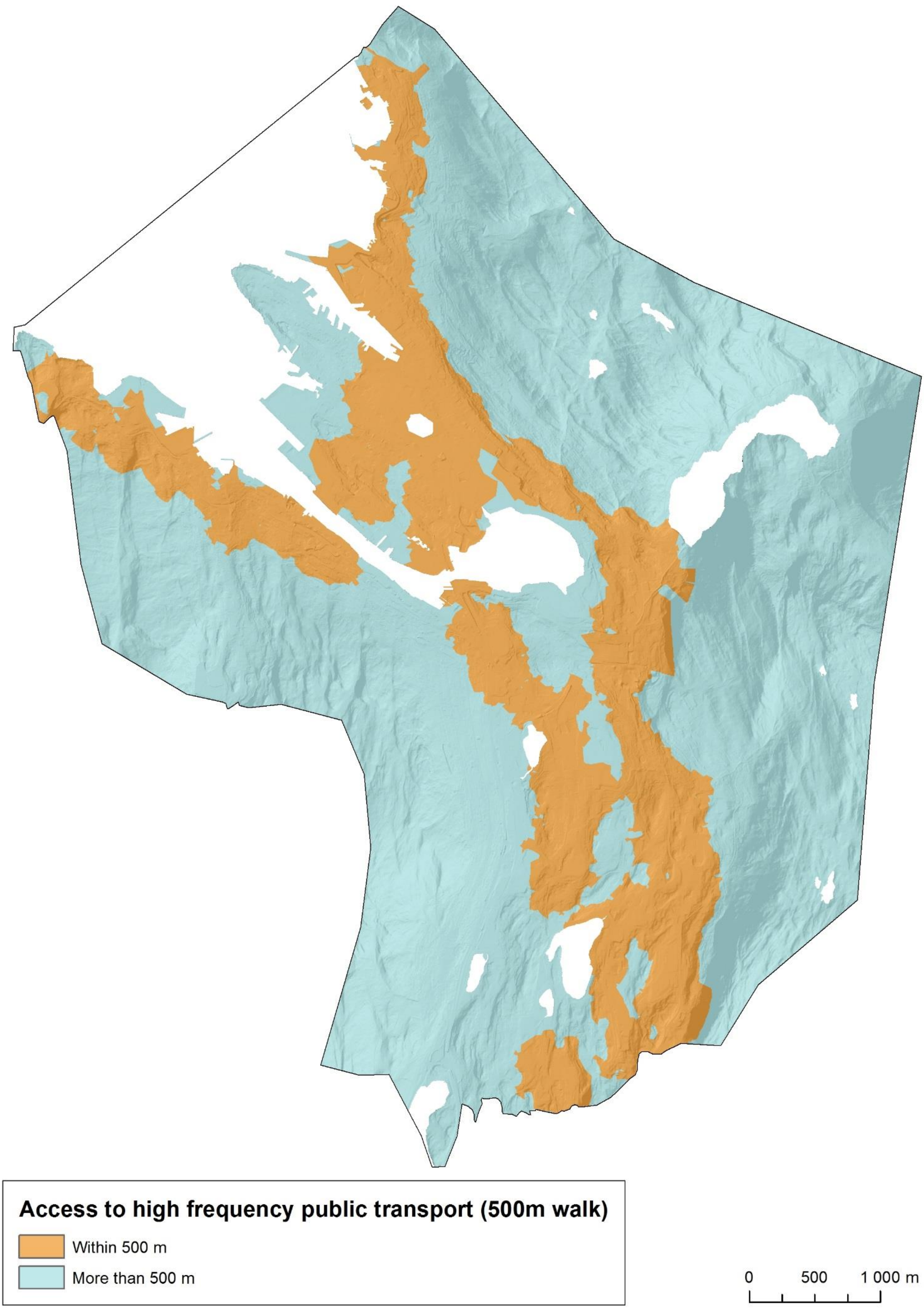


Figure 71 – Map showing the "Access to public transportation" – variable.

I included a bus line to “Laksevåg”, which is not currently a “stamrute”, but will become one within a short amount of time. After having completed the analysis, I found out that the “Laksevåg”-line is further into the future than I initially was given the impression of. Therefore, it should not have been included in the analysis at this stage. To include future improvements to the public transportation network is interesting in a densification analysis because this might release new potential. The new route should be very certain however, so as not to risk development in areas that suddenly will not be served because of plan changes. This is why I did not include the planned new lines of the light rail system. They are still in early planning stages. Having now blundered and still included the Laksevåg line, the bright side is that the map does show the effect a new high-frequency public transportation offer will have on the densification potential in the area.

Secondly, I decided to use 500 m buffers (walking distance) to each stop along the routes, instead of giving each address a value according to distance. My approach is less complicated. Using each address would require an interpolation to produce a usable raster for the overlay analysis. Using fishnet points would be easier. 500 m was chosen based on public transportation guidelines that the distance to a stop should maximum be 400m - 600m. According to Oslo’s Ruter (Ruter, 2012) the distance should be maximum 400 m (i.e. 5 min walking distance). I am including a somewhat larger area, but still within reason. It could be possible to use a distance deterioration weight to further refine the variable. This can be an improvement to investigate in a second iteration.

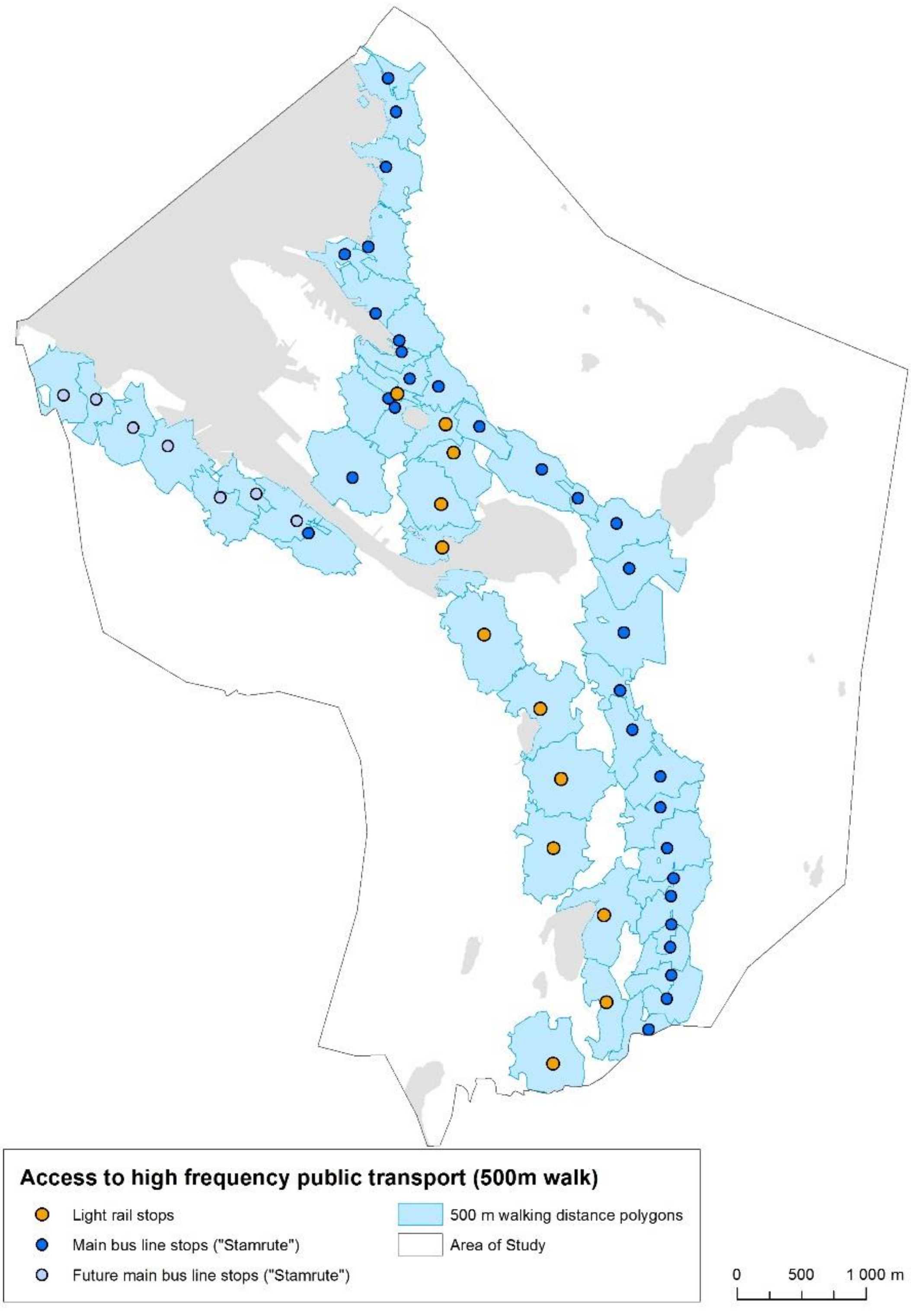


Figure 72 –Map showing the walking distance polygons for each stop. Areas that are overlapped by two or more polygons are distributed to the closest stops.

Access to Green Space

The importance of supplying access to high quality green space is one of the most important lessons I have taken from the literature review. The success of densification initiatives depend on this issue. One cannot get high quality urban areas without green spaces. The Swedish approach of using Sociotope maps and including the quality of green spaces in the analysis is very inspiring. I was not able to include quality in my analysis, mainly because we lack this type of map data in Norway. It could be worthwhile to attempt to gather this data in later iterations of the method.

Instead, I had to settle for a simple measure of amount of green space available. I did, however, evaluate the green space using terrain slope. The Bergen master plan includes a lot of green space, but because the topography in the area is so varied, the amount of usable green space is much lower. Too steep green space was removed from the analysis. It is important to bear in mind that some steep green space has value as, for example, sledging hills. These considerations must be remembered when evaluating the final result of the overlay analysis. The maximum incline used in the analysis is 1:3 as prescribed by the Bergen Master Plan for outdoor areas (Bergen kommune, 2010).

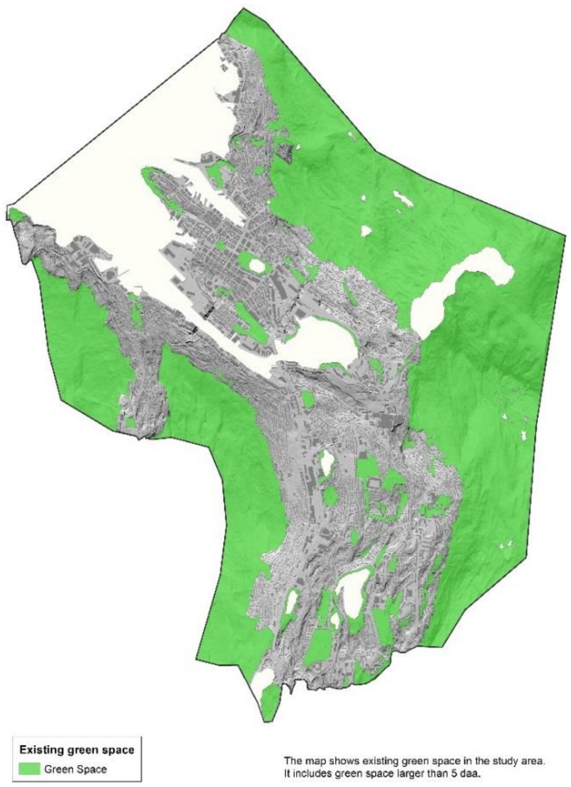


Figure 73 – Map of green space.

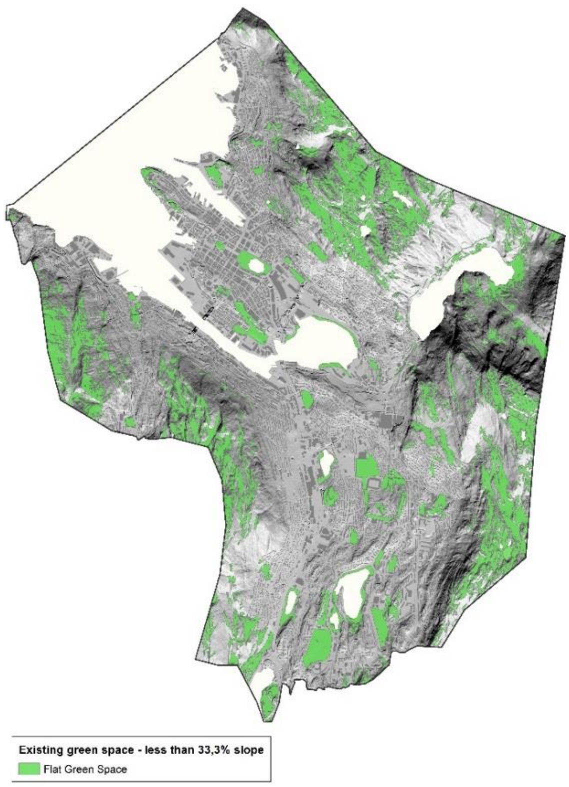


Figure 74 – Map of "flat" green space.

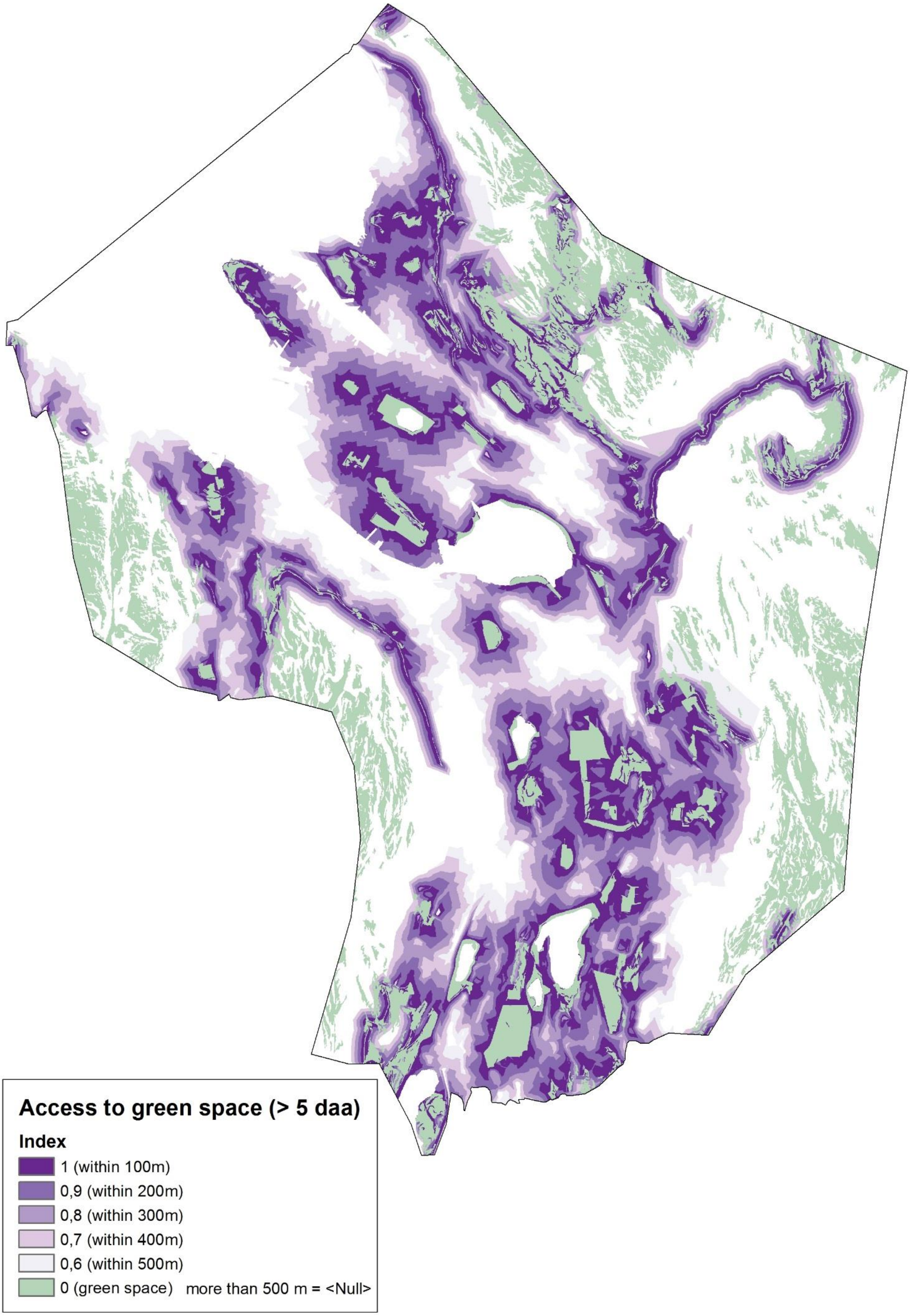
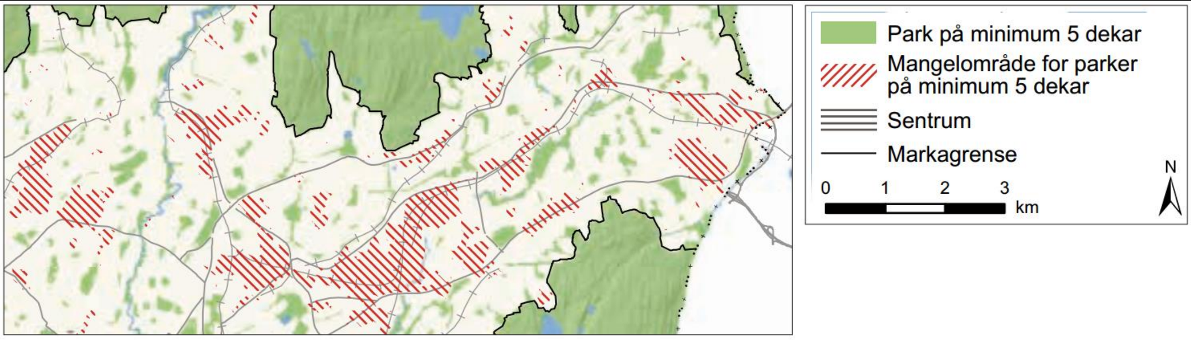


Figure 75 – Map with the "Access to green space" – variable.

I was particularly interested to see if an analysis could show areas that lack a sufficient amount of green space. Areas where a new park will have to be provided before any new development can take place. The map below is an example of how this can be solved.



Kart 3.6 Mangelområder for mellomstore parker. Områder som ikke har tilgang til planmessig sikret park over 5 dekar innenfor 500 meter gangavstand.

Figure 76 – Map showing areas lacking access to parks larger than 5 decare (daa) (Miljødirektoratet, 2014).

Another interesting analysis would be to measure available capacity of existing green space. Using numbers of the amount of green space needed per person it could be possible to evaluate if existing parks are larger than what the surrounding population actually needs. This could reveal areas with densification potential where new green space will not need to be developed. As mentioned, Regionplanekontoret found that 10m2 per person was a good guideline. I did not have time to develop this analysis, but it would be interesting to do so for the second iteration.

Method development

Map data for green space is available from many different sources, created for many different purposes. Available data will vary from city to city. For a densification analysis in Bergen it was most appropriate to use master plan map data. I used both “LNF”, “grønnstruktur” and “idrettsanlegg” object classes. These polygons are not restricted to public green space, and do not consider actual use, only regulated. Cemeteries are not valid as green space. In addition, I found some more polygons in a dataset (anlegr_BK) showing municipal green space not included in the master plan, but which existed in the orthophoto. It is worthwhile spending some time reviewing the map data available, particularly if like in Bergen the master plan is a few years old. Unfortunately, there is not an updated comprehensive dataset of green space in Bergen.

An efficient way to clean the dataset is to erase the green space polygons from the “area of study” polygon and place it above an orthophoto. This makes the evaluation of whether or not to include the different areas more efficient.

After gathering the map data of existing green space for the analysis, the question was how to evaluate people’s access to them. The planning guidelines say this about sufficient access to green space (Miljødirektoratet, 2014):

Larger green space that have at least 1 km walking trails (ideally more than 2 km) must be within 0.5 to 1 km from the dwelling.

Smaller green space, at least 5 daa in size (or 2 x 2.5 daa), must be maximum 200 m from the dwelling.

Green corridors should be maximum 500 m from dwelling areas.

The guidelines place more importance on quality and variation of use than on absolute amount of green space. A GIS analysis cannot quantitatively measure all of this from basic map data. Such an analysis relies on the qualitative production of a green space dataset including quality attribute information, such as the Swedish Sociotope map. My analysis is therefore a simplified version, which is a weakness.

For the Bergen case area, the City Mountains satisfy the demand for large areas. More interesting is here the access to smaller areas within the urban structure. A 200 m maximum access limit is quite strict. It is worth seeing this in connection to the access radii of different groups in society:

Within 10 minutes different groups can travel various amount of distances: Youth 1000m, Seniors 300m, Children with adults 400m, Small children 50m.

The green corridors combine areas for recreation with the consideration for wildlife. Such corridors are not defined in the current Bergen master plan.

Access to green space is measured in different ways. The Swedish analysis measures the amount of green space within 1000m. Because of the differences in movement radii of different people that all need access to green space, I decided to use a distance scale for the access to green space variable. Since 200m would not cover much land, I decided to increase the distance buffer to 500m. This is the same distance used in the map in figure 76 showing in the “Urban Green Structure Planning” guidelines (Miljødirektoratet, 2014).

Table 9 –Distances to green space converted to the overlay value scale.

Distance to green space larger than 5 decare	Overlay index
Within 100 m	1
Within 200 m	0.9
Within 300 m	0.8
Within 400 m	0.7
Within 500 m	0.6
More than 500 m	0
Green space	0

That the areas further than 500 m from green space is given 0 means that the map can be used to find areas that are in need of new green space. Giving the green space itself 0 is a choice to reduce the “attraction” of this space for densification potential in the analysis. Existing green space is very much under pressure from densification. If these areas were to be included in the analysis (giving them the highest values) this would nullify the access variable values for surrounding areas. Should the green space disappear, the surrounding areas would no longer have the same value. In my opinion, the existing remaining green space within the urban structure should be made “holy”. It should not be touched. If an analysis of green space capacity finds that an area has more green space than is needed for the existing population, the consequence should be to increase the population by densifying the existing built environment, NOT to reduce the amount of green space.

The index’s linear distance decay could be further refined for the second iteration. Perhaps a weighted distance decay can be found.

Production

Data needed: Green space map data, pedestrian network (going outside the area of study), elevation raster for the slope analysis, water polygons, case area polygon, snap raster.

Gather and clean the green space map data into one feature class. Delete the polygons smaller than 5 daa, but check whether some of these belong to a larger unit.

Use the height raster in a slope analysis. Reclassify the result to create a binary raster where the value 1 is given to cells with slope 0 - 33 percent rise, 0 to the rest. Use “Raster to polygon” to convert to a vector dataset (Do not Simplify polygons).

Use the slope polygons to “Erase” the green space polygons.

The green space polygons are now ready for the Service Area Analysis. Using walking distance along a network is fine for an analysis within the urban structure (smaller green space). It cannot be used for the larger green spaces outside the city, such as the Bergen city mountains. Here one has to use linear distance.

I went back and forth on using Euclidean linear distance or to use distance along the street network. A simple 500 m linear buffer is more erroneous in the Bergen topography than a service area network buffer. But the Network Analysis is not flawless either. Particularly when it comes to snapping distance. The origin points snapping to the network produces some error, and the way the polygon borders are created around the network lines produces more. The resulting polygons need to be cleaned and evaluated manually, and some errors must be accepted. The inaccuracy may be around 100 m. Important is which snapping and search distance to use. I chose 100 m outside of the network, thinking that this is possible to walk off the road. But I do not have a scientific basis for this number, so the actual borders of the polygons are uncertain. Generalizing the result polygons would not be a solution. Rather it is important to convey the uncertainties of the value boundaries, for example by letting the result map have somewhat larger cells.

Because the Service Area analysis only takes points, not polygons as input, I had to represent the polygon borders with points. To do this I first simplified the polygons to get the number of vertices down.

“Simplify polygon” – Algorithm: Point_remove, No_Check, uncheck “Keep collapsed points”. There is an error in ArcGIS for this tool. The input “simplification tolerance” is not present in the tool window. A workaround is to right-click the tool in the Search tab and choose batch instead.

Then use “Feature vertices to points” – point_location: All

Check results and add points manually where a polygon has a long straight border that lacks a point.

Run a Service Area analysis loading the points as origins. Search tolerance: only 50 m. Default break set to [100 200 300 400 500]. This will produce five different buffers.

Export the buffers to feature classes, and “Union” them. Clip away buffer segments in water or outside the area of study.

Union with the green space polygons.

Give the polygons the corresponding index-values for the overlay.

Convert to raster using “Feature to raster”, remember the snapraster.

Evaluation

This is a very complex approach, and I would probably settle for a normal buffer analysis in later projects. Scripting this approach to a new tool would be great. The topography in the area of study does require network analyst for a reliable result however, particularly on the urban mountainsides. There is a weakness in the Network Analyst logic in the need for network snapping. This weakness will particularly affects the analysis in the close range, particularly the 100 m buffer. I tested using a 50 m buffer, but decided it had too many errors to be trusted. The linear buffer analysis is better for such short distances.

Access to water

I copied the Swedish analysis in producing this variable as a 500 m buffer. Had I considered it more beforehand I might have decided to treat the "access to water" the same way as "access to green space". There is no solid reason behind my treating these two differently. Though one could possible argue that the access to green space is more important than access to water, simply because green space has a greater variety of use for different people. Having a view to water is one of the most important qualities that water can offer. Because of this, one can also argue that distance to water is not such an important variable in terms of densification pressure. What is more important is the actual sight of water, so that dwellings with 100 m from water, but which do not see the water being blinded by other buildings, are not affected by the presence of water in the vicinity. For a second iteration of the method, it could be a good idea to look into research on the effect of water on development pressure. It would also be interesting to test an analysis technique using line of sight blocked by 3D buildings and terrain.

Production

Data needed: pedestrian network, water polygons, case area polygon, snap raster.

Simplify the water polygons and convert the vertices to points with the same approach as the previous variable. Run the Service Area analysis using the same settings as above. I only created one 500m buffer, but there is no scientifically founded reason why not to create several buffers for this variable as well.

If choosing to use only one buffer, the approach is a bit different than the one described above from this point:

Union the buffer with the water polygons and the "area of study" polygon. Delete the buffer polygons that are outside the area of study. Give the objects the correct values for the overlay index. The buffers, minus those in water, get the value 1 and the remaining objects get the value 0.

Feature to raster. Use the snap raster.

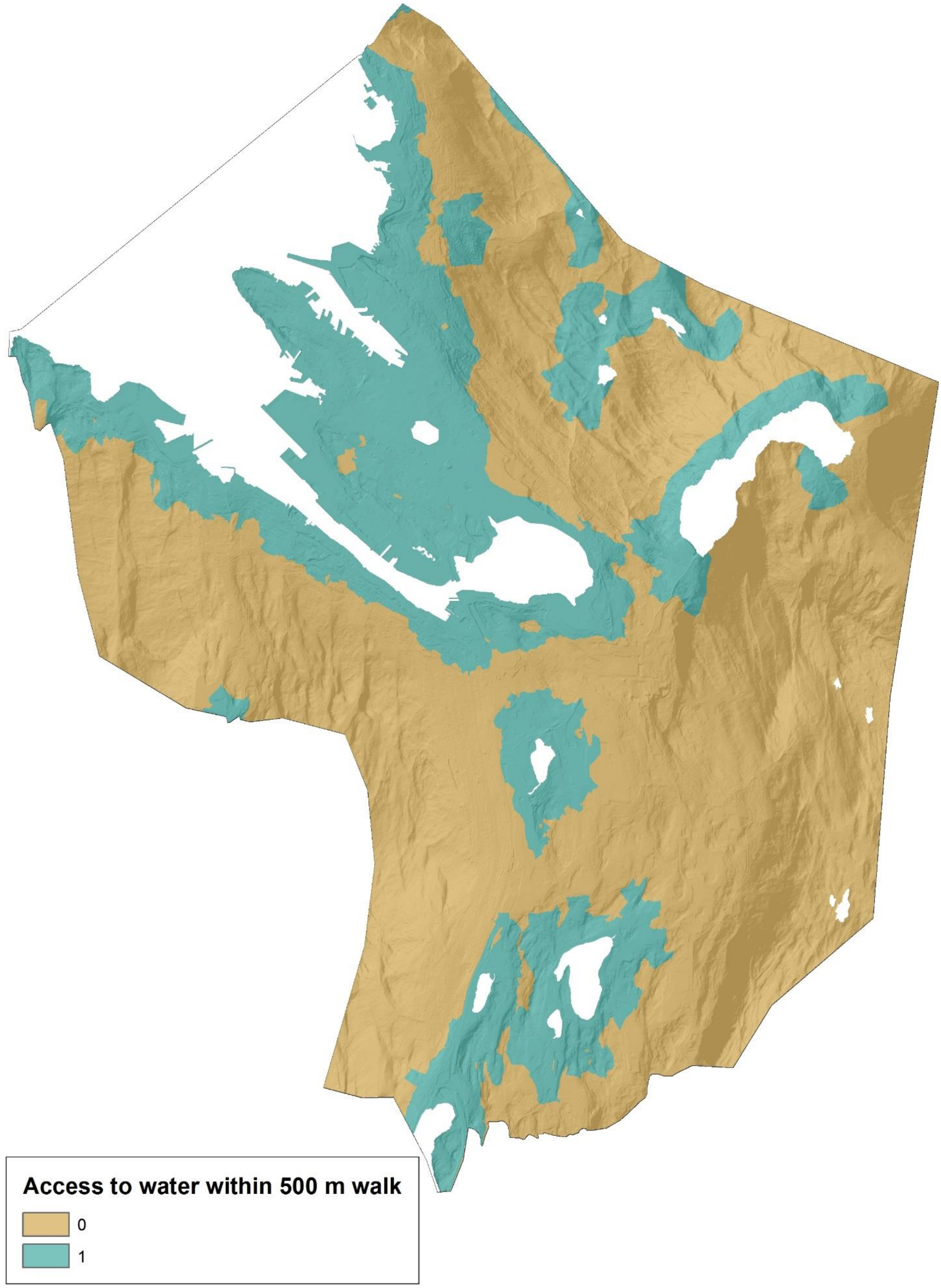


Figure 77 – Map of the "Access to water" – variable.

Industrial land

To create this raster I used the homogenous zones that are classified as "Næringsbebyggelse" (i.e. business districts). These are areas of a certain size and a clear typological business/ industry building structure. There are some smaller areas not included, because they only included one or two buildings and resembled office buildings more than industry. The areas were compared to the "Næringsareal" Master Plan polygons. The master plan polygons are not ideal to use for this analysis, because they do not differentiate between industry and other businesses. The "Industrial Land" variable is meant to single out areas with older industry and "C-area" businesses (ABC-method) that is likely to relocate to the city periphery. The choice of the polygons for this variable was therefore founded on the likelihood of redevelopment of the areas. Office buildings belong in the urban areas. That an area is selected for densification does not mean that the existing businesses need to move, however. Business areas are much easier to densify than residential areas. Existing business buildings, office buildings included, can be replaced by new and taller business buildings, thus giving room for more companies in the same area.

In addition to the industrial land, I included the harbour areas, the freight terminals and a bus depot. Whether or not all of these areas are truly candidates for densification is uncertain however. A city needs these functions, it cannot only survive on dwellings. People need to work. The freight terminals are hot candidates for relocation outside the city limits, the harbours not so much. Bergen is a maritime city, with its identity linked to the arrival of ships of all shapes and sizes. It would be a loss to the city should there be no room for them anymore. For a second iteration of the method, more time could be spent on choosing the areas to be included in this variable.

Production

Data needed: homogenous zones, "area of study" polygon, snap raster.

Select the areas to be included in the analysis. Export them to a new feature class.

Union this feature class to the "area of study" polygon. Create a new attribute for the overlay index. Give the industrial zones the value 1, give the rest the value 0.

Feature to raster, remember to use the snap raster.

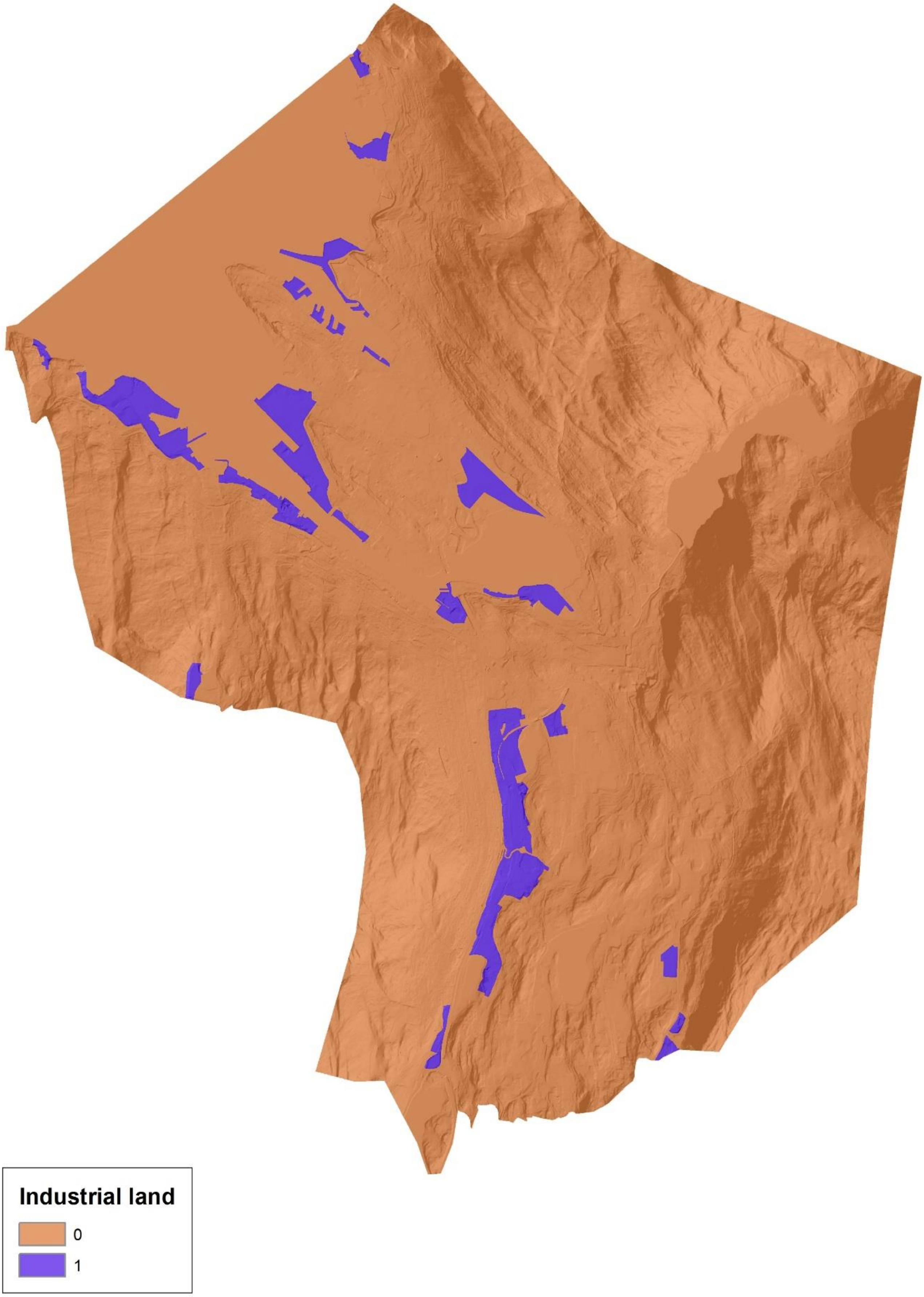


Figure 78 – Map of the ''Industrial Land'' – variable.

Protected land

There are many different types of land that are protected from development or change of any kind. The interviews and literature mention these: historic buildings and heritage sites, certain recreational green space, nature reserves and other protected natural environments, wildlife corridors, protected agricultural land, waterfront (100 m belt), and finally important lines of sight. This last one is difficult to represent accurately in a map, but the others are usually georeferenced.

Heritage sites and objects

How far protected cultural sites should count in a densification analysis is a topic that needs debate. A city cannot freeze its development completely. It must adjust to contemporary society. At the same time, historic sites are important for a city's identity and for the well-being of its inhabitants. The presence of historic buildings in an area should influence the form new development will take. There are numerous ways to organize a sufficient amount of floor space. Sometimes it may be necessary to move the buildings to a new location in order to preserve them, however.

A suggestion for how to determine the significance of heritage sites and objects could be to give them a "heritage factor". This factor can be multiplied with a "functionality factor" evaluating the site's current utility. Sites in the densification zones would lose protection value because of this. On the other hand, quantifying the decision in this way seems insufficient and risky. I think the debate, ideally a public debate, between heritage professionals and other relevant fields, politicians and the general public is the most appropriate course of action. Efficiency cannot be the priority when deciding on the fate of hundreds of years old pieces of our history.

The map data used for this variable is mostly copied from the master plan "hensynssoner". Individual historic buildings or objects ("enkeltminner") have not been included. Heritage sites, or heritage environments ("kulturmiljø"), are more important than single objects in terms of densification potential at the regional/ city-wide scale. Historic buildings and objects become an issue at the detailed local scale in part 3 of the analysis. They can only be evaluated superficially using GIS tools and need individual consideration in each new development project. I have also included site polygons shown in the latest regional plan with high or very high priority.

Protected green space

The green space included in the protected land variable are those with protection in a master or regional plan. Green space in the category “friluftsliv” (outdoor recreation in wild nature outside the city limits) and listed as “very important” by the Hordaland Region are included in the analysis. This mainly comprises the City Mountains. Parks and other recreational green space within the city limits are not included as protected land. They are included in the “Access to Green Space” variable, but it can be debated if they should also have been included here. The first iteration overlay maps gave them higher densification values than appropriate. In addition to these two types of green space, there exists the protected natural environments with important biodiversity. These are included as “hensynssoner” (special interest zones) in the master plan and are also included here. There are no wildlife corridors in the case area.

Other types of protected land

The case area does not contain master plan protected agricultural land or waterfront protection. The waterfront 100 m belt in general applies for the whole country, but is more important outside the urban areas. Public access to the water is an important consideration, however, but is best left for the detailed local scale of the analysis. The protection of agricultural land should be included in the analysis if such areas exist. The protection of agricultural land is one of the main arguments for densification in Norway.

Landscape is an issue included in the regional plan. It is a difficult issue to include in a densification analysis, because it does not necessarily rule out development. The consideration of landscape poses some limitations on the type of development that can take place, the typology and structure of the development. This is therefore also an issue for the detailed locale scale, not the regional/ citywide scale.

One or several variables?

The different protection types are often included as separate variables in Norwegian geographical analyses. I have decided to change this and use the Stockholm approach, which gathers all of them into a single variable. This is done to reduce their overall importance in the overlay analysis, and to show that the protection of such sites is just one of many considerations in urban planning. It might well be that these sites should be given precedence, but then this will be a discussion for the weighting scheme development of the overlay. Here the relative importance of all variables can be considered together.

Production

Data needed: Case area polygon, snap raster, protected land map data

The production of the "Protected land" variable is mostly a matter of collecting the needed map data.

As mentioned I included polygons, but not point (or line) represented protected sites. Most of the polygons came from the "hensynssoner" layer of the master plan. This includes zones for natural environments with important biodiversity and heritage environments ("kulturmiljø"). In addition, some heritage site polygons with high and very high values were included from the regional plan. And finally, the "friluftsliv" polygons listed by the region as very important were also included. Which types of land included in the variable will differ from city to city. The consistency between these should be to include sites of regional and citywide importance. Individual heritage buildings and objects should be included in the local scale analysis in part 3.

<u>List of object types</u>

Naturmiljø KPA
Kulturmiljø KPA
Båndlegging KPA
Friluftsliv
Kulturminner regional plan – svært høy verdi
Kulturminner regional plan – høy verdi

All of the included polygons are merged together into a single polygon and given the densfication value 0. This polygon was then "Unioned" to the case area polygon. The "non-protected" land is given the value 1.

Feature to raster is used to convert the data to a raster. The snap raster was used.

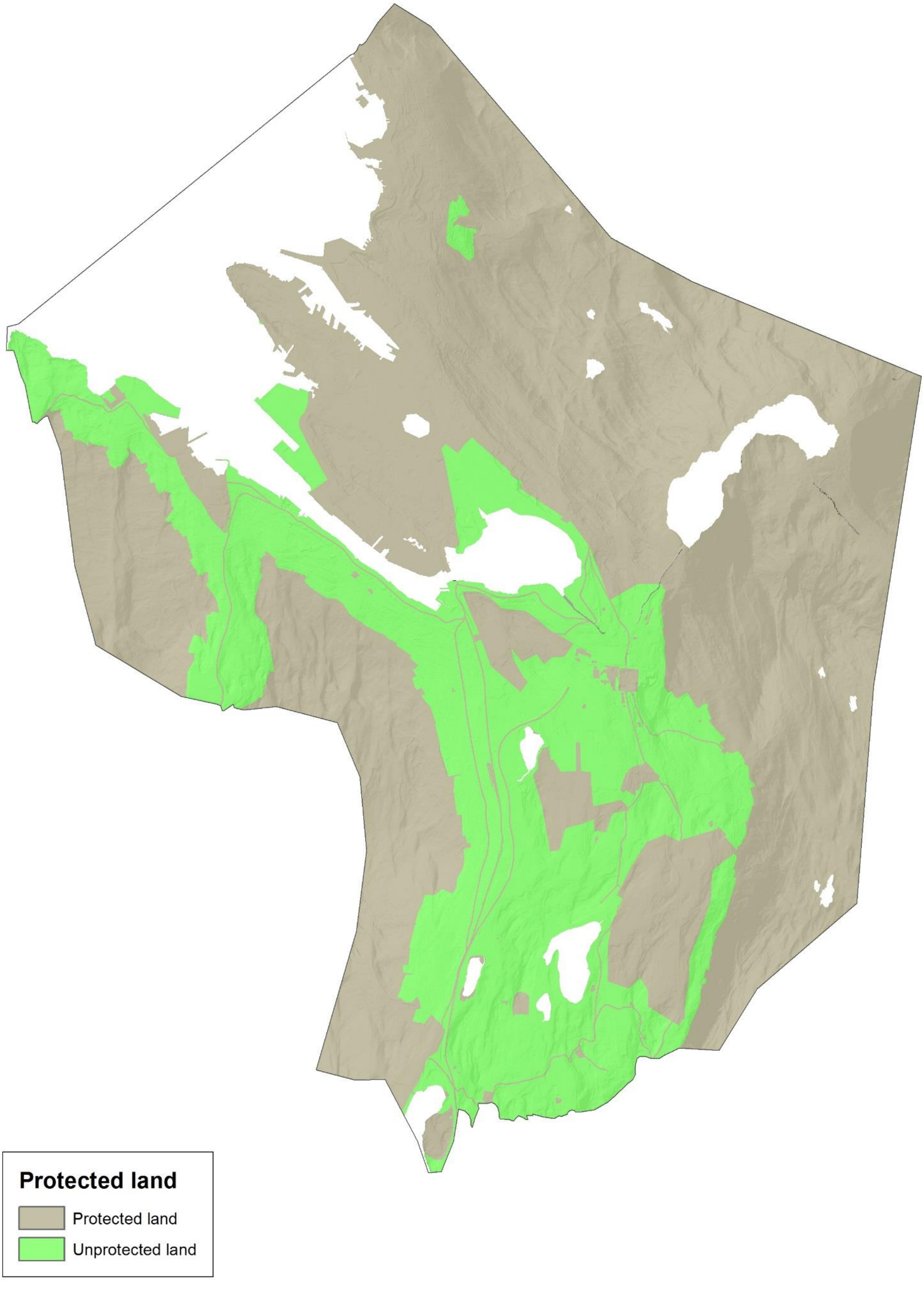


Figure 79 – Map of the "Protected land" – variable.

Spaciousness (OSR)

The concept of spaciousness adds existing densities to the analysis. After having created the dataset over homogenous zones, it was a simple task to calculate the FSI and GSI values for each area using building polygons and building points with floor space information. Then the OSR (Open Space Ratio) was calculated in a separate field using these measures.

OSR = (area size – building footprint)/floor space

This variable is not linear, because as the density approaches “unbuilt land” the OSR value approaches infinity. See figure 54 above.

To be able to use this variable as part of the overlay analysis I had to convert the values to the overlay value scale between 0 and 1. Using the logarithmic formula listed below I was able to fit the values appropriately.

Modified spaciousness index = 1 - e^(-1.5*OSR)

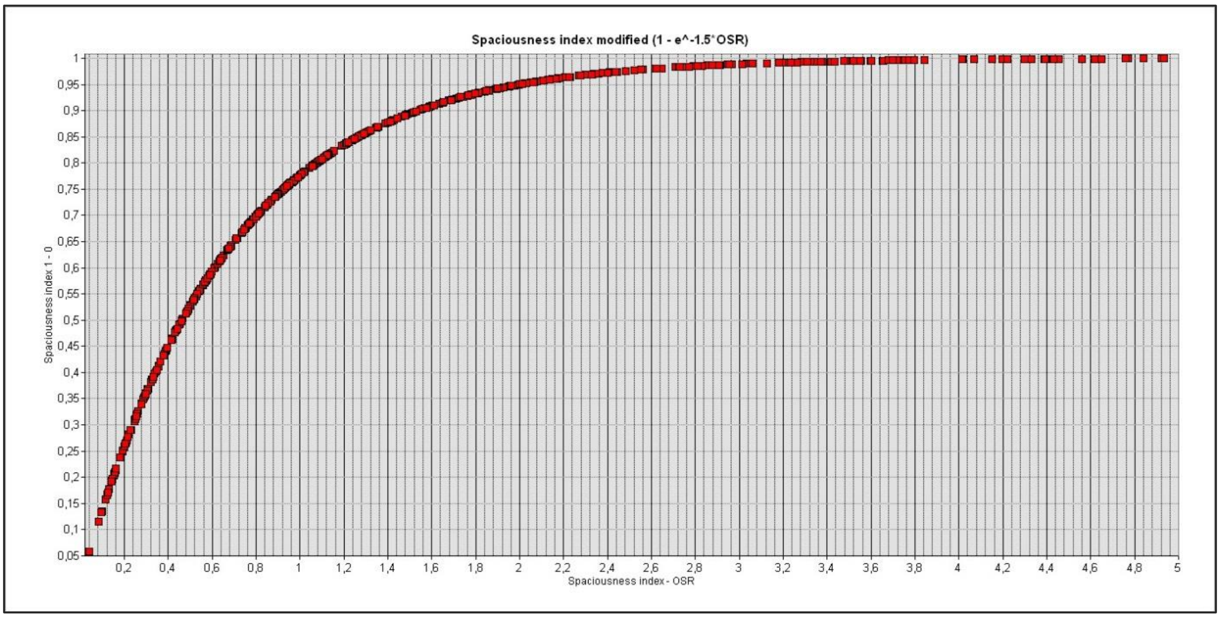


Figure 80 – Shows relationship between the original OSR values and the modified values in the 0 -1 scale.

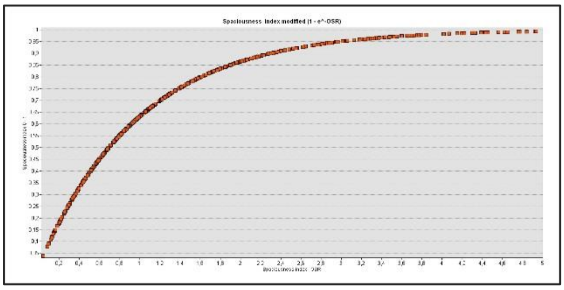


Figure 81 - (1 - e^-OSR)

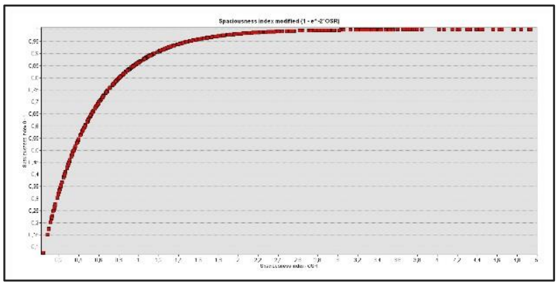


*Figure 82 – (1 – e^-2*OSR)*

This function produces values between 0 and 1. The exact curve of the graph can be modified by changing the value with which OSR is multiplied (in this case -1.5). It is necessary to understand what the numbers actually represent to determine which curve is the best fit. According to Berghauser and Pont (Berghauser Pont and Haupt, 2010) the appropriate OSR value is, like other density measures, a matter of subjective opinion. They refer to Hoenig, who first introduced the concept. He considered an OSR value of 1 as the minimum required for adequate spaciousness (Berghauser Pont and Haupt, 2010). In Amsterdam only the Bijlmermeer meet this standard (Berghauser Pont and Haupt, 2010). Therefore, I will have to determine the appropriate curve based on local conditions in Bergen, and choose a value that is not an extreme departure from the existing built environment.

The concept of the "compact city" is frequently mentioned as an ideal in the public debate in Bergen at the moment (Smith-Sivertsen, 2015, Skjold Lexau, 2015, Gjelsvik, 2015, Siverts, 2015). There are differing opinions, but there seems to be a general consensus that the existing historical centre should remain intact. This is also the densest part of the city, and a highly valued qualitative, relatively well-functioning area, something the soaring property prices can support. One could therefore say that the density in the centre of Bergen can function as an ideal to which the surrounding city can measure an appropriate increase in density. Therefore, one should not strive for a higher density than exists in the city centre. The OSR values in these areas should indicate that no more densification is desirable.

The 0 - 1 scale, as used in the overlay analysis, seeks to give a value to densification potential when looking at spaciousness. The closer to 1 the higher the densification potential. The closer to 1 the higher the OSR value, the larger the spaciousness. When determining densification potential one should evaluate whether an area has more than enough space, or whether or not it has too little space. Areas that lack spaciousness should not be densified. The value zero therefore signifies that densification should not take place. The value 0.5 is therefore neutral areas given this value are not clearly candidates for densification, but can at the same time sustain some densification.

The choice of the curve should bear in mind local densification ambitions. I believe that the curve chosen represents Bergen well. The areas in the historical centre that have an OSR value up to 0.4 should not be densified further. This OSR value should therefore fall below 0.5 on the 0-1 scale. Looking at the areas in the category OSR 0.4 to 0.6 I consider these areas to fall around this neutral 0.5 value. Therefore, I decide that the OSR value 0.5 should more or less have 0.5 as a value on the 0 -1 scale. The chosen formula is a good match in this regard. The two graphs in figures 81 and 82 show different options, both of them have values too far in either direction. At the same time, they are not extremely different and the difference between them will not affect the overall results significantly.

The white unbuilt areas in the map are given the value 1. As unbuilt land they get a very high value for the variable spaciousness, even though they will get a very low value for other variables, such as protected land.

Production

Data needed: case area polygon, snap raster, homogenous zones, water polygons.

I assume that the OSR values have been calculated already and stored in an attribute in the homogenous zones dataset.

Create a new attribute and calculate the converted overlay values using the formula described above.

Union the homogenous zones with the case are polygon and the water polygons.

Give the water polygons the overlay value Null.

The rest of the polygons on land (unbuilt) is given the overlay value 1.

Feature to raster, using the snap raster as template.

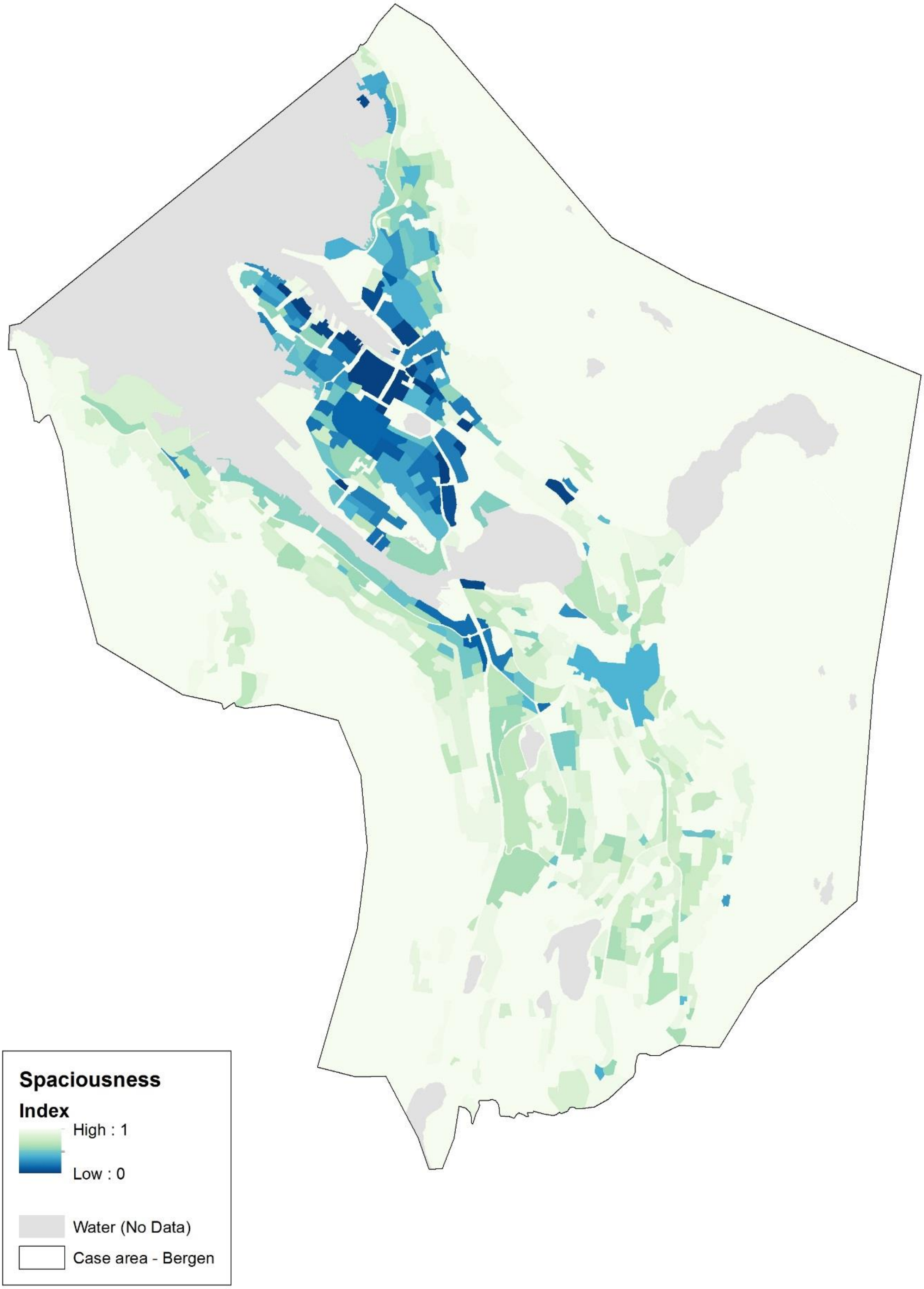


Figure 83 – Map of the "Spaciousness"- variable raster.

Complexity of ownership

This variable looks at the size of properties and the number of property owners in an area. It is included in the analysis so that the likelihood of success for densification initiatives can be evaluated. The more people that have to be included in negotiations for the purchase of land or neighbours that may have complaints about a new development, the more complicated, time consuming and costly it will be to secure an agreement.

The idea to include this variable comes from the Stockholm analysis. Regionplanekontoret operationalized the variable by measuring the number of properties per hectare, i.e. looking at the sizes of properties. The larger the property sizes, the fewer owners to deal with. I decided to try to improve the accuracy of this measurement through information about the number of owners per property. I also included information about the number of "andelseiere" (part owners) in "borettslag" (cooperative housing), which does not appear in the cadastral data. There are many housing cooperatives in Norway and in the case area. These properties are deceptive in that they are very large and are listed with only one owner in the cadastral database (i.e. the housing cooperative itself). In reality, there may be hundreds of part owners that have a say in negotiations affecting the property.

Exactly how complicated it will be to negotiate a deal with a housing cooperation depends on its internal organization and in particular on the voting scheme they use. Both simple majority and stricter schemes, like a 2/3 majority, exist. If there is a board representing the housing cooperative it is easier to negotiate with it than with each individual part owner. "Borettslagsloven" (The Norwegian Housing Cooperative Act) § 7 -11 states that voting is conducted through simple majority, but that a stricter voting scheme can be set in the housing cooperative's ordinances ("vedtekter"). At the same time this phrasing is found in § 7 -13: "Generalforsamlinga kan ikkje gjere noko vedtak som er skikka til å gi visse andelseigarar eller andre ein urimeleg fordel til skade for andre andelseigarar eller laget.»[17] Whether or not this paragraph applies for a new development project seems to need clarification in each individual case.

[17] English translation: "The general assembly cannot approve a motion which may give some part owners or third parties an undue advantage at the expensive of other part owners or the housing cooperative itself."

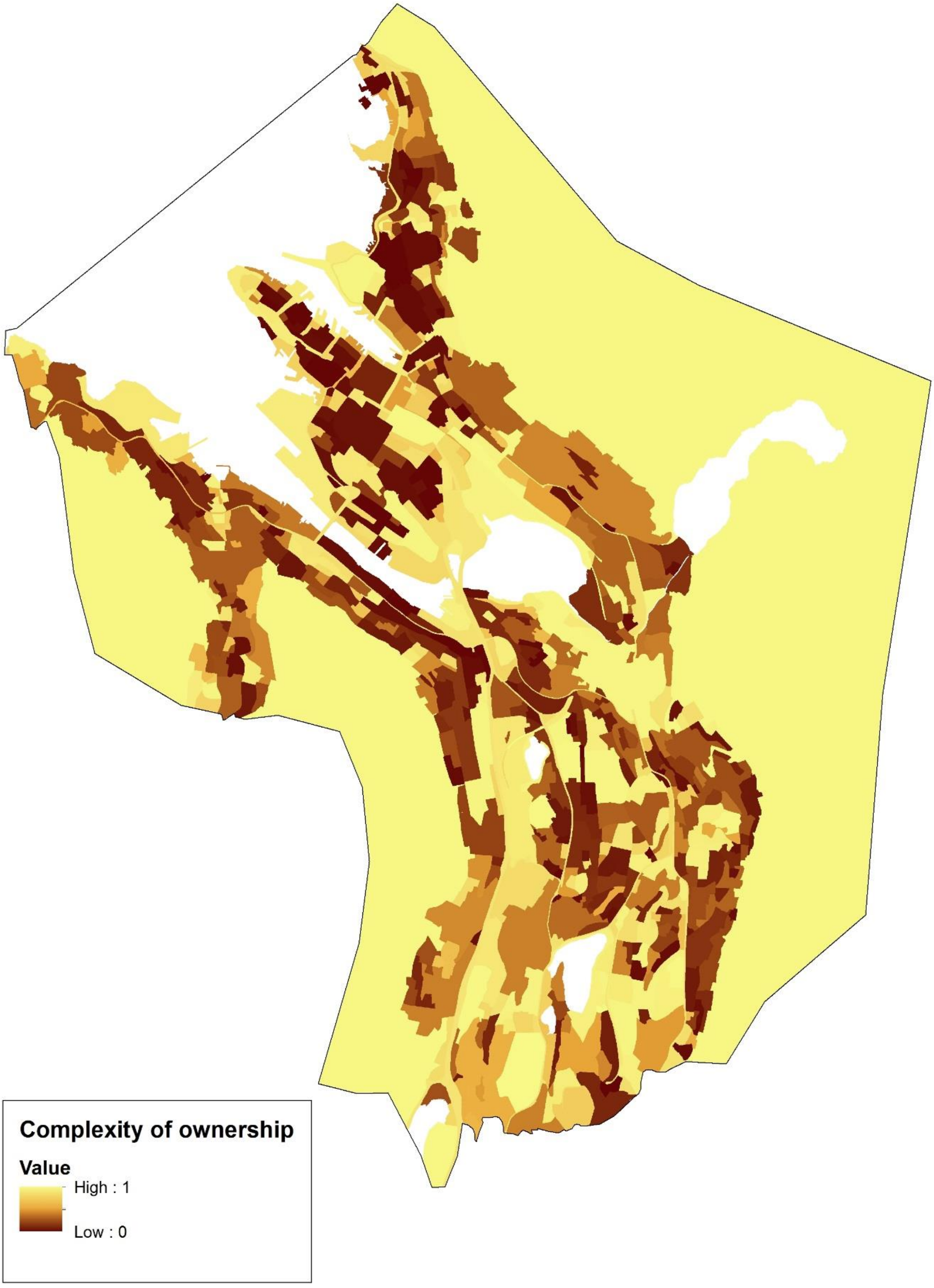


Figure 84 – Map of the "Complexity of ownership" – variable.

Production

Data needed: Cadastral polygons with GBNR (unique property number). Address point dataset which includes the street addresses and GBNR of the property, case area polygon, snap raster, water polygons.

Excel-export of cadastral data ("Matrikkelen") produced by "Statens kartverk" (Norwegian Mapping Authority) where they had included a field with the number of owners registered on each property (GBNR).

Excel-export of housing cooperative data supplied by Ambita (Previously called "Norsk eiendomsinformasjon"). I received access permission through "Statens kartverk". This data is stored in a separate database from the "Matrikkelen". It does not link the part owners to the GBNR of the property, instead you have to link them using the street address of the building where their apartment is registered.

1. Open the two excel files in ArcMap. Use "data export" (All) to copy the data into geodatabase tables.

2. Create a join key for the housing cooperate data using the street address. This information is found in three separate fields ("GATENAVN", "HUSNUMMER", "BOKSTAV") that have to be combined into one. Compare the form of the values of the fields with the same values in the address point data to make sure they match. Some housing cooperatives do not have street address information. These are not many, so the addresses can be added manually. Often the address information is written in the name of the housing cooperative. Make sure to check street addresses where an apostrophe is included. If they don't match, rewrite them. Python is useful for this.

Add field (string) → use "Field calculator" to calculate the key:

[GATENAVN] + [HUSNUMMER] + [BOKSTAV]

Create the corresponding key in the address point dataset. Make sure each key is unique in the address point dataset.

3. Use "Summarize" on the key field in the housing cooperative dataset. Include the field containing the housing cooperative's name. Now you have the number of part owners (Count field) on each address belonging to the housing cooperative.

4. Join the summary table to the address point data. Export the join to a new point feature class.

5. Check the cadastral polygons. Those with identical GBNR should be dissolved into multipart features. Some of the cadastral polygons do not have GBNR information. This is because of faulty information in the Matrikkel database. Since it is impossible to know anything about the number of owners for these polygons, give each of them 1 owner in a new field called "Number_of_owners" BEFORE merging into multipart. The multipart feature operation can be performed using "Dissolve" and the fields "GNR", "BNR" and "FNR", which combined make up the "GBNR". But you might as well create the join key first and use this.

Create the join key using GBNR that will join the cadastral polygons with the excel-exported cadastral data containing the number of owners. The key is created using the fields "GNR" (3 integers), "BNR" (4 integers) and "FNR" (3 integers).

Add field (string) → use "Field calculator" and python to calculate the key:

str(int(!GNR!))+str(0)+str(int(!BNR!))+str(0)+str(int(!FNR!))

(The extra str(0)+ are to ensure that the numbers do not get mixed up because the BNR and FNR have some values with only 1 number, some with 2, some with 3 and the BNR also has some with 4 numbers. The number of zeros must be changed so that the BNR section of the key always have 4 numbers and the FNR section always have 3 numbers. This is not necessary to do with the GNR value. Example result: 1640041008)

afterwards convert the string to long integer:

long(!GBF_string!)

6. Now for the number of property owners registered in "Matrikkelen". Create the key using the same method described above.

7. "Summarize" on the key to get a new table with the sum of all "Aktuelle eiere", "Hjemmelshavere", "Festere" and "Framfestere" for each unique GBNR.

8. Join the sum table to the cadastral polygons using the key.

9. Use "Spatial join" to join the point data containing the number of part owners in the housing cooperatives to the cadastral polygons.

10. Create a new field where you sum the number of property owners and the number of part owners for each polygon. This field shows the total number of owners per property. This can be used to create an interesting additional map.

11. For the overlay analysis, the data is better aggregated to the homogenous zones level using spatial join. Union the case study area with the tare and the homogenous zones. Feature to point the cadastral polygons, remember to tick the box for a point "inside". Spatial join the points to the union polygons. Create a new field, where the number of owners per decare is calculated.

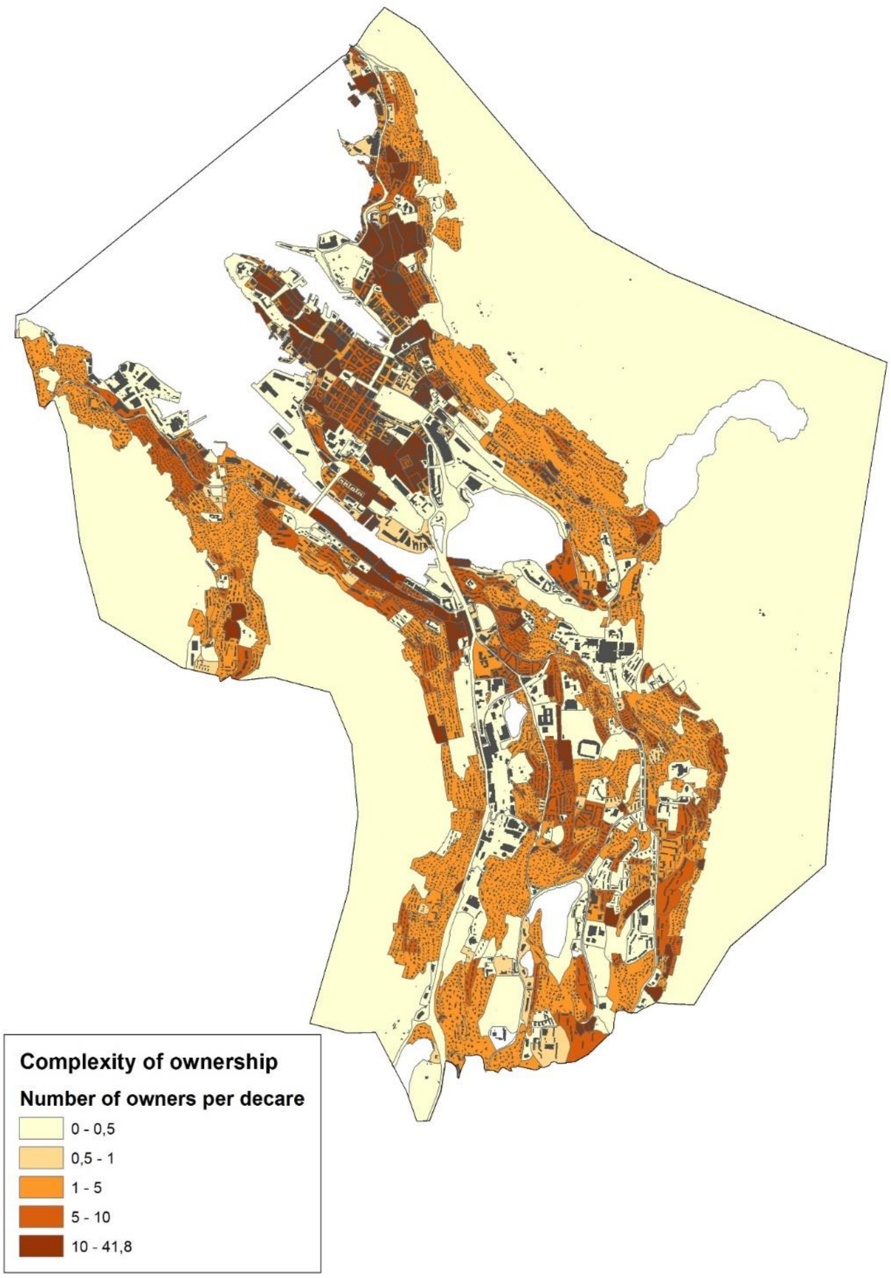


Figure 85 – Map of the homogenous zones with the number of owners per decare.

12. To convert these values to the overlay scale the same technique was used as for the spaciousness variable. Choosing the correct formula was again based on which areas should fall above or below 0.5 as densification value. This is a methodological weakness. The correct formula should be based on further study.

Modified ownership complexity index = e ^ (-0.4 * "Number of owners per daa")

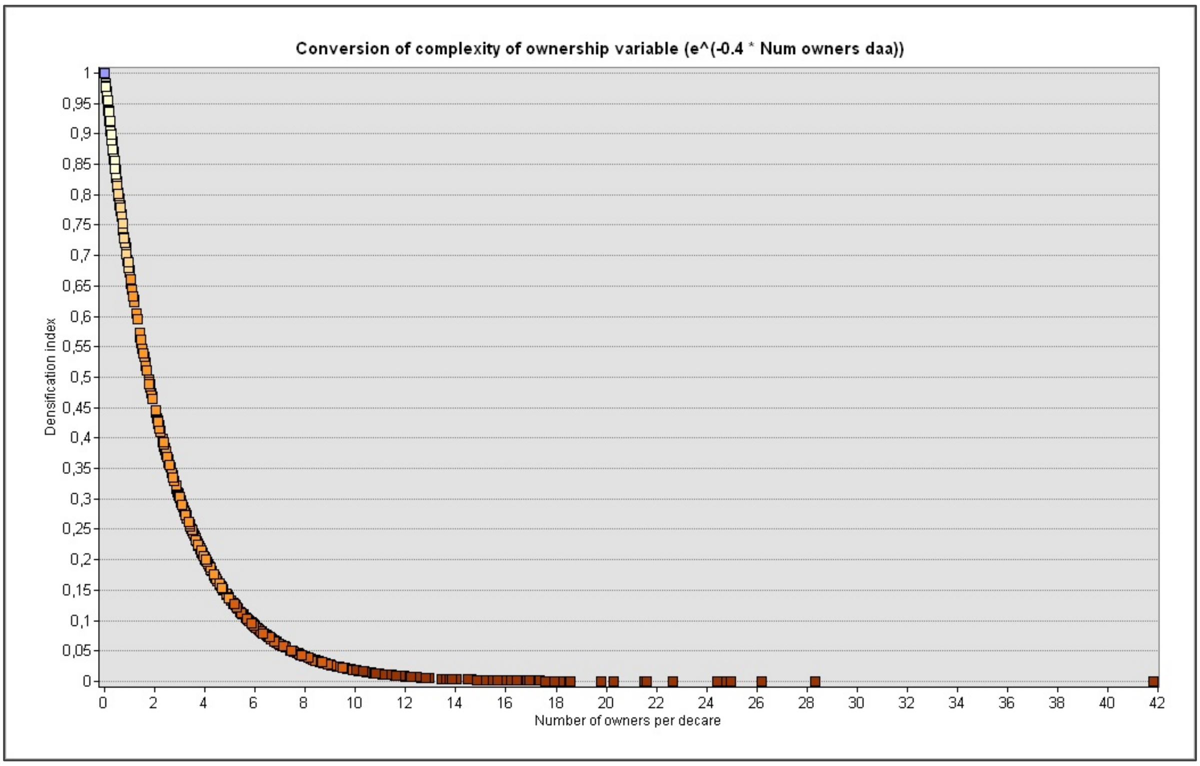


Figure 86 – Graph showing the conversion of the ownership complexity values to the 0 to 1 scale used in the overlay.

Calculate field (Python):

Pre-logic Script Code:

Def e_calc(Antall):

    Return math.e**(-0.4*Antall)

(Variable name) =

e_calc(!Number_of_owners_per_daa!)

13. Feature to raster.

Utilization of existing public transport

This is the only “densification need” variable from the Stockholm analysis that I have included in my analysis. I will explain this below in the next chapter. The variable examines how well the existing public transportation system is utilized. Areas with low densities that have access to high-frequency public transportation are identified with densification potential. Increasing the density in these areas will benefit the public transportation system with a larger customer basis. This will allow higher frequencies and even better transportation than before, which will make more people choose public transportation over the private car (Norheim and Ruud, 2007). Densification in these areas will boost this positive circle.

This variable uses the same 500 m walking distance polygons used in the “Access to public transportation” variable. 500m is also the same distance used in the Stockholm analysis for the current variable, except that the Swedes use linear distance from the public transportation stops instead of distance along a network. The amount of floor space per decare within the polygons is calculated. The “per decare” is included to control for the varying sizes of the walking distance polygons.

Production

Data needed: 500 m walking distance from pub. trans. stops polygons, building points from “Matrikkelen” that have floor space information (BRA), area of study polygon, water polygons, snap raster.

Clean the building points dataset. Delete irrelevant points “tilbygg”, “påbygg”, etc. and delete “Garasje anneks til bolig / fritidsbolig”.

Erase the water polygons from the walking distance polygons if not yet done. Keep the polygons as multipart if split in two by water.

Spatial join the building points to the walking distance polygons. Sum on “Bruksareal Totalt”.

Create a new field and calculate the density: BRA_per_daa = (Sum_Bruksareal_Totalt / Shape_Area)*1000

Convert the density value to the overlay value scale. It will be a relative scale only comparable in the area of study.

Utilization index = 1 – (BRA_per_daa / max value of dataset)

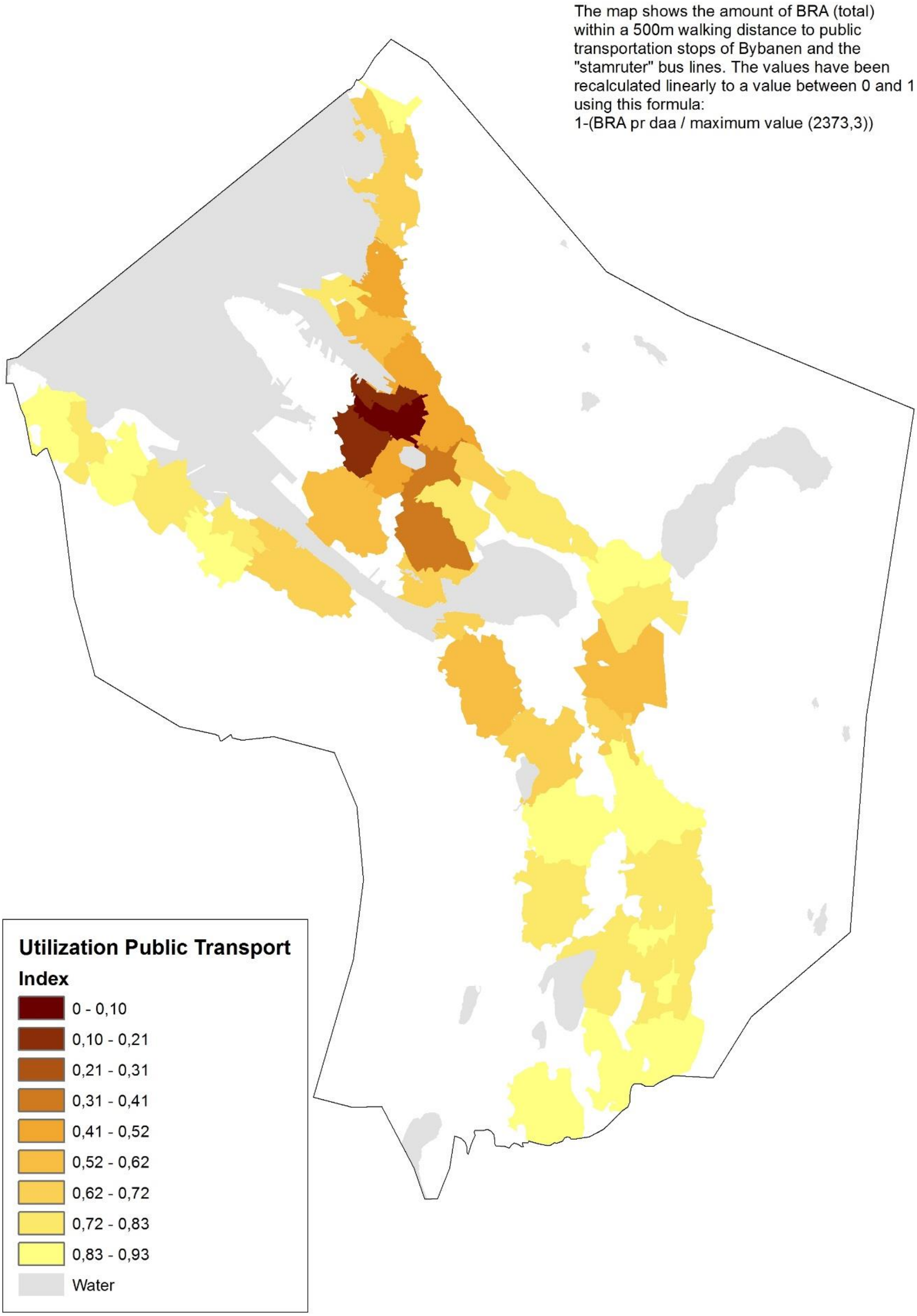


Figure 87 – Map of the "Utilization of public transportation" – variable.

It is necessary to use a relative scale for this variable because cities have such widely different vantage points. The maximum amount of floor space in the case area was about 356 000 m2, while the maximum in the Stockholm analysis was 2 000 000 m2.

Feature to raster after having unioned the walking distance polygons to the area of study polygon.

Variables not included in this iteration

The variables described above are the variables included in the overlay analysis for this first iteration of the method development. In this chapter, I will briefly describe variables that were not included in the analysis, but that should possibly be included in the second iteration. They were not included either because they were not relevant for the area of study, because I only later found that they should possibly have been included, or because I was unsure about their usefulness.

The three "densification need" variables from the Stockholm analysis that I did not include do belong in the overlay analysis, but they were not ideal for the area of study. These variables are better suited for the regional scale, i.e. the Stockholm region and the larger Bergen region.

Figure 88 – Map of the variable "Population Basis for Services". Not used in the overlay analysis.

Table 10 - variables not included

Mixed use – Amount of dwelling floor space relative to other use floor space	The variable is described in the mixed use chapter. There it was decided not to include it in this iteration, but it should be included in the second iteration for a larger case area. This is because the other mixed use measure can give a high level of mixed use to an area without any dwellings. Therefore, the amount of dwelling floor space versus other floor space is a necessary consideration, but on a higher scale than the current area of study.
Population basis for services (figure 88)	The variable needs a better justification and operationalization to be included in the overlay. I measured the number of people within 1000m of each raster cell using Kernel Density. Instead of a relative scale conversion, I used the UN Habitat goal of 15 persons per daa (1 – (#persons_daa/15)). The variable as it stands seems flawed, however. It should show that the centre of Bergen needs more people. The priority should be to increase the population here first. But the variable gives a higher value to areas with lower densities than the centre.
Cohesion of building structure	The area of study has good cohesion of the urban structure, so this variable did not affect the analysis to a significant degree. This is why it was not included. It would work better on the regional scale to evaluate where there are large unnecessary gaps in the urban area.

Noise	Not included because it can be mediated. At least noise along roads. Airport noise is more serious, and is more justified to include in the overlay analysis.
Flood zones	A difficult variable to include because it does not rule out development. It can also be mediated. It depends on the type of flood zone. Some areas are so exposed that they should not be developed. Where reliable map data exist these should be used, otherwise the evaluation of this variable should be left to part 3 of the analysis or for each individual project.
Existing plans	This variable is often used in the Norwegian analyses I have examined. It looks at unused development potential in existing plans. This does give an idea of the difficulty of implementing new development in an area, but it is also problematic to give plans, which may be old and outdated an impact on the analysis.
Existing buildings' age and general condition	An interesting variable when planning in a longer perspective, such as 20-30 years. The cheap and rapidly constructed residential buildings constructed after WW2 are soon ready for refurbishment. In a certain time period, very poor concrete was used. These buildings will not last long, and may offer potential for more radical transformation. The variable was not included for lack of time.
Recycle value of buildings ("Gjenbruksverdi i bygg")	This variable and others used by Mosebach are interesting, but difficult to add to the

	scale of the overlay analysis. They are too detailed. At least, I was not able to think of a good GIS operationalization, at least not within the current time frame.
Sunlight access	The topography variable does not cover this issue. Examining the overlay map it seems that the areas on the northeast sloping mountainside are possibly given higher values than they should. A variable measuring amount of sunlight access might mediate this.
Betweenness (figure 89)	The map below shows the result of my experimentation with this variable. I did not include it in the overlay, because I evaluate it to be more important for part 3. It is more a "HOW" variable, than a "SHOULD" variable.
Connectivity	I did not include this variable in the analysis for lack of time, but also because I am unsure about where it belongs. In the overlay, or instead in part 3? The variable is so central in many sources that it should be included in some way.
View	A good view is an important factor relating to densification pressure. It is not easy to measure, however. The observer point analysis has the right technique, but will only allow maximum 16 input points. A batch operation could possibly work using fishnet points.
Diversity	Talen's definition of diversity refers to social diversity in the population. A Norwegian equivalent to the Simpson

	diversity index could be interesting to test in the second iteration.

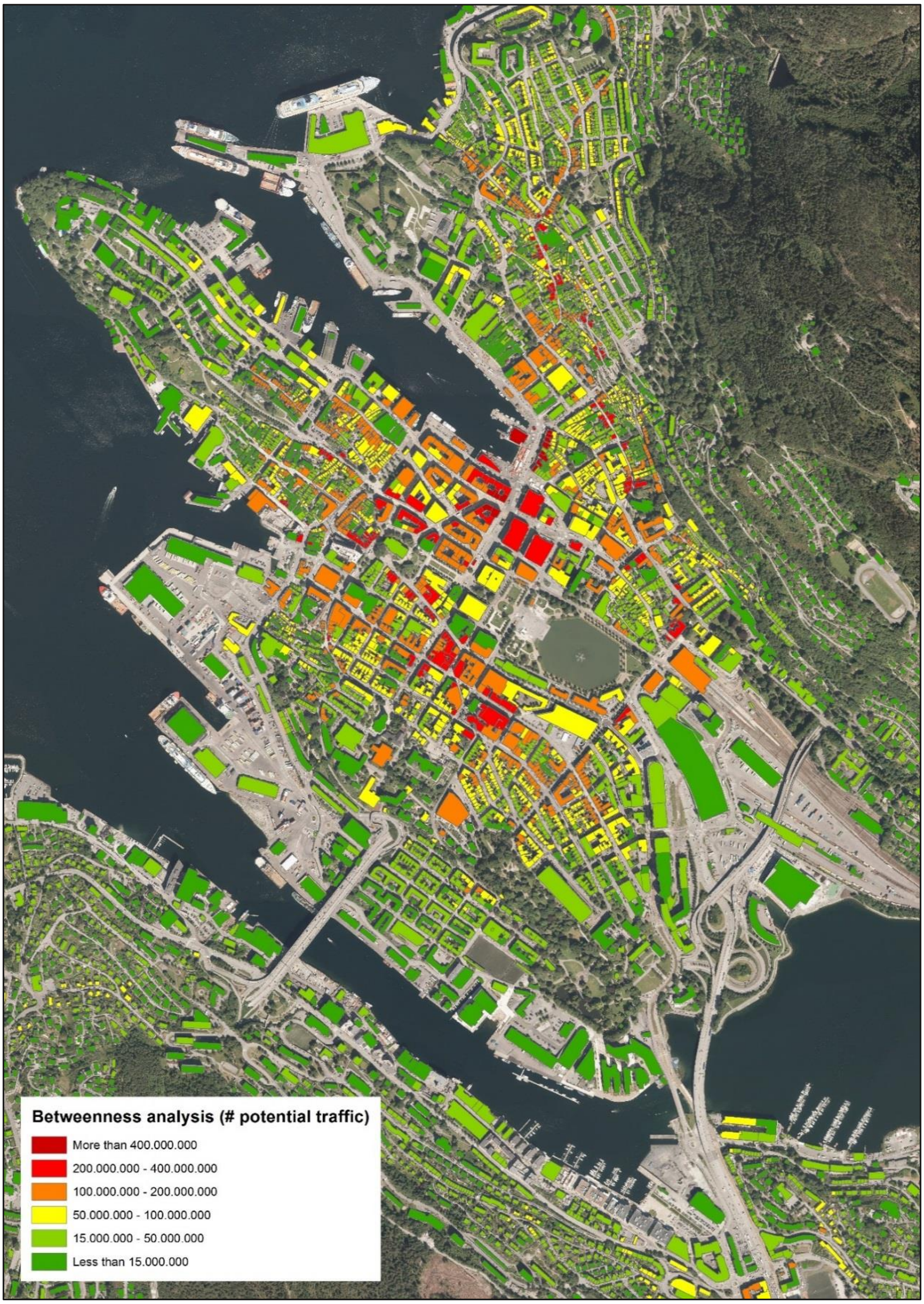


Figure 89 - Betweenness analysis - counts the number of shortest paths passing each house.

“Temporary” variables

In terms of densification potential it is questionable whether variables that are easily changeable should be included in the analysis. These variables may therefore be good candidates for elimination. An example is noise pollution along roads. Buildings can be placed strategically to protect open spaces from the noise. Roads can be moved underground. Noise pollution from an airport is a different matter, because it is much more difficult to mediate.

Another such temporary variable is distance to public transportation, at least with regards to bus transport. Bus routes are relatively easy to relocate, rail based public transport not so much. In the Norwegian context however, many existing bus routes do not have a sufficient population basis, and would benefit from more potential passengers. Access to public transportation is such a significant variable with regards to sustainable development that this variable should nevertheless be part of the analysis.

Overlay analysis – with weights

The variables are now ready as rasters with the same value scale and with cell arrangements that match. If some of the rasters have NoData within the area of study these must be reclassified to zero (except water). “Reclassify” can be used for rasters with discrete values. For rasters with continuous values use “Is Null” followed by “Con” (see help: “How to change NoData cells to a value”.

For the first overlay analysis, the variable rasters are all added to a simple addition operation in the “Raster Calculator” without giving any of them extra weight. It is also important to divide the result with the number of variables (and weights) included, so that the values can be compared across different scenarios. For this first overlay, the values must be divided by 14. Ex: (Variable1 + Variable2 + Variable3)/3

The Classification scheme

The main decision to make at this point is how to classify the resulting overlay values. The values range between 0 and 1, where those cells with the maximum value in each variable will get the overlay value 1. This means as before that the value 0.5 signifies neutrality. The areas with a densification value of 0.5 do not stand out as either very good candidates for densification nor as very bad candidates. I wanted this neutral class to stand out, so I had to use an odd number of classes. Five classes is appropriate because they will show some variation in the scale, while not being so many that it is difficult to tell the difference between the colours in the map. Setting the class boundaries is the most difficult task, particularly since I did not have actual research to base the decision on. In the end, I chose the boundaries seen in the below map because I wanted to limit the areas standing out with densification potential. A result saying that you can densify everywhere is not very useful. It should rather show distinct areas where efforts can be focused. Exactly where to set the class boundaries should be a matter of political discussion. As can be seen in the map below this classification scheme leaves the majority of the area in the neutral class.

I did not have time to experiment with the weighting technique used in the Chinese example. This may be something to examine at a later point in time.

The map shows that many of the areas currently under public discussion as candidates for densification also are among those with the highest densification potential in the analysis. This includes the freight terminal area by the train station, the harbour area by the mouth of the "Puddefjorden", and areas along the light rail line, such as Kronstad, Sletten and Danmarksplass. Mindemyren also has high values. This area is already planned, but has not yet started the massive transformations to come.

On the other hand, there are also some areas standing out with densification potential, which in reality are not good candidates for densification. This includes the harbour in front of the old fortress north of the centre, church lots and the lots of other monumental buildings. The parks have several places been given high densification values, but I have cheated and hidden them behind the tare layer (white areas). Somewhat surprising is the high densification values along the Laksevåg line. As mentioned, this bus line should not have been included in the analysis, because it is not yet a "stamrute". The overlay map would probably look different if it had not been included. On the other hand, this might mean that there is a lot of potential in this area that can be release by increasing the public transportation offer. An issue with this area is that it is located on a northeast facing mountain slope, which would not get high values in a sunlight access variable. This should be tested in the second iteration.

Interesting to note is that there are much fewer areas with very low densification values than areas with high values.

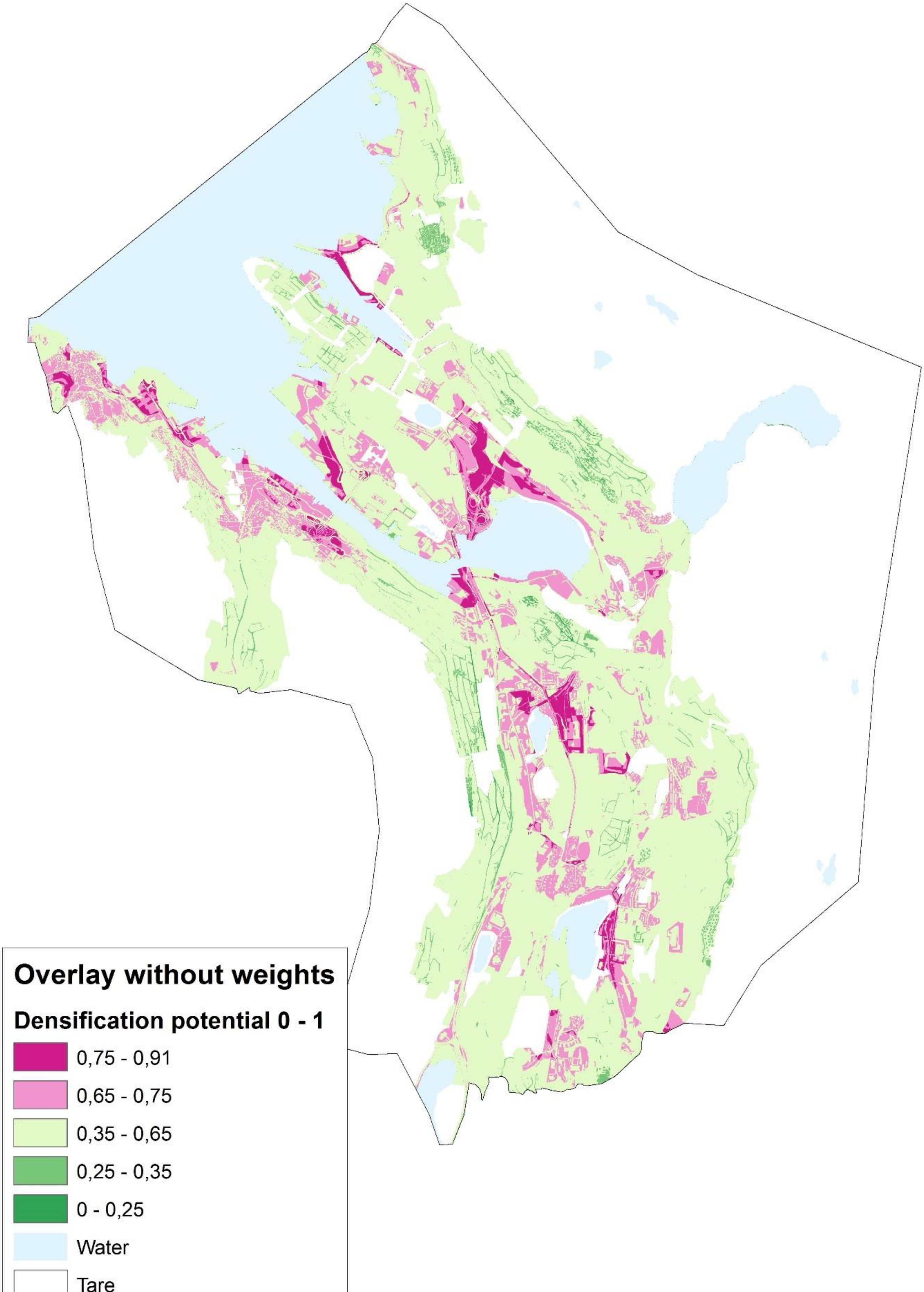


Figure 90 – Result map of the overlay analysis without weights.

Scenarios

Using weights on certain variables, it is possible to produce different scenario maps. These maps show densification potential based on different priorities. Though I tend to think that the overlay map telling us where we "should" densify, should try to incorporate as many perspectives as possible. This is the nature of city planning after all. Densification affects so many aspects of the city that it is risky to reduce an analysis to one or a few main perspectives. Producing different scenario maps is nevertheless useful as a basis for discussion. It would be interesting to compare the urban planner's ideal densification map to the heritage protector's ideal, or the ideal map of the property developer. The urban planner's map would for example exclude property borders as a variable. Below will be presented some example scenarios. A table showing how the different variables are weighted in each is also available.

Table 11 – Overview of variables and weights in the different overlay scenarios

Variable	Weight in different scenarios					
	Protection as priority	Sustainable transportation	Simpler and less expensive	Old n' green	Without existing pub. transport	Without existing buildings and owners
Topography	1	1	2	1	1	1
Unbuilt land	1	1	2	1	1	0
Access to existing infrastructure	1	1	2	1	1	0
Flexibility in the built environment	1	1	2	1	1	1
Distance to city centre	1	3	1	1	1	1
Mixed use – number of functions	1	2	1	1	1	1
Access to public transportation	1	3	1	1	0	1
Access to green space	1	2	1	3	1	1
Access to water	1	2	1	2	1	1
Industrial land	1	1	2	1	1	1
Protected land	3	1	2	3	1	1
Spaciousness	1	1	2	2	1	1
Complexity of ownership	1	1	3	1	1	0
Utilization of existing public transport	1	2	1	1	1	1

Protection as priority

The only difference between this map and the unweighted map is that the protected land variable has a triple weight. This more or less removes the densification potential from the protected land, but at the same time it increases the densification values of areas without protection. This is an interesting point to discuss. If we put very high value on heritage sites and objects, other priorities must be reduced. The resulting map does not seem very realistic, however. The “protection as priority” scenario would possibly have worked better if the protected land variable was given a negative weight. If the protected areas was given the value -3, the unprotected land would keep their unweighted values and the areas with high densification values in the protected areas would simply be deleted, reducing the overall amount of land with densification potential. This seems more logical than that the amount of land with densification potential increases in a scenario focusing on protection.

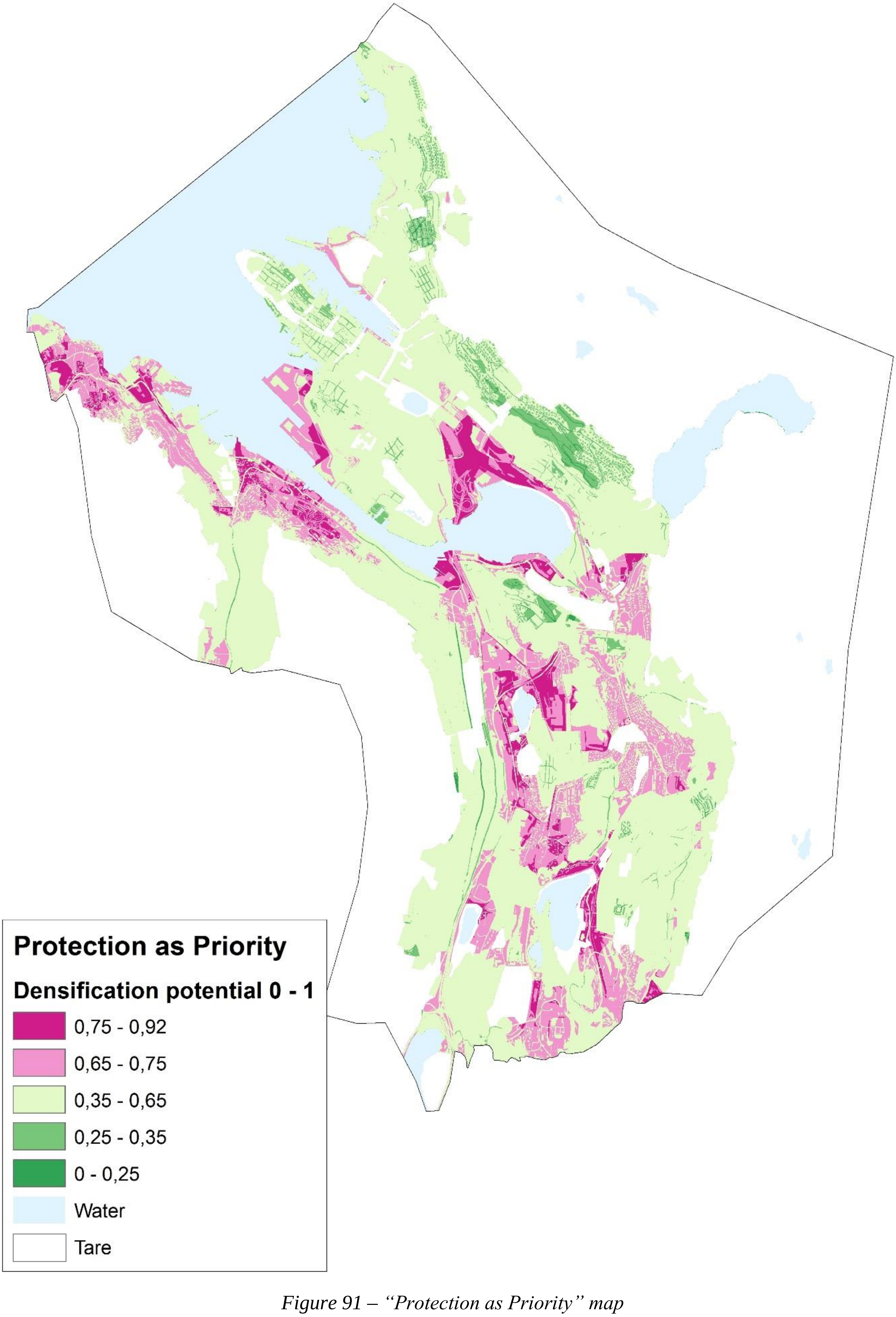


Figure 91 – "Protection as Priority" map

Sustainable transportation

If the priority is to ensure the maximum amount of sustainable transportation, then the city centre and areas along the high frequency public transportation lines get very high densification potential. This means that the protection of heritage sites and objects in the city centre will have to be reduced. Realizing the potential in many of the areas in this scenario will require significant amounts of demolition and radical transformation, particularly in the closed block structures in the city centre. We also see that the densification values are reduced in the more peripheral areas like Fantoft. This is because the relative scale of the "distance to the city centre" variable give these areas very low values. Too low, it can be concluded from this. Areas like Fantoft are in transportation terms not that far from the city centre. It is a 20 min travel by light-rail. This suggests that the relative scale of the "distance to the city centre" variable should be changed to one either based on the whole city area, or it should be based on research into what are acceptable travel times by public transportation. Aud Tennøy's research can be an option here (Tennøy, 2011).

This scenario also brings out areas with very low densification values, along the mountainsides in particular.

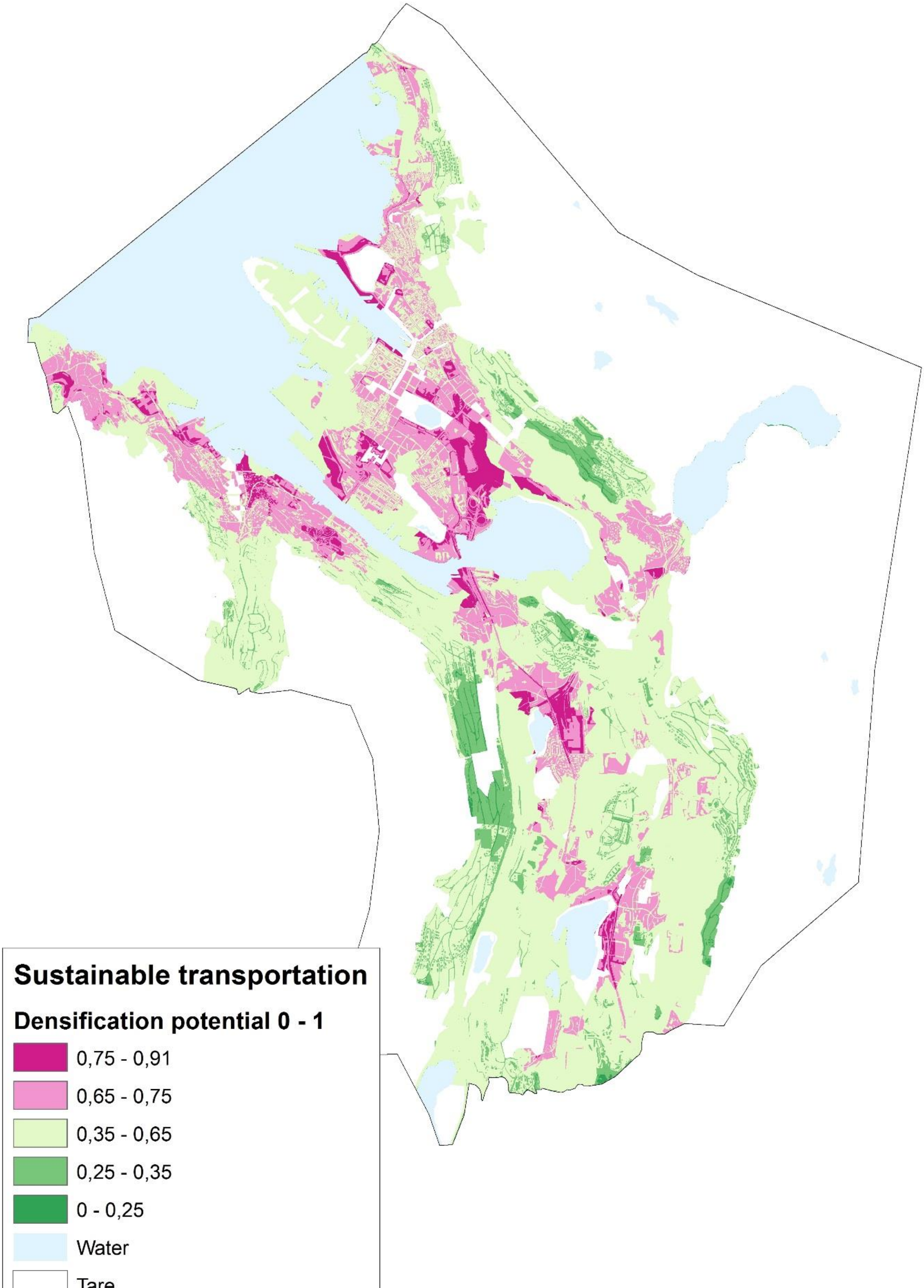


Figure 92 – Sustainable transportation map

Simpler and less expensive

The idea behind this scenario was to attempt to make a map based on the requirements of the property developer. It does not include densification pressure variables, however, so it might not be exactly what was attempted. Property developers will be interested to find areas where they can get the highest prices, which relies on the attraction of access to green space and other such variables.

The industrial land in emphasized in this scenario, as is most of the sports fields.

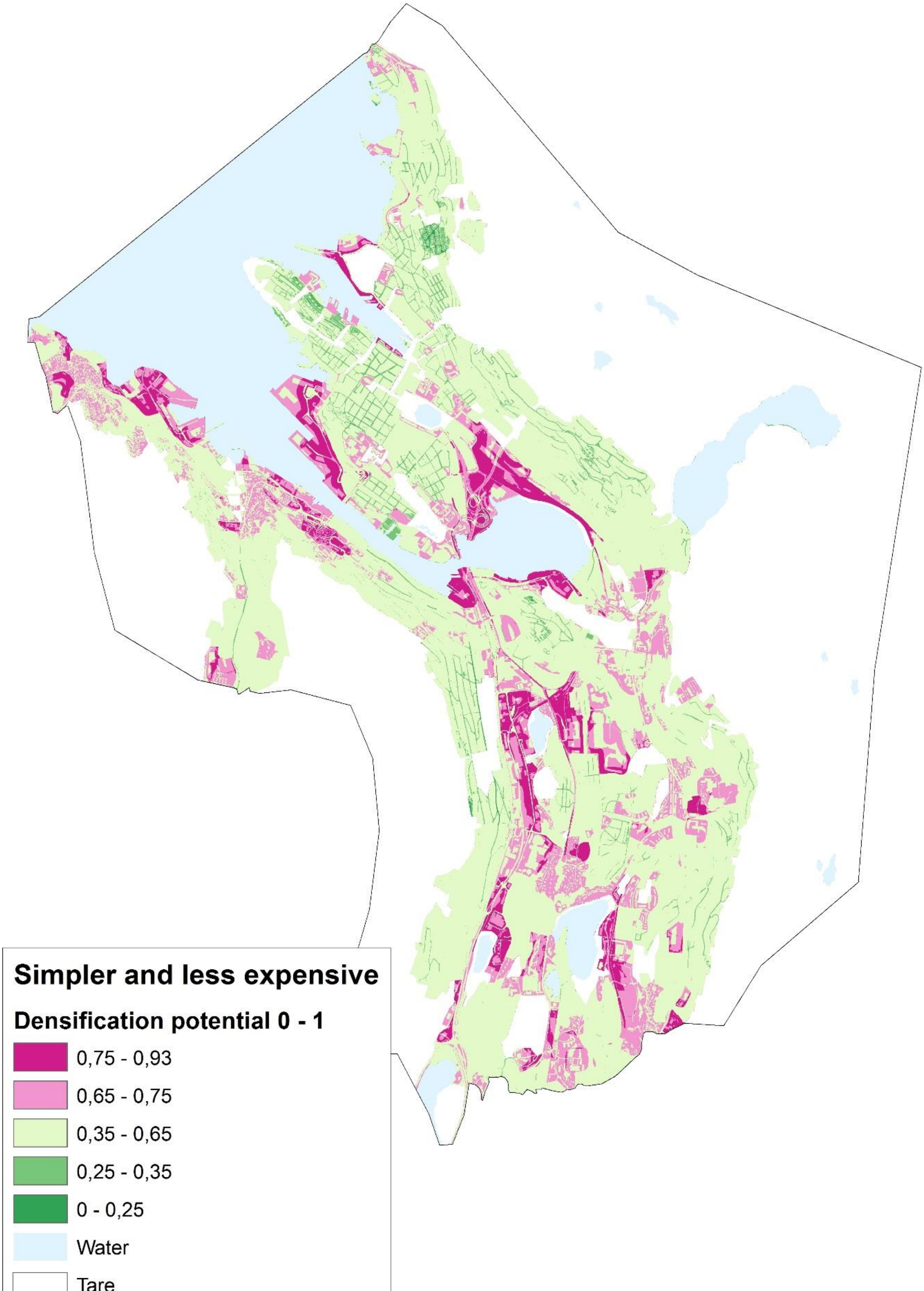


Figure 93 – "Simpler and less expensive" overlay result map

Historic and green

This scenario gives priority to the protected land and access to green space and water. It also gives more weight to the spaciousness variable, in an attempt to spare the existing public green space, while assigning the densification to areas with high levels of spaciousness compared to the older city areas. The map shows that many of the villa areas will have to endure significant amounts of densification in this scenario. Not all, it should be noted. Villa areas close to green space and water have particularly high densification values, which seems reasonable, at least around very large green spaces. An example is Storetveitmarken, which can certainly endure much higher densities than those found in the villa areas around, while still providing good quality urban areas.

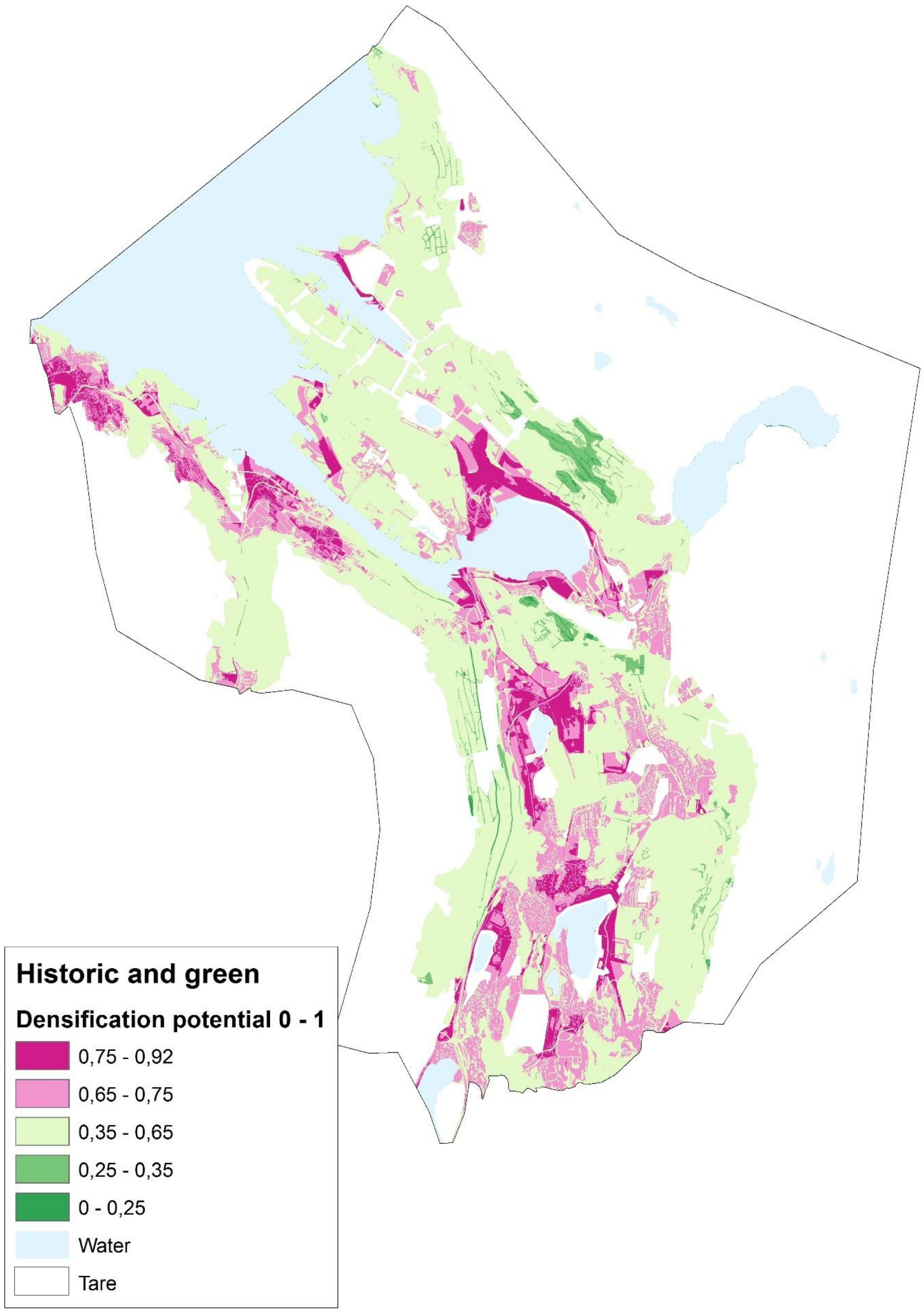


Figure 94 – "Historic and green" overlay result map

Without existing public transportation

This scenario is included as a test to see which areas have high densification potential if one leaves out the existing public transportation system. This could be used to identify areas with high potential if they were to receive a better transportation system. This includes Møllendal, Brann stadium, Mindemyren, and the southern areas along Fjøsangerveien.

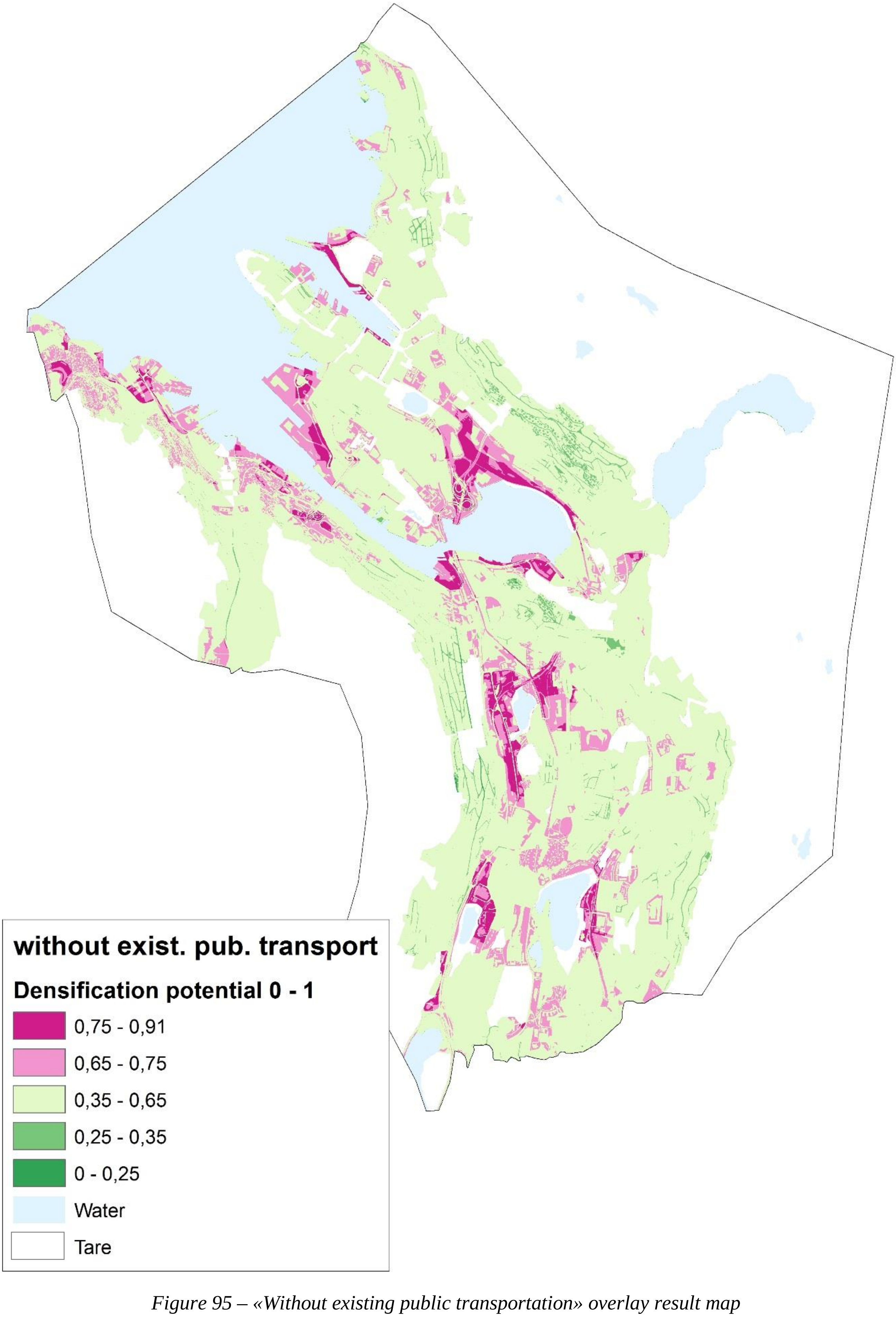


Figure 95 – «Without existing public transportation» overlay result map

Without existing buildings and owners map

A scenario removing the importance of existing structures and ownership can evaluate each areas underlying potential. It is a map useful if radical transformation was chosen as the densification scenario. OBS! An error in this map is that the “flexibility” variable should also have been removed.

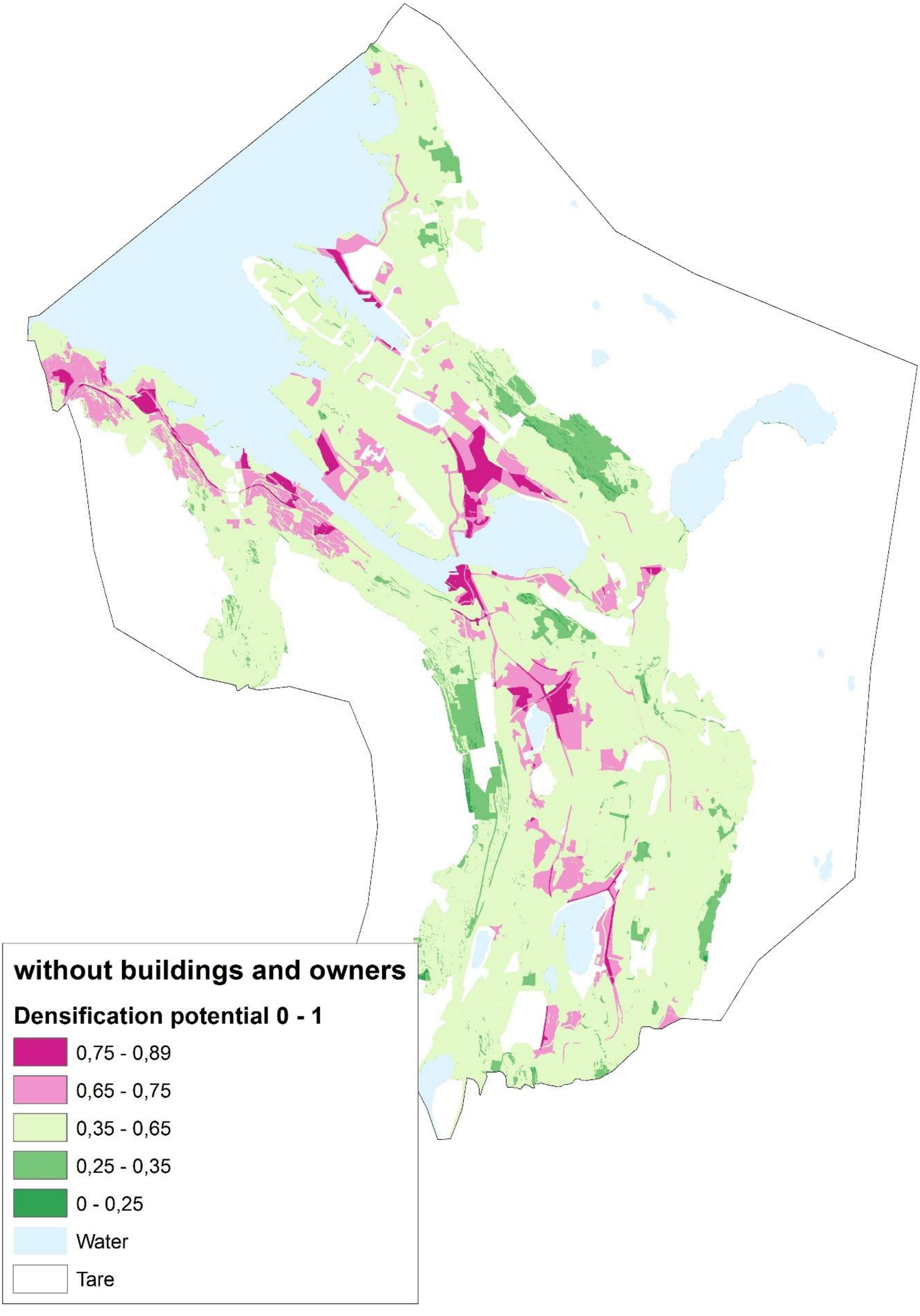


Figure 96 – "Without existing buildings and owners" overlay result map

Overlays of the overlays

This map is an overlay of all the different scenarios and the map without weights. It shows which areas get densification values over 0.65 in all the maps. These areas have higher credibility as potential sites for densification initiatives. I would choose one of these to be included in part 3 of the analysis.

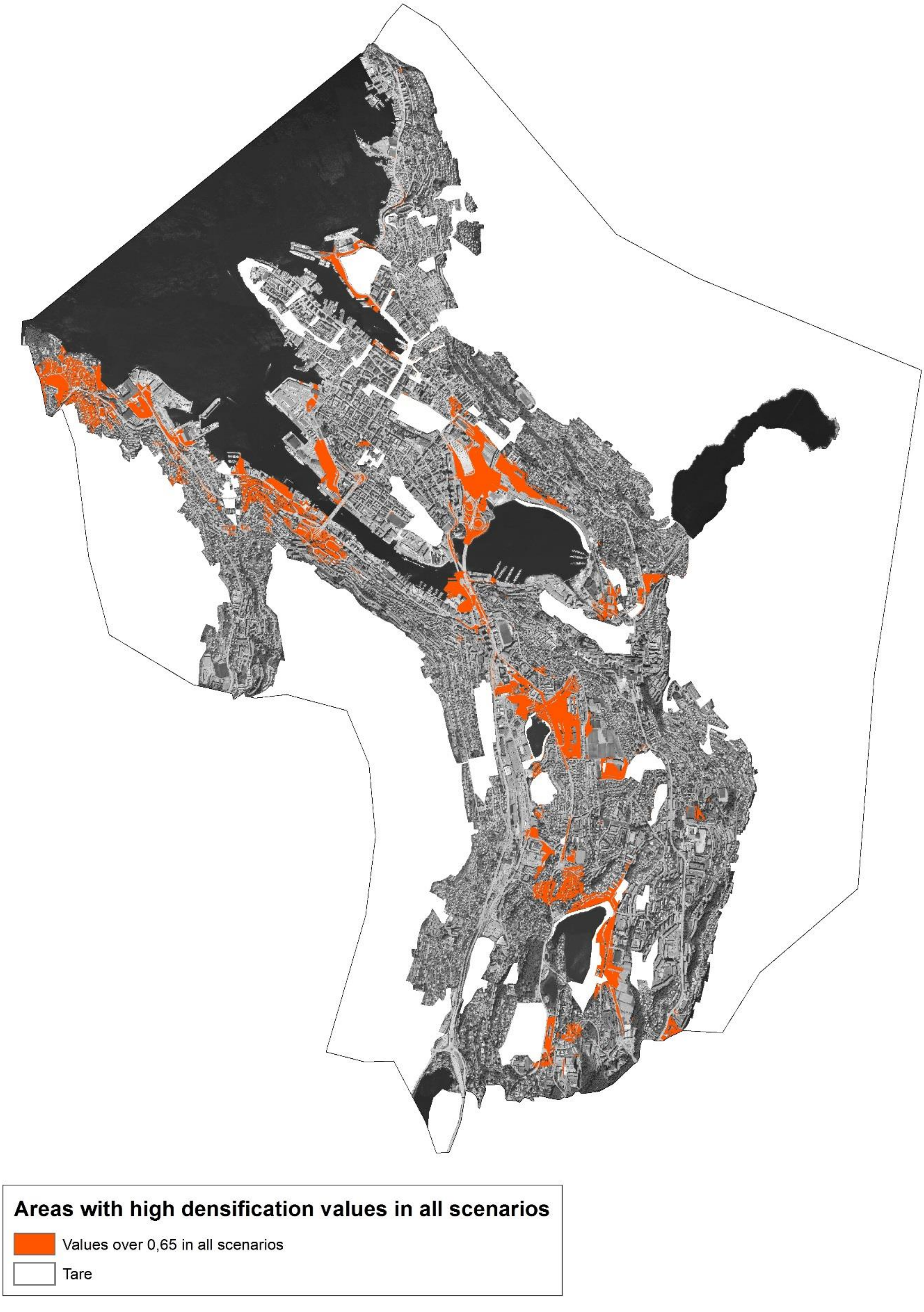


Figure 97 – Overlay of the overlays – high densification potential

Opposite is the corresponding map of the areas with low values in each scenario. There are quite few of these.

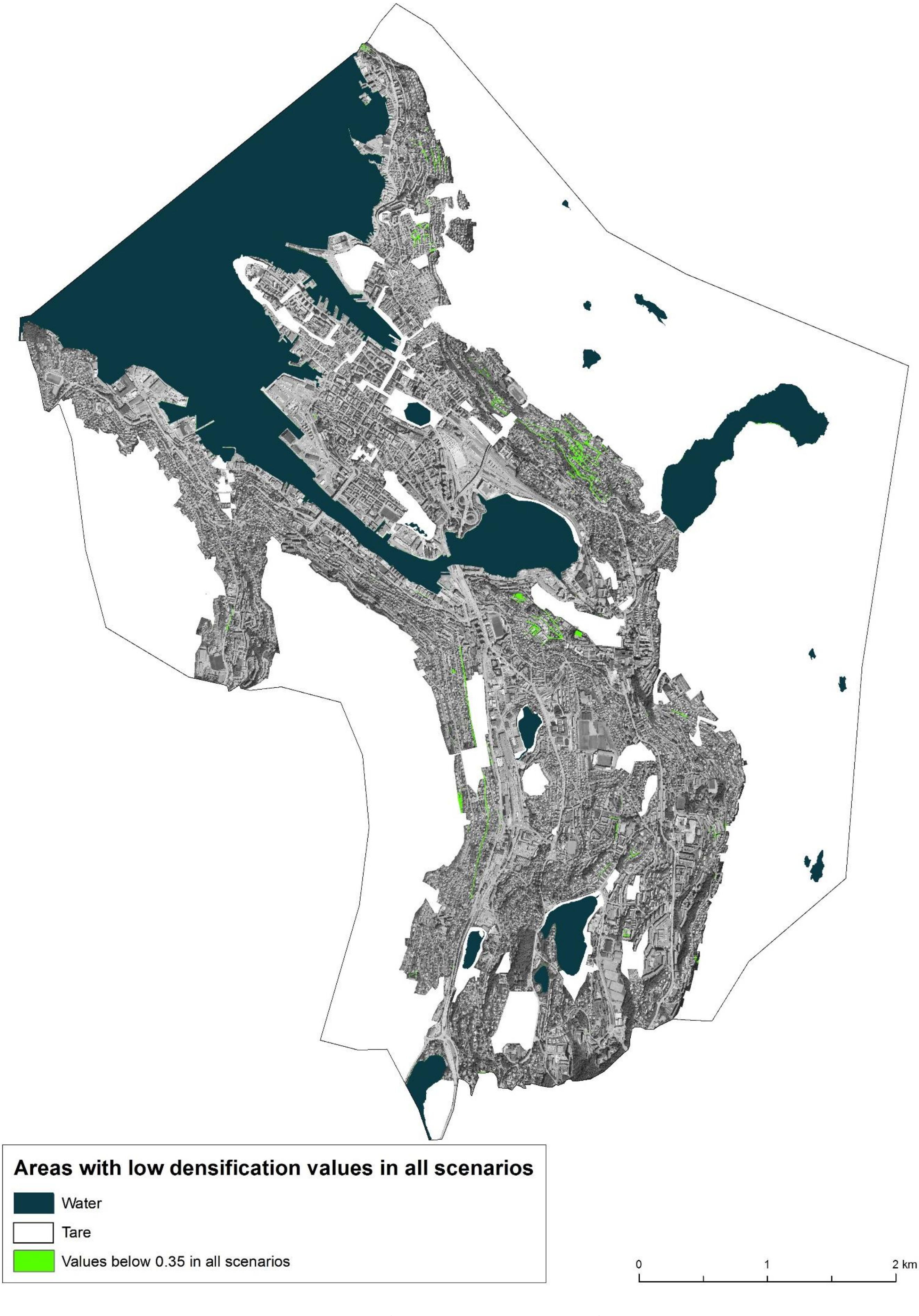


Figure 98 – Overlay of the overlays – low densification potential

Finally, a map is included that tests Spacescape's variables for the prediction of property prices, at least the ones I have produced raster representations of. The map does not include the variables "Access to the pedestrian street network" and "Urban closed block building structure". The included variables are also slightly differently operationalized than Spacescape's variables. In addition, the map seem to lacks some variables affecting property prices in Norway, like view. The map should be tested by comparing it to actual property prices. Gerrit Mosebach[18]'s method of registering the prices listen in Finn.no for a certain period could be a way to do this.

Variables included:

- Access to public transportation
- Access to green space
- Distance to the city centre
- Mixed use – number of functions
- Access to water

[18] Interviewed in Oslo January 30th 2015

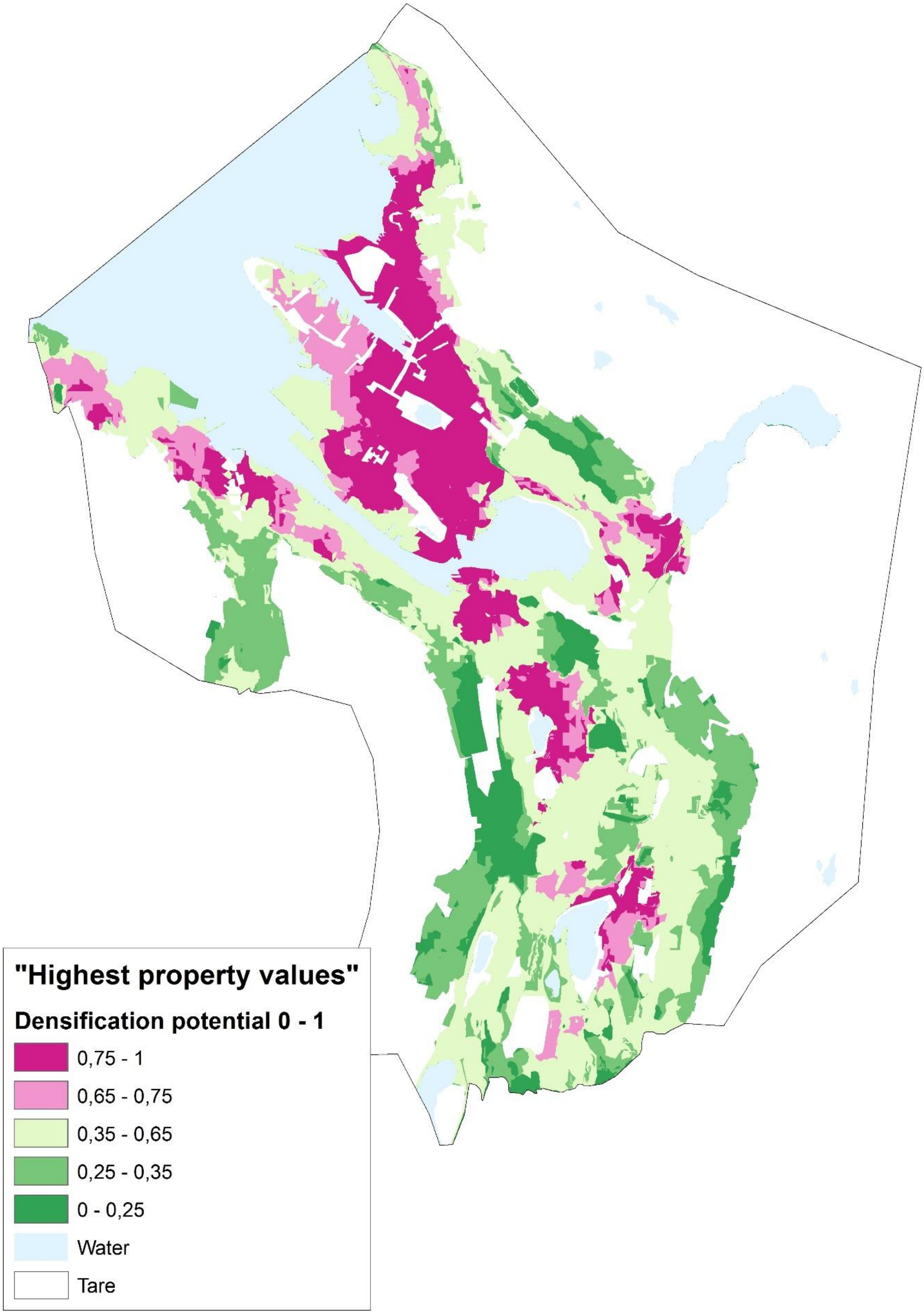


Figure 99 – Map testing Spacescape's variables (Note! Not all) for the prediction of property prices.

Evaluation of individual areas

Kronstad

The Kronstad area has high densification values in all the scenarios, though the boundaries change somewhat. The area has rather low density values, both in terms of FSI, GSI and spaciousness values, and in terms of the number of dwellings per decare. Large sections of the area consists of business buildings with plenty of open space, there are some villa areas and other low-density typologies.

The new university college has recently opened. It has already increased the density on the lot significantly, but it still gets a high densification value in the analysis. This potential is not realistic in the short terms, but in the long term, the typology allows for an increase in density, most practically through an increase in the building heights.

The high densification values of the area comes from the combination of access to the light-rail line, a short distance to the city centre, much unbuilt land, high spaciousness, no protected land, access to both green space and water, and in general high values for all the variables. The green space available is not very large, however, so a high increase in density in the area will demand a new park or an expansion of the existing one around the lake.

The harbour freight terminal

This area by the mouth of the “Puddefjorden” is often brought up in current discussions about densification of the Bergen city centre. Interesting in the analysis is that it does not always get a high densification value in the different scenarios. A section of the area to the south has a high value in each scenario. This area lies within the 500m buffer of a high-frequency bus stop. It is also just within the 500 m maximum distance to green space. The rest of the harbour suffers from a lack of access to public transportation, green space and to a certain degree access to existing infrastructure. It receives high values for the rest of the variables. This gives the area a high value in the “protection as priority” scenario, neutral values in the “sustainable transportation” scenario, a high value in the “simpler and less expensive” scenario and in the “without existing public transportation” scenario. We can conclude that the area has significant densification potential, but that this will require the establishment of a new park larger than 5 decare in the area, and that the area must be connected to the high-frequency public transportation system.

Evaluation

The overlay analysis works quite well. The different scenario maps makes the discussion of different priorities easier and more concrete. The scenarios are also valuable in the evaluation of individual areas.

Calculate abstract numbers of floor space potential

At this point, it is interesting to calculate approximate numbers of new floor space potential for each scenario. These numbers will still be abstract and based on the discrepancy between actual densities and political goals, but they will be useful for the comparison of the different scenarios.

Production

Data needed: Overlay rasters, population point data, building points with floor space data.

"Reclassify" the overlay rasters to 0 – 1, where cells with values higher than 0.65 get the value 1.

"Raster to polygon" the rasters. Do not "simplify polygons".

Delete unnecessary polygons using the attribute "gridcode" = 0. Use "select by attribute".

"Erase" the polygons using the "tare" feature class.

Batch works great for these operations.

We now have the total areas in m2 classified with densification potential in each scenario.

To find the existing population and floor space numbers use:

Select by location – all population/ building points within 5 m from the polygons. The 5 m search radius is to include buildings within the polygons where the footprint is not part of the polygon.

Table 12 – Approximate numbers for densification potential for each scenario.

Scenario	Total area with densification potential (daa)	Difference to "No weights"	Existing population	UN habitat goal population (15 p/daa)	Diff-erence (in pop-ulation)	Existing floor space (mill m2)	Floor space needed (p*54*2) (m2)	New building heights needed (# floors)
No weights	2581	-	9976	38715	28739	1.1	4 181 220	6.5
Protection as priority	3317	+736	14621	49755	35134	1.5	5 373 540	6.5
Sustainable transportation	3365	+784	26257	50475	24218	3.2	5 451 300	6.5
Simpler and less expensive	3162	+581	7645	47430	39785	1.1	5 122 440	6.5
Old n' green	3862	+1281	17327	57930	40603	1.7	6 256 440	6.5
Without existing pub. Transport	2331	-250	6143	34965	28822	0.9	3 776 220	6.5
Without existing buildings and owners	1990	-591	6700	29850	23150	1.1	3 223 800	6.5

How to calculate these approximate numbers in the best way? Should we remove 50% or the area for different kinds of tare including business floor space and schools, like Asplan Viak does (Asplan Viak, 2014)? The idea is that the densification areas can take advantage of existing facilities to a certain degree. Many of the parks have unused capacity for instance. It is difficult to evaluate this thoroughly though, so for now it might be best to stick to the 50% approximation. This means that the amount of floor space needed to house the new population will need to be doubled. In addition, the open space needed must be accounted for, which may also account for at least 75%.

According to SSB the average Norwegian person consumes 54 m2 of dwelling floor space. This number is used to calculate the floor space needed to house the future population.

To calculate the new building heights this formula can be used:

New building heights = Floor space needed (m2)/(Total area (m2)*0.25)

The UN habitat goal of 15 persons per decare will result in a building height of 6.5 floors if we assume that 75% of the area is not covered by buildings. For the second iteration of the method it would be interesting to see what building height would be the result if we used the flexibility values of the existing typologies to differentiate the building heights within the densification zones. Another interesting calculation would be if we set out to get an average 15 persons per decare for the whole area of study. How high must the building heights be in the densification zones, if the remaining area is not developed?

The expected population growth for Bergen in the next 30 years is around 60 000 new inhabitants. How do the different scenarios accommodate this figure? The table reveals that the densification zones can accommodate more than half the expected growth in some of the scenarios, and that in the other scenarios they can accommodate more than one-third. These numbers are quite high, which is very encouraging. It means there is really no need to expand the city limits further, since an area only one-sixteenth the size of the municipality can accommodate so much of the expected growth. For this potential to be realised we will have to commit to a radical transformation scenario for these densification zones, however. But such a transformation will not require the construction of high-rises.

Evaluation

A point of critique is that a more accurate estimate of the amount of land actually used for buildings should be found for the calculations of new building heights. May be I can use the spaciousness measure? I have run out of time, and will have to save this for the second iteration.

The numbers of new inhabitants calculated based on the UN habitat goal is encouraging, but they may not be very realistic. If we set out to increase the population on the areas to reach the UN goals, while still not transforming the areas completely, but respect the existing structures, we will have to build much taller than 6.5 floors many places. Further conclusions concerning the validity of the numbers will have to wait for a more detailed study in part 3 of the methodology.

Part 3 – Detailed local scale analysis using CityEngine

I ran out of time working on part 2 of the method, so I was not able to develop a detailed proposal for part 3. I will therefore only present my ideas and intentions, and hope that I will be able to develop them further at a later time.

The areas identified with densification potential in part 2 will in part 3 be analysed on a more detailed local scale. The goal is to examine "how" densification should take place using a different set of variables, such as daylight access and connectivity of the street network. Volume studies based on different scenarios are created using CityEngine. More detailed estimates for potential new floor space can be calculated and the impact of different densification techniques can be evaluated. The choice between simple infill or more radical area transformation can be compared using CityEngine's dynamic Report function to calculate increases in floor space, number of dwellings, etc. Using CityEngine in this way, we will be better able to answer the central question: "What will this density look like?"

The idea behind the different scenarios on this local level is in part taken from the Stockholm analysis (Regionplanekontoret, 2009). They developed detailed proposals for the placement of new buildings using four different densification scenarios as described in the chapter on the "flexibility" variable above.

Densification scenarios from the Stockholm analysis:

1. Infill
2. Lift
3. Renew
4. Transform

For each of the scenarios they were able to calculate the amount of new floor space and, derived from this, the number of new inhabitants that can be housed. The figure below shows the maps used to represent the different densification scenarios at the local level. I wish to examine how well CityEngine can be utilized for a similar analysis conducted in 3D.

Figure 100 –Snip from Spacescape's webpage dealing with the Stockholm analysis (Spacescape, 2014a). The maps show two different densification scenarios for one of the areas examined in the analysis.

CityEngine has a dynamic reporting function that can give detailed calculations of different measures, such as floor space, number of dwellings and land use mix, based on the building volumes created using a rule-based script. If the building volumes are changed in the map the reported numbers change dynamically. This appears to be a very powerful tool, with a lot of potential for urban planning. The software is already in use all over the world.

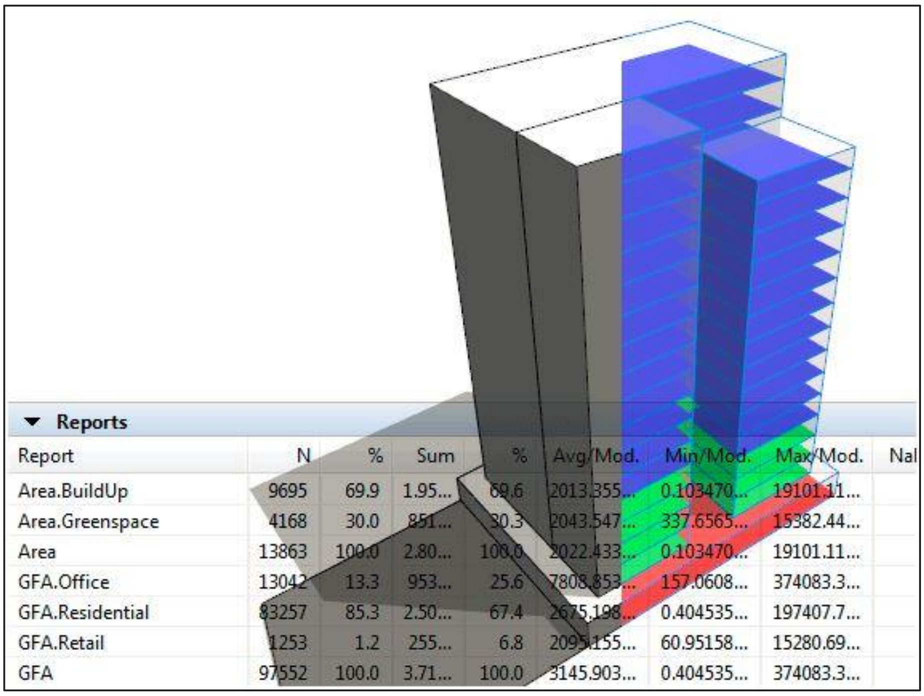


Figure 101 – Snip from ArcGIS Resources showing CityEngine's reporting function (ESRI, 2015).

I was in particular inspired by a presentation given by the Singapore Urban Redevelopment Authority during the 2014 ESRI User Conference. Here they showed how they utilized CityEngine to develop new projects.

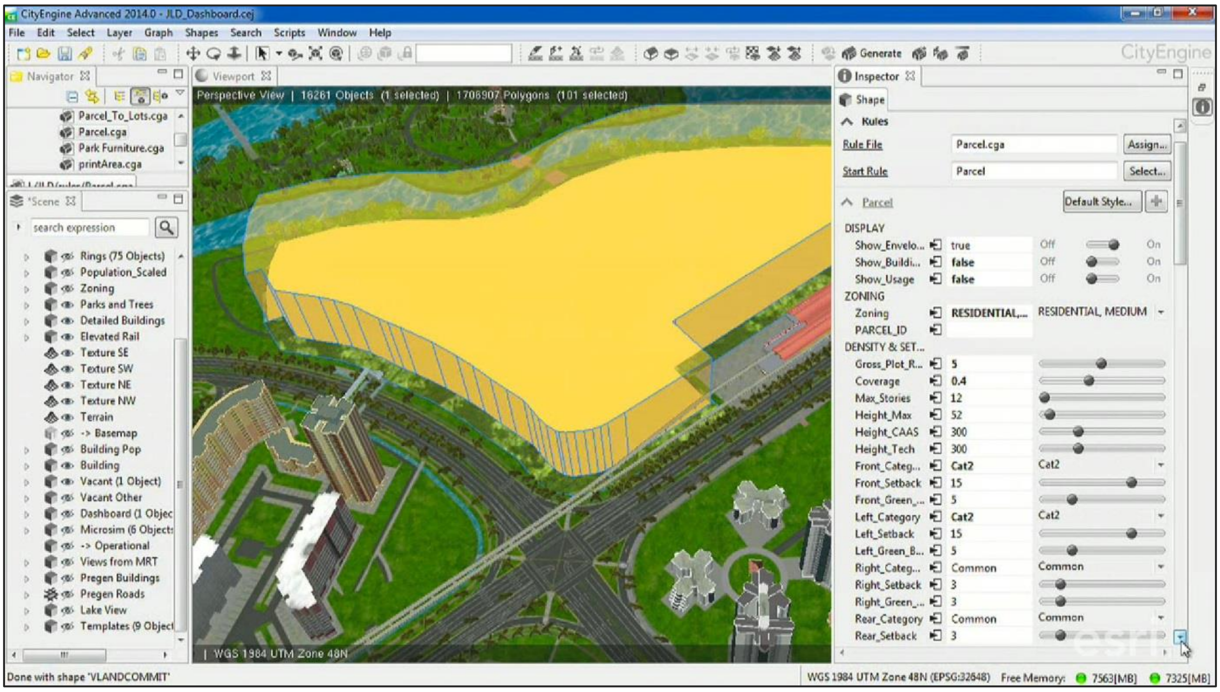


Figure 102 – Snip from the video-presentation, showing CityEngine in action (Chua and Lau, 2014).

I was able to experiment a bit with the software after having spent some time learning the techniques. Through my experimentation and by studying Jussi Viinikka’s master thesis on CityEngine (Viinikka, 2014), I have found that it will take time to produce an accurate 3D model of the existing city on which to base the analysis. The main issue is still a question of processing power for normal computers. Basing the model om FKB multipatch objects requires a lot of processing power and is sometimes more than the computer can handle. A better option would be to use approximate building volumes based on the 2D building footprints and use the CGA rule script to produce volumes based on a height attribute. This takes advantage of the logic behind CityEngine and is much easier for the computer to handle processing-wise. This solution means that analyses will not be completely accurate, since they will use simplified versions of the buildings. For the purposes of a master plan they should be accurate enough, however.

There is another possibility that would allow us to use an accurate and fast 3D model of the existing city in the analyses. Google Earth’s new city models are auto-generated based on photogrammetry. The buildings load as a single mesh, not as individual objects, and the rendering is very fast compared to older models. If we could take advantage of this technology in our GIS tools a vast new horizon of analytical possibilities will open up.

The real strength of CityEngine comes into play when we start to model new buildings and areas within the existing city. The rule-based approach of CityEngine means that the software will take many of the decisions for us in the construction of the city, while we as planners can focus on the planning rules that the model will follow. We can for instance decide that the buildings in an area will have heights ranging from 4 to 6 floors. The software will apply this rule to the entire area and produce buildings with random heights that match the rule. Continuing we can give the buildings rules that specify how great the lot coverage should be (GSI value), and the ratio of dwelling floor space to business floor space. The flexibility of the CGA scripting language means that we can apply more or less any rule that we wish on the models. We can also edit individual buildings manually should we so wish, using tools similar to those found in SketchUp.

Viinikka notes how the use of digital tools are present in urban planning, but that the tools quite often are optimized for other tasks. CityEngine is among the first 3D softwares that directly targets urban planning. Utilizing computer aided design in the planning process makes plans more accurate and reliable. This means that the plans are more detailed and are able to answer questions in earlier planning stages. The workload is shifted to the early planning stages, but the qualities of the plans increase and the production of alternatives is made much easier using computers. (Viinikka, 2014)

Variables

The variables to be included in part 3 of the methodology is as mentioned variables that help us decide “how” to densify an area. There are numerous factors that play into how a building is designed and positioned. It is important to note that it is not the intention of this method to take over the job of the architect. The idea is still to work in the domain of the urban planner, who needs volume studies to be able to write good regulations for plans. The literature I have studied has provided ideas for many variables to be included at this point, among others; daylight access, wind, important sightlines, privacy, energy consumption, exposure ratio and connectivity. Some “HOW”-variables have already been mentioned in the variable chapters for part 2. These include the consideration of heritage buildings and objects, the waterfront 100 m belt, landscape concerns and the capacity of social infrastructure. I unfortunately do not have time to properly treat the question of which variables that determine how to densify will be included for part 3. The experience working with part 2 of the methodology has shown me that combining this decision with practical experimentation with the software and the analysis works very well. I will therefore leave this question for a later time.

Evaluation

The individual variables and the method for part 2 of the analysis has already been evaluated in the relevant chapters. Several suggestions for improvements from the first iteration of the methodology has been given. Following the DSR method this phase requires that all deviations from expectations are noted, and hypotheses are made about their causes. This is what I have attempted to do in a way that suits the product.

Sometimes the variables have been produced a bit rashly, but if I were to develop these completely before assembling the overlay, I would not have had time for the overlay itself. The variables are generally reliable, though beware of the border regions between classes in the overlay maps. It was very inspiring to develop the methodology in this experimental and creative way, whilst working towards a second iteration. It left me with many ideas for future improvements.

An important question is whether or not the method can be used in other cities, or if it only works for Bergen? The classification of the homogenous zones are tailored for the area of study in Bergen. It might have to be revised if it does not fit a general Norwegian typology. In addition, the flexibility variable must be redeveloped for Norwegian conditions. Thirdly, some of the variables were not included because they did not fit the current area of study. These will be useful on a larger scale. Fourthly, some of the variables had values that were relative to the area of study, and may not be used in other areas. These will not be comparable from city to city. Ideally, scales should be found that are generally valid.

Another issue is whether the method is feasible in a master plan time frame. It may be too time consuming and require a skill set not always available in a municipality. The general use of such a densification method may lie some years into the future, but the techniques are not so difficult that urban planners will not be able to handle them. If new national datasets (homogenous zones) can be introduced together with the improvement of existing ones (3D functionality of FKB map data) the workload will be reduced substantially.

Evaluating the method in hindsight, I see that it will probably benefit from using more of the techniques described in the interviews. Particularly concerning the use of population density and worker density.

Answering the research questions

This section will attempt to give concluding answers to the research question and to the remaining research sub-questions. Research sub-question 1 has already been answered in the above chapters. Research sub-question 2 has also been answered as far as I am able at this point. I have not given a sufficient answer to the question of which variables "decide how to densify".

The third sub-question: "How well suited are GIS tools to portray and analyse these variables" can now be answered based on the above variable chapters. GIS is, like maps in general, not able to give a perfect description of reality. Reality is too complex. We use analytical tools like GIS to help us organize and to simplify reality, so that we are able to get our heads around that which we are trying to analyse. That the variables in the analysis are operationalized in a simplified way is therefore not necessarily a problem, but something we have to bear in mind when interpreting the results of the analysis.

The variables that have been included in the analysis are those that were possible to portray using GIS techniques to a satisfactory extent. Certain variables are not ideally represented however. This includes the "access to existing infrastructure"- variable, which should have been based on more information. The problem here is not limitations in the GIS techniques themselves, but in the data available. We simply do not have reliable map data about the entire water and waste management network and where how much available capacity is located. As mentioned, using map data to evaluate where the risk of rockslides rule out development is also a challenge. Some decisions will have to be based on qualitative reading of thick reports, not through the examination of a map.

A general conclusion that can be drawn from the thesis work is that GIS is a very useful tool for densification planning and the decisions that have to be made in the field of urban planning. Representing scenarios spatially as done with the overlay analyses makes the discussion points much more concrete. The current densification debates in Norway seem to suffer from the fact that people lack a clear mental image of what they are debating. The maps produced through the thesis will be able to mediate this problem.

This brings us to the fourth and final research sub-question. “Can GIS tools be utilized better in densification planning than what they are today? In which case, how?” The answer to this question is “absolutely”, at least with regards to Norwegian densification planning. There is a lot of sophisticated work already being done abroad. The method I have started to develop is a proposal for how GIS tools can be utilized better in the Norwegian context. It still needs a lot of refinement, but includes many good techniques and ideas for future improvements.

The main research question: «How can GIS tools be utilized to identify urban areas with densification potential?” has hopefully be answered to a certain extent. This thesis has certainly not been able to explore all the ways GIS can be useful for densification planning, but it has been able to utilize a wide spectrum of tools within the comprehensive ArcGIS package. Other software do have some additional toolsets, which I was not able to test at this time. GIS tools are able to identify urban areas with densification potential through the evaluation of spatial variables that help us determine what a good neighbourhood is and that help us achieve political goals for contemporary urban planning. Representing these variables in a map makes them easier to interpret and to compare. Densification planning and urban planning in general require that priorities are set, and GIS can help clarify what impact these priorities will have. GIS may not be able to answer all questions necessary to achieve good densification, but combined with more qualitative techniques we have a better chance of making the right decisions.

Conclusion

To Summarize the results we can say that GIS can be used to create maps that simplify and organize the massive amount of information we have to deal with in densification planning. Most of the variables we need to consider have a spatial quality, though some of them require techniques that have not quite been developed yet, or that the average computer cannot manage at the moment. We can work around this, however, and we are able to give well-evaluated conclusions based on the use of, among other tools, GIS.

Norwegian densification planning can benefit from the development of more advanced GIS techniques than those currently in use. We do not have to look far for inspiration, as Sweden has done much of the work before us. We Norwegians are rather new to the problem of running out of space for our cities. This means that we do not have to reinvent the wheel, but that we can learn from the experiences of our more urban neighbours. This thesis has started the development of a new GIS based methodology for identifying densification potential in Norwegian cities. It is based on existing literature and methods currently in use in other countries. I have attempted to fit these to the Norwegian context and am fairly content with the result of this first iteration. There are plenty of improvements to be made in the second iteration, however. This master thesis has built a good foundation on which to continue the refinement of the method.

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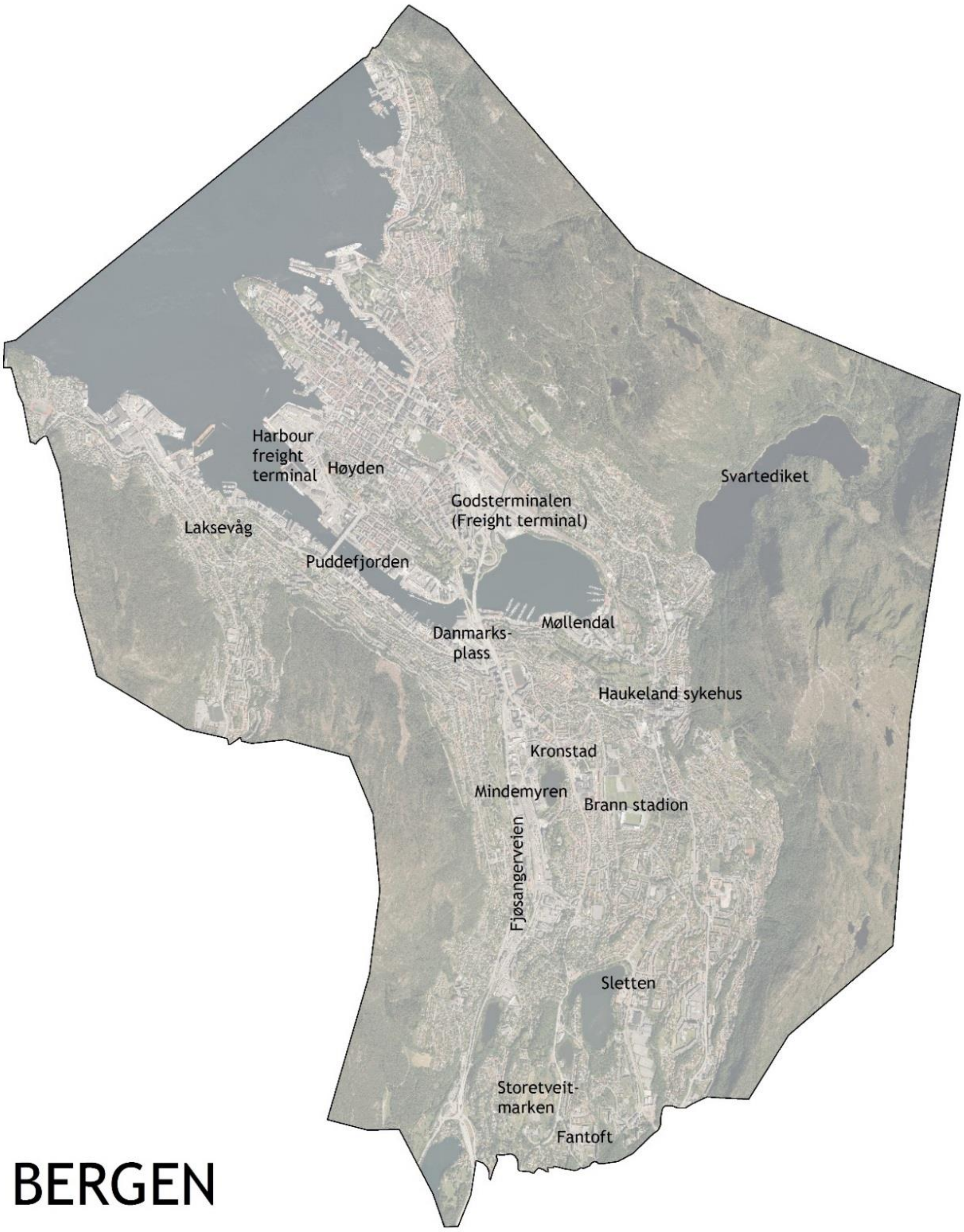
Appendices

APPENDIX A: Map of Place Names



Place names referenced in the thesis.

APPENDIX B: Interview questions

(Norwegian only)

Spørsmål:

1) Kan dere kort presentere dere selv og stillingen deres, og hvilken tilknytning dere har til den fortettingsplanleggingen som foregår i Trondheim i dag?

2) På hvilket detaljnivå jobbes det med fortetting og fortettingsplanlegging i dag? Har man en helhetlig planlegging, f.eks. på kommuneplannivå, eller jobbes det heller i det små f.eks. i reguleringsplan for reguleringsplan?

3) Hvilke analyse-metoder og verktøy brukes i denne planleggingen?
   3b) Hvordan brukes GIS-verktøy konkret?

4) Hvordan definerer dere tetthet? Eks. befolkningstetthet, boligtetthet, etasjeantall, fysisk form. 4b) Har dere ulike definisjoner i nye utbyggingsområder og i fortettingsområder?

5) Hvilke variabler brukes i analysene av fortettingspotensiale/ utbyggingspotensiale, og hvilke betraktninger er spesielt viktige for dere? Eks. folketall, tilgang på grøntareal, nærhet til tjenester, konsekvenser f.eks i forhold til kollektivtrafikk. 5b) Hva er «god» fortetting for dere?

6) Planlegging er viktig, men ofte ser man at den faktiske implementeringen ikke samsvarer med planene. Hvilken gjennomslagskraft har fortettingsplanleggingen i den faktiske utbyggingen i Trondheim i dag? Hvilken politisk status har denne planleggingen i kommunen? Eventuelt, hva tror dere kan være årsakene til at fortetting ikke blir gjennomført, eller ikke gjennomført etter intensjonen?

Det er spesielt interessant å se på hvilke analysemetoder og verktøy dere bruker. Altså er spørsmål 3 det viktigste. F.eks. databaser dere har opprettet, kart, osv.

Appendix C: List of informants

Municipality of Trondheim	Svein Åge Relling, GIS engineer
	Ragna Fagerlid, architect/ urban planner
	Synøve Tangerud, engineer/ urban planner
Asplan Viak Oslo	Øyvind Dalen, GIS engineer
	Gunnar Berglund, GIS engineers (prev. Municipality of Oslo)
Municipality of Oslo	Gerrit Mosebach, architect/ urban planner
	Silje Hoftun, social scientist/ urban planner
Municipality of Bergen	Endre Leivestad, GIS engineer
	Svein Heggelund, GIS engineer
	Stein Furru, architect/ urban planner

Discussion partners:

Asplan Viak Bergen	Øyvind Sundfjord, GIS engineer
	Fredrik Boge, GIS engineer
	Torhild Wiklund, architect/ manager
	Fredrik Barth, architect/ urban planner
	Steinar Onarheim, GIS engineer

Appendix D: Interview with Svein Åge Relling

Municipality of Trondheim, 2nd of December 2014

Svein Åge Relling is a geographer, statistician and GIS expert working for the Municipality of Trondheim. He mainly works with population statistics and predictions. In this capacity, he also enters into areas relevant to densification planning, such as finding potential for residential development. He has conducted analyses, particularly at the master plan level, that has looked into densification potential. Here GIS has been an important tool. The municipality does not have employees or permanent groups that specifically work with densification planning. They instead conduct analyses of development and densification potential on a project basis, mostly in relation to master plan development.

Relling showed me examples of analyses he is working on that are aimed to find densification potential for residential development, and to find business potential in an area. The business analysis selects areas that in the master plan has been given certain land use classes: centre mixed use ("sentrumsformål"), business, harbour and rail. Total floor space (BRA) is counted for each area and divided according to type of business. Using a type of ABC-method classification of businesses given in the master plan, he tries to see how much available BRA will be gained if the "wrongly placed" businesses are moved to more appropriate locations in the city. In addition, he tries to give an estimate of how much new land for business or industry is necessary to move these businesses. Finally, a comparison of the assigned intensity requirements of the areas and the existing built structure can give an estimate of development potential. In "centre mixed use" areas, where there is both housing and businesses, this analysis will have to make assumptions about the balance between the two. Relling said that official numbers has not been set at the moment, but that he will probably end up working with a 50/50 mix.

The analysis of potential for residential development follows the same logic. The existing number of dwellings per decare is compared to the minimum numbers set in the master plan. These analyses only give a "theoretical potential" for development, since they do not examine actual physical conditions in the areas. Relling points out that this is a weakness in the analysis, which ideally should be improved.

Densification is defined as the number of dwellings per decare, and as minimum intensity, so that also non-residential structures are included. The current master plan defines minimum levels of density for different areas in the city. The city centre has a minimum residential density of 10 dwellings per decare. District centres and areas along the main public transport corridors have been given a minimum density of 6 dwellings per decare. 3 dwellings per decare is the general rule for the rest of the existing residential areas. New development areas will have a minimum density of 6 dwellings per decare. Business development in areas with a well-developed public transportation system must have a minimum intensity of 140% BRA.

The analyses areas for residential development potential are the standard “planning zones” defined by the municipality. They generally correspond to the school districts, and therefore do not take internal physical homogeneity into consideration. Relling and his colleagues view this as a weakness in the analysis results. Each zone’s total area is deducted those sections that are not relevant for development. This includes roads, green space, public use (“offentlig formal”), institution land and areas currently under development. There is a continuing discussion whether or not green space and areas with cultural relics (“kulturminne / kulturmiljø”) should be included in the analysis. The remaining area for each zone is used to calculate the average density. Relling moves from ArcGIS to Excel when starting these statistical calculations.

In addition to this, the municipality also performs other densification analyses, for instance maps showing total BRA per area, or building footprint per area. This gives an indication of urban form. These maps are only used for illustration purposes, however, and are not included in the analyses for densification potential.

There is in fact a significant densification taking place in Trondheim. In the 2000s about 80% of residential development occurred within the existing urban structure, according to an analysis conducted for the last master plan development. This corresponds with the goals in the current master plan. According to Rellling, this process is developer driven. Developers wish to maximize utilization of their properties. The job of the city planners is therefore to restrain them, in order to secure good urban qualities.

At the same time the politicians have allowed massive new areas for residential development on the city fringes. As Relling has understood it, the motivation for this, at least in part, was a political wish to keep housing prices down. This urban expansion is a cause for concern within the municipal administration. These new areas are much larger than what is actually needed for expected development in the coming years. This could result in a halt in densification. Relling questioned if the problem could be communication, if the actual numbers were not coming across to politicians.

An additional interesting piece of information Relling could offer concerns the data quality available. The Municipality of Trondheim now has a very good database of building BRA in the cadastral dataset. In recent years, they have done a big job of registering BRA for each building, and now there is only a small percentage of buildings that have not been properly registered.

Relling was not able to answer all of my questions, particularly concerning which factors are important in an evaluation of densification potential, and what is considered good densification. He directed me to some of the city planners for additional answers.

Appendix E: Interview with Ragna Fagerli and Synøve Tangerud

Municipality of Trondheim, 9th of December 2014

The question I asked them was: Which variables are important to include in an analysis of densification potential? We ended up talking mostly about which factors limit the possibility to densify in an area. They said that most of this is treated in the master plan, both in the regulations/ provisions in the plan and in various reports produced in connection to the master plan development. Among these are the "High-rise report" (Høyhusrapporten) and the urban space norm (Uteromsnormen). The factors they mentioned during the interview were:

- Green space, wild life corridors
- Urban space, particularly in connection to sunlight conditions
- Geotechnics, in Trondheim quick clay in particular is a problem
- Noise pollution. In the public transportation corridors, they allow residential construction up until 70 DB noise levels.
- Historical value and important historical sight lines. An example are the sight lines to Nidarosdomen. These areas are often marked by restriction zones in the master plan.
- The river corridor, the flood zone. Here it is possible to develop, but extra measurements are required.
- Public services. Some areas are set aside for the development of new public services, such as schools or day care centres. If a large area is being developed for residential construction, the municipality will say that a certain plot is needed for the development of public services, football fields, etc. Then densification will not be allowed here. The municipality will then usually buy the land for market price.

It is important to remember that a new area under residential development will need a lot of land for various common functions, such as day care, roads and bus lanes. So that not all the land is available for densification. This must be included in the calculation of densification potential, and it means that the yellow areas (residential land use) in the plan will often have a higher density than the requirements to accommodate the average density measures set in the master plan. How they set the boundaries for the calculations of density are referred to in the master plan.

- Distance requirements to railroads and roads

- Negative effects on existing structures. This can be exacerbated by steep terrain. The effect of the neighbours' sun light conditions is a particularly important factor.
- Politics and job creation. They mentioned this in relation to the transformation of industrial land within the city limits. As planners they cannot suggest that businesses should relocate outside the city. This has to do both with the job issue, but also it can have to do with the city's identity. The old remaining industries have a long history in Trondheim, like the chocolate factory Nidar. It would not be popular if they were asked to relocate. Instead, it is possible that the businesses themselves will decide to relocate. If the allowed density levels in an area are increased significantly, this will increase the value of the land correspondingly, which might be a good incentive to move to a less expensive area outside the city limits. On the other hand, this contains a risk that the business will decide to relocate outside the region, or even outside the country, which equals a loss of jobs for the city.
- Water mains in the ground and flood ways. Water mains in the ground will prevent development directly on top of them. Generally, the ability to densify is limited by the need for surface water management. This can be combined with the creation of green space and parks.

As mentioned most of what we talked about was also covered in the materials for the master plan. Synøve Tangerud mentioned that they were less happy with the regulations concerning green space. These are not detailed enough. They end up fighting every day for the existing green space. There are requirements in the "urban space norm" concerning new green space in connection to new developments. The master plan also contains lines indicating new walking paths (turveitrasé). Regulations require that these paths will be surrounded by "green corridors" of minimum 30 meters width.

- Realty structures or property structure. Ragna Fagerli said this should not be an issue when evaluating densification potential, but an issue that nevertheless is necessary to look into. Many property owners make joint decisions difficult. She mentioned the example of the housing cooperatives (borettslagene). The building structure in these areas are often modernist, and have plenty of open space, which is technically easy to densify. Their densification potential is huge. But since the housing cooperative owns the land it mean that a 2/3 majority of the members is necessary to allow densification. This makes the process more difficult.

Another thing mentioned was the practical implications of adding floors to existing buildings. Modernist block structures often seems quite simple to densify by adding two or more floors. It is not so simple, however, because the structure of the buildings may not be able to bear the extra pressure, and the fire regulations are very strict. They require that each unit be a separate "fire cell", including the stair well, which may demand that a new stair well is constructed. This makes the project much more expensive. In addition, there is the demand for elevators in buildings above a certain number of floors. Tangerud said that this could be an incentive to densify for the residents. Two more floors on top of their building could mean that they can all benefit from a new elevator. She continued to said that incentives to densify, such as a new park or new services, are mostly trumped by residents individual wish for a view, privacy, and to avoid noise and more cars in the street. Neighbours are generally negatively set towards densification, even though the city in general is positive towards it. It is a problem of NIMBYism.

Appendix F: Interview with Øyvind Dalen and Gunnar Berglund

Asplan Viak Oslo, 30th of January 2015

Øyvind Dalen and Gunnar Berglund, both employed by Asplan Viak Oslo, are among the top in their field in the Oslo region. Dalen is a GIS engineer and Berglund is a geographer with a long background in GIS. Berglund recently left the municipality of Oslo, and therefore has knowledge of how the municipality works in connection to densification planning analyses. He had a central role in the analyses of densification potential for the new Regional plan for land use and transportation in the Oslo region. Dalen lead the work to develop the A.V. report on methodology for densification potential described in the thesis. He has also performed similar analyses for several other projects. These experiences makes the two some of the leading experts on densification analysis in Norway.

This text sums up the most important talking points during our meeting.

Reference areas

An important tool is the use of reference images from other areas within the same city that have a higher density than the plan area/ or a desired density. There are no standard way to portray certain densities, and it is easier to understand comparisons within the same city, particularly for non-planners.

Density measurement

They use population and workers per area as density measurement. A combination of the two gives a density measure in terms of activity. In addition, they also use floor space (BRA) per area as a measure, for certain calculations. The regional plan used the term "Områdeutnytting" (a type of FSI), measured as BRA per area displayed in percentages. So 100% områdeutnytting means that BRA equals the total plan area. BYA (building footprint) is also used. "Utnyttelsesgrad" on a parcel is a term municipal employees understand, but it does not clearly say which amenities are included. "Områdeutnytting" may therefore be better.

Modifiable area unit problem

The problem of defining the area boundaries was discussed in length. Area polygons have been defined in different ways according to the available map data. Dalen referred to a database that was created for Bergen in 2004-2005 where the built structure had been classified into homogenous areas (dense residential area, medium dense residential area, industry, urban space, etc.). The question is whether this database has been updated since then.

The problem is to determine where to draw the boundary to the residential area? If we use “bydel” (district), then which functions and amenities should be included? This is difficult to standardize. This is why it is so important to include reference areas in the analysis, to aid interpretation of the results. Concrete examples are needed that the reader understands. It is also important to explain properly how the analysis is conducted, which amenities are included, where the boundaries are drawn.

Land use zones can be split into blocks using the street network, thus creating smaller units. It is also possible to use the AR5- dataset and do the same split into blocks.

Another possibility is to make a raster map, where a buffer (150 m) is calculated for each cell where the “utnyttingsgrad” (FSI) is calculated. This is a way to avoid the MAUP. They used the building footprint rather than the floor space in their analysis.

Both Dalen and Berglund use buffers to define the examined areas. 1 km is a radius that is frequently used. They also use zones derived from distance along the street network, which relates to accessibility. The areas are classified according to centrality, which can refer to distance to the centre or public transportation hub.

Whether the analysis is performed on a higher or a more detailed level is also an important consideration. The use of more theoretical calculations of density potential is useful at higher levels, to reduce the workload.

Example projects by Asplan Viak

“Delutredning 2 - Utbyggingspotensiale i kollektivknutepunkt» (Plansamarbeidet om areal og transport i Oslo og Akershus) 25.06.2010, version 1: An analysis developed by Berglund as a basic analysis for the Regional plan. They looked at 200 public transportation «hubs», buffered them and calculated the density. The conclusion was that it in theory is possible to develop “infinite density”(«uendelig tetthet er mulig»).

“Hvordan skal Sarpsborg vokse rapport” 2013-05-26, version 5: They used aerial photos to locate areas with potential. Used a municipal plan, which included regulations of maximum building height as a foundation for the calculations. They chose areas based on their local knowledge.

Areas were categorized according to centrality and prescribed different densities to each. They used BRA to calculate the “Utnyttelsesgrad” for the buffers. These numbers had to be improved certain places, as the Matrikkel is faulty. %BRA could have been used, but that is used for individual parcels, so it would be confusing to use it for a whole area. So they used BRA for the whole area instead.

The buffers where clipped according to scenarios. In one scenario, the agricultural land was clipped, in another it was included. Same thing with green space and other objects. They clipped large main roads, but not smaller access roads. The examples aerial photos are useful because you can make certain that the same types of amenities are included in the area calculation. It is quite easy to manipulate the results according to what is included within the density areas.

Their analyses can make proposals for what level of density can be developed, by showing various examples, but they do not enter into the discussion of how the local development in the plan area should look like in detail.

Vepor (Veiledende plan for det offentlige rom) plan type, Municipality of Oslo: Everything between the buildings. A plan type in Oslo, which aims to make the developers see their project in connection to the neighbour’s project. How to create a place. Not legally binding.

Example methodology

Below is a flow-chart showing the method behind the identification of development potential in the Asplan Viak’s “Guidelines for densification analysis in public transportation hubs” (Veileder for fortettingsanalyser i knutepunktområder, 2014). The flow-chart shows the process used to map the current situation, with existing residential and workplace density and accessibility.

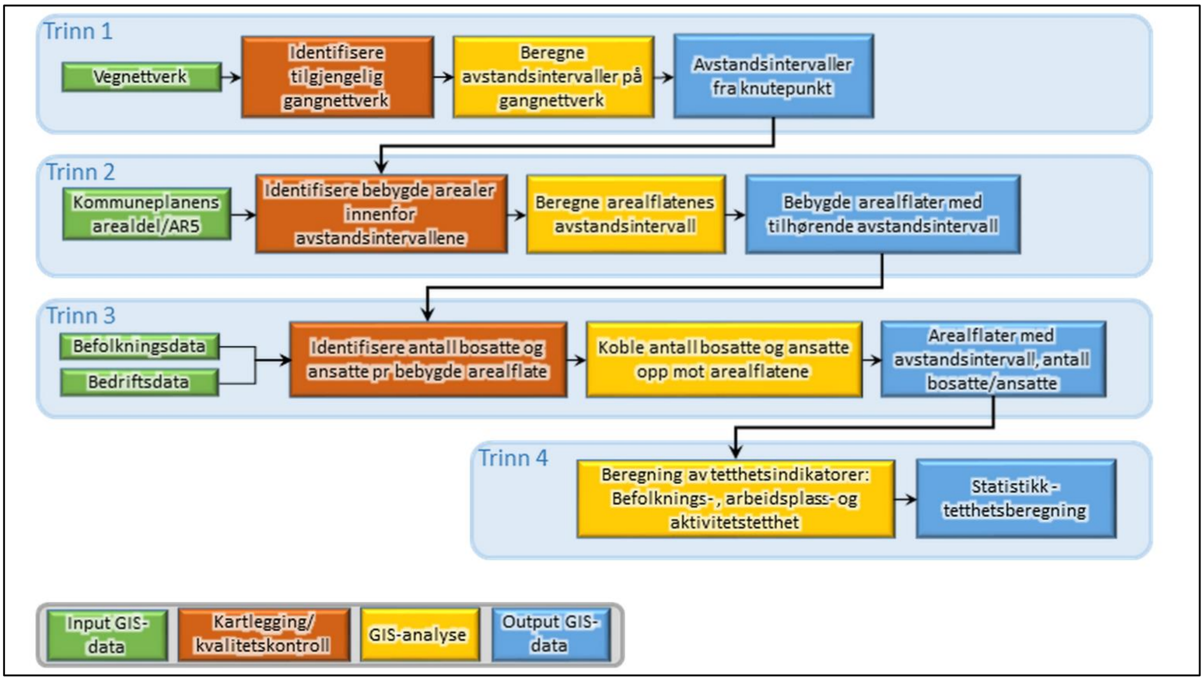


Figure 103 – Calculation of density – new guide to calculating density in central areas (Asplan Viak, 2014).

An example calculation:

Current population density + a given number of new inhabitants → Future population density.

Give photo examples of this density.

They do not actually consider the built structure at all, except looking at overall BRA.

They usually work with buffer analyses around centres and calculate density within the buffer.

To sum up the discussion Dalen pointed out that there are many different ways to conduct the analyses, and that it is a problem that the issue of **quality** is removed from consideration.

Appendix G: Interview with Gerrit Mosebach

Municipality of Oslo, 30th of January 2015

Gerrit Mosebach has an extensive background as a planner. He was educated at TU Berlin as an architect specializing in urban planning and has, among other places, worked in Berlin and Rotterdam. He has also been a lecturer at NTNU, AHO and BAS. He ran his own consultancy firm in Oslo, before he commenced working for the Municipality of Oslo in 2008. He was central in the planning process in Groruddalen, and he has worked on various planning levels and with both analysis and planning of new development. Mosebach does not himself work with GIS tools. He works with Adobe Illustrator and similar software.

Mosebach is of the opinion that GIS analyses are useful, but that they are more registration tools, than analysis tools. An analysis is more than a registration of facts. It includes an interpretation of the registered data. They cannot be used to interpret the information to propose a concrete new development. For this more qualitative analyses are needed. He emphasizes the importance of visiting the areas and talking to the inhabitants and the business leaders, to identify the actual potential. Ideally, the plans of the property owners in the area should be examined, what they plan to do with their land. The quality of the existing built structure should be evaluated. Is it economical to demolish existing buildings? What is the "Gjenbruksverdi" (value of "reuse")? What are the driving forces in the community? Is there a need to densify, how is the market, the property prices?

Evaluate the Driving forces,

User interests,

Project goals

He mentioned "Realistisk byanalyse" as a way to examine the physical structure in an area, but that this method also had its weaknesses. In particular, that it does not examine the driving forces behind development, such as the market, and the user interests in the area. It does not examine the three variables mentioned above. Realistic city analysis focuses on the physical structures, the cadastral structure, morphology, functions and axes.

It is necessary to perform an analysis of place ("Stedsanalyse"). Here mental mapping, Kevin Lynch style, is a method he frequently used. "Barnetråkk" (childrens' places) is a simplified mental map. It is necessary to include the people in the area in the analysis, to understand their concerns and wishes. Participation is key for a successful planning process! NIMBY can change to PIMBY (Please in my back yard). Neighbours and the city antiquarian are strong opposing forces against development. It is also important to remember that areas are very different. It is very important to treat a residential villa area different from a brown-field transformation area.

Mosebach mentioned many techniques he has found useful, for instance comparative methodology. Stability maps is another useful method. They shows areas, like villa areas, as very stable and unlikely to change, while areas currently undergoing planned as more unstable and easier to develop. Property prices can be mapped using Finn.no. Digitize points showing houses for sale with their sales prices over a period of for example two weeks.

The final product of the analysis should be a map showing the recommended development. I.e. how the analyses are interpreted.

Appendix H: Interview with Silje Hoftun

Municipality of Oslo, 30th of January 2015

Hoftun is a project manager for the «Hovinbyen»- development in Oslo, with a background as a social scientist. She works at the Municipality of Oslo, Department for urban development. She has participated in evaluations of densification potential in connection the new master plan. Here they used the difference in existing floor space (BRA) and the floors space regulated in existing plans as the development potential in an area. They also calculated potential by taking an example area with known density and superimposing this in the area being examined.

The current way density regulations are written is problematic, for instance the prescribed intensity written as 100% intensity ("utnytting"). As soon as we write a number in the regulations this is all people see. They forget the qualitative regulations, for instance concerning open space. The number does not say anything about built form, but this is difficult for people to grasp.

«Med én gang man skriver et tall er det det eneste folk ser, de glemmer de kvalitative bestemmelsene.»

Appendix I: Interview with Endre Leivestad, Svein Heggelund and Stein Furru.

Municipality of Bergen, 10th of February 2015

Endre Leivestad is responsible for the availability of data and software in the municipality, he does not actually do much analysis work, but has a good overview of the work done in the administration concerning densification planning. Stein Furru has worked with densification planning in many different projects. An interesting recent project was connected to the light rail stops at Wergeland, where densification is a central goal. Svein Heggelund is the GIS expert in the Municipality of Bergen that does most of the analysis work connected to density measurements and densification planning. He has, among other things, experimented with different density measurements and area units, to see whether or not they show the same trends.

Densification is currently a hot topic in Bergen, particularly in connection to the ongoing development of the new master plan. There are discussions in the municipality about where densification should take place; in the central areas with good public transportation accessibility, or in the periphery where densities are much lower relative to the political goals. Leivestad mentioned the paradox that the new large and expensive apartments constructed in the centre areas are not bought by families with children, but by senior citizens. In terms of the amount of traffic generated by these groups it should have been the families that lived in the centres. They travel more to work, to recreational activities, etc. Despite of this the families generally settle in the periphery, where they are completely dependent on car-based transportation.

Densification planning is generally connected to the master plan level, along with the "area plans" (områdeplaner). The "compact city" will be a central theme in the new master plan. The actual implementation of densification is left to private developers. The current master plan has a strategy for densification around public transportation hubs. These areas are defined as "centre zones" that are given maximum density (% BRA) and building height (m) regulations. The regulations are to some extent linked to land use. These regulations where adopted in the "Wergelandsplanen". The goal is that 85% of densification will occur within the concretely defined centre zones in the master plan. An issue Svein mentioned that concerned them is that the urban area of Bergen has expanded more than the other large

Norwegian cities in recent years. They could not conclude to what the reason for this could be.

Furru described how they evaluated the densification potential in Wergeland. They did not use GIS, but model work, and placed as many buildings as they felt was responsible in the model to see what the limit was. In this way, they tested the area's density limit. They tried to increase the density to the political goal, but found that this was more than the area could handle.

GIS is not used for detailed concrete analysis of densification potential, but is in their opinion better for more general abstract analyses of larger areas. The municipality uses the ArcGIS platform.

Heggelund has experimented with different density measurements. The main ones they have ended up using are floor space per area (BRA/daa), population density (interestingly measured as m2 per person) and dwelling density per area (# dwellings/ daa). They compare densities between districts (bydeler), where they also compare the average floor space per inhabitant for each districts. Different area units of analysis was also tested. They use both "grunnkretser" and "levekårssoner" (aggregates of "grunnkretser" meant to have an approximate similar number of inhabitants (5000), large enough to ensure anonymity).

Heggelund was sceptical to the use of distance to a centre point as a way to measure centrality. The example he used was Prinsenkrysset in Trondheim. He is sceptical to the use of a single point, and thinks an urban area (polygon) is better instead, because not every neighbourhood in a city will be oriented towards the main city centre. A Bergen example they mentioned is the district Fana, which has a large shopping centre at Lagunen. Many people will do their shopping there instead of in the city centre. On the other hand, they may still commute to work in the city centre.

Other variables they mentioned was access to green space and social facilities, meeting places. They were not sure how to measure these variables in a map, however.

Concerning data quality we talked about floor space data in the Matrikkelen. Those buildings used in the calculation of property taxes have quite good accuracy. Other buildings, like garages and outhouses do not have very accurate BRA numbers.

They strongly emphasised the need for me to understand the data available. This was necessary for all data sources, including green space, business registry and floor space. The datasets are all constructed based on different considerations, which are necessary to be aware on when interpreting results. Most of the data will also require some cleaning before using them in an analysis.