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Space Syntax:
Exploring the applicability of sociospatial theory during the COVID-19 pandemic
Evidence from Groningen

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Master's Thesis

To fulfill the requirements for the degree of
Master of Science in Environmental & Infrastructure Planning
at University of Groningen under the supervision of
Prof. dr. C.H. Yamu (Faculty of Spatial Sciences, University of Groningen),
Dr. F.M.G. van Kann (Faculty of Spatial Sciences, University of Groningen)
and
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February 15, 2022

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Acknowledgments

I would like to express my special thanks and gratitude towards the following people, whom without this thesis would not have been possible.

- Dr. Claudia Yamu, for her invaluable Space Syntax insight and supervision during the development of this thesis.
- Dr. Ferry van Kann, for having to unexpectedly take up the torch of supervision midway the writing of this thesis.
- PhD. Efstathios Margaritis, for his co-supervision and Space Syntax knowledge, in aiding both Ferry and myself.

Further gratitude is expressed towards the volunteers of this research, who assisted during the fieldwork.

- Stijn Rommets
- Reinder Boomsma
- Anouk Feijen
- Tim Smit
- Tara Kraaieveld

Abstract

The COVID-19 pandemic has had a significant impact on society. At the time of writing this thesis it is, in fact, still having a major grip on the gears that keep our society running. During multiple pandemic lockdowns inflicted by the Dutch government, socio-economic processes have been brought to a halt, in attempts to minimise the spread of the virus. This has put a lot of stress on the social well-being and the economic functioning of cities, with increasing consequences of social malaise. It is this scenario that has questioned the urban resilience: meaning how well can a city cope with the effects of a global pandemic. This research aims to put sociospatial theory into practise, in order to see if it is capable of evaluating the well-functioning of urban settings during a pandemic lockdown. If so, then this field of social sciences might provide solutions to mitigate the negative effects of lockdowns (or pandemics) on cities, improving aspects like safety, quality of life and maintaining socio-economic stability.

During this research Space Syntax is the applied sociospatial theory, to evaluate on the movement patterns of pedestrians and cyclist during one of the lockdowns in the Dutch city of Groningen. Through a mixed-method approach of field observations, Space Syntax analysis and statistical analysis, this research aimed to determine the applicability of Space Syntax for evaluating and predicting the well-functioning of urban space. This research concludes Space Syntax to be a viable candidate for both evaluating and predicting the functioning of urban space during a pandemic situation. Space Syntax allowed for comprehensive insights into the movement patterns of inhabitants of the city, without the requirement of complex resources. Additionally, the statistical analysis concluded the observed movement patterns of inhabitants to be in line with the expectations of the Space Syntax theory, justifying it's usage as a predictive tool. Finally, Space Syntax' practical and visual approach towards communicating information, was found ideal for both experts and non-experts.

Existing limitations of Space Syntax, as well as the context in which this research was conducted, apply to the concluding statements of this thesis.

Keywords: Space Syntax; Urban Resilience; COVID-19; Angular Integration Analysis; Angular Choice Analysis; Social Distancing

1 Introduction

This section will introduce the general outline of this research. First will be explained what reasons motivated the establishment of the research that has been conducted: the COVID-19 pandemic. Then secondly, this line of reasoning will be put into a wider context, as to why this can potentially be a relevant learning opportunity for more general issues tied to the urban environment. Thirdly, a brief introduction will be given to the theory applied during this research: Space Syntax. Finally the research questions will be introduced, as well as the overall outline of the thesis.

1.1 COVID-19: Urban Socioeconomic disruption

At the time of this writing, the COVID-19 pandemic has been having a grip on society for quite some time. Early 2020 marked the beginning of a virus that would influence the day to day lives of many dutch citizens (Rijksoverheid, 2020). Merely two months after the initial signs of the virus, the dutch government had to announce the first lockdown in order to minimise the spread of the virus. Two lockdowns have been put into place over the course of one year. While the first one seemed to be quite effective, the second seemed less so (RIVM-IV, 2020).

The lockdowns have been very demanding on society. Not only is the effectiveness of a lockdown in general strictly tied to the behaviour of people, it has also been very demanding on the overall well-being of people and the economy. People have been sacrificing social interaction to ensure the safety of others, with the consequence of an increase in social malaise (like loneliness, anxiety and depression) (Palgi et al., 2020). Additionally due to a decrease in economic activity in certain business branches (like restaurants and entertainment) (CBS, 2020), the economy has had to put up with a lot of strain, further increasing the uncertainty of people's day to day lives. This has also caused the debate regarding people's willingness to remain compliant with the lockdown measures (or any measures taken). Over the course of the pandemic, even though the situation became more severe, it has been argued that people's willingness has been diminishing. This observation would then be reflected by busy shopping streets and traffic rates not dropping as much as anticipated (Dagblad van het Noorden, 2021; RTL Nieuws, 2021).

1.2 Urban Resilience

It are these kind of stories that have raised the question whether or not a city is designed to show a significant amount of resilience against situation like a global pandemic, or in other words: unforeseen shock events in general. Resilient, in the sense that socioeconomic activities within a city are not affected in any particular manner. Cities economic centres, consisting of various shops and businesses (being part of vulnerable business branches), rely on the well-functioning of the urban environment. This means human behaviour should not be changed in any way, that would harm the socioeconomic activities within an urban environment. This in favour of maintaining social well-being and thriving economic activity for vulnerable business branches. Then, the question is what can be done to get new insights in the debate on urban resilience: how could one measure socioeconomic activity, reflect on it, and develop new insights. This all in the relation to the built urban environment.

Considering the sustainable development goals of the United Nations (see figure 1), which includes the development of sustainable cities and communities (UN, 2020), exploring the well-functioning of urban space during the COVID-19 pandemic seems like a relevant endeavour. In fact, the United

Nations (2021) states in their development plans that COVID-19 has shed a new light on the vulnerable aspects of cities and that there is now an opportunity to re-evaluate how urban space is utilised. For example, COVID-19 has put more stress on the housing market, leading to more slum dwellers worldwide in lower income classes. Also, rapid urban development has skewed convenient access for citizens to public transport, a disconnect between citizens and the urban economy further strengthened by the pandemic. Then also, the spatial configuration of urban structures is in need for better optimisation of open public spaces for movement of citizens, this not only to reduce the congestion of public transport, but also to improve the quality of life for citizens and allow them to go outside safely (like many people were in need for during the pandemic). Finally, overall the message by the UN and their sustainable development goals (United Nations, 2021) seems that cities and their socioeconomic processes has been negatively affected by the COVID-19 pandemic. At the same time they see cities as *engines of economic recovery* (United Nations, 2021, p. 48), thus the place to re-evaluate how cities can become more resilient in terms of sustainable and socially inclusive development. This research wants to contribute to that notion by utilising specific sociospatial theory, and see if it can be put into practise to evaluate and explain socioeconomic phenomena during the COVID-19 pandemic. This, all in order to gain further insights into the improvement of public open space in cities.

1.3 Space Syntax

In order to put sociospatial theory into practise during this research one particular set of that theory has been chosen: Space Syntax. The second chapter of this research will further elaborate on the theory that makes up the foundation of what Space Syntax is in an epistemological sense. For now, a brief historic overview will be given.

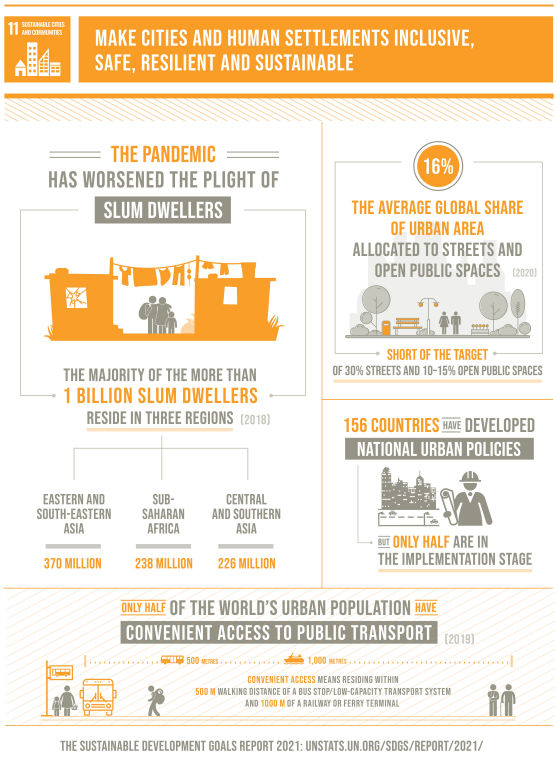


Figure 1: UN Sustainability goal concerns on cities, copied from (United Nations, 2021)

In general Space Syntax can be referred to as a collective term, consisting of a multitude of theories and concepts that allow for the analysis of human behaviour in relation to the spatial configuration of public spaces. These public spaces can vary from the interior of buildings, to open public spaces like town squares or street networks. Through various analytical techniques that have been developed over the past forty years, Space Syntax has established itself as a well-accepted tool for research on the built environment. The initial theory was developed by Bill Hillier and Julienne Hanson at the University College London during the late seventies and early eighties (Hillier & Hanson, 1984; Hillier & Leaman, 1973). As of today it is used in various sectors like architecture and urban planning. This, in order to get a better understanding of how spatial configuration, that is how different spaces relate to each other based on their connectivity, affects the behaviour of the people who traverse through them.

The theory of Space Syntax introduces two propositions in order to make the connection between space and human behaviour (Hillier & Hanson, 1984; Holmes, 2016). First, it is proposed that there is an intrinsic link between space and society. This is done by describing both the entity that is a society and the entity of space as structures with similar properties. Second, the entity of space as a structure can be reduced to an abstract mathematical representation. The variables of this mathematical representation would then describe the spatial configuration of that structure. What this means is that by viewing spatial structure as a representation of social structure, that would be a society, changes in social and cultural behaviour can be quantified.

1.4 Research Questions

The intent of this research is threefold. First, it wants to explore whether or not Space Syntax can be considered as a viable tool to manage, understand and improve urban resilience in the face of events that disrupt the urban socioeconomic equilibrium. Though COVID-19 is the trigger that started this research, it's not an integral part of the research. Instead a more generalised view is taken, considering COVID-19 as the unforeseen "shock event" utilised to evaluate Space Syntax' viability. Secondly, this research aims to provide a general, but comprehensive, understanding of what Space Syntax is. Finally, those two combined are discussed in order to provide insight on the applicability of Space Syntax for government agencies, especially at municipal level. Therefore, the research questions are as follows:

To what extend can Space Syntax analyse the well-functioning of space, given the circumstances of disruptive shock events, like the COVID-19 pandemic?

This main question will then be answered through the following sub-questions:

Q1. What is the epistemology of Space Syntax?

Q2. How can it's theory be applied in practise during this research?

Q3. What insights can the results provide, in relation to it's epistemological and practical boundaries?

1.5 Thesis Outline

This thesis will be divided into several sections. Section 2 - Literature Review will discuss the epistemological position of Space Syntax. This will be done in order to get a better understanding of how the theory came to be. It is important to understand what Space Syntax exactly is, and also what it is not. By determining its capabilities and limitations, this research wants to ensure that the results later on are interpreted in a meaning full way. Next is section 3 - Methodology, this section will give an overview of the most relevant analytical techniques that can be applied in practise, as well as explain the ones chosen in this research in full detail and why. In this section the areas researched will be introduced, namely four open public spaces in the city of Groningen. Section 4 - Results will showcase the results of the conducted research. The results will primarily be presented in a visual fashion, consisting of maps and graphs. Some comments will be provided regarding the circumstances during the research for context, while abstaining from subjective reasoning. It is in section 5 - Discussion that subjective reasoning will take place. In this chapter the results will be discussed while reflecting on the theoretical framework put together by the literature review. Finally, section 6 - Conclusion will provide the final conclusion on Space Syntax' viability as an analysis tool for improving the urban resilience during the circumstances of the COVID-19 pandemic.

2 Literature Review

This section will deal with the theory that makes up the foundation of Space Syntax. First, Space Syntax is given an epistemological position within the realm of science. This in order to determine what Space Syntax actually is, what its origins are and what is attempt (not) to be. This should aid later on during the discussion of the results, as then the scientific boundaries of the theory are known. Second, the essentials of the applicable theory are explained, this will to a certain extend be incorporated in the methodology of the conducted research. Then some of Space Syntax' strengths and criticisms are discussed. This is not to undermine the acknowledgement of the theory, but one should be aware of this when interpreting the results. Finally, the theory will be linked to the COVID-19 pandemic as a reasoning on why Space Syntax could potentially be used to evaluate the well-functioning of an urban environment.

2.1 The epistemology of Space Syntax

In order to understand were Space Syntax resides within the realm of epistemology, it's origins have to be explored. Netto (2015) discusses how the theory of Space Syntax finds its origins back to the 1970s, where Hillier and Leaman (1973) discussed the Man-Environment Paradigm (MEP) and its paradoxes. They argue that this paradigm is problematic, as it considers that the physical environment has no social content, and that society has no spatial content. In other words the MEP enforces researchers to think that an environment, and the society that resides within it, have no influence on each other's properties, they are mutually exclusive (Hillier & Hanson, 1984; Hillier & Leaman, 1973). The MEP considers an environment as 'inert' or 'lifeless', thus not as an evolving organic entity, and it considers a society in a very abstract manner. The main criticism by Hillier and Leaman (1973), is that this causes contradictions with definitions of an environment and society, that are more faithful to the complexity of reality. A discussion that is still relevant in modern geography and planning, when seeing both the works of Habermas (1984) and Marcuse (1941) are implemented in planning practice. In essence they argue that environments and societies are interlinked and organically evolve with each other, and that this cannot be ignored in order to get an understanding of the inner workings of both through the lens of social sciences.

Later on Hillier and Hanson (1984) systemized the critique on the paradigm by developing a sociospatial theory that would link an environment's and a society's formation process. Their work combined the studies of spatial structure related to settlement formation with anthropology. They intended to point down a fixed 'social logic' within the process of forming build structures, a logic that would be universal among various scales and cultures. Within the book of The Social Logic of Space, the authors utilize the general theory of structuralism in order to connect the spatial and social realms. Structuralism as a theory implies that some parts of human culture must be understood by their relationships to a broader system (Calhoun, 2002).

Structuralism is about finding the structures that underlie in all the social phenomena that make up our lives. Hillier and Hanson (1984) take on the idea of Lévi-Strauss (Netto, 2015), who described structuralism as a means to reject the concept of human freedom and choice. Instead, human experience and behaviour are supposed to be dictated by various structures. This notion was used to develop the idea that the structure of a built environment represents the structure of a society. Then, it is those structures that give form to the social phenomena that cannot be experienced by the individual within a built environment. So, Hillier and Hanson (1984) speak of a relationship between two types

of structures within a built environment: the relational structure and the geometric structure (Netto, 2015), and that those have an influence on the social behaviour of a society that lives within the built environment.

The social behaviour that is meant by Hillier and Hanson (1984) are the movement or walking patterns of settlers, that influence the formation of the built environment. It is at this point in time that the authors start to intrinsically link the formation of the urban environment, with the formation of social structures. This was at a time when, according to Netto (2015), the formation of societies was still discussed as an exclusive sociological theme by the works of Goffman (1967) and Giddens (1984). Hillier and Hanson (1984) used the works of Émile Durkheim on organic social solidarity to pinpoint the variables that would dictate the relationship between the built environment and social organization, which were size and population density. These two variables could be considered for spatial analysis of social organization. The idea is that population size and density influence the rate of encounter of social actors, which in turn would influence the process of forming social relationships between actors. Basically what is meant by the authors is that an urban structure (a city or settlement) forms and grows based on social interdependency between actors (as will also be found relevant during this study). This is because different actors play different specialized roles within a society in order to keep to global structure functioning (society as a whole). The higher the rate of encounter, the more specialized actors have to become in order defend their relevance within a city. This hints a the formation of historic city cores, dictated by economic centres having many specialized shops. This process of establishing relationships is called the *configurational process*, resulting in the configuration of societal and spatial structures.

So the Space Syntax theory profiles itself as a 'hybrid epistemology' Netto (2015, p. 29), which is a combination of sociology and anthropology with elements from geometry and mathematics. Hillier and Hanson (1984, p. 200) themselves refer to it as a 'framework to bridge the gap between a statistical view and a structural view of social reality.' Therefore, Space Syntax in a historical sense of spatial planning, seems to come forth out of a response to the criticism on the technical rationale (Marcuse, 1941), much seen in the seventies. In urban planning one cannot make decision based on findings that were done in complete isolation, social context is required. Therefore, it incorporates principles from the communicative rationale (Habermas, 1984), providing a contextual meaning to mere mathematical principles: what it means in the context of society. This discussion is still seen in modern planning theory, when for example looking at the works of de Roo (2016). Here it is seen that both the communicative- and technical rational have their relevance in planning and geography, they exist on a spectrum. This spectrum then exists in order to deal with complexity, a concept which is an essential part of Space Syntax.

2.2 The applicable theory of Space Syntax

As a continuation of The Social Logic of Space, Hillier (1996, 2007) developed the theory of Space Syntax further in is work Space is the Machine. This work lays the foundation for the research conducted in this thesis. Where Hanson further developed the configurational analysis techniques for the interior of buildings, Hillier (1996, 2007), did this for the built urban environment. Hillier (1996, 2007) states that Space Syntax requires four aspects in order to conduct urban analysis: (1) A concise definition of what is considered a space; (2) A set of analytical techniques in order to analyse the urban structures, which are defined as networks interlinking space and formed by the placement, grouping and orientation of buildings; (3) The social context needs to be incorporated in the analysis,

by observing how the networks of space relate in a wider context. In other words: how do people use space and why. This is done by looking at various social phenomena like: movement patterns of pedestrians, land-use or social well-being; (4) The development of theories on how an urban network relates to social, economic and cognitive factors, which in turn shape the network urban network and influences the aforementioned factors. The fact that this is still discussed and utilised by Van Nes and Yamu (2017) is a testament to it's relevance even twenty years later.

2.2.1 To- vs. Through-movement

Space Syntax focuses on two aspects of the urban network. These are called to-movement and through-movement (Van Nes & Yamu, 2017). To-movement represents the accessibility potential of a particular segment in the network, while through-movement represents the likelihood of people traveling through sets of segments in relation to all other segments in the network. It is important to note that in the context of this research the urban network is represented by the network of streets. These metrics represent the relational patterns of the urban structure, and can be weighted by using a distance value (which in turn represents the type of travel mode). Distance can be measured using either a metric, topological or geometrical unit. Metric uses the segment lengths of streets, topological uses the amount of turns needed in order to move from one segment to another. Finally geometrical distance also looks at the amount of turns, but uses the angle of the turns as an additional weight value.

Initial measures were done by observing small settlements, in order to verify the theories involving Space Syntax. As computational power increased, so did the scale at which Space Syntax analysis could be conducted. When the computational power became available it allowed for more comprehensive city-wide analysis of spatial configurations in relation to social phenomena, such as pedestrian movement, land use patterns, or the distribution of crime (Van Nes & Yamu, 2017).

2.2.2 Extrinsic & Intrinsic properties

Hillier (1996) made the distinction between two spatial properties. First, *extrinsic properties* determine how units of space are interrelated: their *spatial configuration*. These properties influence the laws that determine the outcome of the spatial configuration, this is what Hillier and Hanson (1984) studied when understanding the process of settlement formation. It meant that urban structures are considered as sets of multiple spaces, that are linked together, were topological characteristics have an influence on the relationship between these spaces. One can consider such a space as a streetsegment, a town square or a particular room. Then, the way these spaces are connected to other spaces, like the next street or an adjacent room, determines the interaction between the spaces: the movement of people and their activities. When one looks at these extrinsic properties, the entity of space does not have a physical form, one only looks at an abstract representation of all structures within a space, and thus how they relate to each other. Hillier states that a space has multiple functions in terms of human movement and/or occupation, which is considered a representation of these spatial relationships. Extrinsic properties are not visible, but can be experienced in terms of how a space is formed or functions.

Secondly, there are *intrinsic properties*. Unlike extrinsic ones, the intrinsic properties are visible. This is about the physical elements of a space, such as shape, volume, size, materials or placement of objects. These elements relate to the social purpose of a physical space. It should be noted at this point that Space Syntax itself only looks at the extrinsic properties. It is the focus on the extrinsic properties that allows Space Syntax to provide an abstract representation of urban structures, though which extrinsic properties are relevant depends on the context of the research.

2.2.3 The axial map

When applying Space Syntax, most of the time the longest and fewest sight (or movement) lines are considered the ones that can properly represent a publicly accessible space see figure 2 and 3 (like the interior of buildings or street networks). The abstraction of urban structures into these sight (or axial) lines forms the basis of Space Syntax analysis. When the drawing process is completed, the urban structure is represented by a map comprising of axial lines. An axial map allows for the representation of a street network without the usage of scale dependent properties. Which is beneficial, since according to Mehaffy (2014) urban structures and it's containing processes occur in a similar fashion across various scales. Scales like, locally within buildings to city-wide street networks.

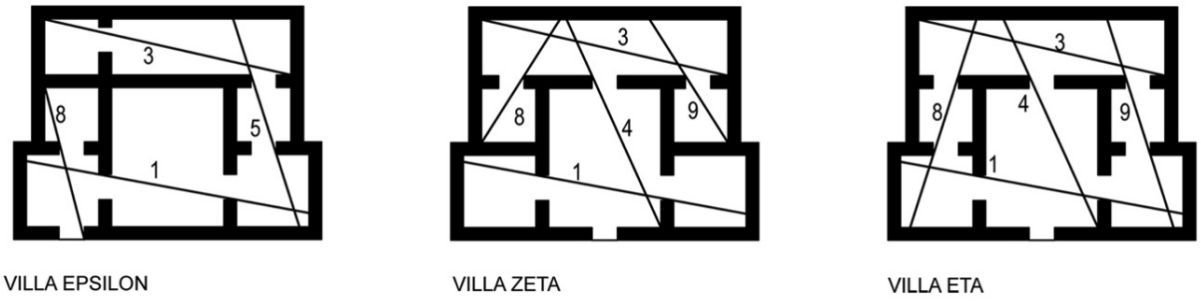


Figure 2: Image showing the sight lines within a space that comprise the axial map, copied from Ostwald and Dawes (2011)

When developing an axial map, one can identify low numbers of long streets and a high number of short ones. This shows a non-linear relationship between length and occurrence of street segments. According to Yamu (2014), this shows a natural formation of street networks, in the sense that long segments represent main roads used for longer distances, while shorter ones represent short and/or local travel. This phenomena of non-linear distribution, reminiscent of a normal distribution, is often seen within nature, biology and sociology. However, even though Space Syntax can be applied on various scales independently, phenomena in a city are scale dependent. People's behavioural choices depend on the scale at which the activity takes place, thus one has to consider the differences in movement characteristics when it comes to, for example, the differences between pedestrian and car travel. According to Hillier (2012) peoples behavioural choices occur bottom-up and are self-organising, which in turn dictates the spatial form of a city.

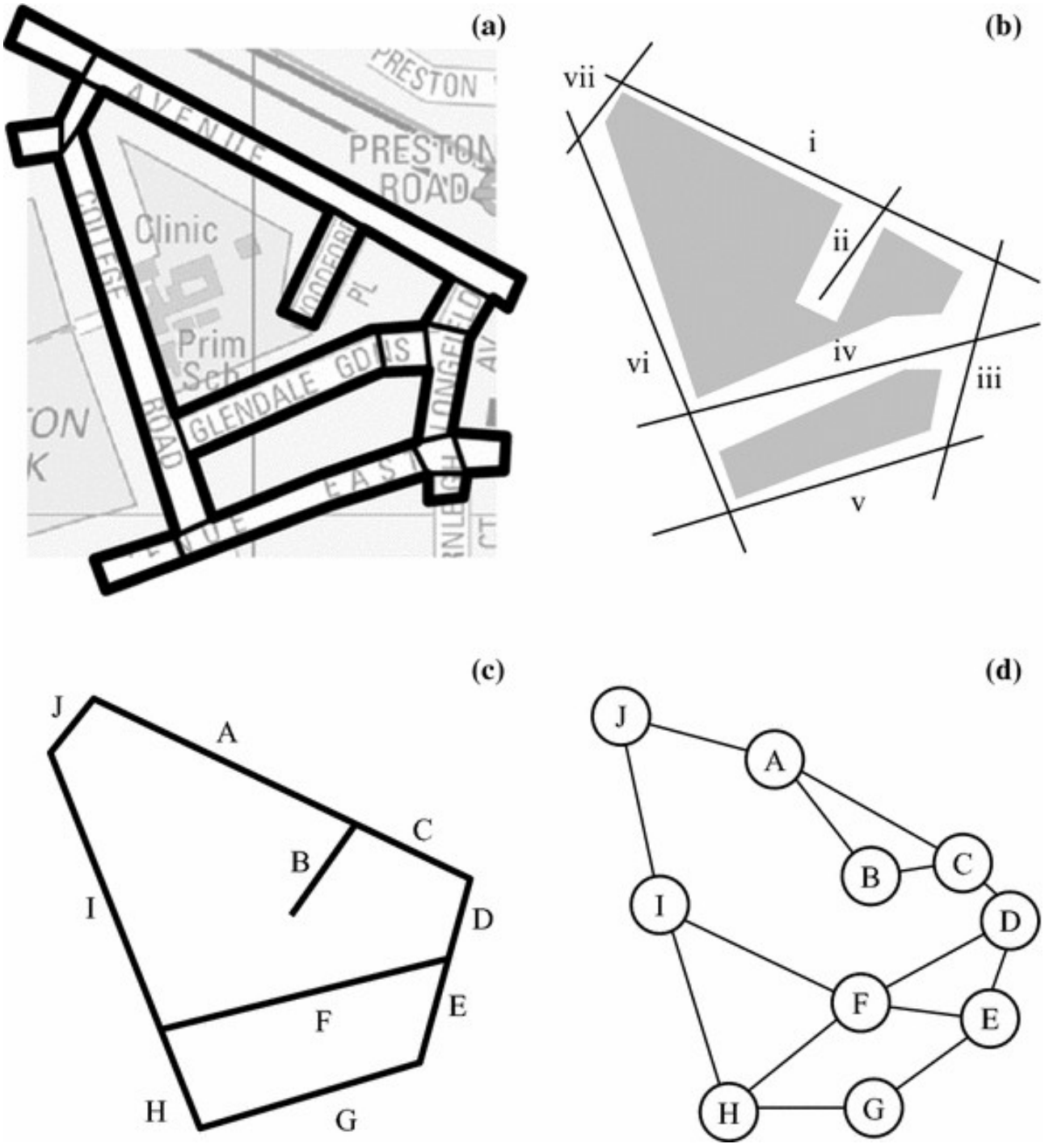


Figure 3: Image showing the reduction process of a street-network down to its topology, copied from Summers and Johnson (2017)

2.2.4 Intergration & Choice

Hillier (1996, 2007) described cities as a structure that has, in an ontological sense, two types of networks: a so called foreground network and a background network. The foreground network represents the streets that are used in global urban formation processes, in other words city wide movement patterns. These movement patterns are tied to the economic functions of a city, giving an indication of were economic centres or amenities are settled. This pattern is considered universal in the formation

of cities, independent from cultural context. As an example, the most well globally integrated streets within a city have the most potential for generating a variety of shops. This, in a sense seems a logical phenomenon, as shops tend to serve a wider range of citizens when connected to globally well integrated street. In settlement formation this causes the natural appearance of historic city centres, filled with a wide variety of shops. Of course a bigger city can have multiple (economic) centres, and then all of these centres are connected with each other through the foreground network, typically depicted by main roads that are relatively straight and have a higher capacity. Because the foreground network is then the most efficient route to travel through and to city centres, citizens intuitively gravitate towards these streets when traveling. People who live at the same location will most likely traverse identically through an urban street network, even when they are not aware of each other, this is defined as *co-presence*.

Co-presence is considered the foundation for the formation of a community, because when people become aware of each other's presence, social connections (or constructs) are formed. This in turn creates a social structure, which again can influence the urban build structures Hillier (1996, 2007). This formation process is then reflected in city centres being surrounded by (sub) urban communities at the city edges, creating a distribution of central and peripheral sections of a city. In a sense this distribution is in a constant reformation as cities develop over time (Hillier, 2012). As discussed by Van Nes and Yamu (2017), centrality is seen as an important factor in order to understand the relationships that form built urban structures. Additionally, the concept of centrality is related to the kind of social activities that take place within a city. So, the rate of centrality, of a particular section of an urban network, defines if a location should be defined as central or peripheral. Because Hillier (2012) describes the distribution of centrality as dynamic by adding a temporal component, one can look at cities' development starting with an initial structure that follows a fixed pattern, forming streets and building layouts. Then, followed by the development of a cities' (economic) functions. It are then these functions that, over time, dictate the development of city centres and periphery. It is important to note that Space Syntax itself does not have a temporal component for describing a city's development, thus what is observed with Space Syntax is a static snapshot of a particular moment in a city's development process. The functions of a city are tied to the social behaviour of it's inhabitants, like travel behaviour and shopping. This establishes the link between social behaviour and the built environment, and that city centres are not topologically fixed, but dynamic.

It should be noted that, even though the temporal component is not an intrinsic part of Space Syntax, it is not entirely omitted either (Griffiths, 2011). This is because, as already said, cities are dynamic. Thus, the existence of a temporal component is acknowledged in some form. What Hillier and Hanson (1984) essentially do is underplaying the temporal component in favour of consistency on the relationship between a city's morphology and socioeconomic circumstances. This tends to limit Space Syntax' temporal view, thus making it situational. For that reason, for example, historic fields in urban research have found it difficult to embrace Space Syntax (Griffiths, 2011). But on the other side of the argument, the research by Hidayati, Yamu, and Tan (2019) is a successful example of historic urban research incorporating Space Syntax. The key lesson here, is that the relevance of the temporal component is tied to the data resolution. An analogy here would be comparing Space Syntax to a film: one picture represent a static observation, while twenty four pictures in a second reveal the dynamics of the situation.

The aforementioned centrality is measured with two types of calculations: (1) integration and (2) choice. Integration represents the 'to-movement' potential, thus how likely a particular street segment

is considered as a destination. This is calculated in relation to all other street segments in the network. The integration value of a particular street increases, as the number of turn decreases. The integration analysis has been refined by the work of Turner (2001, p. 30). Choice represents the 'through-movement' potential, thus the likelihood of people intuitively gravitating towards particular street segments for traversing through an urban structure. The angle at which street segments connect with each other, plays a role in the amount of gravitation people tend to have towards a particular street segment (Dalton, 2001). It seems that, in the process of wayfinding, people tend to navigate more easily through straight and long lines. As people orientate themselves through an urban structure, to judge the walkability of a pathway, one prefers angles that maintain straightness, like 90 or 180 degrees. Angles that are not as straightforward in understanding the orientation, such as 30 or 60 degrees, tend to be avoided. This because people find it disorientating. In short, people prefer the least complex route towards an end destination (Dalton, 2001).

2.3 Theory of natural movement

The settlement theory, that Space Syntax incorporates, allows Space Syntax to predict the effectiveness of spatial interventions. This judgement is based on the social and economic phenomena that currently take place in the area under scrutiny. Because the relation between the spatial and social realms are bi-directional in theory, Space Syntax can potentially also give an indication of how well certain social and economic phenomena would manifest within a planned spatial intervention. This has already been applied in practice, in order to understand the manifestation of crime, social segregation, anti-social behaviour or the well-functioning of economic centres (Van Nes & Yamu, 2017).

The centrality of integration and choice can influence the well-functioning of economic centres (Van Nes & Yamu, 2017). As already mentioned, there are three variants to quantifying centrality. Each one of these require a slight difference in perspective. First, metric centrality depicts an absolute centre within an urban structure, thus something is located in the middle of an area. The middle of the area represents the starting point for all shortest paths to the edges of the area. Second, topological centrality is a centre point relative to the number of direction changes needed in order to reach the edges of a particular area. This centre point implies the starting point for the fewest direction changes to the edges of the area. In other words, the strength of topological centrality is tied to the amount of crossings and turns within a street network: the more fragmented the weaker the measured centrality. Weak topological centrality is not beneficial for the economic potential of a city centre (Van Nes & Yamu, 2017), as it makes destinations less attractive. Finally, geometric centrality does not only look at the number of turns, but also the angle at which the turns have to be taken. This helps identifying the main roads that give access to a city centre. The geometric centre point means that, considering it as a starting point, it allows for the straightest routes towards all edges of a particular area.

Economic centres are the places where various specialised economic amenities spawn, and the concept of centrality plays a role in the potential of these amenities: the foreground network. This has to do with the fact that centrality describes the area of influence of, for example, a particular shop. If a shop is located at a street with a high degree of centrality, it would mean that it attracts potential customers from further away within the city, as the effort required for travel is relatively less complex. This relates to the natural movement theory of Turner, Penn, and Hillier (2005) on economic processes, were economic and social activity are linked. Here it is typical in the development of urban environments that attractors, such as shops or large retail firms, tend to place themselves around street segments with a high degree of centrality (highly integrated streets). Then, it is also implied that as

more shops place themselves along highly integrated streets, the more economically relevant the area becomes, thus attracting more people.

This description helps to understand that economic centres are not fixed, but dynamic. The development of economic centres is a continuous process, where they change shape, size and location. Hillier (1999, p. 119) describes how the success of an economic area requires a strategic position in terms of local (the direct vicinity) and city-wide (in terms of the whole street network) integration. Either of these depictions of integration can change due to changes in the street network, and thus what is considered the optimal location for economic amenities will change as well (Hillier, 1999, p. 110). Then, naturally, over time the placement of shops and firms will shift towards the new highly integrated centre.

Looking at the works of Hillier (1999), van Nes (2005), Van Nes and Yamu (2017) and Desyllas (2000): it seems that Space Syntax predictive nature is mostly based on economic activity. It is through the lens of economic activity that Space Syntax attempts to predict social behaviour. This is defended by the notion that people's behaviour in urban space depends on their motives and intentions, thus the assumption that there is rational decision-making at play. Therefore, specific intentions are considered difficult to determine. This is what makes it hard for Space Syntax to predict social behaviour after spatial interventions. The predictive nature on social behaviour therefore takes a more pragmatic or general approach by incorporating rational choice theory. It looks at society in an economic sense, determining were people will go based on economic intentions. The studies of Hillier (1999) and van Nes (2005), have shown that economic amenities such as shops and firms benefit in terms of economic vitality, when placed at highly integrated streets. Thus Space Syntax can predict general travel or movement intentions of people, by looking at those that are economically motivated.

Then the background network consists of the streets within the network that are highly segregated, related to local residential streets. The structure of these streets is linked to local social culture (Van Nes & Yamu, 2017). One aspect were Space Syntax is limited, is generalising social segregation. Economic segregation is generalised using rational choice theory, but social rationality incorporates a wider range of possibilities. This is due to people having a wide variety of social intentions on the individual level. This means that in order for Space Syntax to work additional context is required of the specific neighbourhoods that are studied, regarding: inhabitants behaviour and social relationships. Even though generalisation is limited in a social context, previous studies have found social patterns regarding segregation. Areas with a low accessibility and that are visually isolated (few sightlines and entryways to the interior of buildings), tend to see an increase in crime and negative social phenomena (Hillier & Sahbaz, 2005; Hillier & Shu, 2000). It is not the case that highly segregated areas always imply that negative social phenomena will arise, this is also linked to the amount of co-presence within the area. What this means is that even when an area is globally segregated, a healthy sense of community (social connections) can form, which in turn moderates the amount of negative social phenomena. It is when areas are both locally and city-wide segregated that there is potential for social malaise to emerge (Hillier, 1996).

2.4 "What Space Syntax is not"

In addition to describing Space Syntax' epistemological position, Netto (2015) also addresses some confusion around its theories. It is important to highlight what Space Syntax's is not in relation to its origins, in order to avoid some unnecessary criticism.

The first aspect of the theory that should be addressed is that Space Syntax is not a comprehensive theory that is capable of describing a city's formation and transformation process as a whole. This is because Space Syntax at it's core is static, not including a temporal dimension that would allow the description of dynamic processes. Netto (2015) puts it into perspective of other works that attempt to develop a comprehensive theory that could describe and quantify the formation process of cities. He looks, for example at the work of Jane Jacobs' the Economy of Cities (Jacobs, 1969). It is in this book that economic processes take centre stage in the physical development of cities. Here, as a reaction to economic growth, purposes and development of buildings, infrastructure or citizens change over time. What both the work by Jacobs (1969) and other works explained in Netto (2015) make clear is that the formation process of cities are complex and that many approaches in quantifying the process fall short in finding formation patterns that could be universally applied (Allen, 2012; Batty, 2013; Bettencourt, 2013; Portugali, Meyer, Stolk, & Tan, 2012; Wilson, 2008). As already mentioned before, Space Syntax can only provide snapshots of the dynamic processes at play. However, of course one can argue that with enough snapshots over time, dynamic processes can be interpreted.

There's not a linear causal relationship between time and the formation of cities, Space Syntax has to acknowledge this in order be a comprehensive theory. In simple terms it means that there is no "if this, then that" relationship in the formation process of a city, different stages can occur at different times in different order depending on the city. (Van der Leeuw & McGlade, 1997). Additionally, the formation process of cities should be explained within three dimensions, namely (1) growth: the initial state of a city; (2) densification & expansion: how a city's socio-economic structure changes; (3) architectural form: the physical transformation (Wheaton, 1982). Wheaton (1982) considers this the forces of urban development, as a representation of changes in socio-economic relationships (morphology) within a city. Space Syntax only deals with two of these developmental forces, namely the growth and the densification & expansion (Hillier, 1996, 2012). This is because the relationships between the social and spatial realms is explained through the concept of co-presence, found within the settlement theory that Space Syntax is based on.

Secondly, Space Syntax is not describing 'the city as a self-contained structure'. As discussed by Netto (2015), Space Syntax never aspired to be a theory that would be able to describe society's formation processes as a whole (in relation the space). Instead Space Syntax only looks at some particular aspects of society, namely the 'social information' (Hillier & Hanson, 1984, p. xi) that puts restrictions on the formation processes of social relations within an urban structure, that would otherwise be entirely random. So it cannot cover all aspects that could potentially form sociospatial relationships.

Of course, it is debated that there is some existing overlap between the theoretical boundaries of Space Syntax and what could potentially be a comprehensive theory of a city as a whole (Netto, 2015). The key difference between Space Syntax and a comprehensive theory of the city is primarily that sociospatial theories, like space syntax, omit much of the physical changes to an urban environment. At the same time, urban theories tend to omit the existence of social structures within a cities formation

process. David Harvey already mentioned as far back as 1973 that in order for theory to successfully describe a city's state, it has to take one of two stances: (1) Describing the city's formation laws as if it were self-contained within its own structure; (2) Describing the city through social relations, that are part of a wider phenomenon or structure (Harvey, 1973, p. 304). Netto (2015) seems to agree with Harvey (1973), that the first stance is criticised. When looking at the city as a self-contained structure, one is omitting the fact that a city (and its phenomena) are in reality related to other systems (cities), which in turn are part of the same whole. Most urban studies tended to fall into the first category, and it wasn't until the works of Batty (2013) and Bettencourt (2013) that a shift occurred towards the second one. Space Syntax has always remained into that second category. The key difference here, according to Netto (2015), is that Space Syntax incorporates the principles of social organisation. This is something that other urban theories do not, even though they incorporate social attributes in their theoretical models. The irony here is that even though Space Syntax is based on the principles of social organisation, it does not explicitly add social variables to it's theoretical model. Space Syntax negates the idea that the relationship between space and social processes can be reduced to a few variables, instead it relies on the social solidarity principles by Durkheim: social reasoning generates social and spatial patterns. What this means is that traditional urban theories tend to neglect the idea that social attributes are part of a larger social context, in favour of abstraction. Netto (2015) argues that one may criticise Space Syntax for this lack of explicit explanation of the city, but on the other hand traditional urban theory comes with its own limitations.

Lastly, Hillier (2012, p. 152) has pointed out himself that Space Syntax is not a mathematical theory. Instead it utilises a combination of mathematical ideas to come up with the components that can represent the sociospatial system of a city. According to Netto (2015) the use of mathematics in spatial sciences has been questioned since the quantitative movement in geography. He gives three reasons in particular: First, there's seems to be a fear of mathematical reduction, as it might come at the cost of the symbolic and experiential meaning of space. Thus, that spatial sciences should not be blind for "what cannot be seen or measured". Second, too much emphasis on mathematical reduction might hinder the observation of social phenomena, as the relational properties of those phenomena might require complexity in order to understand it. Third, there exists a strong believe in the capabilities of discursive language and a misunderstanding in its limits. On one hand, discursive language helps with defining the importance of what can not be objectively defined as 'important' through subjective reasoning. This, as opposed to the more analytical nature of mathematics. On the other hand, discursive language also has its limits when it comes to describing the complexity social phenomena.

When it comes to the mathematical principles involved with Space Syntax, it would be unfair to state that it is describing obvious social phenomena, and thus making it redundant (Netto, 2015). Society experiences the concepts of co-presence and between movement, in relation to the urban structure, on a daily basis. This is what makes it feel self-evident, because Space Syntax touches upon what is experienced by an urban society. However, this type of judgement is not unheard of, as Netto (2015) argues. He argues about theory on spatial economics by von Thünen (1826) and Weber (1929), where Space Syntax also finds some of it origins, that those theories can also be perceived as obvious, due to being part of what is experienced daily. Those are well-established theories, looking at the relationship between distance and locations of economic activities, as well as the diversity and density of those activities. What defends the relevance of Space Syntax here, is that understanding the relationship between space and social phenomena is a complex matter to understand. Space Syntax aids in translating the non-discursive description of something as complex as social phenomena, into discursive language. This is beneficial since non-discursive descriptions tend to be more capable of

pinning down complexity, but Space Syntax also acknowledges (not without failure) the importance of discursive language as a means to give meaning to what is observed. This, despite the fact that discursive language has a limiting tool-set to conceptualise complexity. The intent of Space Syntax is to bring awareness to the complexity of social phenomena. Netto (2015) then finishes off with the argument that the entire point of scientific theory is to establish reasons as to "why" and "how" things occur in the natural world and that the "why" and "how" for Space Syntax are not as self-evident as they seem.

2.5 The strengths of Space Syntax

The hybrid nature of Space Syntax' epistemology serves as its primary strength. Since the conception of the theory it has contributed to the understanding of how and why cities are spatially structured the way they are. This, all in relation to the societal structure that makes up the urban society that lives within cities (as explained by the theory above).

Space Syntax can be used at various scales and levels within research on the built environment, ranging form city wide street networks to local public space like town squares and the interior of buildings. Additionally, since Space Syntax functions context independently, it is suitable for all types of settings with different built environments, societies, politics and cultures. This can be seen by a variety of researches that have implemented Space Syntax in their practices, take for example the work by Hidayati et al. (2019). Here they did an analysis of the path dependent mobility inequality in the city of Jakarta. Space Syntax was used within a multi-method approach, in order to triangulate an historical narrative about how the city of Jakarta has become more car dependent is the past 80 years. By researching the path dependent relationship between land-use and transport policies, using a combination of different data collection techniques, an historical narrative could be formed. Space Syntax was used to interpret the historical transformations of Jakarta based on street maps of three different time periods. They found using Space Syntax that as the city grew, the highways became more important over time. As a result of that, the potential of the historic city centre gradually diminished. This was reflected by the Space Syntax measurements and the dislocation of economic amenities in the historic centre. What this meant was that Space Syntax allowed for insight in long term spatial impacts, caused by spatial policies enforcing car dependence. Since there was not a lot of data available on the spatial history of the city, Space Syntax complemented the historic narrative. As discussed by the authors, Space Syntax allowed for an abstraction of the streetnetwork, which narrowed down the complexity of the analysis. This made it easier to see how history changed the urban core of the city and vital streets of the past became less important. To them the strengths of Space Syntax is that it can help decision makers to become more aware of the long term effects of policy implementations, since the long term effects are frequently overshadowed by short term political ambitions. The visual nature of space syntax makes it easier to communicate the results to people with different backgrounds, bridging the gap between science and practice.

Another example would be that of Dursun (2007). Were Space Syntax was integrated with architectural design processes, in order to re-evaluate existing urban architecture and improve the experience of visitors and by-passers. This was done at an open public space in London: the Trafalgar square, and the Tate Britain museum. In both cases walking patterns were observed, measured and compare to Space Syntax analysis. The Trafalgar square as perceived as unsafe, with lots of traffic. This would discourage people from actually utilising the square, and they would just pass by. Space Syntax provided insights into possible solutions, like new pedestrian pathways and a better staircase.

Space Syntax also allowed for better communication between various people involved during different stages of the design and construction processes. The Tate Britain museum used Space Syntax to choose an optimal layout for a wing extension, improving the navigability and immersion for visitors of the museum. Both the works of Hidayati et al. (2019) and Dursun (2007) show a successful implementation of Space Syntax in practise. This despite dealing with different scales, cultures or political environments.

2.6 The criticism on Space Syntax

Even though there is praise for Space Syntax in the scientific community, does not mean that it comes without criticisms. In fact there have been critical views on the theory by various authors (Batty, 2001; Jguirim, Brosset, & Claramunt, 2014; Kostakos, 2010; Montello, 2007; Netto, 2015; Pafka, Dovey, & Aschwanden, 2020; Penn & Turner, 2001; Ratti, 2004b; Turner, Doxa, O'Sullivan, & Penn, 2001). What these authors share in common is mostly a criticism on Space Syntax' empahsis on reductionism. Therefore, Space Syntax seems to come short in situations when contextual information that is omitted, is in fact crucial to drawing proper conclusions. For example, in the case of Penn and Turner (2001) it is criticised that Space Syntax' does not account for spatial attractors that have an influence on the movement of people through urban structures, like stations. Montello (2007) criticises Space Syntax for being ambiguous in nature, because metric spatial properties are undervalued. What is meant is that distance and direction of movement also have a significant influence on behaviour. In short, Montello (2007) makes clear that physical- three-dimensional properties are downplayed (as also said by Penn (2003)). It is also argued that due to nature of Space Syntax' theory on settlement formation, it cannot understand the "individual", but only look at society as a whole.

One of the greater criticisms on Space Syntax' applicable theory comes from Ratti (2004b), arguing about how axial maps are blind to geometric properties of space and instead only focus on topology. This implies that it doesn't matter what the length of a street segment actually is, and is treated as any other street segment that an equal amount of connecting points with other street segments. Ratti (2004b) explains that, even though street segments can be topologically similar, distance and angles still play a significant role in the choice people make when deciding their routes. Then, Ratti (2004b) continues this argument by stating that Space Syntax' axial maps are oversimplifying reality by being discontinues. What this means is that multiple urban structures with varying morphological properties are seen as topologically identical until a certain threshold point, which is not in line with reality. As seen in figure 4, Ratti (2004b) shows two topologically identical grids, but at figure 4 (b) the correlation between the axial map and natural movement patterns makes a big inconsistent shift. In figure 5 the threshold point is seen at which the axial map can be interpreted as two possibilities. A final statement that is made by Ratti (2004b) is that the integration values produced by Space Syntax depend on the city chosen and that areas researched require a buffer area when creating axial maps for the analysis. If this is not done the analysis will generate a so called edge effect, where the outer edges of the map generate artificially low values. This, since only a limited portion of a street network is converted into a map, making the analysis unaware of anything beyond what is drawn (Gil, 2015). So for accurate results, a decent amount of buffer has to be drawn into the axial maps that are used as input for the Space Syntax analysis. It should be noted that Hillier and Penn (2004) attempted to defend their theories against the criticism by Ratti (2004b), only for Ratti (2004a) to restate the criticisms.

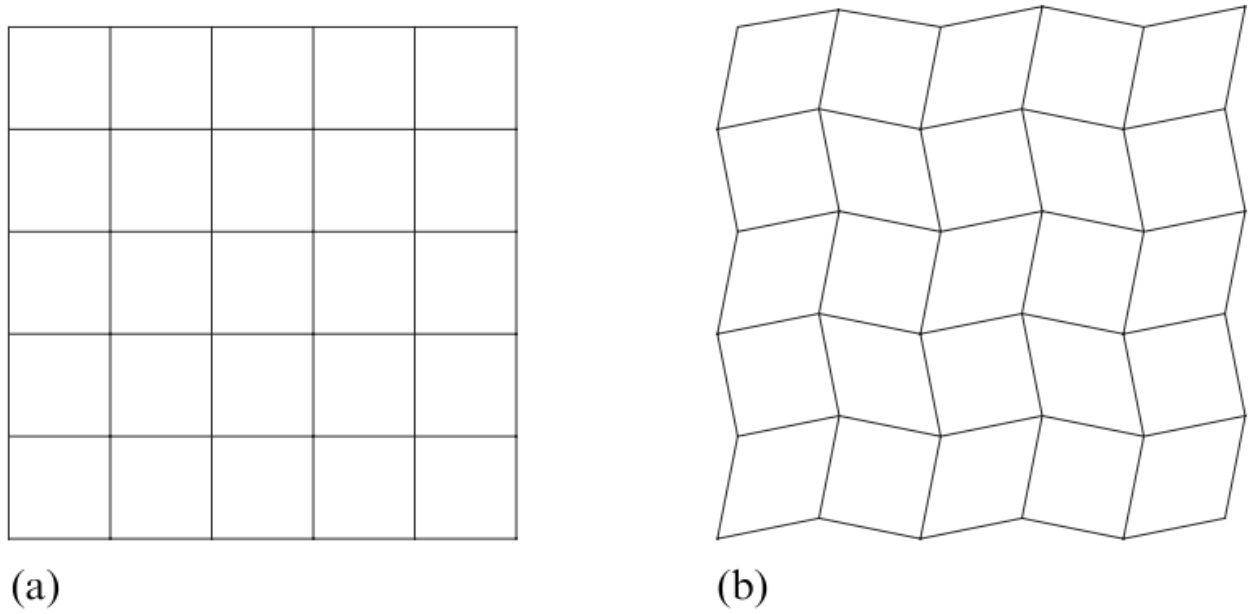


Figure 4: Image showing two grids with an identical topology, copied from Ratti (2004b)

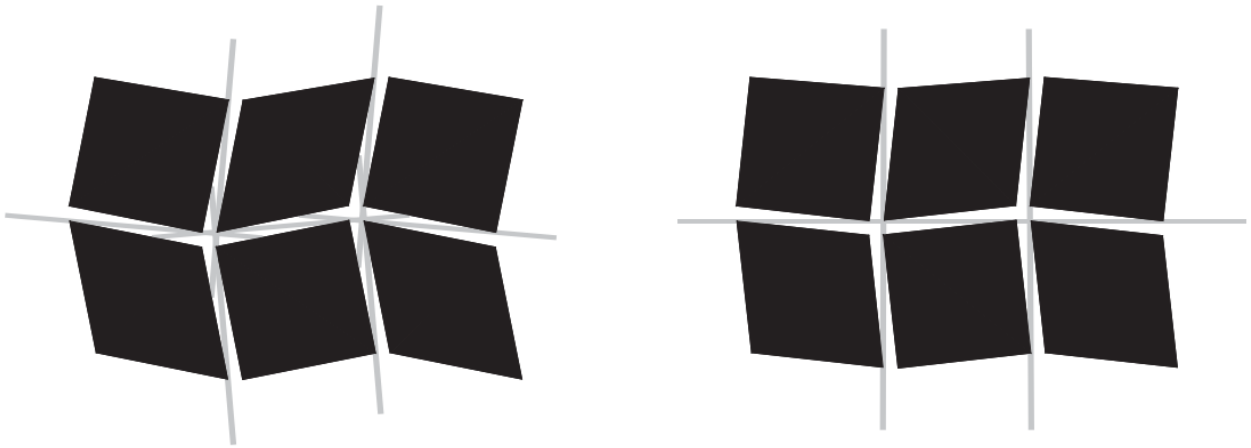


Figure 5: Image showing the dilemma of interpreting the orthographs axial lines in figure 4, copied from Ratti (2004b)

Finally there is also some criticism on the practicality of Space Syntax. It has been found by (Jiang & Claramunt, 2002), that generating an axial map is time consuming and lacks a clearly defined methodology. This is because axial maps are drawn manually. While it is clear that one must draw the least possible lines, some scenario's allow for a subjective interpretation. This can for example happen at simplifying complex intersections. Furthermore, the process become prone to error when maps are becoming too large. Simply put, when two persons are given the same map, they can interpret different axial maps.

2.7 Application in a new situation

The COVID-19 pandemic could potentially be an interesting situation to evaluate. When looking at the theory Space Syntax is based on, which makes certain assumption on how social and economic activity take place, one might think whether or not Space Syntax will function as is expected. Due to the pandemic and the consequential lockdowns the natural movement of people within spaces has been heavily restricted, or maybe even disrupted. During the pandemic people had to consciously evaluate and change their natural behaviour in terms of movement, both literal walking patterns and when making daily trips to amenities. Since the Space Syntax theory has elements that base human behaviour on economic intentions, it would be interesting to see how this changes when certain amenities are structurally closed for a longer period of time. The city of Groningen, especially the historic city centre, consists of many amenities that were forced to close down during the lockdown, with the exception of grocery stores and essential amenities like pharmacies. Observing these extraordinary scenarios might contribute to new insights for urban planning and making cities more resilient against socioeconomic disruption. Of course it should be noted that this research strives for insights that hopefully do not exclusively work in pandemic situations, but also in similar shock event situations that disrupt the socioeconomic equilibrium of a city.

In order to accommodate to the pandemic situation, field observations will take place at places with an expected abundant amount of moving people. This will be four public open spaces, which will include two parks and two economic centres. Since Space Syntax is heavily reliant on economic activity one could argue against the incorporation of parks, since parks are tied to leisure activities and thus question the economic incentive of park visitors. However, Space Syntax has been utilised on parks in the past. As Koohsari, Kaczynski, Mcormack, and Sugiyama (2014) describe, public open spaces are all bound to the socioeconomic fabric of an urban environment. This means that Space Syntax is relevant in optimising the utilisation of parks, by optimising its integration and choice potential in relation to the surrounding urban environment. In the past this has been done for example, by relaying pathways or changing physical features of parks and plazas, influencing movement patterns. By increasing the integration and choice potential, more people would travel through parks, thus increasing the likelihood of visitors for leisure activities (Koohsari et al., 2014). Thus, parks can serve as an indirect metric for the surrounding urban environment, in addition to evaluating the parks themselves.

2.8 Concluding remarks

So Space Syntax is in essence multiple things. It's not only a theory, but can also be seen as being its own epistemology. Then, it is also a tool-set of analytical techniques that can be put into practise. The benefit of Space Syntax lies in its hands-on approach to bridging the gap between the technical and communicative rationale, attempting to take what is best from both. However, in the process of bridging that gap, some sacrifices are made. This, results in a more generalised, but also comprehensive, view on the functioning of spaces. Figure 6 shows the theoretical framework summarised in a graphical representation. In the next section the theories discussed will be implemented in a methodology for the analysis of open public spaces in Groningen, to see how they function under the circumstances of the lockdown.

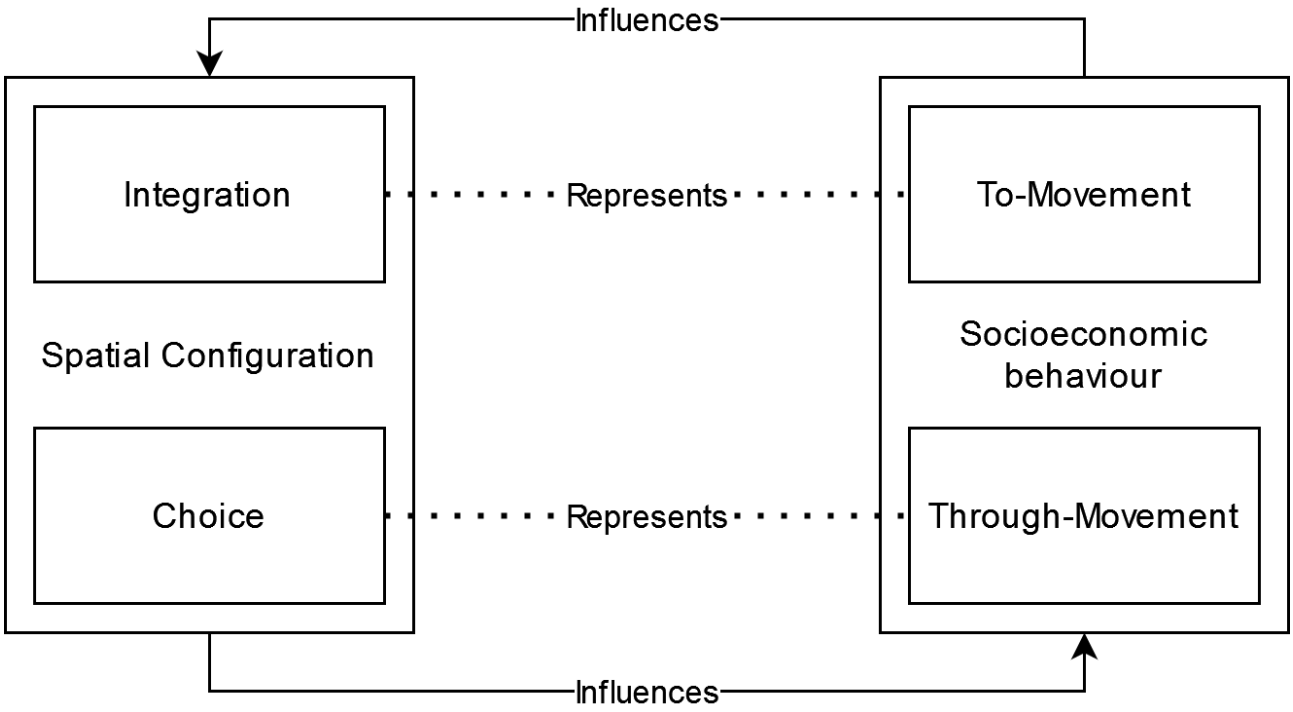


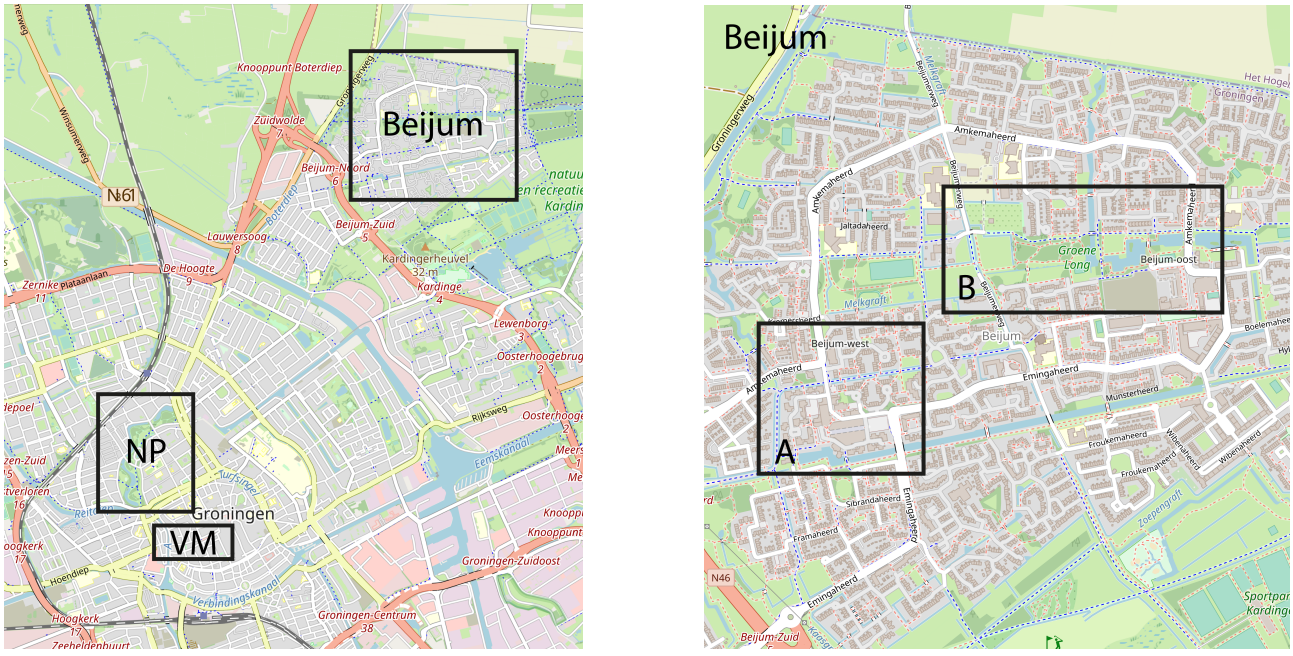
Figure 6: Theoretical framework summarised

3 Methodology

This section will provide a description of the methods applied during this research. As an extension of the epistemology of Space Syntax, as described in section 2, a description of the applied theory will be provided. Relevant, as in all the theory that is either applied in practise during this research, or was part of the decision making process resulting in the final research design. This section will be divided into two parts: first, the methodology of the Space Syntax analysis will be described. Second, a description of the fieldwork will be provided. Finally, it will be described how these two methods will be combined for further statistical analysis and interpretation. The majority of the explanations provided are sourced from the Space Syntax methodology manuals by Al-Sayed, Turner, Hillier, Iida, and Penn (2014); Nes, Song, and Mohamed (2010); Nes and Yamu (2021).

3.1 Areas of interest

This research will use the city of Groningen as it's research subject. Considering the COVID-19 pandemic and the closure of many amenities that have an influence on the socio-economic equilibrium of the city. Two types of areas have been chosen: shopping areas and parks. These types of areas have been chosen to ensure the presence of movement. Parks were chosen under the assumption that people would travel there for leisure activities, since most socio-economic amenities have been closed during the lockdown period. For the shopping areas it was a requirement to have at least one grocery store present (one of the few amenities still active). Then it is best practise to have a variety of areas in terms of global and local integration within the street network of the city Nes and Yamu (2021). One preferably wants two areas with a high global integration, and two areas with a low global integration (segregated). For the highly integrated areas the Noorderplantsoen and the Vismarkt were chosen, for the segregated areas the Beijum Shopping Centre and the Beijum Bos were chosen (see figure 7).



(a) City overview

(b) Beijum in more detail

Figure 7: Map of the city of Groningen, highlighting the areas of interest.

3.2 Space Syntax analysis

The first phase of this research involves conducting Space Syntax analysis. This is done by generating a graph representation of the spaces that are analysed. Through the means of various software packages these maps will be created. There are two primary representations of space, which are the axial map and the convex map. Both maps are the results of analysis methods used for evaluating and predicting socio-economic activity.

3.2.1 Representation of space: axial map

As described by Al-Sayed et al. (2014), Space Syntax views movement of people in an abstract manner, which in an urban context is represented streets. What follows is that these street spaces are reduced to the longest traversable lines that cover all convex spaces as seen on a map. This reduction process is also seen in figure 8. These traversable lines are called axial lines or "lines of sight" (Al-Sayed et al., 2014, p. 11) (b). How these lines intersect defines how they are topologically related. These relationships can be represented by a graph G_A, consisting of nodes or vertices (c). The graph vertices will represent the axial lines (or streets): $V_A = \{V_{A1}, V_{A2}, ...V_{An}\}$. A second layer of lines will represent how the vertices intersect within the network of vertices (d): $L_l = \{L_{l1}, L_{l2}, ...L_{ln}\}$. The amount of "spatial adjacency", which is the amount of connection points one particular vertices has with other adjacent vertices, determines how the spatial configuration of the overall structure will look like in the final axial map (e). Two spaces in graph G_A are considered adjacent when it's possible to enter one space directly from the other and vice versa. This is without the need to cross other intermediate spaces. Which in turn means that the relationships between spaces is considered non-directional. For example: if one has the line L_k in graph G_A, which represents the adjacent relationship between the axial lines i and j, then this is formulated as $L_k = (v_i, v_j) = (v_j, v_i)$.

In an axial map, the rate of integration is in its most basic principles represented by the change in directions between two axial lines. The integration value of one particular axial line is measured in relation to all other axial lines in the network. Since the axial representation is purely topical, all geometric properties are ignored.

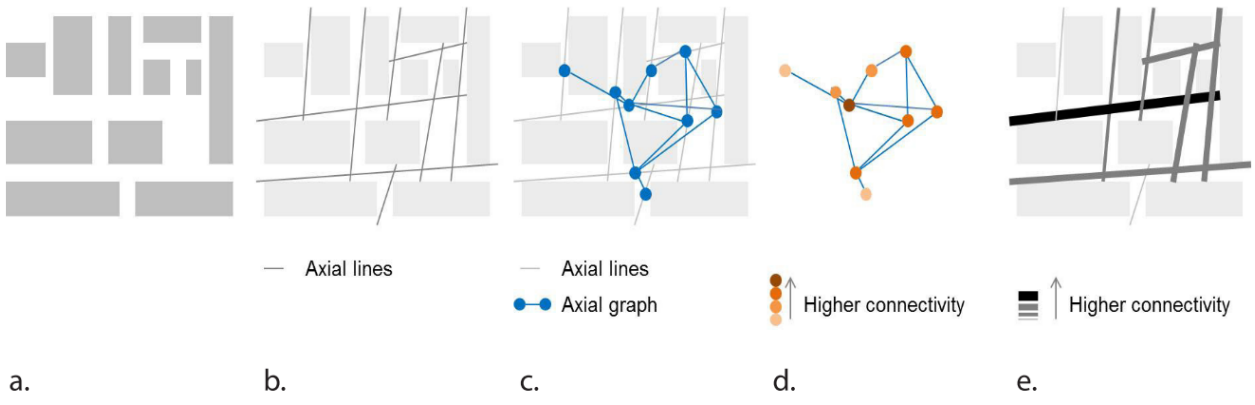


Figure 8: The process of interpreting space as axial lines, copied from Al-Sayed (2014)

3.2.2 Representation of space: convex maps

As opposed to axial maps, convex maps don't use sight lines to represent traversable space. When developing a convex map, space is reduced to the most minimal contours of the traversable space, resulting in convex shapes. These confined shapes, or spaces, are linked together with entry points. Again, spatial adjacency is measured by topological depth. Two spaces are considered adjacent when they are paired with one entry-point, that has bi-directional access.

The process on how the convex map is conceived can be seen in figure 9. In a graph G_c the topological information is made up of two components. Again, vertices that represent space, though instead of axial lines these are convex shapes (c): $V_C = V_{C1}, V_{C2}, ...V_{Cn}$. This is complemented with lines $L_A = L_{A1}, L_{A2}, ...L_{AL}$. Similar to the axial, the lines of L_A represent the adjacent relationships between spaces (d). The number of connections one convex space has in relation to all other convex spaces determines the rate of connectivity in the final map (e).
For this research the axial representation is chosen in order to conduct the analysis. In terms practicality drawing axial maps is a more convenient option. This has to do with the scale of the maps and the spatial structure of street networks. Convex shapes are logically more convenient for the interior of buildings by drawing a minimal version of the outer walls of closed rooms and doorways. Since drawing every outside perimeter of a street network is prone to errors and very time consuming, the axial representation is naturally the better option for calculating topological depth.

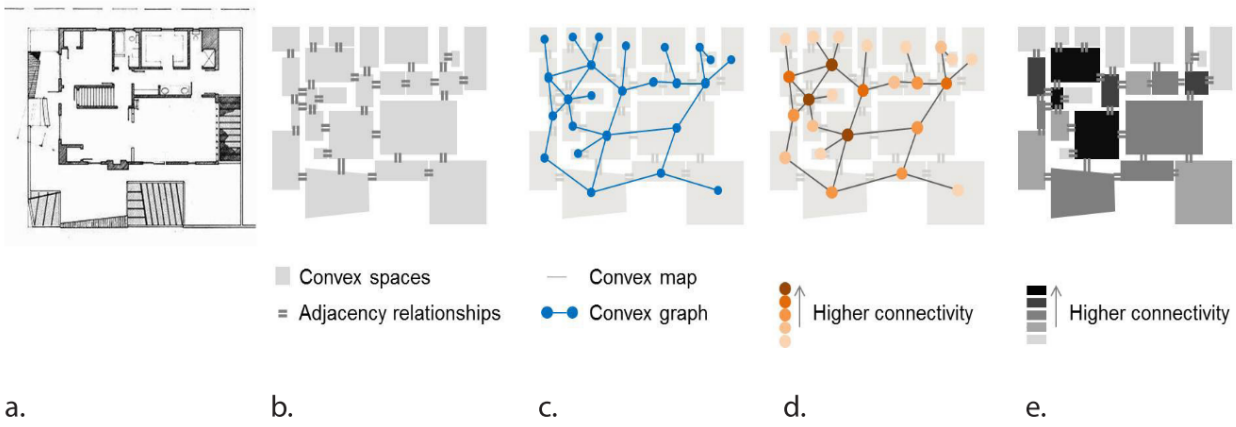


Figure 9: The process of interpreting space as convex shapes, copied from Al-Sayed (2014)

3.3 Calculating Topological Depth

The way by which topological depth is calculated is relatively straightforward. In fact, it can be done by hand if one desires to do so. However, over the years, software development has produced various tool-sets which can be used to calculate topical spatial relationships (van Nes, 2019). Figure 10 shows the manual process of calculating the topological depth of space, through the means of an axial map. Integration is determined by the number of directional changes that occur when travelling through a street network. Integration turns out higher when the number of turns required to reach another street is low. This also means that when a street has a low integration value, when a lot of directional changes are required when going somewhere else in the street network. There are two variants of integration that can be calculated: (1) global, which is the spatial integration of a street axe in relation

to all other street axes in the network; (2) local, which is identical to the global integration, but the step depth is capped at a maximum amount of turns.

Figure 10 shows the manual process of calculating global integration of a small axial map. This is the analysis process carried out automatically by the software called DepthmapX Turner (2007). DepthmapX then represents the amount of integration by colours, the spectrum goes from red to blue. Red means that a street axe is highly integrated in the network, while blue means a street is highly segregated. As was seen in figure 8c, that showed the vertices and lines, in the second part of figure 10 the axial lines are represented by nodes and the relationships (intersections) are represented by the lines. Figure 11 shows how local integration is calculated. The topological depth at which the analysis takes place is capped at a specified number of directional changes. This is done to see how well a particular street is integrated within a local radius (like a neighbourhood).

3.4 Angular Segment Analysis

A more refined iteration of Space Syntax analysis, is the angular segment analysis method. Angular segment analysis combines the insights of the axial map together with those of visibility graph analysis (Turner et al., 2001). Know from visibility analysis, that it is based around the idea that people have preferred movement patterns based on the visibility of their surroundings. As is concluded by Dalton (2001), people tend to prefer straight lines when orientating themselves through space. Figure 12 shows what this means for the axial map analysis. The axial map is broken up into segments and the angle at which segments connect are measured. The angles then represent an additional weight value that is incorporated in the integration calculations as seen in figure 13. Because people prefer straightness, angles between 90 and 180 degrees have a higher weight value, while rare angles such as 30 and 60 degrees have a lower value. This is because these values are linked with people losing their way. Additionally people tend to choose streets that are the longest, the combination of longest and straightest implies that people tend to avoid complexity for orientating themselves (Dalton, 2001).

DepthmapX will be able to do these calculation automatically by: (1) providing an axial map; (2) convert it to a segment map; (3) running the angular integration and choice analysis. For this research it is decided to manually draw axial maps using AutoCAD, this will be done by tracing the street segments. While it is possible to re-use an existing map or use road centre-line data from external sources to automatically generate axial maps, this is prone to many small conversion errors that have to be identified and corrected. Moreover, a consistent interpretation of crossings, roundabouts and dead-end streets and under/overpasses is required. This, since the research will only deal with pedestrians and cyclists. Considering the size of the maps used, it is more efficient (and consistent) to draw the maps manually. From DepthmapX the variables angular choice and integration will be normalised in order to reduce extremes caused by edges of the map. These final variables for further analysis will be referred to as Normalised Angular Choice (NACH) and Normalised Angular Integration (NAIN).

$$NAIN = \frac{(Node\ Count\ Radius\ n)^{1.2}}{Total\ Depth + 2} \tag{1}$$

$$NACH = \frac{\log(Choice\ Radius\ n) + 1}{\log(Total\ Depth\ Radius\ n) + 3} \tag{2}$$

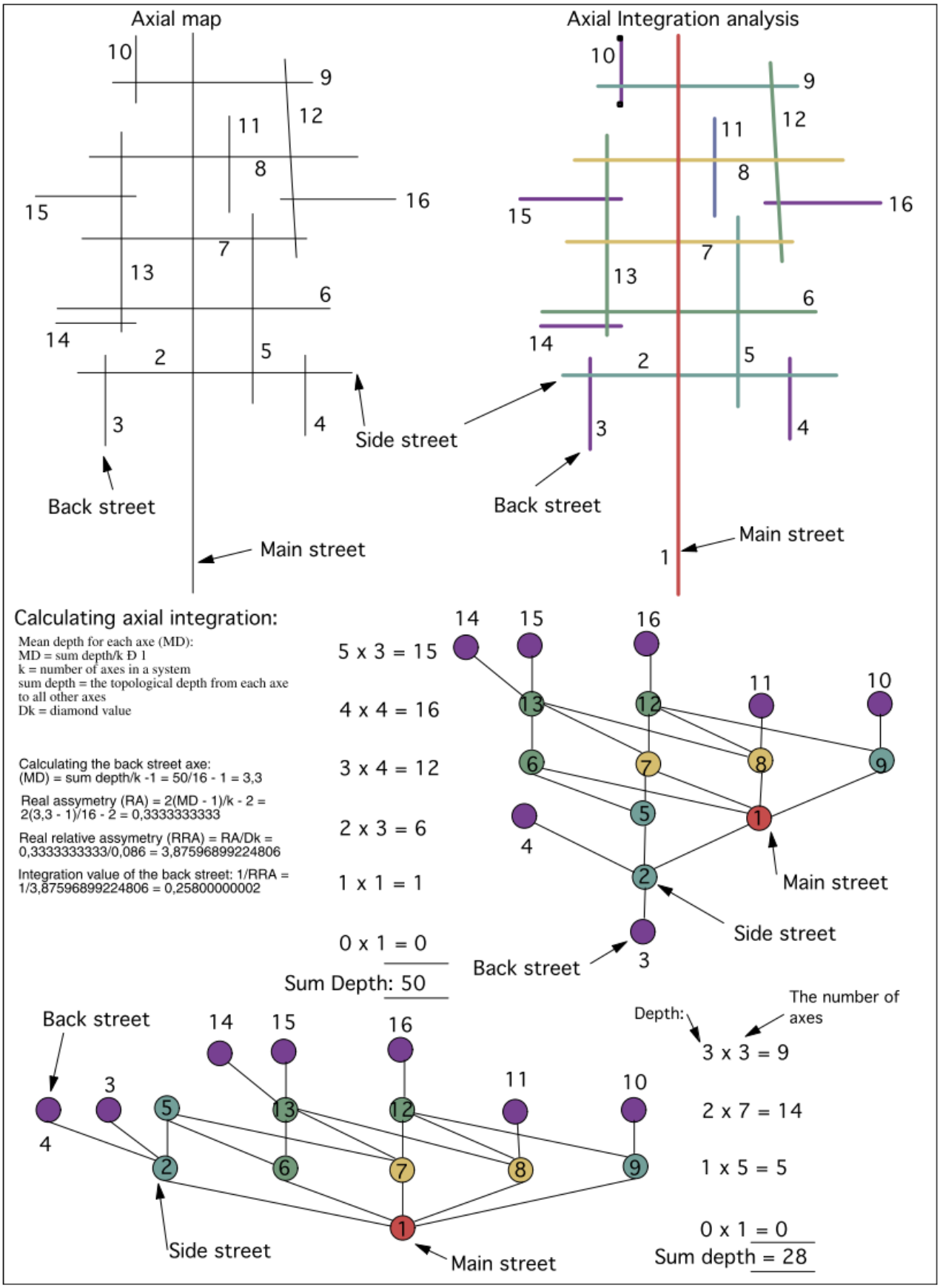


Figure 10: The process of calculating integration, copied from van Nes (2019)

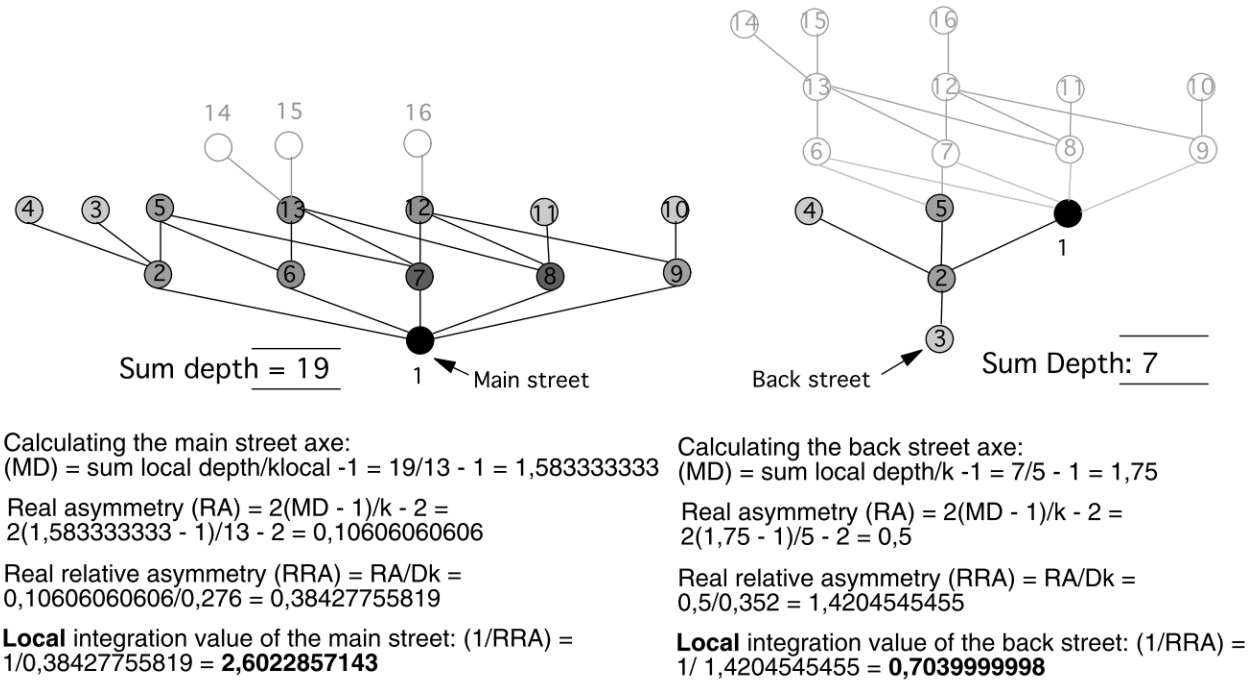


Figure 11: The process of calculating local integration, copied from van Nes (2019)

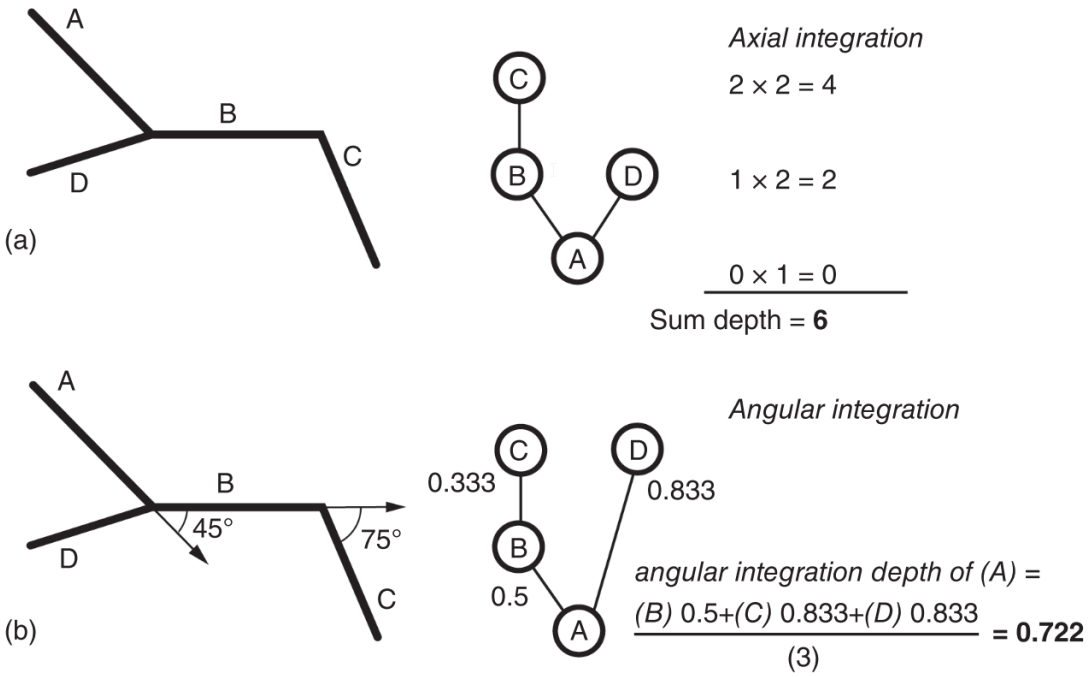


Figure 12: Axial versus Angular Integration, copied from Van Nes and Yamu (2017)

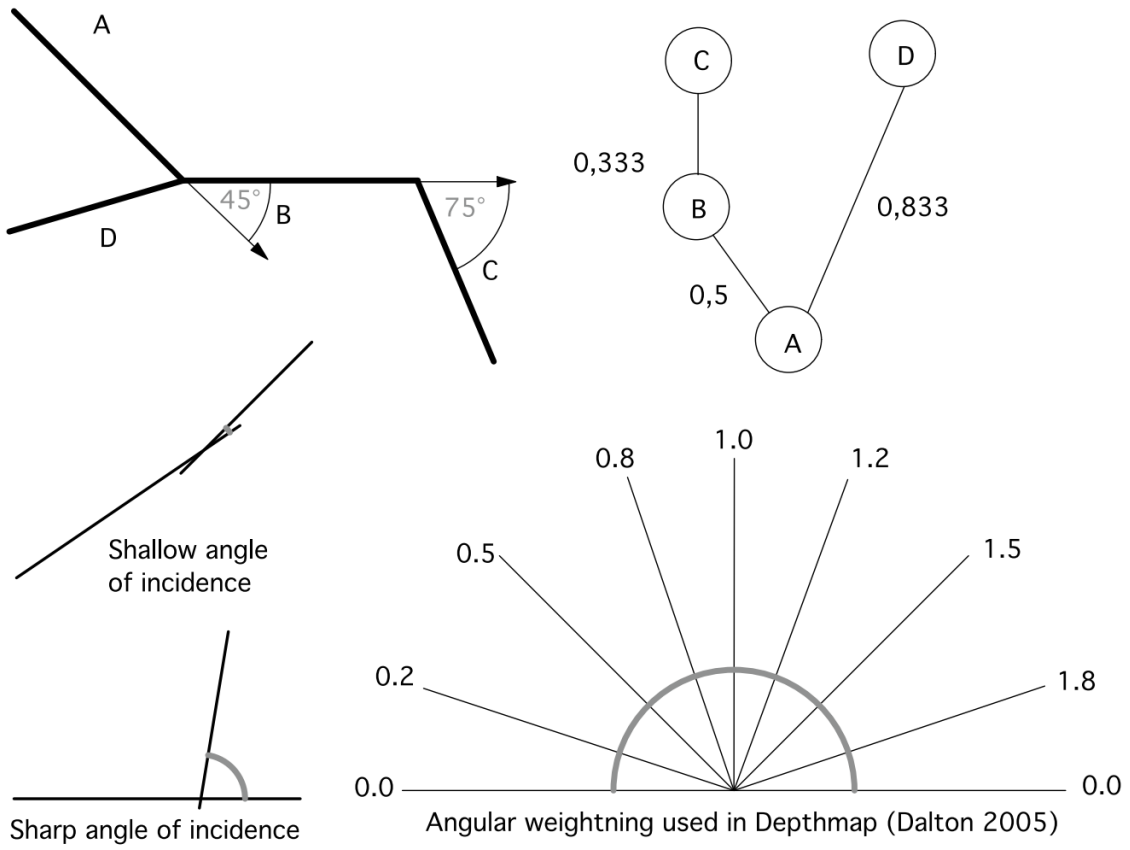


Figure 13: Explaining the weight value of angular analysis, copied from van Nes (2019)

3.5 Field observations

In order to interpret the space syntax analysis in a meaningful manner, it has to be complemented with empirical data socio-economic behaviour. This is because when empirical data is compared with the analysis, a stronger (context dependent) relationship can be interpreted between space and society. Space Syntax knows a multitude of field observation techniques, for this research "gate counts" has been chosen. In a sense this means that this research uses a mixed-method approach, combining qualitative and quantitative data sources.

3.5.1 Gate Counts

Gate counting is the principle of tracking the flow of human movement through the urban environment. As stated by Nes and Yamu (2021), the method has been used by Hillier and Iida (2005) to prove that highly integrated streets go paired with high amounts of human movement, while segregated streets tend to have less human activity. Gate counts can be used to track various modes of travel, like cars, cyclists and pedestrians. Under normal circumstances these measurements tend to correlate well with the results from angular analysis. The technique also allows for visual interpretations when projecting the results on a map, as well as for statistical analysis. It is important that the data is collected consistently in the form a documented procedure, that is the same for all areas researches within the same research. The procedure is as follows:

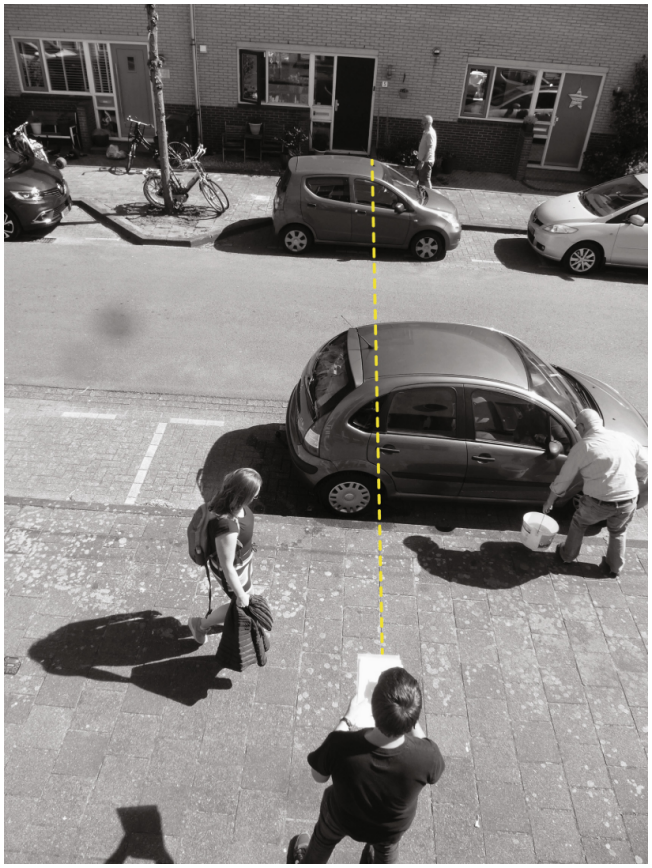


Figure 14: Gate counting, copied from Nes and Yamu (2021)

First the areas that are going to be studied have to be explicitly defined on a map. The key here is to choose areas in order to get a variety of areas that are used in different intensities, thus from very busy to almost a lack of activity.

Second, when the areas have been chosen the gate positions have to be determined. One way to determine the gate location is by doing the Space Syntax Analysis first, and determine the gate positions based on those. It is suggested to incorporate a minimum of 25 gates per location (Grajewski & Vaughan, 2001), since more gates means a more detailed representation of the street network. At each gate one person notes all pedestrian of vehicles passing through. It is important that one person should not cover more than 10 gates in an hour, so that 5 minutes per gate remain possible. The remaining time is preserved for walking between gates.

Third, during the counting one should draw an imaginary line across the street, which included the sidewalks (figure 14). One should then only count the people and/or vehicles that crossed those lines. The start and end time should be noted down in order to calculate the flow-rate per hour later. On quiet streets one person can cover the entire street, counting both pedestrians and vehicles. On busy streets the workload should be split. This can be done by (1) splitting the 5min equally in counting vehicles and pedestrians; (2) two persons covering different modes of transport; (3) two persons cover pedestrians on either side of a street, while one person counts the vehicles.

Fourth, gates counted in sequence should be covered twice in one round of observations. For example, if gates 1 to 10 are counted, then one should continue with 10 again moving towards gate 1.

Observations should be done on a variety of days, ideally two weekdays and two weekend days. Then over the day several rounds of observations have to be done that cover both peak and off-peak hours of activity. This should include early mornings and late evenings, though should be adapted to the societal norms of the areas studied. Additionally weather conditions, like temperature and precipitation have to be registered as well, which will influence travel behaviour.

Observed people should also be divided into categories that suit the areas studied. This to add an additional information layer to the observations. Most of the time the observations are divided into similar categories covering demographics like gender, age and occupied activity. This can be seen in figure 15.

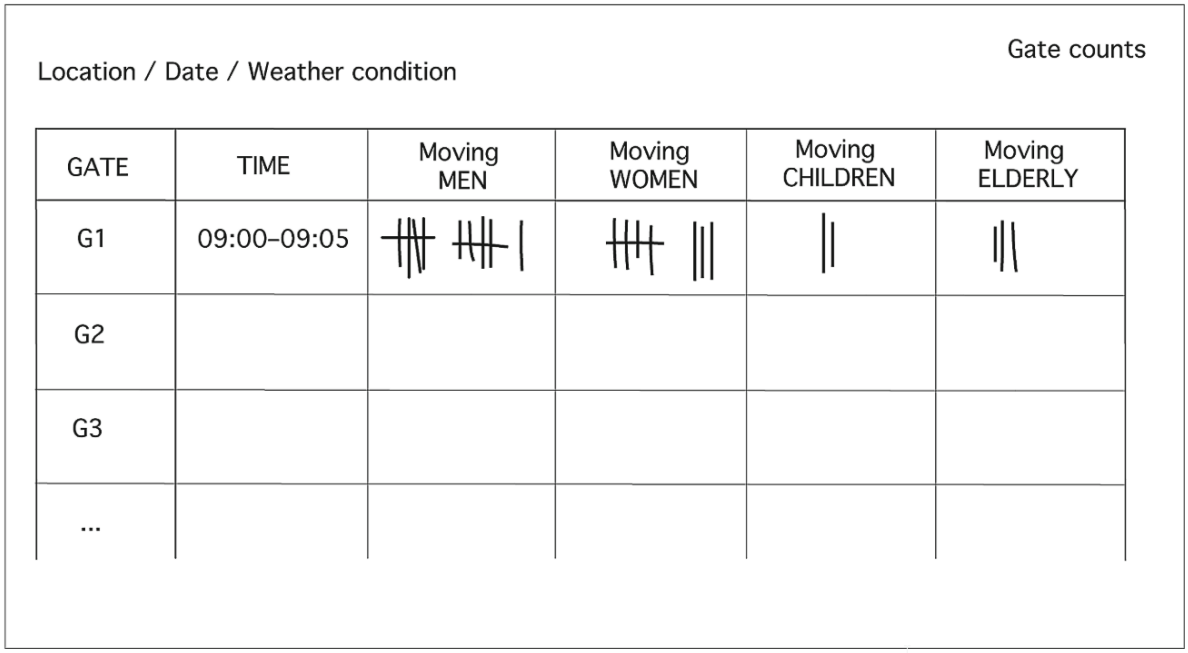


Figure 15: Gate counting sheet, copied from Nes and Yamu (2021)

To minimise errors during the data collection, it is advised to have multiple people do the observations at the same location. This is beneficial since one person can make the same systemic errors. It also reduces the workload, which is beneficial for convincing other people to volunteer. Volunteers should then start on the opposite edges of the areas and work towards the middle, then they should pass each other until the reach the other side at the end of a session and repeat this process. That way one covers an area evenly throughout the day, avoiding the situation where one side of an area is only covered during less busy hours. Naturally, the more people involved the more accurate the data.

While other methods such as movement tracing give a more detailed representation of movement, those require also many volunteers. Gate counting was chosen for the very reason to deal with the limited amount of resources available, this being time and volunteers. Gate counting would allow to get more observations in a shorter amount of time. It also lowers the bar for volunteering, since one session takes two hours maximum. This makes it easier to convince people to participate in the data collection process, considering early and late day times, during the winter period with changes of unfavourable weather conditions.

3.6 Statistical Analysis

Statistical Analysis will be used in a descriptive manner in order to speak into more detail about the observations. Additionally, statistical tests will be run in order to verify the similarities between the Space Syntax analysis and the field observations. This is relevant since the idea behind this research is to see if the theory based on the socio-economic principles remain in tact during a lockdown, when most economic activities are put on hold. In the case that the observations remain statistically similar one can use Space Syntax analysis as a relevant tool to evaluate on spatial design policies. Since the data contains continuous variables for NAIN, NACH and all the people counted during the fieldwork, the correlation tests that will be run are either: Pearson's product-moment, Spearman Rho or Kendall's tau b. Pearson's will be run if the variables are normally distributed and there is a clear linear relationship between the variables. Normality will be checked using the Shapiro Wilk test for normality. If the variables are not normally distributed and don't have a linear relationship, then Spearman Rho and Kendall's tau b will be used. By the means of scatter plots the presence of a monotonic relationship will be checked (an assumption of Spearman Rho), regardless both Spearman Rho and Kendall's tau b will be presented. Finally, see figure 16 for an overview of the methodology.

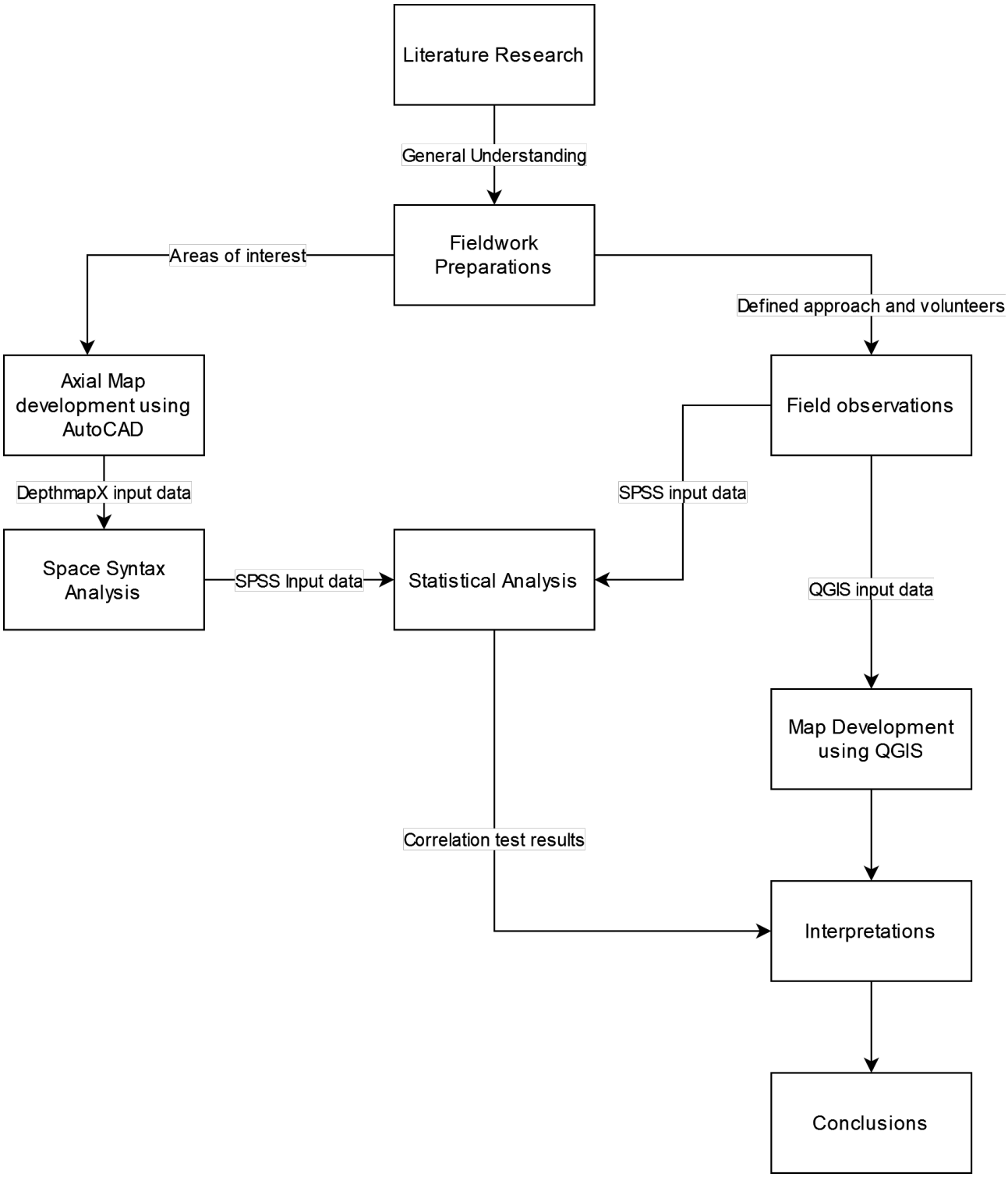


Figure 16: Methodology Schema

4 Results

This chapter will present the results of the conducted research. The results will be given per location. Maps will be presented showing the movement of people as observed during the fieldwork, followed by a map of the results calculated by DepthmapX.

4.1 RAW Axial Map

As input for DepthmapX, an axial map was manually traced using two reference maps extracted from OpenStreetMaps (OSM). Using the areas of interest as centre points for these maps, the dimensions resulted in having a 2km buffer around all areas. These two maps had a 1:4000 scale and were merged together to become one map that could be traced using AutoCAD. The final RAW axial map is seen in figure 17. Effectively this map cover a radius of $12km^2$. Roads not accessible for pedestrians and cyclists are omitted from this map, such as highways. QGIS was used to add metric dimensions to the lines, and was then converted to a MID file as input for DepthmapX.

Figure 17: Raw Axial Map

4.2 Fieldwork

The fieldwork was eventually done within two weeks. It started on the 27th of January, until the 7th of February 2021. Each week consisted of the Wednesday, Saturday and Sunday. The first week consisted of measuring the highly integrated areas: the Noorderplantsoen and the Vismarkt. The second week consisted of the segregated areas in Beijum, being: the shopping centre and the park in the centre of the neighbourhood. During those two weeks the areas were measured in parallel during two hour sessions. These sessions being from 8:00-10:00, 11:00-13:00 and 15:00-17:00. Volunteers were given instructions on the counting procedure, as well as a map with all the gate locations. These maps of the gate locations and the provided instructions can be found in the appendixes B through D.

4.2.1 General Statistics

After the observations were done, all the people accounted for were manually entered into an excel sheet. The figures 18 to 21 show some general statistics of the observations. In total 23327 people were accounted for over the span of two weeks. On average 238 people were accounted for per day.

	Moving Men	Moving Women	Moving Children	Moving Elderly	People with Pets	Total Moving People
All	10507	10408	879	1050	483	23327
BB	283	323	142	111	106	965
BW	745	670	233	231	38	1917
NP	3849	4003	239	182	212	8485
VM	5632	5412	265	526	82	11917

Figure 18: Total people accounted for.

	Moving Men	Moving Women	Moving Children	Moving Elderly	People with Pets	Total Moving People
All	109	108	9	10	4	238
BB	17	20	8	6	6	59
BW	54	48	16	16	2	136
NP	127	133	7	6	7	275
VM	157	151	7	14	2	330

Figure 19: Mean movement of people accounted for

	Wednesday	Saturday	Sunday
BB	51	74	36
BW	130	212	71
NP	266	332	232
VM	240	474	236

Figure 20: Mean movement of people per day

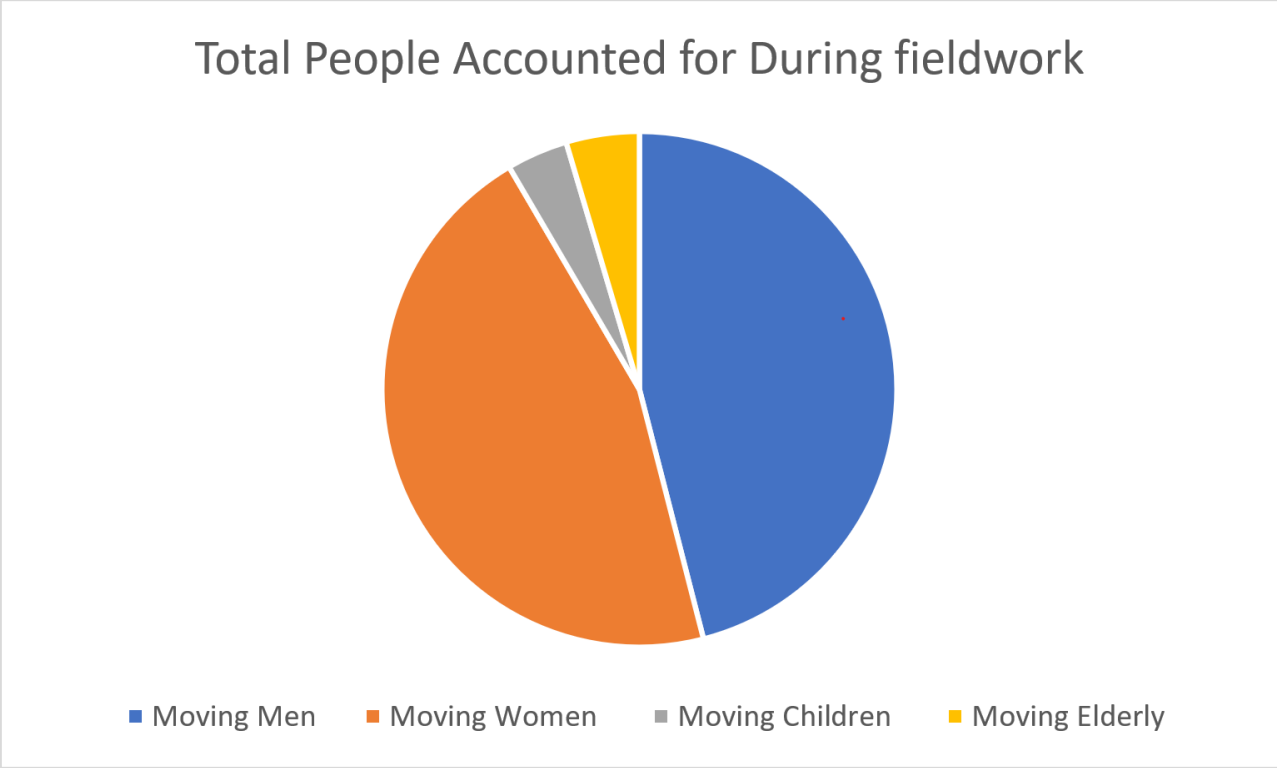


Figure 21: Total movement demography

4.2.2 Noorderplantsoen

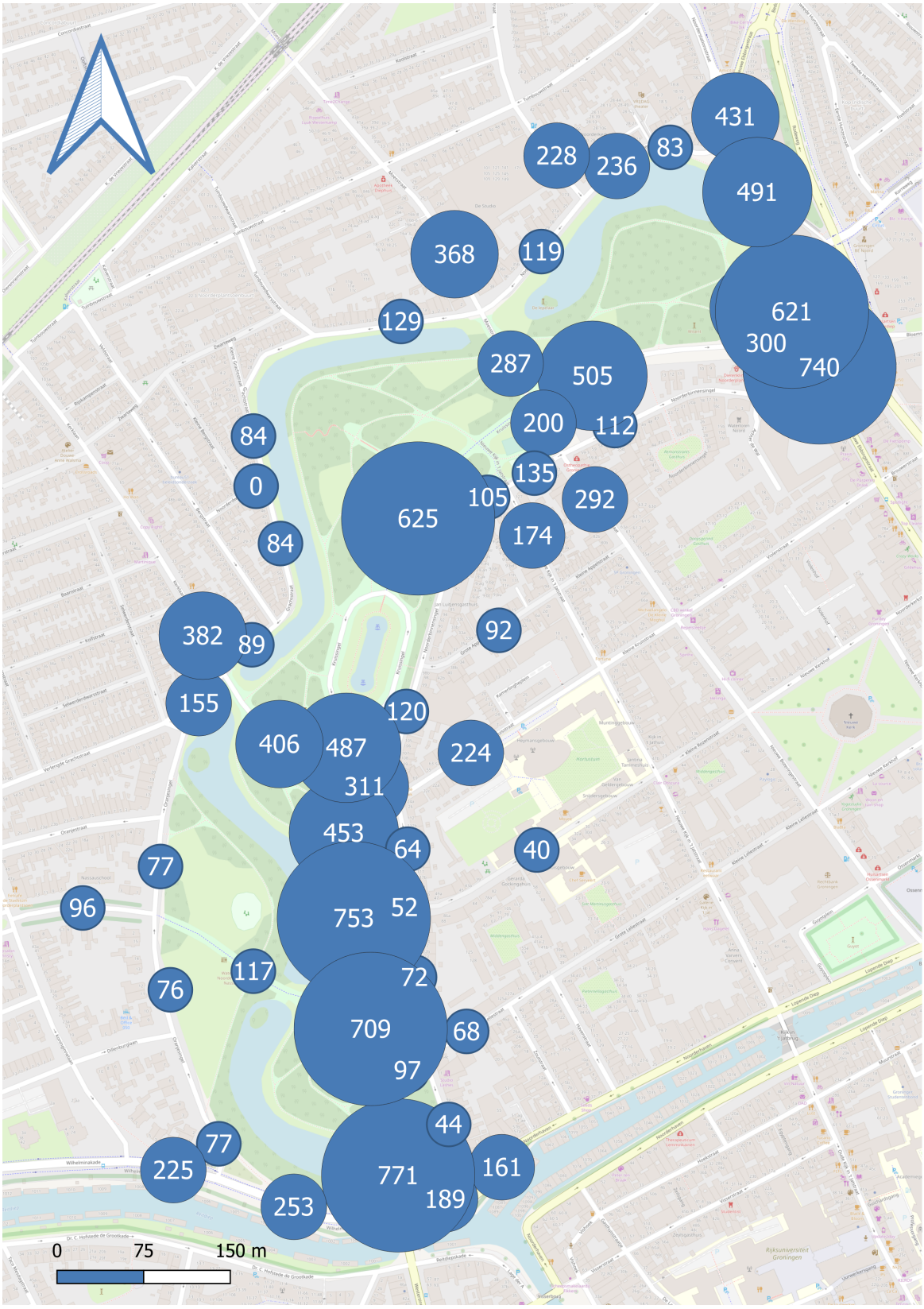


Figure 22: Average movement of people in the Noorder Plantsoen

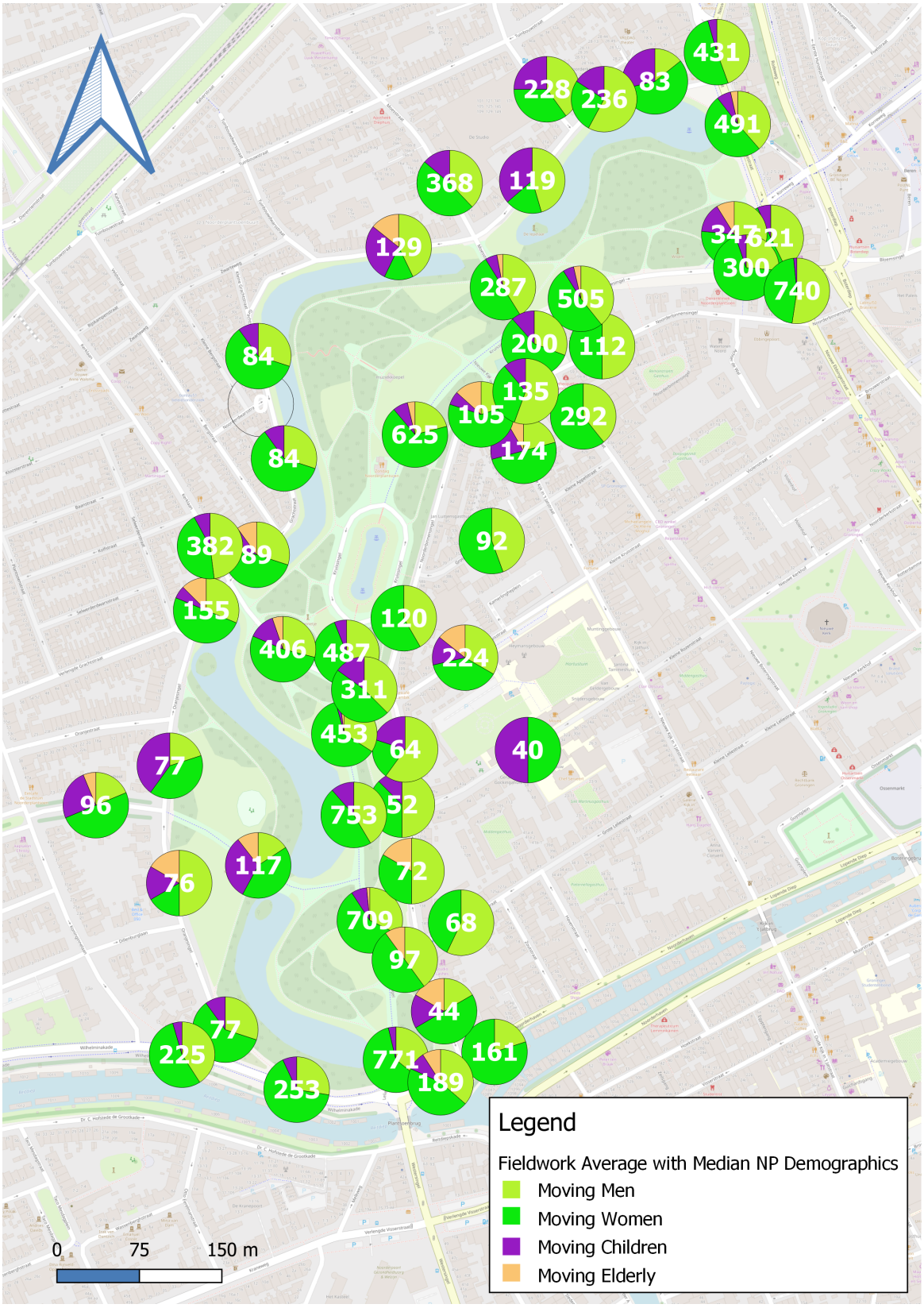


Figure 23: Average movement of people in the Noorder Plantsoen, with median demographics

The figures 22 and 23 show the results of the field observations. All data points were merged using QGIS in order to extrapolate the movement of people per hour seen in both figures. Figure 23 additionally shows the median composition of the observed demographics per location. Note the high amount of throughput around the main bicycle pathways (the Lely-, Kruis- and Botersingel) that cross through the entire midsection of the Noorderplantsoen. Additionally the amount of movement is higher around the streets that cross directly through the park horizontally. As for the demographics, the inside of the park seems to favour women in particular while male are more observed around some parts of the Noorderbinnensingel at the edge of the park. For a more elaborate explanation of the NAIN and NACH variables presented in the following sections, see chapters 2 and 3 on to- and through-movement.

Figure 24: NAIN R1201 (Blue < 1.1 ; Red > 1.30)

Figure 25: NACH R1201 (Blue $<$ 1.0 ; Red $>$ 1.20)

The figures 24 and 25 show the local movement results from the DepthmapX analysis. These "heatmaps" show a movement and integration potential conform Space Syntax theory. With a radius of roughly one kilometre these two maps represent short trips on foot or by bike. Figure 24 shows how the Noorderplantsoen integrated locally with its surroundings. The most well integrated streets are the ones that directly cross the park and provide access to the other side. Note how the main bicycle path has turned red, but that the roundabout is considered less well integrated due to its oval shape. As for figure 25, this shows the predicted preference of people's route of choice when travelling no further than one kilometre. This corresponds well with the observations of the fieldwork. Note here how the hierarchy of the streets is projected. The red represents the high preference, corresponding with the streets that allow entry and exit of the park. This is in contrast with the meandering pathways within the park itself.

Figure 26: NAIN R12014 (Blue < 0.90 ; Red > 1.1)

Figure 27: NACH R12014 (Blue < 0.9 ; Red > 1.20)

Figures 26 and 27 show the city wide movement resutls from the DepthmapX analysis. They can be interpreted in the same way as with the previous figures, the difference being that the movement radius is twelve kilometres, corresponding with city wide trips. These radii should by interpreted as long bicycle trips. Thus, figure 26 shows how well the Noorderplantsoen integrates with the rest of the city, note that the contrast between low and high integration potential is more emphasised. The streets that in this map integrate the best are the ones that allow to directly cross to the other side of the park in any direction. This is logical since the map should be interpreted as a location cyclist simply pass through. Figure 27 then shows the hierarchy of preferred streets when passing through. Interesting to note here that not the entirety of main cycle paths are highlighted in red, on the left of the roundabout (the Kruissingel) in the middle of the park a sandy walking path is considered as a more ideal option to travel.

4.2.3 Vismarkt

Moving on to the Vismarkt, figures 28 and 29 show the results of the fieldwork. Note the high movement of people per hour passing from the Astraat to the Vismarkt. In terms of demographics, similar to the Noorderplantsoen, the majority of the observed people passing by were women. However note the strong presence of elderly at the Kleine der A alongside the canal.

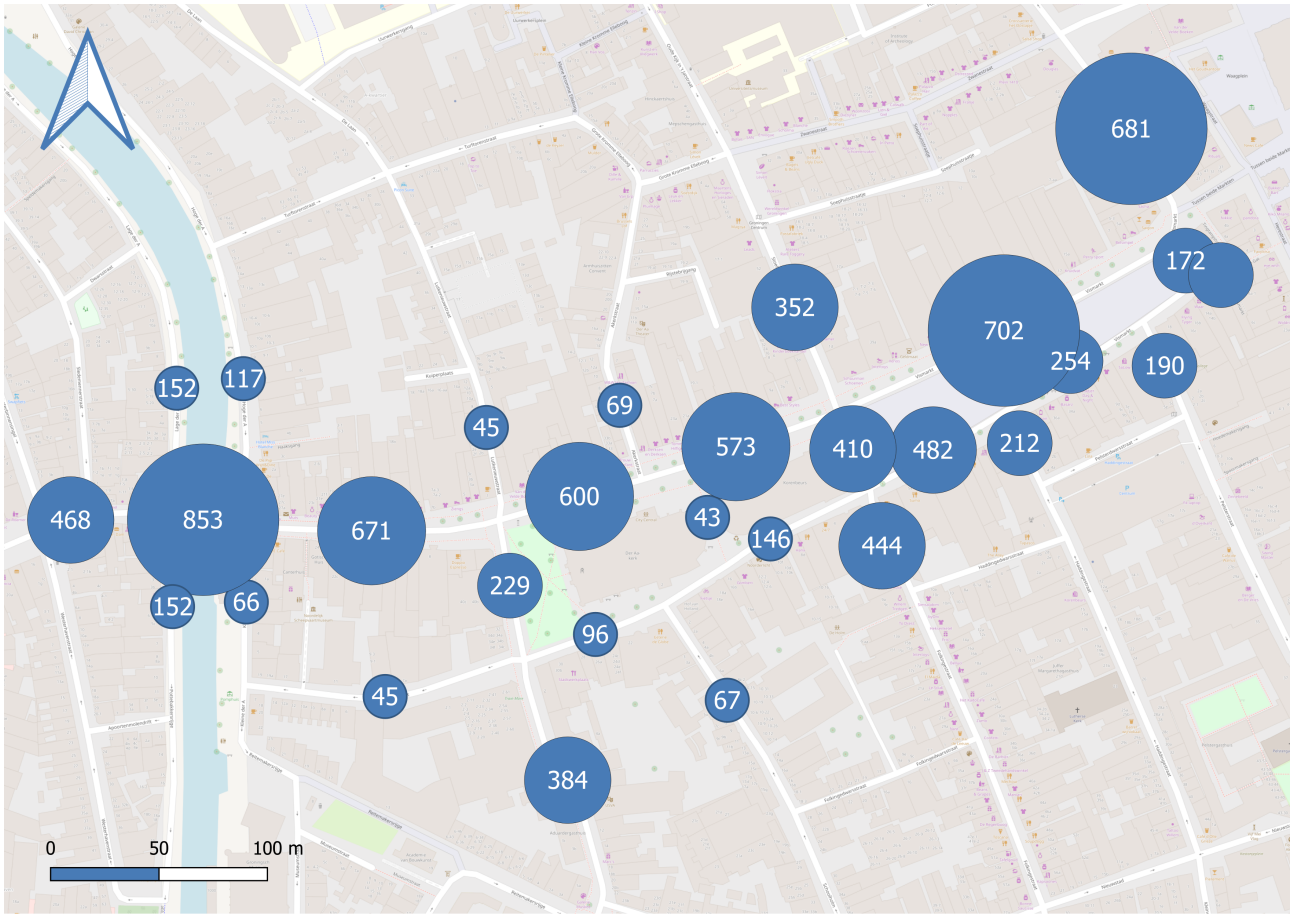


Figure 28: Average movement of people on the Vismarkt

Figures 30 and 31 show the local movement potentials in terms of integration and preference. Figure 30 shows the integration potential in the context of short walks and bicycle trips. Note here how the Astraat and Vismarkt are highly integrated with the local surroundings, as well as the Akerkhof in front of the Albert Heijn. Figure 31 indicates a preference for the Astraat and the Akerkhof in front of the Albert Heijn, since these streets appear to be relatively straight and connect further beyond the canals, this is why angled alleyways tend to turn blue (indicating a low preference). It is interesting to note that the integration (figure 30) visually corresponds better with the observed fieldwork than the the choice map (figure 31).

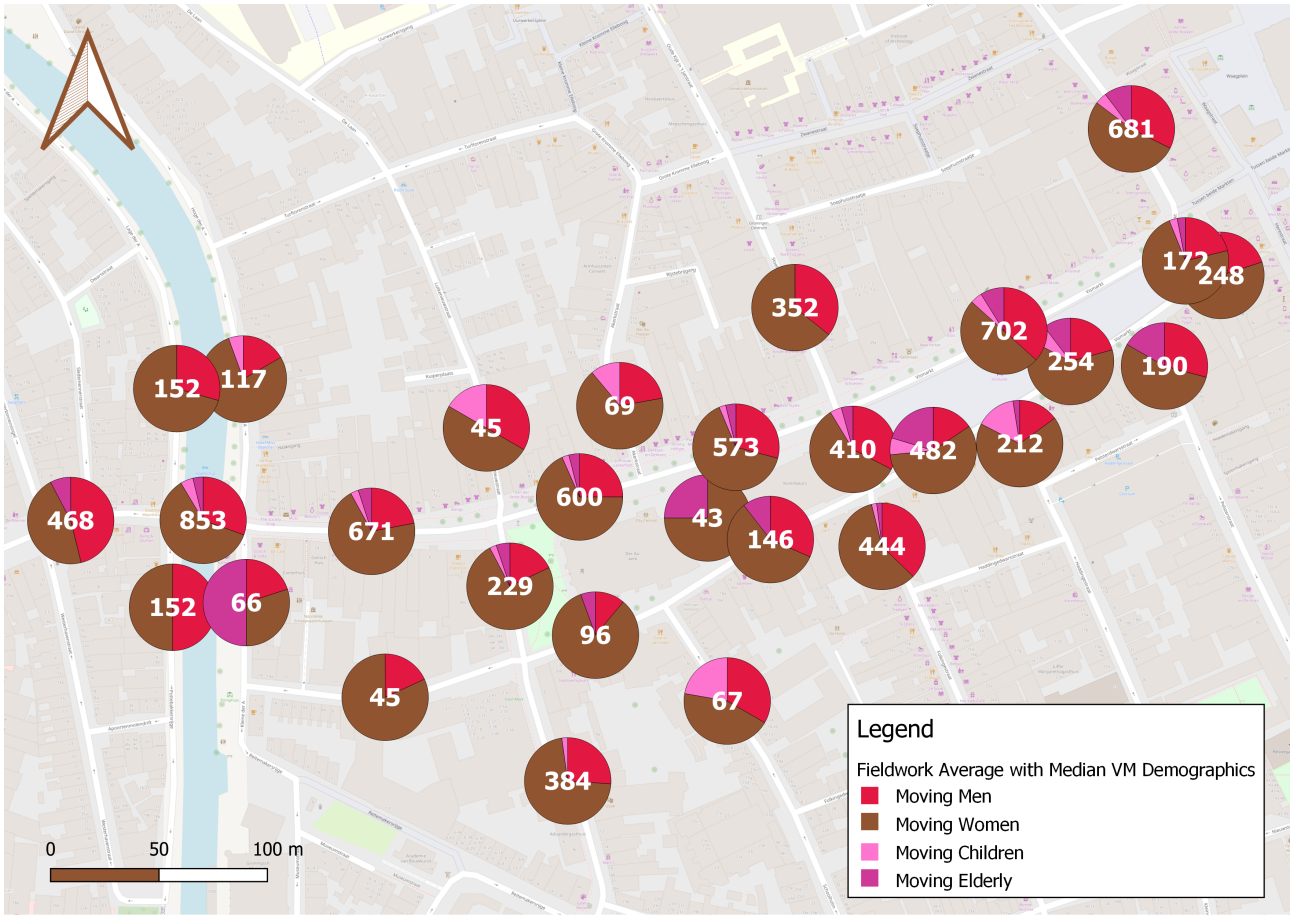


Figure 29: Average movement of people on the Vismarkt, with median demographics

Figure 30: NAIN R1201 (Blue $<$ 1.0 ; Red $>$ 1.30)

Figure 31: NACH R1201 (Blue $<$ 1.0 ; Red $>$ 1.20)

Figure 32: NAIN R12014 (Blue $<$ 1.0 ; Red $>$ 1.20)

Figure 33: NACH R12014 (Blue < 0.9 ; Red > 1.20)

Again, figures 32 and 33 correspond with the levels of street integration and people's preferred route choices as predicted by the Space Syntax software. The figures represent city wide movement, thus the maps should be interpreted as people passing through on bikes. Interesting to note that the Akerkhof in front of the Albert Heijn turns out to have a considerable high integration potential, see figure 32. This is probably due the central location of the street passing straight through the city centre and connecting with the station. Figure 33 complements this observation, but also highlights the Astraat. This shows the preferred streets when people pass through the Vismarkt and corresponds visually with the fieldwork, indicating that most people observed on bicycles simply intended to pass through the location.

4.2.4 Beijum Shopping Centre

Next are the locations observed in Beijum, being the Shopping centre and the local park. As to being an overall lesser well integrated locations, the amount of people per hour observed are lower compared to the city centre. The figures 34 and 35 show the movement of people per hour. The bicycle pathways seem to have the highest movement of people, together with the main road that circles through the neighbourhood. The least amount of movement is seen in the dead-end streets that provided access to housing. Note that the inner part of the shopping centre leans more towards the men demographic and that one particular street exclusively reports children.

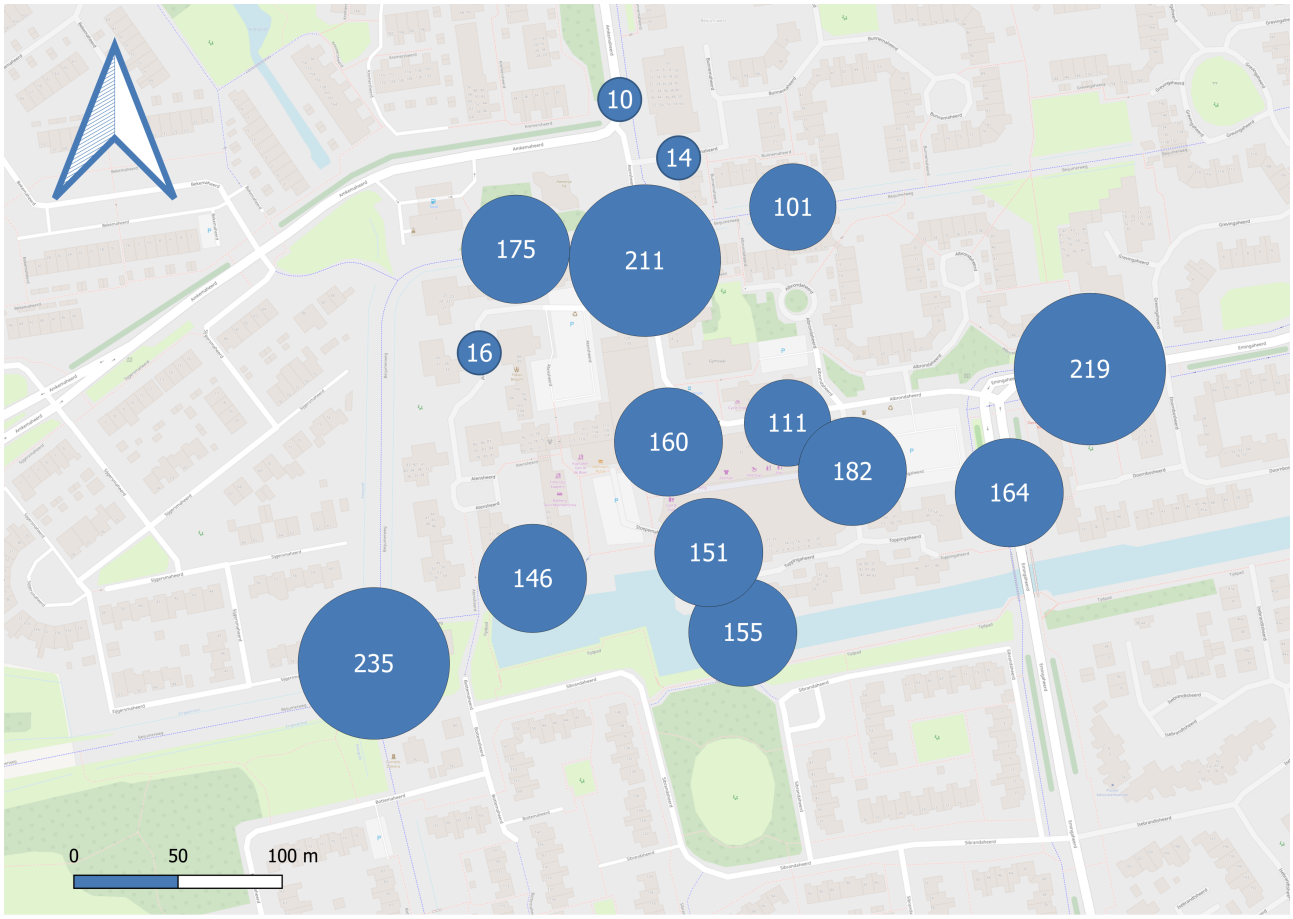


Figure 34: Average movement of people at the Beijum Shopping Centre

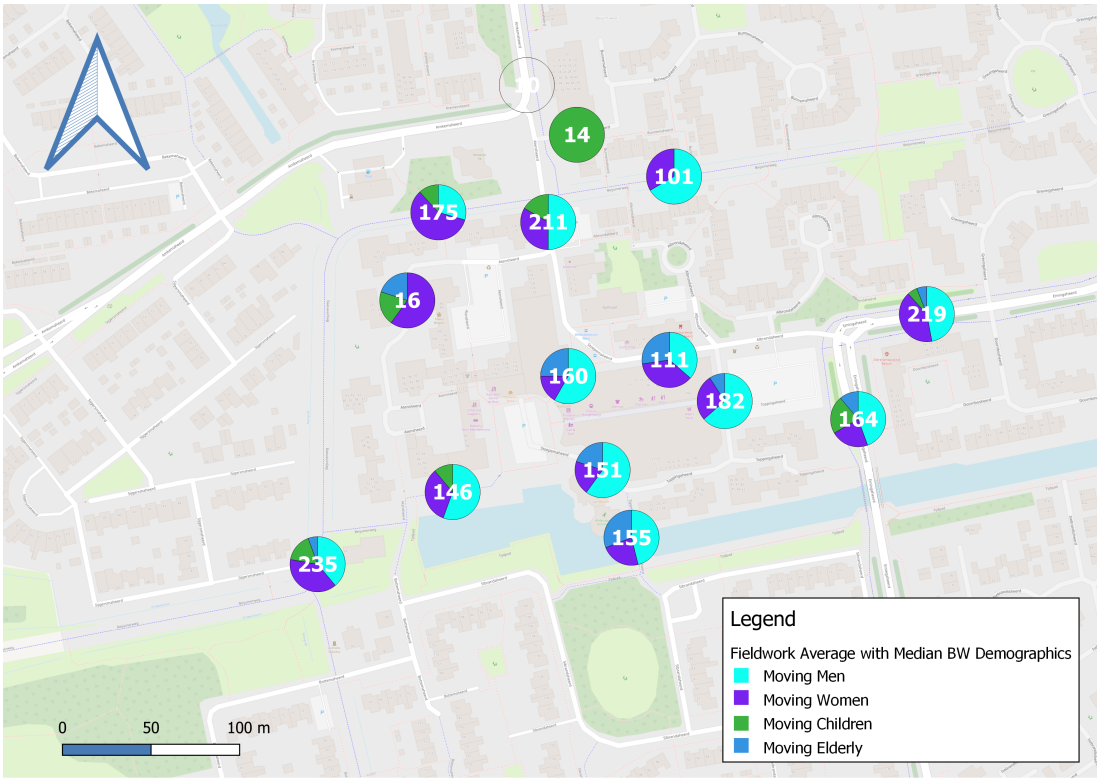


Figure 35: Average movement of people at the Beijum Shopping Centre, with median demographics

Figure 36: NAIN R1201 (Blue < 1.0 ; Red > 1.30)

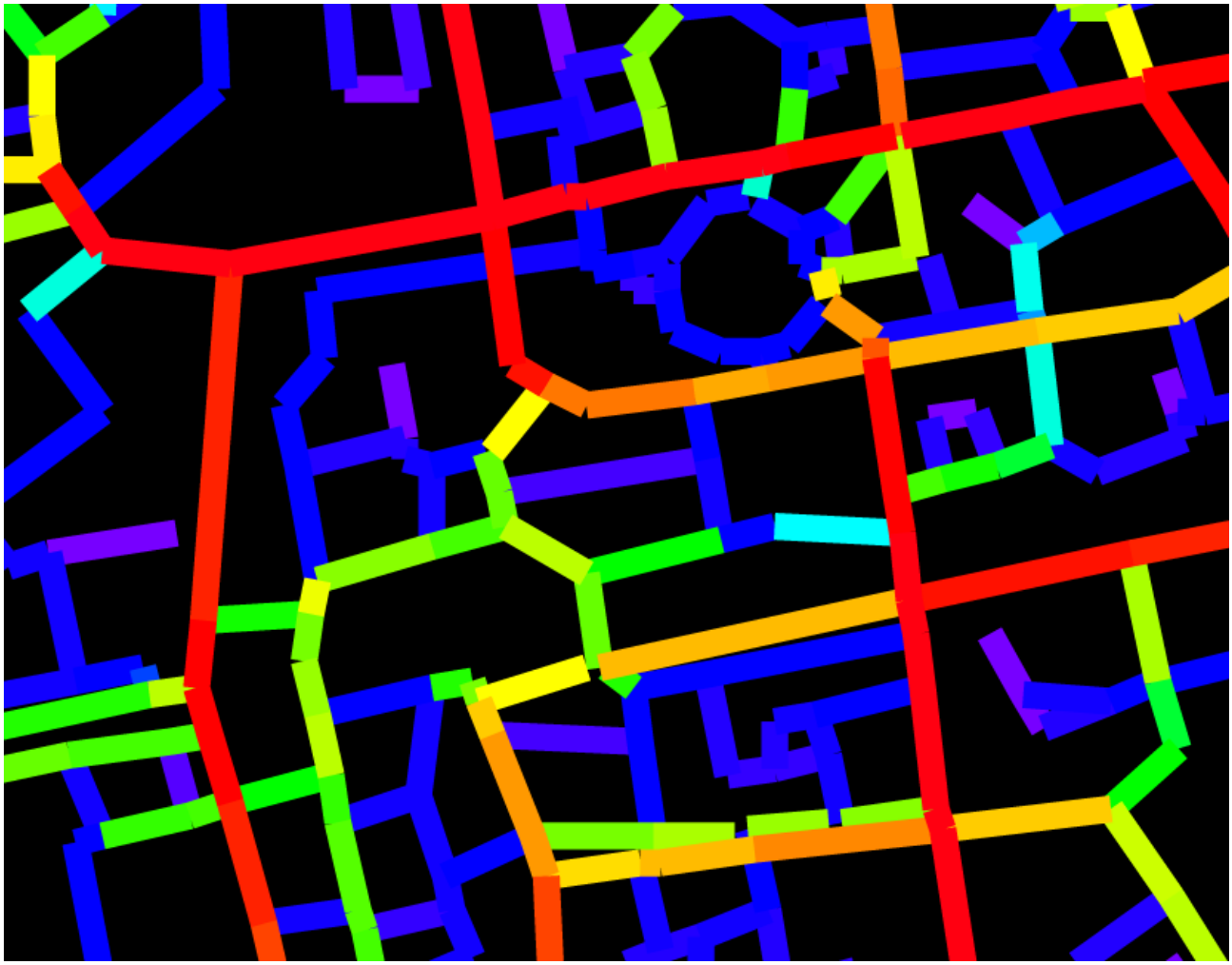


Figure 37: NACH R1201 (Blue $<$ 1.0 ; Red $>$ 1.20)

The figures 36 and 37 show the results of the integration and choice analysis of the shopping centre for a local movement radius of roughly one kilometre. Looking at figure 36, almost all streets turn out blue (low integration). This is due to all of the complex angles of what can be considered dead-end streets. The highlighted segments are in fact the main road that goes through the entire neighbourhood, and the cyclist pathways. The same can be said about figure 37, since the only straight lines are the main road and the cyclist pathways, these turn out to have the highest preference when walking or cycling through the neighbourhood.

Figure 38: NAIN R12014 (Blue $<$ 0.80 ; Red $>$ 1.0)

Figure 39: NACH R12014 (Blue $<$ 0.9 ; Red $>$ 1.20)

There is not a lot to say about the figures 38 and 39. Again, the difference here is that the movement radius considers travelling through the entire city. However, since Beijum is located at the edge of the city, one should interpret these maps as either leaving or entering the neighbourhood. So then figure 38 shows that the main road and the bicycle pathways integrate the best with the rest of the city when cycling. This is a logical observation, since these streets are the only ones that allow to enter or exit the neighbourhood. Figure 39 puts an emphasis on this contrast between the main roads and dead-end streets. It shows that according to the space syntax analysis, people do not want to traverse through the complex meandering street segments, and immediately would look for the nearest cyclist pathway or exit to the main road.

4.2.5 Beijum Bos

The final observed location is the Beijum Bos, a park like location in the centre of the Beijum neighbourhood. The figures 40 and 42 show the movement of people per hour according to the field observations. The general amount of people moving through the location is relatively low, with the exception of the bicycle pathway that crosses straight through the neighbourhood: the Beijumerweg. This allows one to travel between the north and south part of the neighbourhood. While sometimes exclusively men or women were observed, the overall split between woman and men seem to be relatively equal (figure 42). Note that at only one place children were observed, at the Beijumerweg.

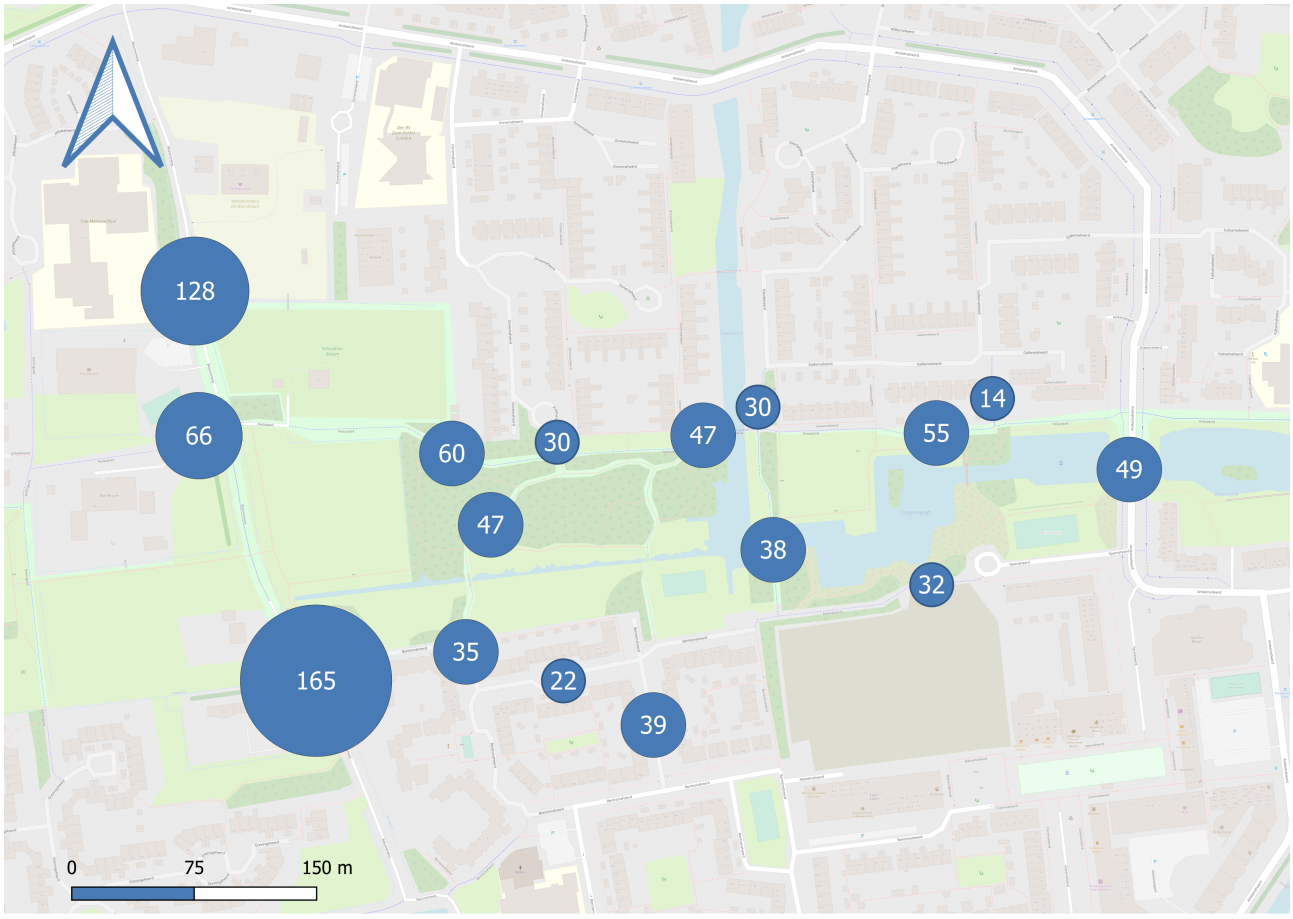


Figure 40: Average movement of people at the Beijum Bos

Figure 41: NAIN R1201 (Blue $<$ 1.0 ; Red $>$ 1.30)

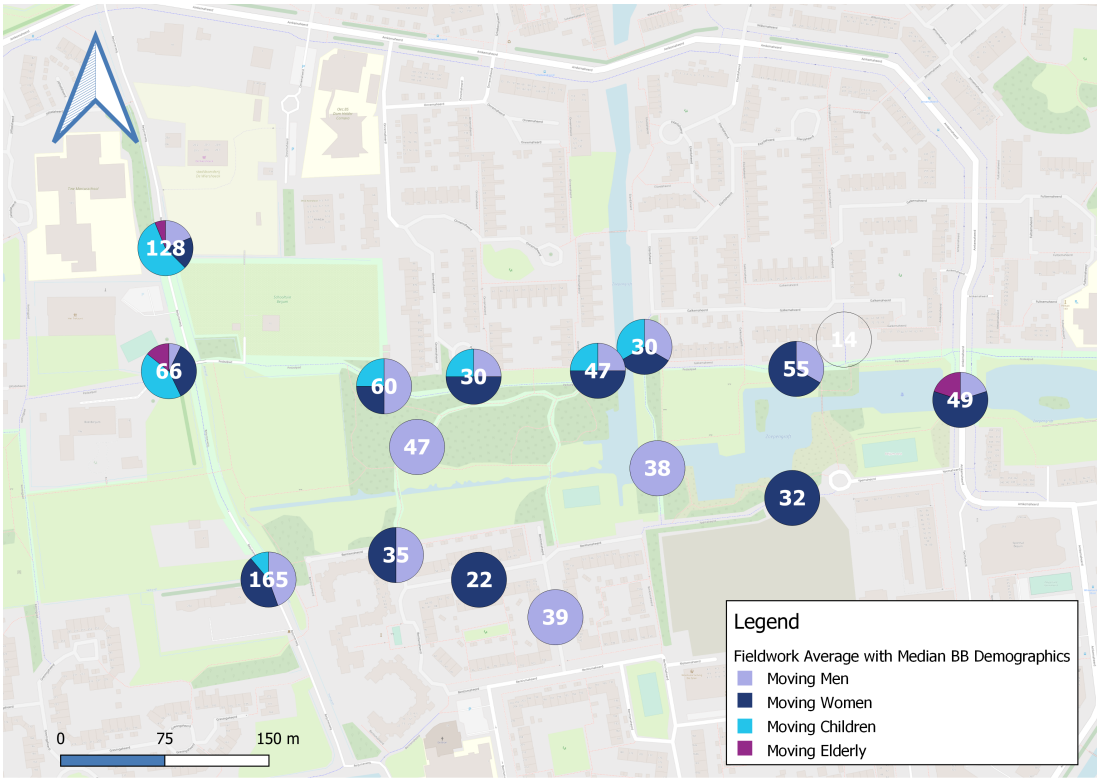


Figure 42: Average movement of people at the Beijum Bos, with median demographics

Figure 43: NACH R1201 (Blue < 1.0 ; Red > 1.20)

Similar to the results of the Beijum shopping centre, the figures 41 and 43 show a strong contrast between the main roads and the dead-end streets. These figures represent the local movement of cyclists and pedestrians walking through the neighbourhood. In terms of integration (figure 41), the main roads and cyclist pathways are highlighted in red, while the dead-ens streets are highlighted in blue. Giving the indication that the red roads are better integrated within the neighbourhood. Then, figure 43 indicates that the straight bicycle pathways, with parts of the main road, the Amkemaheerd, are preferred roads for travelling through the neighbourhood.

Finally the figures 44 and 45, are also similar to the results of the Beijum shopping centre. Figure 44 shows the integration values in relation to the rest of the city, with a movement radius of twelve kilometres. This means that when travelling to the city centre for example, the cyclist pathways and the main road are the best options, since these connect well with the rest of the city. In terms of preference (figure 45), coincidentally the cyclist pathways and the main road of the neighbourhood have a high preference potential (highlighted in red). This is due to the long and traight lines of the street segments.

Figure 44: NAIN R12014 (Blue < 0.80 ; Red > 1.0)

Figure 45: NACH R12014 (Blue < 0.9 ; Red > 1.20)

4.3 Statistical Analysis

Correlation analysis was done to see whether or not the hierarchy of street segments and the movement of people correlated with each other. Both the movement of people and the space syntax variables were not normally distributed, as shown by the Shapiro-Wilk's test results (p. $< .05$) (figure 46).

The correlation tests show a positive correlation between the movement of people per hour and all NACH and NAIN variants (figure 47). There's an indication that as the Space Syntax variables increase in value, the movement of people go up as well. This observation is considered significant for both Kendall's Tau b and Spearman's Rho (p. < 0). In practical terms, what this means is that when the integration and choice potential of streets are improved, it's likely that more people will use them. The scatter plots generated for analysis are found in appendix A.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PPH	,205	1148	,000	,755	1148	,000
NACH R1201	,083	1148	,000	,830	1148	,000
NACH R12014	,101	1148	,000	,934	1148	,000
NAIN R1201	,054	1148	,000	,986	1148	,000
NAIN R12014	,094	1148	,000	,966	1148	,000

a. Lilliefors Significance Correction

Figure 46: Tests of Normality

Correlations

			PPH	NACH R1201	NACH R12014	NAIN R1201	NAIN R12014
Kendall's tau_b	PPH	Correlation Coefficient	1	,280**	,360**	,383**	,378**
		Sig. (2-tailed)	.	0	0	0	0
		N	1151	1148	1148	1148	1148
Spearman's rho	PPH	Correlation Coefficient	1	,396**	,514**	,551**	,544**
		Sig. (2-tailed)	.	0	0	0	0
		N	1151	1148	1148	1148	1148

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 47: Correlations

5 Discussion

This section will discuss the results given in chapter 4. First, remarks regarding the space syntax analysis will be given per location. Here possible explanations/interpretations of the maps will be given. Second, this will be reflected upon in combination with the field observations. Standout features of the field observations will be discussed, regarding what was (not) expected. Third, the explanations will be complemented by discussing the literature research done in chapter 2. Finally remarks will be given on the enrichment of existing literature and possible follow-up research.

5.1 Reflecting on literature

After establishing the theoretical framework in chapter 2, and having used Space Syntax in practise, it is possible to reflect on the information obtained. Considering the theory of Space Syntax it's general principles rely on natural processes, describing some sort of status quo in which these processes take place. When looking at the results of both the Space Syntax Analysis and the fieldwork, knowing that they correlate in a significant manner, it seems that the circumstances of the COVID-19 pandemic do not disrupt this status quo. This can have multiple explanations, such as that people are simply creatures of habit. A pandemic might not disrupt peoples general movement patterns in a significant way, especially considering the times at which the fieldwork took place (which was during times people would go to work, have a break, or go home). In this sense people would simply use the same routes to go to work, have lunch, go home, do grocery shopping, etc. What ties into this observation is considering the amenities closed during the lockdown situation, which are considered "non-essential" ones. The closure of shops and restaurants might just be a small part of the socio-economic processes that make up the city, whereas essential amenities such as grocery stores, opticians, general-practitioners and basically all other job providing sectors excluding entertainment and catering, make up the majority of a city's socio-economic makeup. Though, having done the fieldwork and knowing the pre-covid situation within the areas observed, the lockdown does have an impact on the amount of socio-economic activity within the city, but not as much on a change in the hierarchy of street segments and route preference. This was somewhat observed during the weekend on the Vismarkt, where the socio-economic activity increased due to the presence of the market.

The second thing that stood out when using Space Syntax in practise was the usage of mathematics. The theory of Space Syntax uses mathematical ideas for its practical implementation, as explained in chapter 2. Though when having used Space Syntax' tool-set, it makes one realise how less the mathematics have to do with the theory itself. Upon reading the works of Hillier and Hanson, almost all theory is explained through arguments that find their origins in social sciences, having nothing to do with mathematics. The calculations of, for example the NAIN and NACH values, do only exist as an answer to the "how?" as opposed to the "why?".

Third, what needs to be considered is that these findings cannot be taken as context independent. As seen in previous research that applies Space Syntax circumstances around similar phenomena might be fundamentally different between cities, considering factors such as culture, economy or political climate. For this reason similar research should be conducted in other cities. When given the argument that other Dutch cities might be applicable to the findings in this research, since these cities might be similar, followup research is still recommended as to determine whether or not those similarities are justified.

Fourth, the strengths of Space Syntax during this research was its practicality and how it could be implemented at all the locations. All the locations, while similar, still vary in terms of context. Context here being things like, weather, the amount of people, the size of the area. Yet the analysis, and the fieldwork were successfully applied around all location. More important, Space Syntax allowed for comparisons between the locations studied, regardless of some contextual factors. Space Syntax' simplicity helped asking questions about the environments that one would initially not think about or look at. It helped questioning the context of each individual location, asking question like: (1) why people prefer certain pathways?; (2) how does that relate to the neighbourhood and to the city as a whole?; (3) can this be explained though historical developments of the area's studied. Space Syntax forces the researchers to reflect on both the social and physical characteristics of an environment and find possible solutions to problems that ware both seen and not seen. This in turn made matters concrete, structured and simple, which is beneficial when communicating the information towards non-experts.

Finally, the criticisms do hold up. The practise of Space Syntax analysis has been debated in the past and during this research it has been shown that it is prone to errors. These errors are simply a question that can be answered in one particular way: the need for a standardised and comprehensive approach to practising and interpreting Space Syntax. This is a problem that Nes and Yamu (2021) want to address with their book. A lot of the data input, and thus output, is defined by the interpretation of the researcher. This already starts with the development of the axial maps that are used as input for the analysis. Every researcher might have a different approach to interpreting complex street situation, like crossings, roundabouts or pedestrian exclusive alleyways. Since the nature of Space Syntax Analysis is discontinuous, small geometric differences can have noticeable impact on the final results. These kind of interpretive errors can be solved by either standardisation or providing comprehensive documentation of prior findings in research.

5.2 Space Syntax Analysis

Regarding the Space Syntax analysis of this research, it was in line with what is expected from the theory. When looking at the Space Syntax results, purely based on the way it functions, it's a fairly straightforward explanation. Starting with the hierarchy seen in the street network, the highest values of both NAIN and NACH are seen in the city centre at the Vismarkt. From a city wide perspective this is natural, since being in the city centre means that all places are equally accessible (considering one can go in every direction towards the edges of the city). The city wide NAIN values then slowly decrease as one comes closer to the edges of the city. The city wide NACH values then contribute in showing the preferred routes based on the angle at which street segments cross. Then, of course, the straightest routes are perceived as the most preferred. Coincidentally, when inspecting these segments on OpenStreetMaps or through the fieldwork, the high NACH values can be paired with higher capacity roads or busy streets with a clear intention to either serve lots of amenities or move people to other places as quickly as possible. This NACH hierarchy can be seen really well in Beijum, where all the streets with housing have really low NACH values, while the bicycle pathways and main roads come up highest in the hierarchy. In the city centre this NACH hierarchy has a less stark contrast, which is probably due to the different natures of the environments. The city centre is an historic location that has been naturally evolving over the course of a couple centuries, while Beijum is a purposefully designed neighbourhood of the last century.

As for the local NAIN and NACH values, the same line of reasoning holds true. But the difference is that one should evaluate the results on neighbourhood level and not on the city as a whole. Because the step count of the calculation is changed to a radius more in line with local movement, one could interpret the local values as having a short walk or a trip to the local supermarket. In city wide calculations the economic centre of a city would be revealed in the hierarchy, now that is the economic centre of the local neighbourhood. For Beijum this holds true, as the highest NAIN values are seen at the entry point of the neighbourhood. This is also were the local shopping area is placed. Seen in the NAIN results of Beijum, the integration of the street segments get lower further away from the entry point that connects the neighbourhood with rest of the city. This has to do with the fact that the entire neighbourhood is connected through one main road and a few bicycle pathways. Naturally the bicycle pathways have an equal NAIN value, since these have multiple exit points for the neighbourhood, while the roads can technically only be exited from the highway. The NACH values for Beijum highlighted the straightness of the main road and the bicycle pathways, additionally with some potential shortcuts that could be used through the neighbourhood. Within the city centre the NAIN contrast between high and low values was almost not apparent, because there are a lot of short street segments that connect well in all possible directions. However the NACH values helped to highlight the streets with the most preference when travelling locally through either the city centre or the Noorderplantsoen. On the vismarkt it showed the local preference of people traveling from the station to the Noorderplantsoen. For the Noorderplantsoen itself, it showed how people would prefer to walk through the park or simply cross it to get to a local destination. It highlighted to hardened roads that cross right through the park, while the sandy pathways with lots of angles remain having a low NACH value.

5.3 Fieldwork

The fieldwork has helped in order to give the Space Syntax Analysis context, as well as to proof that the theories applied would still hold true during the lockdown situation. Overall the fieldwork went well with a few setbacks. Two of the biggest issues were coping with the weather conditions and having enough volunteers throughout the process. The good thing is that all assigned gates were accounted for on all days throughout the two planned weeks. The locations that had to be measured in parallel were done so, however due to the lack of volunteers not all locations could be checked twice within two hours as instructed. This was dealt with by having one volunteer measure multiple gates at the same time by standing on either strategic locations, or by filming and counting afterwards. For this reason the busiest streets might have had more throughput than observed. This probably has no consequences for the perceived hierarchy in movement of people per hour, but it should be noted that the flow of people at busy streets usually caps at around 50 people in five minutes. This is probably due to the processing limitations of one person who has to both look and write down. The weather conditions, such as rain and snow, might have had an influence on the amount of people being outside.

When looking at the observations, overall they coincide very well with the expectations made by the Space Syntax results. The observed hierarchy in the NAIN and NACH values are perceived during the fieldwork in all locations. Though this doesn't mean that there weren't a few exceptions. For example, when comparing the Leliesingel of the Noorderplantsoen with the Noorderbinnensingel, which are two parralel streets, they have fairly similar NAIN and NACH values. Yet, when observations were done, almost all people would prefer to go through the park and travel along the Leliesingel. This shows a contrast in both preference and functionality of these two streets, were the Noorderbinnensingel is almost exclusively used to park cars and enter adjacent buildings, the Leliesingel is used

to travel through the park, either to experience the park itself or to quickly cross to the other side. This presumable has something to do with the fact that people potentially prefer green environments or simply because the Leliesingel conveniently connects with the Westersingel with the Korreweg. Another potential interpretation can be the restaurant/cafe at the centre of the park, serving as an attraction for visitors. At the Vismarkt what stood out were two things: (1) people don't use narrow alleyways, even when well connected. (2) there's a place with little movement of people, but with an exceptionally high amount of observed elderly at the Kleine der A. The first observation can potentially be explained by the lack of amenities in small alleyways, but knowing that most amenities were closed that couldn't be a sufficient answer. Another possible explanation is that people prefer routes that don't feel secluded and provide overview of the surroundings, which has to do with perceived safety. In this context perceived safety has less to do with traffic safety, but more with hostility. As for the amount of elderly at the Kleine der A, no potential explanation could be found when further inspecting the surroundings and needs to be researched further. Perhaps that there are some elderly related amenities in the vicinity this research was unaware of, which use this street segment as a connector. Perhaps its simply that elderly avoid busy complex situations and prefer tranquil routes to navigate through the city. At Beijum there was one particular situation were there were a lot of children, which can simply be explained by the presence of a daycare. It should be noted that more children were observed at the Noorderplantsoen and Beijum than at the Vismarkt. This probably has to do with the urban settings, were at the Noorderplantsoen children were observed playing at the playgrounds and mothers would walk with babies in strollers. In Beijum this could be explained by having a different inhabitant demographic, being more oriented at families rather than young adults in the city centre.

The final observation that stood out was the importance of certain amenities. To be more precise, essential grocery amenities had an observable impact on the amount of people being observed. When the Vismarkt had the actual market in place, it was a lot busier shifting the hierarchy in favour of the streets across the Vismarkt in front of the Albert Heijn. In Beijum the opposite was observed, when the grocery store were closed on the Sunday morning almost no people were seen. This would imply the purpose strong specificity of the shopping area and the street designed solely for travelling towards it. Though it should be noted that amenities success depends on how well the streets are integrated. Beijum has multiple shopping areas, not just the one observed during this research. A second shopping area's adjacent streets where observed with little to no movement throughout all days, this can be explained when comparing the observations with the maps of the Space Syntax analysis, were the integration drops as one moves away from the neighbourhood entrance. The second shopping area therefore is at the edge of the most secluded area of the neighbourhood, so one could argue that people intent do to shopping either at the other shopping area because it's integrated better with the neighbourhood, or because people might visit the shopping area while leaving or entering the neighbourhood. Hillier actually debates that integration and economic centres have a symbiotic relationship, so one can imply the other and vice versa.

5.4 Comparison to similar studies

Finally, it is important to put this research into perspective to similar research done in the past. This should give a better understanding of the capabilities of Space Syntax, whether or not it is applicable within the context of similar scenarios, and if it is a recommended tool for government agencies (like municipalities).

When looking at similar studies revolving around parks and plazas, is that there is a focus on improving the utilisation of those environments. It is about adapting movement patterns that encourage engagement with the surroundings, which is achieved by changing the physical characteristics of those public open spaces (Koohsari et al., 2014; Mahmoud & Omar, 2015). In that evaluation process one looks solely at the walking patterns and puts it into context through existing physical characteristics of the environment. This implies that situational context is not relevant in use cases revolving around Space Syntax, in fact section 2, related to the temporal component, confirms that Space Syntax is blind to these circumstantial elements. This means that in hindsight COVID-19 should've played a less central role in developing the research design. Even when looking at Space Syntax studies that are related to COVID-19 and social distancing, COVID-19 itself is not part of the research design, rather just a trigger factor (Kareem, Yasin Baper, Bapir, & Kareem, 2021; Yao, Shi, Zhang, Liu, & Luo, 2021).

What also should be noted, is that Space Syntax is solely used as an evaluation tool to get a better understanding of the current or past situations. This in order to make adaptions to the environments, in order to get a desirable new situation. It is not used as a predictive tool. In the context of for example the studies of Kareem et al. (2021); Yao et al. (2021), Space Syntax was used to pinpoint places where there was an increased likelihood of spreading COVID-19 on local level. This in order to make physical changes to the environments, and successfully improve social distancing. On this local scale, other Space Syntax related techniques were used. This is for example the isovist map, instead of the axial one.

So what should be taken out of this, is that: (1) Space Syntax is fairly universal in its application by omitting situational context, making it useful for other pandemics and shock events in general; (2) It works best as an evaluation tool and (3) other Space Syntax related techniques would've been better suited for evaluating actual movement patterns. This, since the axial maps only allowed for looking at the locations their potentials as whole, in relation to its surroundings.

5.5 Recommendations

Recommendations for the enrichment of literature are as follows. Throughout this discussion it is seen that Hillier's theory on Space Syntax remains in tact within the context of this research. Therefore, the first recommendation would be to confirm this statement within various other contexts, meaning other cities, countries, political settings and cultures.

The second recommendation would be to further investigate the demographic nature of the results, as not for all observations a potential explanation could be found. This also has to do with the limitations of quantitative analysis. Qualitative research might be able to uncover more details intrinsic to the environments that have been studied.

Third and finally, the insights of this research could potentially be used to evaluate on urban design and policy practices in order to provide a safer environment during a pandemic situation. As the COVID pandemic has been going on during the writing of this research, Space Syntax has already been used in order to provide more pandemic resilient environments. It has been used to evaluate the spread of the virus, come up with spatial layouts for social distancing or how to utilise Space Syntax as a communicative tool to maintain a crisis situation. In other words, the relevance of such researches is justified given the uniqueness and severity of the situation, in the hopes of being prepared better for the next similar crisis.

6 Conclusion

The aim of this thesis was to answer the question: "To what extend can Space Syntax analyse the well-functioning of space, given the circumstances of disruptive shock events, like the COVID-19 pandemic?". This section will provide the final conclusions to this main question. In order to give a proper answer, space syntax has been evaluated on essentially three aspects: (1) evaluating the usefulness of space syntax based on it's epistemological position within social sciences; (2) how the (theoretical) tool-set of space syntax would translate into research practice; (3) Whether or not the practice of space syntax would be beneficial for government agencies.

6.1 The epistemology of Space Syntax

Despite also having fair criticisms, the past forty years of research surrounding Space Syntax have provided a well grounded theory. Space Syntax takes concepts and ideas from past well-established research, and moulds them into a hybrid theory that attempts to connect the social and technical rationales within the field of social sciences. As for that reason alone Space Syntax contributes to the societal and scientific interests. First, because in the field of social sciences the technical and communicative approaches seem to be discussed often as separate opposites, rather than being incorporated within each other. Thus filling a niche but important research gap within the field of social sciences. Second, because in planning practise this hybrid between mathematical ideas and social context can provide insights that are simplistic and efficiently obtained, without losing the awareness of the importance of social context. Thus, providing insights that are meaningful to society.

6.2 Application in practise

One key aspect of Space Syntax is that along with the establishment of the theory, this theory has also been tweaked and refined to accommodate for practical application. Various tool-sets have been developed to aids both researchers and urban planners. For one, some of these practises have structurally and successfully been applied during this research. Even without fully comprehending the past forty years of research on the topic of Space Syntax, the core applicable principles have been documented in a straightforward fashion. Together with the aid of automated software applications and visual feedback, information was presented primarily visually. This would be beneficial in order to communicate results towards individuals not familiar with the research field. One criticism would be that the research methodologies are, while documented, scattered around various research papers. Though this criticism is largely addressed with the book by Nes and Yamu (2021), providing a central and comprehensive description of the theory and practice. Also, what this study (and other similar studies) confirm, is that Space Syntax is fairly universally applicable in issues related to public open spaces. This implies that even outside the academic sphere, institutions like municipalities or consultancy firms could potentially take it upon themselves to apply the tools Space Syntax provides. The requirement of minimal resources also makes it ideal for smaller companies, government agencies and NGO's, who lack the financial capacity to use expensive alternatives to solutions that Space Syntax can potentially provide. Planners would benefit from Space Syntax as an evaluation tool, to address structural socioeconomic problems/phenomena, as has been successfully done so in the past.

6.3 The provided insights

There are two ways to look at the insights provided by this research. First, in this thesis Space Syntax was applied to see whether or the movement of people within the city of Groningen would significantly change during a pandemic lockdown. By combining field observations of real-life movement and software analysis the answer to this questions was that the preference of chosen routes did not change. However, the second way to look at the provided insights, is with focusing on the secondary ones. The secondary insights are a results of further investigating the Space Syntax analysis in combination with the fieldwork. The Space Syntax approached helped to provide an overview of potential insights to further investigate. In the process of observing movement with demographic characteristics smaller scale areas peeked interest, due to interesting phenomena. Further investigating these phenomena leaded to new insights that otherwise might've been overlooked. Space Syntax in that sense provided (or even forced) an alternative, and comprehensive, look at the COVID-19 lockdown situation. Given that other studies related to COVID-19, successfully used implemented Space Syntax as an evaluation tool, it would be a suitable tool for the next pandemic in that sense. It is a tool that generates insights to come up with solutions, but it does not generate the solution itself.

6.4 Limitations

Since Space Syntax itself is blind to external context, the the findings of this research might be applicable in other situations. However, given the limited data resolution, this should be verified by follow up studies. The limitations given through the epistemological boundaries of Space Syntax will remain constant at any given research. However: physical, societal and political conditions might differ in other cities at different times. For example, weather conditions and the political setting might've affected the results of the fieldwork. Furthermore, the aid of more volunteers during the data collection might've provided more accurate results. And finally, the design of the axial map might've differed when provided by a different researcher.

Despite of this, given the similarities between Dutch cities in terms of historical development, political setting, culture and weather conditions. It is safe to say that similar results would've been generated in other Dutch cities.

6.5 Future research

Future research should head in two directions: (1) the enrichment of general planning theory; (2) finding more practical applications of Space Syntax. The gap between the social and technical rationale in planning theory is still a niche that could be explored and enriched further, Space Syntax can be used as a current benchmark that attempts to fill that gap and open the debate at finding other (similar) approaches. As for the practical application of the theory: this research has already hinted at the usefulness of Space Syntax to evaluate (and potentially predict) movement patterns of people within cities. Future research should focus on exploring potential practical applications of Space Syntax. For example, how the insights it provides can help municipal decision makers in various planning scenarios. Finally, conducting similar studies as within this thesis within different contexts would aid in further verifying and generalising the results of this thesis.

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Appendices

This section will contain additional visual and material used during this research. The content shown here was either not relevant for the main text or simply could not be incorporated within the text cohesively.

A Scatter plots

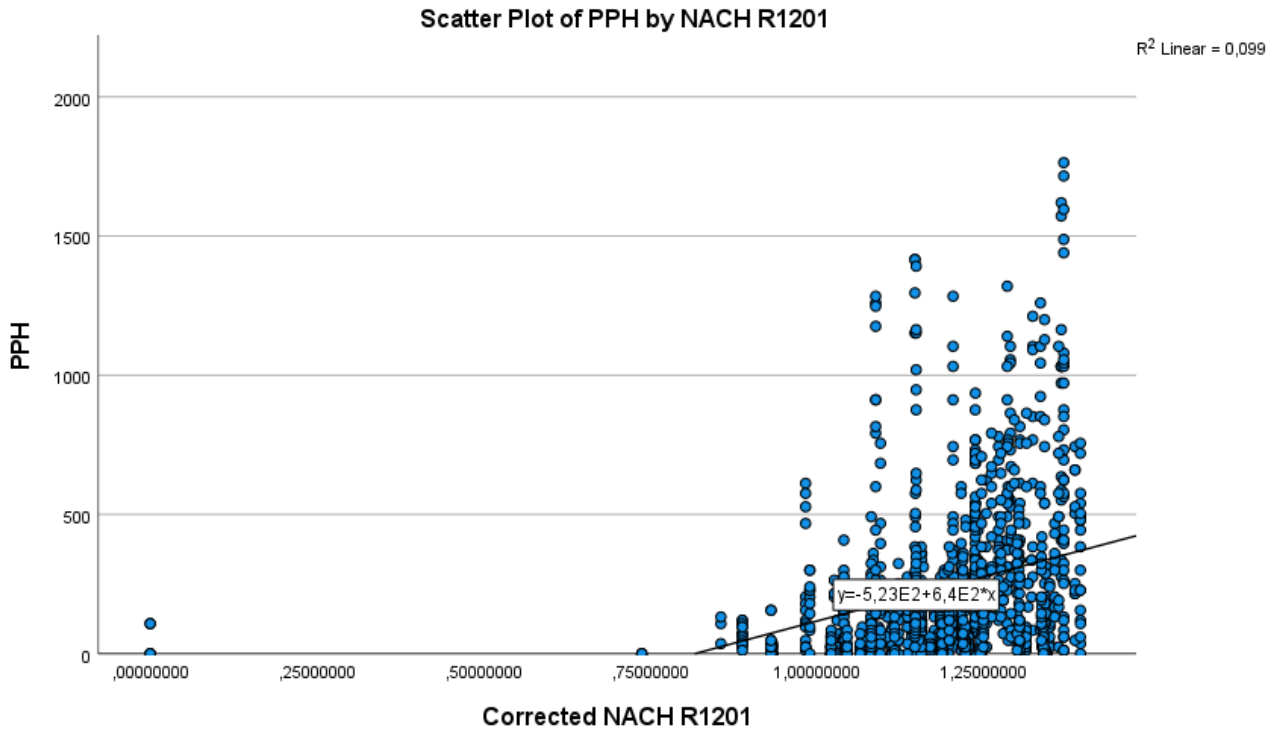

Figure 48: Scatter plot of the relationship between PPH and NACH local

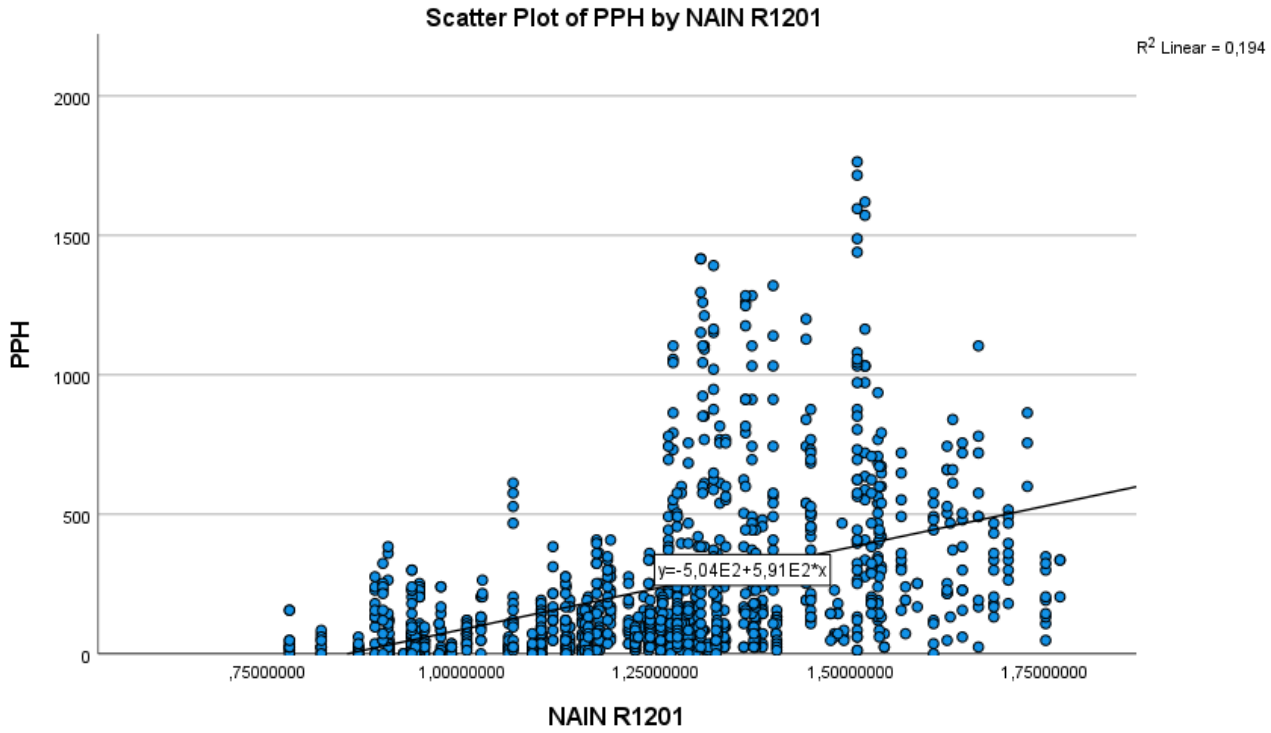

Figure 49: Scatter plot of the relationship between PPH and NAIN local

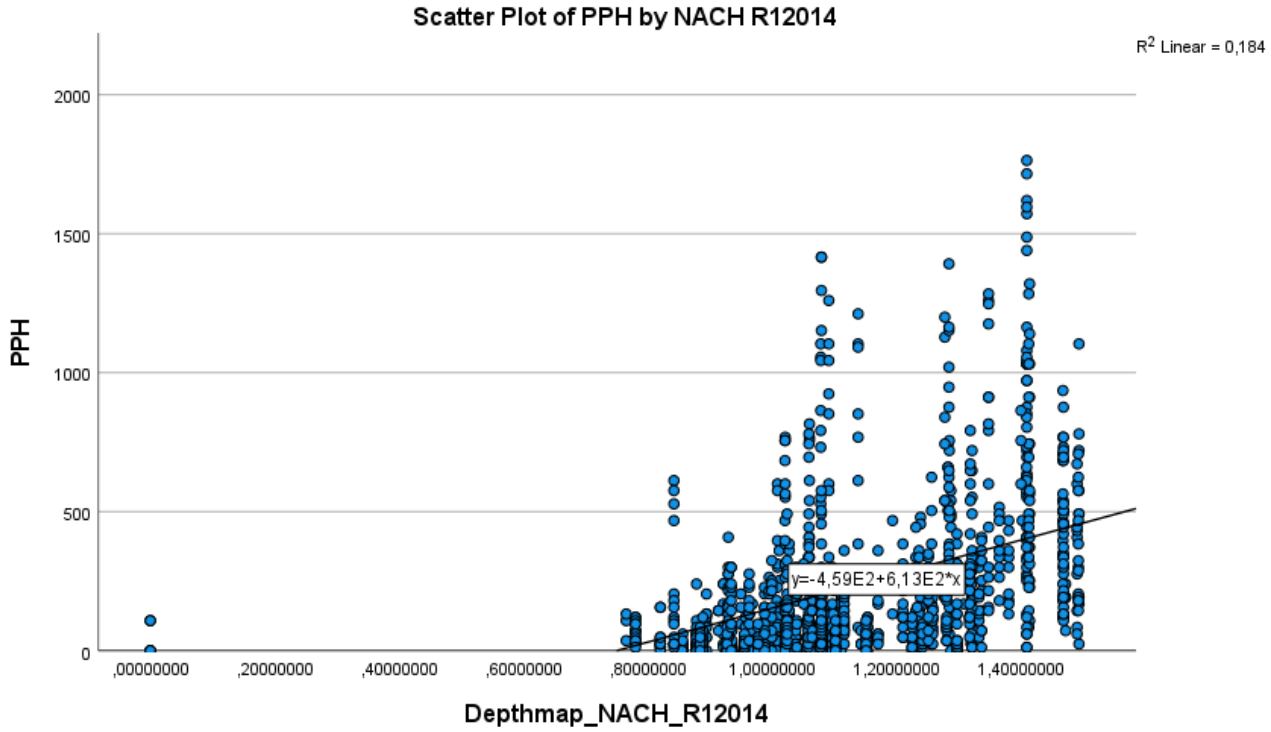

Figure 50: Scatter plot of the relationship between PPH and NACH global

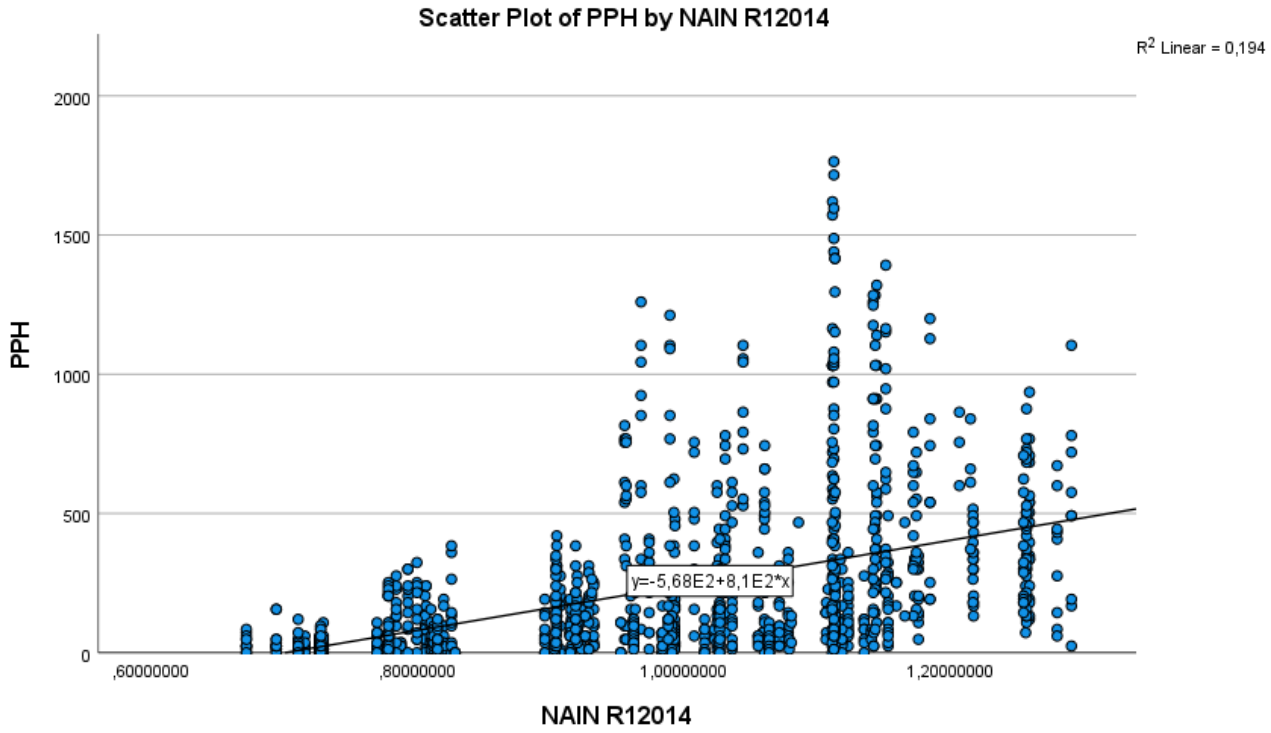

Figure 51: Scatter plot of the relationship between PPH and NAIN global

B Gate Locations

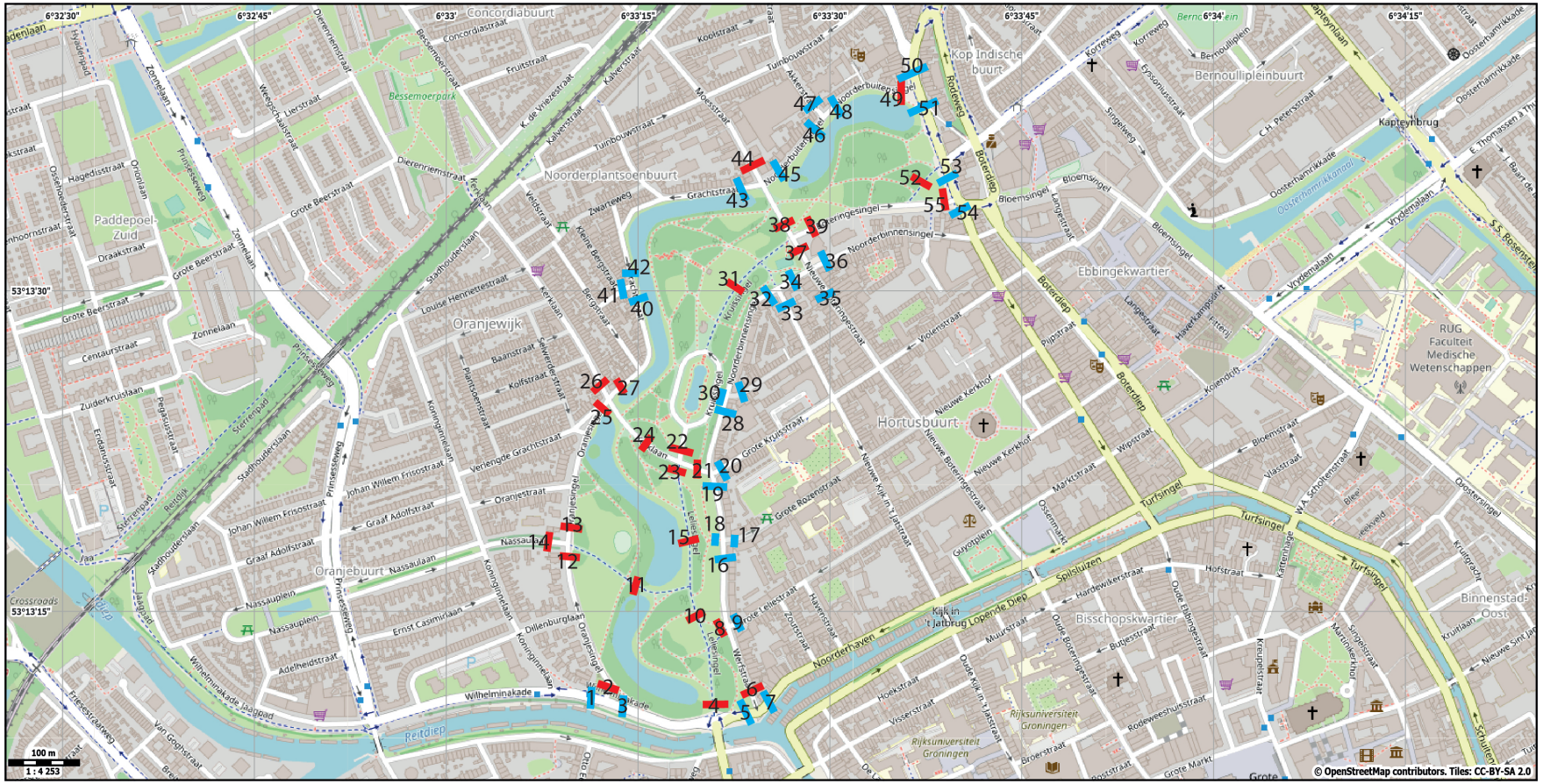

Figure 52: Gates placement in the Noorderplantsoen, red gates were prioritised during volunteer shortage

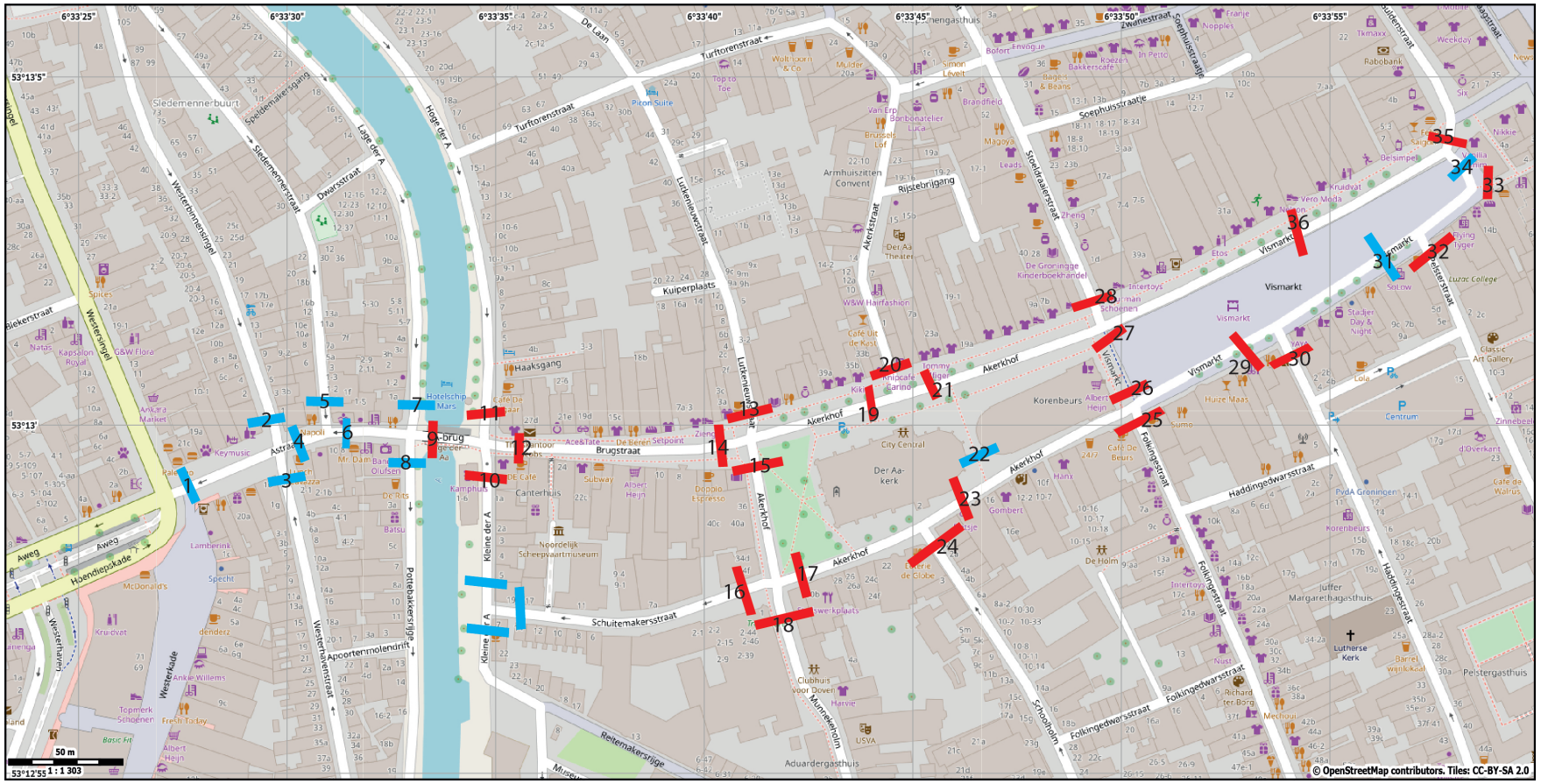

Figure 53: Gates placement in the Vismarkt, red gates were prioritised during volunteer shortage

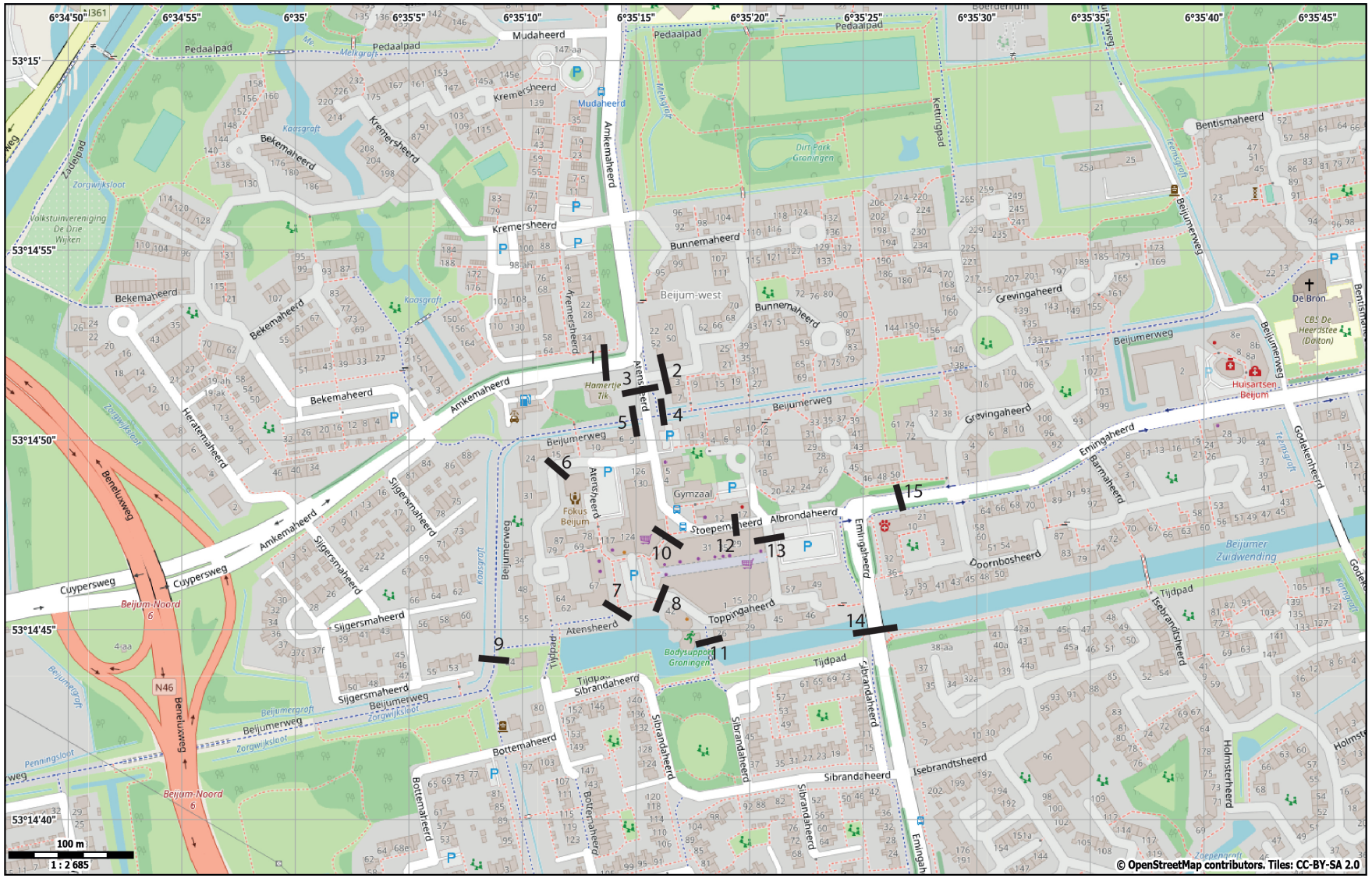

Figure 54: Gates placement in the Beijum shopping centre

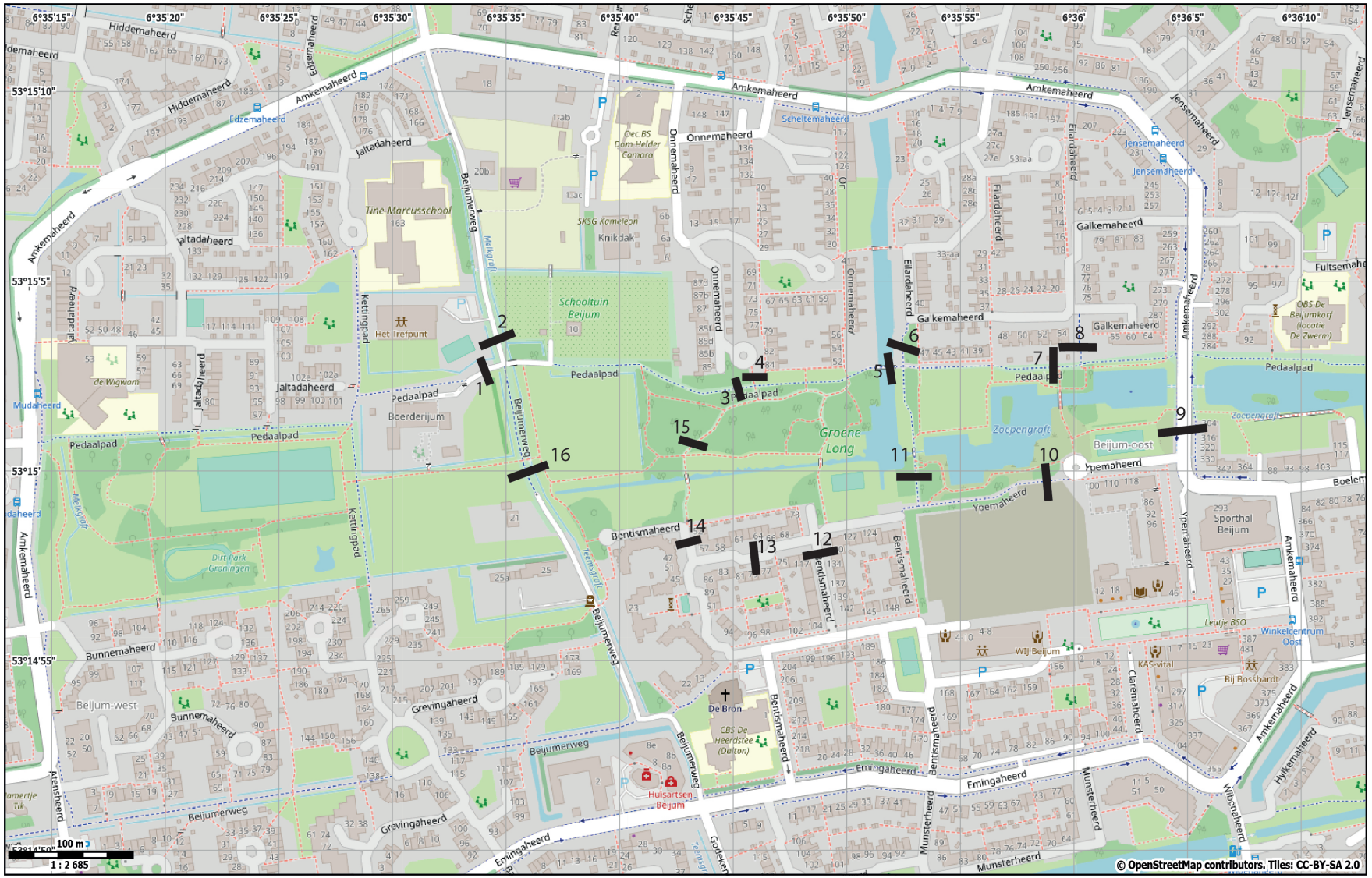

Figure 55: Gates placement in the Beijum Bos

C Volunteer instructions (Dutch)

Instructies voor meten:

- Beide personen starten het uiteinde van de locatie.
  - Men loopt dezelfde route in tegengestelde richting.
    - Aan het eind van de tijdsinterval eindigen beide personen op de startpositie van de ander.
- Markeer de locatie, datum en weersomstandigheden.
- Tel bij een ”poort” beide kanten van de straat in beide richtingen.
  - Markeer het poortnummer.
  - Markeer de begin- en eindtijd.
  - Tel voetgangers en fietsers.
    - Indien rustig, tel meerdere poorten tegelijkertijd (bijv. op kruispunten).
  - Tel: Mannen, Vrouwen, Kinderen (-18) en Ouderen (65+)
    - Als er wordt gelopen met een huisdier, markeer dit als een extra tel naast de persoon in de laatste kolom.
  - Stop na 5 minuten.
  - Ga naar de volgende poort.
  - Herhaal totdat the tijdsinterval van 2 uur om is.
- Indien te weinig tijd of vrijwilligers, meet enkel de rood gemarkeerde poorten.
- Indien er tijd over is, ga door met meten van andere poorten totdat de tijdsinterval om is.

Geplande intervallen:

- 8:00 tot 10:00
- 11:00 tot 13:00
- 15:00 tot 17:00

D Observation sheet

Location: _____

Date: _____

Weather Condition: _____

Gate #	Time	Moving Men	Moving Women	Moving Children	Moving Elderly	With Pets

Figure 56: Counting sheet for fieldwork