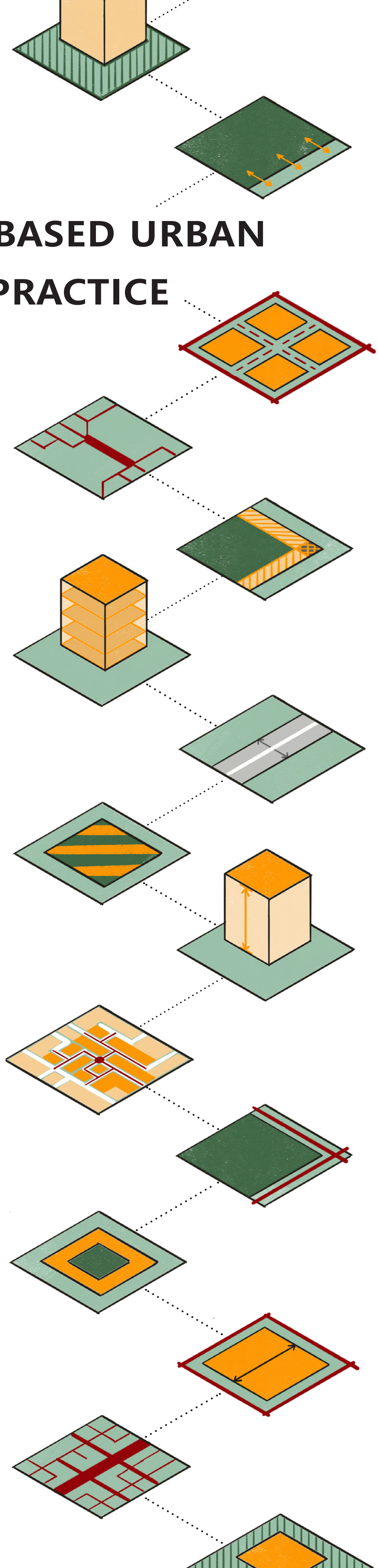
Towards an evidence-based urban design and planning practice



Developing a Digital Tool Prototype for Designing Based on the Theory of Natural Movement

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Supervisor: Meta Berghauser Pont

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CHALMERS
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Abstract

In times of increasing urbanization, population growth, and climate change, densification has been identified as a key strategy for sustainable urban planning. However, denser cities come with challenges on their own. By employing evidence-based design (EBD) approaches, urban planners can better understand how the built environment affects, and is affected by, peoples experience and use of it. Bill Hillier proposed one such approach with Space syntax and the Theory of Natural Movement, which aids urban planners in planning urban environments which facilitates human activity. This theory is the core concept for this thesis due to its ability to show the relationship between the street network, the distribution of density, and the flow of pedestrians, in cities and urban settings, which makes it a suitable framework for combining different quantitative morphological methodologies and investigating their relationship.

This thesis aims to contribute to the implementation of EBD approaches in urban planning and design by proposing a way in which practitioners can use the Theory of Natural Movement to guide both the planning of streets and the distribution of function in an integrated process at early design stages and prototyping a digital tool which makes use of these conclusions. Three research areas are investigated: first, a literature review of the core concepts of the Space syntax and Spacematrix methodologies, which act as the primary theoretical methodologies for the thesis; second, an overview of existing digital tools to understand how they support urban planning practice; and third, a case study into Swedish planning documents and practice based on Backaplan, Gothenburg, together with a workshop with the Gothenburg urban planning office.

Based on this research, a prototype for a digital tool is developed. Based on a simple urban model consisting of simply surfaces and networks, the tool promotes a design process based on the Theory of Natural Movement by using the network as the primary design tool and facilitating network- and surface-based analysis for a comprehensive outcome assessment. The basic functionality is described together with an example design process to better understand the steps involved both for user and software.

Keywords:

Theory of Natural Movement, Space Syntax, Spacematrix, Evidence-Based Design, Digital Tool

Table of contents

1. Introduction **8**
1.1. Background 8
1.1.1 Bill Hillier and the Theory of Natural Movement 8
1.1.2 On evidence-based design approaches in urban planning 9
1.1.3 Systemic and absolute measures of urban space 10
1.1.4 Problem description 10
1.2 Thesis aim and framework 11
1.2.1. Research questions 11
1.2.2. Scope & delimitations 11
1.2.3. Method 11
1.2.4. Thesis outline 12

2. Research **13**
2.1. Theory 13
2.1.1. Describing the properties of the urban network - the Space Syntax methodology 13
2.1.2. Describing density through the spacematrix methodology 16
2.1.3. Further empirical support for the link between density, network and movement 19
2.1.4. Examples of bridging the logics of network and surfaces 20
2.2. Existing digital tools 22
2.2.1 List of investigated tools 22
2.2.2 Analysis and points of interest 23
2.3. Urban planning in Sweden 26
2.3.1. A case study of planning documents for Backaplan, Gothenburg 26
2.3.2 Support from the Urban planning office of Gothenburg 27
2.3.3 Analysis and points of interest 27
2.4 Conclusions on research 32
2.4.1 On units and measures to describe the city 32
2.4.2 On design approaches and design stages 32
2.4.3 On bridging the logics of network and surface 32
2.4.4 On other functions of interest for the tool 33

3. Prototype synthesis **34**
3.1. Representation of the city: the model 35
3.2 Functionality and making changes in the model 37
3.2.1 Drawing streets and dividing surfaces 37
3.2.3 Describing relations through rules 40
3.3 User case: Example of a design process 43
3.3.1 Drawing out a new scenario 44
3.3.2 Assigning additional properties 46
3.3.3 Applying rules 48
3.3.4 Displaying the result 50

4. Conclusions and discussion **51**
4.1 Aim and result 51
4.2 Other reflections 51
4.2.1. Challenges to making the tool a reality 51
4.2.2 Avoiding the trap of deterministic planning 52
4.2.3 Application in suburban environments 52
4.2.4 Regarding movement surface typologies 53
4.2.5 Further work with the prototype 53

Afterword **54**

Author background **55**

References **56**

Appendix: Measures and units in the tool **59**

Unless referenced otherwise, figures and illustrations in this work are the authors own.

1. Introduction

1.1. Background

With the world population steadily increasing (Ritchie et al., 2023), and a continued trend of urbanization with over 50% of the world's population living in cities as of 2017 (Ritchie et al., 2024), the increased pressure on urban environments present great challenges for the economic, social, and environmental sustainability of cities and their inhabitants. The built environment should optimally ensure aspects such as equal access to resources, healthy environments, and the vitality of the land. Among other things, urban density has been identified as a key aspect for urban planning to consider. For example, UN Habitat writes on their web page about urban planning:

> *"For cities to develop in a sustainable and inclusive way, they must become more compact, absorbing population growth by increasing their density. Only through agglomeration will cities have the power to innovate, generate wealth, enhance quality of life, and accommodate more people in a sustainable manner." (UN Habitat, 2024)*

A concentration of people does not only reduce the use of land, which is a limited resource, but it also reduces car usage, promotes public transport usage and walking, and can improve accessibility to jobs, healthcare, and other services as well as creates opportunities for people to meet in public space. One example to this intention is the 15-minute city concept which has gained traction in recent years, where inhabitants find all their needs met within a 15 minute walk or bike ride from their home (Pozoukidou & Chatziyiannaki, 2021). Ullrich et al. writes in an article from 2024:

> *"[Pedestrian movement] has become more important within the sustainable development agenda, as walking is crucial to reducing urban emissions and fostering liveable cities. Therefore, urban planners need to take pedestrian movement into consideration as part of the workflow of planning and designing cities." (Ullrich et al., 2024)*

1.1.1 Bill Hillier and the Theory of Natural Movement

One of the theories that has emerged as significant for walkability and co-presence comes from the field of Space Syntax. It was developed by Bill Hillier and his associates in the 1980's and -90's to measure and describe the built environment, with the aim of reaching conclusions on correlations between built form and social behavior. This means that unlike other quantitative morphological schools, Space Syntax not only describes the built environment but also endeavors to understand how the built environment impacts people. His book Space is the machine (1996) is seen as the central work within the field. In it, he outlines the central concepts within Space Syntax and explores the relationships between the configuration of built space and aspects of social life, both through the tools of Space Syntax methodology, but also in a more philosophical sense.

Central to the Space Syntax methodology is what Hillier called the Theory of Natural Movement. The theory states that movement in an urban street network is determined, all other things equal, by the configurational properties of the grid itself (Hillier et al., 1993). This is a change from earlier theories of movement, which were more focused on the movement to and from certain attraction points, which could in their simplest form be described as a density of something like activities, people, or gross floor area. The Theory of Natural Movement instead focuses on movement through the network and considers these attraction points not as start- and endpoints, but rather as drivers of movement through the network. And while movement certainly influences the placement of attraction points, for example on how commercial activity gathers on busier streets, neither attraction nor movement have any real influence over the configuration of the network. In short, there is an asymmetric triadic relationship between these three:

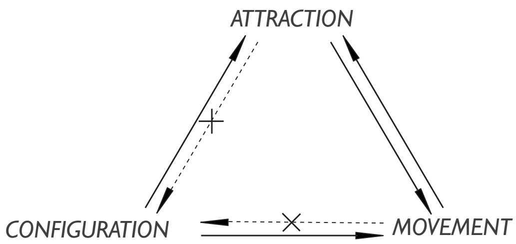


Figure 3: The triadic relationship between attraction, movement and network configuration. Configuration can influence both attraction and movement, but they cannot influence the configuration, only each other. (Published in Hillier et al., 1993)

1.1.2 On evidence-based design approaches in urban planning

Through years of studies, Hillier and others in the field showed that there was empirical evidence to support the Theory of Natural Movement and argued for its usefulness for urban planners in understanding their designs and how they performed. This question was important for Hillier, who wrote:

> *"The most common problem with architectural theories is that they have too often been strongly normative and weakly analytic, that is, it has been too easy to use them to generate designs, but they are too weak in predicting what these designs will be like when built." (Hillier, 1996)*

This core idea of predicting design performance based on empirical data makes Space Syntax a useful methodology for what is today known as evidence-based design, or EBD. The term evidence-based design is inspired by evidence-based medicine, a term coined in the early 1990s (Peavey & Vander Wyst, 2017) during a transition in medicine practice from being mostly based on experience and intuition to the more rigorous studies and controls of today. The first formally recognized definition of the term was made in 2003:

> *An evidence-based designer, together with an informed client, makes decisions based on the best information available from research and project evaluations. Critical thinking is required to develop an appropriate solution to the design problem." (Hamilton, 2003)*

In general, EBD approaches have not yet been widely accepted in urban planning, nor in architecture practice in general. One reason for this is that EBD requires an existing structure from architectural theory for analyzing and evaluating designs (Sailer et al., 2009), however very few such structures have been widely adopted. Another is that EBD approaches are sometimes criticized as being deterministic in practice, where design becomes a process of optimizing certain parameters to a fault. In such situations, critics argue, architecture tends to lose its connection to human perspectives, culture, history et cetera, and become generalized structures directly derived from available data rather than interpreting it. Hillier himself was aware of this with the Space Syntax methodology and writes in Space is the machine:

> *"In a sense, one might say that by emphasizing natural movement, Space Syntax offers a normative idea of what constitutes good design and a successful outcome. However, experience suggests that there are many different ways to design a ghetto, but very few ways of designing an integrated system. Space Syntax needs only be invoked for the more difficult task. In this, however, it often offers no more than a powerful aid to the designer's intuition and intentions. It does not tell designers what to do. It helps them to understand what they are doing." (Hillier, 1996)*

In this quote, Hillier also emphasizes the main strengths of EBD approaches: helping urban planners (and designers in general) understand what they are doing, and what consequences their design has. It offers structures with which to analyze, understand, and compare different design choices, and emphasizes the need to support these choices with data and empirical understanding of the context.

1.1.3 Systemic and absolute measures of urban space

For EBD urban planning approaches, data means measures of urban space, which is the expertise of the urban morphology field (Moudon, 1997). This field has its roots both in geography and architecture and has gained more and more traction in urban planning practice over the last decades, giving urban planners tools for describing and understanding the urban landscape. Space Syntax of course is part of this field, but part of a certain subfield which Moudon refers to as Space-Morphology, a field which concerns itself with the characteristics of geometries in the urban setting, using a mathematical approach to describing them.

Within this sub-field, Space Syntax differs from more traditional descriptions of urban space. Where the usual description of space focuses on the individual units that can differ in size and scale (e.g. plots, neighborhoods and cities), Space Syntax uses a systemic description of urban space (Berghauser Pont, 2018). This means that the properties measured are for the most part a way of describing how each unit relates to other units in a system. This difference can also be expressed in terms of two different logics, where the traditional description is a logic of individual urban spaces, and Space Syntax instead uses a logic of urban networks.

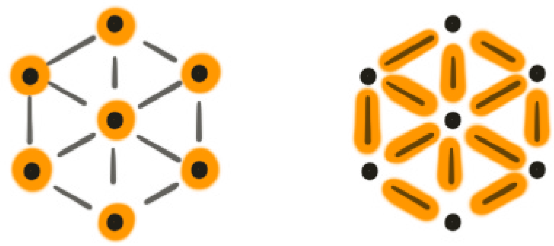


Figure 6: An illustration of the focus on individual units (left) versus the systemic thinking of Space Syntax (right).

1.1.4 Problem description

Despite this difference in approach and logic, the two are clearly connected in some way, not only because they both describe the same urban environment. The planning of streets does not only influence the movement in the city but also impacts occupation in the form of different land uses and densities. The Theory of Natural Movement acknowledges this as illustrated in the triadic relationship; however, it does not explain how these two logics fit together, only that there is a connection between configuration and attraction, and that both influence the distribution of pedestrian flows creating urban places with high intensity and quiet places with lower co-presence of people.

The problem then is to explain how the design logic of the street network and the design logic of built space is connected, or, in other words, what the relationship between properties of movement and occupation is. If such a connection could be made, urban planners would have a powerful, combined framework for working with both street networks and built spaces and be able to employ an EBD approach based on synergies between properties.

1.2 Thesis aim and framework

This thesis aims to explore how urban designers can actively use an evidence-based design approach based on the Theory of Natural Movement in urban planning, by showing how the logics of network-based and surface-based planning can be connected into a combined design logic. The thesis uses the Space Syntax methodology to describe properties of the network, and the Spacematrix methodology to describe the density of urban space. Finally, the thesis aims to anchor the theory into practice through the prototyping of a digital tool meant to facilitate this combined design logic.

1.2.1. Research questions

What are the main characteristics of the design methodologies of Space Syntax and Spacematrix, and how can they be used in urban planning and design practice?

How could a set of morphological elements, attributes, and relationships be formulated to support the combination of these methodologies and ease the application of theory into practice?

How can these morphological elements, attributes, and relationships be implemented in a digital tool to facilitate evidence-based urban planning in the early, exploratory design stages?

1.2.2. Scope & delimitations

While some factors correlate positively with higher urban density, such as shorter transports and higher economic activity, there are also important negative correlations to ecology, social impact and health, as shown in a study by Berghauser Pont et al. (2020). As the focus of this thesis is on the connection of network accessibility and density, some of these aspects will be addressed indirectly, such as the impact of more walking on health, while others, like the impact of higher density on ecology, will not be covered at all.

Although the division of urban space into plots has important consequences for urban diversity, as investigated in the study of parcellation (Bobkova, 2019), this aspect will not be investigated in this thesis, and plot division will mainly be considered a tool with which to create a basic unit for measurements and comparison.

The thesis will not aim to challenge research within its themes and theories, nor to seek to be a comprehensive summary of all discourse. Similarly, while there are multiple models for describing urban space, the thesis will motivate the choice of the Spacematrix methodology without going further into the merits of each available model.

The application of theory to practice will be done based on the Swedish urban planning process and will not consider how the process might look like outside of Sweden.

1.2.3. Method

The thesis employs a research-for-design method, working iteratively between research and design to develop a digital tool prototype. The research is done in three parallel areas, each informing each other along the process.

A literature study will be undertaken to set the theoretical foundations for the thesis, primarily focusing on literature on Space Syntax and especially the Theory of Natural Movement. Because the description of the network is well developed in this literature, while attractions and density are less emphasized, the Spacematrix method is included as well to gain a method for describing built space.

A qualitative review of existing urban planning and urban analysis tools will be conducted, to get a frame of reference for how these tools handle the design logics of network and surfaces, measures density and properties of the network, and more. The selection of tools will be based on a general relevance to the topic of the thesis and should therefore not be seen as exhaustive or exact.

A case study of the Swedish planning process will be made by looking into the urban planning documents of Backaplan, a current development project on the north side of Gothenburg. The purpose of this study is to get a deeper understanding of the urban planning process, both in terms of how urban planning practice operates, how data is gathered, and how the resulting designs are presented.

Finally, two workshops will be held with representatives from the urban planning office (Stadsbyggnadsförvaltningen) in Gothenburg. The purpose of these workshops was both to further gather knowledge about urban planning practice, using the case study of Backaplan and the digital tool review as discussion material, but also for the representatives to act as reference users for the digital tool prototype, making functionality requests and giving feedback on design ideas.

At the end of the thesis, a prototype for a digital tool will be created, using text and image to describe key functionalities and concepts. As part of the prototype, an example of a design process will be created and presented.

1.2.4. Thesis outline

The thesis consists of four chapters, the first being this introduction.

In the second chapter, the three areas of research are described one by one in terms of the process and key findings within that area. At the end of the chapter, some summary conclusions are made about the research which might particularly impact the development of the digital tool prototype.

In the third chapter, the prototype of the digital tool is presented and key functionalities explained step by step. To further explain the tool, a typical design process will be presented following the same steps as the main descriptions.

In the last chapter, conclusions regarding the research questions are discussed, together with additional discussion regarding possible strengths, challenges, and possible futures for the digital tool prototype.

2. Research

As described in the method, the research of this thesis has been focused on three different areas. This process has been parallel and iterative, where each area of research has simultaneously helped inform and put perspective on the others, but for the sake of the reader, it is presented in a more linear fashion in this chapter starting with theory, followed by an overview of existing tools and then a case study of the planning process in Sweden. The chapter ends with a section highlighting some major conclusions from the full material.

2.1. Theory

The first part of the research was on the theoretical foundations for this thesis, and on understanding their characteristics and constituting elements that in a most fundamental way can be divided into space for **occupation** and space for **movement**, as described by Hillier (1996). For the first, space for occupation, the thesis builds on the Spacematrix methodology, while for the second, space for movement, the thesis also builds on the Space Syntax methodology. This information will then be of use when interpreting both the digital tools and the urban planning practice.

2.1.1. Describing the properties of the urban network - the Space Syntax methodology

As described in the background, the Theory of Natural Movement stipulates that movement in an urban street network is determined, all other things equal, by the configurational properties of the grid itself (Hillier et al., 1993). This means that if a network has an even distribution of attraction points – human residency, for example - it will still see variations in movement patterns, simply due to how the grid is configured. The reason for this, Hillier et al. argues, is that while points of attraction can affect movement, and movement affect attraction, neither of these properties can change the basic configuration of the network. On the other hand, the network configuration has a direct and profound influence over both aspects, as they act within its boundaries and are therefore dependent on it.

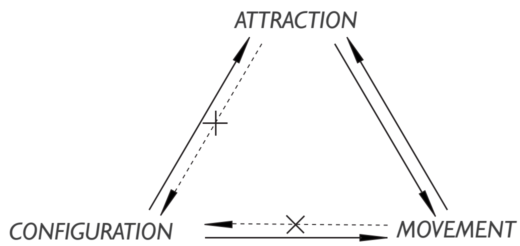


Figure 3: The triadic relationship between attraction, movement and network configuration (Published in Hillier et al., 1993)

Through analysis of several case studies, Hillier et al. shows that there is empirical evidence to support the theory, and that measures used within the Space Syntax methodology to describe the properties of a network and its constituent parts also to some degree correlate with the amount of movement on a given street – meaning that it to some degree predicts this natural movement.

To measure this phenomenon, Hillier and associates developed what they called the Space Syntax methodology, which continues to be developed until this day. The formal core of the Space Syntax methodology is primarily concerned with the analysis of built space and the interrelation between different units therein (Ekelund & Koch, 2012). To find these relations, Space Syntax describes rooms topologically, rather than geometrically or geographically. For analytical purposes Space Syntax most often describes the relationship between spaces either through **axial lines** (roughly the representation of the shortest unbroken distance between two rooms, comparable to sight lines) or **line-segments** (line-segments ending at each intersection, generated either from an axial map, or from a path center line map). Although Hilliers original models used the first representation, the second one is more common today as it has been shown to be the most flexible representation model (Stavroulaki et al., 2017).

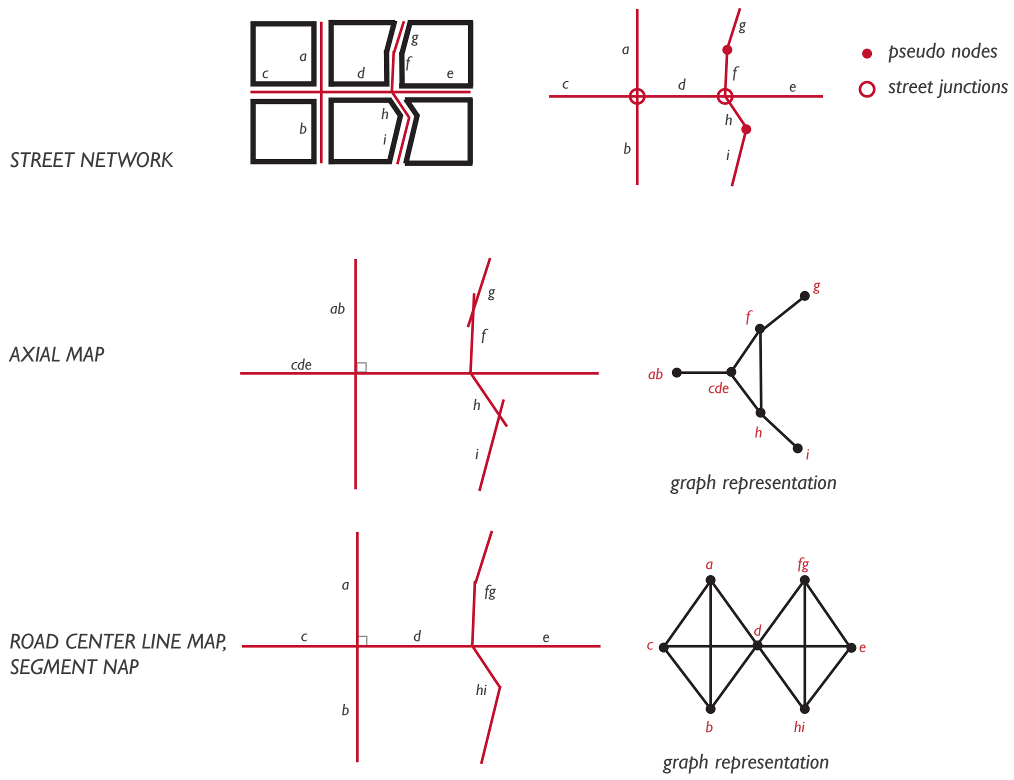


Figure 4: Illustration of the difference between axial lines and line-segments, based on the same map. Based on Stavroulaki et al. (2017)

The Space Syntax methodology has several measurements used to describe certain properties of spaces. The most common term is **centrality**, meaning how central a particular segment is in the network. Centrality is measured either as **integration centrality**, which measures how topologically close a segment is to every other segment in the network, or as **betweenness**- or **choice centrality**, which measures how often a segment appears as part of the shortest path between any two points in the network.

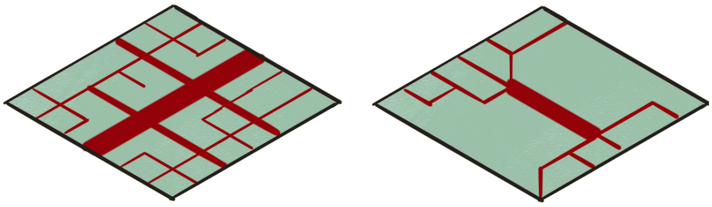


Figure 5: Higher centrality, here visualised as thicker lines, measured in terms of integration (left) and betweenness (right).

Calculating distance in the network is done by adding up the distance needed to move from one network segment to the next along the path (Hillier & Iida, 2005). The most basic distance model is **metric distance**, where the distance between two segments is simply calculated as half the sum of their **segment lengths (l)**. However, other models use a topological weight definition to describe the "effort" needed to traverse the network. **Topological distance** counts the number of direction changes needed to traverse the network, while **angular distance** sets a value based on the **segment angle (α)** between 0 (straight ahead) and π (180° turn) for each turn and adds that up as the network is traversed. Hillier and Iida (2005) showed that based on data on pedestrian movement, the angular distance model has the highest correlation with pedestrian movement out of the three.

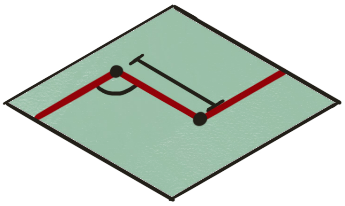


Figure 6: Illustration of the network segment length and segment angle.

Over time, research has continued to test the Space Syntax model and measures against pedestrian data to continue validating the models. Stavroulaki et al. (2019) tested the two centrality measures against a large set of pedestrian movement data from three European cities and found that while angular integration performed slightly better than angular betweenness, the best models were where they were both accounted for. They could also see a good statistical fit with **accessible density** (using the measure FSI, or Floor space index, that will be explained in further detail in the next section), a measure developed by Berghauser Pont and Marcus (2014) to calculate, in similarity with the systemic approach used in Space Syntax , how much floor area can be reached within a certain network distance.

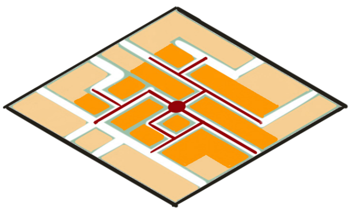


Figure 7: Illustration of accessible FSI, measuring the density reached within a certain distance.

2.1.2. Describing density through the spacematrix methodology

According to Berghauser Pont and Haupt (2021), describing density – meaning, distribution of function over an area - has often been regarded as complicated due to confusion regarding the definition of what exactly is measured. The broad definition of density is a quote D=B/A , where B is the amount of something of interest within a limited area A, but B could be anything from number of dwellings to square meters of dwelling, to square meters of building footprint, to something else completely. Additionally, the question is also the delimitation of area A, because whether parks, streets or squares are included obviously matters for the outcome, as does scale. For instance, comparing a high-density block (where A is the area of the block) with a low-density of a city (A in this case is the area of the city) is of little relevance. The problems of describing the area A are central to what is known in geography as the modifiable areal unit problem or MAUP (Openshaw & Taylor, 1979).

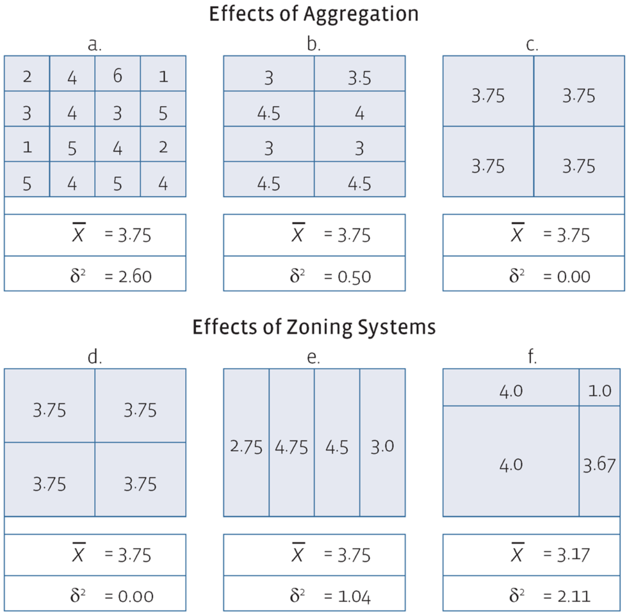


Figure 9: The MAUP problem as illustrated through the effects of scale and zonation on the mean value ($\bar{X}$) and variance (δ2) (interpretation of Jelinski and Wu (1996), in Dark and Bram (2007))

In their book *Spacematrix* (2021), Berghauser Pont & Haupt propose a system through which to measure and compare density and built space. The system addresses the MAUP by electing to let the ground area A defined through the street network, the buildings and the non-built space which exists between them. Each unit is an aggregation of units on the previous level, and the difference is non-built space of different kinds – referred to as tare space - which creates a systematic definition of what is measured within each unit. The five units in the model are, from smallest to largest:

- **The building,** which is defined by the footprint of the building itself.
- **The lot** (also known as parcel or plot), which is the sum of the built area and non-built (predominantly private) area within a legal boundary designated for building. The tare space between the lot and the building is therefore all the non-built space; if the lot is completely built over, no such tare space exists.
- **The island** or urban block, which consists of one or multiple lots together with any designated non-buildable space, which are the tare space between the island and the lot. The border of an island is defined by the surrounding streets, or if no such streets exist, the boundaries of the lot.
- **The fabric,** which consists of multiple islands with a homogenous typology, together with the streets which surround them. Streets which are primarily used to access the islands are included within the fabric definition, while circulation streets which are primarily used to move across from one fabric to another or around the city are not, instead considered the border of the fabric. In cases where no circulation street exists, the boundary of the fabric is drawn through the middle of an access street, or that doesn't exist either, along the boundaries of the lot. The combined street area of access streets and circulation streets together constitute the tare space between fabric and island.
- **The district,** which consists of multiple fabrics together with large, non-built areas that are not included in the definition of fabrics, such as parks, sports fields, and circulation streets. These of course make up the tare space between the district and the fabric. The boundary of the district is drawn through the middle of the circulation streets around it; where no such exists, it coincides with the boundary of the fabric.

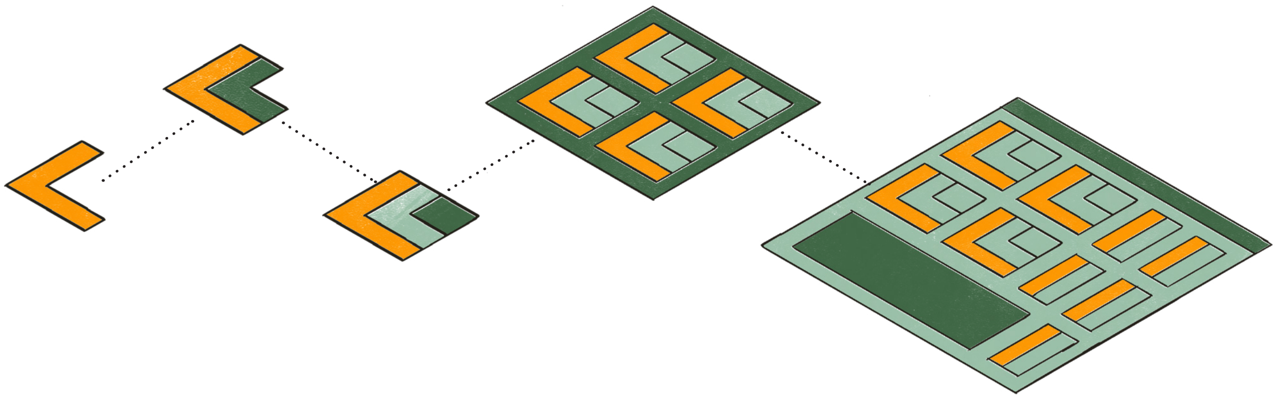


Figure 10: The five units in the Spacematrix model, from left to right in order of appearance in the text, with the tare space between a scale and the previous scale is drawn as dark green. (Based on Berghauser Pont & Haupt, 2021)

Parallel to these units, the authors set up a system of measures to describe density. First are four basic measures: the **base area** of a surface **(A)**, the **built-up area** or footprint of a building **(B)**, the **gross floor area** of a building **(F)**, and the network length **(l)**, which readers recognize from the precious section. From these, several additional measures are derived, the most important ones for this thesis being:

- **Building intensity**, also known as Floor Space Index or **FSI**, is the relation between the gross floor area and the base unit area, and is calculated as *FSI = F / A*. In Sweden, this is also known as *exploateringstal* or e-tal.
- **Coverage**, also known as Ground Space Index or **GSI**, is the relation between the built footprint and the base unit area, and is calculated as GSI = B / A .
- **Spaciousness**, also known as Open Space Ratio or **OSR**, is a measure of the amount of non-built space at ground floor level per gross floor space F. It is calculated as *OSR = (1 - GSI) / FSI*.
- **Building height (L)** is the average height of buildings within a base unit. It is calculated as *L = FSI / GSI*.
- **Network density (N)** represents the concentration of networks in an area, giving a perspective on how much space is occupied by network. It is calculated as $N = (\sum l_f + (\sum l_e / 2)) / A$, where l_i and l_e is the length of fabric inside and on the edge of a base area unit respectively.
- **Grain of the network (w)** represents the indicative distance between street and street in the net-work, generalizing the grid as square. This helps add a perspective to the base area of an urban block (i.e. island), which could take on any shape or form but still have the same area. The grain of the network is calculated as $w=2/N_f$, where N_f is the network density in a fabric.

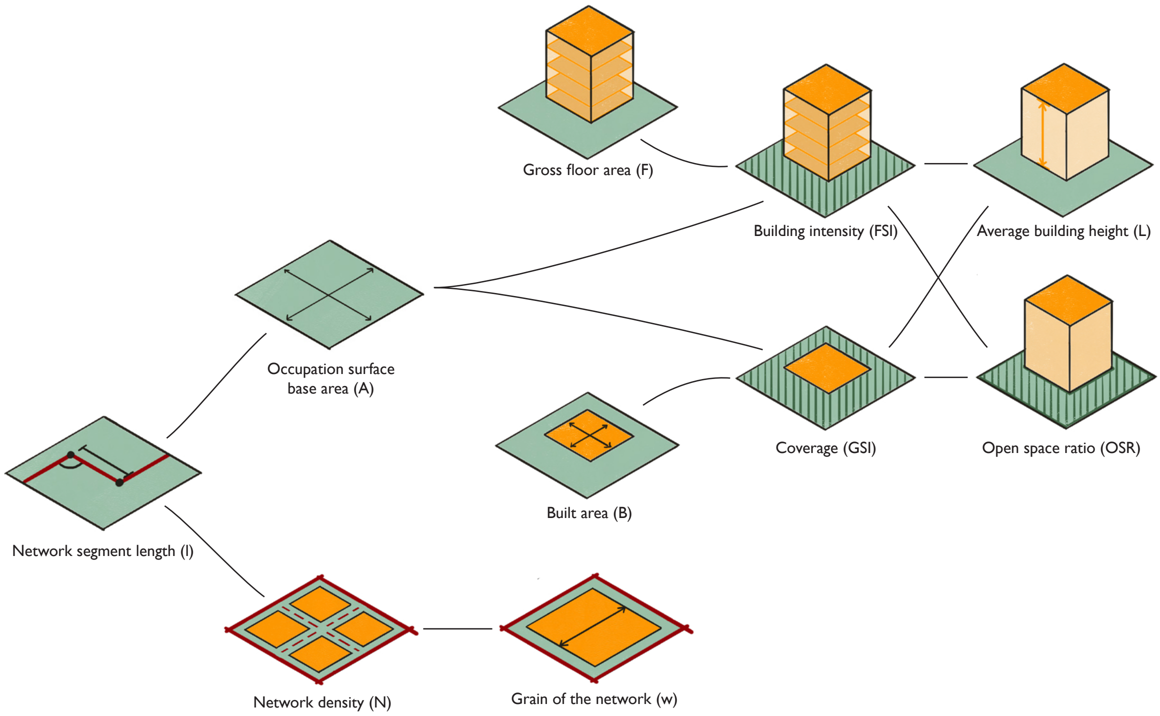


Figure 11: The measures of the Spacematrix system and their relation to each other.

With this system, measuring the density of an area is not limited to one single aspect, but rather captures a multitude of perspectives. What's more, by standardizing the system of measures, it is possible to make comparisons between different areas and relate measures of density to urban form and other performances, something which the authors discuss extensively in the book.

To visualize comparisons between areas, Berghauser Pont and Haupt created the **Spacematrix**, a three-dimensional diagram from which their book gets its name. The diagram, with GSI, N and FSI on the x-, y-, and z-axes respectively, makes it possible to plot different areas in three-dimensional space and compare them based on these aspects. For the sake of easier representation and communication, the more common projection is what they refer to as the **Spacemate**, a two-dimensional diagram FSI (GSI) which leaves N out. In this format however, the additional measures of L and OSR can easily be added in as well, showcasing their relationship to FSI and GSI in the same diagram.

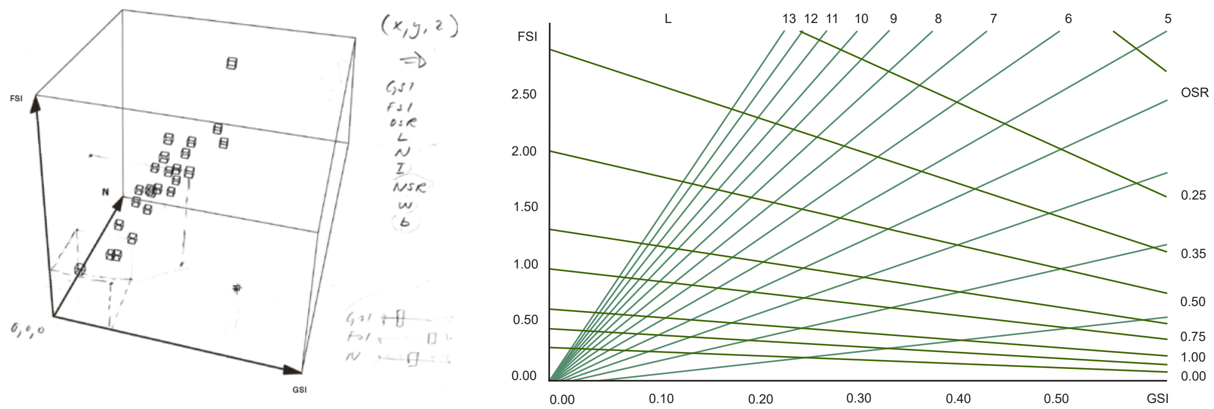


Figure n. The complete Spacematrix (left) and the FSI(GSI) projection of the Spacemate (right) from Berghauser Pont and Haupt (2021).

2.1.3. Further empirical support for the link between density, network and movement

In a study by Berghauser Pont et al. (2019), the same non-directed cluster analysis used to identify built typologies in the Spacematrix was also used to identify street types, based on measuring angular betweenness centrality at different scales. The study could identify four types, and by testing correlations between density, street types and data on pedestrian movement in Stockholm, Amsterdam and London, they were able to show that both street type and density had weak but significant correlations to pedestrian flow, but that the correlation increased significantly when both types were used together. Their findings indicate that while network centrality indeed gives a general idea of the distribution of pedestrian flow, like postulated by Hillier in the Theory of Natural Movement, building types and density were good indicators of the general number of people in the street and especially, better indicators of urban rhythms, showing which streets were more used during different times of the day.

A subsequent article by Bolin et al. (2021) confirmed this in a large statistical analysis, and concluded that pedestrian count did indeed depend on density, street types, and their interaction. Further, they showed that certain attractors in the network had different effects on movement: schools seemed to have a small effect on pedestrian movement, while local markets and the presence of public transport stops seemed to have a larger effect.

Altogether, these results not only show additional support to the Theory of Natural Movement but also show that there is merit in the aim of this thesis, and that to get a better understanding of pedestrian movement in urban environments, both network and distribution of density must be accounted for.

2.1.4. Examples of bridging the logics of network and surfaces

To be to design using both the logic of the street network and their centrality as well as the logic of surfaces and their density, the two must be connected in some way. Earlier studies have tested different approaches to doing this, four of which will be described here.

Yu and van Nes (2014) use additive rasterization, a common approach in GIS. By rasterizing both network and surfaces and then adding together the results, a heatmap of the city is created where different levels of centrality and density can be discerned. The model makes it simple to combine two by nature very different logics, and leaves room for adding even more aspects to the analysis (in their article, Yu and van Nes also uses the Mixed-Use Index model for additional analysis). The resolution of the analysis is, however, dependent on the resolution of the rasterization, and information does get lost in the process as neither the original shapes of blocks nor network is perfectly captured through the rasterization.

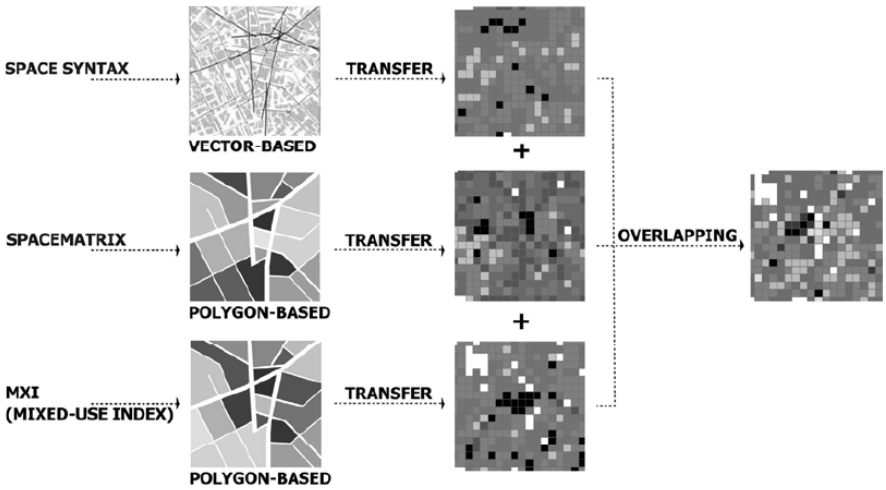


Figure 12: The additive raster process used by Yu and van Nes (2014).

Vialard (2013) proposes using the block face as the medium to carry information about both street and block, as an element which belongs to both street and building. This model does also make it possible to capture variations in both network properties and building properties along the street. The shape and character of the urban landscape is also maintained, unlike with the rasterization model. However, this model becomes very fine-grained, where every individual block face is mapped, unlike the Spacematrix model for instance which can describe density over larger areas.

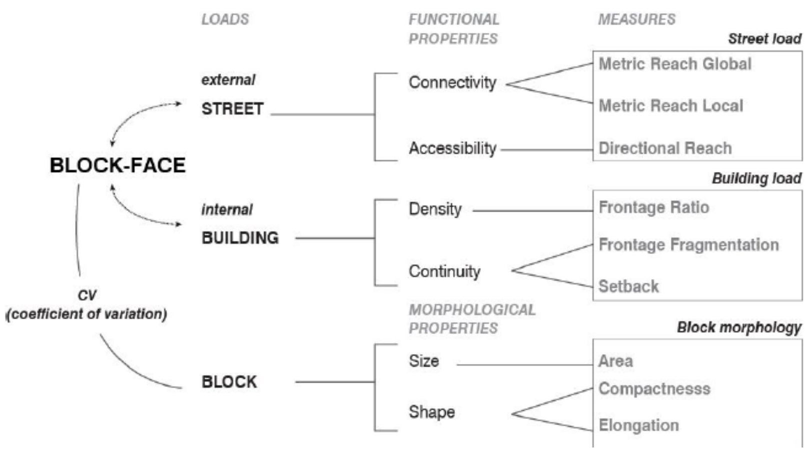


Figure 13: Vialards system for transferring properties onto the block face (from Vialard, 2013).

Araldi and Fusco (2017) opts to transfer properties to the built environment to the network, motivated by taking the point of view of the pedestrian. Their method is to calculate a proximity band for each street network segment, an area in the immediate urban space which is both closer to this street segment than any other segment, and within a certain distance from the segment, using generalized Thyssen polygons. Several indicators are then set up to describe the character of the area within these proximity bands. This model does get closer to a human actor in the urban network, and describes the character of every street, however it does miss out on the top-down perspective, as it does not consider what is outside the proximity bands reach.

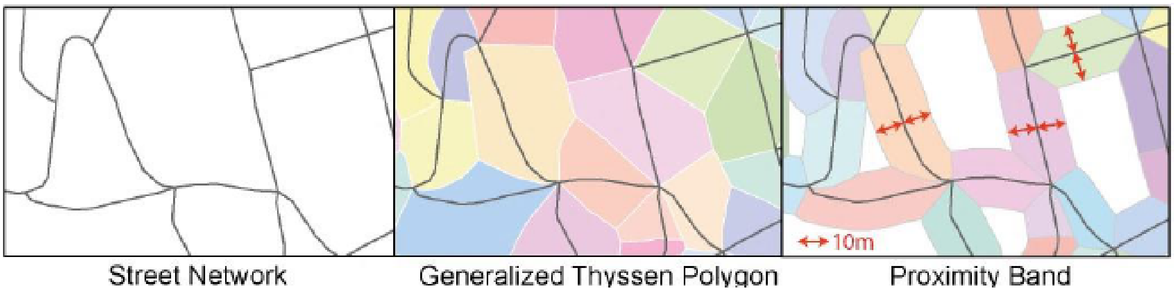


Figure 14: The method for calculating the proximity bands around each street segment (Araldi & Fusco, 2017).

Berghauser Pont and Marcus (2014) also aim to relate properties of the built environment to the human actor; by using a new network measurement they call **accessible density**. The measurement describes the density of something within a set radius from a certain point but moving along the network instead of applying the radius geographically (i.e. as the bird flies). The amount of reachable floor space within a radius, for example, would generate a type of accessible floor density, or accessible FSI. The point of departure can either be a network segment, or any surface which is close to a segment, upon which the closest segment becomes a representative “starting point”.

Like Araldi and Fusco’s model, this approach is closer to how a human being would perceive density but based more on what they are able to reach by moving along the network, than what they see at a particular street. The model uses a network model similar to the Space Syntax methodology, but since the point of departure can be anything, information of the accessible density can still be maintained as information of a surface.

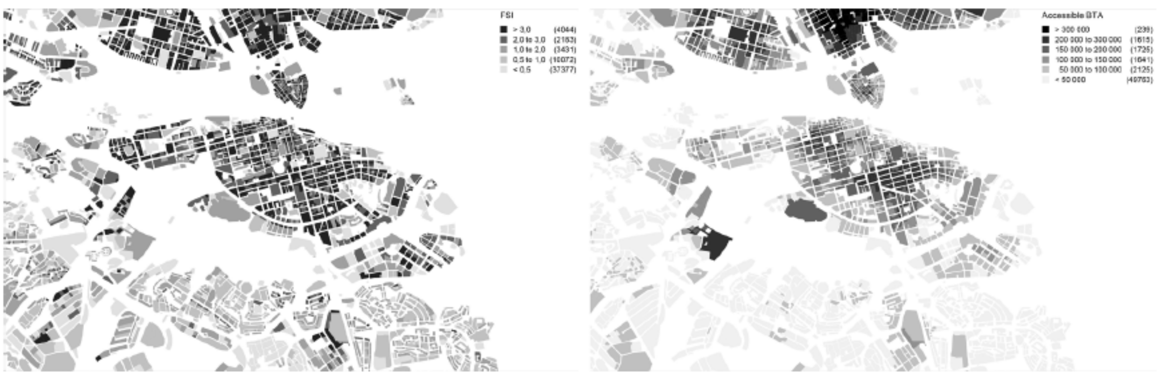


Figure 15: Two maps measuring density using the area measure (left) and the accessible density measure (right). (from Berghauser Pont & Marcus, 2014)

2.2. Existing digital tools

The second part of the research was to investigate the characteristics of existing digital tools which are used in urban planning today. The tools were assessed qualitatively and not following a systematic review approach, serving more to understand what the range of tools looks like today and compare them roughly to each other, than to give an in-depth analysis of any one tool. The purpose was to create a set of references for the later task of developing a tool.

2.2.1 List of investigated tools

The selection of tools was not made with any specific method but rather picked based on recommendations from colleagues and supervisors, and searching for relevant terms on the internet. Some of them are established tools in the urban planning field, others were recommended based on their ability to do Space Syntax analysis, and yet others picked based on how they handle certain characteristics. The selection should therefore not be seen as exhaustive.

- **QGIS** is a digital geographic information system (GIS) first released in 2002 (QGIS, 2024). QGIS is free and open-source and has a big community developing the program and creating new plugins for different tasks. The program is used in all types of spatial analysis, not only urban morphology.
- **Place Syntax Tool (PST)** is an open-source tool for performing spatial analyses developed by researchers at KTH and Chalmers together with Spacescape AB (Stavroulaki et al., 2024). The tool uses Space Syntax methodology together with conventional descriptions of attractions in a combined accessibility analysis. The program is available as a free plugin to QGIS.
- **Urban Calculator** is a design support tool developed by the Spatial Morphology Group (SMoG) at Chalmers (Urban Calculator, 2024), which acts as an interface and runs PST as the calculation engine. The tool lets urban designers and planners test different network configurations and run quick Space Syntax analyses, to support decision-making in an early design stage.
- **DepthMapX** is a spatial network analyze tool designed to understand social processes within the built environment, currently developed at Space Syntax Laboratory, The Bartlett, UCL (UCL Space Syntax, 2024). It works mainly by mapping different elements and their relationships into graphs and analyzing them to highlight potential social or experimental significance.
- **Modelur** is a parametric urban design and planning tool developed by the company of the same name (Modelur, 2024). The program focuses on testing different volume configurations in urban spaces, bringing plan drawings into volume and providing several measures for the resulting buildings for the user to evaluate.
- **Autodesk Forma** is a tool for pre-design and schematic design stages, supported by various analytical and AI-driven tools (Autodesk, 2025). Developed by the Autodesk company, it is integrated with a large ecosystem of other tools, like AutoCAD, Revit, Dynamo and Rhino.
- **Giraffe** is a digital twin tool for mapping, scenario planning, design and analysis (Giraffe, 2025). It is designed with a wider audience in mind, with finance analytical tools and APIs which load in urban data, to allow for a common platform of communication between different parties.
- **ArcGIS Urban** is a 2D and 3D modelling software for urban planners, architects and stakeholders in urban planning projects (Esri, 2025). It can handle large-scale projects and keeping an overview of multiple projects at the same time, and can be connected to ArcGIS CityEngine, another Esri product, for more advanced and detailed functionality.
- **Hektar** is a generative design tool where suggestions for possible urban block configurations are generated from input parameters (Parametric, 2025). The user sets basic geometric parameters such as boundary and interior paths, and numerical thresholds such as density and coverage, and building configurations are then procedurally generated, exploring alternatives within these boundaries.

- **DeCodingSpaces Toolbox** is a plugin for Grasshopper (Abdulmawla et al., 2025) which is a visual programming environment integrated into the Rhinoceros 3D software (McNeel, 2025). It consists of a library of programming components which runs Space Syntax analysis on Grasshopper geometry, together with some basic parametric components which generate designs based on the analysis. Additional design work is made possible through the general Grasshopper workflow.

2.2.2 Analysis and points of interest

Detailed below are the comparisons which turned out to be of most relevance to the later development of the digital tool prototype.

Scale, detail level, and design stage

Urban planning projects can be of very different scale and detail level, and this often has a connection to the design stage (something which will be discussed more in detail in chapter 2.3). This puts different demands on a tool, for example on the amount of data needed for detailed modelling over large projects, or more importantly what information and detail is of interest for an urban designer at a particular stage.

Out of the investigated tools, most were able to handle a range of scales from designing singular buildings to planning out entire districts. Some seemed more limited in size, like Hektar being limited by the demand of auto-generation in larger areas. The level of detail was often similar on all scales, the most common representation being colored areas for plots or plan areas, and colored volumes representing buildings, with lines marking each floor.

Overall, the scale and level of detail indicates that most tools were intended for earlier design stages, to give preliminary project details and an overall situation, but before the detailed shape of buildings was decided. Some did go into more detail, letting the user give the buildings more shape and character, some even allowing the user to import models from other projects to display in detail in the environment. Out of all the tools, only the ones dedicated to Space Syntax were in a 2D format, the rest were in 3D.

Figure 19: ArcGIS Urban had one of the most extensive modelling spaces both in terms of scale and detail level. Screen capture from the ArcGIS Urban web application (Esri, 2025).

Designing structures and/or objects

One relevant aspect for a digital urban planning tool is whether it is built around designing a structure, meaning the relationship between objects, or designing individual objects and the properties they have. This relates directly to the methodologies investigated in the theory section. Space Syntax could be said to be primarily a structure-based methodology as it is focused on the configuration of network segments, while the Spacematrix methodology can be said to be primarily object-based, although the different aggregate scales do create an inherited relationship.

Out of the investigated tools, the ones that could be said to be primarily structure-based were indeed also the ones that were concerned with Space Syntax. The other tools were focused on drawing up individual structures and assigning them properties, and their relationship was not of concern other than to tally up their aggregated properties. The DeCodingSpaces toolbox was unique even among the others, as it allowed users to conditionally apply parameters on built objects based on properties in the network. This extensive structure logic thus included both surfaces and networks, while additionally placing the networks in a higher design hierarchy.

Analysis modes in the tool

The main modes of interest to this thesis are the network centrality analysis used in the Space Syntax methodology and density analysis used in the Spacematrix methodology. Based on the tools assessed in this thesis, it seems that Space Syntax has not found widespread adaptation in general urban planning tools yet. In fact, there was a noticeable difference in functionality and design options between tools that did have Space Syntax and those that did not, which has already been partly discussed in earlier sections. A notable exception was once again Hektar, which informed the user how far one could reach from the project area along the street network, which in line with Space Syntax, uses a network model for the analysis.

The tools that focused on built environment objects used a multitude of density measures. Among them, the measures of FSI, GSI and OSR were common, although sometimes under other names. There was often functionality to calculate them based on a sub-set of properties, like the amount of residential and commercial floor space, and often the option to see aggregated data for different areas.

In addition, many of the tools included other analyses relevant to urban planners, such as sun hour analysis, shadow studies, wind studies, green area per inhabitant, approximate project cost, and more. These are however outside of the scope of this thesis.

Drawing and design units

A major focus of a digital tool is how the user can draw and what morphological units are used. Out of the investigated tools, most focused on drawing surfaces on the ground to demarcate different areas, commonly also working with volumes to draw up buildings or building envelopes. The usage of streets varied between either interacting with the surfaces in some way, for example by becoming a boundary between two plots, or on the other hand just being a stretch of surface on which no building could be placed. The exception here was of course the tools based on the Space Syntax methodology, where the network is of primary interest. Urban Calculator opted not to have any surfaces except for the footprint of buildings, while PST could use the surface drawing capabilities of QGIS as part of its procedure, and DeCodingSpaces could do the same with Rhino.

Generative or user-guided design

Another note of interest was whether the tools let the user design themselves, or if the tools generate design solutions for the user. This of course is tied to the concerns about EBD and deterministic design, which will be discussed in chapter 2.3.3. Most of the investigated tools turned out to be primarily user-driven in their design process, letting the designer either work out everything by hand or use simple rules or generative functions to design. Some gave suggestions based on parameters which users could choose to follow on their own volition. Hektar once again differed considerably as it was mainly a generative design tool, with minimal user input other than setting the parameters. Another notable outlier was DeCodingSpaces, which by virtue of being a Grasshopper plugin was able to adapt to the users' needs and work both generatively and analytically, provided that the user set up a program first. It was also able to generate urban blocks from the network, using an offset function.

Top-down or bottom-up design process

As final note of interest concerns whether the tools employed a top-down or bottom-up design process. For most tools, the properties of design elements simply aggregated into a total for the entire project. This can be called a bottom-up design approach, where the user designs the basic elements, and sees what the outcome becomes. On the other hand, Hektar and Modelur are at least partially examples of top-down approaches, where a main design property is set first, and the effect of this goal then applies to elements within the project. In Hektar, this is in the work of goals for e.g. net floor space, which is distributed over the project area. The user cannot directly influence the structure itself, only the parameters which generate them from the top level. In Modelur, the user can divide their area into sub-areas and link them, so that properties from a top level is automatically applied to lower levels as well unless another property is specified at that level.

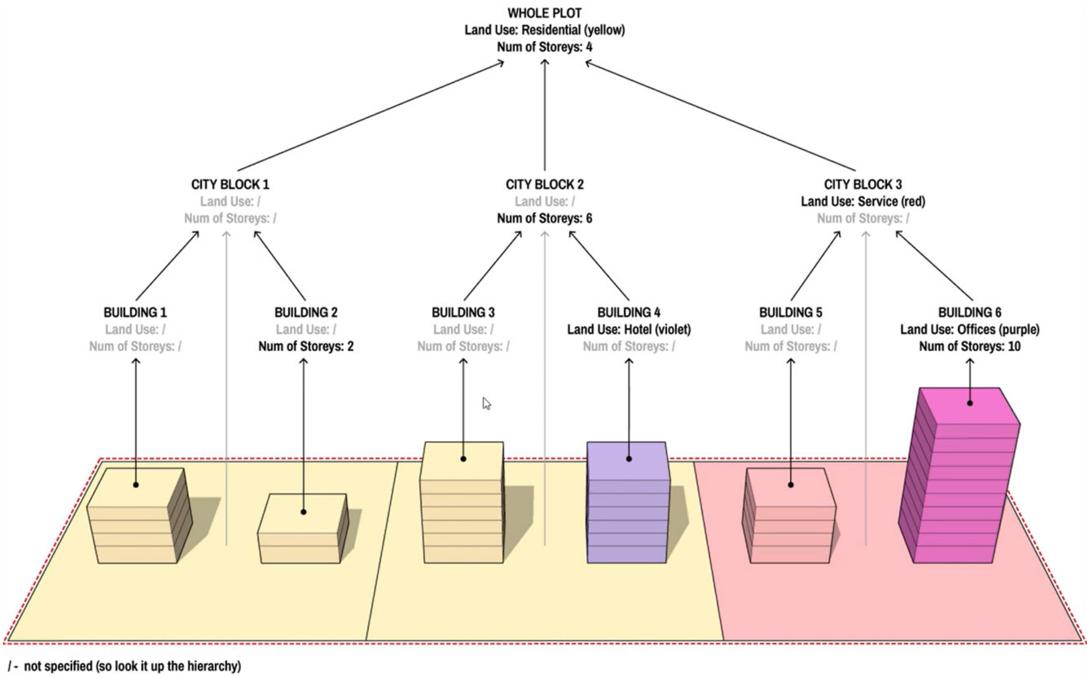


Figure 20: The top-down approach used in the Modelur software, where the properties of Land use and number of stories are inherited from the top level down. (From Modelur, 2024)

2.3. Urban planning in Sweden

The third part of the research was to investigate the urban planning process and practice, with the aim of understanding the requirements for a tool to support the Swedish planning practice. To do this, a recently developed project was analyzed using a qualitative non-systematic analysis. Besides this, two workshops were organized with the city of Gothenburg. The purpose was, like with the digital tools, to get an overview and a frame of reference for the urban planning process.

2.3.1. A case study of planning documents for Backaplan, Gothenburg

As part of the research on urban planning, a case study of the planning documents for Backaplan, Gothenburg, was conducted to get a frame of reference for what Swedish urban planning documents contain and how they are formulated.

Backaplan is located on Hisingen, on the north side of the Göta Älv river (Göteborgs stad, 2013). The project area of approximately 90 hectares is today dominated by retail and industries. At the southeast corner of the area Hjalmar Brantingsplatsen, a large public transport node connecting Hisingen to the rest of Gothenburg, is located. The goal of the project is to transform the area into a dense residential area with central city character, with roughly 2 200 new apartments and additional commercial and public space (Göteborgs stad, 2025).

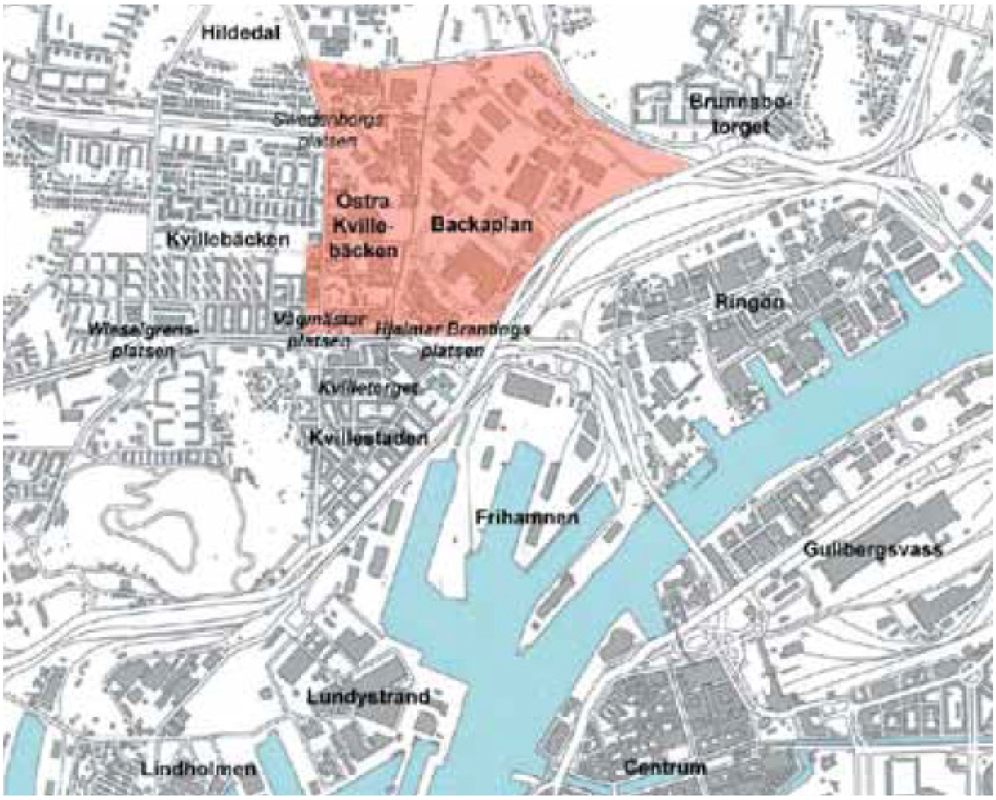


Figure: The project area of Backaplan. Illustration from the document Översiktsplan för Göteborg, fördjupad för Backaplan (Comprehensive plan for Gothenburg, focused for Backaplan). (Göteborgs stad, 2013)

For this particular project area, there is a **focused comprehensive plan** (*Översiktsplan för Göteborg, fördjupad för Backaplan (Göteborgs stad, 2013)*), a **plan program** (*Program för Backaplan inom stadsdelarna Backa, Kvillebäcken, Tuve, Lundby, Tungstadsvassen och Lundbyvassen i Göteborg. (Göteborgs stad, 2019)*), and five **detailed development plans**, out of which this thesis has looked specifically at detail plan 2 (*Detaljplan för centrumbebyggelse inom Backaplan inom stadsdelarna Kvillebäcken, Backa och Tingstadsvassen. (Göteborgs stad, 2022)*). These three documents have been the references for this thesis. Going forward in the text, these documents will be referred to using abbreviations: FÖP (from Fördjupad Översiktsplan), PRP (from Programplan), and DP (from Detaljplan) respectively.

The **comprehensive plan** (ÖP) for Gothenburg is not included although it covers the project area, because it is primarily a strategic document that only gives a general idea for the long-term development in a city. It very rarely details blocks or buildings, and often only vague boundaries for large districts, and notation and illustration are often more to illustrate strategic principles, without necessarily correlating with a specific geographic feature.

2.3.2 Support from the Urban planning office of Gothenburg

To get a better understanding of the urban planning process and what needs practitioners might have for a tool to meet, two workshop sessions were conducted with members from the Urban planning office in Gothenburg (Göteborgs Stadsbyggnadsförvaltning, going forward referenced with the abbreviation SBF). The first was held in February, and was aimed at presenting the research material, discuss the conclusions, and both get a deeper understanding and catch any misunderstandings that appeared. It was also a chance to pitch and discuss some early design ideas and ask for preferences regarding different kinds of tool functionality. The second session was held in April and was focused on presenting a draft for a digital tool prototype, to get first reactions and some feedback before finalizing the prototype.

2.3.3 Analysis and points of interest

Detailed below are the conclusions which turned out to be of most relevance to the later development of the digital tool prototype.

Scale, level of detail, and planning stage

To compare the scales, the Spacematrix system of district-fabric-island-lot-building will be used. The conversion between this system and the different levels of detail in the planning document is of course not 1:1, however the workshops with the SBF indicated that the definitions felt familiar enough to their practice, and they could relate them to the different levels of detail used in the planning documents, which is why it is used here.

With the ÖP as a basis, the FÖP looks more specifically at one section of a city and gives more detail to the strategies for that area. This is not always necessary but is sometimes done whenever an area is going through a total rehaul, like with Backaplan. In this document, the scale is mostly on the level of district, fabric and island, compared to the Spacematrix model. For example, many of the measures in the document concern the entire district, while there are preliminary, broad strokes for the function distribution. Because the street network is drawn in this stage as well, the individual blocks are also demarcated. In one illustration, a preliminary plan for the buildings in the area is illustrated, however it is without much detail and holds no legal power for the final design of the buildings, which is the purpose of the DP.

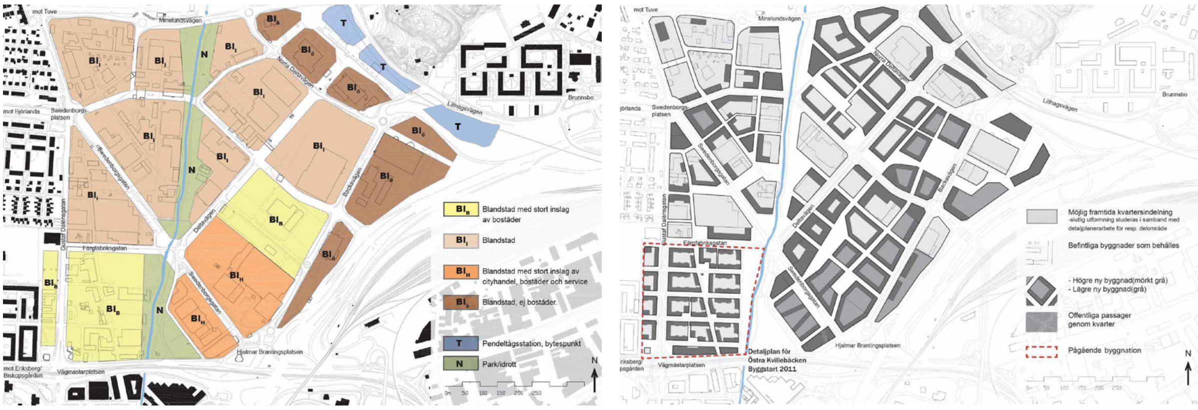


Figure 23: A preliminary functions distribution on a fabric scale (left), and a preliminary block structure on an island scale (right) Göteborgs stad (2013).

The PRP works as a middle stage between the more general strokes of the ÖP/FÖP and the very detailed level of the DP. This document is sometimes skipped over, if the project area is small enough and the ÖP/FÖP detailed enough to directly inform the DP about relevant topics. In more complex cases however, the PRP takes the next step from the ÖP/FÖP and sets the general structure of the area. It also starts getting into more details on the island scale based on the decisions on the fabric scale, distributing functions and buildings in a more permanent structure. Analyses get appropriately more detailed as well, and quantifiable indicators connected to this are used to support design decisions, such as amount of green area per apartment, distribution between residential and commercial space, and so on. Visuals to give an idea of the character of the area are included, but the final designs of buildings are still open.

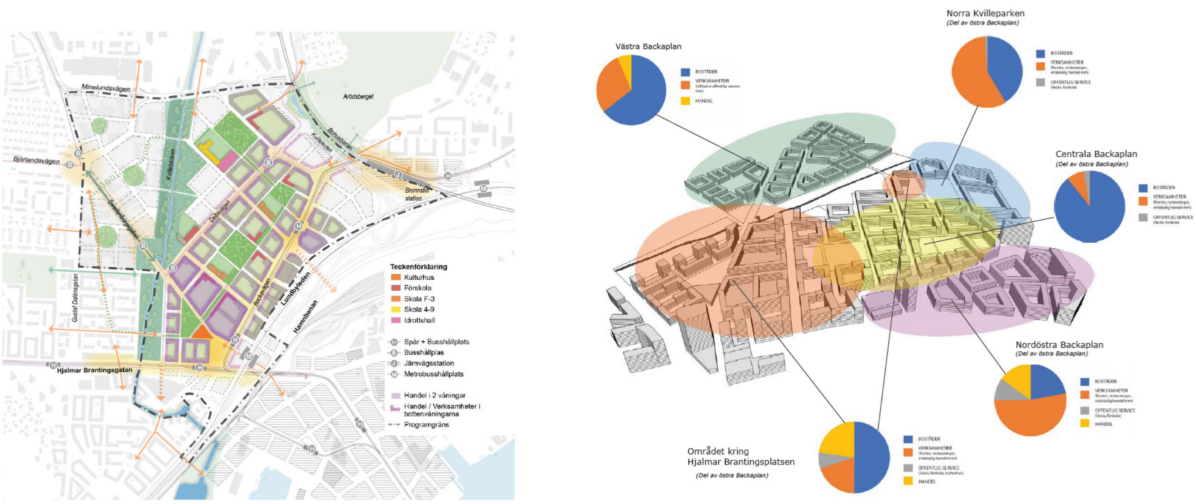


Figure 24: Examples of illustrations in the PRP, detailing the distribution of different functions in the area (left) and the proportions of residential and commercial activity in different parts of the district (right) from Göteborgs stad (2019).

When a project reaches the DP stage, the focus is on specific details of the area. Building height, footprint, and any visual, structural, and functional requirements are all set through this document. As such, the primary scale of the DP starts at the island and goes down to the lot and the individual buildings, unlike previous documents. Because the structure is set already, there is very little option for the DP to change anything about the configuration of streets and instead works within the limits given from previous documents. For larger projects such as Backaplan, there are often multiple DPs, each focusing on one part of the larger project area.

It should be noted that the planning process is not as linear as these documents might make it seem. Work on the different scales often informs or challenges each other, shaping the outcome in that process. The ÖP does however always come first, and work with FÖP/PRP is generally started before the DP, because they handle the general structure of a project, such as the configuration of the street network. This procedure can sometimes be a source of issues, according to the SBF, as it can be hard to go back and change the network at later design stages even when consequences appear which might have merited revisiting it, at which point they are limited to working within the given parameters. They voiced interest in a tool which would aid them in foreseeing the impact on later design choices in an early stage, to hopefully avoid these issues.

Planning with structures and/or objects

There was an evident transition between these two approaches between the broader documents and the more specific documents. In the FÖP, the structure is of primary relevance as it sets the street network, the main nodes and connections, and thus connects the area to the rest of the city. In the PRP, the network is set and so the focus on structures is reduced, however the placement of buildings within that network, specifically regarding their relation to other things - schools, green areas, public transport - becomes more important. Finally, at the DP level there is very little structure thinking, as both network and function is distributed, and the DP mostly focuses on individual parts and their properties.

On both workshops, it was noted that this transition is not only tied to the documents, but mainly to the design phase, which is reasonable considering a lot of decisions depend on the configuration of the street network and block structure, and therefore that must be decided early. However, it was noted that structure planning was sometimes locked in a bit too early, and that planners sometimes identified issues at later design phases where they would have wanted to go back to look at the street network again but were unable to for different reasons. In such cases, the most they could do was work with the "second level" of structure thinking as seen in the PRP, with distributing and moving things around within given parameters. As such, there was definite interest in strategies they could employ to get better predictions and understanding of the impact on late-stage design choices already in early-stage design.

Analysis in urban planning

Comparing the planning documents showed that density was analyzed continuously all through the planning documents, although at different scales and levels of detail. However, the units used to describe density differed with more general terms in the early stages (e.g. floor space over the project area) and more specific terms in later stages (e.g. private green space per residential unit). Some of the units in the Spacematrix methodology were used in the documents, but not all of them. This was also confirmed in the workshop with the SBF, where they said that they felt familiar with most of the units present in the methodology, but did not use them all in their daily work, mostly sticking to FSI, GSI and OSR. They also did not use them as systematically as the Spacematrix methodology suggested, which is visible in the documents as well, where the measurements seem tied to either established practice or to indicators set to measure certain qualities.

Space Syntax analysis was made for the FÖP and used to argue the configuration of streets and aspects such as their function, mode of transport, et cetera. In the PRP, the Space Syntax analyses done in the FÖP analysis was not available, and arguments on the placement of functions and activities in relation to the streets were made though the established street network from the FÖP. The reflection from the SBF on the issue was that it could sometimes be hard to explain to stakeholders what the results of the space syntax analysis meant, often having to explain that streets with high centrality values are not necessarily better. For that reason, interpreting the analysis often helped with discussion. There had been in-house tests of using more structured typologies connected to Space Syntax measurements, using the analysis to identify strategic main paths and nodes throughout the city, however it had not gained traction as a standard in their design process yet.

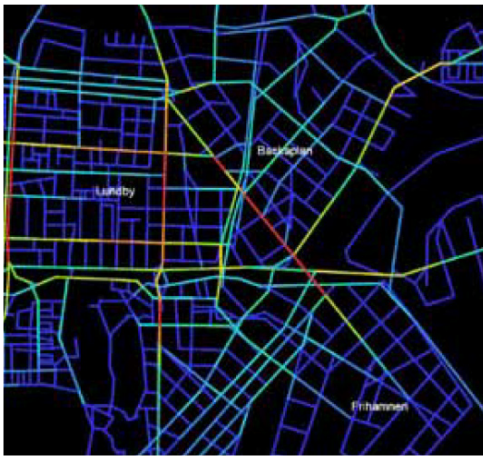


Figure 25: Space Syntax analysis before and after the new street network, done as part of the analysis for the FÖP (from Göteborgs Stad, 2013).

In addition to these, there are numerous other analyses done for the planning process, on social, ecological, geological, and many other issues. However, like the analyses in the digital tools, these are outside of the scope of the thesis.

Rules in urban planning

The intention for the built environment is often done through different rules. In the FÖP, they are often formulated in more open ways, described as intentions or strategies about the character of the area, such as describing the focus on commercial activity around Hjalmar Brantingsplatsen. But there are also more specific descriptions of the properties of certain streets, areas, or points of interest, for example describing which streets should be prepared for commercial activity on the ground floor level or marking certain views or qualities around the area that should be taken into consideration for further planning.

In the PRP, the style of rules is similar, but more of the rules are quantified and given measures, such as preventing building within ten meters of the brook running through the area, or formulating relative conditions, like dividing the percentage of commercial and residential space in an area.

The DP details the exact regulations for how developers are allowed to build. The document consists of two parts, one describing the rules and structure in written terms, the other a map showing their outcome. While the map is absolute in the way it describes aspects such as building height, that is often described through several rules in the general text: a certain height in an area, additional height allowed along a certain street, a new height set specifically for a certain plot of land.

Figure 26: The DP as described in a map. All the different letters are codes describing different conditions which apply within a certain area, products of the many different dules described in the DP.

Regarding rules, the SBF mentioned that they sometimes used parametric tools like Grasshopper formulate different rules. This approach helped them test different approaches quicker than having to manually assign different properties to each specific area, making it very useful for early design stages. However, they needed to have full control over the drawing process in later stages and saw little use for tools that “designed for them” at that point, though perhaps seeing potential value in a tool that could help assure whether all rules were accounted for in their final design.

2.4 Conclusions on research

Based on the research in the three areas, there are some major conclusions that can be made which will support the synthesis of the digital tool prototype that will be presented in chapter 3.

2.4.1 On units and measures to describe the city

While some digital tools used volumes to designate buildings, it seems that a representation based on just lines and surfaces, together with a set of measurements, can be enough to give a good representation of the city, as seen both in the various tools investigated and the case study of urban planning documents. This means that the library of measurements from the Space Syntax and Spacematrix methodologies are effective to describe the built environment from a planning perspective.

The Spacematrix system of scale units also seems very well suited for the tool. It has support in drawing practice where city districts are divided into fabrics and urban blocks. It also shares similarities with the systems in some of the digital tools that were reviewed, which helped programs deliver compound area calculations and statistics.

2.4.2 On design approaches and design stages

It was noted by the SBF that they tended to work both in a bottom-up design approach, trying different design solutions to a problem, and in a top-down approach, working within the boundaries of certain goals. However, they also noted that urban planning was often directed by larger goals set through political decisions, which makes it necessary to work in a top-down manner. Based on the review of existing digital tools, there were very few that work strictly top-down, most instead opting for a bottom-up approach, which indicates a gap which a new tool as proposed in this thesis could fill.

Regarding the design stage, the SBF described that the urban network was usually set in an earlier design stage, which means that this stage is the most relevant for this tool. Like mentioned before, they also expressed interest in a tool which would help them predict the impact that design choices in this early stage had on the later stages. This idea is similar to some of the tools, but none does it for both surfaces and networks, which once again indicates a niche for the prototype. An additional note is that working in earlier design stages lets the tool have a simpler representation of the city, which fits well with the conclusions about the simple representation of the city in the previous section.

2.4.3 On bridging the logics of network and surface

It was evident that none of the tools intentionally aimed to combine the logics of networks and surfaces, although some had taken some first steps in that direction. However, the SBF noted significant interest in a tool capable of this for the same reasons mentioned before, as this would help them anticipate impact on later, surface-based design outcomes from early-stage network planning. This, again, indicates a gap for the tool to fill, and a clear directive for function.

The literature from chapter 2.1.4 showed that there are approaches for practically achieving this. However, they had different approaches on the direction of the logic, either translating the properties of the surface to the network or from the network to the surface. While the systemic thinking of the network should be prioritized for the Theory of Natural Movement to be an active part of the design process, the case study showed that the final product is primarily a representation in the form of surfaces, not network segments, and that this is the case even as the project moves from early project stages to later ones. Therefore, it seems wise to choose a translation from network to surface for the tool.

In this context, the definitions of movement and occupation surfaces by Hillier (1996) holds a lot of merit as the definition of movement surface is so explicitly tied to the network, as they both represent aspects the possibility for movement in the urban environment. This definition could therefore act as a bridge between the logics of network and surface.

2.4.4 On other functions of interest for the tool

The ability to use multiple density variables is well established in digital tools, the possibility of linking them to building typologies will prove very useful in communicating the meaning of the measures to practitioners and stakeholders, as noted also by the SBF.

Similarly of interest is of course to present the result visually. The most common way is of course to use different colors in visual presentations of the information, something which many of the tools did in one way or another. Another is using the Spacemate and Spacematrix from said methodology to represent data and their relation to each other in a graph. Using both gives additional context to the data and might be the most informative way.

Using conditional rules as a design tool also seems to have merit, based on the comments from the SBF. This would be especially true for an early planning stage tool, where urban planners would want quick scenarios to test and compare, and could work similar to parametric programming, like the SBF did using Grasshopper.

3. Prototype synthesis

Based on the research and conclusions made from it, this chapter will now present the synthesis of the digital tool prototype. In the first section, the very basic function of how the tool represents the city is discussed, followed by all other functionalities central to how the tool operates and supports urban planners. Lastly, an example design process is presented following the same structure, to show how these functionalities could work in action. Conclusions and discussion about the prototype follow the final chapter.

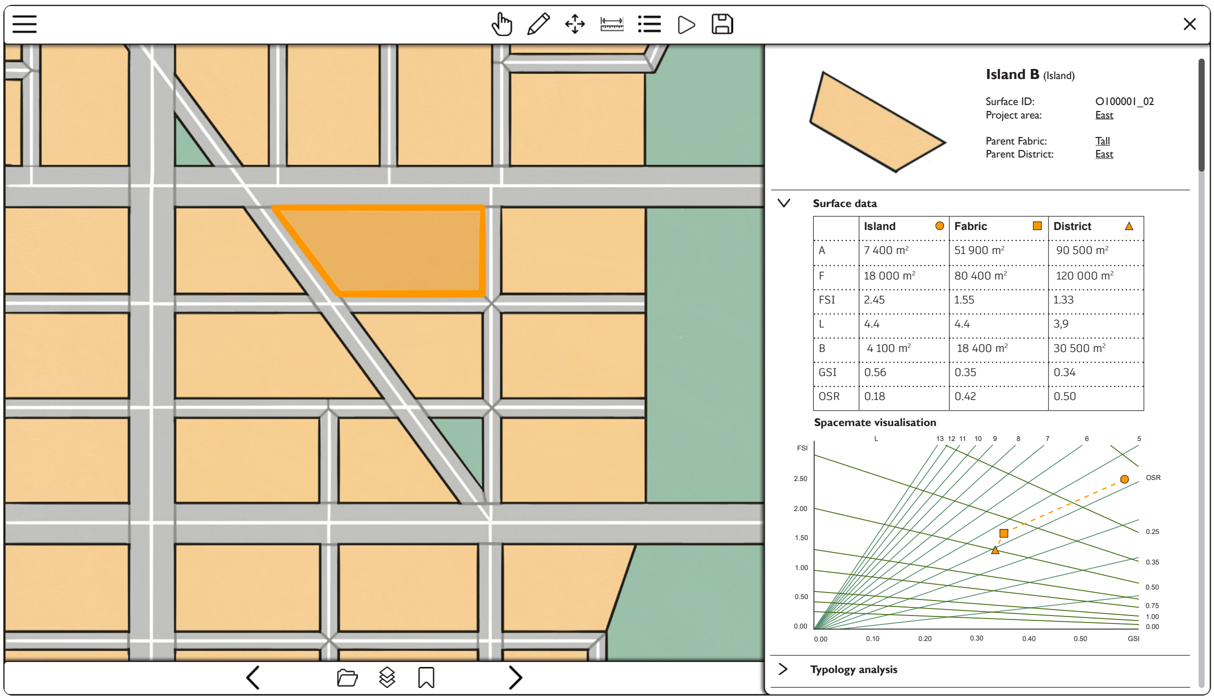


Figure 1: A mockup interface showing what the tool might look like when a user interacts with it.

3.1. Representation of the city: the model

To combine a network- and surface-based approach to representing the urban landscape, the tool is based on a model with two different layers, interacting with each other. The first is the surface layer, where the urban landscape is represented as a continuous, non-overlapping layer of surfaces. The second is the network layer, where the street network of the city is represented as a line segment network representing the road center line.

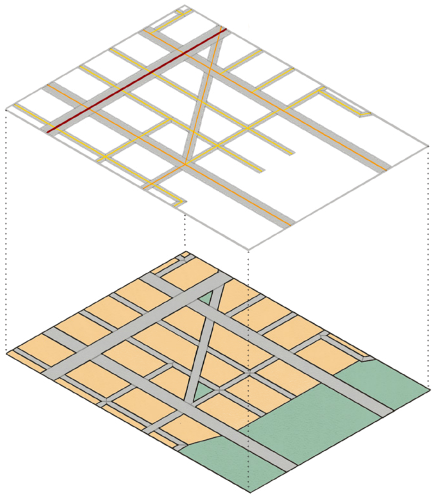


Figure 3: The two constituent layers of the model separated, with the network layer on top and surface layer below.

Surfaces in the surface layer are of two types: surfaces for **movement**, which represents streets of all kinds, and surfaces for **occupation**, which represents blocks and buildings, but also parks and non-built spaces, which are considered as occupation surfaces with a gross floor area of zero. This is based on the definition made by Hillier (1996). In the context of the tool, the polygons of movement surfaces are defined by a symmetrical offset from a network segment. Occupation surfaces, on the other hand, are defined from the movement surfaces surrounding them, in the "empty space" between the network segments. Additional properties of these surfaces can then be described through measures, as described further on.

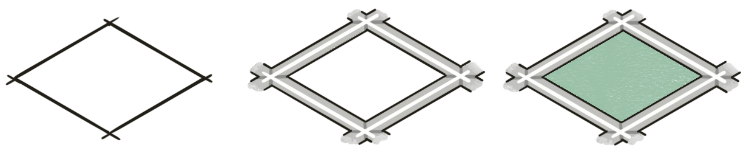


Figure 4: The network segments are the basis for the movement surface, which in turn are the basis for the occupation surfaces (here in green).

This combined model creates a setting in which the urban landscape is primarily created through the configuration of the street network, which defines the movement surfaces and in turn the occupation surfaces, which follows the basic proposition of the Theory of Natural Movement. In practice, this means that the user only needs to draw the streets as lines (network segments) and define the width of the streets; the streets as surfaces (i.e. movement surfaces) as well as the urban blocks (i.e. occupation surfaces) are then automatically generated.

This is quite different from most of the investigated tools, which focus primarily on drawing surfaces and volumes, but very similar to the generative process of the DeCodingSpaces toolbox, as seen in chapter 2.2.2. All the same, this representation maintains a strong connection to drawing practice, both in early phases where urban planners draw up the street network to establish desired connections and passages without specifying the function of the land around, and in later phases where the network is set and focus is on the density and functions of the urban blocks.

Another benefit of this model is that movement surfaces act as a link between network logic and surface logic. The program can run network analysis for the network segments, and because they each have a dedicated surface explicitly connected to it, the properties of the network can be translated onto a dedicated surface underneath. Through this, rules handling the relationship between network logic and built logic can be formulated simply as rules for surfaces and for the interface between them. This approach arguably has similarities to all of the approaches investigated in chapter 2.1.3, but is not based directly on any of them, rather adopting a mix together with approaches seen in the digital tools.

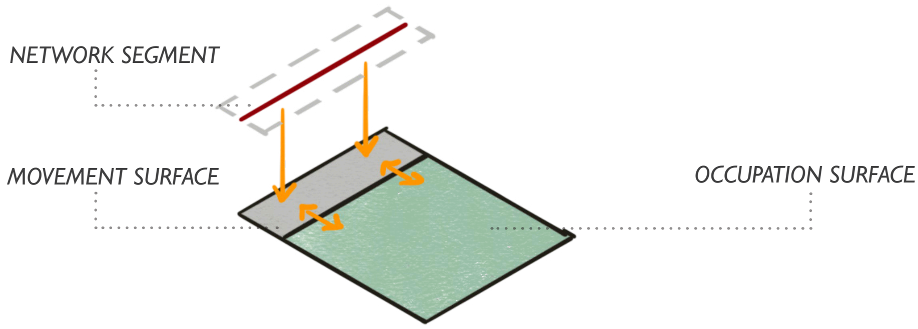


Figure 5: The properties of the network can first be translated to the movement surface, and the relationship between occupation surfaces and network can then be described as the relationship between two surfaces.

The model additionally has three defined units for scale, which are related through aggregation. The first is the **island scale**, only covering occupation surfaces. The second is the **fabric scale**, which consists of both movement and occupation surfaces, combining groups of surfaces on the island scale. A fabric unit does not include occupation surfaces with a gross floor area of zero such as parks. The third and final is the **district scale**, which combines groups of surfaces on the fabric scale, together with occupation surfaces not included in a fabric such as the parks mentioned earlier. This is based on the Spacematrix methodology, omitting the two smaller scales of properties and buildings. As discussed in chapter 2.4, this system has support both in urban planning and drawing practice, as well as in existing digital tools.

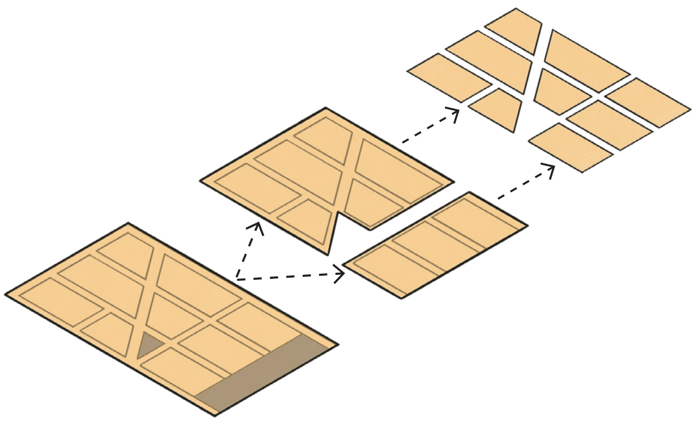


Figure 6: The same area as represented on the island, fabric, and district scales.

Just like the individual occupation surfaces, the fabric and district scales are both defined by the network lines which outline them, with the difference being that they include occupation surfaces in their area as well. For the interior network segments, the full area of the movement surface is included, and for the exterior segments making up the outline, half of the movement surface within the outline is included.

3.2 Functionality and making changes in the model

In this chapter, the basic actions the user can take to make changes in the model, and the functionality that supports these actions, are described.

3.2.1 Drawing streets and dividing surfaces

As mentioned before, the basic drawing action in the tool is simply to draw a street segment. The user can draw a line wherever but if there is an existing street network, the new lines will snap automatically to the nearest existing street to ensure that a continuous network is secured that can be analyzed using the Space Syntax methodology. Besides this first step that will be explained in more detail below, the tool will go through three additional steps:

1. Connecting the line segment connects to the existing network by splitting it into separate segments if it overlaps with any other network segment, snapping it to existing segment if it is within a certain tolerance threshold, and cutting off segments that are less than a certain threshold.
2. Offsetting a certain distance to each side of the line to create the outlines of the movement surface, and if the line ends in a dead end, adding the same offset to the end of the line segment. This offset is automatic but can be set by the user, and the user can also select a street segment and change the offset manually.
3. Creating a new movement surface using these offsets as the boundary curves, subtracting the same surface from any underlying occupation surfaces.
4. Should the new movement surface split the occupation surface into two or more separate surfaces, the tool creates two new surfaces with identical measures to the previous one (see measures in chapter 3.2.2).

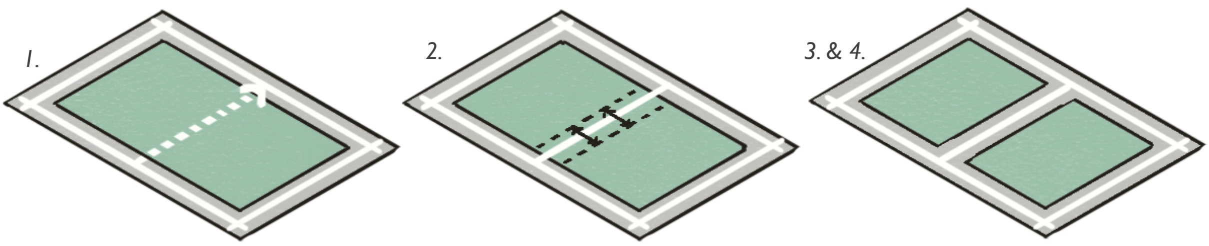


Figure 5: A new street segment is drawn, and a new movement surface created underneath, splitting the existing occupation surface into two.

If the user moves a line segment, moves an endpoint of a line segment, or deletes a line segment, the tool goes through a similar process, but rebuilds the occupation surfaces wherever needed. In that case, the properties of the larger of the two occupation surfaces are used for the new surface.

With the new line drawn, the network configuration has changed, and the user is able to run Space Syntax analysis on the network again to get an overview of the new properties of the network. This is the same functionality used in the existing Space Syntax tools (PST for QGIS, Urban Calculator, and DeCodingSpaces) as seen in chapter 2.2.

3.2.2 Properties of surfaces

The basic properties of surfaces are described through a set of **measures**, based on the Space Syntax and Spacematrix methodology, as described in chapter 2.1. Measures are divided into two groups: those belonging to the network, and by extension to the movement surfaces, and those belonging to the occupation surfaces. They can be either **inputs**, meaning the user sets them manually, or **outputs**, meaning the tool calculates and presents them to the user, or both, which means they can both be manually set or calculated by the tool. The full list of measures for the program can be seen in *Appendix: Measures and units in the tool,* however an illustration of their relationship is seen below.

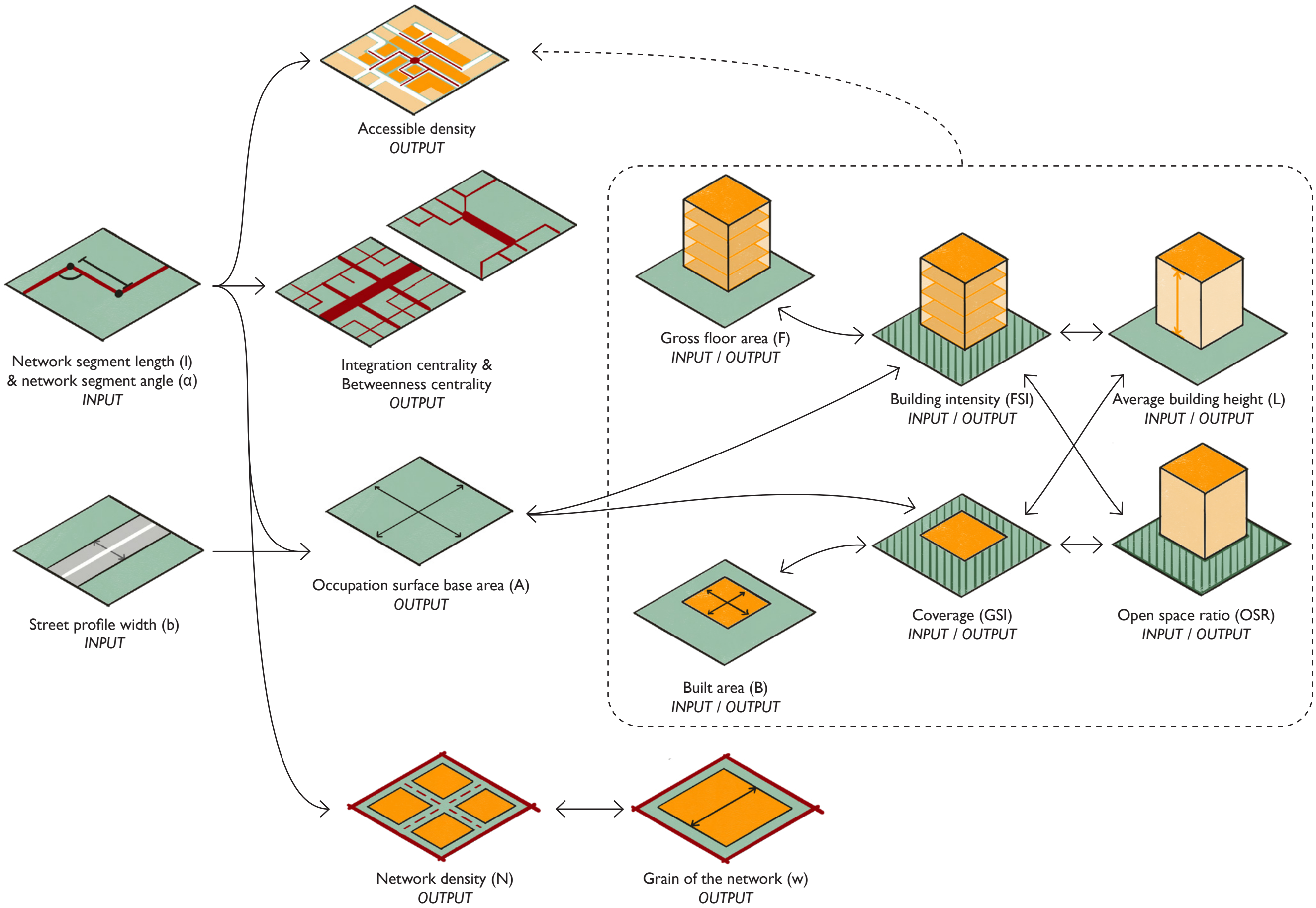


Figure 6: The measures of the tool, and their relationship to each other.

For the movement surfaces, the only input measures is street width, which together with the street segments that the user has drawn defines the base area of the movement surface. The Space Syntax measures of integration and betweenness centrality are output measures that cannot be set by the user as they are inherent properties of the whole street network. These measures are thus outputted by the tool as properties of the movement surfaces. The same goes for accessible density, which is also a result of network analysis.

For occupation surfaces, the base surface is similarly an output generated based on the street network that is drawn by the user. Based on this network, the tool generates first the movement surfaces and then the occupation surfaces, as described before.

For the properties of the occupation surfaces, the situation is different from the movement surfaces for two reasons. First, the measures of density can be manually assigned to the occupation surfaces by the user. Further, a varying set of measures can be defined by the user as input. The reason that not all measures can be defined by the user is because the measures of the Spacematrix methodology are all mathematically interconnected; as soon as two measures are given as input, the rest are calculated as output by the tool. This means that the building footprint, gross floor area, building intensity, coverage, building height, and open space ratio can all be both inputs and outputs, but the user can only choose two as input at the same time - for instance, building footprint and building height - with which all the other measures become output. The exception to this is the network density and grain of the network, which are both outputs from the network drawing and cannot ever be an input.

As an aid to contextualizing measures, the program uses directed cluster analysis to map the measures to a library of **typologies**, combinations of predefined measures. Typologies can both work as input by the user for the program, characterizing an area with a package of measures at once, or as an output from the program, telling the user what character a surface has based on its measures. The typology library contains pre-defined typologies from available research, but the user can also contribute and define their own typologies to use in their design process.

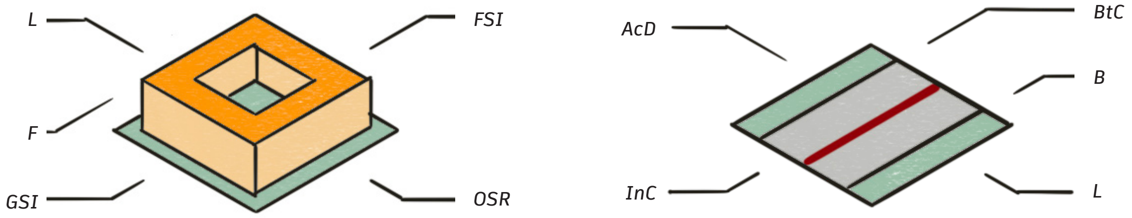


Figure 7: A certain built typology is associated with a specific set of, or a specific range of, measures.

For occupation surfaces, typologies give a sense of the density and distribution of space within an area. The system for characterizing built typologies is based on the Spacematrix methodology, as seen in chapter 2.1.2, and can concern multiple of the measures for occupation surfaces. Because most of these measures can be both input and output, these typologies can also be used in both ways, either letting the user input a combination of measures at the same time or informing them of what typology is created in a certain scenario.

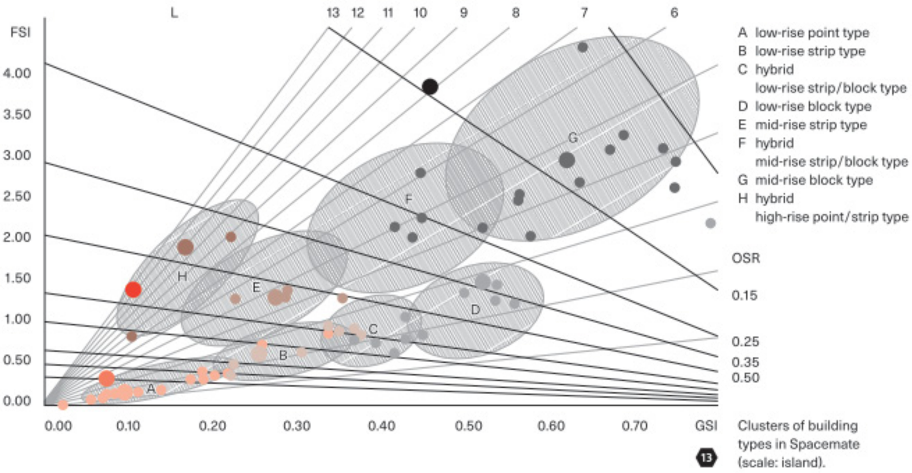


Figure 8: The eight built typologies found by Berghauser Pont and Haupt could be the basis for the typology system. Illustration from Berghauser Pont and Haupt (2021).

For movement surfaces, these typologies are based on the street profile width together with one or more of the network properties. In this way, they give an image of both potential activity on the street, and how much room this activity can be distributed over, both questions of interest as shown in chapter 2.3.2. Given that network properties can only be an output, these street typologies are limited to being outputs as well. (It should be noted that this methodology of defining street typologies is novel for this thesis; while the idea shares similarities with the work by Berghauser Pont et al. (2019) discussed in chapter 2.1.1, their work does not include more than one centrality measure nor the street width. This topic is discussed further in the final chapter.)

The final property of a surface is their scale unit, and with it also a reference to which surface they are related to on a higher or lower scale, meaning every surface unit on the island scale has a reference to the fabric and/or district they are part of. This functionality is central to the tool, because it is used for **property aggregation** and **- distribution**. Property aggregation means that all the measures on the island scale are aggregated and summarized for the fabrics they are part of, giving that fabric a character just as well as each individual surface. The same thing happens up to the district level. Distribution means that measures given to a surface unit on a higher scale are automatically distributed to all individual surfaces that are part of that larger unit.

This system of multi-scale descriptions of density is also from the Spacematrix methodology and allows users to employ both top-down design approaches through distribution, as well as bottom-up exploratory design approaches through aggregation, like discussed in chapter 2.4.

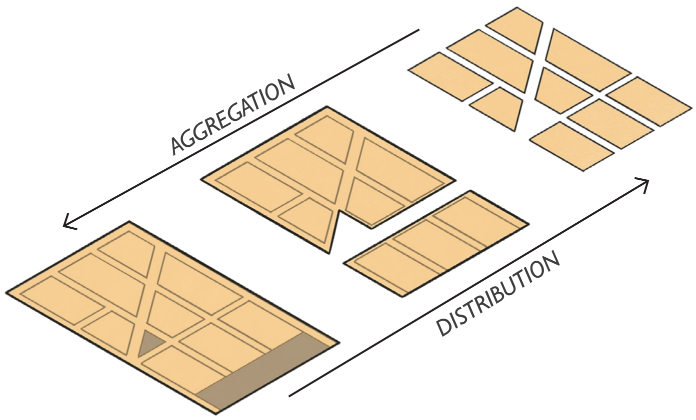


Figure 9: Aggregation and distribution through the scale units.

3.2.3 Describing relations through rules

As an alternative to manually assigning properties, the tool allows users to set up rules which automatically apply certain measures on occupation surfaces should certain conditions apply. This follows similar systems seen in both the digital tools investigated and in planning practice, as described in chapters 2.2 and 2.3 respectively.

Rules in the tool are formulated based on three basic types of application, as well as three different contexts for describing the condition, making a total of nine types of rules. The types of application are **surface rules**, which apply a measurement or condition evenly on a surface once the rule is activated; **zone rules**, which apply a measurement or condition only within a certain sub-area of a given surface; and **block face rules**, that apply a measurement or condition to a certain side of a surface, regardless of the distance between the edge and potentially built space. An example of these three would be defining the building height for an entire surface, for any building within 20 meters of a street, or for any building facing in the direction of the street.

The application contexts instead describe how the rule relates to the surface that it is applied to. **Imposed rules** are defined for a surface A and apply to any surface B next to them, for example a rule that applies to any block next to a certain street. **Activated rules** are defined for a surface B and activate once a surface of type A is next to them, for example allowing the side of a block to be unbuilt should the street next to it have a sufficiently low centrality. Finally, **intrinsic rules** concern only the surface it originates from and has no relation to other surfaces.

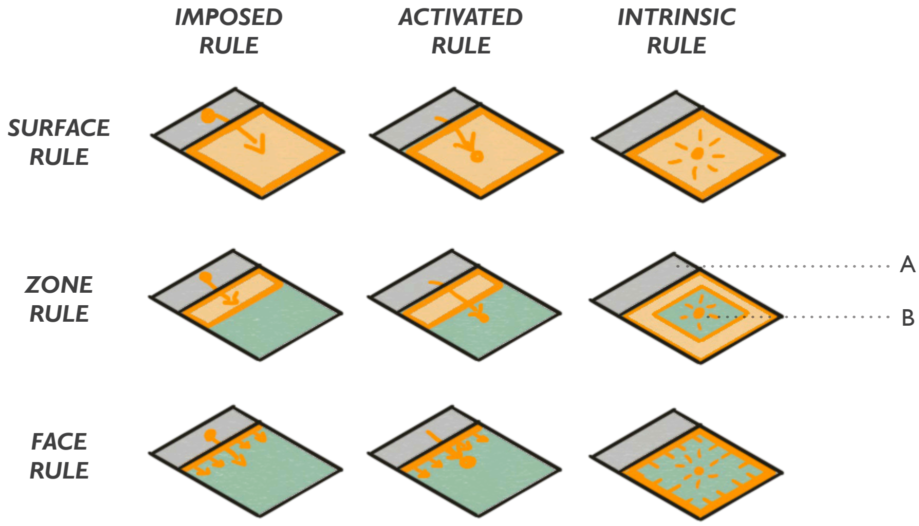


Figure 10: The nine basic types of rules as described before. The dot represents the origin of a rule, the context represented either by an arrow (Imposed and activated rules) or by the radiating lines (Intrinsic rules).

A tenth type of rule exists in paralell with these: **inherited rules**, by which rules applied on one scale may have effects on other scales as well. For example, dictating the building height for a district means that that rule applies for all the occupation surfaces within that district.

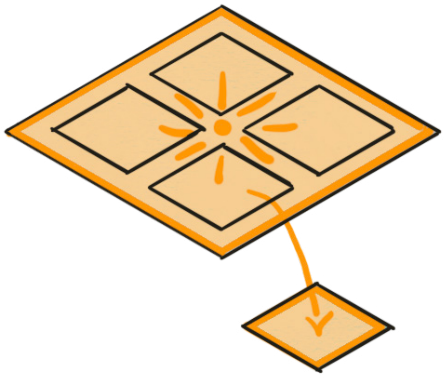


Figure 11: A rule placed on the fabric level gets inherited to one of the constituent islands.

A rule can be tied to a certain entity, either a movement or an occupation surface, but can also be tied to a condition, being activated or applied only if that condition is met. For example, a rule which defines the building height of any occupation surface next to a movement surface with a certain centrality could be applied to one specific movement surface, but it could also be applied to every movement surface in the workspace which reached the centrality threshold. Since rules apply measures, they are also able to apply typologies to some extent, although the mathematical relationships between the measures of density still has to be followed.

Rules have a system of hierarchy which the user can define and rearrange. Rules higher up the hierarchy will override ones lower down the hierarchy, and should the tool find two rules on equal footing conflicting, the user is notified and asked to define their hierarchy.

3.2.4 Analysis and displaying results

As the user draws up networks and defines measures manually and through rules (i.e. **input**), the tool continuously redistributes whatever properties are defined in accordance with the set rules and measures (i.e. **output**). The tool also runs Space Syntax analyses of integration centrality, betweenness centrality, as well as accessibility, measuring the access to measures of occupation surfaces within a set distance in the network, on the command of the user. The results are available for the user through text and tables in the interface and are also displayed using the Spacemate for occupation surfaces and similar tools for movement surfaces. The tool also presents information about the typologies tied to the measures, and the user can also explore the typology library and compare the measures in their scenario to those of other typologies to see what measures might need to change.

To help the user interpret the scenario on a wider scale, the tool can also display measures and properties visually through color or other visual indicators. The user is able to define the properties that should be shown and can filter on different measures for both movement and occupation surfaces, highlight where different rules apply, filter on different scale units, and more.

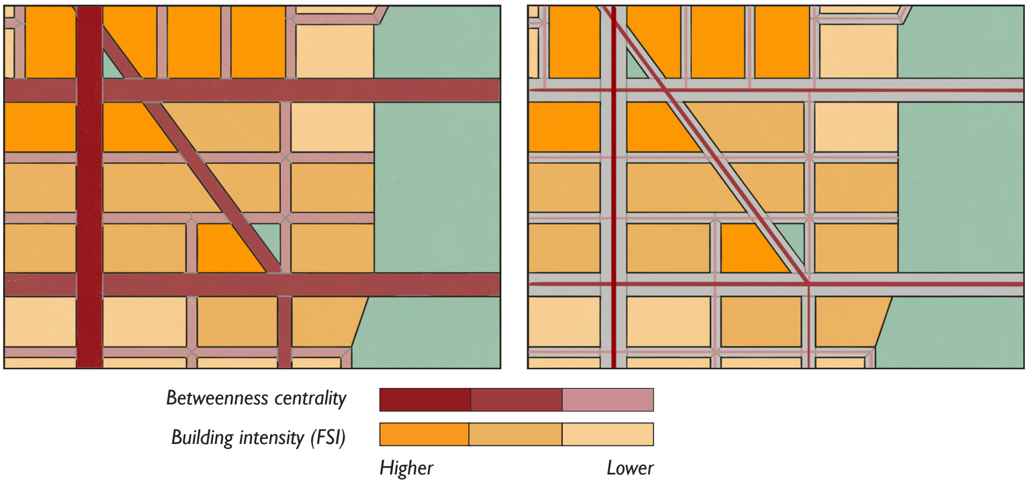


Figure 12: Two different visual displays showing the building intensity (FSI) and betweenness centrality in terms of high to low, helping the user see how well they synergize with each other.

As the design process progresses, the user can save their scenarios along the way and compare different scenarios to each other. The tool can present the comparison both in the form of tables and data, and using similar visual comparisons and overlays, either side by side or using color to indicate differences in measures between scenarios. This information supports the user in developing the scenarios further and guides them in which design approaches to take to reach certain planning goals. The user can also choose to export data from compared scenarios, with data in tables and chosen visual comparisons, as well as a compilation of applied conditions and rules set to achieve the exported scenarios.

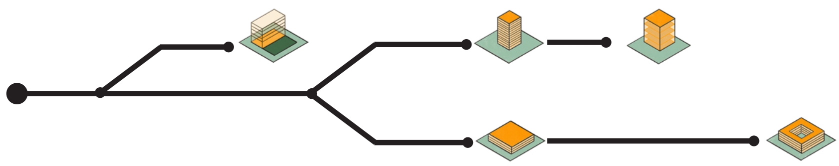


Figure 13: Saving different scenarios along the way lets the user go back and compare to see progress or compare the qualities of different scenarios.

3.3 User case: Example of a design process

For additional clarity, an example of a design process is presented below. The data behind the design process was gathered by first drawing up the process in a CAD program and then calculating measures along the process with a Microsoft Excel sheet, tailored specifically for this design process example.

In this scenario, the user starts out with a project area defined by a district with a total area of roughly 90 500 m2, in turn consisting of two islands of 37 000 and 25 000 m2 respectively, together with some streets and a section of park. For naming reasons, let's call the district *East*.

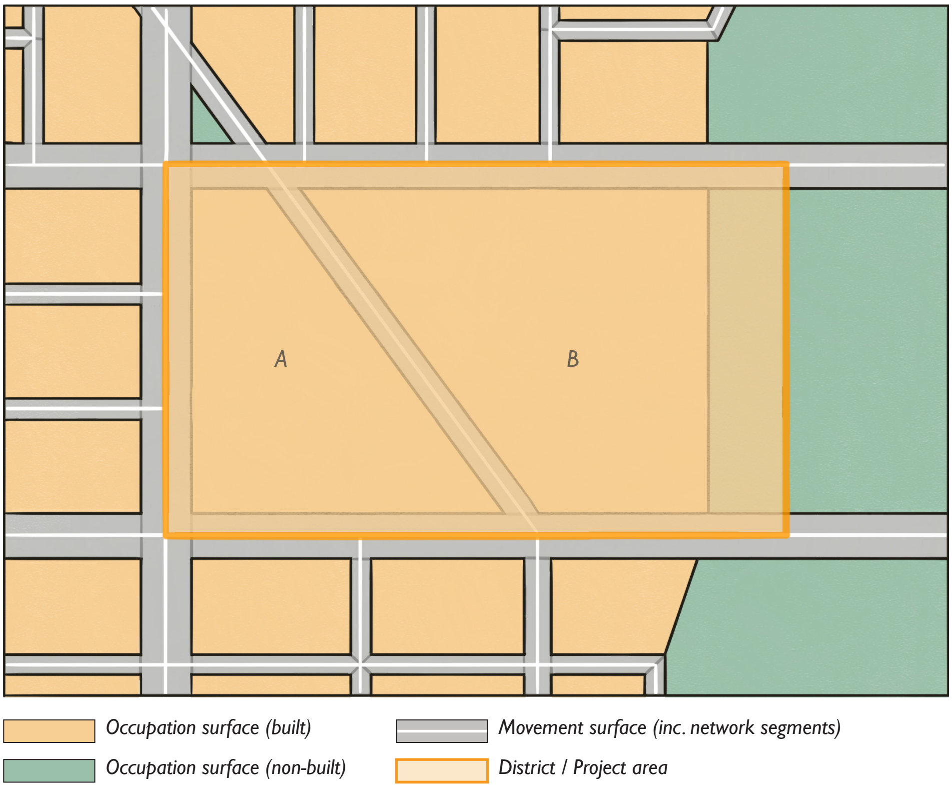
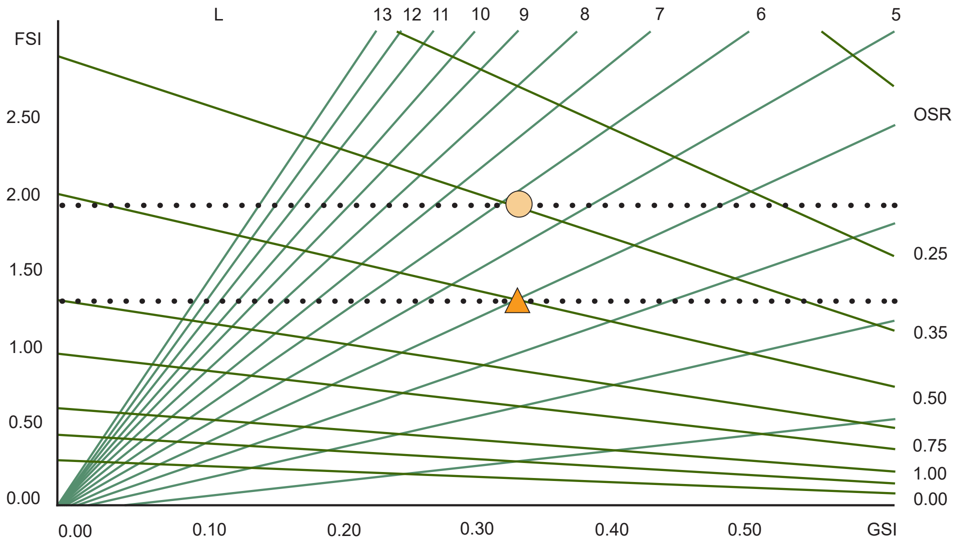


Figure 14: The project area "East" starts out as two separate islands A and B, bounded by streets and a section of park to the east.

The user uses a top-down design approach, by starting with a goal of fitting in roughly 120 000 m2 of gross floor area (F) in the project. They lock in this value to the top scale level, the district which defines the project area, and the tool immediately redistributes the floor space area between the two islands that is part of the district with respect to their relative size. Because both A and F are known, the tool can now present a floor space ratio (FSR) value for each unit as well, however the rest of the measures remain unknown.



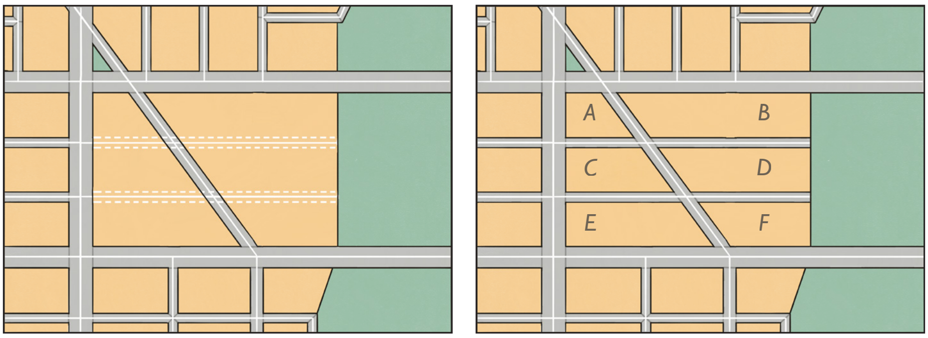
Dist.	Isl.	A (m2)	F (m2)	FSI (-)	L (-)	B (m2)	GSI (-)	OSR (-)
East		90 500	120 000 ( )	1,33	-	-	-	-
	A	37 000	71 600	1,93	-	-	-	-
	B	25 000	48 400	1,93	-	-	-	-

Figure 15: The tool presents the known measures in a table and marks this out graphically for the user with the Spacemate. In this case, the FSI is known, but without other measurements, the markers could be anyqhere along the line. Note that the grow floor space (F) is locked in at the district level and distributes down to the islands.

Should the user want, the tool can already provide basic information about what typologies might be reasonable considering the known information, and the user can use this to further guide the design. However, this optional step will be omitted in this example for the sake of simplicity.

3.3.1 Drawing out a new scenario

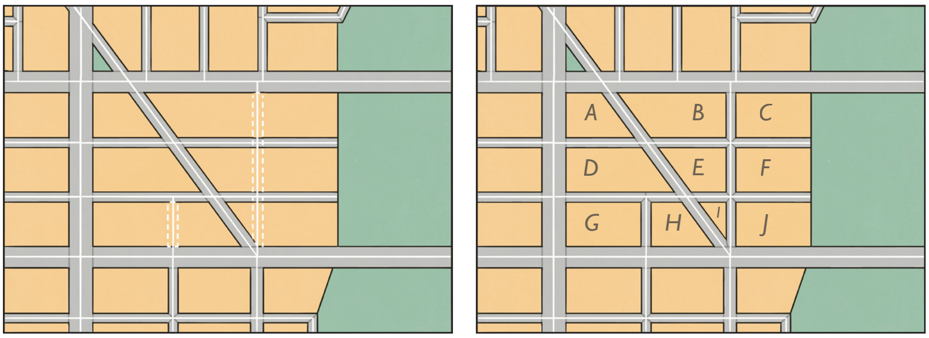
The next step for the user is to draw up new streets in the area to divide the big islands into smaller units. First, the user draws two new streets horizontally, creating six islands from the two original. The tool immediately redistributes the gross floor area accordingly.



Dist.	Isl.	A (m2)	F (m2)	FSI (-)	L (-)	B (m2)	GSI (-)	OSR (-)
East		90 500	120 000 (🔒)	1,33	-	-	-	-
	A	4 200	9 100	2,19	-	-	-	-
	B	14 100	30 900	2,19	-	-	-	-
	C	7 400	16 100	2,19	-	-	-	-
	D	10 900	23 900	2,19	-	-	-	-
	E	10 600	10 500	2,19	-	-	-	-
	F	7 700	16 900	2,19	-	-	-	-

Figure 16: New streets are drawn (top left) and the district changed from two to six islands (top right). The tool distributes the floor space accordingly (below).

Then, the user draws up vertical streets, dividing the six islands into a further ten.



Dist.	Isl.	A (m2)	F (m2)	FSI (-)	L (-)	B (m2)	GSI (-)	OSR (-)
East		90 500	120 000 (🔒)	1,33	-	-	-	-
	A	4 200	9 600	2,31	-	-	-	-
	B	7 400	17 000	2,31	-	-	-	-
	C	6 000	13 900	2,31	-	-	-	-
	D	7 400	17 000	2,31	-	-	-	-
	E	4 200	9 700	2,31	-	-	-	-
	F	6 000	13 900	2,31	-	-	-	-
	G	6 000	13 900	2,31	-	-	-	-
	H	3 800	8 900	2,31	-	-	-	-
	I	1 000	2 300	2,31	-	-	-	-

Figure 17: New streets are drawn (top left) and the district changed from two to six islands (top right). The tool distributes the floor space accordingly (below).

3.3.2 Assigning additional properties

Satisfied with the general shape of the area, the user goes on to run the Space Syntax analysis to get the properties of the network, and creates a visual overlay of the betweenness centrality measures of the streets and the FSI of the built surfaces, as seen below:

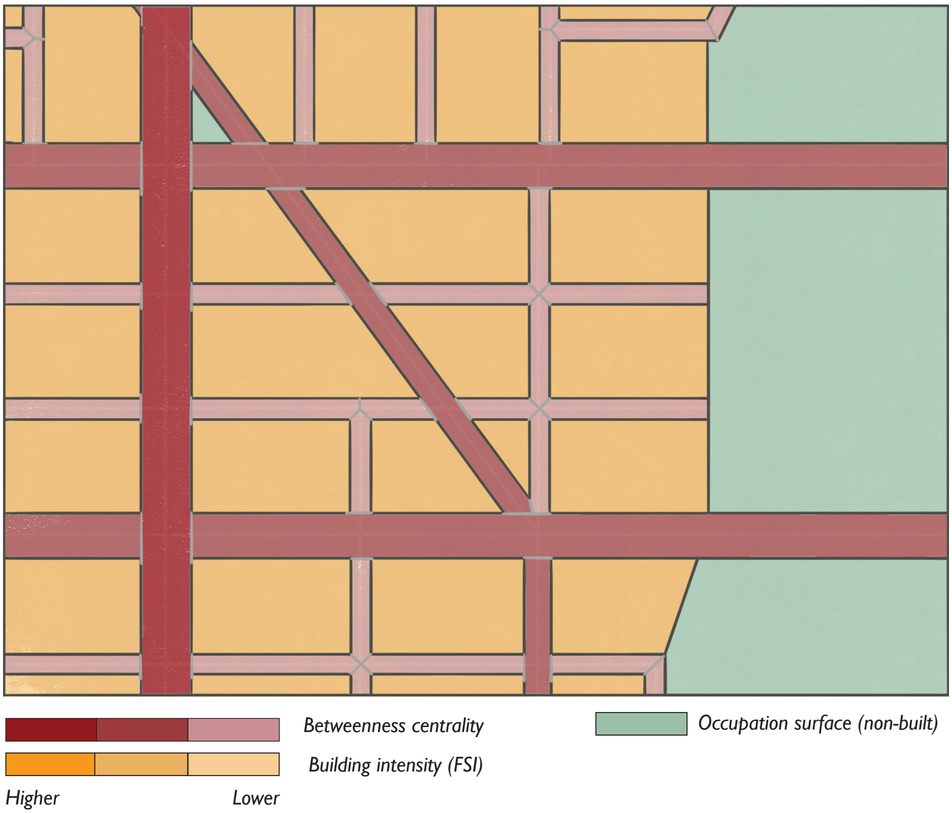


Figure 18: A visual overlay showing the FSI of the built surfaces (occupation surfaces) as well as the Betweenness centrality of the street surfaces.

As mentioned before, the tool has spread out the floor space evenly in regard to each island's size, leading to a completely equal FSI. However, the user notes that the centrality is decidedly higher on the main street going north to south than in the small streets within the project area. To achieve a more synergistic situation between the distribution of people (density) and the possible movement of people (centrality), the user decides to take measures to shift the density towards more central areas.

The user starts by creating two fabrics within the district, holding seven and three islands respectively. For the larger fabric, they assign a base building height of four stories, and for the smaller one, they choose three instead. Then, they remove the smallest island from the built count by manually setting the gross floor space to zero. This also removes it from its fabric, as non-built surfaces are not included in that scale. The scenario now looks like this:

Dist.	Fabr.	Isl.	A (m2)	F (m2)	FSI (-)	L (-)	B (m2)	GSI (-)	OSR (-)
East			90 500	120 000 (🔒)	1,33	3,6	33 100	0,37	0,48
	Tall		51 900	77 500	1,49	4,0 (🔒)	20 700	0,40	0,40
		A	4 200	9 800 (▲ 9 600)	2,36 (▲2,31)	4,0	2 600	0,63	0,16
		B	7 400	17 400 (▲ 17 000)	2,36 (▲2,31)	4,0	4 600	0,63	0,16
		D	7 400	17 400 (▲ 17 000)	2,36 (▲2,31)	4,0	4 600	0,63	0,16
		E	4 200	9 800 (▲ 9 700)	2,36 (▲2,31)	4,0	2 600	0,63	0,16
		G	6 000	14 200 (▲ 13 900)	2,36 (▲2,31)	4,0	3 800	0,63	0,16
		H	3 900	9 000 (▲ 8 900)	2,36 (▲2,31)	4,0	2 400	0,63	0,16
	Low		24 700	42 500	1,72	3,0 (🔒)	12 400	0,50	0,29
		C	6 000	14 200 (▲ 13 900)	2,36 (▲2,31)	3,0	4 100	0,69	0,13
		F	6 000	14 200 (▲ 13 900)	2,36 (▲2,31)	3,0	4 100	0,69	0,13
		I	6 000	14 200 (▲ 13 900)	2,36 (▲2,31)	3,0	4 100	0,69	0,13

Figure 19: The two new fabrics with set heights (above) and the measures of each unit (below). Comparisons are made before the height distribution.

Because two of the occupation surface measures are now set (in addition to the base surface area), the rest of the measures can be calculated. The user notes however that changing the building height did change little in terms of the density, as the tool compensated for the limitations by giving the islands in the "Low" fabric a higher GSI, which means that additional action needs to be taken.

3.3.3 Applying rules

In this scenario, the user chooses to apply three rules to try to shift the distribution of floor space even more. First, two face rules aiming at pushing floor space out towards the edges of the project area:

- Along the main street (the street going from north to south, noted for its high betweenness centrality) there should be an unbroken building fronts, and buildings should be six stories high.
- Along the secondary streets (the two streets going east to west marking the north and south borders of the project area) the buildings should also have an unbroken front, and buildings should be one story higher than the base height of the island.

Next, a zone rule which lessens the amount of available area in the "Low" fabric, thereby forcing the program to redistribute some of the available floor space to the other fabric:

- If an island has a side facing the park, the first ten meters of that island in the direction of the park may not be built upon.

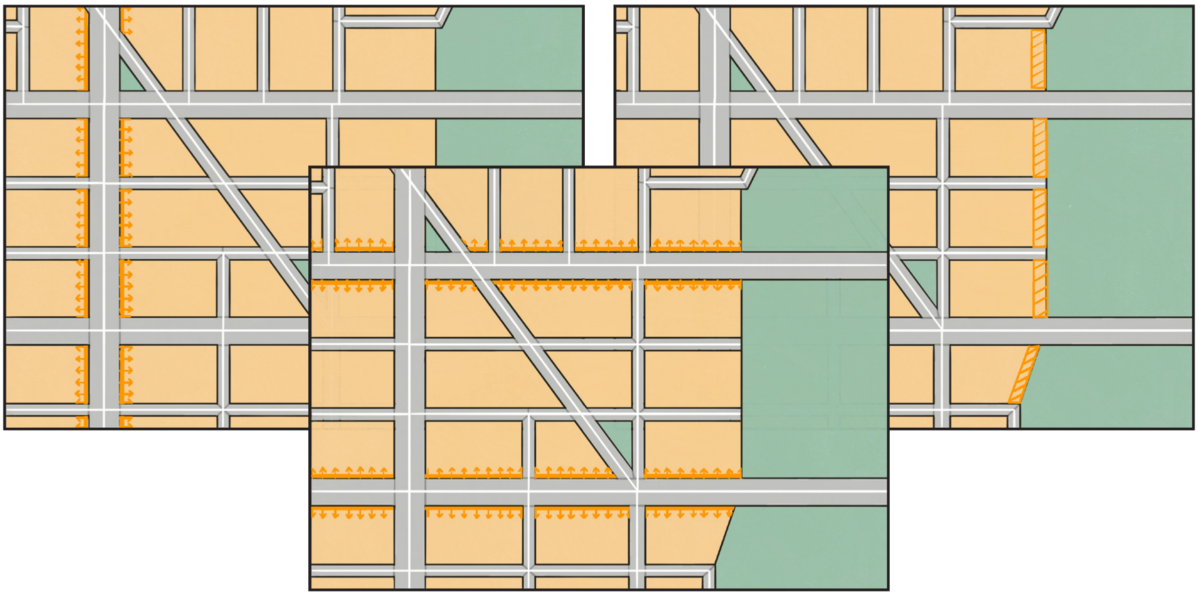


Figure 20: The faces affected by rules 1 (left) and 2 (middle), and the zone affected by rule 3 (right).

With this, the tool redistributes the gross floor space according to the rules again to the following result:

Dist.	Fabr.	Isl.	A (m2)	F (m2)	FSI (-)	L (-)	B (m2)	GSI (-)	OSR (-)
East			90 500	120 000 (🔒)	1,33 (- 1,33)	3,9 (▲3,6)	30 500 (▼33 100)	0,34 (▼0,37)	0,50 (▲0,48)
	Tall		51 900	80 400 (▲77 500)	1,55 (▲1,49)	4,4 (▲4,0) (🔒≥4)	18 400 (▼20 700)	0,35 (▼0,40)	0,42 (▲0,40)
		A	4 200	10 200 (▲9 800)	2,45 (▲2,36)	4,6 (▲4,0)	2 200 (▼2 600)	0,53 (▼0,63)	0,19 (▲0,16)
		B	7 400	18 000 (▲17 400)	2,45 (▲2,36)	4,4 (▲4,0)	4 100 (▼4 600)	0,56 (▼0,63)	0,18 (▲0,16)
		D	7 400	18 000 (▲17 400)	2,45 (▲2,36)	4,3 (▲4,0)	4 200 (▼4 600)	0,57 (▼0,63)	0,18 (▲0,16)
		E	4 200	10 200 (▲9 800)	2,45 (▲2,36)	4,0 (- 4,0)	2 600 (- 2 600)	0,62 (▼0,63)	0,16 (- 0,16)
		G	6 000	14 700 (▲14 200)	2,45 (▲2,36)	4,8 (▲4,0)	3 100 (▼3 800)	0,52 (▼0,63)	0,20 (▲0,16)
		H	3 900	9 300 (▲9 000)	2,45 (▲2,36)	4,5 (▲4,0)	2 100 (▼2 400)	0,56 (▼0,63)	0,18 (▲0,16)
	Low		24 700	39 600 (▼42 500)	1,61 (▼1,72)	3,2 (▲3,0) (🔒≥3)	12 100 (▼12 400)	0,49 (▼0,50)	0,32 (▲0,29)
		C	6 000	13 200 (▼14 200)	2,2 (▼2,36)	3,3 (▲3,0)	4 000 (▼4 100)	0,66 (▼0,69)	0,15 (▲0,13)
		F	6 000	13 200 (▼14 200)	2,2 (▼2,36)	3,0 (- 3,0)	4 000 (▼4 100)	0,69 (- 0,69)	0,14 (▲0,13)
		I	6 000	13 200 (▼14 200)	2,2 (▼2,36)	3,3 (▲3,0)	4 000 (▼4 100)	0,66 (▼0,69)	0,15 (▲0,13)

Figure 21: The new table of measures after the rules are applied, with comparisons to before application.

3.3.4 Displaying the result

Looking at the results, the user can see that the rules did indeed help shift the gross floor space towards the "high" fabric and away from the "low" fabric. Using the same visual overlay again and showing the relationship between FSI and betweenness centrality, the user can also see that the two operate with more synergy now, focusing movement and density of people around the same areas:

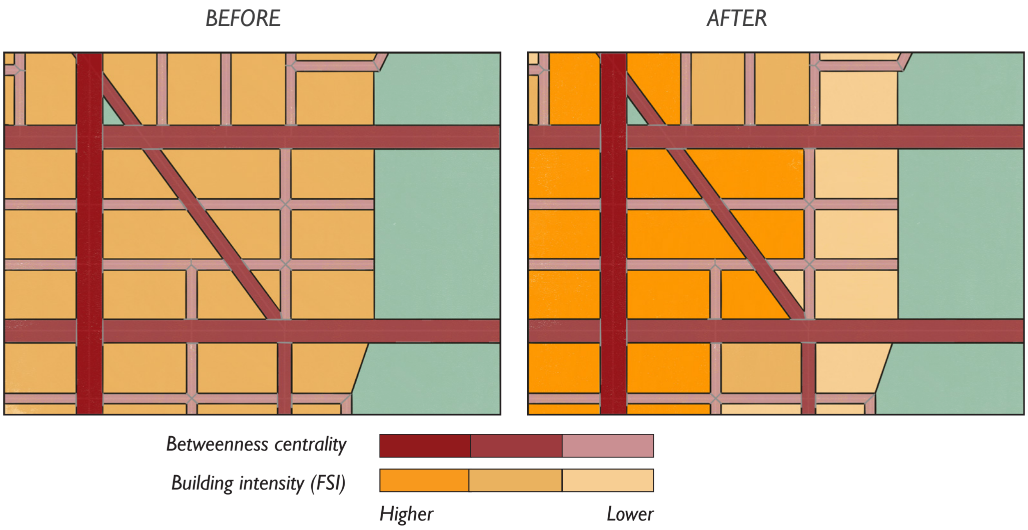


Figure 22: A visual overlay showing the FSI of the built surfaces (occupation surfaces) as well as the Betweenness centrality of the street surfaces, comparing before (left) and after (right) the application of building height and rules.

The user can also see that the building footprint decreased slightly for each island, which therefore made GSI slightly lower and OSR slightly higher. However, the GSI is still pretty high and the OSR pretty low, especially for the islands in the "Low" fabric. To remedy this, the user could proceed by either fine-tuning the rules to improve these numbers, set a new rule to define a floor for the OSR, or try a new approach altogether by defining other measures than the building height. As they continue to work, they can save their different scenarios along the way and compare them similarly to the comparisons made above.

4. Conclusions and discussion

In this concluding chapter, conclusions about the prototype and how it meets the aim and research questions of the thesis are made, together with some additional discussion regarding the future of the tool and some challenges and opportunities that could be considered.

4.1 Aim and result

Through the digital tool prototype, this thesis has shown a possible way for urban planners to actively use an evidence-based design approach based on the Theory of Natural Movement, which was the main aim of the thesis. Using the network drawing as the main tool for designing makes sure that the network logic is central to the tool, and the concepts behind the Theory of Natural Movement remain integrated in the design process from start to finish. With the tool being anchored in the research, it ties into both theory and practice and bridges them together, making theory more accessible to practitioners.

Regarding the research questions, the main design methodologies of Space Syntax and Spacematrix have both been investigated and reflected on both in comparison to design practice and to a set of existing digital tools. Relevant morphological elements, attributes, and relationships from both were collected to make the basis of the library of measures and units, the scale system, the rules system. These were applied to the context of a digital tool, and to support this, a proof of concept in form of a prototype and an example design process from said tool was presented.

With this, the thesis has not only achieved what it set out to do but also contributed to the field of urban planning by exploring the benefits of actively using the Theory of Natural Movement, and the Space Syntax methodology, as well as showing a possible way that it could be done. Additionally, by using a digital tool as a way of expressing the findings, the thesis shows that implementing these ideas into practice is possible, and perhaps not far into the future.

On a more theoretical level, the thesis adds to the discourse about urban morphology and spatial measures by showing another way through which the logics of network and surface can be combined, adding to the work done by Yu and Van Nes, Vialard, Araldi and Fusco, Berghauser Pont and Marcus, among others. However, the thesis has not investigated the strengths and weaknesses of this model compared to the others on a deeper level and so leaves that work to future research.

4.2 Other reflections

Outside of the frames of the thesis aim, some additional reflections warrant including in the thesis.

4.2.1. Challenges to making the tool a reality

While the thesis does show proof of concept for the digital tool, programming the tool has not been part of the process. Therefore, there remain questions about some challenges of implementation. One such question is whether the tool would run smoothly, or if the calculations of network properties, built space measures to distribute, and rules to follow, might become very heavy and unruly. Programming the tool in an efficient way would surely be important to be able to properly use it in practice.

Another question is if the data the tool uses – street networks and measures, for example – is readily available, or if there is a lot of preparations needed before the tool can be used. A partial answer to this question is that data is increasingly available, reasons being for example increased digitalization, better digital models such as digital twins of cities, and increased interest in analysis methods such as Space Syntax which does require data that this tool uses. However, for the tool to be implemented, this question must be taken into consideration.

On the same theme, developers would do well to consider how the tool fits in a larger ecosystem of digital tools, as well as how it fits into an established design process. This regards aspects such as importing and exporting data, for example. This has not been part of this thesis, except for considering the general process of design practice and the functionality of a selection of tools, however for a tool like this to be of interest for urban planners, an important factor is also being able to use it without having to make major changes, or even concessions, in the established workflow.

4.2.2 Avoiding the trap of deterministic planning

Like mentioned in the introduction, critics of evidence-based design approaches have often claimed that there is a tendency for design and planning to become too reliant on data and by consequence become deterministic in their outcome, missing other aspects which shape cities such as culture, history, aesthetics et cetera. It is important to acknowledge that the prototype tool presented in this thesis does risk facing similar criticisms, as it relies on data, algorithms and distributing measures to meter out density and other aspects.

However, it is important to be clear about how the tool should be used, for that same reason. It should not be seen as a comprehensive planning tool, but rather an early drawing and analysis tool. With this tool, urban planners can draft up scenarios based on data and then modify the scenario to accommodate other aspects which this tool cannot capture. Some aspects might even be possible to capture in a simplified aspect in this tool – preserving cultural heritage areas could, for example, be represented by locking in their density measures on the island they stand on, preventing the tool from redistributing floor space there and "rebuild" it. In any case, the tool is not meant to plan cities by itself, but rather to help urban planners understand and plan for certain aspects of urban space with precision and better understanding.

4.2.3 Application in suburban environments

In this first prototype, the tool is considerably better at planning in dense urban grid situations, where there are very clear borders between the street and the block or plot. This type of environment is common in city centers. Here, the dense typologies require the available space to be used in certain ways that is easy for the program to describe and for the planner to imagine.

Further out from the city core, the division between street and building is often not as clear cut, and the islands created can be big, green areas with houses dotted in them and just a few access streets reaching out to the houses. In such a setting, the tool has a harder time accurately describing the environment, because it has no way of describing the houses as separate details. In short, all houses could just as well be pressed into one corner of the open space as they could be evenly spaced along the access roads, and the tool wouldn't know the difference. In situations such as this, the planner must use the typologies function to compare with real settings and use their imagination, or a separate CAD tool, to interpret what the space might look like.

4.2.4 Regarding movement surface typologies

As briefly mentioned in chapter 3.2.2, the concept of movement surface typologies combining both systemic measures from Space Syntax and other measures like the street width does not have the same theoretical backing as the typologies for occupation surfaces, which were based on Berghauser Pont and Haupt (2021). The idea of these typologies was inspired by the multiscale centrality profiles identified by Berghauser Pont et al. (2019) on one hand, and the four street profile types in the manual Designguide för smarta gator (Designguide for smart streets) by Ståhle et al. (2022) on the other. These two look at Space Syntax properties and spatial properties respectively. There was also an expressed interest from the SBF in investigating this a bit, to get a more nuanced picture of the potential of a street. Due to time constraints, this concept could not be fully developed, and no actual typologies are defined as part of this thesis, but the concept seemed promising enough to include in the prototype nonetheless.

4.2.5 Further work with the prototype

As with any project, many ideas planned for the prototype were not possible to include due to time constraints or other factors. The first and most obvious is of course to write the code for a functional digital application, to test the functionality in practice.

Other than that, a noteworthy function would be to add a fourth scale unit to the prototype, and let users divide up a surface into separate parts with separate properties. That would allow users to plan out separate buildings, mark out courtyards and open spaces, and be able to use the digital tool a little further into the design process.

Another function would be to add properties concerning usage. This would allow users to differ between commercial and residential space, or between motorized and pedestrian streets, for example. It's common for tools to have the functionality to differ between uses, especially for floor space where it's often of interest to see how many apartments or how much commercial space is created in a project. This function would also give more dimensions to typologies and give a more nuanced image of the project in general.

Finally, adding a third layer to allow users to place points in the urban landscape would create the conditions for extended accessibility functions. In short, the tool would be able to not only calculate the accessible area within a distance, but also the accessible amount of something. It would also complement the usage functions well, as the presence of something might sometimes be more relevant than the specific area it occupies – for example, the presence of a healthcare facility, or the number of bus stops close by.

The author hopes that, should anyone take interest in developing the prototype further, some of these functions are considered in the process.

Afterword

A good word to describe this work is "different". It's different from anything else I've done in my time at Chalmers, it's different from what most of my peers did for their theses, and it's also different from what I expected to do when I wrote the project plan alomst a year ago.

The core idea was the same: developing a prototype for a digital tool for urban planners, combining Space Syntax with measuring of density. But in my mind I expected to spend my time creating big, complex Grasshopper scripts, and not expecting how much time I would spend trying to wrap my head arount the theory behind it, or being able to clearly and concisely communicate an idea based on said theory.

But different doesn't mean bad, and writing this thesis has been a great journey. I leave Chalmers equipped with a field of knowledge I did not expect a year ago, but which I am excited to continue developing. There are so many ideas that I did not have time to fully develop as part of this work, and I'm itching to get a shot at it in the future. I hope that this thesis manages to communicate this curiosit.

A word of thanks to my friends at the "office space" on the fifth floor is in order - working with this thesis would have been even tougher without your company and support. Thank you also to Julia for your endless encouragement, and for your patience with my long days and late nights.

Finally, thank you to my supervisor, Meta Berghauser Pont, for introducing me to the field of spatial morphology, and for challenging me, supporting me, and teaching me so much along the way. It really has been fun.

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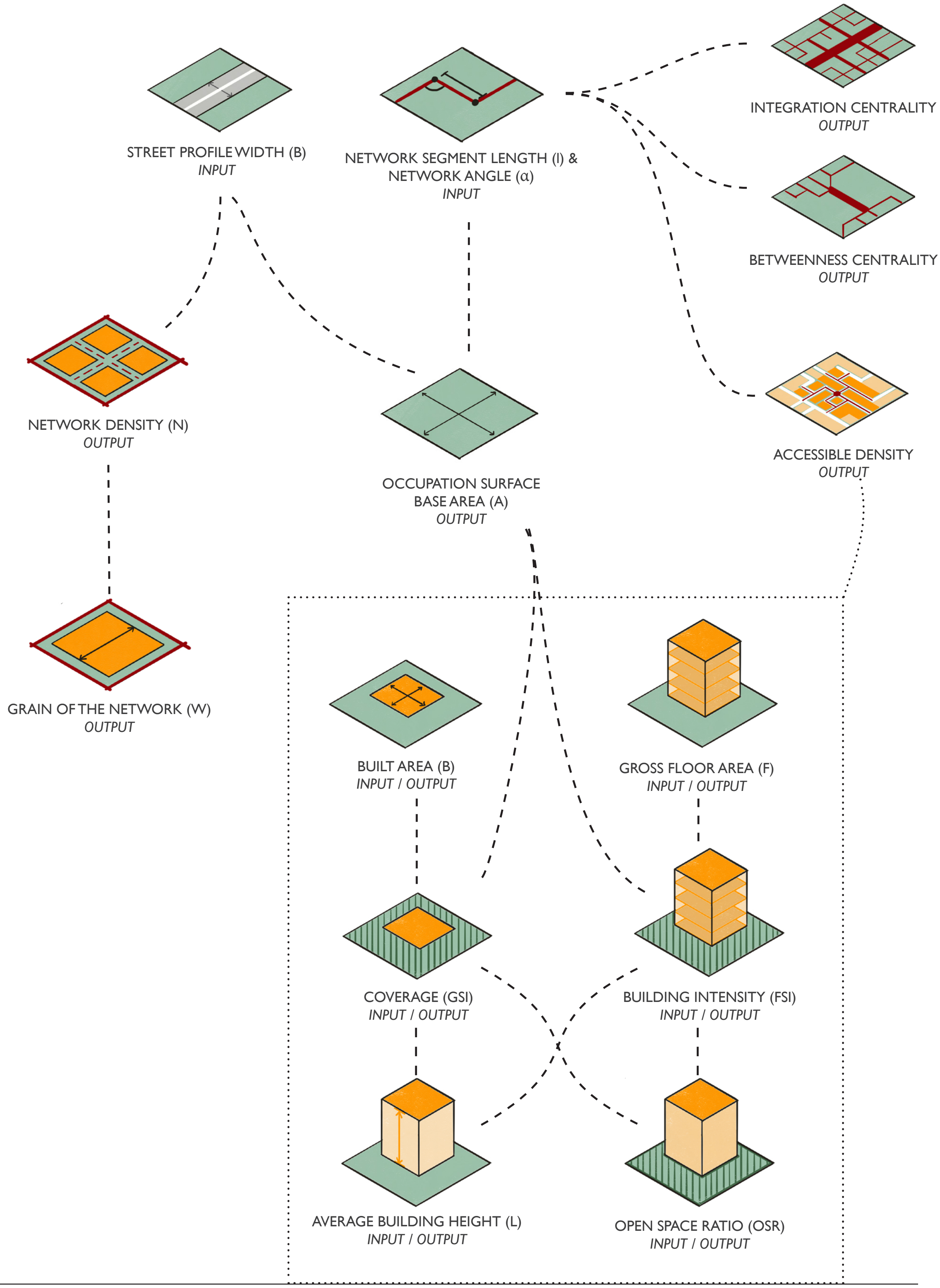
Appendix: Measures and units in the tool

	Measure	Description	Input or output
Movement surfaces	Street segment length (l)	The length of the street segment from node to node.	**Input**; comes from the network segment the user draws.
	Street segment angle (α)	The angle between two street segments.	**Input**; comes from the network segments the user draws.
	Street profile width (b)	The width of the movement surface measured perpendicular to the street segment length.	**Input**; there is a standard width, but the user can manually choose a larger width.
	Integration centrality	Measures how topologically close a street segment is to every other segment in the network (or a subset of it).	**Output**; comes from the network segment, calculated through network analysis.
	Betweenness centrality	Measures how often a segment appears as part of the shortest path between any two points in the network (or a subset of it).	**Output**; comes from the network segment, calculated through network analysis.
	Accessible density	Measures how much of a certain measure, such as floor space, can be reached within a certain network distance.	**Output**; comes from the network segment, calculated through network analysis.
Occupation surfaces	Base area (A)	The area of an occupation surface poly-gon.	**Output**; comes as a result of drawing the network around an area.
	Built area (B)	The area taken up by the footprint(s) of building(s) within an occupation surface polygon.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Gross floor area (F)	The total amount of floor area within an occupation surface polygon.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Building intensity (FSI)	The relation between gross floor area within a polygon and the area of the same polygon. Defined as $FSI = F / A$.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Coverage (GSI)	The relation between building footprint within a polygon and the area of the same polygon. Defined as $GSI = B / A$.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Average building height (L)	The average height of the building(s) within a polygon. Defined as $L = FSI / GSI$.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Spaciousness (OSR)	The relationship between the gross floor area and the unbuilt area within a polygon. Defined as $OSR = (1 - GSI) / FSI$.	**Both**; can be manually chosen by the user, or calculated by the program from other measures.
	Network density (N)	The concentration of networks in and around a polygon. Defined as $N = (\sum l_f + (\sum l_e / 2)) / A$, where l_i and l_e is the length of fabric inside and on the edge of a base area unit respectively.	**Output**; is a direct product of the drawn network and base area distribution.
	Grain of the network (w)	The representative length between two street segments. Defined as $w=2/N_f$, where N_f is the network density in a fabric.	**Output**; is a product of the network density.

Relationship between the units



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