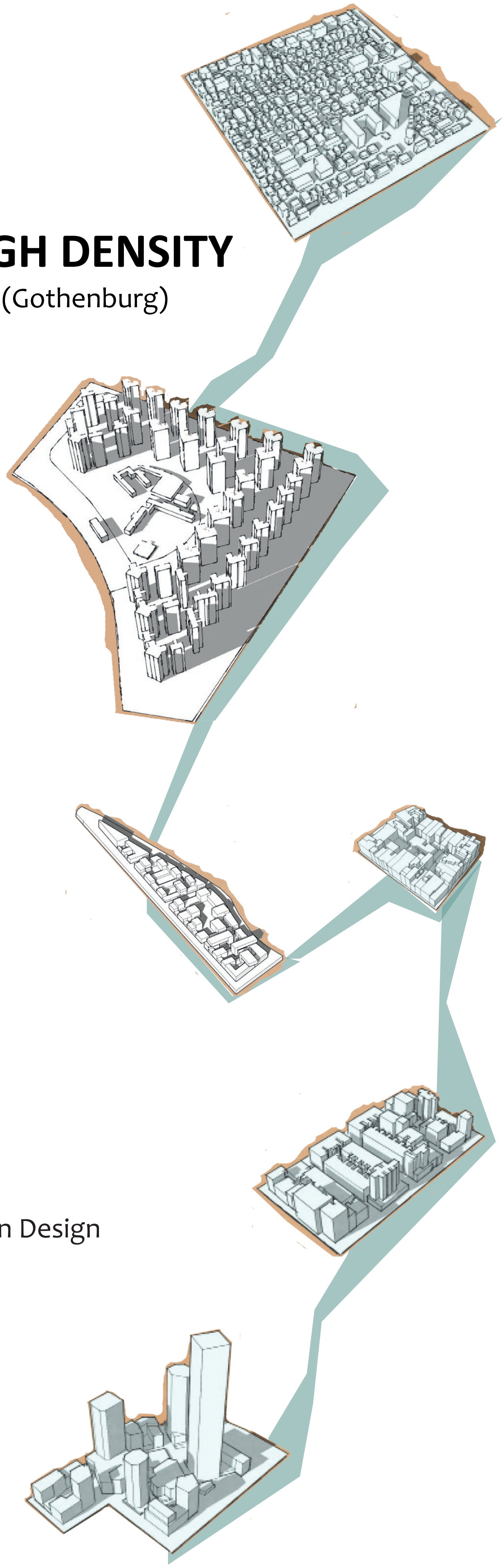
PROS AND CONS OF HIGH DENSITY

A Study of How and Where to Intensify (Gothenburg)



Zonghao Zhang

Master Thesis at Chalmers Architecture
Master Program Architecture and Urban Design

Examiner: Lars Marcus
Supervisor: Meta Berghauser Pont

CHALMERS
UNIVERSITY OF TECHNOLOGY

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A Study of How and Where to Intensify (Gothenburg)

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Keywords : High density blocks, Quality, Urban form, Space syntax

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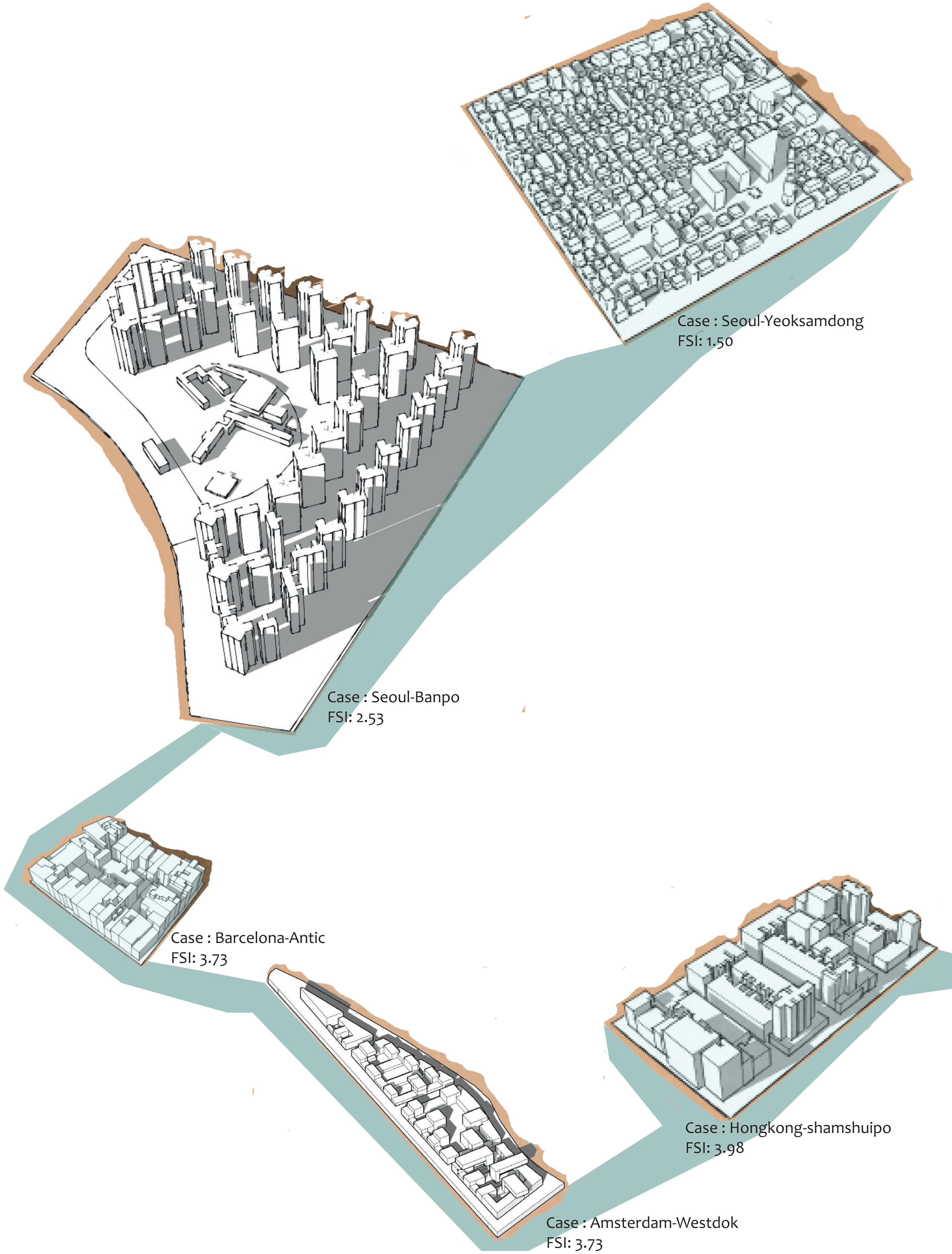
Finally, I would like to thank every single beautiful moment in Sweden. They contribute to the unforgettable, unique and precious experience which I never had before.

Zonghao Zhang
2018-10


Case : Seoul-Yeoksamdong
FSI: 1.50
Case : Seoul-Banpo
FSI: 2.53
Case : Barcelona-Antic
FSI: 3.73
Case : Hongkong-shamshuipo
FSI: 3.98
Case : Amsterdam-Westdok
FSI: 3.73

Abstract

It is an inevitable trend that more and more people live in cities. In 2050, the population of Sweden will increase with 2~3 million and most of them will settle in urban areas. Globally, 60% of the land that will be urban in 2030, has yet to be built (Elmqvist et al.2013). Thus, finding a suitable way for cities to intensify their use of land is an important topic, not least for architects.

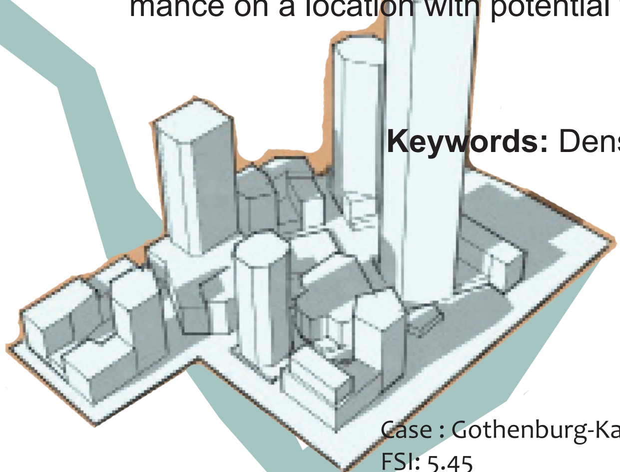
This thesis is aiming at, first, better understanding the relation between density and urban qualities; second, finding locations in Gothenburg with potential for densification and third, apply the findings of step 1 to propose a densification project on the location defined in step 2.

To evaluate the urban qualities, four quality dimensions are included in this thesis (environmental, physical, mobility and psychological qualities), measured using Greenness Index, Sunshine Rate, Street Wall Index, Building Density, Network Density and Openness that have been shown to describe the four quality dimensions well. To analyse the relation between density and urban qualities, six high density areas were selected, based on the classification of block types, ranging from high-rise to compact low-rise; each selected case belongs to one type. Next, density is analysed, an assessment of the qualities is conducted using the proposed measures and a qualitative evaluation and statistical analysis is used to compare the six cases.

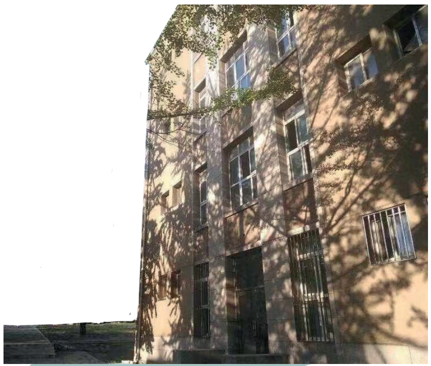
The results of the analysis are used to intensify a location in Gothenburg where I show how to combine high density with high qualities. The chosen location for densification is based on a spatial analysis, includes the current density and two centrality measures (integration and betweenness). In the design phase, the same density analysis and qualitative evaluation are used again to evaluate the qualities of the proposal.

The result of analysis of the six cases (research part A) concludes with three types of quality performance described as *green, urban* and *urban plus* and can be used as design guidelines. The result of the spatial analysis (research part B) provides a strategy of finding potential areas in Gothenburg to densify, but also provides a general methodology how to find such locations in other cities. Finally, the thesis comes up with a design proposal of densifying one block with high quality performance on a location with potential for densification.

Keywords: Density, Urban Quality, Urban Form, Space Syntax



Case : Gothenburg-Karlavagnsplatsen
FSI: 5.45



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Chalmers Architecture

Planning and design for sustainable development in a local context, Hjo

Spatial morphology

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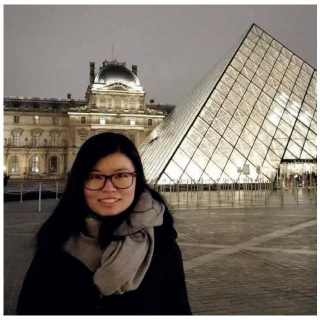
About the Author



Study Background:

Bachelor : Urban Design & Planning
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Master : Architecture and Planning Beyond Sustainability,
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Autumn 2016
Course : Sustainable development and the design professions
Studio: Planning and design for sustainable development in a local context

Spring 2017
Course : Architectural conservation and transformation
Studio : Spatial morphology, Architectural competitions

Autumn 2017
Course : Master thesis preparation course 1&2
Studio: Design and planning for social inclusion

I was born in a big city with nearly 30 million population, Chongqing Municipality. I get used to skyscrapers and living and studying in building jungle. In Chongqing, it is quite crowded, and parks are usually artificial with little natural atmosphere. Forests are far away from cities without easy accessibility. I thought it was how cities should be. In architecture school, we made large scale of both detail and master plan for big cities.

After I moved to Sweden, I found there are a lot of beautiful towns with amazing natural resource. Villas and low rise buildings are the majority dewllings. The departure of the master thesis was formed from the densification trend in Gothenburg because of population growing. I was wondering if it is possible that high density blocks can be combined with high qualities if we cannot avoid urban intensifying.

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III . Proposal

IV . Discussion

I . INTRODUCTION

BACKGROUND:

High density is an interesting and realistic subject in a situation where the population of big cities is growing. While the idea of high density blocks is blooming, many people in western countries still seem hesitant towards it. What are the pros and cons of high density blocks? Is it possible to challenge the traditional blocks we live in by finding some strategies to combine high density blocks with high qualities?

The most common block types in Sweden today are low or medium rise block type and low rise point type. Facing the facts that there is a great lack of housing and the population of Sweden will increase by 2~3 million in 30 years, it could be argued that if existing block types are possible solutions for the immigration trend. In reports, many researchers and organizations support high density blocks.
Nota Ruimte (2006) says that “.....concentrate new development in existing urban areas and to protect agricultural landscapes from urban sprawl. ”
The guideline of UN habitat says that “UN-Habitat supports countries to develop urban planning methods and systems to address current urbanization challenges such as population growth.....
the 3 key features of sustainable neighbourhoods and cities: compact, integrated, connected. ”
It is claimed that urban intensification leads to safer and more vibrant urban areas, support for local business and services, greater social equity and social interaction, and better accessibility to facilities (Jenks et al., 1996).
Le Corbusier introduced high density in terms of high and spacious buildings to give sufficient open green spaces for recreation.

However, high density also has negative effects. People living in disadvantaged areas with high population densities suffered from the combined effects of a lack of access to daylight, fresh air, clean water and adequate sewerage (Ruijter, 1987). In order to solve the problems in overcrowded cities, Baumeister introduced a normative building ordinance (Normalbauverordenung) in 1880 that stipulated a maximum of four storeys and prescribed that the building height should never exceed the street width. Raymond Unwin stated that density should be limited to 30 dwellings per hectare.

Recently there are a lot of building programs going on in Gothenburg (the second biggest city of Sweden) on vacant land, however, it could be discussed where the “best” locations are for developing.

The development of high density blocks could be present as an important type of urban form and ways of living. Instead of taking the place of agricultural land and forests, high density blocks could be a possible approach to creating a more sustainable city.

PROJECT SCOPE:

Aim:

The purpose of the thesis is to find the relations between density and quality performances and provide approaches for blocks to have both high density and high quality performance responding to the inevitable intensifying trend in cities.
Also, it aims at offering an approach to find blocks in cities which have potential to densify.

Practically, the thesis aims to apply the results of research & analysis into intensifying one block in Gothenburg and it can fulfil both quantitative and qualitative goals.

Main Questions:

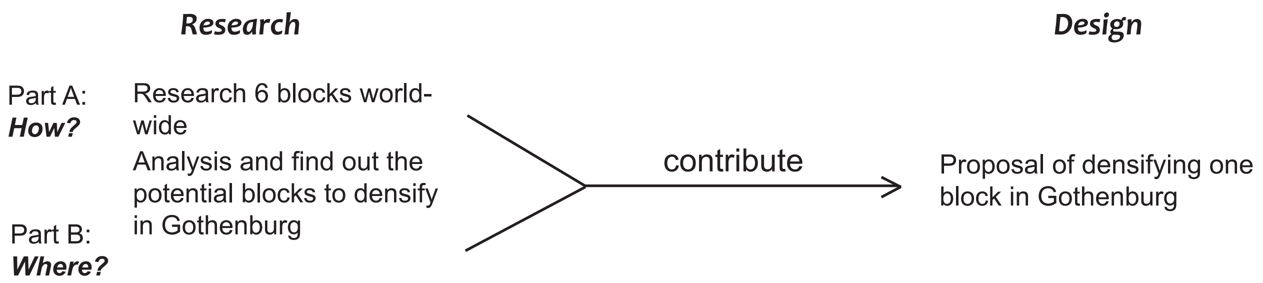
How can high density and high quality performance of blocks be combined?

How to find blocks in cities which have potential to densify?

The first question regards Research Part A and the second question regards Research Part B. The first question will be answered by looking into four quality dimensions (environmental qualities, physical qualities, mobility qualities and psychological qualities) and six quality measures (Greenness Index, Sunshine Rate, Street Wall Index, Building Density, Network Density, Openness) and density measures of 6 selected high density cases to find the relations between density and quality performances.
Practically, the first question will also be answered by the design proposal in which I will densify one block in Gothenburg while increasing quality performances.
The second question will be answered by doing space syntax analysis which are integration, betweenness and building network density analysis to offer the general strategy and I use Gothenburg as site.

Process:

The thesis contains two parts: research and design. Through the research part, the thesis answers the questions of how and where to intensify, which contribute to the design part: the proposal of densifying one block in Gothenburg.



Methods:

Through literature study and previous knowledge, I chose the suitable and doable methods for deciding cases and qualities; analysis and evaluation; densifying process.

In the Research Part A (***How?***), four steps are needed with different methods :
- Step1 : Selection of cases
Method : The cases should represent different building types
I chose 6 cases with high density using the selection method for making it less subjective and each case represents one type block in order to capture more characters within limited cases.
- Step2 : Density analysis
Method : Spacematrix (Berghauser Pont and Haupt 2010)
Spacematrix is used as density measures. It contains FSI (Floor Space Index), GSI (Ground Space Index), OSR (Open Space Radio), and L (the number of floors).
- Step3 : Assessment of qualities
Method : Quantify these qualities based on existing methods from literature.
It is used to analysis qualities of cases and it can bring the 6 cases at the same platform and provide an approach to comparing them.
- Step4 : Assessment of cases
Method : Qualitative evaluation
It is used for comparing the cases in an efficient way.
- Step5 : Statistical analysis
Method : Linear regression, Normal Equation, Standard error formula, Exhaustion method.
They are used to find the relations between density and qualities.

In the Research Part B (***Where?***), one method is used:
- Spatial analysis (Space Syntax)
This method is used to find potential blocks to densify which have high centrality level but low density.

In the design part, one method is used:
-Assessment of proposals
The method is for evaluating proposals within one location.

Delimitations:

In the range of the whole world, there are many different high density blocks. When I started the thesis, 6 typical cases (FSI varies from 1.5 to 5.5) were chosen for researching and analysing, to try to capture the characteristics of high density blocks. It is obvious that only 6 cases can not represent all the high density blocks, but in this way, I can narrow down the scope of this thesis and make it doable within several months.

When it comes to the question of which qualities should be analysed, I spent some time on finding how many qualities a city should care about and what they were. Serag El Din, Shalaby, Farouh and Elariane (2013) classified urban qualities into seven dimensions: environmental qualities, physical qualities, mobility qualities, social qualities, psychological qualities, economic and political qualities based on literature review. The three dimensions social qualities, economic and political qualities are holistic topics and they locate at deeper level of cities.Thus, in this thesis the other four dimensions are the focus: environmental qualities, physical qualities, mobility qualities and psychological qualities.

After the selection of the qualities, I chose Greenness Index, Sunshine Rate, Street Wall Index, Building Density, Network Density and Openness to measure them generally based on literature reading. The measures of the four qualities dimensions are interlinked. It is no doubt that there are much more other measures to analyse these qualities. Based on different situations and society periods, they also might change. The measures I chose here came from the perspective of blocks´ form, which make it possible to manage analysing varies cases at different locations.

In order to find the relations between density and qualities, the measures for density are essential.
Spacematrix focuses on various types of density on the urban block. They are FSI (Floor Space Index), GSI (Ground Space Index), OSR (Open Space Ratio) and L (the number of floors). Spacematrix makes it possible to quantitatively describe the density for 6 cases within the same diagram.

For the potential block finding part, the method for space syntax analysis was learned in the Spatial Morphology studio in the previous study. The data of axial map, segment map and building density map I used for analysis are from 2014. It is the latest datasets I can get and it is impossible for the me to update it by myself. Also, the axial map and segment map are based on pedestrian. I used integration, betweenness and building network density as methods to find potential block. As far as I know, the SMoG group is working on finding the most advanced method within this field.

I hope the thesis can contribute its knowledge to the densifying world by showing possibilities of combination of high density and qualities. Certainly, there are many other approaches to achieve the big goal and it is also important to realise multidisciplinary cooperation.

Figure 1 . Delimitation of urban qualities
[based on Serag El Din, Shalaby, Farouh and Elariane, (2013), Heptagon Shape (2012)]

II . RESEARCH & ANALYSIS

Research Part A

It is the first research part of the thesis. It aims at finding the relations between density and qualities. It contains five parts as follow:

A1 Selection of cases

A2 Density analysis

A3 Evaluation of qualities

A4 Case analysis

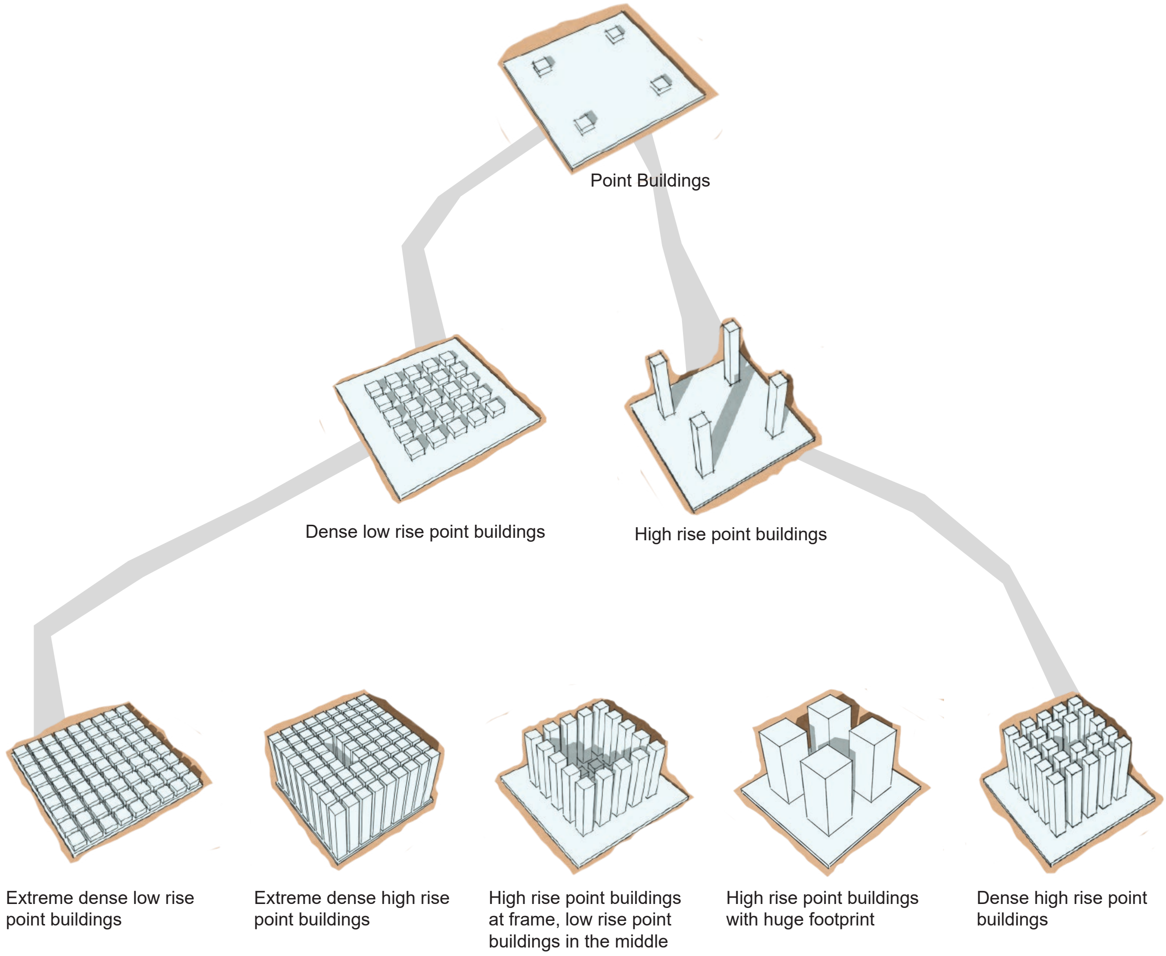
A5 Statistical analysis

A1 Selection of cases

Selection Criteria

In order to capture the characteristics of high density blocks, I need to select blocks in the range of the whole world. I started to classify different typology of blocks based on literature and chose one block to represent each type. Hopefully it will be less subjective and contain a larger range of characteristics.
On the following pages, there are 10 cases showed of in total. Due to time constraints, I managed to analysis 6 of them, based on the data from online map source and SMoG.
Here I need to explain that in the A5 statistical analysis part, actually more cases are needed, and the results are highly influenced by the six cases.

Building types, increasing dense (Uytenhaak, 2009)



Case1. Seoul-Yeoksamdong   Case2.Gothenburg-Karlavagnsplatsen   Case3 : Seoul-Banpo

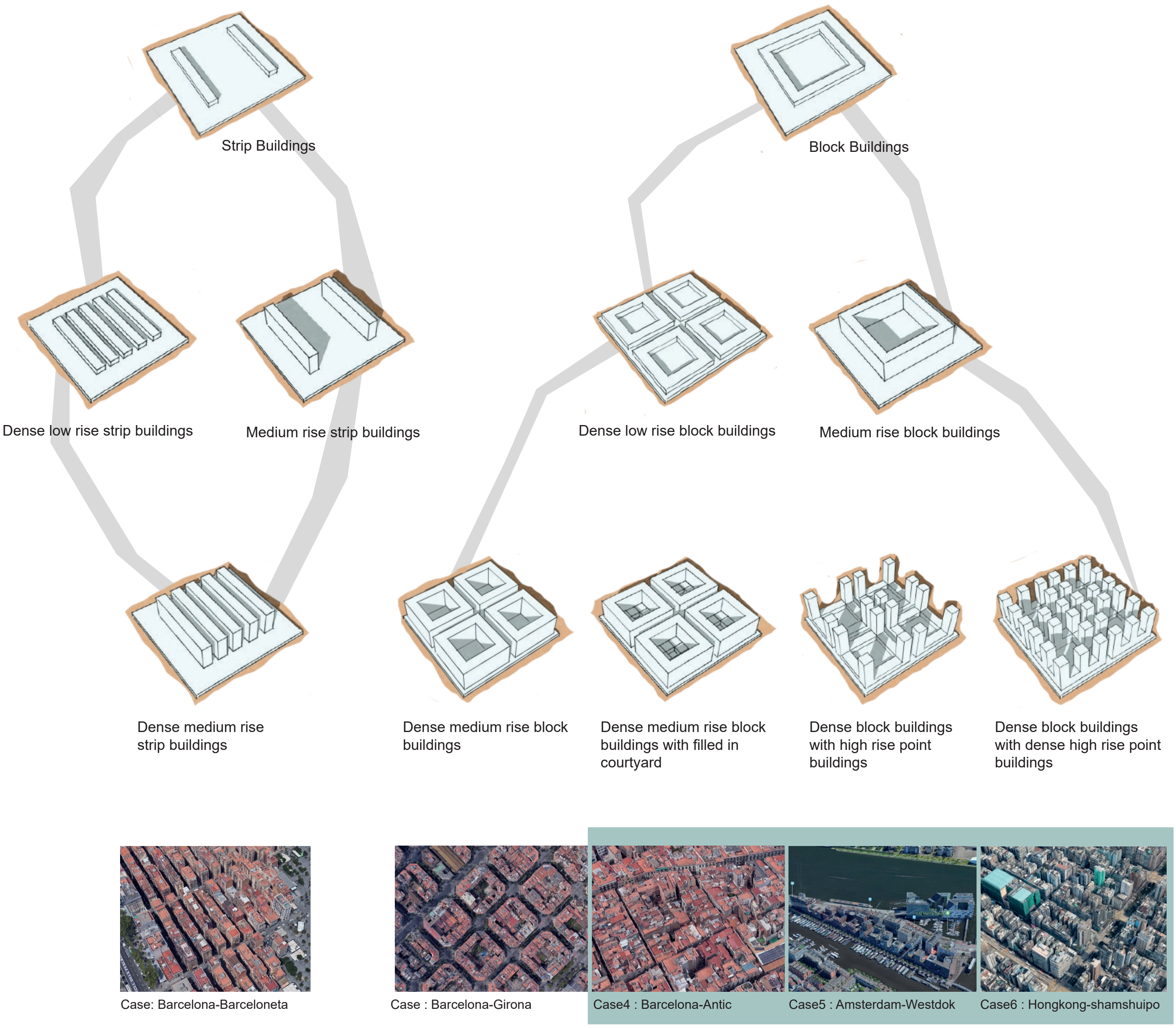


Figure 2 . Selection of cases

Density Analysis-----Spacematrix

There are different density measures from countries to countries. Some countries define density by the number of people per given area (population density), and it is used to plan for new schools, retail and the transit expansion needed for an area; while others define it using the number of dwelling units per given area and it is often used to describe urban development which is more stable than population density (Berghauser Pont and Haupt 2010).

The contribution of Spacematrix method is offering a clear definition of density and for the thesis, it is used as a platform to locate all type of blocks.

The variables of Spacematrix used for the thesis are defined and calculated as follows (on urban fabric level and thus including public streets; for more details see Berghasuer Pont and Haupt 2010):

(1) Floor Space Index (FSI) describes how intense an area is being built and it calculated as follows (on urban fabric level thus urban streets are included) :

FSI = [gross floor area (m^2)] / [area of fabric (m^2)]

(2) Ground Space Index (GSI) demonstrates the relationship between built and non-built space calculated as follows (on urban fabric level) :

GSI = [building footprint (m^2)] / [area of fabric (m^2)]

Where building footprint is the building up surface.

The average number of floors (L) and the open space ratio (OSR) are derived from the basic indicators FSI and GSI and can be calculated as follows:

(3) Building Height (L) measures the average number of stories, it can be derived from FSI and GSI, on the same level.

L=FSI / GSI

(4) Spaciousness (OSR) is a measure of the amount of non-built space at ground level per square meter of gross floor area. This measure provides an indication of the pressure on the non-built space. For example, if OSR is 0.50 of a block, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment , it gets 50 square meters' non-built space.

OSR=(1–GSI) / FSI

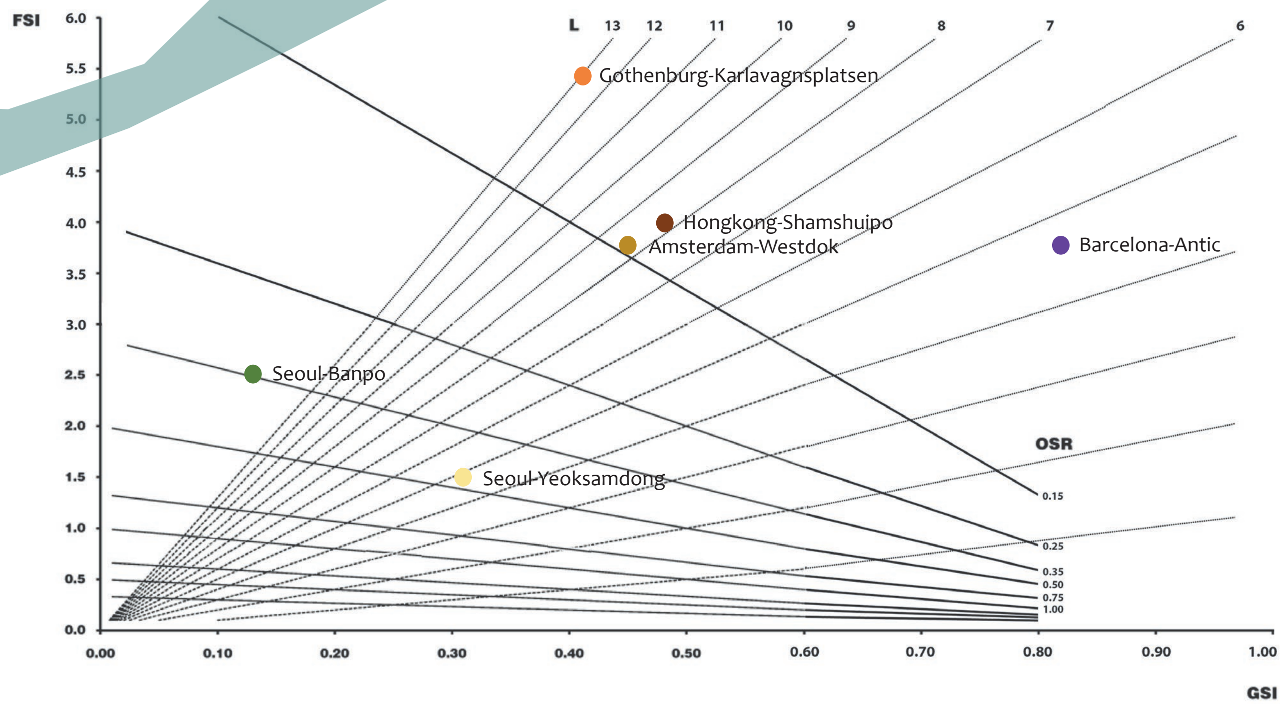


Figure 3. Six cases in Spacematrix

The diagram in Figure 3 shows, where the selected cases are located in the FSI-GSI plane of the Spacematrix. It makes it possible to quantitatively describe the density for blocks within the same diagram. The case Seoul-Banpo with high FSI but low GSI is with high-rise buildings surrounded by large open spaces. The case Seoul-Yeoksamdong with high FSI and medium GSI consists of mid-rise buildings. The cases Gothenburg-karlavagnsplatsen, Hongkong-Shamshuipo and Amsterdam-Westdok with both high FSI and GSI are blocks with high-rise buildings dominated by perimeter blocks. The case Barcelona-Antic with high FSI and extreme high GSI are blocks of mid-rise buildings with little open space.

Quality Analysis

There are many qualities that can be used to assess the different cases. To make advice, I use the framework developed by Serag El Din, Shalaby, Farouh and Elariane (2013). They classified urban qualities into seven dimensions: environmental, physical, mobility, social, psychological, economic and political based on literature review (see Figure 4). As the diagram shows in Figure 4, the seven dimensions are related to each other.

The environmental quality dimension refers to the natural aspects of the neighbourhood.
The physical quality dimension refers to urban fabric, land use, services and facilities and infrastructure.
The mobility quality discusses the accessibility, traffic and transportation issues.
The social quality dimension refers to social justice and equity, interaction and participation between different groups and social integration.
The psychological quality dimension discusses the issues concerning the feeling of citizens toward their neighbourhood.
The economical quality dimension relates to affordable housing and services, providing job opportunities and promoting local business.
The political quality dimension discusses city policies which support the concept of urban quality and to which extent these policies are implemented following Serag et al (2013).
The social, economic and political dimensions are located at deeper level of cities and multidisciplinary cooperation is needed to engage them. Therefore, they are excluded from the thesis.

As we can see from Figure 3, the term they use is " Urban Quality of Life", while I would prefer to change it to "Urban Quality" in the thesis because "Quality of Life" refers to individual perception of their life in relation to their goals, expectations, standards and concerns in the context of the culture and value systems (WHOQoL Group 1998), which is not from the overall scope of cities.

In the following, I will describe the four dimensions used in the thesis.

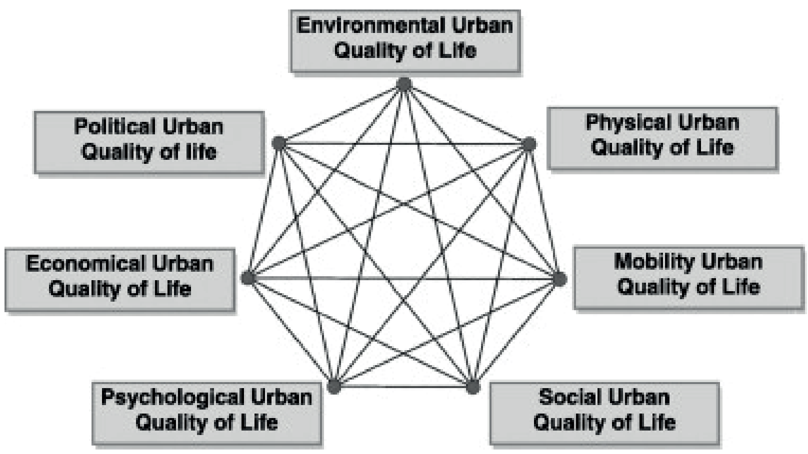


Figure 4 . Urban quality dimensions – Heptagon Shape (the researcher, 2012)
(Serag El Din, Shalaby, Farouh and Elariane, 2013)

Environmental Quality

The first dimension, generically called Environmental Quality, refers to the natural aspects of the neighbourhood. It discusses the quality of natural landscape by the range of green areas distributed within the neighborhood and promoting access to clean air, water and land (Serag et al, 2013).

There is a strong link between urban green space and environmental quality (Givoni, 1991; Selman, 2012). Urban green space is defined as both public open spaces like parks and street plantation and private planted areas around buildings like yard and gardens (Givoni, 1991).

One of the main function of green space is to improve air quality as Hader (1970) summarizes that a diminution of dust is noticeable within green area. Another function is that green space has significant role in urban temperature regulation (Tura, Soromessa, Leta and Argew, 2016), it is partly because radiation is used for photosynthesis when the ground is covered by plants (Meijer, 2007). Although urban biodiversity survival depends on the existence of a variety of spaces (Gilbert, 1991), green space is the one that provide the most favourable conditions to support a greater number of species (Farinha-Marque, 2016). Green space also creates opportunities to combine water storage and wetland treatment in many regions (Meijer, 2007).

Based on literature review, I use Greenness Index of the analysed blocks as one measure for environmental quality. It is necessary to mention that another measure amount of greenness within 1 km is important for grasping the quality with the context. But since I want to understand the qualities of different cases independent from their context so that they can be applied in new locations, I would prefer to ignore the contextual measure.

And the other measure for it is Sunshine Rate because Berghauser Pont and Haupt (2010) discovered that daylight and solar radiation have a great impact on the climate in the city, both in the interior of buildings and in the public space.

Physical Quality

The second dimension, Physical Quality, refers to urban fabric, land use, services and facilities and infrastructure. It provides principle of compact neighbourhood, access to adequate services and facilities, well-defined streets and open spaces (Serag et al, 2013).

Plot is one of the fundamental elements of urban form along with buildings and streets (Moudon,1994; Whitehead ,2001). The character of a spatially defined physical entity makes the notion of plot so distinctive (Kropf, 1997). Vialard and Carpenter (2015) studied the relations between plot and building densities and concluded that larger plots of a more complex shape cause lower building densities. Thus, I would like to use Building Density as one measure for the quality dimension. Siksna (1998) and Vialard (2012) in their studies of modification process of plot and block patterns, discovered that smaller blocks within regular grids absorb changes better. Because block size can be converted from network density, I would use Network Density as the other measure of physical quality.

Mobility Quality

Mobility Quality discusses the accessibility, traffic and transportation issues. It promotes fine network interconnecting streets to encourage walking, reduce traffic load and minimize air pollution. It also provides transit stops within walking distance to allow independence to elderly, youth and who do not drive (Serag et al, 2013).

Urban mobility includes motorized and non-motorized modes. In the thesis, walkability, which belongs to non-motorized mode is mainly discussed. The benefits of increasing walkability of neighbourhoods is not only reducing traffic congestion (Talen and Koschinsky, 2013), but also improving public and private health (Doyle et al., 2006, Durand et al., 2011).

In order to assist in measuring and thus improving the quantity and quality of walkability, many methods have been proposed. Traffic calming, playground and recreation areas are consistently related to both increased walking and decreased injury from a child safety walking and injury perspective (Rothman, Buliung, Macarthur, To and Howard, 2013). The objective built-environment measures which attribute relating to walkability are dwelling density, intersection density, mixed land use, and net retail area (Gebel, Bauman and Owen, 2009). Lacono, Krizek and El-Geneidy (2010) say that walkability is influenced by distance between zones and the amount of activity in destination zone. In the research of Ewing and Handy (2009), street wall index is used as a measure for enclosure which makes outdoor spaces seem room-like (Gordon Cullen, 1961) and increases walkability.

Based on literature review, I propose two measures for mobility quality. One is Network Density and it can be converted from block size and intersection density. It indicated that people are connected with destinations within a reasonable distance and time spending, so they are willing to overcome spatial separation (Handy & Niermeier, 1997) by walking. The other measure is Street Wall Index and it represents pedestrian environment and it influences people's experience of walking.

High density blocks create the possibility for a diversity of destinations. Here I need to explain that Floor Space Index is actually the starting point for selection of cases and it is also a density measure in Spacematrix so I would like to exclude it for the measure of quality. Land use can be changed easily so I will also exclude the measure land use mix.

Psychological Quality

Psychological Quality, it discusses the issues concerning the feeling of citizens toward their neighbourhood, such as the identity of the place (Serag et al, 2013).

The intention of developing the psychological dimension of cities started centuries ago by several theorists such as Hermann Maertens and Camillo Sitte (Ladd, 1987). Oppressiveness, which is opposite to openness, as experienced in urban environments with high-rise buildings, is a form of environmental stress that poses psychological pressure on urban residents (Asgarzadeh, 2012). Parameters of the physical environment, particularly the physical shape of buildings, are the driving factors of oppressiveness (Takei and Oohara, 1977a, Takei and Oohara, 1978). Thus I take Openness as one measure of psychological quality.

The other measure I use for psychological quality is Sunshine Rate because daylight allows physical and psychological healing environments and daylight that gives sense of pleasure (Osterhaus, 2005).

The following figure shows the relations between four quality dimensions and measures based on literature review. Some measures contribute to more than one quality dimension.

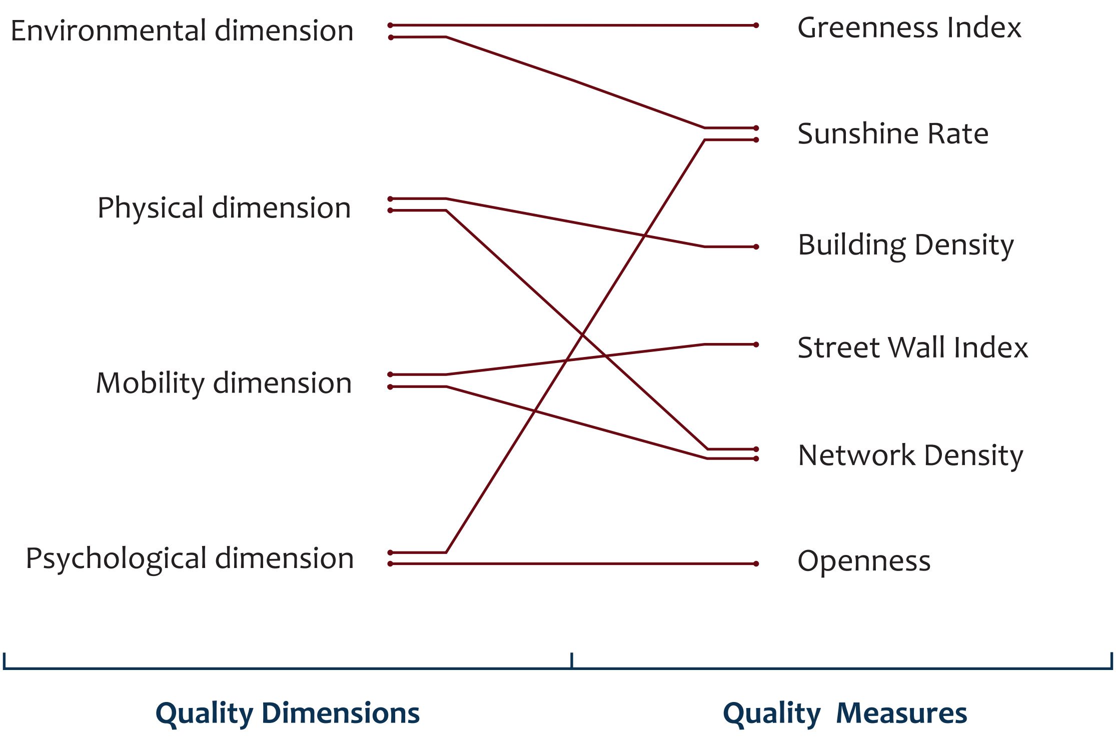


Figure 5. Relation between quality dimensions and measures

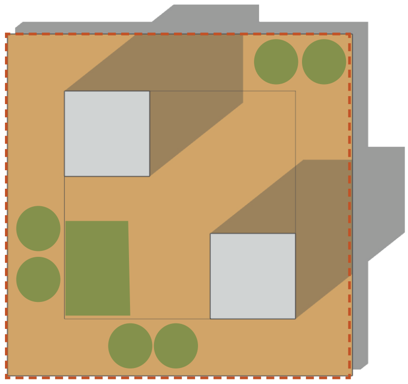
At coming pages, they are the detailed information of six measures.

Measure 1 : Greenness Index

It is a measure of how much of the area is covered by plants. Green area is calculated as vertical projection of plants. The images of cases come from online open map resource. The data is got from Autocad and Microsoft Excel.

$$\text{Greenness Index} = \frac{\text{green area}}{\text{total plan area}}$$

This index uses the unit m^2/m^2.



total plan area*
green area
island / private land
building

* plan area is the private land (plats or "island") plus half the street space surrounding it (i.e. urban fabric)

Standard*:

Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-0.20	0.20-0.35	0.35-0.49

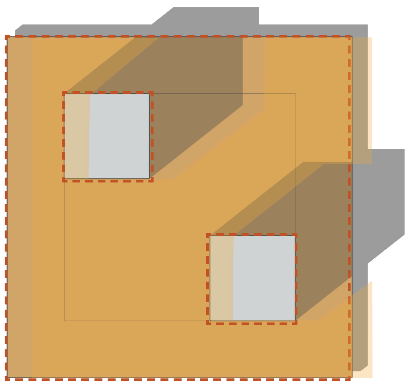
* Standard comes from the data of six cases themselves. The highest value of six cases got score 10. I set score 0-4 as low value, score 4-7 as medium value, score 7-10 as high value for the thesis. I scaled the value, and got the three level ranges.

Measure 2 : Sunshine Rate

It is a measure of how much of the area has sufficient daylight access and the shadow counted are only caused by dwellings. The thesis assumes it as a positive quality from the perspective of Sweden, where sunshine is so precious all year around. The models are made in Sketchup and in order to compare among cases, the thesis locates them at the same time and the same place (UTC+8, 22/12, 12:00). Calculations are done in Microsoft Excel.

$$\text{Sunshine Rate} = \frac{\text{daylight access area}}{\text{unbuilt area}}$$

This index uses the unit m^2/m^2.



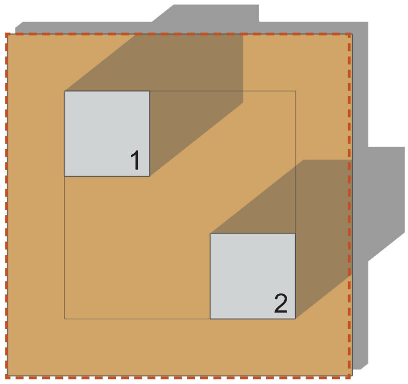
unbuilt area
daylight access area
area in shade
island / private land
building

Standard:

Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-0.21	0.21-0.36	0.36-0.52

Measure 3 : Building Density

Building density refers to the concentration of buildings in an area, in the case of plan.



- - - total plan area
island / private land
building

$$\text{Building Density} = \frac{\text{number of buildings}}{\text{total plan area}}$$

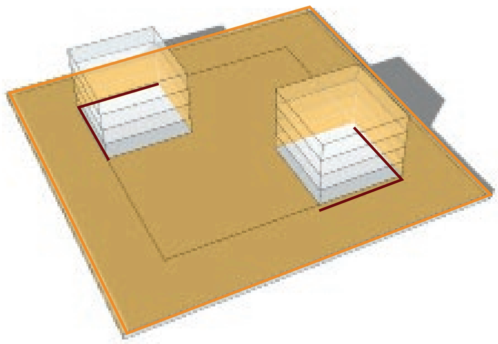
This index uses the unit number / hec.

Standard:

Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-22.05	22.05-38.59	38.59-55.12

Measure 4 : Street Wall Index

It is a measure of the building enclosure degree of an area.



length streets
building facade along streets
island / private land

$$\text{Street Wall Index} = \frac{\text{length of building facade along streets}}{\text{length of streets}}$$

This index uses the unit m / m .

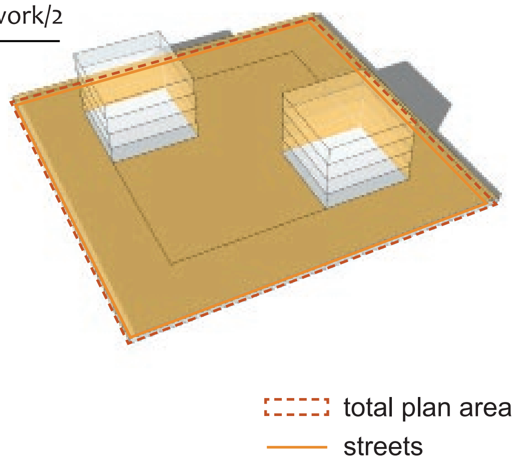
Standard:

Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-0.40	0.40-0.70	0.70-1.00

Measure 5 : Network Density

The density of the network refers to the concentration of networks in an area, in this case the fabric. It is calculated as the sum of the whole internal network and half of the length of the network used to demarcate the base land area (Berghauser Pont and Haupt 2010).

$$\text{Network Density} = \frac{\text{length of interior network + length of edge network/2}}{\text{total plan area}}$$



This index uses the unit m / hec

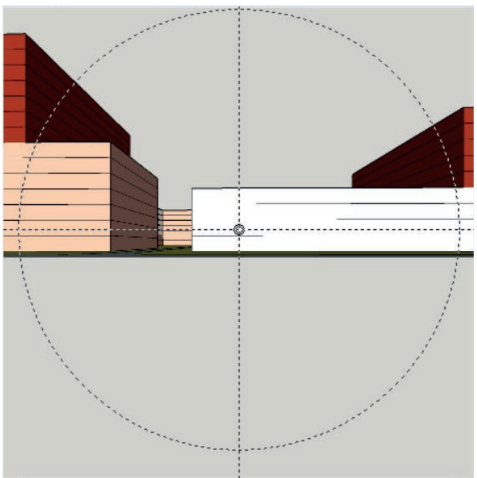
Standard:

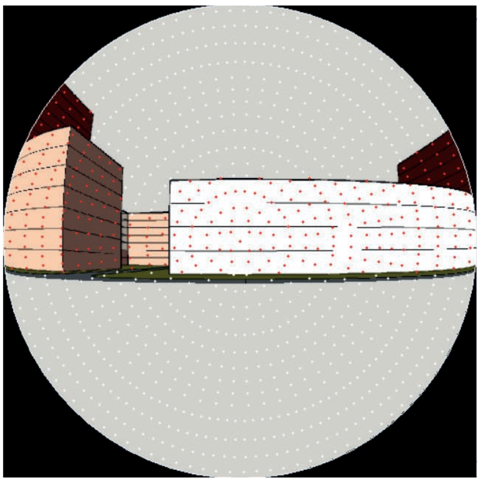
Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-188.83	188.83-330.46	330.46-472.08

Measure 6 : Openness

Openness is the opposite of oppressiveness, which is a form of environmental stress that experienced in urban environments with high-rise buildings, that poses psychological pressure on urban residents (Asgarzadeh, 2012). Pictures from Sketchup model taken on eyesight level 1.65 are used to calculate the amount of building facade in sight. More technical detail can be found below (step1 and step2).

Openness = 1- oppressiveness rate





Solid angle of buildings: 28.6 per cent
Oppressiveness: 0.286

1. Solid angle

An individual views buildings three dimensionally. For analysis, these three dimensional variables were compressed into a two dimensional plane with the visual magnitude measured by a mathematical concept called a solid angle (Asgarzadeh et al., 2014).

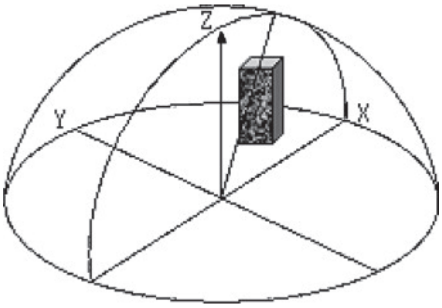


Figure 6 . Calculating solid angle (Asgarzadeh, 2012)

In order to facilitate measurement of solid angle for several images, two computer software are developed that have the ability of calculating this physical parameter: Geocity and SPCONV Projection Converter(VER.6). The latter one was utilized for the thesis. The obtained solid angle value is displayed in percentages.

2. Image selection

All the images were taken from the point of view of a person whose eyesight height is 1.65m, standing in the middle of fringe streets of blocks, with 120 degrees' field of view in software Sketchup. For each case, there are several images and the average rate of them represents the case. The size of images was 90mm*90mm.

Standard:

Value	Low	Medium	High
Score	0-4	4-7	7-10
Range	0.01-0.23	0.23-0.40	0.40-0.58

A4 Case analysis

It is the fourth part of Research Part A. For each case, it contains 3 images, a plan with density measures, densifying process and quality performances.

In the following pages, the radar map shows quality performances of each cases. It contains six measures, they are Greenness Index, Sunshine Rate, Street Wall Index, Building Density, Network Density and Openness. For each quality, the highest value among six cases got score 10, the other cases got proper scores based on ratio between their value and highest value multiply score 10. Score 4 and 7 are the thresholds of medium and high value, respectively.

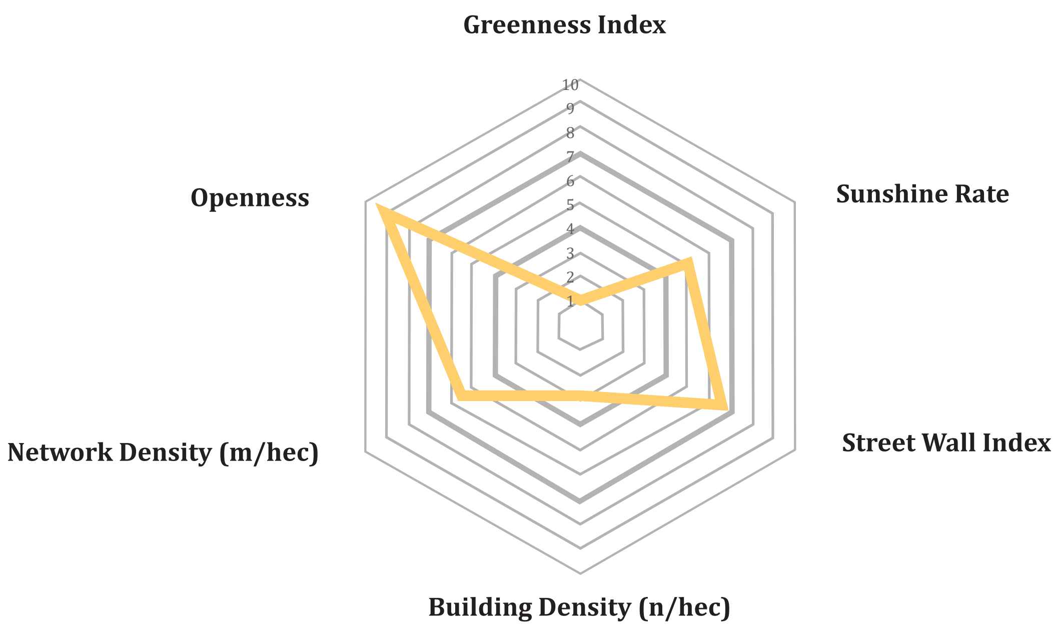


Figure 7 . Quality performance

Case 1 : Seoul-Yeoksamdong

The area of case Seoul-Yeoksamdong is around 20 hectares. The characteristics of the block are that surrounding buildings are high rise point buildings with wide streets, while inner buildings are low rise point buildings with narrow streets. Floor Space Index of case is 1.50, and it is the lowest among 6 cases ; Ground Space Index is 0.31; Open Space Ratio is 0.46, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment , it gets 46 square meters' outdoor space; the average stories are nearly 5, and the case belongs to medium rise blocks.

Plan 1 : 20000
Area: 200792 m²
FSI: 1.50
GSI: 0.31
OSR: 0.46
L: 4.85

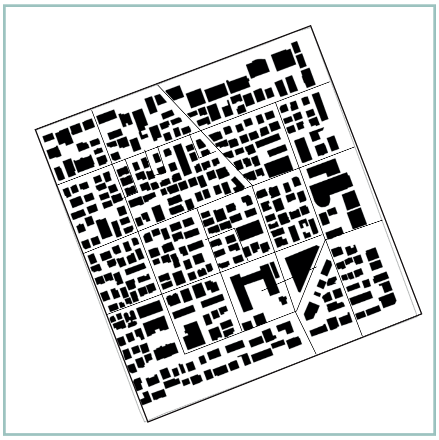


Figure 8 . Plan of Seoul-Yeoksamdong

The case Seoul-Yeoksamdong gets one high quality performance: Openness; three medium quality performances: Sunshine rate, Street Wall Index and Network Density; and two low quality performances, Greenness Index and Building Density.

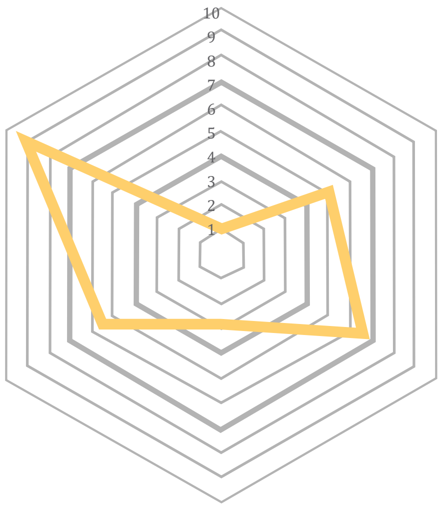


Figure 9 . Quality performance

1 The standard for the thesis is: score: 7-10 High quality; 4-7 Medium quality; 0-4 Low quality

Case 2 : Gothenburg-Karlavagnsplatsen

The case Gothenburg-Karlavagnsplatsen is in plan to build. The area is around 5 hectares. The characteristics of this block are buildings with huge footprint and high rise buildings at top. Floor Space Index of the case is 5.45 , and it is the highest among 6 cases ; Ground Space Index is 0.42; Open Space Ratio is 0.11, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment , it gets 11 square meters' outdoor space; the average stories are around 13, and this case belongs to high rise blocks.

Three pictures come from tengbom.se

Plan 1 : 20000
Area: 47529 m^2
FSI: 5.45
GSI: 0.42
OSR: 0.11
L: 13.13

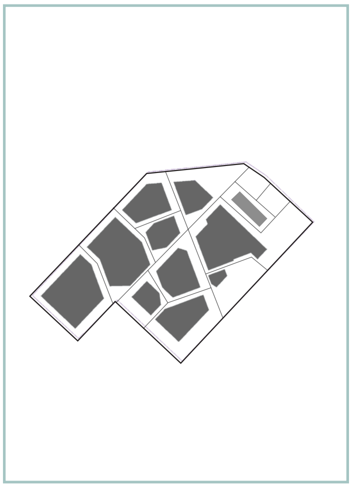


Figure 10 . Plan of Gothenburg-Karlavagnsplatsen

The case Gothenburg-Karlavagnsplatsen gets three high quality performances: Sunshine Rate, Network Density and Openness ; one medium quality performance: Street Wall Index; and two low quality performances: Greenness Index and Building Density.

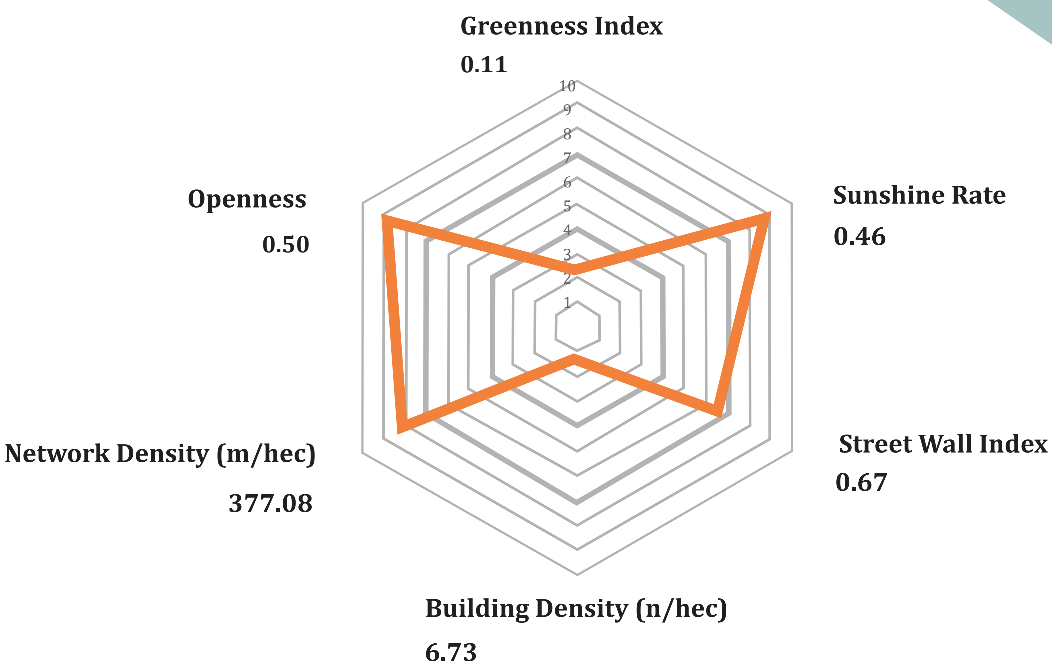


Figure 11 . Quality performance

Case 3 : Barcelona-Antic

The area of case Barcelona-Antic is less than one hectare. The characteristics of the block are high depth block buildings with filled in courtyard. Floor Space Index of the case is 3.73; Ground Space Index is 0.82 and it is the highest among 6 cases; Open Space Ratio is 0.05, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment, it gets 5 square meters' outdoor space and it is the lowest among 6 cases; the average stories are around 5, and the case belongs to medium rise blocks.

Plan 1 : 5000
Area: 7075 m²
FSI: 3.73
GSI: 0.82
OSR: 0.05
L: 4.55

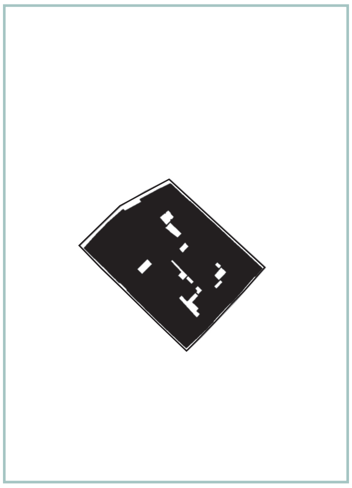


Figure 12 . Plan of Barcelona-Antic

The case Barcelona-Antic gets three high quality performances: Street Wall Index, Building Density and Network Density; one medium quality performance: Sunshine Rate; and two low quality performances: Greenness Index and Openness.

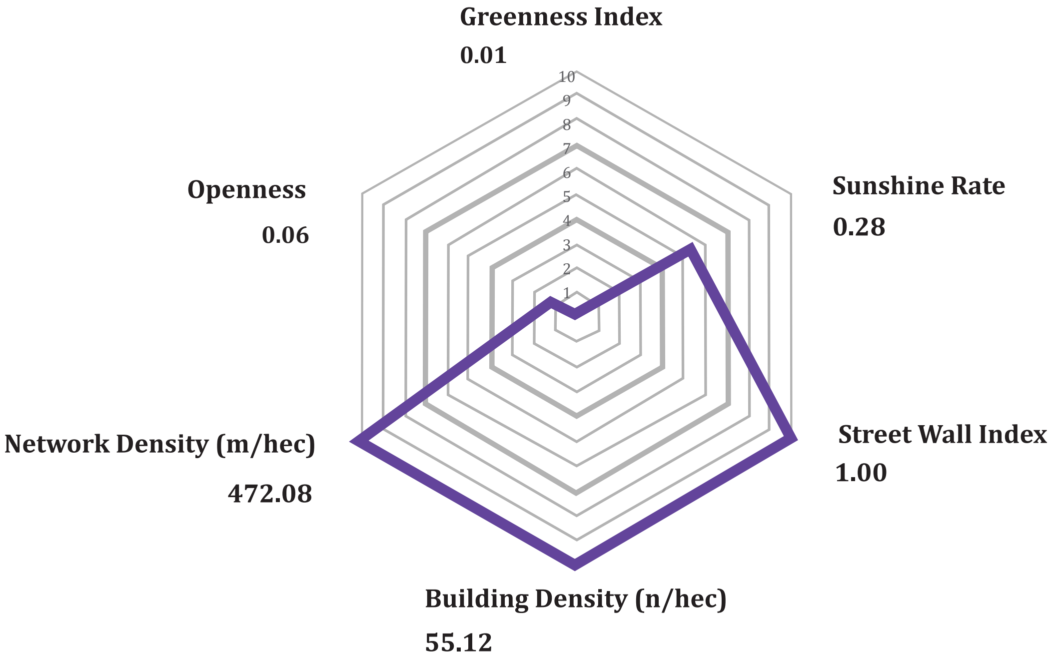
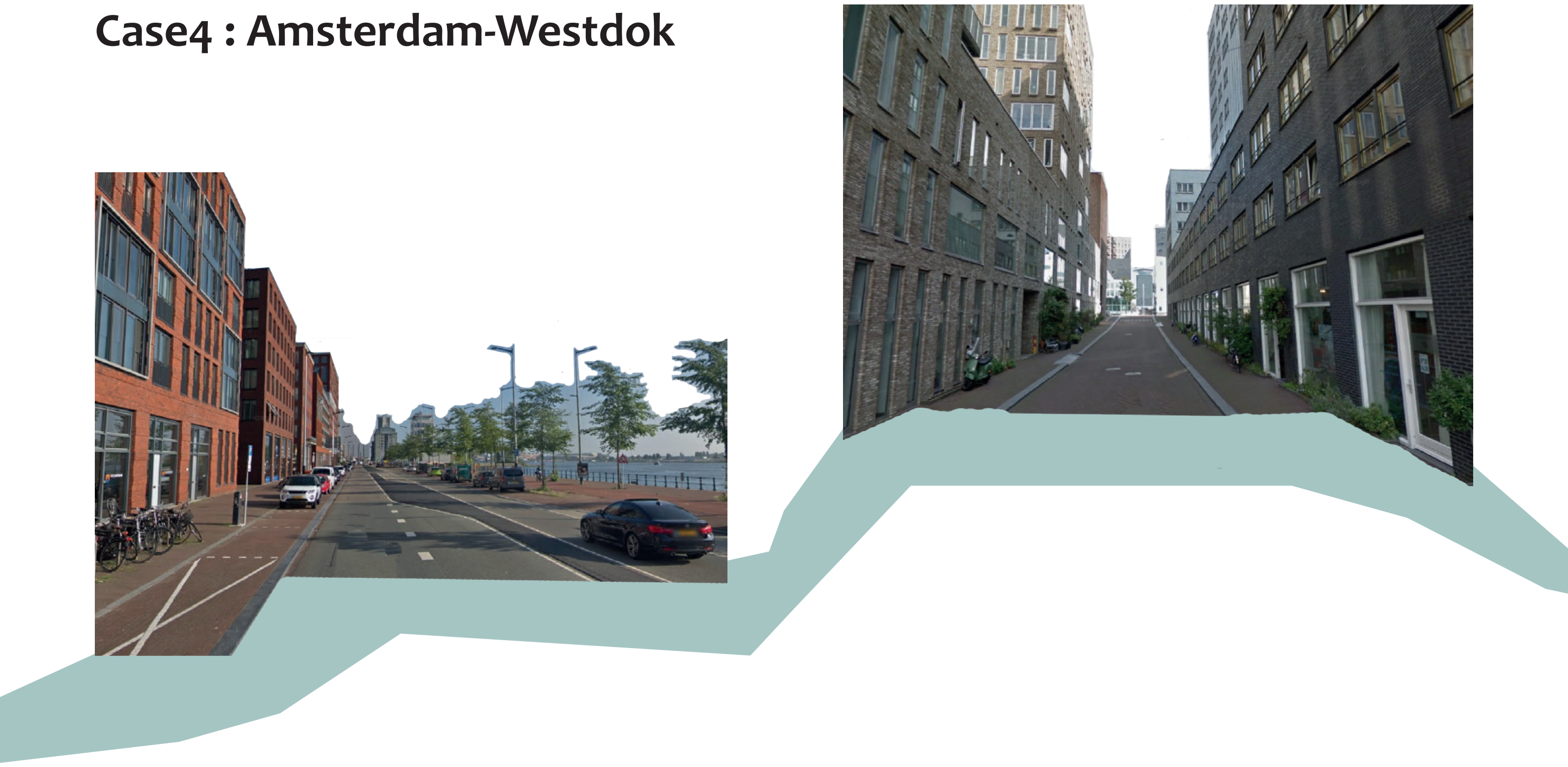


Figure 13 . Quality performance

Case4 : Amsterdam-Westdok



The area of case Amsterdam-Westdok is around five hectares. The characteristics of the block are block buildings with high rise point buildings and partly filled courtyard. Floor Space Index of the case is 3.73; Ground Space Index is 0.45; Open Space Ratio is 0.12, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment, it gets 12 square meters' outdoor space; the average stories are around 8, and the case belongs to high rise blocks.

Plan 1 : 20000
Area: 47529 m²
FSI: 3.73
GSI: 0.45
OSR: 0.12
L: 8.29

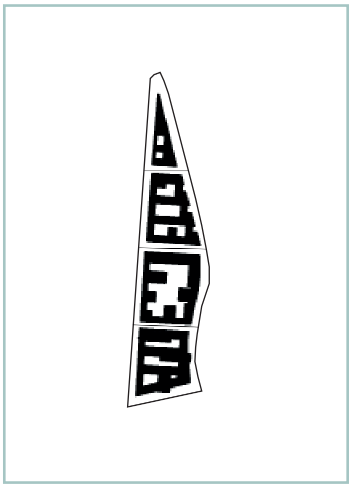


Figure 14 . Plan of Amsterdam-Westdok

The case Amsterdam-Westdok gets four high quality performances: Sunshine Rate, Street Wall Index, Network Density and Openness; two low quality performances: Greenness Index and Building Density.

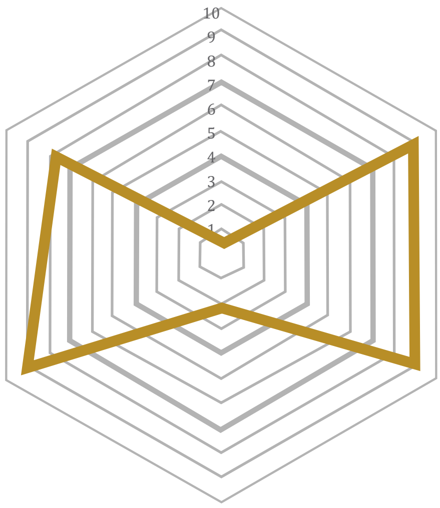


Figure 15 . Quality performance

Case5 : Hongkong-shamshuipo

The area of case Hongkong-shamshuipo is around four and a half hectares. The characteristics of the block are high depth block buildings with high rise point buildings at top. Floor Space Index of the case is 3.98; Ground Space Index is 0.48; Open Space Ratio is 0.13, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment, it gets 13 square meters' outdoor space; the average stories are around 8, which belongs to high rise blocks.

Plan 1 : 20000
Area: 44252 m²
FSI: 3.98
GSI: 0.48
OSR: 0.13
L: 8.29

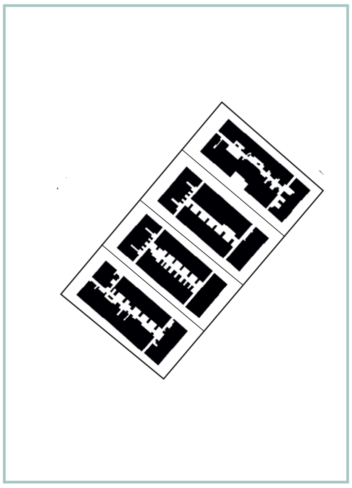


Figure 16 . Plan of Hongkong-shamshuipo

The case Hongkong-shamshuipo gets three high quality performances: Street Wall Index, Network Density and Openness; one medium quality performance: Sunshine Rate; two low quality performances: Greenness Index and Building Density.

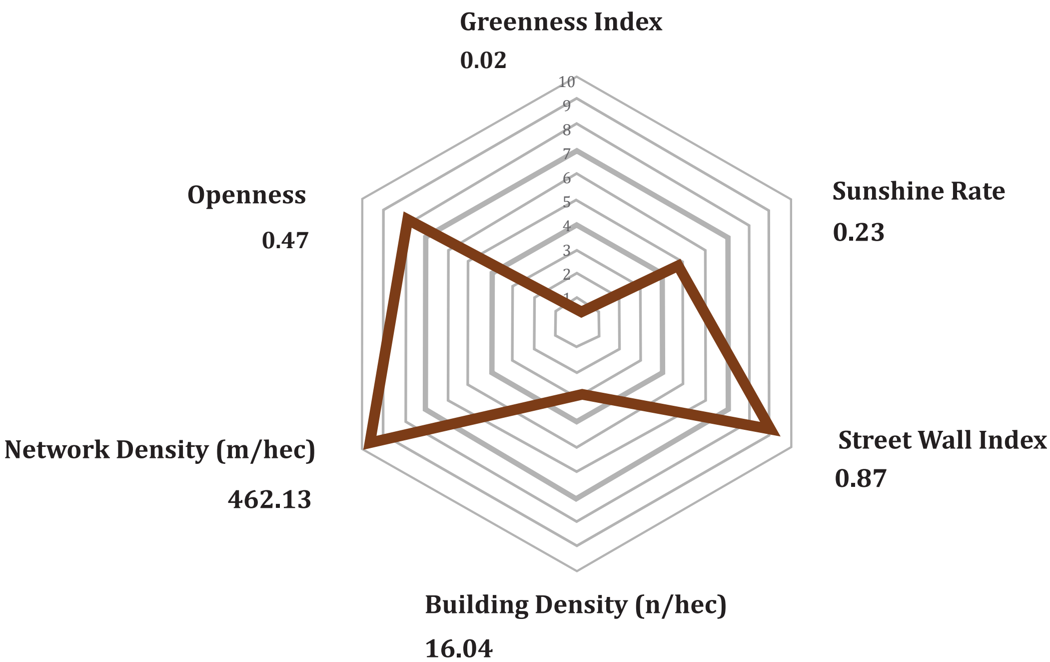


Figure 17 . Quality performance

Case6 : Seoul-Banpo

The area of case Seoul-Banpo is little more than thirty hectares. The characteristics of the block are high rise point buildings. Floor Space Index of the case is 2.53; Ground Space Index is 0.13 and it is the lowest among 6 cases; Open Space Ratio is 0.34, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment, it gets 34 square meters' outdoor space; the average stories are around 20, which belongs to high rise blocks.

Plan 1 : 20000
Area: 308349 m²
FSI: 2.53
GSI: 0.13
OSR: 0.34
L: 20.25

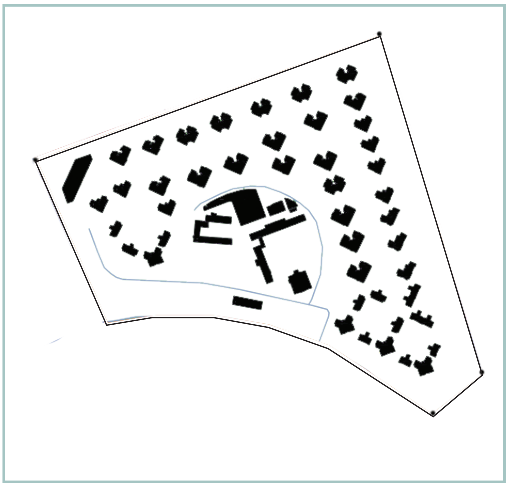


Figure 18 . Plan of Hongkong-shamshuipo

The case Seoul-Banpo gets three high quality performances: Greenness Index, Sunshine Rate and Openness; three low quality performances: Street Wall Index, Building density and Network Density.

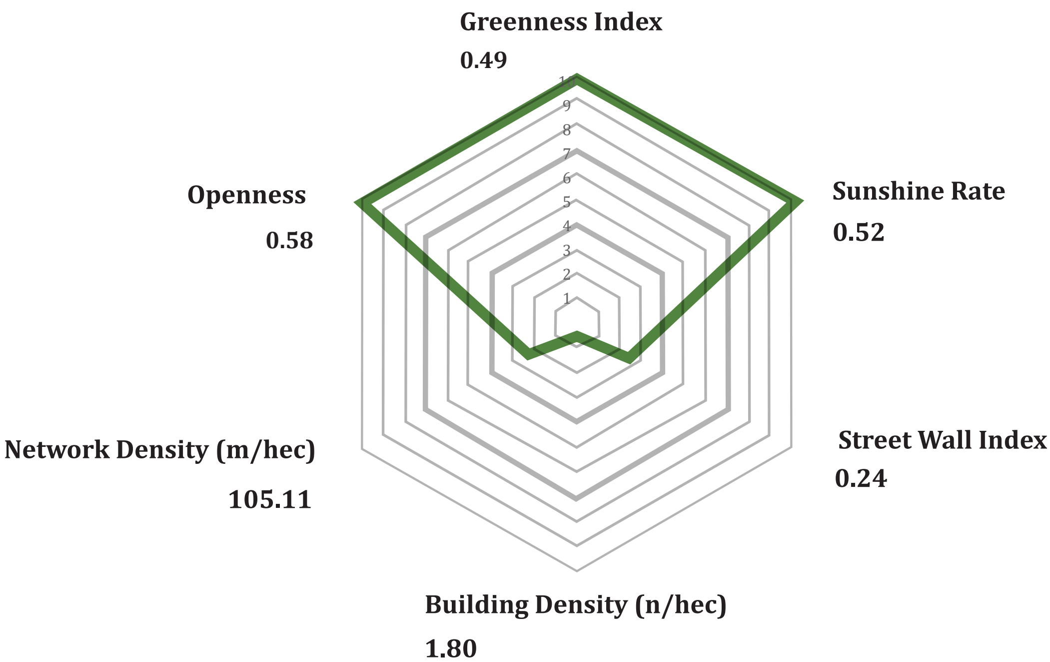


Figure 19 . Quality performance

Research Part A

Conclusion 1

In the following part, I will present firstly the results when looking at the qualities of the cases and see whether it follows some patterns. Secondly, I will give some strategies to improve Floor Space Index according to the 6 high density cases. Thirdly, I will relate the qualities to the density figures by projecting them in the Spacematrix diagram.

Three Types of Quality Performances

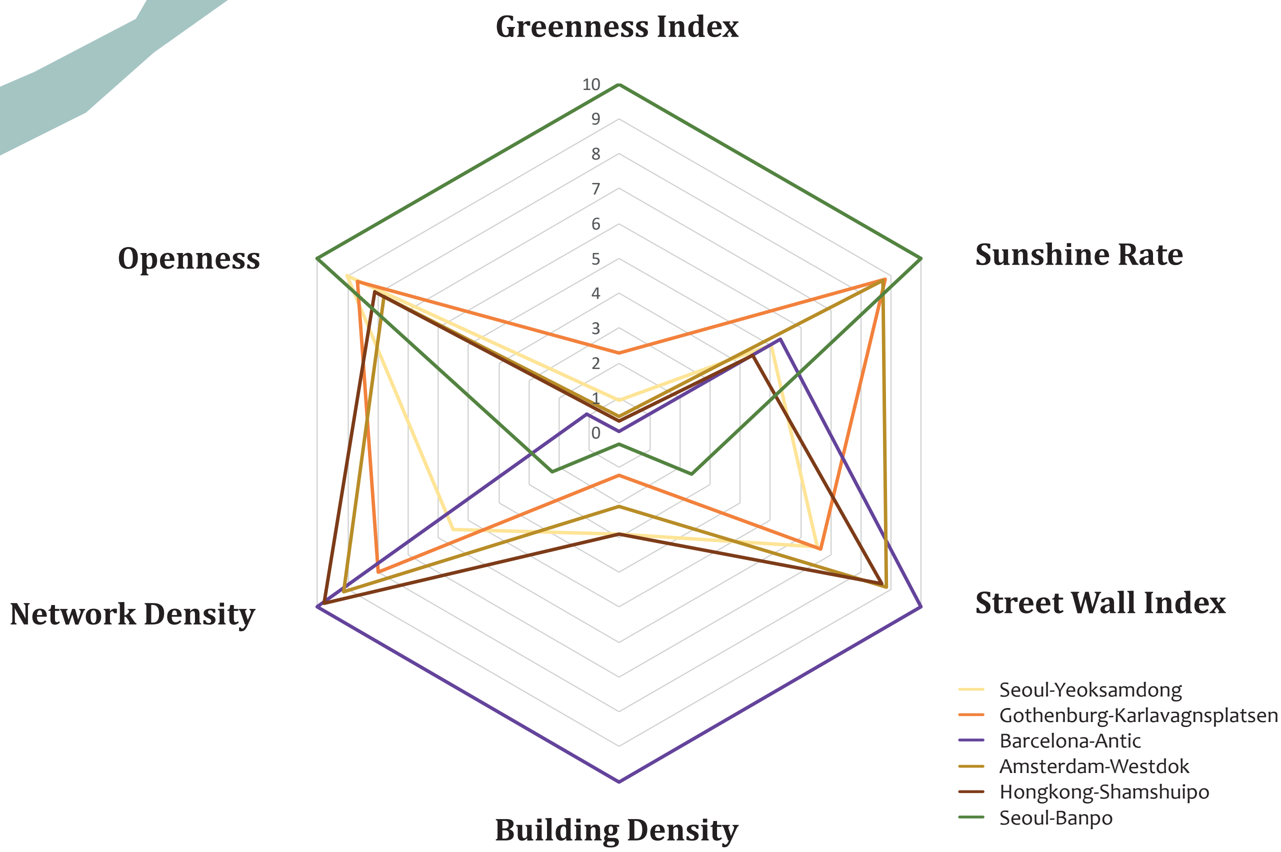


Figure 20 . Quality performances of six cases

As we can see from the collection of analysis results, there are three types of quality performances:

Type 1 GREEN -green line

The type has high quality of Greenness Index, Sunshine Rate and Openness; low quality of Street Wall Index, Building Density and Network Density.

Type 2 URBAN-yellowish lines

The type has high or medium quality of Sunshine Rate, Street Wall Index, Network Density and Openness; low quality of Greenness Index and building density.

Type 3 URBAN PLUS-purple line

The type has high quality of Street Wall Index, Building Density and Network Density, low and medium quality of Openness and Sunshine Rate.

From Type 1 to Type 3, high quality performances move from Greenness index, Sunshine Rate and Openness to Street Wall Index, Building Density and Network Density.

Research Part A

Conclusion 2

The following are the six strategies to improve Floor Space Index come from six high density blocks. They can be applied into design.

Strategies to Improve Floor Space Index

Strategy 1 **Delect low-rise buildings at the edge of super block and rebuild them with high-rise buildings.**

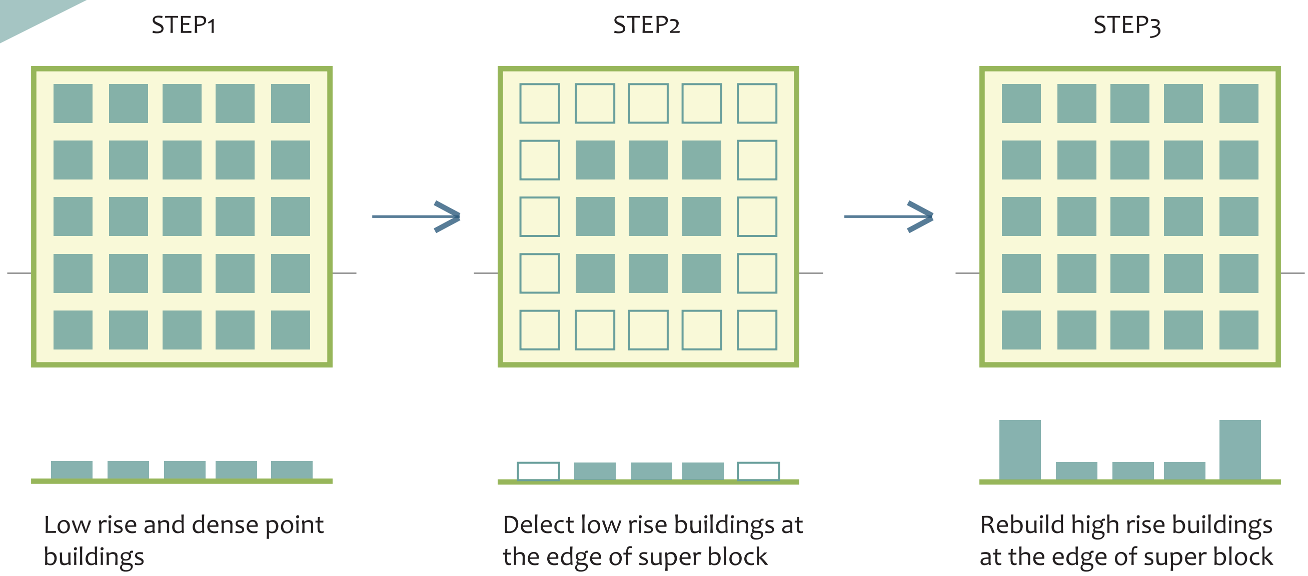


Figure 21 . Improve FSI---strategy 1

Strategy 2 **Add high-rise buildings at top of low-rise buildings**

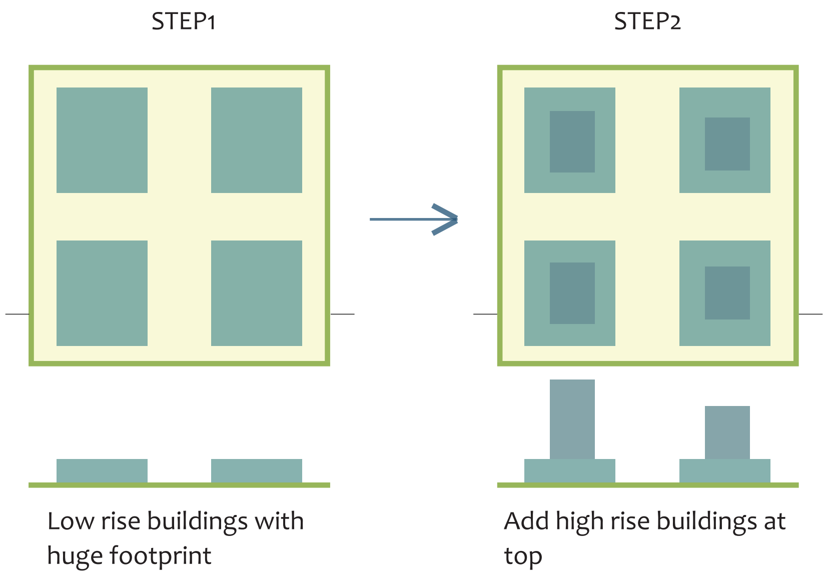


Figure 22 . Improve FSI---strategy 2

— Section line

New buildings build at the top of previous buildings

Strategy 3 Deepen block buildings into courtyard and fill in courtgard with low-rise buildings

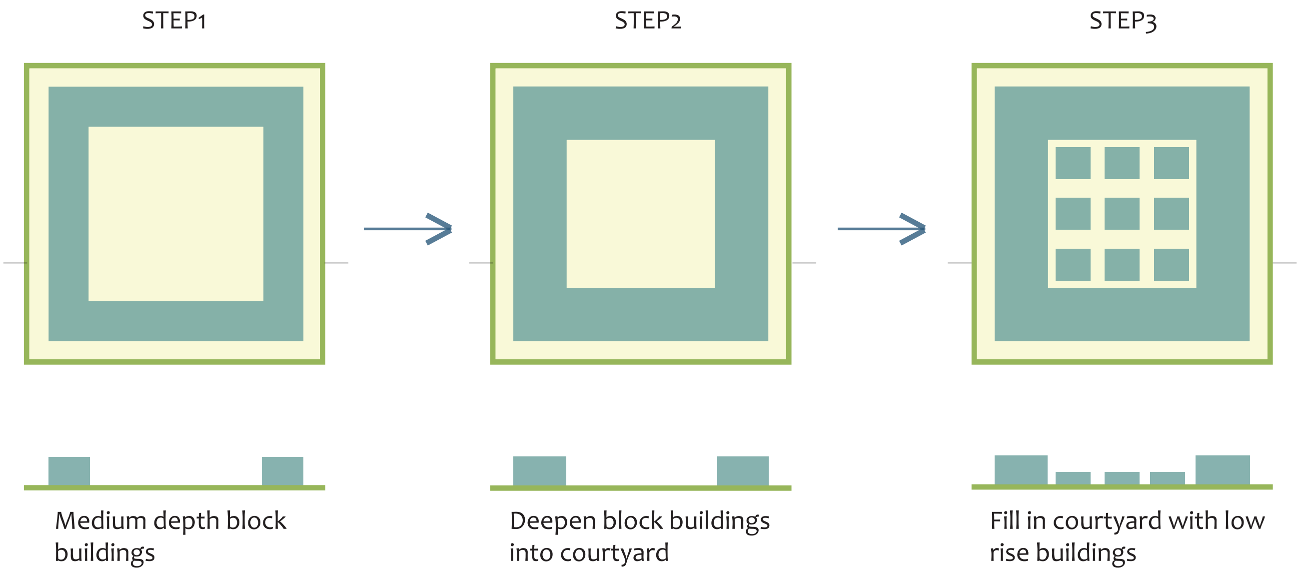


Figure 23． Improve FSI---strategy 3

Strategy 4 Add high-rise buildings at top of low-rise buildings

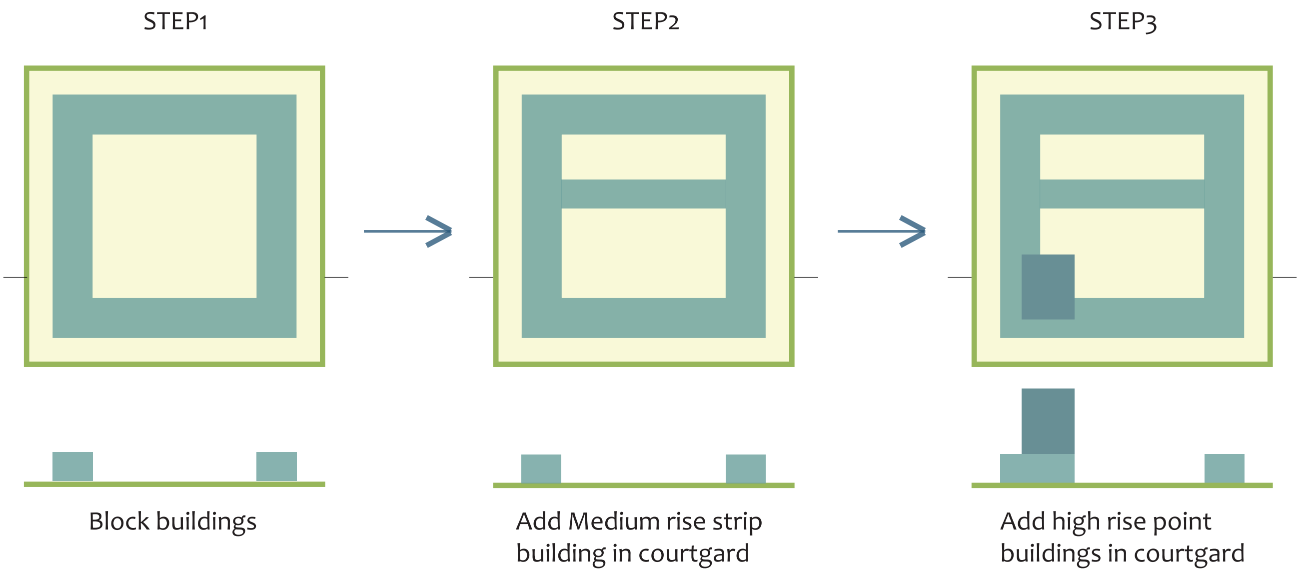


Figure 24． Improve FSI---strategy 4

Strategy 5 **Deepen block buildings into courtyard and rebuild one high-rise buildings with huge footprint by replacing few low-rise buildings**

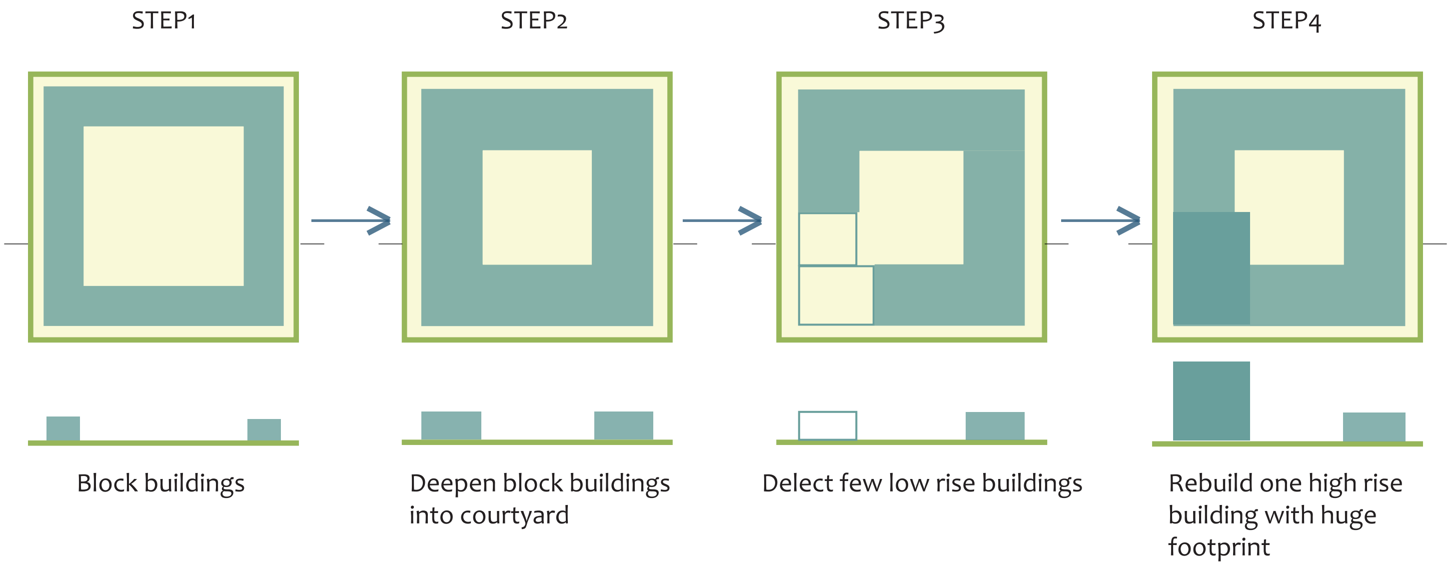


Figure 25 . Improve FSI---strategy 5

Strategy 6 **Add high-rise buildings at empty space**

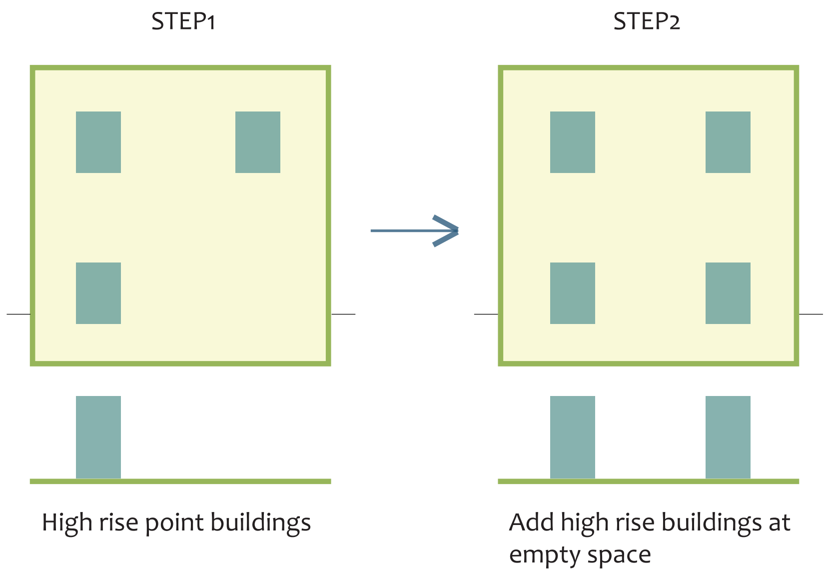


Figure 26 . Improve FSI---strategy 6

Relations between qualities and density

This section is about the statistical methods and tools I used for finding the relations between the four density measures (FSI, GSI, OSR, L) and the six qualities (Greenness Index, Sunshine Rate, Street Wall Index, Building Density, Network Density, Openness), and for making prediction based on their relations.

I used linear regression[1] to get the relations between the density measures and the six qualities respectively. As the values of OSR and L are dependent on that of FSI and GSI, there are indeed only two independent variables. Thus, I used two-variable linear regression here. However, which two density measures are the most linearly relative to each quality is not clear yet. So I tried all the six possible combinations (FSI and GSI, FSI and OSR, FSI and L, GSI and OSR, GSI and L, OSR and L) of the density measures, which means to solve six two-variable linear regression equations for each quality. After solving the linear regression equations, I picked the linear equation with the least standard error—which also means the highest multiple correlation coefficient (R^2)—for each quality and used it as the relation between the density measures and that quality. All the relations between the density measures and the six qualities are listed in Figure 28, Figure 30, Figure 32, Figure 34, Figure 36, Figure 38.

About the tools I used in the approach above, I firstly used Normal Equation[2] implemented by Python Programming Language (the code is attached in appendix 1) to solve the two-variable linear regression equations, i.e. to get the regression coefficients. The computation of standard error and multiple correlation coefficients with two-variables was also done in Python (the code is attached in appendix 2).

With the linear relations I got, now I could roughly predict the range of density measures for proper level of qualities. And I assumed $0 < FSI < 20$, $0 < GSI < 1$, $0 < OSR$, $0 < L$ here. I used the method of exhaustion by dividing the range of FSI and GSI into 5000 pieces and tested all the 5000 * 5000 combination of FSI and GSI pieces to check whether the predicted quality values are above proper level (I set it larger than 0.7 (As explained before, in the thesis, 0.7 of the highest quality value within 6 cases is the threshold of medium and high value) here). By the way, the value of OSR and L in the relations will be got by FSI and GSI according to their conversions. I implemented it with Python Programming Language (code attached in appendix 3) and got the figures in Figure 29, Figure 31, Figure 33, Figure 35, Figure 37, Figure 39.

Figure 27 in the coming page shows the 3 steps of analysing for easier reading and understanding.

1 linear regression: A linear approach to modelling the relationship between a scalar response (or dependent variable) and one or more explanatory variables (or independent variables).
2 Normal Equation: A formula for solving multiple-variable linear regression in mathematics.

A5 Statistical Analysis

Step1:

- Aim: Find the relations between all the pairs of density measures and each quality
- Method: Two-variable linear regression, Normal Equation
- Tool: Python Programming Language (see attached code in appendix 1)
- Input: Data for density mesures and qualities performance value of 6 cases
- Outcome: Regression coefficients and functions of pairs of density measures for each quality

Step2:

- Aim: Find the relations between density measures and each quality with the least standard error
- Method: Standard error formula
- Tool: Python Programming Language (see attached code in appendix 2)
- Input: Data for density mesures and qualities performance value of 6 cases
- Outcome: Standard error and multiple correlation coefficient

Step3:

- Aim: Predict the range of density measures for proper level of qualities
- Method: Exhaustion method
- Tool: Python Programming Language (see attached code in appendix 3)
- Input: Functions got above and the value of proper level of qualities
- Outcome: Locations in Spacematrix with proper level of qualities

Figure 27. 3 steps of statistical analysis

Relations between density and Greenness Index

Strong regressions with 5 density measures combinations for Greenness Index. According to the functions, Greenness Index has a negative relation with GSI. Plantations and buildings are competitors for the ground space.

The combination of variables FSI and L is the most relevant one to Greenness Index, and Greenness Index = -0.1FSI+0.062L-0.027

	R^2	Function
FSI & GSI	0.528	0.014FSI-1.258GSI+0.731
FSI & OSR	0.238	0.116FSI+1.872OSR-0.549
FSI & L	0.968	-0.100FSI+0.062L-0.027
GSI & OSR	0.549	-1.507GSI-0.542OSR-0.998
GSI & L	0.859	-0.274GSI-0.052L-0.162
OSR & L	0.919	0.659OSR-0.056L-0.454

Figure 28. Regressions and functions of density measures combinations with Greenness Index

The area in Spacematrix with high performance of Greenness Index is with high FSI and low GSI. They are usually hybrid point type, high rise blocks. Thus the case Seoul-Banpo with FSI 2.53 and GSI 0.13 gets high quality of Greenness Index and the other 5 cases get low quality performance.

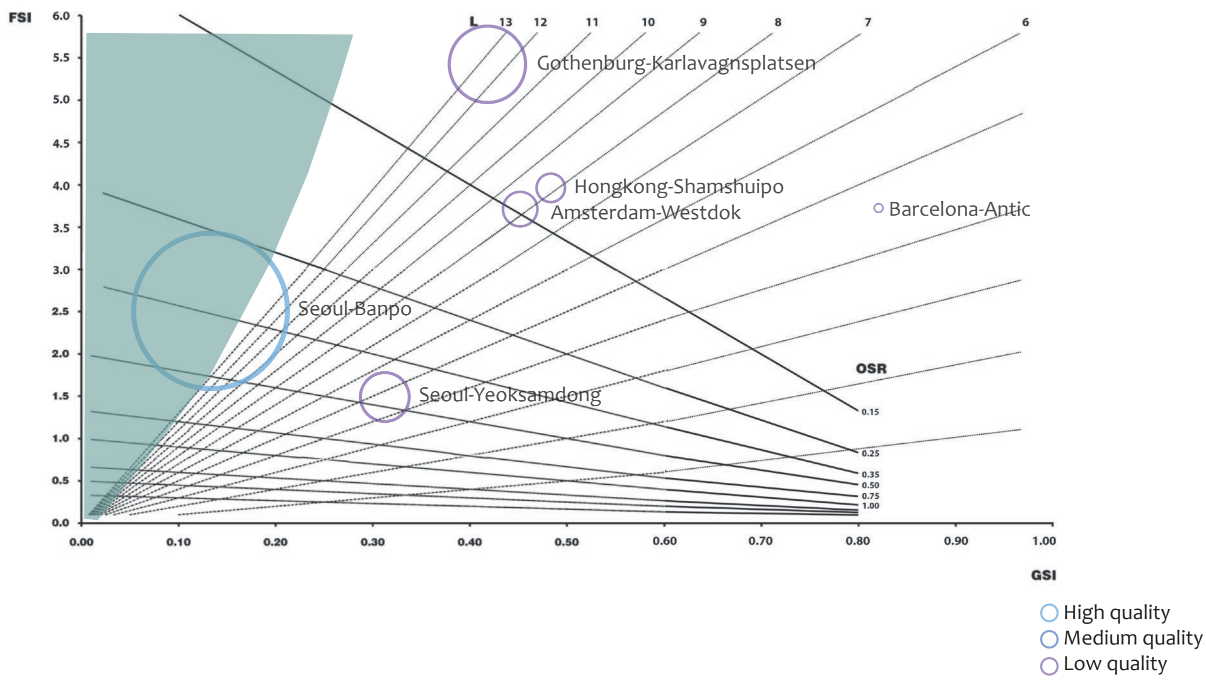


Figure 29. High performance of Greenness Index in Spacematrix

Relations between density and Sunshine Rate

Strong regressions with 5 density measures combinations for Sunshine Rate.

The combination of variables OSR and L is the most relevant one to Greenness Index, and Sunshine Rate = -0.204OSR+0.033L+0.416

	R^2	Function
FSI & GSI	0.490	0.090FSI-0.768GSI+0.725
FSI & OSR	0.176	0.140FSI+1.020OSR+0.011
FSI & L	0.665	0.023FSI+0.032L+0.310
GSI & OSR	0.584	-1.197GSI-1.235OSR+1.474
GSI & L	0.651	0.079GSI+0.034L+0.330
OSR & L	0.666	-0.204OSR+0.033L+0.416

Figure 30. Regressions and functions of density measures combinations with Sunshine Rate

The area in Spacematrix with high performance of Sunshine Rate are blocks with high stories. The three cases Seoul-Banpo, Gothenburg-Karlavagnsplasten and Amersterdam-Westdok get high quality performance and the other 3 cases get medium quality performance. The two cases Hongkong-Shamshuipo and Amsterdam-Westdok are with the same L 8.29, while Westdok has slightly lower FSI and GSI and this case gets much higher Sunshine Rate performance.

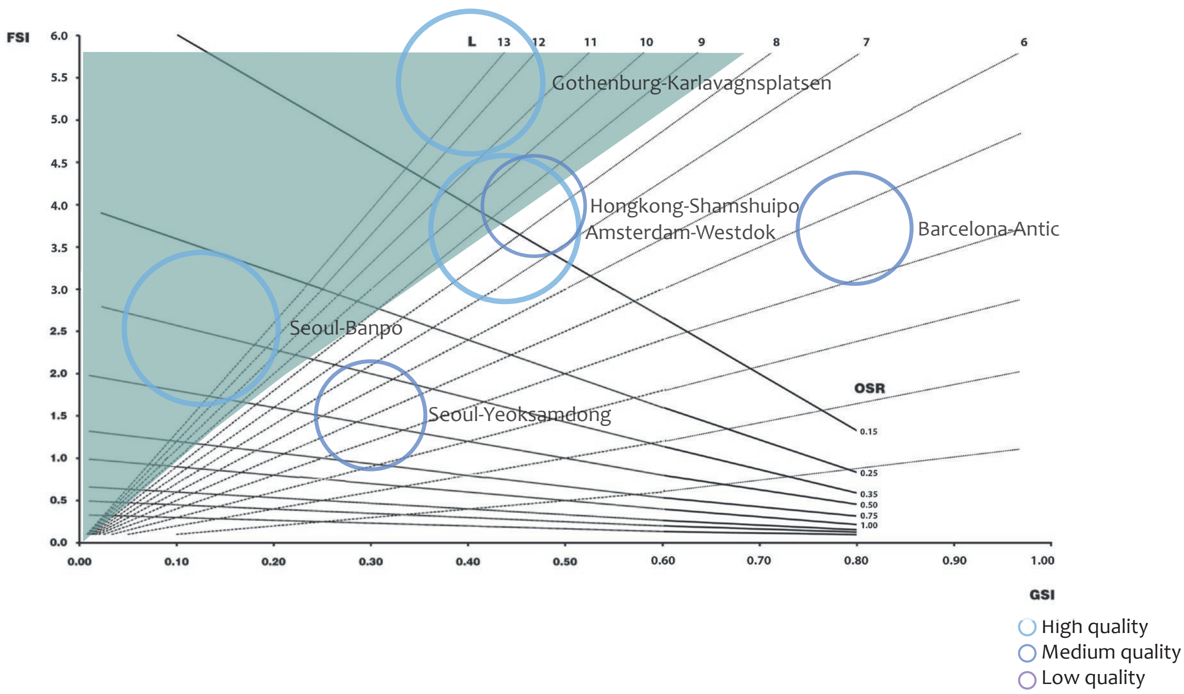


Figure 31. High performance of Sunshine Rate in Spacematrix

Relations between density and Street Wall Index

Strong regressions with all the density measures combinations for Street Wall Index. According to the functions, Street Wall Index has a positive relation with GSI and a negative relation L and OSR. If the block has more built areas, it will have higher Street Wall Index.

The combination of variables OSR and L is the most relevant one to Street Wall Index, and Street Wall Index = -0.886OSR-0.034L+1.236

	R^2	Function
FSI & GSI	0.782	-0.0001FSI+1.053GSI+0.261
FSI & OSR	0.586	-0.144FSI-2.143OSR+1.651
FSI & L	0.924	0.091FSI-0.041L+0.805
GSI & OSR	0.782	1.036GSI-0.031OSR+0.274
GSI & L	0.887	0.676GSI-0.021L+0.628
OSR & L	0.988	-0.886OSR-0.034L+1.236

Figure 32. Regressions and functions of density measures combinations with Street Wall Index

The area in Spacematrix with high performance of Street Wall Index is with a wide range. They are usually with lower OSR and not extreme high L. According to the diagram, the difference of FSI matters little for the performance of Street Wall Index, while GSI has a significant positive relation for it which means that block type is usually with high performance of Street Wall Index. The three block type cases Hongkong-Shamshuipo, Amsterdam-Westdok and Barcelona-Antic get high performance of it. The two dense point type Gothenburg-Karlavagnsplatsen and Seoul-Yeoksamdong get medium performance. The loose point, high rise block Seoul-Banpo gets low quality performance.

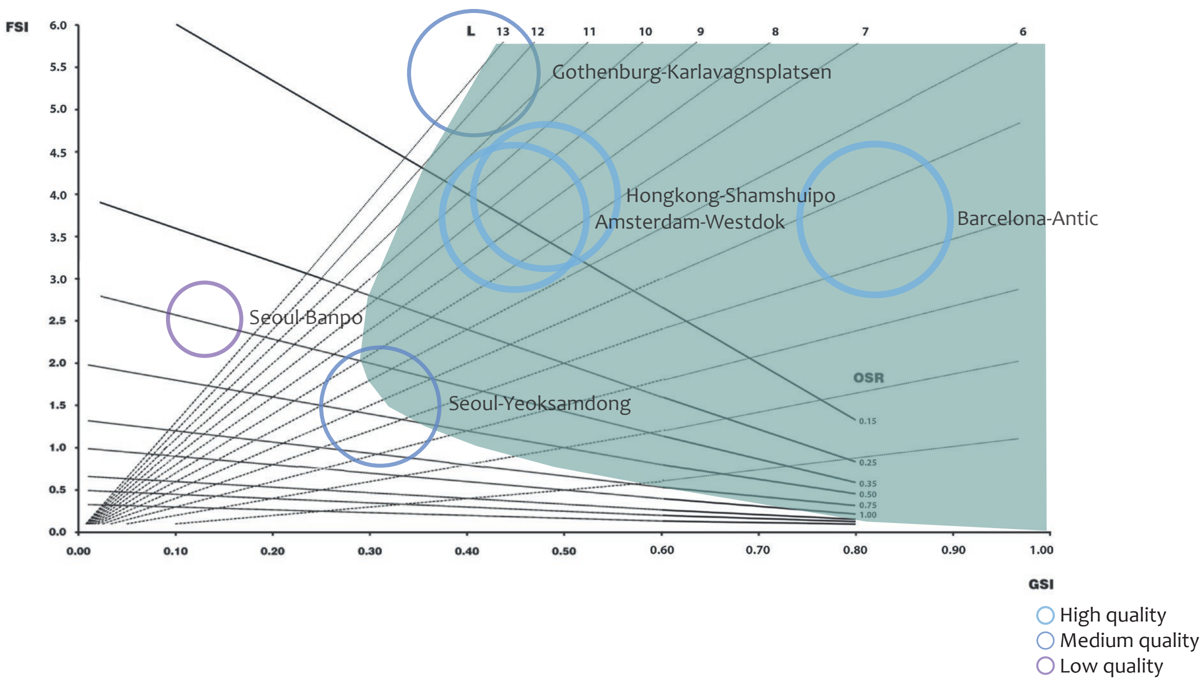


Figure 33. High performance of Street Wall Index in Spacematrix

Relations between density and Building Density

Strong regressions with all the density measures combinations for Building Density. According to the functions, Building Density has a positive relation with GSI and a negative relation with L. If a block has more built area with lower average storeys, it will have higher Building Density.

The combination of variables FSI and GSI are most relevant to Building Density, thus Building Density = -0.104FSI+1.616GSI-0.015

	R^2	Function
FSI & GSI	0.942	-0.104FSI+1.616GSI-0.015
FSI & OSR	0.605	-0.311FSI-3.152OSR+2.043
FSI & L	0.457	0.025FSI-0.039L+0.626
GSI & OSR	0.922	1.937GSI+1.096OSR-0.739
GSI & L	0.809	1.276GSI-0.005L-0.183
OSR & L	0.550	-0.701OSR-0.035L+0.816

Figure 34. Regressions and functions of density measures combinations with Building Density

The area in Spacematrix with high performance of Building Density is with high GSI and medium or low L. According to the diagram, the difference of FSI matters little for the performance of Building Density. The case Barcelona-Antic with extreme high GSI 0.82 and medium average storeys 4.55 is with high Building Density. All the other 5 cases are with low Building Density. Especially, the case Seoul-Banpo with low GSI 0.13 and high average stories 20.25 gets the lowest Building Density.

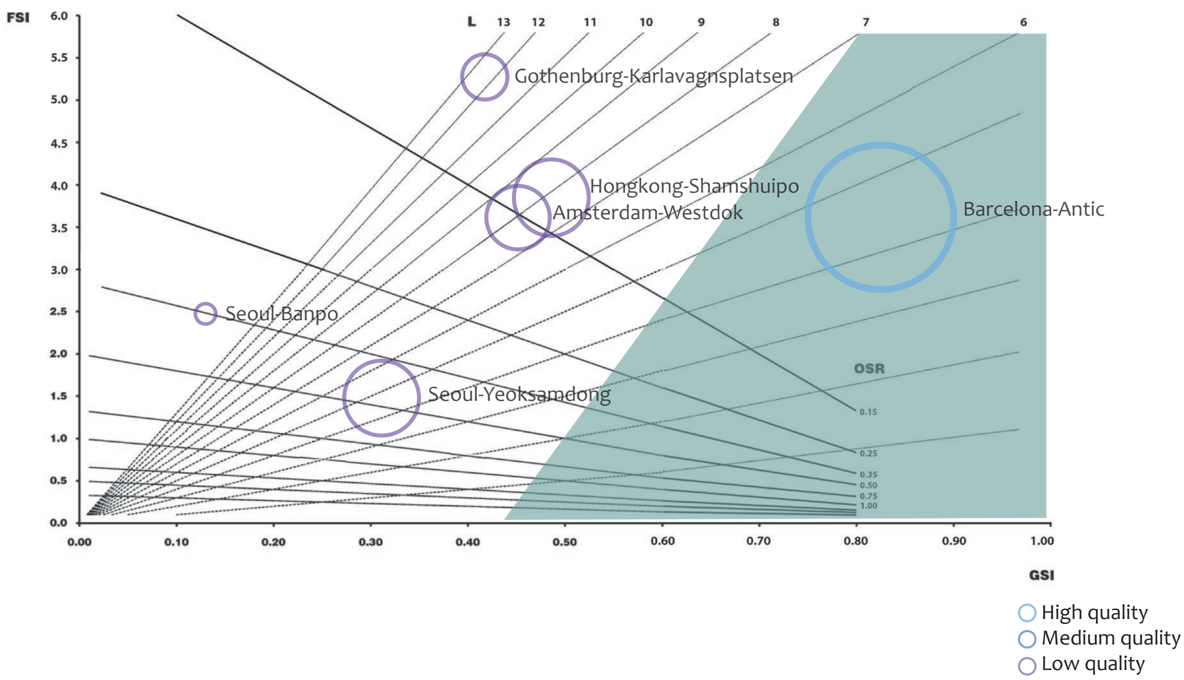


Figure 35. High performance of Building Density in Spacematrix

Relations between density and Network Density

Strong regressions with all the density measures combinations for Network Density. According to the functions, Network Density has a positive relation with GSI and a negative relation L and OSR. If the block has more built areas, it will have higher Network Density.

The combination of variables OSR and L are most relevant to Network Density, thus
Network Density = -1.32OSR-0.029L+1.295

	R^2	Function
FSI & GSI	0.792	0.065FSI+0.974GSI+0.093
FSI & OSR	0.676	-0.073FSI-2.041OSR+1.412
FSI & L	0.921	0.150FSI-0.039L+0.606
GSI & OSR	0.789	0.752GSI-0.727OSR+0.564
GSI & L	0.743	0.949GSI-0.010L+0.431
OSR & L	0.954	-1.320OSR-0.029L+1.295

Figure 36. Regressions and functions of density measures combinations with Network Density

The area in Spacematrix with high performance of Network Density is with a wide range. They usually have a strong and positive relation with GSI. The more compact building blocks get higher Network Density. The outcome is quite similar as Street Wall Index. It seems like the higher Network Density, the higher Street Wall Index. The case Seoul-Banpo with low GSI 0.13 gets the lowest Network Density, the case Seoul-Yeoksamdong gets medium Network Density and the other 4 get high Network Density.

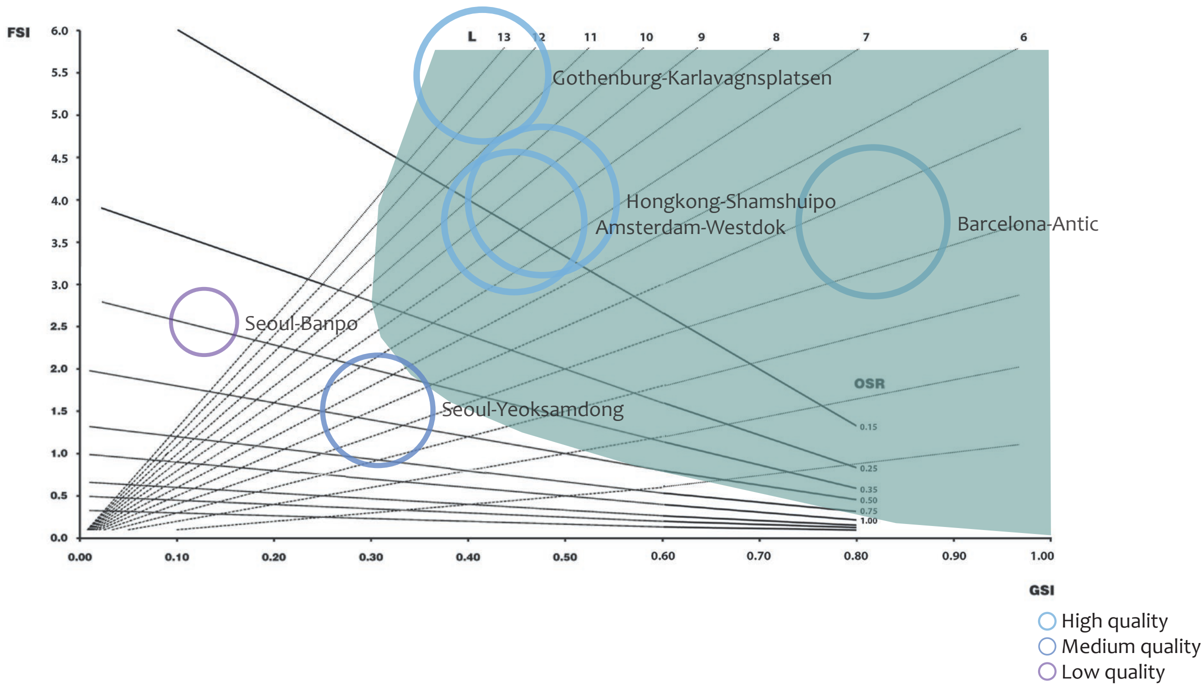


Figure 37. High performance of Network Density in Spacematrix

Relations between density and Openness

Strong regressions with all the density measures combinations for Openness. According to the functions, Openness has a negative relation with GSI. If the block has less built areas, it will be more Openness.

The combination of variables FSI and GSI are most relevant to Openness, thus Openness=0.054FSI-1.442GSI+1.185

	R^2	Function
FSI & GSI	0.911	0.054FSI-1.442GSI+1.185
FSI & OSR	0.689	0.260FSI+3.033OSR-0.774
FSI & L	0.397	-0.061FSI+0.032L+0.635
GSI & OSR	0.891	-1.543GSI-0.443OSR+1.506
GSI & L	0.879	-1.453GSI-0.008L+1.454
OSR & L	0.577	1.003OSR+0.026L+0.285

Figure 38. Regressions and functions of density measures combinations with Openness

The area in Spacematrix with high performance of Openness is with medium or low GSI. According to the diagram, FSI and L matter little for Openness.The more compact building blocks get lower Openness. The case Barcelona-Antic with high GSI 0.82 gets the lowest Openness, all the other 5 cases get high Openness performance.

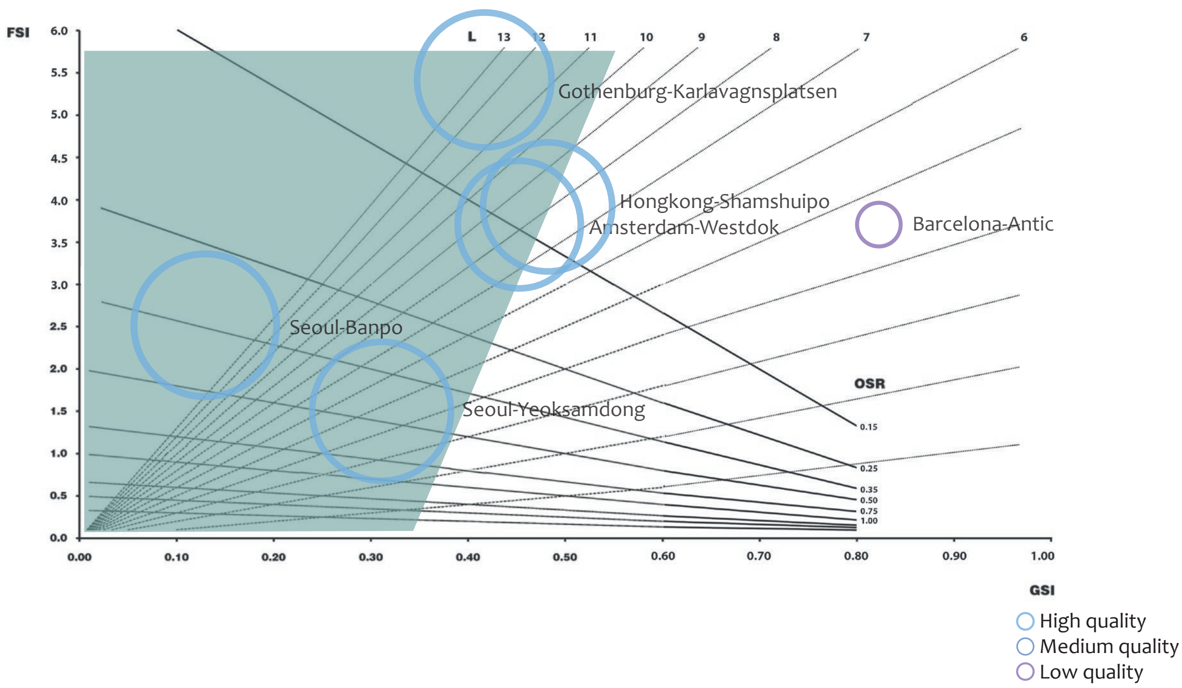


Figure 39 . High performance of Openness in Spacematrix

Research Part A

Conclusion 3

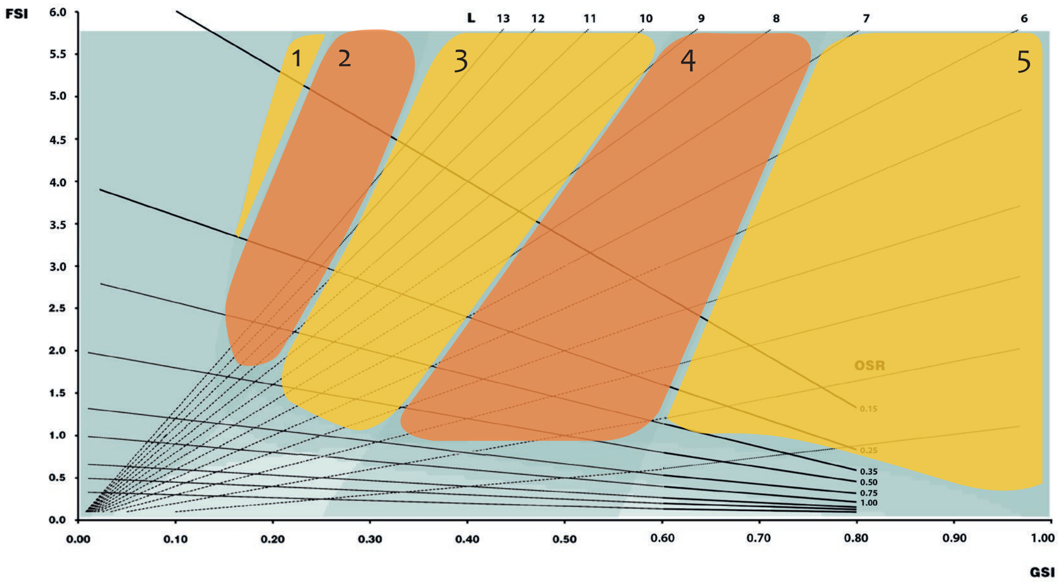
I will relate the qualities to the density figures by projecting them in the Spacematrix diagram, so we can find certain density figures with high quality performances.

Relations between density and quality performances

In order to find the area with least quantity of low quality performance, I calculated and overlapped areas with qualities above medium performance.

According to Figure 33, the two orange areas are with five qualities above medium performance. Area 2 is except Building Density, they are point type, high rise blocks. Area 4 is except Greenness Index, they are block type, low and medium rise blocks. The three yellow areas are with four qualities above medium performance.

Area 1 is except Street Wall Index and Building Density, they are point type, high rise blocks; Area 3 is except Building Density and Greenness Index, they are block type, medium and high rise blocks; Area 5 is except Openness and Greenness Index, they are block type, low and medium rise blocks.



Four qualities of medium and high level performance

Five qualities of medium and high level performance

1 4 qualities except Street Wall Index and Building Density

2 5 qualities except Building Density

3 4 qualities except Building Density and Greenness Index

4 5 qualities except Greenness Index

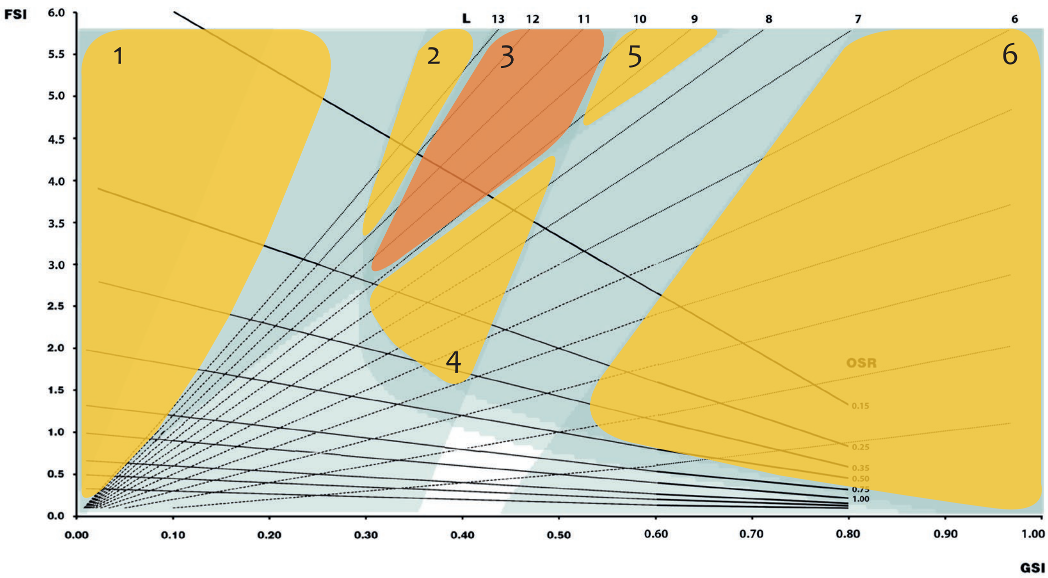
5 4 qualities except Openness and Greenness Index

Figure 40. Overlapping medium and high level quality performance areas in Spacematrix

I overlapped the six diagrams-qualities with high level performance showed before and there is an orange area with four qualities with high level performance and five yellow areas with three qualities with high level performance. (Figure 41)

Area 3 is with high level performance of Openness, Sunshine rate, Network Density and Street Wall Index. They are block type, high rise blocks. The case Amsterdam-Westdok locates in the area.

Area 1 is with high level performance of Openness, Greenness Index and Sunshine Rate, they are point type, high rise blocks. Based on Conclusion 1, it is Type 1 quality performance. The case Seoul-Banpo locates in the area.
Area 6 is with high level performance of Network Density, Street Wall Index and Building Density. They are block type, low and medium rise blocks. It is Type 3 quality performance according to Conclusion 1. The case Barcelona-Antic locates in the area.



Three qualities of high level performance

Four qualities of high level performance

1 High level performance of Openness, Greenness Index and Sunshine Rate

2 High level performance of Network Density, Openness and Sunshine Rate

3 High level performance of Network Density, Openness, Sunshine Rate and Street Wall Index

4 High level performance of Network Density, Openness and Street Wall Index

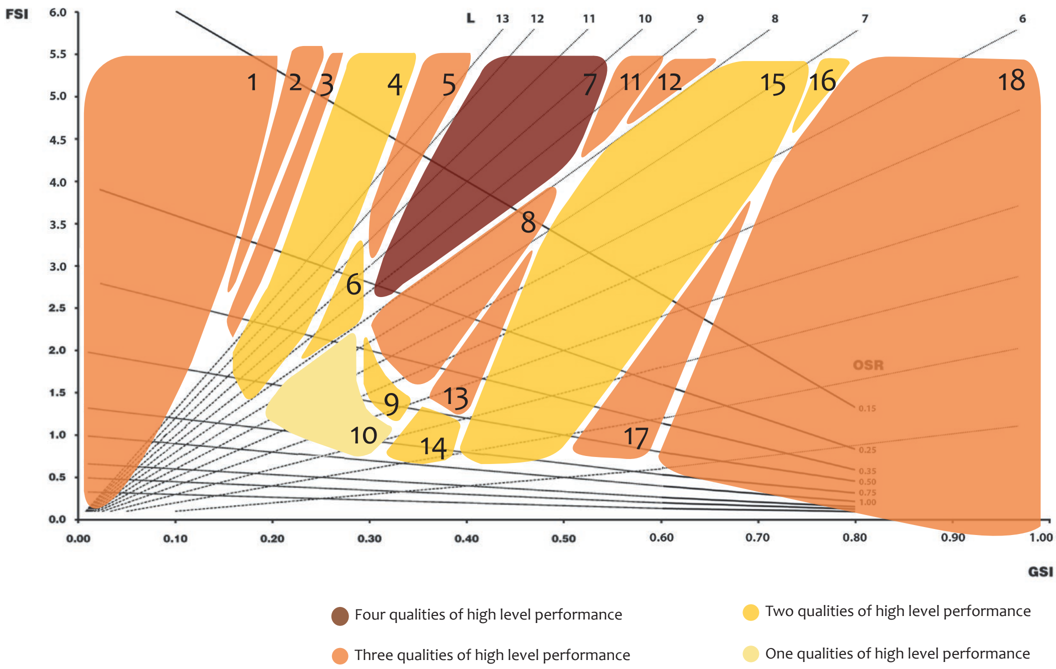
5 High level performance of Network Density, Sunshine Rate and Street Wall Index

6 High level performance of Network Density, Street Wall Index and Building Density

Figure 41. Overlapping high quality performance areas in Spacematrix

In order to build detailed relations with density and quality performance in Spacematrix, I overlapped Figure 40 and Figure 41.

As we can see from Figure 42, there are mainly 18 quality areas in Spacematrix except the blank area with low FSI.
From low GSI to high GSI, the quality performance varies from high level of Greenness Index, Sunshine Rate and Openness to high level of Building Density, Network Density and Street Wall Index. Area 3 is with only one low quality - Building Density, medium level of Network Density and Street Wall Index, high level of Greenness Index, Sunshine Rate and Openness; Area 7 is with four high quality performance - Sunshine Rate, Openness, Network Density and Street Wall Index; Area 15 is with 2 high level quality performance and 3 medium quality performance and one low quality performance.



	1	2	3	4	5	6	7	8	9
Greenness Index	High	High	High	Medium	Low	Low	Low	Low	Low
Sunshine Rate	High	High	High	High	High	High	High	Medium	Medium
Openness	High	High	High	High	High	High	High	High	High
Building Density	Low	Low	Low	Low	Low	Low	Low	Low	Low
Network Density	Low	Medium	Medium	Medium	High	Medium	High	High	Medium
Street Wall Index	Low	Low	Medium	Medium	Medium	Medium	High	High	High

	10	11	12	13	14	15	16	17	18
Greenness Index	Low	Low	Low	Low	Low	Low	Low	Low	Low
Sunshine Rate	Medium	High	High	Medium	Medium	Medium	Medium	Medium	Medium
Openness	High	Medium	Medium	High	High	Medium	Low	Medium	Low
Building Density	Low	Low	Medium	Medium	Medium	Medium	Medium	High	High
Network Density	Medium	High	High	High	Medium	High	High	High	High
Street Wall Index	Medium	High	High	High	High	High	High	High	High

Figure 42. Detailed qualities performance in Spacematrix

Research Part B

This is the second research part of the thesis. It aims at providing a strategy of finding potential blocks to densify in Gothenburg using Space Syntax methodology.
It also contributes to the design phase by deciding location and having a general understanding of the blocks with similar streets centrality in the whole city.
Space Syntax was first set out by Bill Hillier in the early 1980s. In Hillier(2007)'s theory, how parts are put together as a whole is more important than any component itself and it is about relations taking other relations into account. It helps us to understand the gap between unmatched streets centrality and building density by analyzing street network and building density as a whole system.

Process

STEP 1

High Centrality

STEP 2

Low Density Blocks

STEP 3

Low density blocks with high centrality streets

analysis

STEP 4

Blocks which have potential to densify

At Step 1, two methods are used within space syntax which are integration and betweenness by various steps and walking distance. The analysis shows the centrality of roads.

For Step 2, accessible building density is used for doing building density analysis.

At Step 3, the previous 2 steps are combined in order to find out the low density blocks with high centrality roads.

For Step 4, the selected blocks in Step 3 are analyzed , using the selection method again and show the maps of potential blocks to density in Gothenburg. In the coming design proposal part, one of them will be chosed to show how to densify it with high qualities.

Terminology

Integration

Integration (or closeness centrality) is a measure of centrality in space syntax (Hillier and Hanson, 1984). It captures how accessible one place is to all the other place in the system. In the analysis, it is how many steps[1] are needed from one point to another point within certain radius(Sun,2016). Using integration, spaces are ranked from the most integrated to the most segregated.

Betweenness

In contrast with integration, betweenness(or chioce) measures another aspect of centrality (Hillier and Iida, 2005). Choice measures movement flows through spaces. Spaces that record high global choice are located on the shortest paths from all origins to all destinations. (Space Syntax Methodology, UCL). Streets with high betweennes value are more often passed by from one segment to another.

Axial map

Axial map is colloquially defined as the least amount of straight lines that cover all accessible urban space shaped by built form, where each straight line (axial line) represents an urban space that is possible to visually overlook and directly access(Stavroulaki et al., 2017). It is used for integration analysis.

Segment map

Segment map is composed of segment lines that are cut at all intersections. In other words, the axial lines are broken into street segments at all intersection (except where we have unlinks). With this map, one typically does network betweenness centrality (or choice) analysis in space syntax.

---

1 In space syntax, the distance is measured as topological distance. This is different from Euclidean distance. Stpes mean how many turns it needs moving from one axial line to the destination.

Tool and Data

For the selection of potential blocks, QGIS software and PST[1] are used to do spatial syntax analysis: integration and betweenness within various steps and walking distance; accessible building density analysis used for building density analysis.

The data of axial map,segment map and building density map used for analysis are from Spatial Morphology studio.

All statistical analysis is done in Microsoft Excel and QGIS.

1 A plug-in analysis tool in GIS software MapInfo. It can also be installed in QGIS.

Selection of neighborhood scale centers

Selection Criteria

At local scale, Integration R4 and Betweenness 500m are used to analyse the neighborhood scale centers. For integration, it measures how many steps one axial line needs to take to reach all the other lines in the map. 2 steps, 4 steps and 6 steps usually represent the local scale. The results are divided by natural break[1] into 5 groups – low, medium low, medium, medium high and high. In order to find the neigbourhood scale center, the map in the next page only shows the high level of integration streets.

Integration R4

Low	0.35-0.96
Medium low	0.96-1.27
Medium	1.27-1.57
Medium high	1.57-1.93
High	1.93-3.22

Betweenness describes how often a segment is been passed between all segments within a certain radius. 500m walking distance is chosen to do the neighborhood betweenness analysis. The results are divided by natural break into 4 groups, low, medium low, medium high and high. As explained above, the map in the next page only shows the high level of betweenness streets.

Betweenness 500m

Low	0-412
Medium low	412-1171
Medium high	1171-2509
High	2509-9199

For building density, it is measured though the network in a distance of 500m.The data is got from Spatial Morphology studio. The results are divided by natural break into 5 groups – low, medium low, medium, medium high and high. The map in the next page only shows the low, medium low and medium level of the results.

Accessible building density

Low	0.00-0.08
Medium low	0.08-0.27
Medium	0.27-0.72
Medium high	0.72-2.59
High	2.59-8.91

1 A classification method, dividing data into groups by clusters

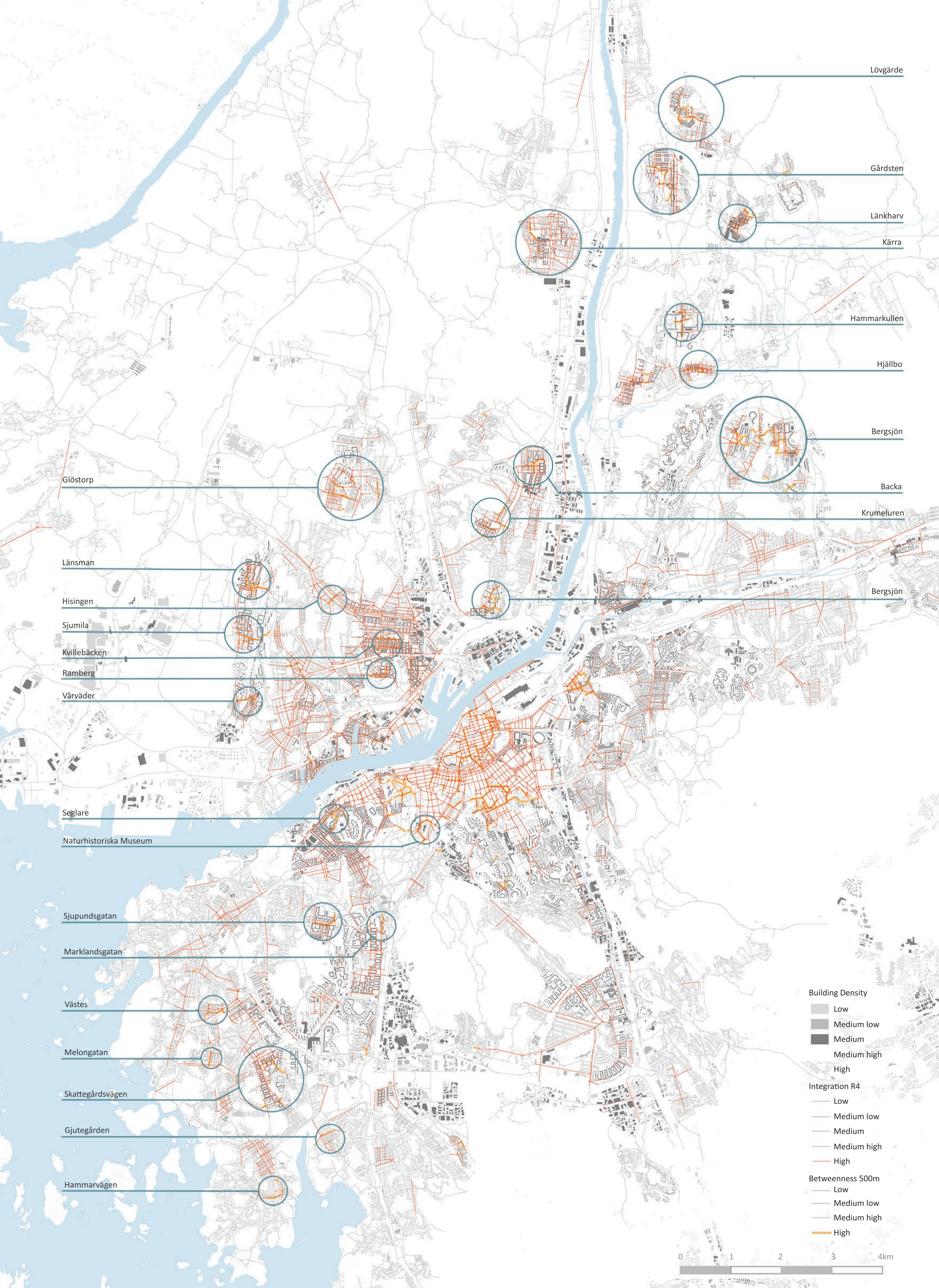


Figure 43. Neighborhood scale centers

Info of selected neighborhood scale centers

Lövgärde

The blocks locate at the end of main road and connects villa areas .It has 3stories and 9 stories apartments, 3 schools and a grocery shop.

Gårdsten

The blocks are surrounding by circle roads.
There are mixed type of 3 and 9 stories apartments with 3 schools and a grocery shop.

Länkharv

It is block buildings and 4 stories apartments

Kärra

They are 4 stories apartments with one school , a grocery shop and playground.

Hammerkullen

There are huge blocks with 8 stories apartments , schools, a gym and grocery stores.

Hjällbo

There are 4 stories apartments a school and a grocery store.

Bergsjön

There are mixed type of apartments with several schools and grocery stores.

Backa

There are 4 stories apartments

Krumeluren

There are 3 stories apartments with 2 schools , a gym and outdoor playground

Glöstorp

There are 4 stories apartments and villas with 3 schools, a sporthall and outdoor playground.

Kvillebäcken

There are 4 stories apartments and villas area with a hospital, a grocery store and outdoor playground.

Skattegårdsvägen

There are 3 and 4 stories apartments with a hospital, a few shops and outdoor playground.

Findings for neighborhood scale centers

There are 26 selected neighbourhood scale centers and there are common characters among them.
All of them are residential areas and most of them are the million program projects. The stories are usually varied from 3 to 9.
They have denser road network than their surroundings, to be more specific, they are either surrounded by green areas or villa areas, and some of them are also near apartments area with less denser road network.
For the building type within the selected blocks, most of them are block buildings and strip buildings. Only for Gård-sten area there are high-rise point buildings.
For the infrastructures, almost all of them have grocery stores and schools. Some of them have gyms and outdoor playground. Only two of them have hospitals, which are kvil-lebäcken and the area near Skattegårdsvägen.

Selection of meso scale centers

Selection Criteria

At meso scale, Integration R16 and Betweenness 2000m are used to analyse the meso center. For different city scales, the steps and radius used for meso center are different which means that 16 steps and 2000m do not always represent meso scale. It depends on the size of the city. But for neighborhood scale, 4 steps and 500m are useful for any scale of cities.
For integration R16 analysis, the results are divided by natural break into 5 groups – low, medium low, medium, medium high and high. The map in the next page only shows the high level of integration streets.

For betweenness 2000m analysis, the results are divided by natural break into 4 groups, low, medium low, medium high and high. As explained above, the map in the next page only shows the high level of betweenness streets.

For building density, it is the same for the 3 scales.

Integration R16

Low	0.23-0.52
Medium low	0.52-0.63
Medium	0.63-0.73
Medium high	0.73-0.83
High	0.83-1.06

Betweenness 2000m

Low	0-22832
Medium low	22832-74380
Medium high	74380-173108
High	173108-474640

Accessible building density

Low	0.00-0.08
Medium low	0.08-0.27
Medium	0.27-0.72
Medium high	0.72-2.59
High	2.59-8.91

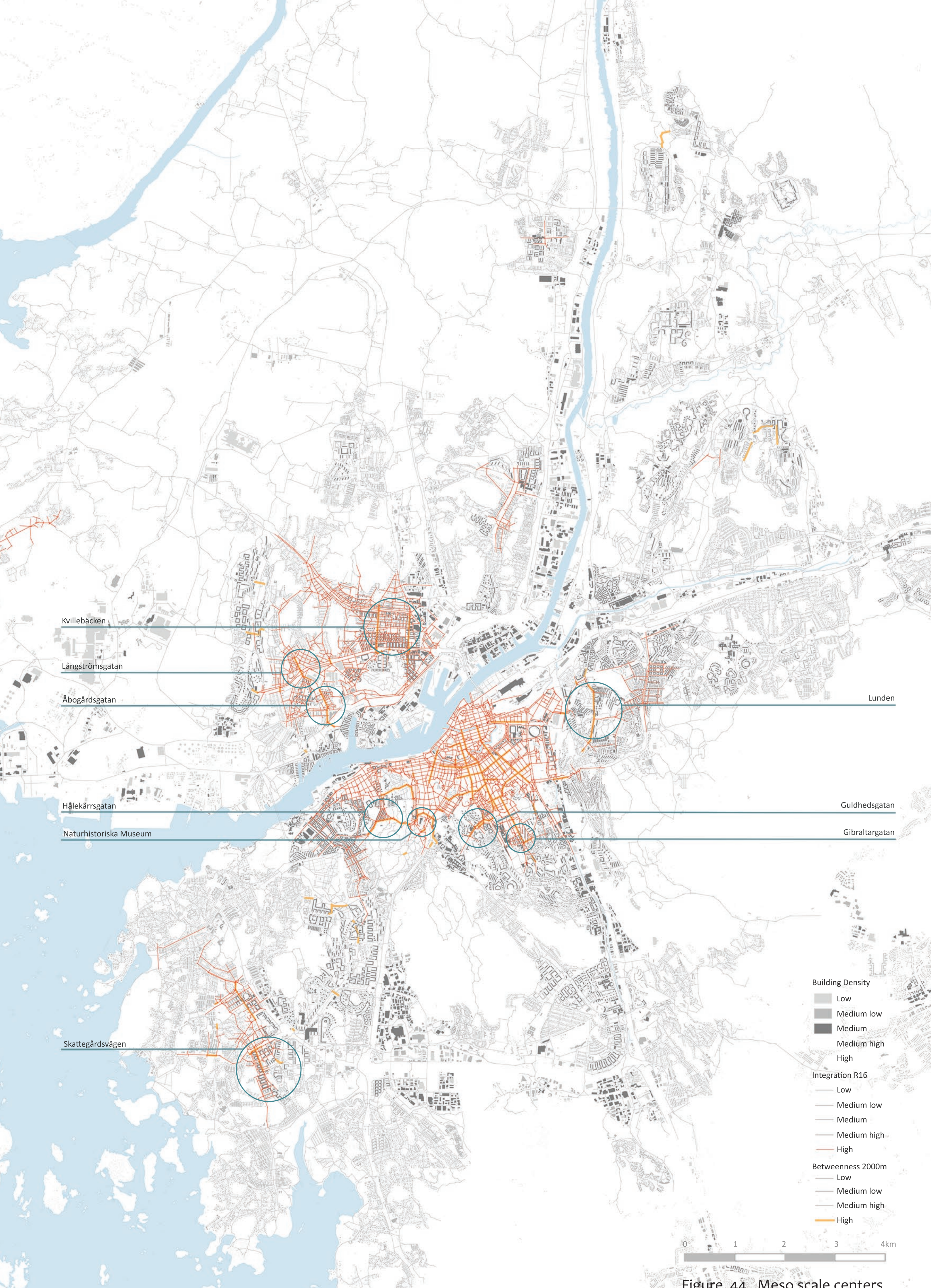


Figure 44. Meso scale centers

Info of selected meso scale centers

Kvillebäcken

There are 4 stories apartments and villas area with a hospital, a grocery store and outdoor playground.

Långströmsgatan

There are villas in the east side of the area with 3 apartments buildings. In the west part of it, there are 4 stories apartments villas and a traffic school.

Åbogårdsgatan

There are 3 and 4stories apartments, villas, a church and a huge shopping block building within the area.

Lunden

It is a residential area with 4 to 9 stories apartments with active frontage.There are large grave area.

Hålekärrsgatan

There are 3 stories apartments with a playground

Naturhistoriska Museum

It is a natural history museum.

Guldhedsgatan

It is a residential area with 4 stories and 7 stories apartments.

Gibraltargatan

There are 4 to 6 stories apartments with active frontage.

Skattegårdsvägen

There are 3 and 4 stories apartments with a hospital, a few shops and outdoor playground.

Findings for meso scale centers

There are 9 selected meso scale centers. 5 (Hålekärrsgata , Naturhistoriska Museum, Lunden, Guldhedsgata, Gibraltargata) of them are located at the frame of the city center of Gothenburg. It is because the streets still remain high centrality but the building density already deceased.
3 (Kvillebäcke, Långströmsgatan, Åbogårdsgatan) of them have large villa areas along high betweenness roads and they are all at north part of Göta River.
8 of them are physically close in the map, only the area near skattegårdsvägen are isolated.
There is a diversity of building types and functions in the selected areas. They are point low-rise villas; point high-rise apartments; middle-rise strip apartments with or without active frontage; huge footprint shopping mall, natural museum and hospital buildings.

Selection of city scale centers

Selection Criteria

At city scale, Integration R30 and Betweenness 5000m are used to analyse the city scale centers. For different city scales, the steps and radius used for city center are different, which means that 30 steps and 5000m are not always represent city scale. It depends on the size of the city. The method to find out which steps and distance can represent city scale is to test, which means that if adding the steps and distance, there is not much difference of the analysis results between them, then the city scale can be represent by the fewer steps and distance,
For integration R30 analysis, the results are divided by natural break into 5 groups – low, medium low, medium, medium high and high. The map in the next page only shows the high level of integration streets.

For betweenness 5000m analysis, the results are divided by natural break into 4 groups, low, medium low, medium high and high. As explained above, the map in the next page only shows the high level of betweenness streets.

For building density, it is the same for the 3 scales.

Integration R30

Low	0.20-0.37
Medium low	0.37-0.43
Medium	0.43-0.48
Medium high	0.48-0.53
High	0.53-0.61

Betweenness 5000m

Low	0-331530
Medium low	331530-1135718
Medium high	1135718-2679260
High	2679260-6904151

Accessible building density

Low	0.00-0.08
Medium low	0.08-0.27
Medium	0.27-0.72
Medium high	0.72-2.59
High	2.59-8.91

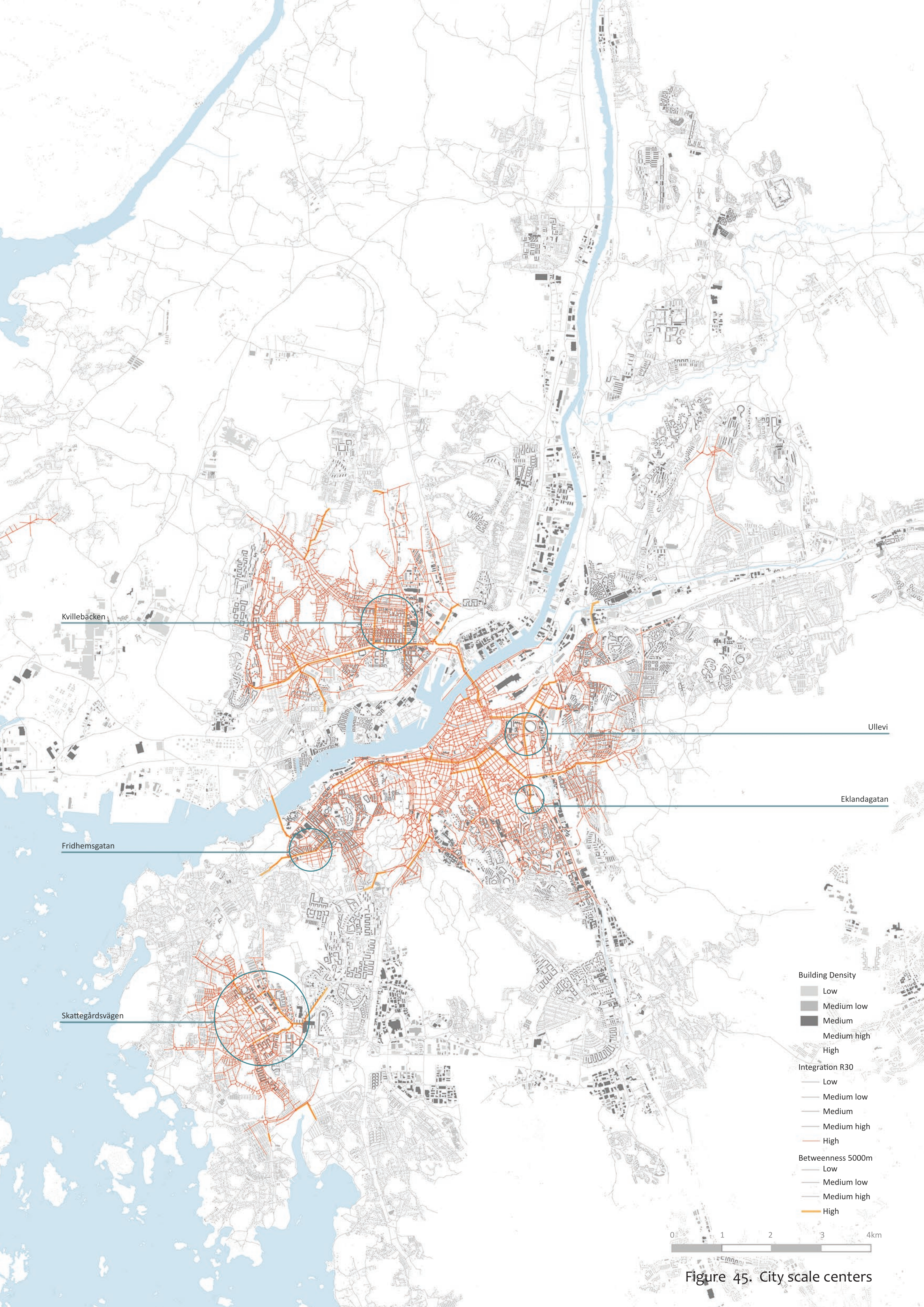


Figure 45. City scale centers

Info of selected city scale centers

Kvillebäcken

There are 4 stories apartments and villas area with a hospital, a grocery store and outdoor playground.

Ullev

There are 2 stadiums with in the area and a lot of high-rise office buildings.

Eklandagatan

There are 5 and 6 stories apartments with active frontage.

Fridhemsgatan

There are 5 and 6 stories apartments withstores and factories.

Skattegårdsvägen

There are 3 and 4 stories apartments and villas with a hospital, schools, a few shops and outdoor playground.

Findings for city scale centers

There are 5 selected city scale centers.
For the area Ullev, it is the 2 stadiums that make it a medium density area. The dense office buildings correspond to the high centrality roads.
For the area near Eklandagatan, it connects Korsvägen which is one of the traffic centers in Gothenburg.
For the area near Fridhemsgatan, it is near the high way which connects north part of Gothenburg.
For Kvillebäcken and the area near Skattegårdsvägen, they are already selected at both neighborhood and meso scale.

Research Part B

Conclusion

This part shows areas which have potential to densify.

Kvillebäcken

There are 4 stories apartments and villas area with a hospital, a grocery store and outdoor playground.

Skattegårdsvägen

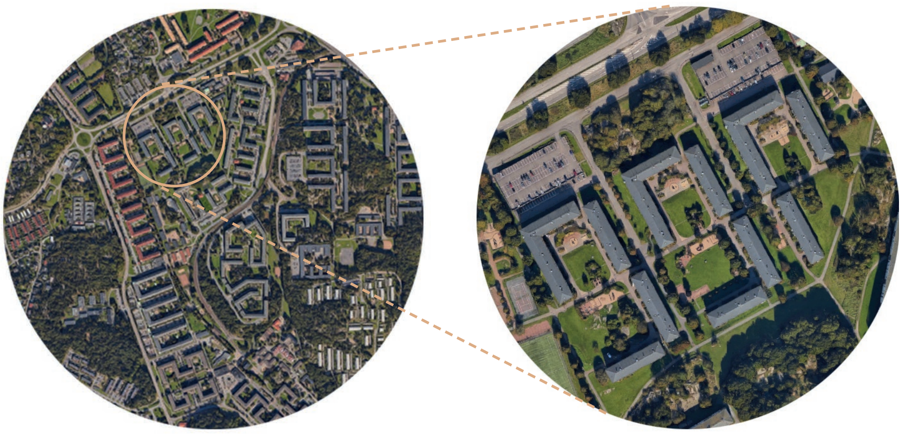
There are 3 and 4 stories apartments with a hospital, schools, a few shops and outdoor playground.

After the space syntax analysis, there are 2 areas shown up among all the 3 different scales. They are Kvillebäcken and the area near Skattegårdsvägen.
Both are near main roads of the city and have dense road network inside and outside them.

At the proposal part, one area will be chosen to densify and improve qualities.

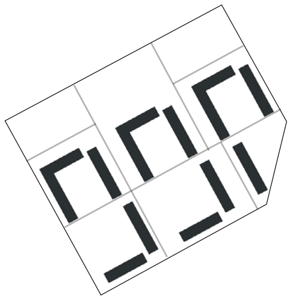
III . Proposal

Site Information



Skattegårdsvägen

Proposal Site



Plan 1:20000

Area: 60303 m^2

FSI: 0.70

GSI: 0.17

OSR: 1.19

L: 4.12

Figure 46. Plan of site

At the proposal part, a block is selected from the area near skattegårgsvägen as the densifying site. The area is around six hectares and there are two parking lots located at northwest of the site. It is with low Floor Space Index 0.7 and low Ground Space Index 0.17. Open Space Ratio is 1.19, which means that if we assume that every 100 square meters' floor area can be regarded as one apartment, it gets 119 square meters' outdoor space. The area is quite spacious. The average stories are around four and it is medium rise blocks.

Quality Performances

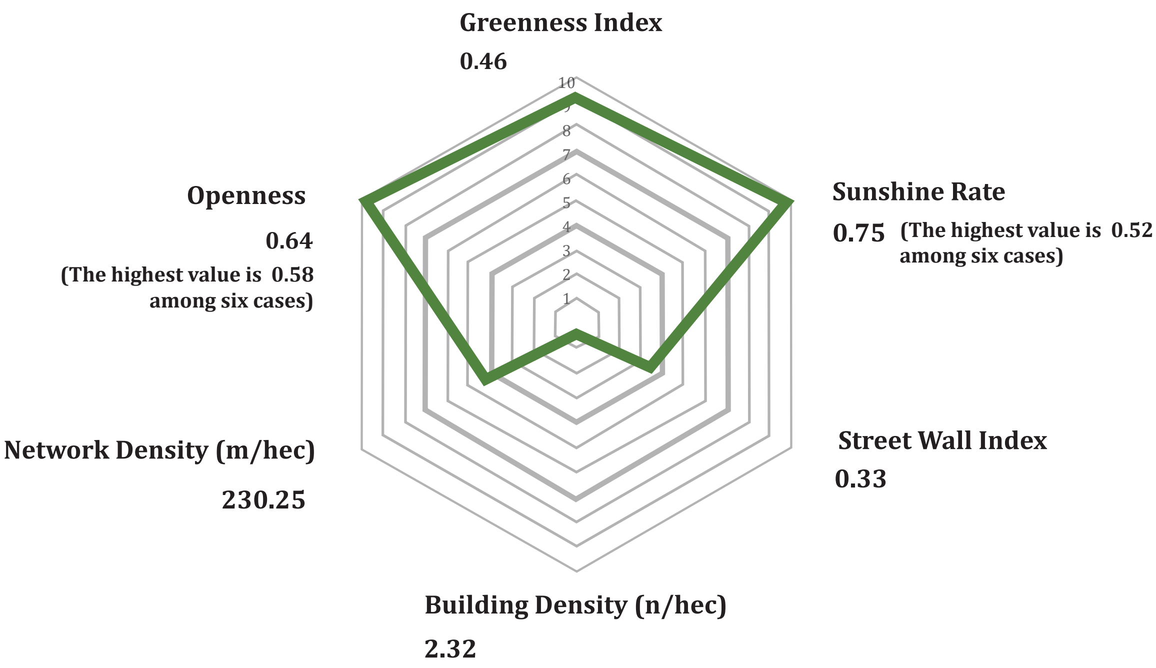
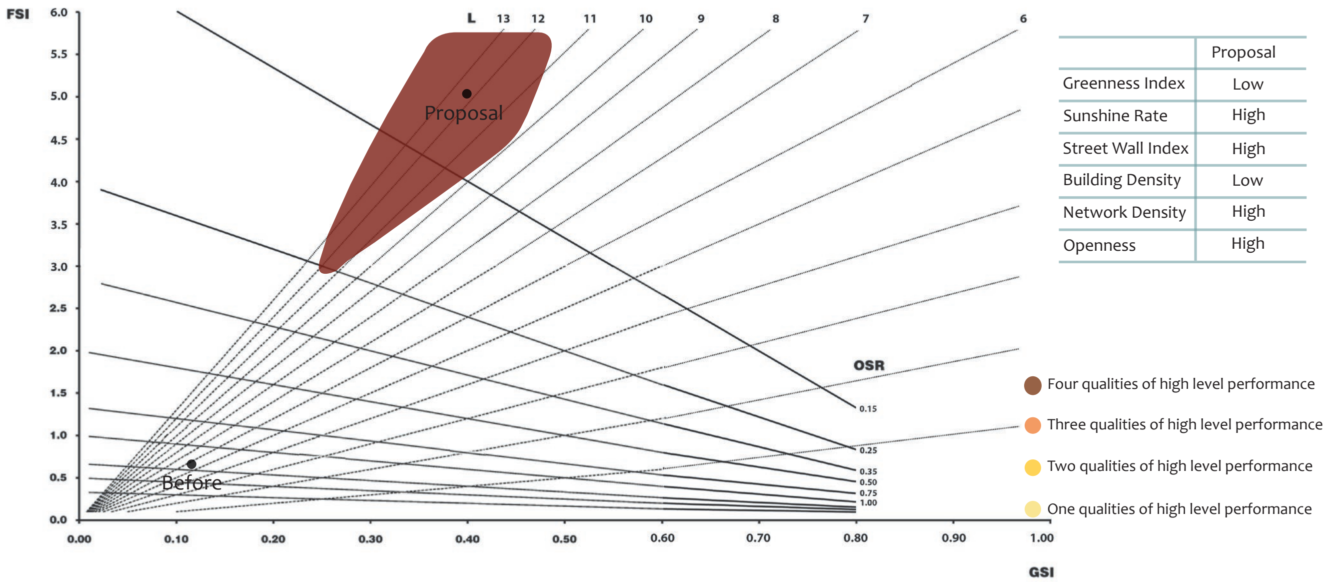


Figure 47. Qualities performances of original site

The diagram (Figure 47) is the quality performances of the original site. It has high quality performances of Greenness Index, Sunshine Rate and Openness; medium performance of Network Density; low performance of Street Wall Index and Building Density. It is similar to Type 1 GREEN quality performance.

Proposal



	Proposal
Greenness Index	Low
Sunshine Rate	High
Street Wall Index	High
Building Density	Low
Network Density	High
Openness	High

Figure 48. Qualities performances of selected density in Spacematrix

Based on the findings of Research Part A , I decide to choose one location in Spacematrix diagram with the most quantity of and the data of four density measures are the input of the proposal. Proposal is with FSI 5.0 and GSI 0.45 and it has the most quantity of high level quality performance which are Sunshine Rate, Street Wall Index, Network Density and Openness.

Quality Performances Prediction

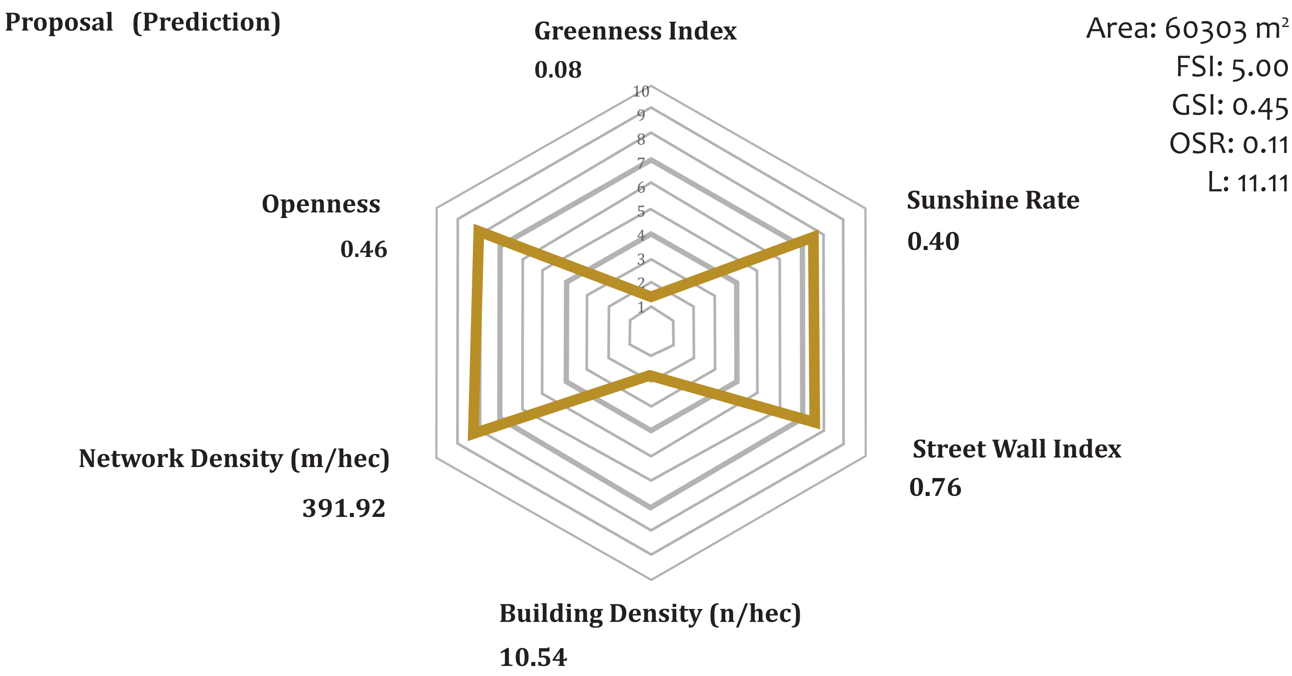
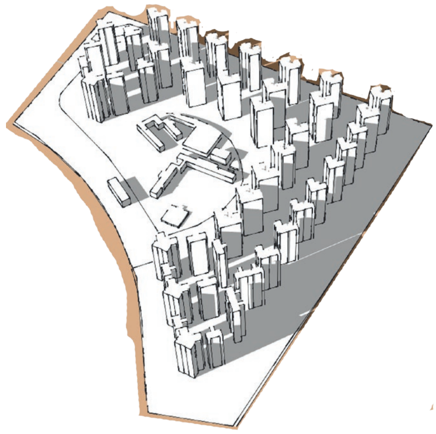


Figure 49. Predicted qualities performances of Proposal

The following diagram (Figure 49) is the predicted quality performances of Proposal based on the findings of relations between density and quality from Research Part A.
As we can see from it, with FSI 5.0 and GSI 0.45, the blocks usually have low quality performance of Greenness Index and Building Density, so I intend to improve the two qualities before designing.

Reflection of Greenness Index



Seoul-Banpo

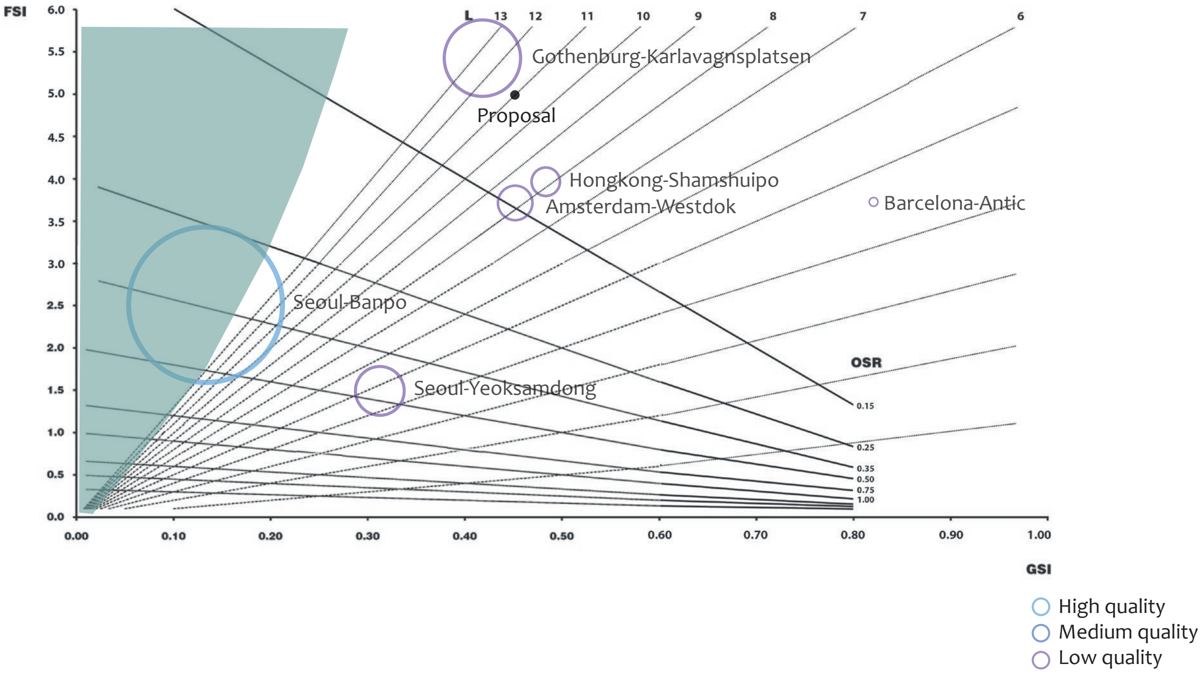
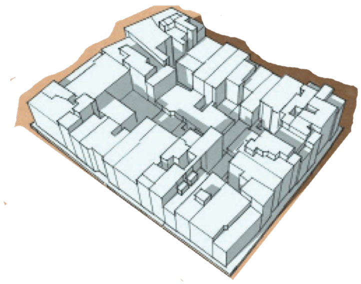


Figure 50. High performance of Greenness Index in Spacematrix

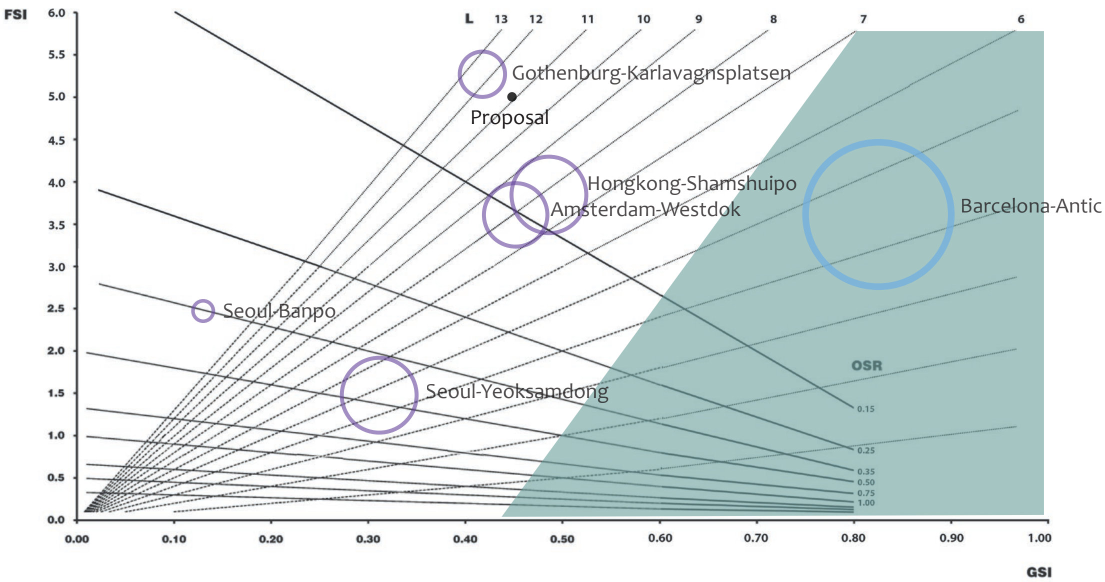
The area in Spacematrix with high Greenness Index is with high FSI and low GSI. They are usually hybrid point type, high rise blocks. Thus, the case Seoul-Banpo with FSI 2.53 and GSI 0.13 gets high quality of Greenness Index and the other 5 cases get low quality performance.

The proposal is with Ground Space Index 0.45 and there would not be as much unbuilt land as case Seoul-Banpo. So instead of only planting on the unbuilt land, I find three alternative methods green courtyard, green roof and green balcony for improving Greenness Index.

Reflection of Building Density



Barcelona-Antic



High quality
Medium quality
Low quality

Figure 51. High performance of Building Density in Spacematrix

The area in Spacematrix with high Building Density is with high GSI and low L. According to the diagram, the difference of FSI matters little for the performance of Building Density. The case Barcelona-Antic with extreme high GSI 0.82 and medium average storeys 4.55 is with high Building Density.

In order to improve the building density, while designing, the method from case Barcelona-Antic small frontages is used.

Proposal (Design)

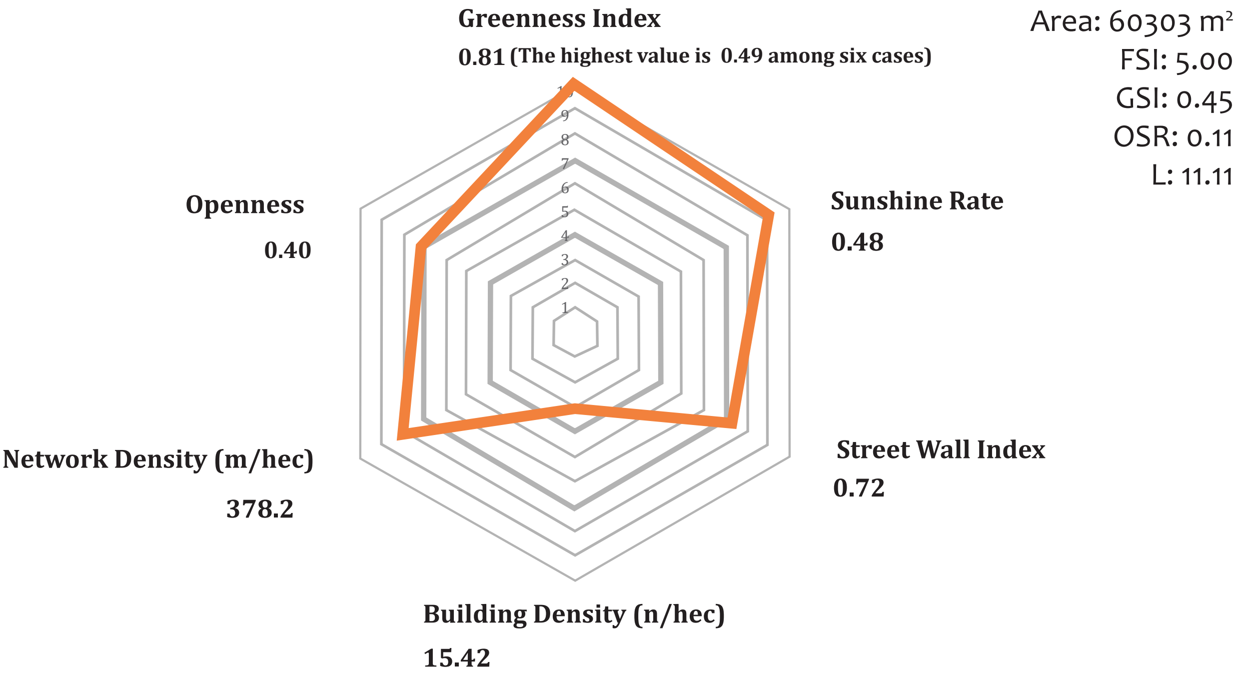


Figure 52. Qualities performances of Proposal

The proposal is with five high quality performances and they are Greenness Index, Sunshine Rate, Street Wall Index, Network Density and Openness. Greenness Index is improved from 0.08 to 0.81 and it is the highest among the six cases. Building Density is improved from 10.54 n/hec to 15.42 n/hec.

In the proposal, green courtyard, green roof and green balcony are applied and they work well for improving Greenness Index. Smaller buildings are also applied into the proposal and it works a little.

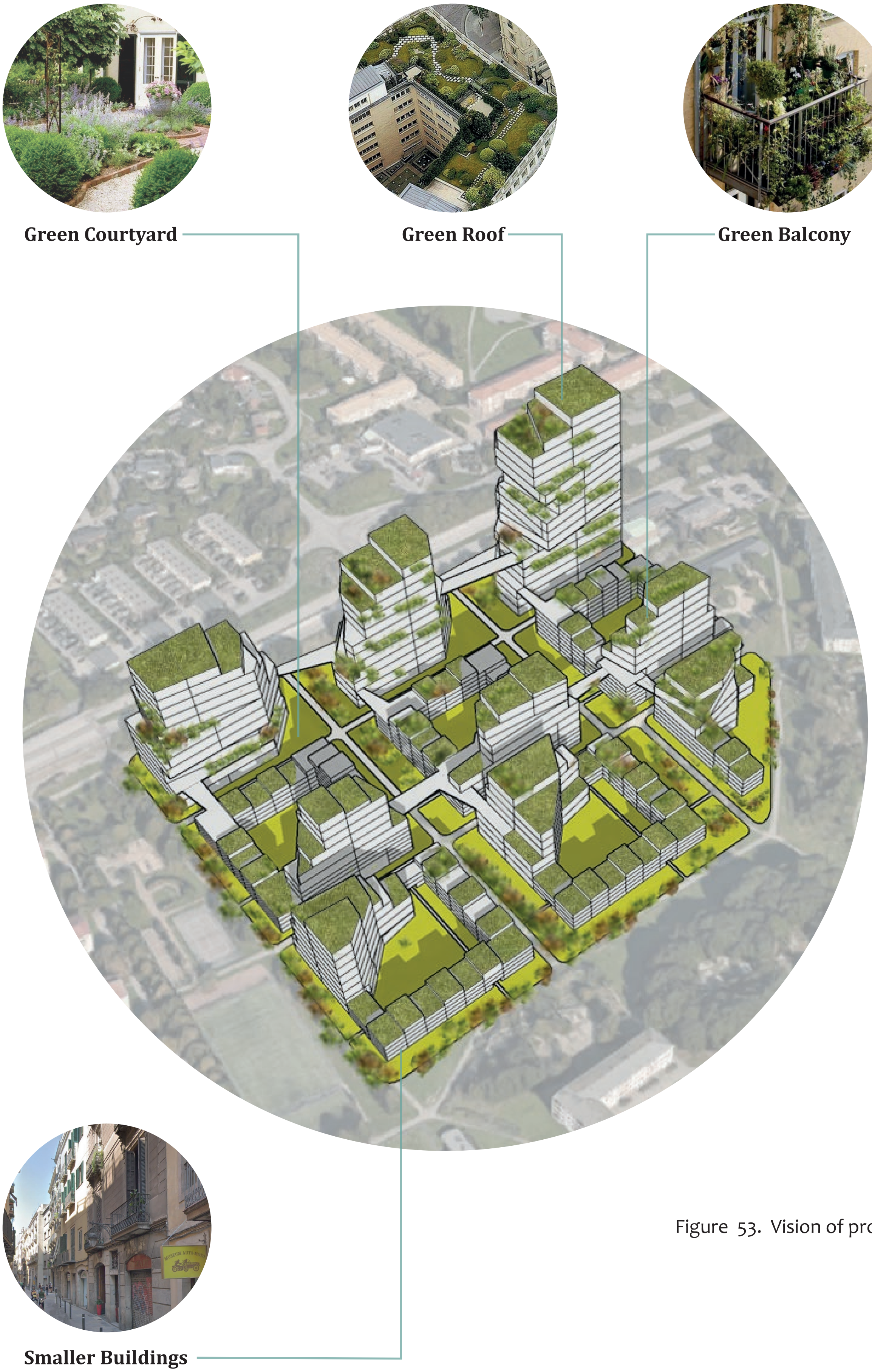


Figure 53. Vision of proposal

Inspiration images come from Pinterest

IV. Discussion

Conclusions

Earlier studies showed that density plays an important role in quality performances and many researchers proposed limitation for density as a solution to certain problems in overcrowded cities.

By analysing both density and quality in six cases, the thesis found the relations between density and qualities and arrived at a better understanding of how different density measures influence different quality performance.

Besides, the thesis also offered a strategy to find blocks with potential to densify using Space Syntax methodology. The thesis concluded three types of quality performances among cases:

Type 1 GREEN:

the type has high quality of Greenness Index, Sunshine Rate and Openness; low quality of Street Wall Index, Building Density and Network Density;

Type 2 URBAN:

the type has high or medium quality of Sunshine Rate, Street Wall Index, Network Density and Openness; low quality of Greenness Index and building density;

Type 3 URBAN PLUS:

the type has high quality of Street Wall Index, Building Density and Network Density, low and medium quality of Openness and Sunshine Rate.

From Type 1 to Type 3, high quality performances move from Greenness index, Sunshine Rate and Openness to Street Wall Index, Building Density and Network Density.
The thesis also found that blocks with certain density would have better quality performances than others by statistical analysis. The results and predictions are highly depending on the 6 cases.
For the quality Greenness Index, hybrid point type, high rise blocks with high Floor Space Index and low Ground Space Index get high quality performance;
For the quality Sunshine Rate, blocks with high storeys get high quality performance;
For the quality Street Wall Index, compact blocks (lower Open Space Ratio and not extreme high average storeys) get high quality performance;
For the quality Building Density, blocks with high Ground Space Index and medium or low storeys get high quality performance;
For the quality Network Density, compact blocks get high quality performance;
For the quality Openness, blocks with medium or low Ground Space Index get high quality performance.
There is an area in Spacematrix diagram with the most quantity of high level performance of qualities and the qualities are Openness, Sunshine rate, Network Density and Street Wall Index. They are with FSI 3.0-5.8 and GSI 0.3-0.55. They are block type, high rise blocks.
In the design phase, it is started with certain density which are predicted with higher quality performance based on the studies and the results from statistical analysis. With the prediction, the qualities with low level performance could be paid attention before designing instead of adjusting after design has already being made.

Reflections

These reflections are made with the research process as a basis for the discussion. In the beginning of the thesis, I tried to categorize types of urban blocks based on the literature of Uytenhaak (2009) and chose cases to represent each type. In the end, I found ten types and ten cases (see p.20-21). There is not a well-agreed definition of how many types of blocks are in the world and what they are. Thus, the types are not limited to the ten I found. Six cases were chosen to do further analysis because of easy access to the data from SMoS group and Spatial Morphology studio. The other four cases have almost the equal research value, but I have to exclude them in order to manage the thesis within several months.

For the quality definition and selection part, I struggled to classify them. Which qualities should the thesis focus on? In order to make the selection less subjective, I found a paper from Serag El Din et al. (2013) where they classified urban qualities into seven dimensions: environmental, physical, mobility, social, psychological, economic and political based on literature review (see p.24). The three dimensions social, economic and political are about social justice, affordable housing, job opportunities and implementable policies and I chose to exclude them because they are holistic topics and they locate at deeper level of cities. It is difficult to relate them into several blocks. Much more time and further study are needed to include them.

In order to measure the selected four dimensions, I reviewed related papers and chose the most common measures and found 6 measures for them in total (see p.27). Some measures contribute to more than one quality dimension. More measures exist and there might not be limitations.

For the statistical analysis part, the purpose is to find the relations between density and qualities. 6 groups of data are prepared and python programming language is selected to do the analysis. The more data there is, the more accurate the result will be. 6 groups of data are the maximum quantity that I could manage for the thesis. The results are highly depending on the 6 cases. It would be better if more groups of data could be included.

For the design phase, one block is selected to densify. The purpose of the design is to show how to apply the research to design and the approach is top-down. The result of location selection came from space syntax analysis. The target density came from the relations between density and qualities.

I made a lot of choices for the thesis. Every time I made a choice, I lost the information of the part that have not been chosen. The delimitations are not totally less important as the selected part. More time and effort would be needed to include them.

What comes next

How can the thesis be further developed by research groups and projects groups ?

Firstly, more high density blocks are needed. From the perspective of statistics and mathematics, more groups of data will lead to more reliable results. They can reach a wider types of blocks and more samples for each type. Moreover, a standard for FSI decided for the real situation may also be needed.

The cases can also be selected within the same city or country for a local program. In this way can the results be more moderate and easier acceptable for the locals but lack of innovations. Thus, it might not be able to solve existing problems in certain cities. In such case it would be better to have two group of cases, within and without certain cities.

Secondly, the dimensions of qualities can be redefined. I used a reference and it defined urban qualities into seven dimensions in general in order to be less subjective. With a research group, the researchers can decide which qualities are more important based on their purpose.

Important qualities could also be proposed and voted by citizens for a local program.

Thirdly, the measures for qualities dimensions can be carefully researched and defined.

For the density analysis, I used Spacematix diagram, and I think the method is good enough to be used for further research.

For the statistical analysis part, the methods can be used with a little adjustment for the code in Python programming language.

For the potential blocks selecting, I used building density in 500 meters distance. Further research can use building density of blocks. Several potential blocks might arise, and the decision can be made based on the specific situation.

In the design phase, more possibilities can be tried. The workshops with locals could be useful.

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Appendix 1

```
import numpy as np

if __name__ == "__main__":
    sample_num = 6
    x_length = 3                      # the num of independent variables + 1 (constant)
    quality_num = 6
    x = np.ones((sample_num, x_length))
    y = np.zeros((sample_num, 1))

    x_filename = "x_osr_l.csv"   # the file path of density measures raw data
    fp_x = open(x_filename, 'r')
    print(x_filename)
    fp_y = open("y.csv", 'r')    # the file path of qualities normalized data

    # Read density measures data
    for j in range(sample_num):
        line_x = fp_x.readline()[:-1].split(',')
        for k in range(x_length):
            x[j][k] = float(line_x[k])

    # For each quality, read quality data and solve linear regression
    for i in range(quality_num):
        # Read quality data
        fp_y.seek(0)
        for j in range(sample_num):
            line_y = fp_y.readline()[:-1].split(',')
            y[j] = float(line_y[i])

        # Normal Equation, theta is the regression coefficients I need
        theta = np.linalg.inv(x.transpose().dot(x)).dot(x.transpose()).dot(y)

        # Print Result
        for k in range(1, x_length):
            print(str(theta[k])[1:-1])
        print(str(theta[0])[1:-1] + '\n')
```

Appendix 2

```
import numpy as np
import math

# Function to compute one-variable correlation coefficient
# will get the same result as CORREL function in Excel
def compute_corrcoef1 (a_x, a_y):
    a_x = a_x - a_x.mean()
    a_y = a_y - a_y.mean()
    return (a_x * a_y).sum() / math.sqrt((a_x * a_x).sum() * (a_y * a_y).sum())


# Function to compute two-variable correlation coefficient
def compute_corrcoef2(a_x1, a_x2, a_y):
    r_y_x1 = compute_corrcoef1(a_x1, a_y)
    r_y_x2 = compute_corrcoef1(a_x2, a_y)
    r_x1_x2 = compute_corrcoef1(a_x1, a_x2)

    return math.sqrt((r_y_x1 * r_y_x1 + r_y_x2 * r_y_x2 - 2 * r_y_x1 * r_y_x2 * r_x1_x2) / (1 - r_x1_x2 *
r_x1_x2))


if __name__ == "__main__":
    sample_num = 6
    x_length = 3                        # the num of independent variables + 1 (constant)
    quality_num = 6
    x = np.ones((sample_num, x_length))
    y = np.zeros((sample_num, 1))
    x2 = np.zeros((2, sample_num))  # used for save variable 1 and 2 (x1, x2)

    x_filename = "x_osr_l.csv"  # the file path of density measures raw data
    fp_x = open(x_filename, 'r')
    print(x_filename)
    fp_y = open("y.csv", 'r')   # the file path of qualities normalized data

    # Read density measures data
    for j in range(sample_num):
        line_x = fp_x.readline()[:-1].split(',')
        for k in range(x_length):
            x[j][k] = float(line_x[k])

    # Save variable 1 and variable 2 into x2
    for i in range(2):
        for j in range(sample_num):
            x2[i][j] = x[j][i + 1]
```

```
# For each quality, read quality data and solve linear regression
for i in range(quality_num):
    # Read quality data
    fp_y.seek(0)
    for j in range(sample_num):
        line_y = fp_y.readline()[:-1].split(',')
        y[j] = float(line_y[i])

    # Normal Equation, theta is the regression coefficients I need
    theta = np.linalg.inv(x.transpose().dot(x)).dot(x.transpose()).dot(y)

    # Compute Standard error
    std = np.sqrt(np.power(x.dot(theta) - y, 2).sum() / sample_num)

    # Print regression coefficients
    for k in range(1, x_length):
        print(str(theta[k])[1:-1])
    print(str(theta[0])[1:-1])

    print()
    # print Standard Error
    print(std)

    # Compute multiple correlation coefficients
    print(compute_corrcoef2(x2[0], x2[1], y.transpose()))

    print('\n')
```

Appendix 3

```
from matplotlib import pyplot as plt

# Compute OSR from FSI and L
def getOSR(fsi, l):
   return 1 / fsi - 1 / l

# Compute L from FSI and GSI
def getL(fsi, gsi):
   return fsi / gsi

# Check normalized Greenness Index
def greennessIndex (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
      return -0.1 * fsi + 0.0616 * l - 0.0273 > threshold
   else:
      return -0.1 * fsi + 0.0616 * l - 0.0273 < threshold

# Check normalized Sunshine Rate
def sunshineRate (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
      return -0.2043 * osr + 0.0334 * l + 0.4158 > threshold
   else:
      return -0.2043 * osr + 0.0334 * l + 0.4158 < threshold

# Check normalized Street Wall Index
def streetWallIndex (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
      return -0.8862 * osr - 0.0343 * l + 1.2361 > threshold
   else:
      return -0.8862 * osr - 0.0343 * l + 1.2361 < threshold

# Check normalized Building Density
def buildingDensity (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
      return -0.1041 * fsi + 1.6158 * gsi - 0.0154 > threshold
   else:
      return -0.1041 * fsi + 1.6158 * gsi - 0.0154 < threshold

# Check normalized Network Density
def networkDensity (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
      return -1.3201 * osr - 0.0288 * l + 1.2954 > threshold
   else:
      return -1.3201 * osr - 0.0288 * l + 1.2954 < threshold

# Check 1-Oppressiveness Index
def oneMinusOppressivenessIndex (fsi, gsi, osr, l, threshold, bLargerThan):
   if bLargerThan:
```

```
return 0.054 * fsi - 1.442 * gsi + 1.185 > threshold
    else:
        return 0.054 * fsi - 1.442 * gsi + 1.185 < threshold


if __name__ == "__main__":
    figure1 = plt.figure()  # Figure for drawing expectGreennessIndex.png
    x = []  # Point data for drawing expectGreennessIndex.png
    y = []  # Point data for drawing expectGreennessIndex.png
    x_greennessIndex = []
    y_greennessIndex = []
    x_sunshineRate = []
    y_sunshineRate = []
    x_streetWallIndex = []
    y_streetWallIndex = []
    x_buildingDensity = []
    y_buildingDensity = []
    x_networkDensity = []
    y_networkDensity = []
    x_oneMinusOppressivenessIndex = []
    y_oneMinusOppressivenessIndex = []

    piexlNum_x = 5000  # Divide x into 5000 pieces
    piexlNum_y = 5000  # Divide y into 5000 pieces

    # Check every x and y piece
    for i in range(1, 1 + piexlNum_x):
        for j in range(1, 1 + piexlNum_y):
            gsi = i / (piexlNum_x)              # 0 < gsi < 1
            fsi = j / (piexlNum_y / 20)         # 0 < fsi < 20
            l = getL(fsi, gsi)                  # 0 < l
            osr = getOSR(fsi, l)                # 0 < osr
            if 0 < l and 0 < osr:
                threshold = 0.4                             # the threshold we set for all the qualities
                boolGreennessIndex = greennessIndex(fsi, gsi, osr, l, threshold, True)
                boolSunshineRate = sunshineRate(fsi, gsi, osr, l, threshold, True)
                boolStreetWallIndex = streetWallIndex(fsi, gsi, osr, l, threshold, True)
                boolBuildingDensity = buildingDensity(fsi, gsi, osr, l, threshold, True)
                boolNetworkDensity = networkDensity(fsi, gsi, osr, l, threshold, True)
                boolOneMinusOppressivenessIndex = oneMinusOppressivenessIndex(fsi, gsi, osr, l, threshold,
True)

                                    # check except Greenness Index
```

```
if (boolSunshineRate and boolStreetWallIndex and boolBuildingDensity and boolNetworkDensity and
boolOneMinusOppressivenessIndex):
          # plt.plot(i, j, ‘.b’)
          x.append(gsi)
          y.append(fsi)
        if boolGreennessIndex:
          x_greennessIndex.append(gsi)
          y_greennessIndex.append(fsi)
        if boolSunshineRate:
          x_sunshineRate.append(gsi)
          y_sunshineRate.append(fsi)
        if boolStreetWallIndex:
          x_streetWallIndex.append(gsi)
          y_streetWallIndex.append(fsi)
        if boolBuildingDensity:
          x_buildingDensity.append(gsi)
          y_buildingDensity.append(fsi)
        if boolNetworkDensity:
          x_networkDensity.append(gsi)
          y_networkDensity.append(fsi)
        if boolOneMinusOppressivenessIndex:
          x_oneMinusOppressivenessIndex.append(gsi)
          y_oneMinusOppressivenessIndex.append(fsi)

    print(i)

  # draw
  plt.plot(x, y, ‘.b’)
  plt.xlabel(“gsi”)
  plt.ylabel(“fsi”)
  plt.xlim([0, 1])
  plt.ylim([0, 20])
  figure1.savefig(“exceptGreenness.png”)
  # plt.show()
  plt.cla()
  plt.clf()
  plt.close()

  figure_greennessIndex = plt.figure()
  plt.plot(x_greennessIndex, y_greennessIndex, ‘.b’)
  plt.xlabel(“gsi”)
  plt.ylabel(“fsi”)
  plt.xlim([0, 1])
  plt.ylim([0, 20])
  figure_greennessIndex.savefig(“greennessIndex.png”)
  plt.cla()
  plt.clf()
  plt.close()
```

```
plt.plot(x_sunshineRate, y_sunshineRate, '.b')
    plt.xlabel("gsi")
    plt.ylabel("fsi")
    plt.xlim([0, 1])
    plt.ylim([0, 20])
    figure_sunshineRate.savefig("sunshineRate.png")
    plt.cla()
    plt.clf()
    plt.close()

    figure_streetWallIndex = plt.figure()
    plt.plot(x_streetWallIndex, y_streetWallIndex, '.b')
    plt.xlabel("gsi")
    plt.ylabel("fsi")
    plt.xlim([0, 1])
    plt.ylim([0, 20])
    figure_streetWallIndex.savefig("streetWallIndex.png")
    plt.cla()
    plt.clf()
    plt.close()

    figure_buildingDensity = plt.figure()
    plt.plot(x_buildingDensity, y_buildingDensity, '.b')
    plt.xlabel("gsi")
    plt.ylabel("fsi")
    plt.xlim([0, 1])
    plt.ylim([0, 20])
    figure_buildingDensity.savefig("buildingDensity.png")
    plt.cla()
    plt.clf()
    plt.close()

    figure_networkDensity = plt.figure()
    plt.plot(x_networkDensity, y_networkDensity, '.b')
    plt.xlabel("gsi")
    plt.ylabel("fsi")
    plt.xlim([0, 1])
    plt.ylim([0, 20])
    figure_networkDensity.savefig("networkDensity.png")
    plt.cla()
    plt.clf()
    plt.close()

    figure_oneMinusOppressivenessIndex = plt.figure()
    plt.plot(x_oneMinusOppressivenessIndex, y_oneMinusOppressivenessIndex, '.b')
    plt.xlabel("gsi")
    plt.ylabel("fsi")
    plt.xlim([0, 1])
    plt.ylim([0, 20])
```

```
figure_oneMinusOppressivenessIndex.savefig("oneMinusOppressivenessIndex.png")
  plt.cla()
  plt.clf()
  plt.close()


  figure_sunshineRate = plt.figure()
```

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