MASTER

Car free Arnhem

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CAR FREE ARNHEM
MASTER THESIS

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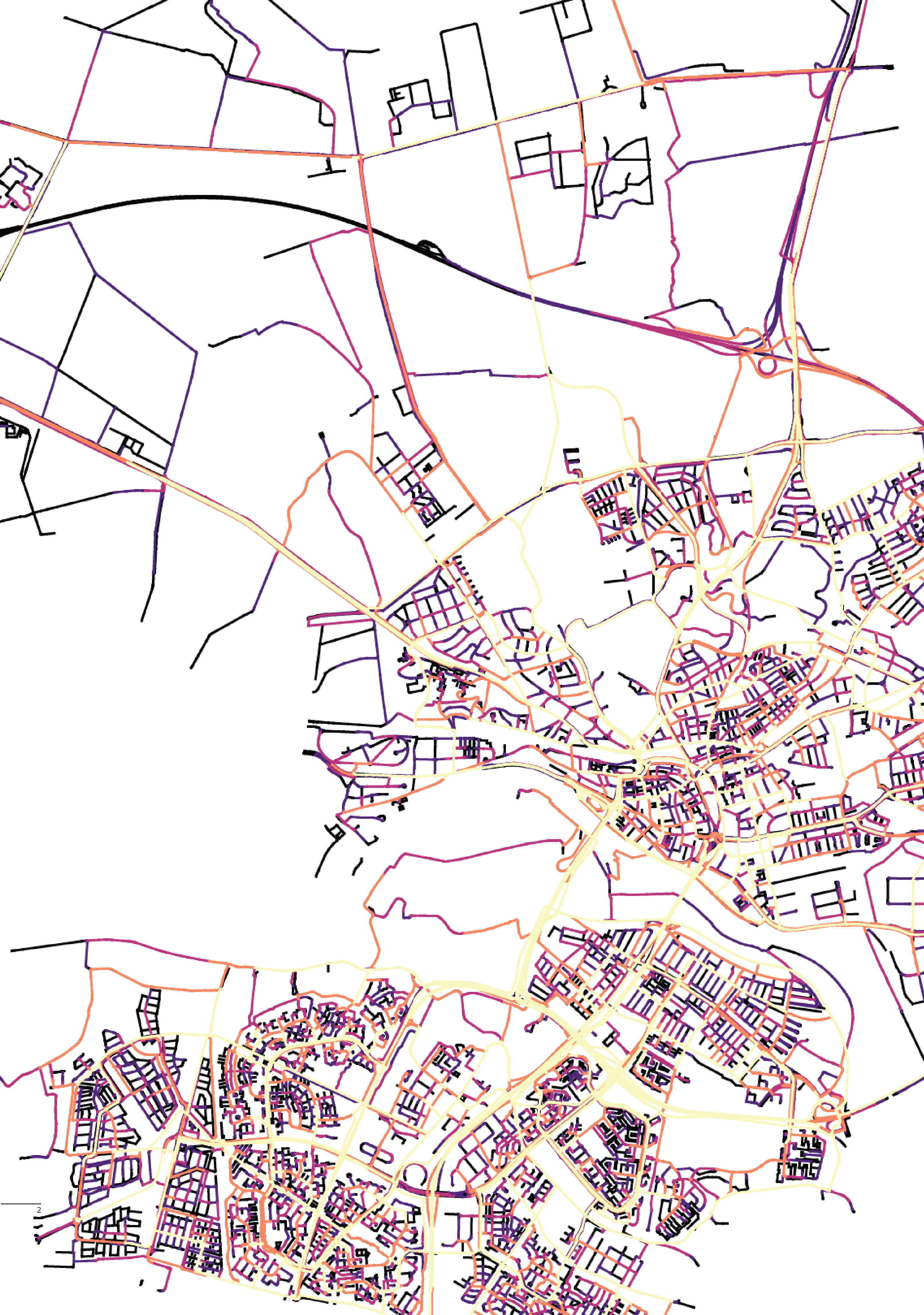

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PREFACE

With this thesis, 8 years of studying comes to an end. I enjoyed writing and designing this master thesis but at the same time I'm glad that this period comes to an end. A new phase starts to which I look forward. Of course, this result could not have been established without inspiration, help and support from tutors, fellow students, friends and family.

Firstly, I would like to thank Dena Kasraian and Gamze Dane for the tutoring sessions and for knowledge they shared. They provided the guidelines towards a successful graduation and encouraged me to aim high but also define my own planning and way of working. I would also like to thank Pieter van Wesemael for his contribution during the preliminary and green light presentation.

Secondly, I would like to thank my fellow students for their inspirational presentations every week. They gave feedback on my work and I learned from theirs. They all did an amazing job!

Furthermore, I am thankful for Ilja, my friends and family. They supported me, gave input on my work and ideas and shared interesting information regarding car reduction in cities.

01

CAR FREE ARNHEM
LITERATURE REVIEW

The first part of this thesis describes the outcomes of the literature review. This review focusses on finding measures that effectively reduce car dominance in cities. By reviewing 26 literature studies, an overview of measures is presented.

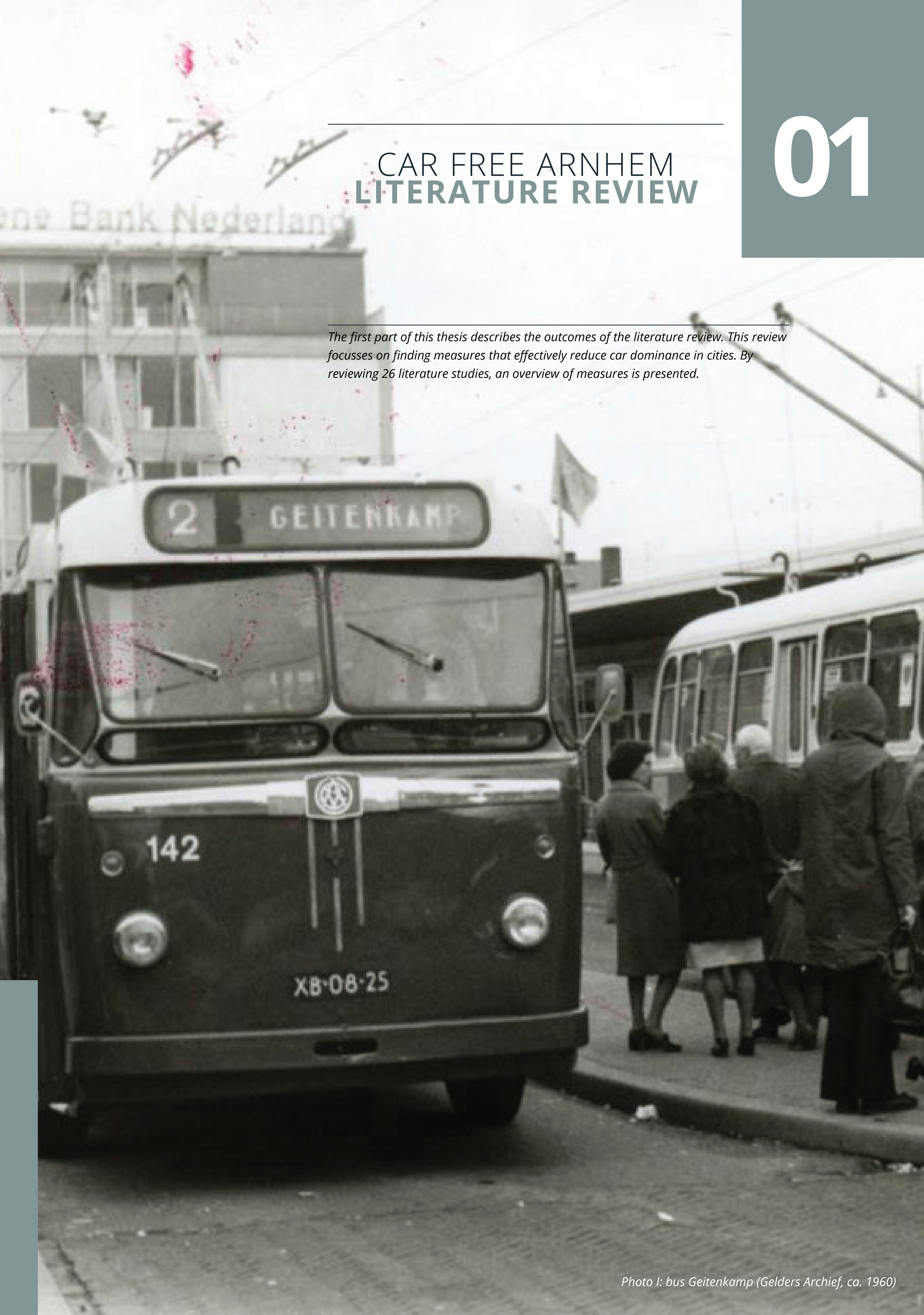

Photo I: bus Geitenkamp (Gelders Archief, ca. 1960)

REDUCING CAR DOMINANCE IN DUTCH CITIES

AN EVALUATION OF THE CAR-FREE CITY POTENTIAL FOR THE CITY OF ARNHEM

ABSTRACT

In 2018, 55% of the global population lived in cities. This number is still increasing and will reach its peak in 2050, with almost 70% of the world population living in cities. The mentality evolved in the past century, described as the 'century of the car', has had a major impact on the development of cities and accessibility of urban centres. Although the world population, especially in Europe, benefitted from the introduction of the car, many problems are linked to private car ownership. There are numerous examples of cities developing strategies for banning cars from their city centre and stimulate public transport (PT), cycling and walking. Nevertheless, the continuously increasing number of cars worldwide is expected to reach 2 billion in 2030. In cities like Copenhagen, Oslo, Madrid, London and Paris, the municipality has implemented policies to restrict or ban cars from parts of the city.

Dutch cities are directly linked to great cycling infrastructure, larger cities have pedestrianized their centres and have implemented other car reducing measures. Although this might suggest a successful reduction of cars in Dutch cities, the opposite is true: the number of cars increased with 1.5 percent in 2021 (compared to 2020) and the number of kilometres driven, increased with 4.8 percent. The city of Arnhem joined forces with the city of Nijmegen in the regional collaboration of 'the Groene Metropoolregio' to ensure the development of almost 100.000 houses in the province of Gelderland. This densification assignment requires a new way of looking at cities in terms of land use and transport system. In literature, there is a lot of information on car restricting, sharing and banning policies and design implementations, which is aimed for direct change in either land use or transport network. Although there are numerous articles discussing different measures to reduce car dominance, this information is scattered, and context of location and historical development are often neglected. Moreover, the involvement of the user is often missing in car dominance reduction measures. Before introducing interventions that affect land use and infrastructure, awareness should be raised. An overview of available interventions on societal and individual level, a proper assessment of spatial and contextual characteristics of the location where these interventions are to be implemented and their potential for supporting these policies is needed to operationalize the phased reduction of car usage in Dutch cities. Therefore, this paper aims to answer the following research question: To what extent can the densifying city of Arnhem become car-free, and how can this car-free concept be strategized?

The first part of this work presents a literature review. This review summarizes the historical development of the car and the reaction in urban development, presents an overview of available interventions and discusses the collaboration of stakeholders. These three elements were then used to analyse three case studies. These case studies and results from literature form the basis on which an approach (toolbox and decision tree) is founded. The second part of this work presents a city strategy and a neighbourhood design, which demonstrates the implementation of different interventions.

This article examines a total of 26 articles and three case studies, presenting an elaborate overview of 10 intervention categories containing 66 interventions across various scales. These interventions require push and pull strategies, stakeholder management, an overview of future development plans and working across different scales. Combing these points of attention and the approach, the interventions prove to be valuable in reducing car dominance in cities.

KEYWORDS

Reduce car dominance, densification, urban design, city strategy, policy, mobility, car-free, car-low

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INTRODUCTION

In 2018, 55% of the global population was living in cities, this number is still increasing and will reach its peak in 2050 with almost 70% of the world population living in cities (Ivers & Fleury, 2020). The past century, described as the 'century of the car', has had a major impact on the development of cities (Brown et al., 2009). Examples of this development are the increased mobility, employment, technological advances and economic prosperity (Nieuwenhuijsen & Khreis, 2016).

Although the world, especially Europe, benefitted from the introduction of the car, many problems are linked to private car ownership. The production of greenhouse gas emissions (GHG) is an important issue in our cities. Currently, cities produce 75% of greenhouse gas emissions (Peter & Swilling, 2012) of which almost half is directly related to the transportation sector (Wiggins, 2020). The reduction of GHG is an important aspect of the sustainability development goals (SDG's). Reduction of GHG can lead to healthier cities, climate action, life on land and below water and responsible production and consumption (Take Action for the Sustainable Development Goals, 2020). Reducing dependency on private car use can thus benefit air quality, reduce the heat-island effect, reduce noise disturbance, improve physical activity level and decrease the number of accidents (Vardoulakis et al., 2016).

To zoom into the contribution of reducing car dominance to create a healthier city, the concept of liveability can be used. Valcárcel-Aguiar et al. (2018) present a concept for urban sustainable liveability that divides the contribution of the built environment to sustainable urban liveability into an economic-, social- and physical dimension. According to this concept, the reduction of car usage can have a drastic effect on the physical dimension in terms of infrastructure and facilities, and congestion and overcrowding. Also, the social- and economic dimension can be indirectly affected. Urban and transport planning policies are proven to have a lasting direct impact on public health and liveability (M. Nieuwenhuijsen & Khreis, 2018). Urban and transport planning policies 'are likely to lead to higher levels of active mobility and physical activity which may improve public health the most and also provide more opportunities for people to interact with each other in public space' (Nieuwenhuijsen & Khreis, 2016).

Although there are many examples of cities developing strategies for banning cars from their city centre and stimulate public transport (PT), cycling and walking, the number of cars worldwide is still increasing, expected to reach 2 billion in 2030 (Sperling & Gordon, 2008). In the Netherlands, 8.3 million cars (stationary more than 90 percent of the time) use the available 14-18 million parking spots (Kansen et al., 2018). These numbers show the major effect of car usage in this highly dense country. Apart from the parking spaces, car infrastructure also affects the land use of both country and city, in terms of road infrastructure, fuel stations, sound barriers, etc, and therefore the urban planning and design. The worldwide population growth and increasing number of cars in cities, thus stimulates the discussion of land use within cities and awakens the question 'to whom belongs the public domain?'.

'There is evidence of much wider and growing interest in policies which adapt the car to the city in place of the more usual destructive attempts to adapt the city to the car' (Topp & Pharoah, 1994). Reducing private car ownership and attempts to reduce the impact of the car on our cities, is not new. In cities like Copenhagen, Oslo, (Rydingen, Hoynes & Kollveit, 2017), Madrid, London and Paris, the municipality has implemented policies to restrict or ban cars from parts of the city (Nieuwenhuijsen & Khreis, 2016). Also in the Netherlands, big cities have pedestrianized their centres, making them only accessible on foot. Apart from banning cars, many cities try to reduce car usage and ownership by implementing car restricting policies and car sharing opportunities (Curtale et al., 2021). Dutch cities are directly linked to great cycling infrastructure. Although this might suggest a direct link to the 'car-free city', the opposite is true: the number of cars increased with 1.5 percent in 2021 (compared to 2020) and the number of kilometres driven, increased with 4.8 percent. Thus, car use in and around Dutch cities is at all-time high (Centraal Bureau voor de Statistiek, 2020).

The region of Arnhem and Nijmegen aims to reduce the number of car trips to decrease the expected increase of residents traveling in and around their cities. Not only to keep their road network functioning, but also to achieve climate goals and therefore reduce GHG (Regio Arnhem-Nijmegen Groene metropoolregio, 2019). The city of Arnhem is, with 164.000 inhabitants, one of the fifteen biggest cities in the Netherlands (Centraal Bureau voor de Statistiek, 2022). The number of cars per inhabitant in Arnhem is 0.8, which is average for the fifteen biggest municipalities in the Netherlands (average of all municipalities is 1.1) (Centraal Bureau voor de Statistiek, 2022b). On many subjects, the city of Arnhem collaborates with the city of Nijmegen and surrounding municipalities at regional level: region of Arnhem – Nijmegen and Foodvalley (Regio Arnhem-Nijmegen Groene Metropoolregio, 2020). To ensure the development of almost 100.000 houses in the province of Gelderland, Arnhem needs a new way of looking at the city in terms of land use (densification) and transport system (both public transport and car). The location of the city of Arnhem, in combination with the newly published environmental vision (Ontwerp Omgevingsvisie Arnhem 2040, 2022), which focusses on densification of the city of Arnhem, makes the city highly applicable for this research.

There is a lot of information on car restricting, sharing and banning policies and design implementations, which are aimed for direct change in either land use or transport network. Although there is a lot of information, this information is scattered and context of the location and historical development is often neglected. Another important gap in measures that reduce car dominance, is the involvement of the user and liveability. Different articles mention the use of push and pull (stick and carrot) measures, but even there the pull intervention aims for change of the urban fabric or transport network. 'For many, infrastructure is invisible and only becomes visible when it breaks down' (Leigh Star, 1998). Currently, interventions that show residents the effect of reduction of car usage within cities, is undervalued.
An overview of available interventions and their effect on liveability, a proper assessment of spatial and contextual characteristics of the location where these interventions are to be implemented and their potential for supporting these policies is needed to operationalize the phased reduction of car usage in Dutch cities. Therefore, this paper aims to answer the following research question:
To what extent can the densifying city of Arnhem become car-free and how can this car-free concept be strategized?
This main question is elaborated in the following sub-questions:
1. How can densification, reduced car dependency and liveability be defined?
2. What does the historical development of reducing car dependence look like?
3. Which existing interventions of reducing car dependence in literature have proven successful?
4. Which stakeholders are involved and how do they interact and/or collaborate in these successful proven interventions?
5. What is the current situation of the city of Arnhem in terms of spatial context, implemented interventions, contextual characteristics and liveability?
6. How can the successful proven interventions be strategized in the city of Arnhem to reduce car dominance and improve liveability at the city and neighbourhood scales?
7. What are the potential implications of this strategy on the urban structures on neighbourhood scale?

Figure 1 shows the methodological approach to answer the sub-questions and finally the main research question. The paper can be divided into five main themes: research, analysis, concept, strategy and design. Each theme has multiple steps.
Firstly, literature research will be conducted resulting in measures to reduce car dominance. To provide a basis of knowledge about the historical development of the car and the city, a brief historic development summary will be given. To provide information on how to use the found measures, stakeholders connected to the found measures will be researched as well. The literature review will be conducted using scientific sources.
Secondly, the analysis part will focus on further elaboration on the found measures by analyzing three case studies and performing a policy analysis. Also, a diagnosis will be performed, which will be a spatial analysis, defining already implemented interventions and defining contextual characteristics of the city of Arnhem.
Thirdly, an approach will be developed using the outcome of the literature review, case studies and policy analysis. The approach will consist of a toolbox and decision tree providing a handle for policy makers and urban designers to use the measures found in literature.
Fourthly, a strategy on how to implement interventions to reduce car dominance in the city of Arnhem will be suggested. The basis for this strategy is the outcome of the analysis phase.
Lastly, a zoom-in design of one of the neighborhoods in Arnhem will be presented. This design will show the implementation of different interventions.

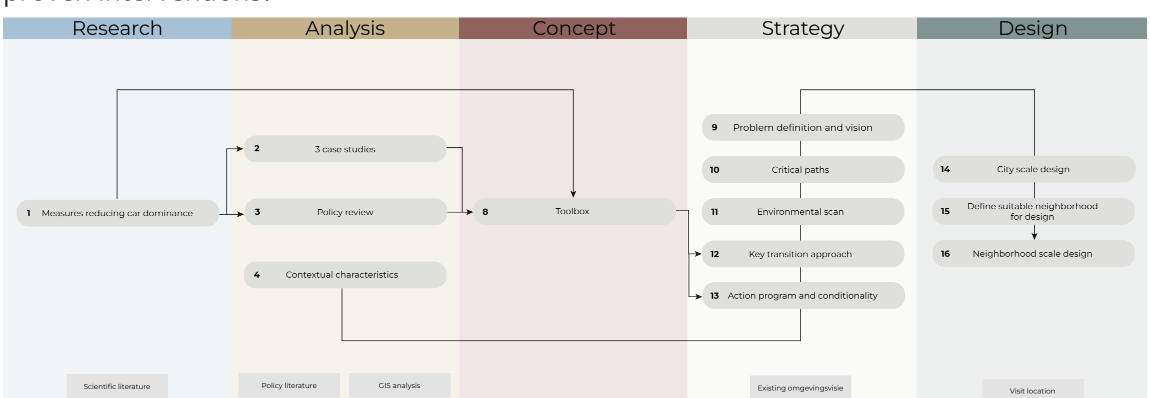


Figure 1: Method

THEORETICAL FRAMEWORK

The definitions and demarcations of densification, reduced car dependency and liveability are examined by literature review. For each of the three parts (see Figure 2), recent research is analysed and a definition is given. This definition sets the basis for the rest of the article.

Firstly, the concept of densification is examined. Both defining densification and measuring densification is discussed. 'In planning literature, residential densification is discussed extensively as a possible way to achieve compact cities, combat sprawl and create urban sustainability' (Broitman & Koomen, 2015). Berghauser Pont et al (2021) define six domains that describe the contribution of densification to urban sustainable development: public infrastructure, transport, economics, environmental impact, social impact and health impact. These domains are then subdivided into multiple sub-domains. According to Berghauser Pont et al (2021), environmental impact, social impact and health impact are negatively affected, whilst transport and economics are positively affected. Public infrastructure has both positive and negative relations with densification.

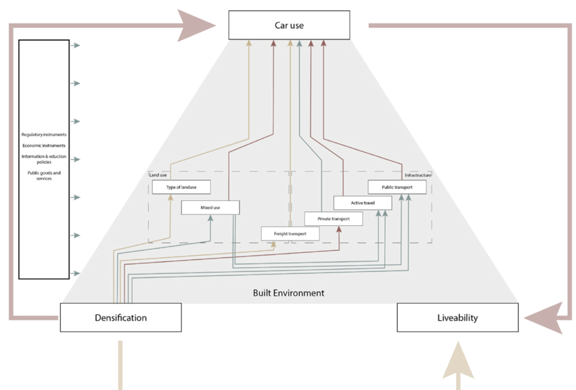


Figure 2: Conceptual model

Crawford (2009) describes the Floor Aria Ratio (FAR) as a tool to measure density of a given site. It multiplies the plot ratio (PR), how much % of the site is covered by the building(s), to the number of stories of the building(s). When the FAR is compared to the human density (number of residents and employees living and working on one hectare), a comparison in density between different areas/cities can be performed. Of course, densification can be perceived differently by different people. One high rise building with 10 or more floors can have the same density as multiple lower four-story buildings. This density discussion has been a sensitive topic in the Netherlands in the development of Sluisbuurt Amsterdam (Starink, 2017). Such density discussions should be approached very carefully.

Secondly, the concept of liveability is examined. Higgs et al (2019) defines seven liveability domains: transport, social infrastructure, employment, walkability, housing, green infrastructure and ambient environment. These domains are policy-relevant liveability domains, associated with transport mode choice.

And lastly, the concept of reduced car dependency is examined. Topp & Pharoah (1994) described a car limited city centre; 'where motor traffic is limited by an area-wide ban to that which is considered to be functionally necessary'. 'A community is not simply car-dependent or not. Understanding the various levels of car-dependency can help us create more resilient and multimodal communities. So where does your community fall on the spectrum? Is it where you'd like it to be?' (Pinder, 2021). The question Pinder (2021) askes is a crucial starting point beforehand thinking of reducing car dependency. The State of Asian and Pacific Cities (2015) describes a spectrum between automobile-dependent cities and new transit cities. Although this is applicable for Asian and Pacific cities, all major Dutch cities provide a well working mass transit system and so the spectrum should be narrowed down towards car dependency. Pinder (2021) describes a spectrum of car dependency that seeks balance between on the one hand 'cars' and on the other 'people'. The five steps of the spectrum, according to Pinder (2021), are: car only, car first, car equal, car last and car free.

As explained in the introduction, the need for reduction of car dependency can be an opportunity and driver for densification (Cooper et al., 2002) and benefit air quality, reduce the heat-island effect, reduce noise disturbance, improve physical activity levels and decrease the number of accidents (Vardoulakis et al., 2016). Although there are also difficulties in reducing car dominance in the way cities are currently designed, the advantages of increased liveability ask for a way to tackle these problems.

The three variables of densification, liveability and reduced car dependency, can all be connected to the built environment. To group the different indicators that are part of the built environment, two categories have been used in the conceptual model: infrastructure and land use. The concept (see Figure 2), shows the relation between the variables that were defined in the last three paragraphs, and filtered for relation to land use and infrastructure. Appendix I shows the sources of the relations of the indicators.

HISTORY OF THE CAR

To better understand the role of the car in our cities and its influence on the development of urban planning and design a brief summary of the history of the car is given. This chapter presents a brief description of life before the car, the introduction of the car in cities, the effect it had on these cities, spatial and non-spatial interventions that have been implemented to adapt the city to the car, the problems that are linked to the car and changes that have been made to adapt the car to the city and the city itself.

Many cities have been adapted to the car in terms of transport system and land use (Jones, 2014), although some cities still have some urban structures that are the results of urban planning before the introduction of the car. The city of York for example, is a medieval town that developed from a roman fort into a city with more than 200.000 inhabitants (York, England - the Viking Capital of England, 2020). Although this city also adapted its urban structures to the car, parts of the inner city are still car free. The preservation of these medieval streets is partly because of the historical heritage, but also because it can't be adapted, without demolition of the urban fabric, to the car. These narrow and hilly streets are only suitable for walking, the most used form of transport at the time. European cities that are older than the introduction of the car, like the city of York, have another aspect that is of importance of its development: the introduction of a train station. Where some cities like Alphen aan de Rijn, Nijmegen, Utrecht and Woerden have commenced from Romain fortresses (Ministerie van Onderwijs, Cultuur en Wetenschap, 2021; Kostof & Tobias, 1999) near a river (just like the city of York), others developed (further) around train stations. In 1886 Carl Benz developed the first stationary gasoline engine, which laid the foundation for the first car (Mercedes-Benz Group, n.d.).

As a car-driver wrote in 1902: 'Travelling means utmost free activity, the train however condemns you to passivity . . . the railway squeezes you into a timetable' (cited in Morse, 1998: 117). And this love for the car can be seen in most western cities: in the city of Arnhem there is even a memorial stone for the first car in the Netherlands that disembarked in the harbour (Kense, 2016). After the second world war, the car industry is boosted and the car becomes available to everyone. The car is no longer something for the rich but is as standard as owning or renting a house (Huddle, F. P. ,1945). The State of Asian and Pacific Cities (2015) describes a spectrum between ultimate automobile dependent cities and new transit cities. The main difference between these extremes is the way they interacted with the introduction of the car in their cities. Some cities did not stimulate cars and focussed on improve of public transport and land-use planning. Others invested in the car and 'built in' car dependence in their cities by reducing public transport investment and taking away space for on street events (e.g. markets) and cycling and walking. (Jones, 2014). There is, of course, a reason for this radical change in priority; numerous benefits that came with the car. Firstly, the car was reason for a drastic increase of- and investment in the motor industry. It increased employment rates and brought prosperity, which created a direct link between economic growth and car dependency. Secondly, people felt independent and safe while driving a car, still one of the most important reasons for people to own a car (Jones, 2014). Jones (2014) describes three stages of policy making for the car. The previously described introduction of the car can be seen as stage one: 'traffic growth policies — a vehicle-based perspective'. This growth policies affected urban planning dramatically. The focus shifted to getting the car as close as possible to the house and work and separating residential and commercial areas.

The second stage Jones (2014) describes, is 'Traffic containment policies — a person trip perspective'. This period is characterized by the containment of growth related to the car, which was boosted by research that showed that public transport could compete with the car in terms of travel time. Later on, more and more research on the problems the car brought to the city was conducted. The car was responsible for bad air quality, noise disturbance, reduced physical activity levels and an increase in number of accidents. In 1973, the city of Amsterdam organized its first car-free Sunday, three months in a row. Although some thought the car-free day was to make people aware of the problems related to the car, the reason for the car-free days were less attractive: it served as a way to limit oil consumption during the OPEC energy crisis (Nehra, 2020).

The final stage, Stage Three: 'liveable cities — activities and quality of life perspectives' (Jones, 2014), is the current situation in terms of policy making and urban planning. The effect that infrastructure related to the car has on our cities is acknowledged and the urge to act is bigger than ever. Reducing car dependence stimulates further development of cities and increase the liveability within these cities.

Something almost all cities in Europa did to reduce car dominance in their city is the introduction of pedestrianized city centres. Cities like Bologna, Aachen, Lubeck, York, etc. all implemented zones in their inner city in which the car was (mostly) not welcome. The aim was to increase visitors in the city centre and to stimulate public transport. The pedestrianized zone was the start of policies and design interventions cities use to reduce car dominance.

Although the urge to reduce car dominance is acknowledged and the first steps have been taken, cars are intertwined in our society and do not have to be removed from our lives. It needs to be acknowledged, that the car is not always the right solution to our mobility problems. Some dense areas are able to function without an extended car network, they function even better without cars and their infrastructure. The car became part of society and people's lives in a period of over 80 years. This also means that time is needed to reduce this dominance, rushing into car-free cities will encounter resistance.

METHODOLOGY

To answer the second, third and fourth research question, a systematic literature review was conducted.

2. What does the historical development of car reducing interventions look like?
3. Which existing interventions of reducing car dependence in literature have proven successful?
4. Which stakeholders are involved and how do they interact and/or collaborate in these successful proven interventions?

Literature review

To analyse the development of car reducing measures, the different types of interventions are compared to the implementation year of the case study. To establish an overview of the available literature on policies and design interventions related to reducing car dominance in cities, a systematic literature review was conducted. To define the role of different stakeholders, the stakeholders named in the case studies and the connections between the different stakeholders are examined. Searching was conducted using Scopus, focussing on case studies and interventions. The following search string was used:

TITLE-ABS-KEY ((car AND free) OR (car-free) OR (car AND reduce AND dominance) AND (city OR urban) AND (planning OR design) AND (mobility OR transport) AND (policy OR strategy))

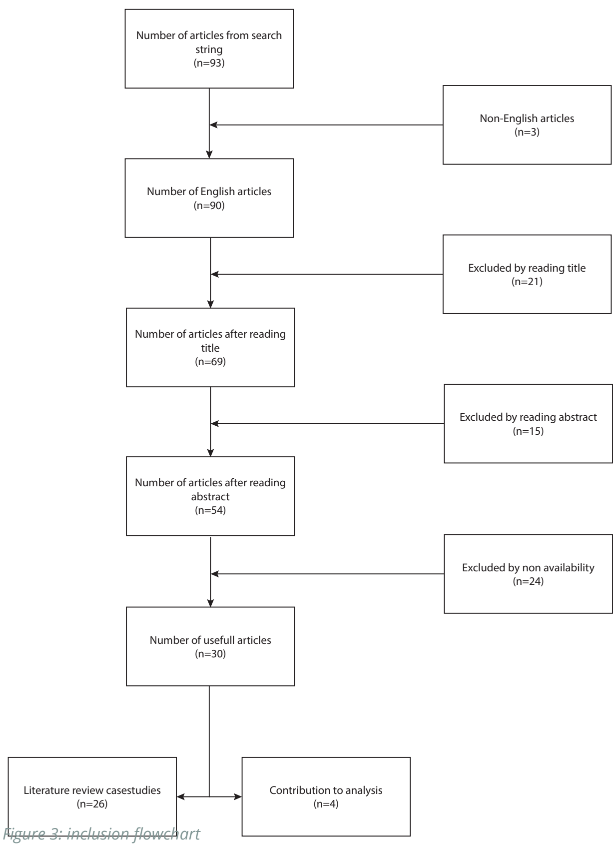


Figure 3: inclusion flowchart

93 articles were found using this string, after reading titles and abstracts reduced to 26 useful articles for the literature review and 4 articles that will be used in the analysis of the city of Arnhem (see Figure 3).
The systematic literature review resulted into 26 case studies (see Figure 3) and even more measures in different classifications and categorisations. For all found interventions, the level of densification is of importance. The cities in the case studies are mostly European (see Figure 4) but differ in size and population.

Figure 4: location of case studies

Categorisation of interventions

To sort and classify the different articles found from the search string and synthesize the findings, categories were determined (see Table 1). Firstly, the scale level is determined. Research from 1980 to 2000 mainly focusses on reducing car dominance within the city centre, whilst more recent research aims for a city broad approach. The scales are defined as national, regional, city, city centre, neighbourhood, street and building scale. The scale level is defined to link the found intervention to the dimension of implementation. Secondly, Stead (2022) describes a conceptual model used for understanding and categorizing policy tools. The research uses the NATO model (nodality, authority, treasure, and organisation) and distinguishes two subtypes of policies: substantive and procedural. Where substantive has direct effect on the goals of a plan and procedural policies affect the process of developing or reviewing a plan (Stead, 2022). This categorisation will show difference in interventions that affect the city directly or influence the process of the strategy. The most valuable categorisation for this literature review are the IPCC classifications Kuss & Nicholas (2022) use: regulatory-, economic-, information- and public goods & services instruments, to classify the different interventions found (Somanathan et al., 2014). These type of policy instruments can show the versatility of an intervention. Fourthly, a distinction between push and pull methods was established. A push policy or design implementation (a car limited zone for example) cannot go without a pull policy or design implementation (improved public transport). Some interventions have a mixed effect, both pushing and pulling (widening the sidewalk). As most articles describe the push & pull strategy as ground rule for reducing car dominance, it should be considered.

Table 1: classification of measures

Scale level	
National scale	National controlled or funded interventions
Regional scale	Regional controlled or funded interventions
City scale	City controlled or funded interventions which need to be involved in the city-wide network
City centre scale	City controlled or funded interventions which can be applied within the city centre, without interacting with other areas.
Neighbourhood scale	City controlled or funded interventions which can be applied within the neighbourhood, without interacting with other areas.
Street scale	City or private controlled or funded interventions which can be applied within a street.
Building scale	City or private controlled or funded interventions which can be applied within a building plot.
Policy types	
Substantive policies	Direct effect on the goals of a plan
Procedural policies	Affect the process of developing or reviewing a plan
Policy instruments	
Regulatory instruments	Rules, standards, prohibitions
Economic instruments	Taxes, subsidies, charges
Information & education policies	Information campaigns, marketing, persuasion, feedback
Public goods & services	Physical infrastructure, planning, provision of services
Strategy types	
Push – approach	Obstruct private car use by regulate accessibility, fees, parking cost, etc.
Pull – approach	Present alternatives to prevent usage of private car use by improving public transport, walking and biking, financial concessions, etc.
Push and pull approach	Combination of push and pull. For example, the widening of sidewalks. Cars are pushed, while people are pulled towards walking.

Sixthly, the found interventions are scored on success and critique. This can help in the choice of context-appropriate interventions to implement. Lastly, stakeholders involved are identified to define the collaboration needed to implement an intervention. This is of importance for the city strategy, which combines the found interventions with implementation per stakeholder.

Results

The results describe the outcome of the literature review, which aims to find information on the historical development of car reducing measures, to find existing measures to reduce car usage and to find information on the stakeholders involved.

To better compare different case studies, a score is needed to describe the density of the city (see Appendix I: Density per case study). This score shows the number of residents per km^2 to get a grip on the density of a city. This score is compared to the residents per km2 (r/km^2) of Arnhem (1616 (r/km^2). On average, the case studies are twice as dense as the city of Arnhem (on average 3489 r/km^2).

A variety of studies from different years (between 1995 and 2022) has been studied. Categories like access control, parking management and road design interventions are mainly suggested in articles before 2000 (mainly push strategies), although often repeated in newer articles. The newer articles (2010 and onwards) mainly focus on awareness, services and subsidies (mainly pull strategies).

To present the results of the interventions found in literature, Table 2 has been created. Firstly, the interventions that were not successful will be discussed (these interventions are not shown in the results table). What was the cause of the non-success and are there also successfully proven examples of the same interventions? In general, articles mention a successful intervention often in combination with the warning: success depends on the goal of the intervention: frequency, duration, and geographic size (Glazener et al., 2022). In Bologna, several parking management interventions were implemented successfully, except for one. Certain parts of the city were only accessible by car for the residents of that area, which drastically reduced car usage within that area. However, due to the large number of permits handed out, car usage was soon back to 90% of its original level. The study of Topp & Pharoah (1994) also pointed out that accessibility of public services for tourists was reduced due to the car restrictions. Stores and traders were affected by this measure. This was also the case in York (Topp & Pharoah, 1994), Bologna and Milan (Bonnel, 1995): car-free areas during daytime (9am to 6pm) led to worried traders, unsatisfied residents (approximately 50%) and prevented expansion of car-free areas. Other restricting measures like cars with number plates with an even number are authorised to be used on even days of the month (Bonnel, 1995), also negatively affected the aim to reduce car dominance. The highest percentage of households with two cars

Table 2: results from literature review (overview)

Category	Intervention type	Intervention strategy	Policy instrument(s)	Measures	Case studies
1] Access control	Limited traffic zone	Push & Pull	Regulatory, Public goods & services	- Access control to the old town - Extension of pedestrian zone - Car ban between 10am and 6pm - Time and weekday dependent access restrictions - Centre closed during shopping hours - Cycling and servicing vehicles are prohibited	1] Bologna 2] Lubeck 3] York 4] Aachen 5] Rome
2] Parking management	Relocate parking	Push & Pull	Regulatory, Public goods & services, Information & Education	- Introduce carpark for long stay - Parking guidance system - Relocate on street parking to parking garages - On street parking for visitors and disabled	1] Bologna 2] Lubeck 6] Cologne 7] Darmstadt
	Reduce parking	Push	Regulatory, Public goods & services	- Reduction of parking spots - No provision of parking spaces in new buildings - Reduction of parking within 300m of public transport - Grading in number of parking (decrease with distance from centre) - Reduce number of parking spaces per housing	1] Bologna 2] Lubeck 3] York 6] Cologne 7] Darmstadt 8] Zurich 9]London 10] 8 German cities 11] Copenhagen 12] Helsinki 13] Rotterdam
3] Public transport system	Frequency and cost	Push & Pull	Regulatory, Public goods & services, Economic	- Increase in frequency of busses - Flattening peak hours - Free transit zones	2] Lubeck 14] Fremantle X] Variety of studies in Europe
	Routes	Push & Pull	Regulatory, Public goods & services, Economic	- Free of charge transport to city centre - Busses that connect car parking - Improve public transport - Public transport within walking distance - Direct connection to city centre and central railway station - Public transport connections towards suburbs - Lanes for busses only	1] Bologna 2] Lubeck 7] Darmstadt 9] London 13] Rotterdam 14] Fremantle 15] Nottingham 16] Tel Aviv 17] Sydney X] Variety of studies in Europe
4] Cycling and walking	Accessible active transport infrastructure	Pull	Public goods & services, Economic	- Revenues from pricing system used to invest in walking facilities - Revenues from pricing system used to invest in cycling facilities - Cycling towards station and city centre 10-15 min - Walking towards station and city centre 40-45 min	7] Darmstadt 9] London
5] Road	Road design	Push & Pull	Regulatory, Public goods & services, Economic, Information & Education	- Different sections of the road per transport mode - Speed restrictions - Special surfaces to indicate type of transport - Prioritize cyclists and pedestrians - Remove sidewalk to create shared space - Improve cycling infrastructure - Temporary cycling lanes to test functionality and usage	7] Darmstadt 8] Zurich 9] London 18] Bern 19] Brighton & Hove 20] Norwich X] Variety of studies around the world
	Road network	Push	Regulatory, Public goods & services	- One-way roads - Ring road to divert traffic	8] Zurich 18] Bern 21] Grenoble 22] Lyon 23] Montpellier
6] Pricing system	Investments	Pull	Regulatory, Public goods & services, Economic	- Toll earnings go into investment of roads and PT - Free PT pass for employees - Free PT pass for students - Free PT for citizens	24] Oslo 26] Singapore 27] Utrecht 28] Catania
	Costs	Push	Regulatory, Public goods & services, Economic	- Distance based charging - Time dependent charging - Charging for car parking spaces at workplaces - Congestion charges	9] London 13] Rotterdam 15] Nottingham 25] Edinburgh 26] Singapore
7] Stakeholders	Needs and influence	Pull	Information & Education	- Pay attention to various needs and influence of stakeholders	24] Oslo 29] Tallinn
8] Awareness	Personal awareness	Push & Pull	Information & Education	- Working from home - Travel plan advice - App for sustainable choices	19] Brighton & Hove 20] Norwich X] Variety of studies around Europe
	General awareness	Push & Pull	Regulatory, Information & Education	- Promotion of biking and parking - Car free days - Information on new (cycling) measures	19] Brighton & Hove 20] Norwich 30] Bristol 31] San Sebastián X] Variety of studies around the world
9] Services	Infrastructure facilities close by	Pull	Public goods & services	- Bike storages - Car sharing facilities - Cargo (e-)bike sharing facilities - Free P&R facilities	7] Darmstadt 16] Tel Aviv 32] Amsterdam 33] Bremen 34] Genoa 35] Milan X] Variety of studies around the world
	Landuse facilities close by	Pull	Public goods & services, Information & Education	- Workplace showers - Supermarket within walking distance - Schools within walking distance - Recreation space within walking distance - Playgrounds within walking distance	7] Darmstadt X] Variety of studies around the world
10] Subsidies	Stimulate e-bike usage	Pull	Economic	- E-bike subsidies	X] Variety of studies around the world
11] Landuse	Area development	Push & Pull	Regulatory, Public goods	- Low traffic neighbourhoods in dense areas	9] London

was established during the implementation of this intervention. In Cardiff and Liverpool (Bonnel, 1995) the municipality aimed to deregulate the public transport. This only affected the contributions made by the local authorities in a positive way, extra costs caused by the increase in car traffic as a result of the decrease in public transport provision made the measure achieve the opposite effect.

Secondly, general suggestions from literature, not directly related to case studies, were examined. Bonnel (1995) already made some simple suggestions related to implementation time and push/pull strategy. Bonnel (1995) suggests to directly relate promotion of PT to limiting other transport modes. He also states that reduction of car usage does not need car banning policies. Policies like dividing up the highways, channelling the traffic, diversions for through traffic, reduction and management of the parking supply and traffic 'calming' can be sufficient in some cases. The third suggestion Bonnel (1995) makes, is that 'gradually introduced policies cause less upheaval in travel habits and let people modify their behaviour'. These suggestions are used in multiple studies as starting point throughout the years.

Thirdly, all found interventions are categorized and classified (see Table 2) and further discussed. Eleven main categories have been established: Access control, parking management, public transport system, cycling and walking, road network and design, pricing system, stakeholders, awareness, services, subsidies and land use. These categories are in several cases subdivided into two intervention types. Furthermore, the intervention strategy (push and/or pull) and policy instrument are assigned to every intervention type. Per intervention type, multiple measures are suggested to affect the intervention type. For example: relocate parking (in the category parking management) can be achieved by introducing one or more measures (access control to the old town, extension of the pedestrian zone, etc.). The last two columns of Table 2 give information about the case studies and references of these case studies. The exact reference and case study per measures can be found in the appendix (see Appendix II: literature review).

Most literature does not focus on the role of stakeholders in car reducing measures. Mostly, the mu-

nicipality plays a big role to stimulate, organize and execute. Older literature points out retailers as an important stakeholder, this stakeholder often holds off car reducing measures in city centres (mostly push measures). The reasons for these stakeholders are the (assumed) lack of accessibility and distribution problems. In newer literature, companies and schools are more involved in the smaller scale reduction of cars on their own property, in collaboration with the municipality and public transport companies. In general, the municipality has to convince its inhabitants of the benefits of car reducing measures. The interplay between these two stakeholders is the most important and most described relation in literature.
Furthermore, the public transport service is a key stakeholder, which is named in almost every intervention related to PT and pricing systems. Appendix II: literature review, shows all stakeholders connected to specific case studies and/or interventions.

Discussion

The theme of car reduction in cities is very widespread throughout literature. Most articles included in this research focus on infrastructure and land use. Although these categories are the basis for reduction of car usage in cities, the behaviour of citizens is also an important aspect. Why do people choose to drive a car and what interventions work best in terms of awareness. This study does cover this behavioural theme partly in terms of awareness interventions, but a more behavioural approach is needed to score the interventions from least to most successful.

Also, the broad literature search string resulted into a lot of interesting articles. But because of non-availability and too specific type of articles, only 26 useful articles (between 1995-2022) have been found. Many articles focussed on the implementation of very specific themes like car sharing, which is a very interesting measure to take into account, but can be part of a single study about car sharing options. A number of articles also focus on country wide problems like long distance travel and specific decision support systems. These articles were also excluded from this research. For further research, a preliminary investigation is proposed to better define the search string.

Conclusion

To conclude the found interventions. Firstly, the level of densification is of importance. The higher the level of densification, the easier car reducing interventions can be implemented. Although most case studies score higher (in comparison to the city of Arnhem) on density (in terms of residents per km2) it is important to anticipate on future densification of cities. Most cities that are highly densified, face many problems related to high car usage. Dutch cities, in this case the city of Arnhem specifically, do have a good cycling and walking infrastructure but are not prepared for a further densification of their city without introducing more car reducing measures. Starting early in the process of densifying cities by reducing car dominance will evade problems of car usage as mentioned in a variety of case studies with higher density score. Car reducing measures should always work hand in hand with the scale of densification and play an important role in the future development of a city.

Secondly, the push interventions should always work together with pull interventions. This strategy is the basis for a successful reduction of car usage. Early articles describe push methods without any pull methods. This results in resistance from civil society and traders. If no alternative is provided, push methods will have a negative effect on the reduction of car usage.

Thirdly, the eleven categories and 17 intervention types should all work together to successfully decrease car usage. When a push method is needed, multiple pull methods from the same, or related, category need to be implemented to balance. These 17 intervention types need to be taken into account when analysing a city and making future plans.

In terms of stakeholders and car reducing measures, a gap in literature has been found. Little is written about the role of important stakeholders in introducing and maintaining measures that reduce car dominance. A review of policy documents is needed to know the forcefield of stakeholders in the city of Arnhem and relate those stakeholders to the different interventions proposed. For all found interventions (see Table 2), the goal of the measure, stakeholders involved and connection to other categories should be taken into account.

Some interventions have already been introduced in most cities (such as pedestrianized centres) but these measures should be reviewed as well. There may be new, more effective, measures. Or an expansion of the current measures that can be highly effective in reducing car dominance in cities.

02

CAR FREE ARNHEM
CASE STUDY REVIEW

The second part of this thesis consists of a brief analysis of three case studies and corresponding policy documents, processing the found results from the preceding literature review into a toolbox, analysis of the city of Arnhem, a city strategy and neighbourhood scale design. The found interventions form the basis for the analysis and design at both city and neighbourhood level. Concluding with a reflection on the effectiveness of the found interventions on the urban design of the city of Arnhem is given, resulting in a conclusion and discussion on the main research question: To what extent can the densifying city of Arnhem become car-free and how can this car-free concept be strategized?

Photo II: Cartesiusdriehoek (Cartesius, n.d.)

This paragraph analyses several car free areas in the Netherlands. The aim is to understand the different types and levels of car reducing measures, the role of densification and its effect on liveability. Interesting is to see the way the found interventions from the literature are implemented in different situations. The case studies are Merwedekanaalzone (Utrecht, neighbourhood scale), Cartesiusdriehoek (Utrecht, neighbourhood scale) and GWL terrain (Amsterdam, neighbourhood scale), all listed as good practices on the national government website for healthy environments (Mobiliteit - Praktijkvoorbeelden, n.d.). The three neighbourhoods all have a different scale and difference in construction progress. GWL terrain (approximately 54.000m2) was constructed in 1998, Merwedekanaalzone (approximately 300.000m2) is almost ready to start construction and for Cartesiusdriehoek (approximately 160.000m2) an urban plan still has to be developed.

Merwedekanaalzone
Research on the possibilities of car reducing and car-free measures often refer to the case of Merwedekanaalzone, a neighbourhood in Utrecht. Although this neighbourhood only exists on paper (the first buildings are demolished and the go-ahead is given to start phase 1) (Weessies, n.d.), the effect of the urban plan on awareness and new possibilities for car reducing measures is significant. At the same time, other initiatives are undercut by the enormous attention Merwedekanaalzone receives.

The matrix of case studies (see figure X) shows the way the neighbourhood is designed. Making use of existing public transport, both bus and tram routes, the area is well connected to the city centre. Except for four short roads going into the area, the neighbourhood is fully car free. Cyclists can easily cycle towards all directions, reaching the city centre and station within 1.5 km.
Although the area is car free, most buildings facing the existing street network have a parking garage, serving a small percentage of the residents. Almost all surrounding neighbourhoods provide free parking, so the question can be raised what the effect will be on the surrounding neighbourhoods in terms of traffic and parking nuisance.
Most of the area is accessible for everyone, the semi-private areas are located within the building blocks. Car sharing and bicycle parking, but also a supermarket and playgrounds make the area attractive to its residents, but also for residents of surrounding neighbourhoods. The denser and higher buildings serve as a shield for the noise of trains and cars, making the inner part of the neighbourhoods quiet and calm.
Two new cycling bridges show the intentions of the neighbourhood: stimulate cycling and reducing the usage of cars. With two supermarkets, multiple playgrounds, a high school and a school, the area provides close by amenities.
A challenge for the design is to manage the various stakeholders that own parts of the new neighbourhood and existing buildings, making it harder to renew the whole neighbourhood.

To conclude, the neighbourhood of Merwedekanaalzone is a great example of a car free neighbourhood. It provides a lot of amenities, is close to the city centre and train stations and densifies the city within its ring. The lack of parking within the area can affect the number of cars in surrounding neighbourhood, making the car-free potential questionable.

Cartesiusdriehoek
A relatively new project is this case of Cartesiusdriehoek in Utrecht. This site is currently occupied by a number of industrial buildings and buildings of the national railway company 'NS'. In 2017, a first vision document for the area was written, including a first urban elaboration (Snelling Berg et al., 2017). Although a few buildings are already under construction, the majority of the area (phases 3-6) will be constructed in 2024.
The matrix of case studies (see figure X) shows the way the neighbourhood is designed. The area makes use of the existing train station 'Zuilen' and bus station to the South of the main street. Station Utrecht centraal is bikeable within 2 km (when the new cycle path underneath the train track is constructed).
Although the neighbourhood advocates being car-free, a two-way road connects almost all buildings within the area. Also, a number of parking garages is located East, forcing cars to drive through the neighbourhood. The surrounding neighbourhoods to the North and West have free parking, while the neighbourhoods to the South and East have paid parking. Although the neighbourhood is well reachable by car, bike and on foot, a connection to the South is missing due to the large marshalling yard. The new bike connection to the East is a fast connection to the city centre.
Most of the area is accessible for everyone, the semi-private areas are located within the building blocks. Car sharing and bicycle parking, but also a supermarket and playgrounds make the area attractive to its residents, but also for residents of surrounding neighbourhoods.
The denser and higher buildings serve as a shield for the noise of trains and cars, making the inner part of the neighbourhoods quiet and calm.

To conclude, the neighbourhood of Cartesiusdriehoek shows options for a car reduced neighbourhood close to a train station and surrounded by infrastructural elements. The parking garages within the area draw cars in, raising the question why the garages are not located close to the existing road network. Also,

Figure 5: casestudy maxtrix (p1)

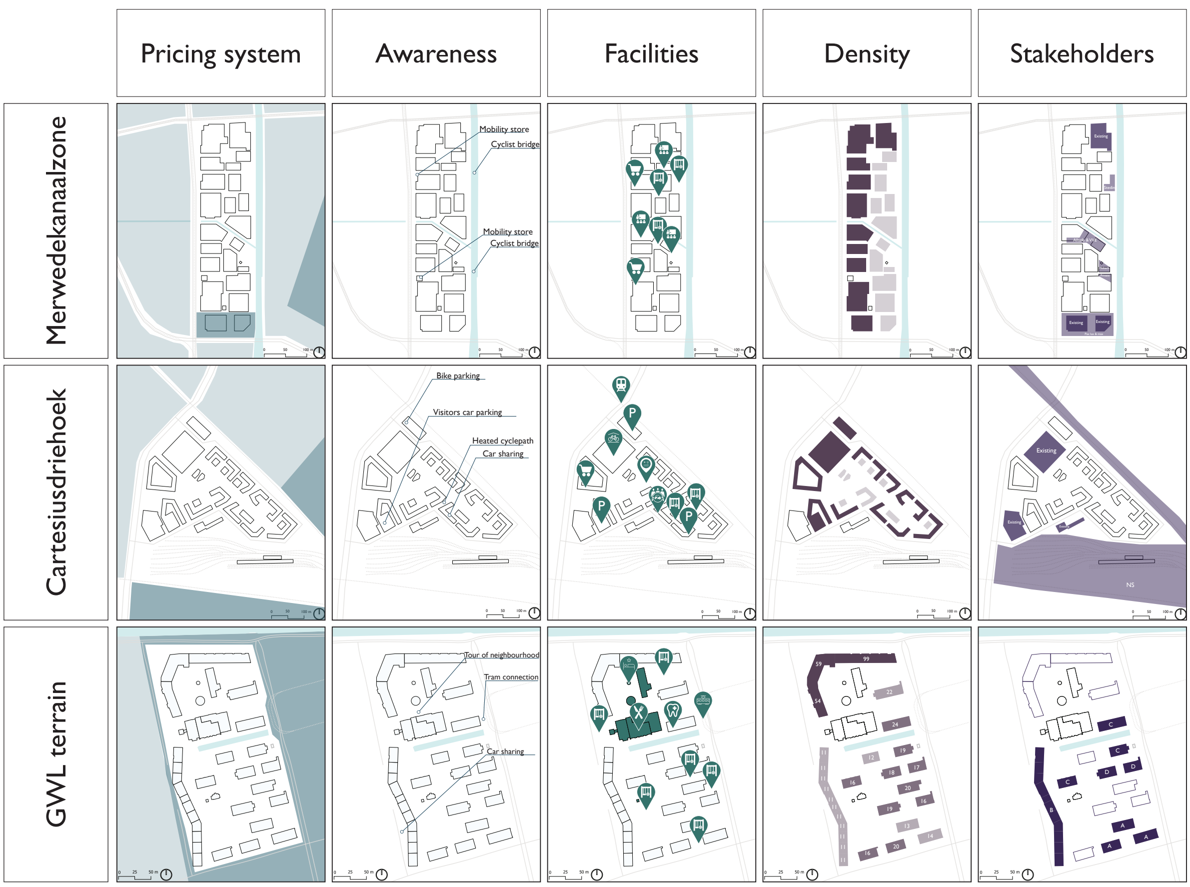


Figure 6: casestudy maxtrix (p2)

the lack of parking within the area can affect the number of cars in surrounding neighbourhoods. Lastly, the lack of semi-private green connected to the public areas can create a hard boundary between public and private.

GWL terrain

One of the early-stage car-free neighbourhoods in the Netherlands is the neighbourhood of GWL. After the municipal water authority left the area in 1989, plans for a new neighbourhood were established and in 1998 a new neighbourhood was completed (Ontstaan Van De Wijk - GWL Terrein, 2023). Although the water authority left the site, multiple elements still remind of that time period. Such as the pump building and water tower, that received a new function as restaurant and eye catcher (Het GWL-terrein - Rainproof, 2023). In 2023 a revised plan for the neighbourhood green will be introduced, since the past 20 years the development of new sustainable research and shifting priorities had its effect on the way a neighbourhood is experienced (Masterplan 2023 - GWL Terrein, 2023).

The matrix of case studies (see figure X) shows the way the neighbourhood is designed. Three bus stops and a tram stop, connecting the inner city. At 2.5 kilometres, Amsterdam 'Sloterdijk' station is accessible walking and by bike.
In terms of road network and parking, the neighbourhood is dependent on its surrounding neighbourhoods. The area itself has no parking spaces, but close by, a lot of on street parking is surrounding the neighbourhood. Also, the industrial site on the West of the neighbourhood provides space for free parking. Within the neighbourhood, cyclists are not allowed. Around the North and East of the neighbourhood a cycling path is connecting the neighbourhood with the rest of the city.
To make people aware of the car-free elements in the neighbourhood, a tour trough the neighbourhood, car sharing possibilities and a tram connection towards the city centre is provided. The area comprises multiple playgrounds for the neighbourhood itself and surrounding neighbourhoods. The former pump building is transformed into a restaurant, a dentist is located in a mixed-use building and a small hotel is located in the North of the area.
The density of the neighbourhood concentrates around the Northern street (9 floors high), facing the canal. Most other buildings are around 5 floors high, making the neighbourhood equally dense compared to surrounding neighbourhoods.
Four housing associations and a number of homeowner associations form a quite complicated group of stakeholders for the maintenance of the surrounding area (Plattegrond - GWL Terrein, 2023).

In conclusion, the neighbourhood of GWL terrain shows that it is possible to incorporate a car-free area within a dense city like Amsterdam. Notable is the lack of bicycle parking, apart from the official and unofficial parking on street level, as recommended in literature. Also, the on street car parking around the neighbourhood stands out as a point of improvement, combined with the free parking in the industrial area West of the neighbourhood. Takeaways for design are the way the heritage of the neighbourhood has been preserved and the level of car-free has been introduced in a highly dense area.

Conclusion

The three different neighbourhoods show how car reducing measures can shape an influence the design of a neighbourhood. All three cases have its pros and cons, providing examples of the use of interventions to reduce car dominance. The difference in scale and time of construction must be taken into account. But in general, these neighbourhoods serve as best practices to design neighbourhoods with almost no car usage.

03

CAR FREE ARNHEM **APPROACH**

This chapter describes the approach, which is a combination of a toolbox and accessory decision tree. The approach helps policy makers use measures when planning and design cities to reduce car dominance.

Photo III: City of Arnhem (Samen Werken Aan Een Gezonde En Veilige Leefomgeving, n.d.)

This chapter describes the approach, which is a combination of a toolbox and accessory decision tree. The approach provides a framework for policy makers to use the measures, derived from literature, case studies and the policy analysis, when planning and designing cities. The approach does not provide a guideline for urban design but presents systematic steps to reduce car dominance. The decision tree and the toolbox are based on measures found in the literature review and take the user through different paths within the ten themes of the review. It also demonstrates the connections between the different scales and how one intervention can impact others.

The toolbox

Urban planning and design is a complex and challenging process that requires access to various tools and techniques. To streamline this process, a toolbox has been developed that presents the different measures to reduce car dominance (see figure 7). This toolbox (see appendix III) has been designed to stimulate the design of a city which is focused on active- and public transport and reduces car dominance. In this alinea, the measures suggested in the toolbox will be briefly discussed.

Figure 7: Overview of Toolbox

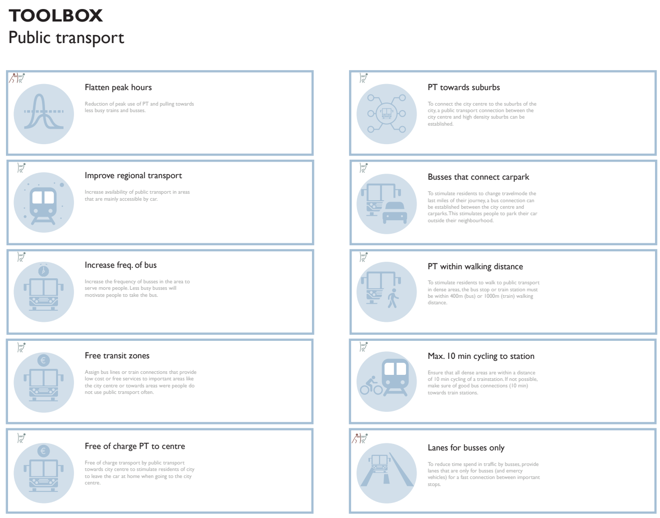


Figure 8: Public transport toolbox

Public transport

One of the most important themes of the approach is public transport. To stimulate the use of other transport modes, public transport in and around the city needs to be on point. On a national and regional level, two problems occur when using public transport (mainly focussing on train connections): overcrowding and limited public transport available. The most effective solution to overcome overcrowding is to flatten peak hours. This requires a shift of inhabitants from taking the train or bus between 07:00-09:00 (push) towards taking the train or bus before 07:00 or after 09:00 (pull). The same solution can be used in the afternoon. One important stakeholder to take into account are the public transport providers, who need to execute this measure.

When limited public transport is available, an improvement of public transport is required. A new bus stop or train station requires sufficient people to make use of this stop or station; increasing the number of people who live in the neighbourhood (densify or expand) can both benefit the use of this stop or station as well as the increase of amenities and active transport infrastructure.

On city scale, two variables can be defined: the mode of transport (roughly bus or train) and type of densification (city centre or city suburb). The increase of frequency of busses can help reducing overcrowding public transport. Less busy busses motivate people to take the bus. To stimulate people to take the train within the city, in Arnhem there are 3 sprinter stations which serve a large part of the city, free transit zones can be established. This stimulates residents to take the train from their neighbourhood towards the city centre (instead of driving a car through the city).

To also stimulate people who live in the suburbs to use public transport, better public transport infrastructure is required towards the suburbs. This can be established by connecting the city centre and/or main train station to the suburbs, but also by connecting the suburbs to a carpark or mobility hub. This provides the opportunity for residents who live in the suburbs to have a car and use the car, but not have a car dominated street or neighbourhood.

On neighbourhood level, the use of active transport is of importance. To connect inhabitants to bus stops or train stations, the stop or station needs to be within walking distance (400m bus, 1000m train) or within cycling distance (10 minute towards train station). To make sure busses are on time and are not obstructed by traffic, lanes for busses can be established on street level.

TOOLBOX
Road network

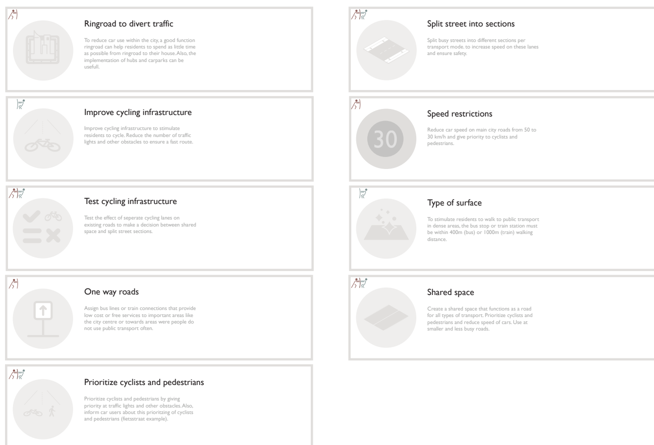


Figure 9: Road network toolbox

Road network
Although the aim of this approach is to reduce car dominance, the car should not be forgotten. To reduce car dominance, a solid car network needs to be established around the city. Within the city, a smart way of providing facilities for those who need to use the road by car or another four-wheel vehicle, need to be provided as well.

A distinction between network and design of streets can be made. Regarding city scale level network, a well-functioning ring road around the city is required to minimize the number of cars going into the city without the city being their final destination. The design of city scale roads always depends on the location and importance of the road. But an important measure to take into account is the improvement of cycling infrastructure. This is directly linked to the active transport toolbox. To make sure the cycling road functions as expected, the new connection can be tested before implementing it.
In terms of neighbourhood scale road network, one-way roads effectively reduce car dominance in neighbourhoods without closing down streets for the car. This measure can be combined with the prioritisation of cyclists and pedestrians in terms of reduction of waiting time at traffic lights and removing obstacles. Always inform car users about changed situations.

Measures regarding road network always come down to actual street design. Various measures can be used to reduce car use. Streets can be split into sections to increase speed and ensure safety per transit mode. This measure works best on busy streets with relatively high car use. Creating shared space works better for less busy streets or streets that are mainly in use by cyclists and pedestrians. Reducing car speed to 30 km/h ensures safety and often also flow speed. Lastly, using different materials of surface to show what type of transport mode is using what area, increases safety as well.

TOOLBOX
Active transport

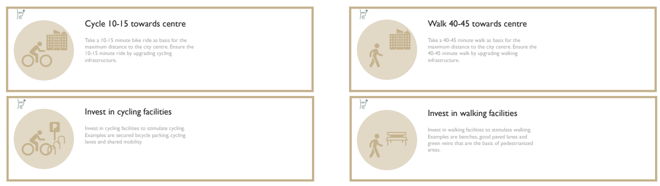


Figure 10: Active transport toolbox

Active transport
Active transport can be divided into accessibility and providing facilities for both pedestrians and cyclists.

To reach optimal use of cycling infrastructure, facilities like secured bicycle parking in the city centre, separate cycling lanes with limited traffic lights and shared mobility need to be taken into account. Furthermore, a maximum of 10-15 minutes of cycling to the city centre and public transport stop (preferably train station) must be established.

The same is suggested for walking. Investment in walking facilities is required to reach the optimum of active transport. Examples are benches, paved lanes and pedestrian roads that follow green veins in and around the city. This ensures the use of walking paths not only to get to a destination but also to use for recreation. A maximum of 40-45 minute walk towards the city centre is suggested.

Parking management
For parking management, literature suggests two categories of measures. Firstly, parking can be relocated towards car parks for long stay (mobility hubs) or redistributed by using parking guidance systems. These systems show which parking spots are still vacant within a certain part of the city. This measure eventually makes space to reduce parking.

Secondly, parking spots can be reduced in various ways. Parking that is located close to public transport can be reduced. Preferably, the public transport stop i s upgraded as suggested in the toolbox of public

TOOLBOX
Parking management

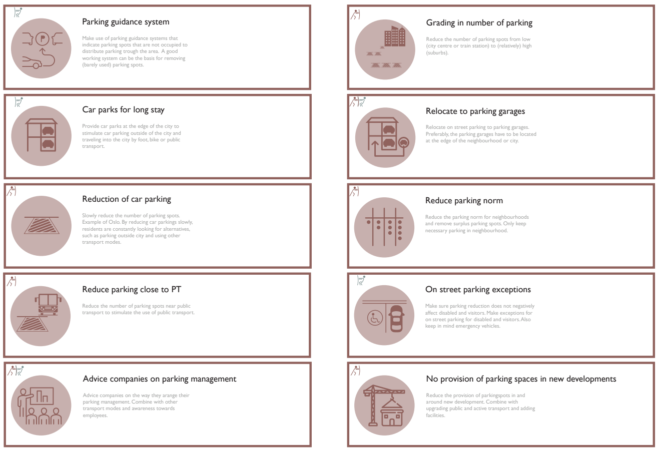


Figure 11: parking management toolbox

transport. Another option is to grade the number of parking, making sure that sufficient parking is available in the outer city, while reducing parking closer to the city centre. Lastly, the number of parking spaces can be reduced in general step by step. Making sure that every year a certain percentage of the total parking spaces is removed. This assures that residents have time to find other modes of transportation or parking further away from home.

On neighbourhood level, parking can be reduced by relocating parking to existing parking garages. Often cities have a large number of underground parking, which is mainly in use during shopping hours. These parking garages can also serve as parking for local residents. As suggested in the city scale parking interventions, a reduction in number of parking spaces can also be established. On neighbourhood scale, the parking norm can be reduced for both new projects and existing areas.

Important exceptions are disabled and elderly. It is important to make sure that people who need their car to get close to their home still have the opportunity to get close to their home. Also, emergency vehicles should be able to reach every door up to a few meters.

TOOLBOX
Accessibility

Figure 12: accessibility toolbox

Accessibility

In terms of accessibility, various measures can be used to reduce access of cars, but also of cyclists and service vehicles. On neighbourhood level, two different categories can be distinguished: neighbourhood and city centre. The city centre is already a car and bike free area in most cities and can be strengthened by disallowing cyclists and service vehicles. Extension of the pedestrian zone is also an option when expanding the city centre. Furthermore, the city centre must be closed at least during shopping hours, extending this further and further. On neighbourhood level, the pedestrianized zone can also be extended, also making sure the area is accessible for distribution of stores and residents during certain hours.

TOOLBOX
Pricing system

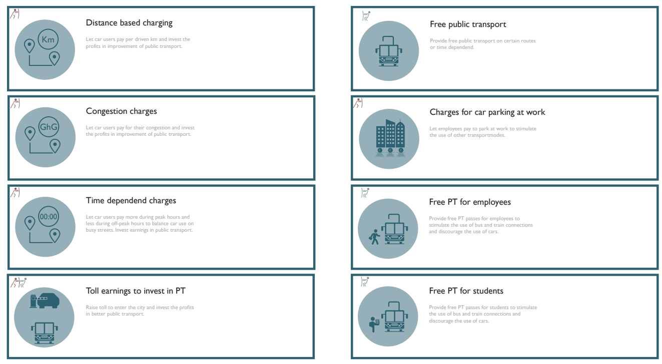


Figure 13: Pricing system toolbox

Pricing system

A transition, such as the energy transition, always has its price, so does the transition to reduce car dominance. Various measures can be implemented to increase parking cost as a push measure, but also use the earned money to create new pull measures.
On a national and regional level, charging for car users is a must. This can be performed by distance-based charging or congestion charging. Both measures have their advantages and disadvantages and could also be combined.

On city scale level, access to certain areas within the city can be charges at busy hours of the day. This serves as a way to flatten peak hours and balance the use of roads during the day. Pull measures are free public transport and use toll earnings to invest in public transport. These two measures work hand in hand. The toll earnings can be used to supply free public transport. The car user than pays for the people who choose the bus or train within the city.
For buildings and companies, some individual choices can also stimulate the use of other transport modes. Provide free public transport passes for employees (or students, in regard to universities and schools), which can be partly paid by charging working who use a parking spot at work.

TOOLBOX
Awareness

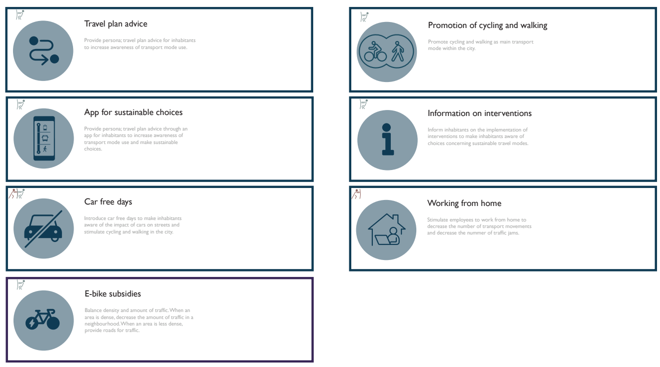


Figure 14: Awareness toolbox

Creating awareness

Throughout all government scales and companies, a subsidy on e-bikes or regular bikes can help stimulate residents and employees to use the bike as transportation to work. E-bikes can cover distances up to 20km and can work as a replacement of the bus.
On neighbourhood level, awareness can be divided into personal awareness and general awareness. Personal awareness focusses on the trips one personal takes and the way that person makes choices regarding their transportation modes. A personal travel plan advice or an app that supports sustainable choices can help creating awareness about individual travel behaviour.

General awareness aims to show a neighbourhood what the effect of car dominance in their neighbourhood is. Organising car free days within a neighbourhood can help visualise the effect of the car. In general, promotion of cycling and walking is of importance. Good infrastructure towards public transport stops and the city centre plays a crucial role. Lastly, always inform residents on interventions regarding car reduction. Show the push and pull measures that will be implemented and the effect it has on their neighbourhood.

Companies and universities can also stimulate employees and students to work partly from home to reduce travel movements and use of square meters of office working places. The corona pandemic has set base for this new working partly from home culture.

Facilities

Providing facilities for residents of a city is an important factor to reduce travel movement outside of neighbourhoods and the city.
On national and regional scale, the importance of car sharing should be addressed. A high number of people own a car but do not use it on a daily basis. Car sharing can help reducing the number of vehicles in the city.

Within car free or car low neighbourhoods, especially neighbourhoods relatively far away from public transport, the mobility hub plays a vital role. This parking garage can be equipped with various transport modes: shared mobility (cars, (transport)(e-)bikes and electric scooters) and bike storages, which can be used as a way to travel the last mile (from parking your car in the hub towards your house).

TOOLBOX
Facilities

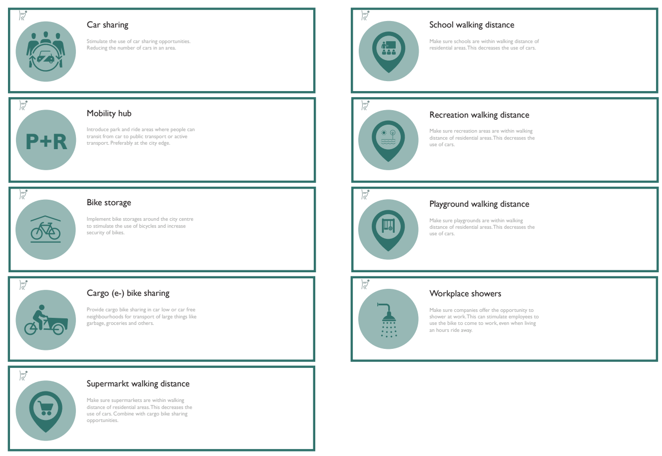


Figure 15: Facilities toolbox

On neighbourhood level, amenities that are within walking distance provide cause to not leave your neighbourhood but use the facilities within your neighbourhood and therefore not use the car. Important facilities to have within walking distance are: supermarkets, schools, recreation and playgrounds.
On building and company scale, a workplace shower can stimulate people to walk or bike towards work instead of using the car.

Densification

Reducing car dominance and densify can work well together. When densifying, space that used to be car parking or roads can be used to built new housing, offices or commercial buildings.
Three measures that combine car reduction and densification are as follows: create low traffic neighbourhoods, cluster densifications around public transport and make use of mixed use development. These measures combine public transport, the reduction of cars and the increase of residents (and therefore amenities).

TOOLBOX
Density

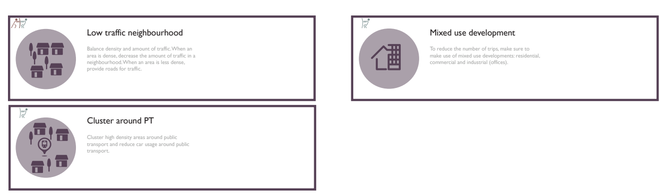


Figure 16: Density toolbox

Stakeholders

Finally, an important measure is to always identify stakeholders in combination with the implementation of measures. Disabled, elderly, retailers, public transport suppliers, etc. All stakeholders are of importance, know their neighbourhoods and are willing to think and participate in rethinking our transportation network. When they are left out of this, they will not be.

TOOLBOX
General aspects

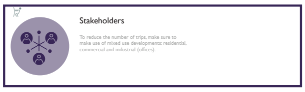


Figure 17: Stakeholders toolbox

Decision tree

The decision tree (see figure 18) helps categorizing the different interventions for different scales. It consists of circles that require making a choice and squares that propose solutions. Relations between different themes are shown with green arrows, showing connections that strengthen each other, and red arrows, showing connections that contradict each other. For example, introducing long-stay car parks (mobility hubs) requires upgrading public transport connections to that car park to pull residents towards the mobility hub.

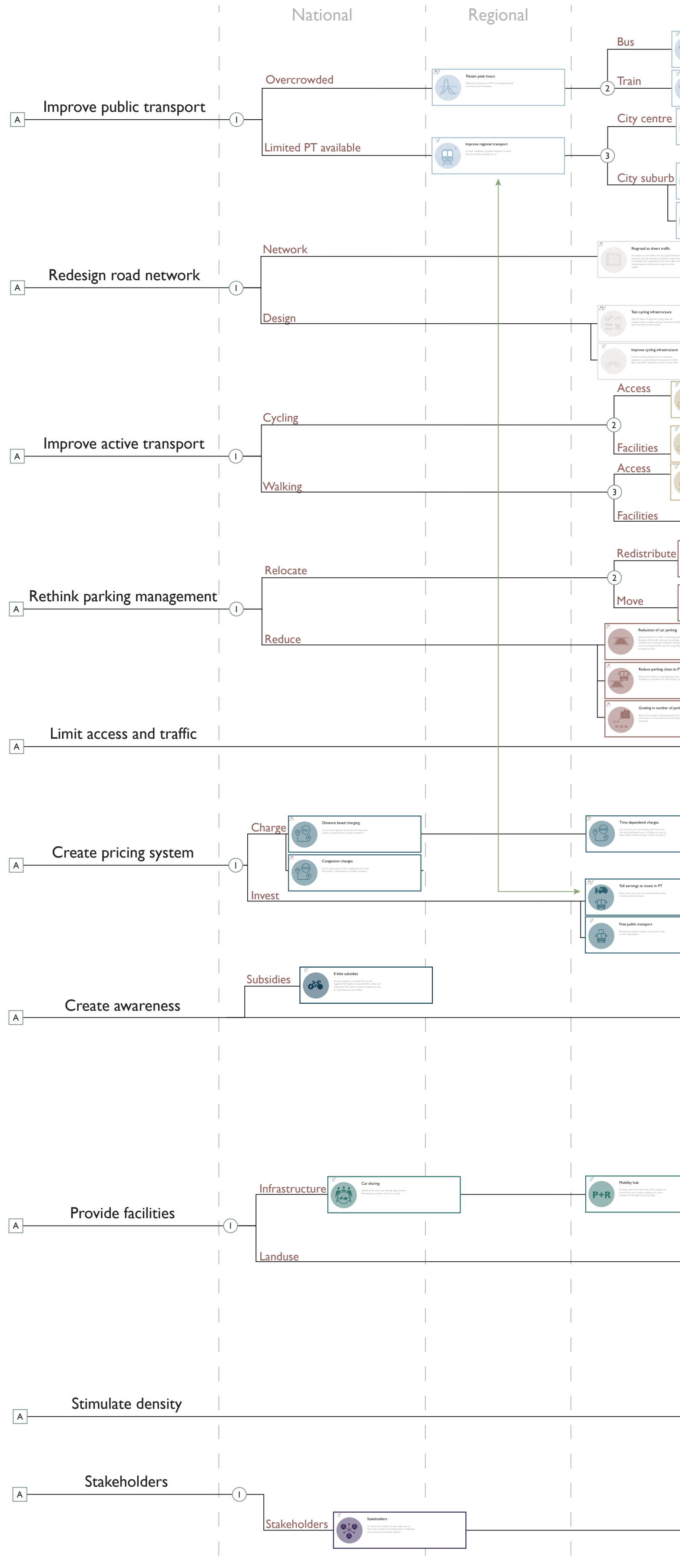
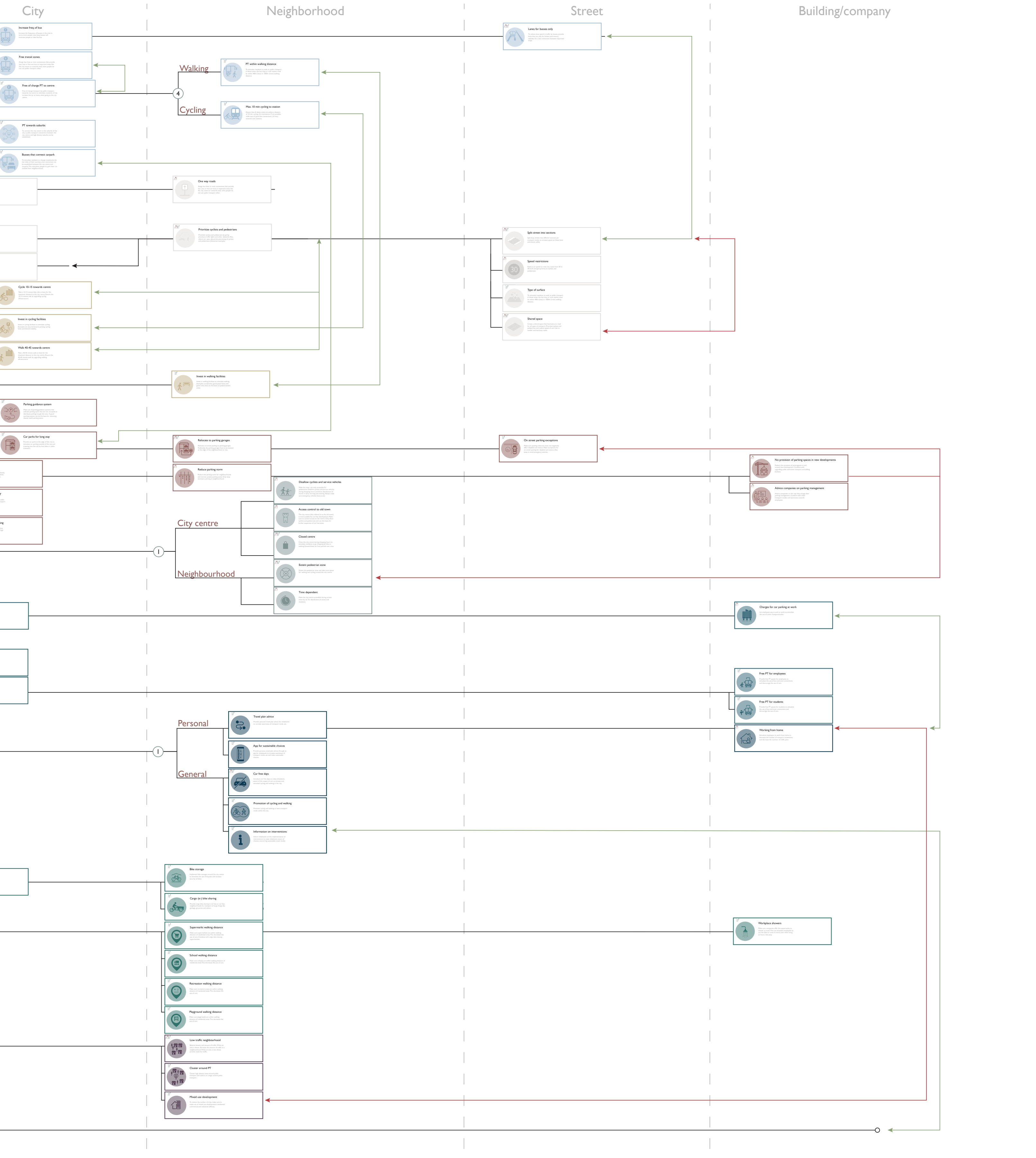


Figure 18: Decision tree



City
Neighborhood
Street
Building/company
Increase freq. of bus
Free transit zones
Free of charge PT to centre
Walking
4
Cycling
PT within walking distance
Max. 10 min cycling to station
Lanes for busses only
PT towards suburbs
Busses that connect carpark
One way roads
Prioritize cyclists and pedestrians
Split street into sections
Speed restrictions
30
Type of surface
Shared space
Cycle 10-15 towards centre
Invest in cycling facilities
Walk 40-45 towards centre
Invest in walking facilities
Parking guidance system
Car parks for long stay
Relocate to parking garages
Reduce parking norm
On street parking exceptions
No provision of parking spaces in new developments
Advice companies on parking management
Disallow cyclists and service vehicles
Access control to old town
City centre
Closed centre
I
Neighbourhood
Extent pedestrian zone
Time dependent
Charges for car parking at work
Free PT for employees
Free PT for students
Personal
Travel plan advice
Working from home
I
App for sustainable choices
General
Car free days
Promotion of cycling and walking
Information on interventions
Bike storage
Cargo (e-) bike sharing
Supermarkt walking distance
Workplace showers
School walking distance
Recreation walking distance
Playground walking distance
Low traffic neighbourhood
Cluster around PT
Mixed use development

04

CAR FREE ARNHEM
CITY ANALYSIS

To structure the analysis of the city of Arnhem, a number of themes will be discussed in this chapter. Firstly, the historical development of the city of Arnhem, in terms of built-up area, roads and water structures, is given. Secondly, a policy review is conducted, summarizing all future plans for the city of Arnhem.

Photo IV: inner city (Inner City of Arnhem, 2021)

HISTORICAL DEVELOPMENT

This section describes the historical development of the city of Arnhem and its surroundings in five maps. The maps show the development of the main infrastructure, urban fabric and surrounding villages. Understanding historical development can help understanding the way cars have changed the city and what the city used to be like (without cars).

Arnhem around 1650

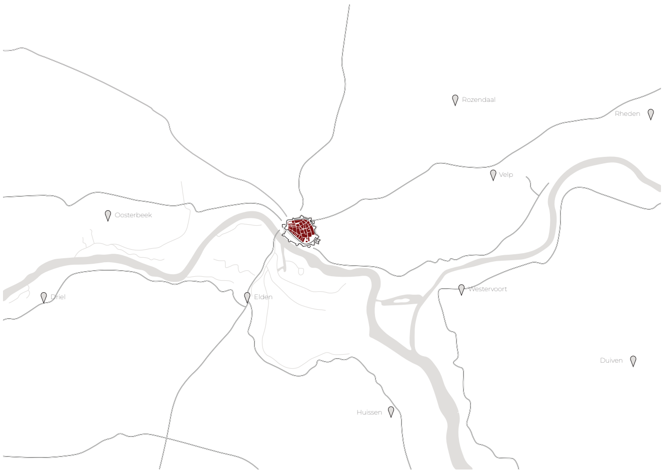


Figure 19: Arnhem around 1650

In 1233, the city of Arnhem gained its city rights from duke Otto II (Vries, De, 2020b). As capital of the Veluwe region, the city developed into an important zone for merchants, jurisdiction and government (Keverling Buisman & Meurs, Van, 2009). Around 1600, the city is surrounded by its medieval city walls and castle-moats. Between 1596 en 1606, the fortification of the city of Arnhem are built as is the case in many other cities in the Netherlands in that time (Vries, De, 2020d). This fortification shaped the city and will have an effect on the current situation of the city of Arnhem as well. Although the first maps of that region already mention villages like Velp and Oosterbeek, the only cities of importance in the region are Nijmegen (city rights in 1230) and Arnhem.

Arnhem around 1850

Figure 20: Arnhem around 1850

200 years further in time, the most important change in the spatial development of the city of Arnhem, is the demolition of almost all fortifications and city walls. From 1817 onwards, the city removes all fortifications and starts developing a city park around the city centre. After 1829, also the medieval defensive structures are mostly removed (except for the city gate West of the city centre, which still exists) and replaced with large white houses 'herenhuizen' (Vries, De, 2020a). The demolition is part of the city expanding outside of its city walls. Also, the introduction of the railroad that connects Arnhem towards the West (connecting Utrecht), North (connecting Zupthen) and East (connecting Emmerich (Germany)) is an important development and stimulus for the city of Arnhem to further expand. The railway station provides a new way of travelling and transportation. Although the railway provides opportunities, inhabitants try to stop the development of the railway through their city, because it requires high dikes that separate the city from the Veluwe and Sonsbeek park (Vries, De, 2020c)

Arnhem around 1930

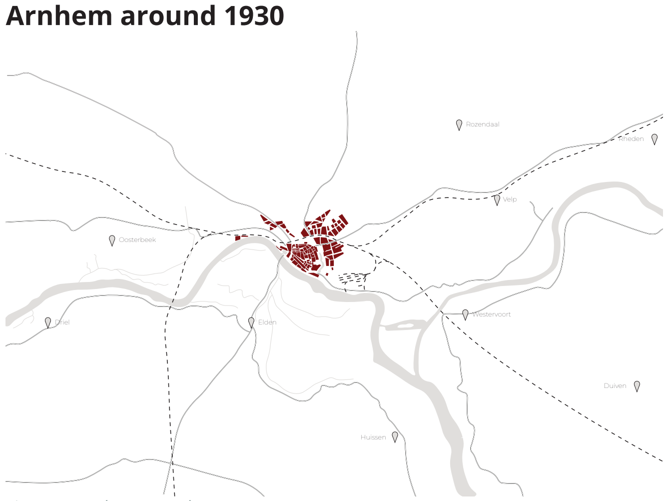


Figure 21: Arnhem around 1930

Around 1930, the railroad connection between Nijmegen and Arnhem has been established. Now Arnhem is accessible from the directions of Utrecht, Zupthen, Germany and Nijmegen by train. As is the case with all major cities in the Netherlands, the city of Arnhem has been affected by the industrial revolution, followed by the second world war. This period, between 1850 and 1950, has had a dramatic effect on the urban development of the city and surrounding region (Wagenaar, 2004). The industrial revolution resulted in introduction of industrial areas close to the city centre. This can be seen by the vast rail structures East of the city centre. Even today, these industrial areas, which are located between the river (to be accessible by boat) and the railroad (to be accessible by train) play an important role in the spatial structure of Arnhem.

Arnhem around 1965

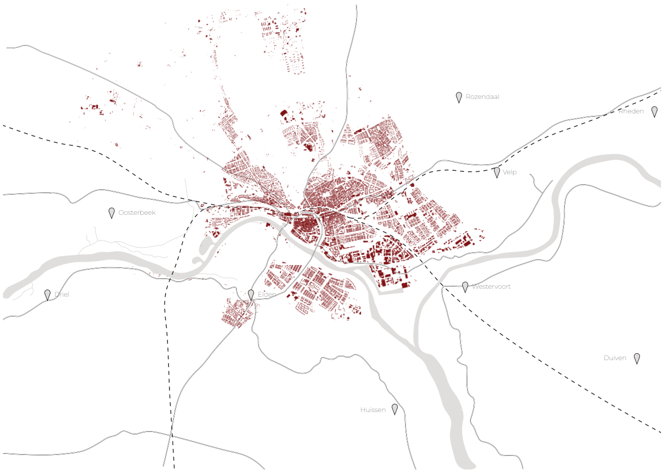


Figure 22: Arnhem around 1965

The main visible change in urban fabric after the end of the second world war and 1965, is the expansion of the city of Arnhem South of the river Rijn. Because the part of the city North of the river Rijn is located between the village of Oosterbeek on the West, the village of Velp on the East and the Veluwe on the North, the only option to expand the city is South. But what is even of higher importance, is the introduction of the car and its effects. Part of the parks around the city centre are removed to make way for a fast connection between the motorways and residential areas in Arnhem. The car and its roads take over the city.

Arnhem around 2023

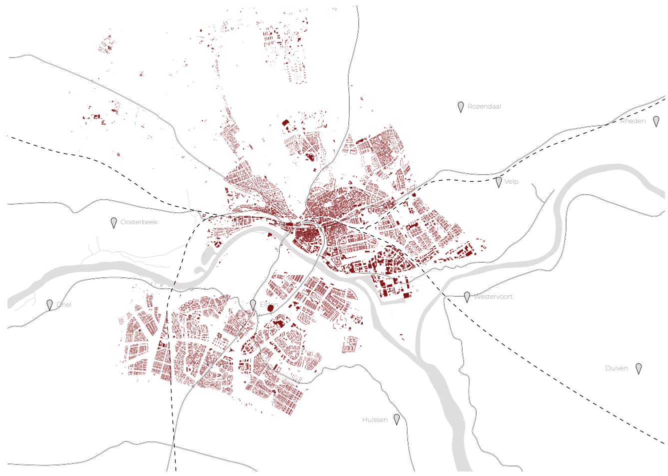


Figure 23: Arnhem around 2023

Between 1965 and 2023, Arnhem expanded its city even further South. The neighbourhoods of Schuytgraaf is the most memorable expansion in the last 20 years. A neighbourhood with over 6500 housings to the South-West of Arnhem (Home | Schuytgraaf Arnhem, n.d.). Now, the city of Arnhem no longer focusses on expansion of the city but has to densify in order to create more housing for its (new) residents. Also, the focus has partly shifted from cars towards other transportation modes.

POLICY ANALYSIS

To better understand the current and future situation of the city of Arnhem, a policy review of ambition, strategy and vision documents related to the city of Arnhem is conducted. This review sets a basis for the city strategy and also provides an overview of plans related to the urban design of the city of Arnhem structured by scale.

The national environmental vision (nationale omgevingsvisie (NOVEX)) has assigned 16 attention areas (NOVEX-areas) in the Netherlands (see figure 24) (Aanpak per Gebied - De Nationale Omgevingsvisie, n.d.). The provinces in which these areas are located are asked to develop spatial visions addressing sustainable, affordable and accessible housing and clean energy and healthy nature. One of these sixteen attention areas is Arnhem-Nijmegen-Foodvalley. An area in between Amersfoort, the Veluwe and the border to Germany. The city of Arnhem is located in the heart of this area.
Because the national government only assigned certain areas as attention areas but does not develop spatial plans and vision for these areas, the provinces and regions are asked to develop these plans.

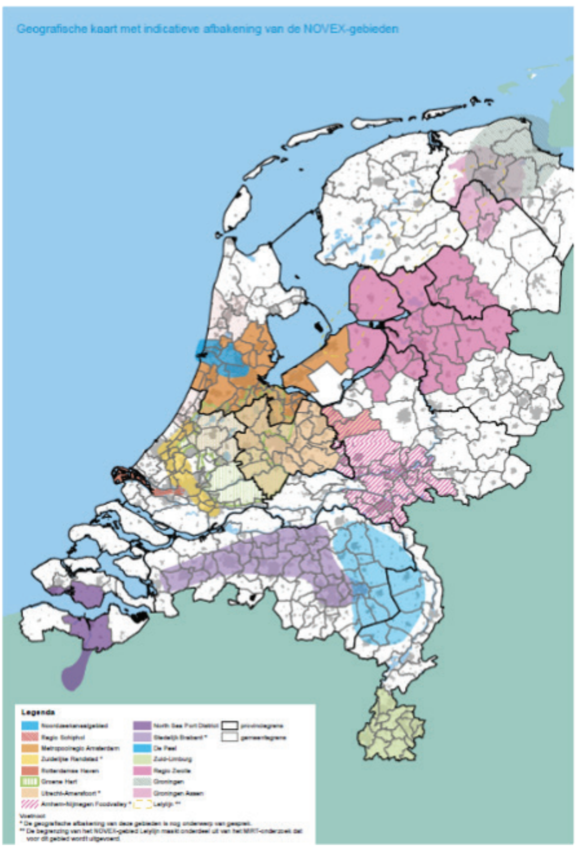


Figure 24: Novex areas (Aanpak per gebied - De Nationale Omgevingsvisie, n.d.).

The province of Gelderland has its own environmental vision (see figure 25), taking into account the national environmental vision and woondeal (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. ,2020). This vision focusses on energy transition, climate adaptation, circular economy, biodiversity, accessibility, business climate and residential and living environment (Provincie Gelderland, n.d.). In this vision, new areas for residential development are highlighted around the West and South of the city of Arnhem. In terms of densification, the vision suggests the transformation of all sorts of buildings into residential buildings. In terms of accessibility, the vision highlights the use of electric vehicles and the future use of self-driving cars. Apart from a short sentence about stimulating other modes of traffic, no concrete plans have been suggested for public and active transport.

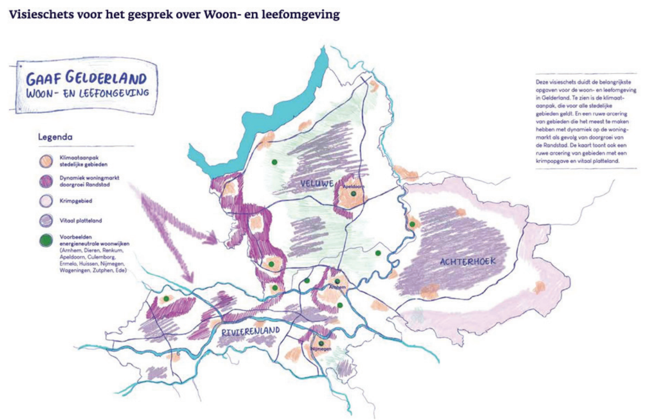


Figure 25: Vision Gelderland (Provincie Gelderland. ,n.d.)

The regional collaborations around the city of Arnhem have a major influence on the choices that the municipality of Arnhem makes in their vision and strategy. Arnhem collaborates in the regional government 'Groene Metropoolregio' (Stuurgroep Versterking regionale samenwerking, 2020). This region has set its goal on becoming the most circular region of the Netherlands, balancing the city, villages and green within the region. Arnhem, together with the city of Nijmegen, also collaborated in a regional collaboration agreement. This agreement with the national government targets the construction of 50.000-60.000 new houses before 2050 in the region of Arnhem and Nijmegen (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. ,2020). The aim is to have constructed 35.000 houses before 2030. In ten years (the agreement was signed in 2020), the construction of 35.000 houses in an already highly urban area causes a lot of challenges. The woondeal describes briefly how to address a couple of these challenges. For example, the investment in public transport before constructing new residential areas. More location bound challenges are addressed in the environmental vision which the city of Arnhem published in 2021.

This environmental vision describes nine goals on city scale level (Gemeente Arnhem, 2022). 1) Arnhem as green, creative and enterprising 'energy city' 2) busi-

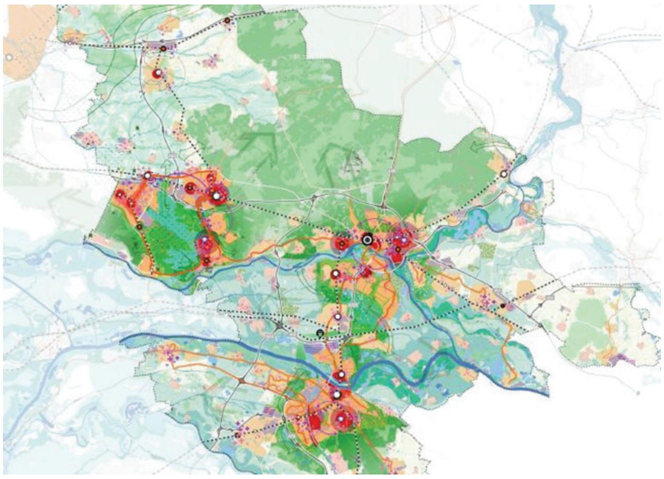


Figure 26: Regional vision (Stuurgroep Versterking regionale samenwerking. ,2020).

ness climate for schools and innovation in combination with the energy sector. 3) More space for cycling and walking, invest and built in areas within the current city that are well connected to PT. 4) create housing for disabled, low budget and disadvantaged social position. 5) mixed functions: work and live in the city. 6) attractive, healthy, green living environment. Paying special attention to changing climate. 7) Healthy neighbourhoods 8) prevention of energy poverty and become more sustainable. 9) transform the inner city from 'buy centre' to 'meeting place'.
How can this influence the reduction of cars on city scale level? In terms of density, the city acknowledges that space to build is scares. Efficient use of land is needed. Examples of this are high rise buildings (although the city of Arnhem does not intent to build large high rise neighbourhoods), build new houses and offices around public transport and therefore aim for mixed use buildings and areas (Gemeente Arnhem, 2022).
In terms of liveability, the city aims to decrease the car speed to 30 km/h and reduce car usage in the city centre. These two measures will effectively improve the air quality and safety of the residents (Gemeente Arnhem, 2022).
Specifically, the vision names a number of car reducing measures: 1) Thinking about car-free zones in the city. 2) Shared mobility. 3) Places that are denser, need less car usage. 4) Design of public space aiming for reducing car speed. 5) Tourists can park their car outside the city and take PT to the city centre. 6) More cycle highways to stimulate long distance cycling. 7) Reduce roads for cars and busses if the roads are not used anymore (as much as they used to) (Gemeente Arnhem, 2022).
The city of Arnhem furthermore tries to reduce car usage by stimulating cycling and walking but at the same time focusses on a robust car network (Gemeente Arnhem, 2022).

In conclusion, a mismatch between the national- and provincial visions and the regional and municipal

Figure 27: Municipal vision (Gemeente Arnhem, 2022)

vision can be seen. The region and municipalities are more focussed on densification within the existing city, where the national and especially provincial governments suggest focus on the West of Arnhem as an expansion area. Furthermore, the city of Arnhem focusses too much on e-cars and e-bikes as a solution to problems related to the car. This unfortunately only solves the problem of congestion partly and has a minimal effect on the reduction of car usage within the city. Instead of suggesting city wide interventions, the municipality of Arnhem needs to focus on assigning attention areas for car reducing measures. In general there is almost no mention of car reducing, car low or car free development in the omgevingsvisie of the city of Arnhem.

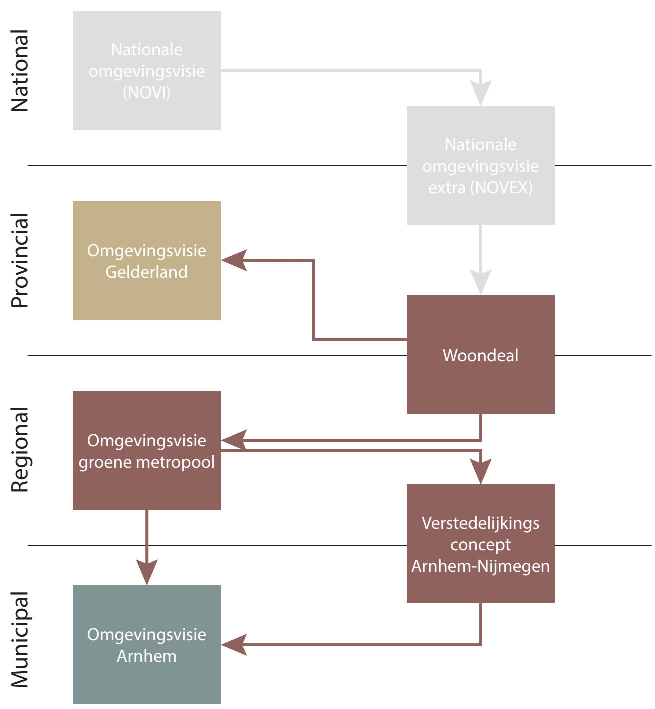


Figure 28: policy documents and their relations

CONTEXTUAL CHARACTERISTICS

This section describes the contextual characteristics of the city of Arnhem and its surroundings using the ten categories from the toolbox as basis. For each category the basic characteristics will be explained and mapped, serving as a knowledge basis for the city strategy. Firstly, a short introduction on the province and the four key cities will be given.

The province of Gelderland

The city of Arnhem is the capital of the province of Gelderland. As mentioned in the historical development, the city functions as an important economic centre for the East of the Netherlands. Although Nijmegen is the oldest and biggest city (in terms of Residents) of Gelderland, Arnhem is still the capital of the province. The north of Arnhem is the most Southern part of the national park 'de Hoge Veluwe'. Most of the residential and industrial areas of the province of Gelderland are located around Nijmegen and Arnhem. But the last 30 years, the city of Apeldoorn has developed as the second city of Gelderland (after Nijmegen), and therefore a new economic heart (see figure 29).
All maps have been designed using qgis (QGIS.org, n.d.), PDOK data (Diensten - PDOK, n.d.) and OpenStreetMap data (OpenStreetMap contributors., 2015).

Figure 30: Train stations (1000m buffer)

Public transport

The four train stations in within the city of Arnhem serve a large part of the North of Arnhem. The city centre and more dense neighbourhoods are all within 1000 meters of a train station (see figure 30). The South of Arnhem is relatively poorly covered in terms of accessibility of trains. Only one station provides access to the regional train station. The bus network does cover all of Arnhem, even the less densely populated areas (see figure 31).

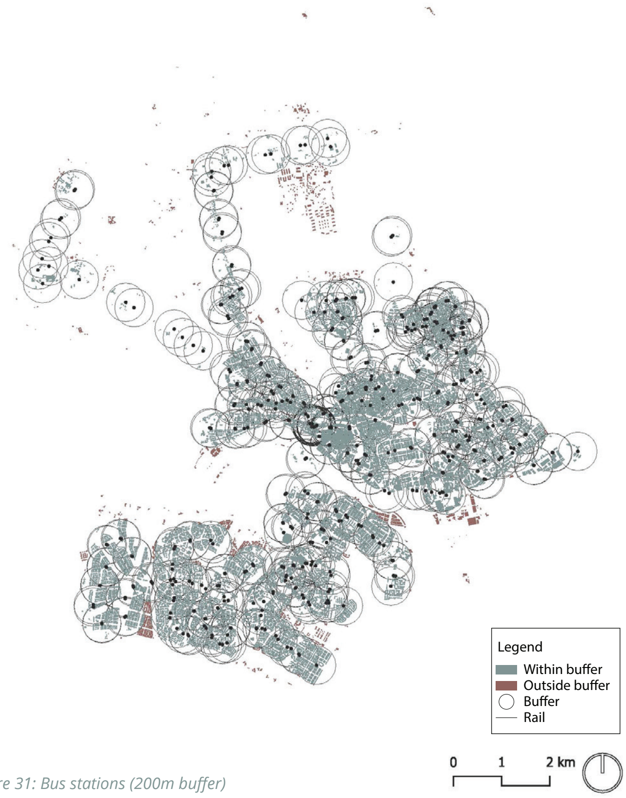


Figure 31: Bus stations (200m buffer)

Road network

Figure 32 shows the road network of Arnhem. The city is enclosed in the North by the A12 motorway. To the South, Arnhem is connected to the city of Nijmegen through the A325 motorway. One of the challenges Arnhem faces, is the lack of a ringroad around the city. When travelling by car from Nijmegen towards the East of the Netherland (Doetinchem) or towards the North (Apeldoorn), the primary road 'the Pleijweg' is the most logical road to take. This requires a transition from the A325 motorway towards the N325 primary road, which happens in the centre of the Southern part of Arnhem. This affects the Southern part of Arnhem in terms of traffic nuisance and pollution.

Active transport

In terms of cycling, the city of Arnhem is well reachable. It is located in the centre of the provincial bicycle road infrastructure and is located near the Veluwe, which makes recreational cycling attractive in this area.
The city itself provides a vast cycling network, although (as shown in figure 33) this network is not well connected. The focus of the city of Arnhem is neighbourhood based and is not city scale based.
The pedestrian areas in the city are mostly focussed on commercial activities. The city centre, the

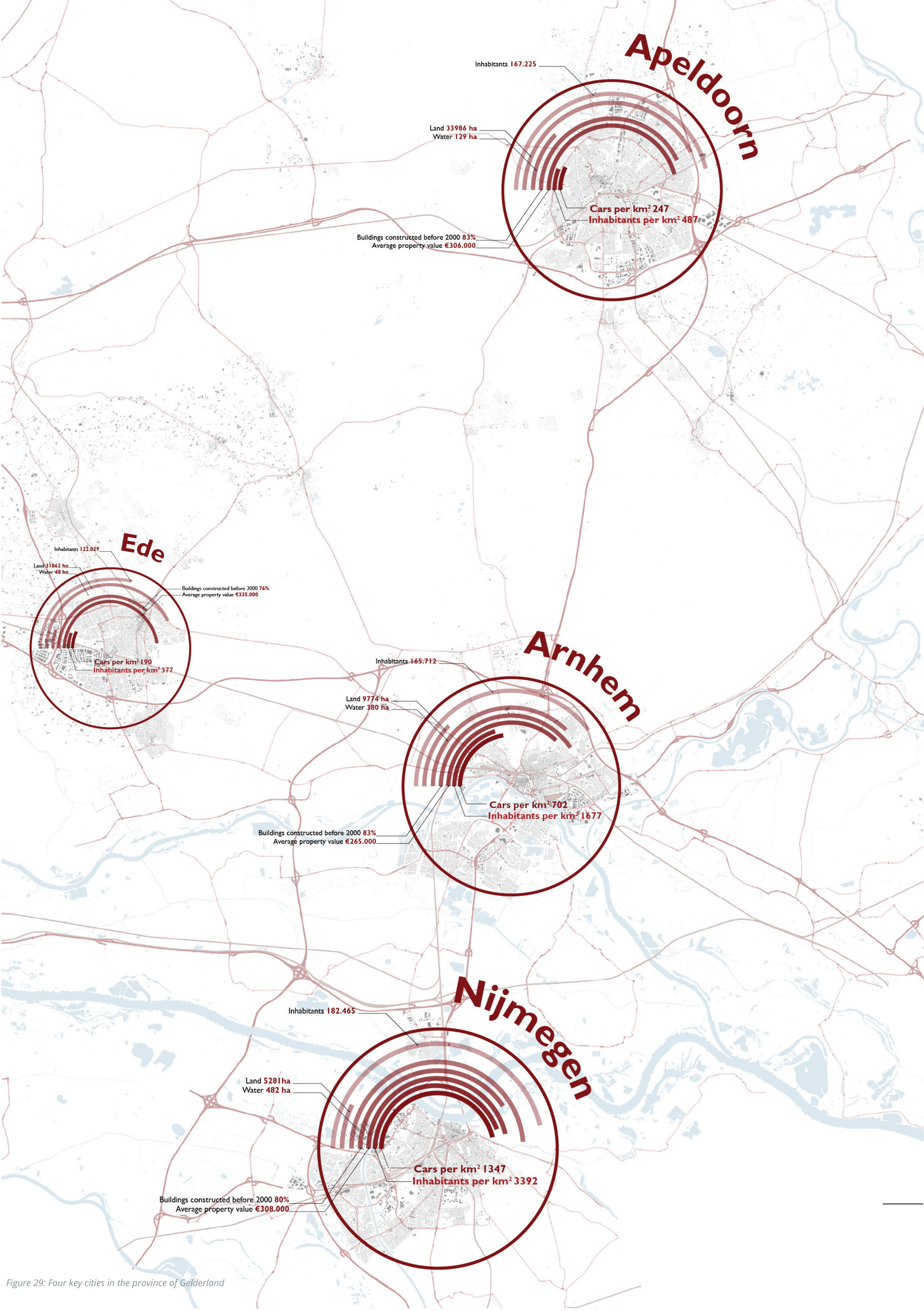


Figure 29: Four key cities in the province of Gelderland

Presikhaaf mall and Kronenburg are the pedestrianized areas. Another important area for pedestrians is the Sonsbeek park, but this network is not visible in figure 33 because it is not part of the pedestrianized area of Arnhem.

Figure 32: Road network

Figure 33: Active transport

Parking management

On city scale, parking for cars is well supplied (see figure 35). Most parking garages are located in the North of Arnhem, which can be explained by the density of the city and the availability of on street parking and parking on property. Most large on street parking spaces are located around the Kronenburg mall in the South.

The municipality is already reducing on street parking around the city centre and has mapped all on street parking (see figure 34).

Figure 34: On street parking (city centre)

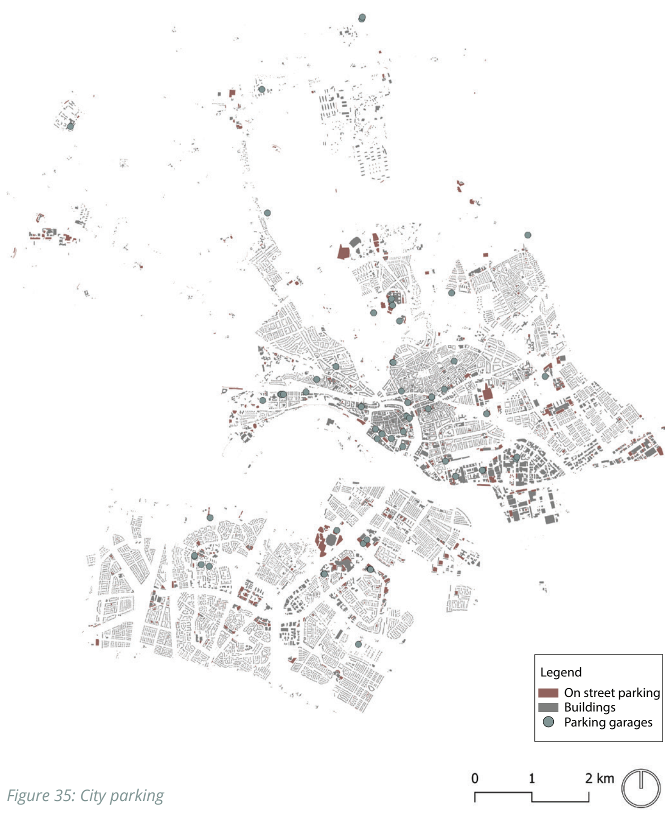


Figure 35: City parking

Accessibility

There is not an easy way to map the accessibility for a city. Accessibility can be seen as the easiest way to access the city, but also to reach facilities, public transport stops or other places. Figures 30 and 31 show the accessibility of the public transport. Figure 36 shows how well integrated the roads within the city boundaries are (red indicates well integrated and blue indicates poorly integrated). This also shows how heavy roads are used to travel within the city from one to another place.

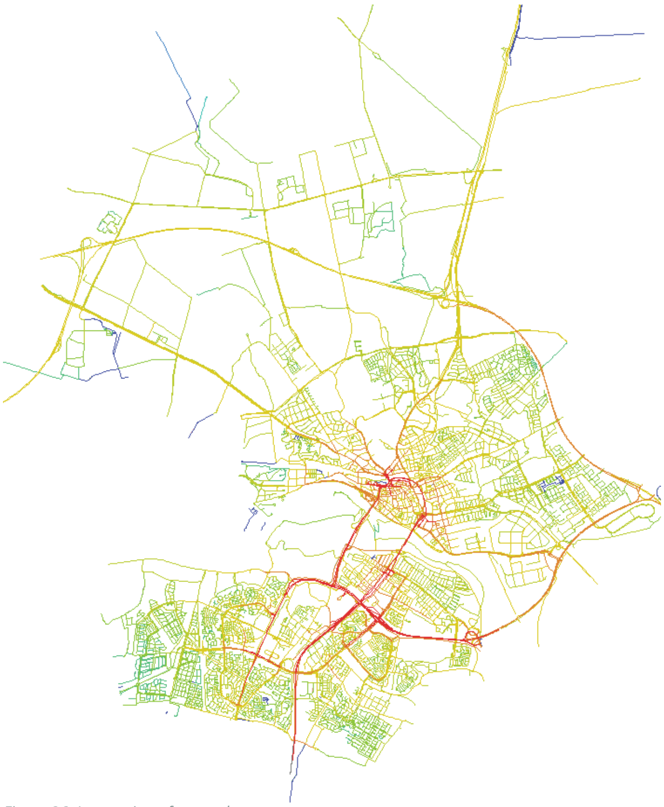


Figure 36: Integration of network

Figure 37: Paid parking

Pricing system

The city of Arnhem is hesitant in expanding the paid parking areas. Currently, only the city centre and directly surrounding neighbourhoods are part of the paid parking area. This only includes approximately 5-10% of the total built-up area, although this is the densest area. The South of Arnhem does not have any paid parking areas, as can be seen in figure 37.

Awareness

There are various ways to make residents aware of the effect of the dominance of the car. The city of Arnhem does not actively share these facts, as concluded in the policy analysis. Ways to make residents aware are: show the air pollution in terms of particulate matter (PM10 and PM2,5) and nitrogen (as mapped by the Province of Gelderland), the effect of traffic nuisance (see figure 38) and showing the effect of the car by removing the car from (parts of) the street.

Figure 38: Traffic nuisance

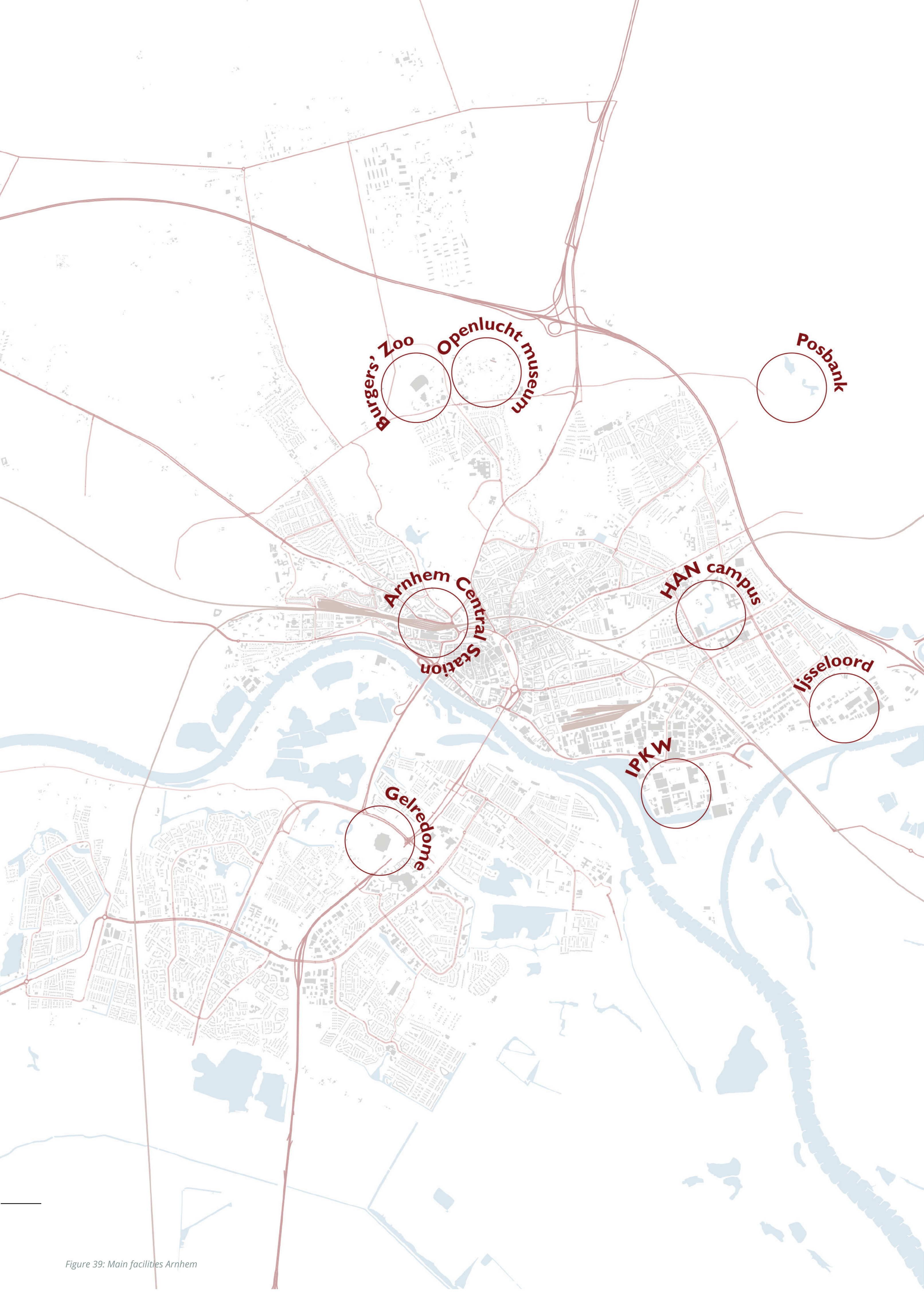


Figure 39: Main facilities Arnhem

Facilities

Figure 39 shows the characterizing facilities in the city of Arnhem. Apart from central station 'Arnhem centraal', the city possesses various other amenities. In terms of industry and offices, the Ijsseloord and Industriepark Kleefsewaard (IPWK) are important economic centra in the region. The campus of Hogeschool Arnhem-Nijmegen (HAN) provides space for students and companies to perform research. In terms of recreational activities, the Gelredome (soccer stadium and event location), Openluchtmuseum (Museum), Burgers' Zoo and the Posbank (part of the Veluwe national park) provide various leisure opportunities.

Density

As discussed in the first chapter of this work, defining density, and deriving conclusions from that definition can be quite complicated. To show the density of the different neighbourhoods in Arnhem, figure 40 shows the number of residents per km2 per neighbourhood. In general, the Northern part of the city is denser and therefore provides more housing. The Sonsbeek park and industrial area to the East are the least dense areas (in terms of residents).

Figure 40: Density (residents per km²)

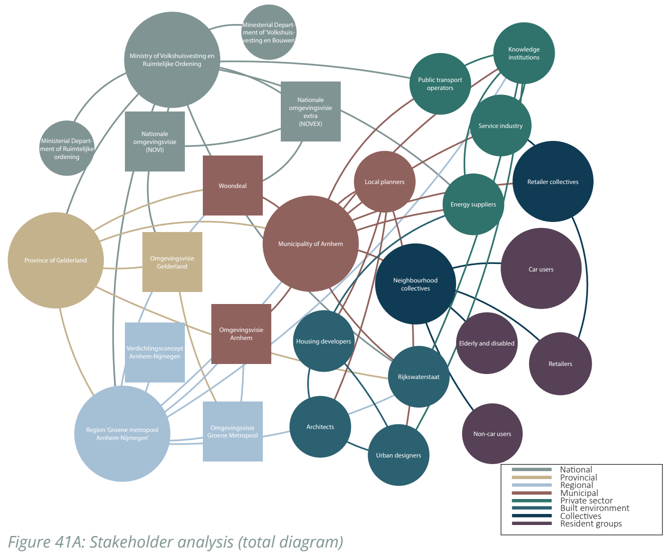


Figure 41A: Stakeholder analysis (total diagram)

Stakeholders

Finally, the relation between stakeholders that affect the city of Arnhem in terms of car usage and car reduction have been analysed. The stakeholder analysis arises from the policy analysis and literature review. These two previous steps showed stakeholders that affect the found measures (literature review) and affect the policy making in general (policy analysis). Figure 41A shows a diagram of the different stakeholders that affect the reduction of car usage. Figure 41B shows the simplified version. Eight groups of stakeholders have been identified: national government, provincial government, regional government, municipal government, private sector, built environment, collectives and resident groups. This can be simplified by combining the groups to: government, private sector and users. This paragraph highlights three important connections within the stakeholder forcefield.

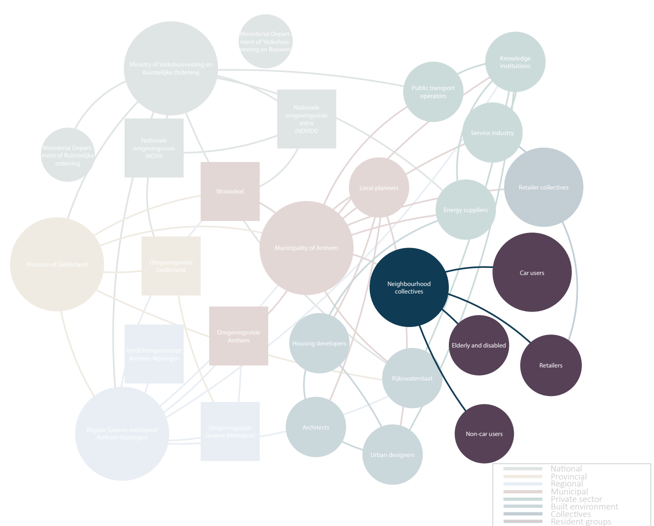


Figure 42: Stakeholder analysis (Collectives)

Firstly, the role of the neighbourhood collectives (see figure 42). In terms of awareness, the neighbourhood collectives (and also retailer collectives) can play an important role. Various groups of users have different

opinions and face challenges related to car reduction. The car users are partly willing to reduce their use of the car and can address the problems on neighbourhood level that prevent them from using public or active transport (Puiu et al., 2022). Elderly and disabled often are also willing to make a shift, but need better walking infrastructure (benches and shadow) and some require access to car-free areas to unload groceries or have better access to their homes (Choi et al., 2017). As mentioned in the literature review, the retailers often play a crucial role in the awareness of car-free pedestrianized areas in centres of the city. Lastly, the non-car users are important to bring into the discussion: they have the knowledge and reasons to not use a car.
Secondly, the municipality plays a vital role (see figure 43). All casestudies from the literature review mention the municipality as key stakeholder, which is no surprise since the municipality has the resources and connections to make the reduction of cars in the city happen. A good collaboration with Rijkswaterstaat, public transport suppliers and the service industry (car sharing suppliers, bicycle parking and car parking companies) are crucial in the transition.
Lastly, the planners and designers (the built-environment) need to convince other stakeholders of the benefits of car reduction in new and existing areas (see figure 44). They have to show the effect of a pedestrianized and cyclists orientated area. The three case studies from chapter 2 give an idea of the awareness these stakeholders can create by designing and developing these areas.

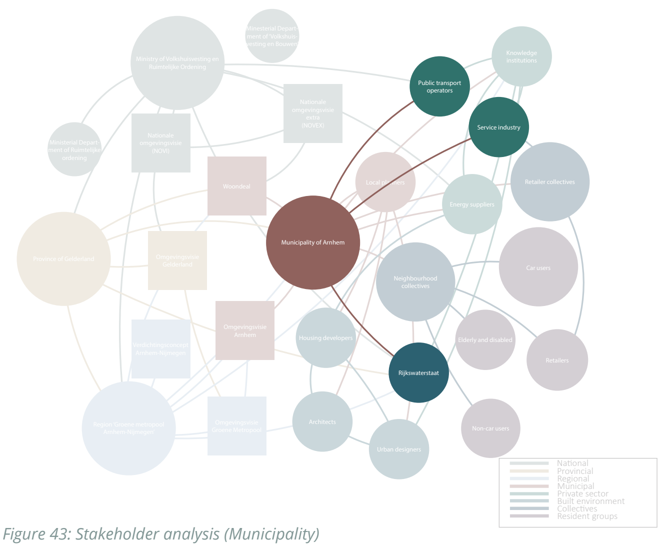


Figure 43: Stakeholder analysis (Municipality)

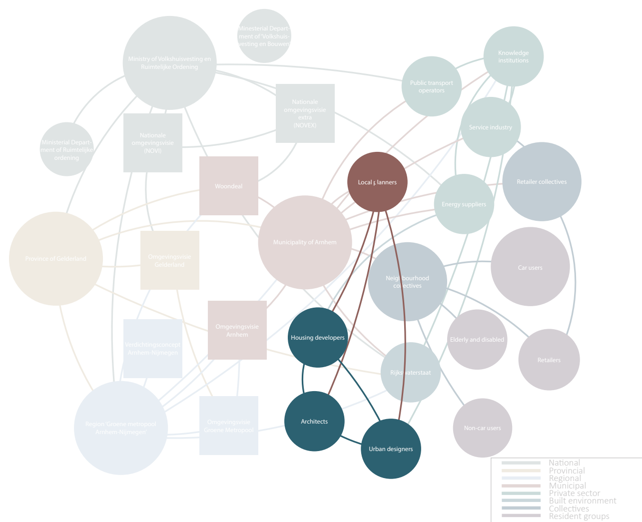


Figure 44: Stakeholder analysis (Built Environment)

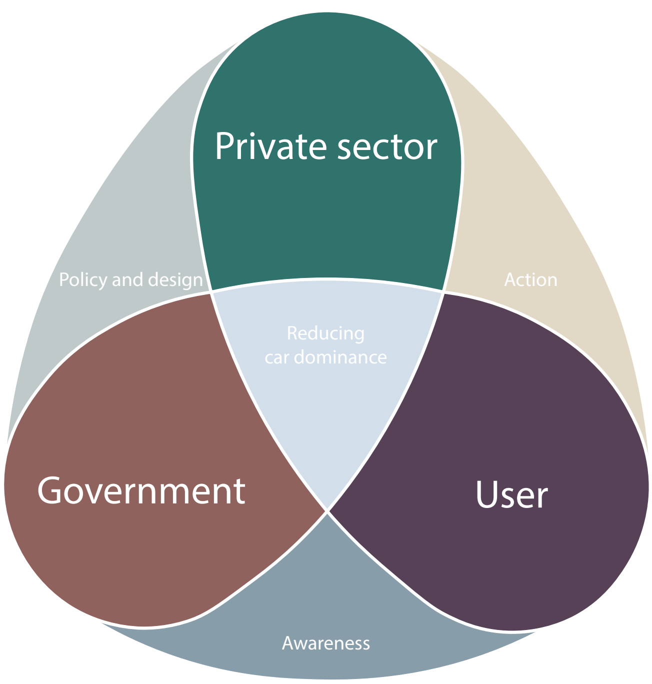


Figure 41B: Stakeholder analysis (simplified)

05

CAR FREE ARNHEM
CITY STRATEGY

This chapter describes the implementation of car reducing interventions on city scale. The basis for this city strategy consists of interventions that function on city level as explained in the toolbox decision tree and the lessons learned from the policy analysis and case studies.

Photo V: Arnhem central station (Hellendijk81, 2016)

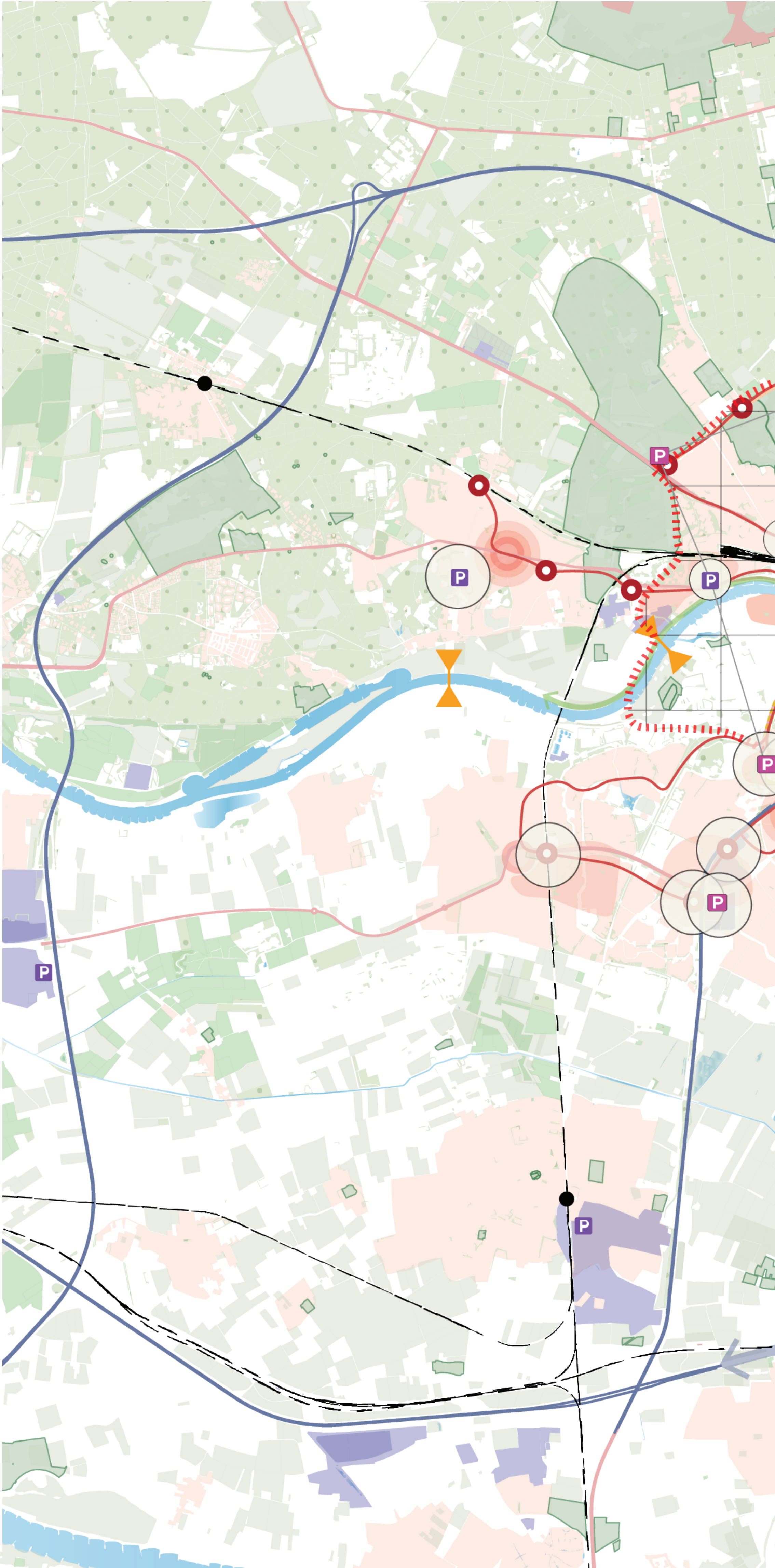
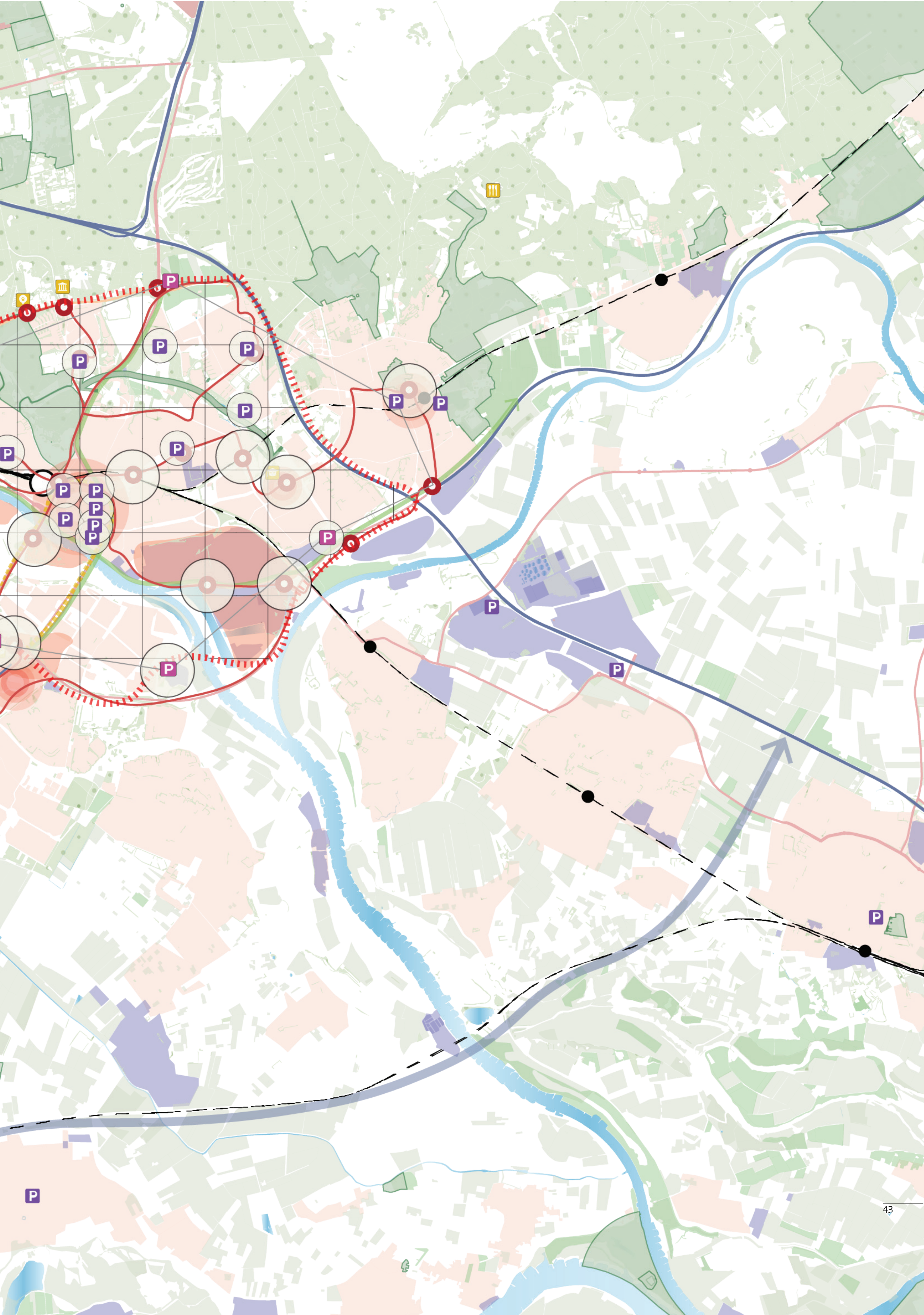


Figure 45: city strategy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THE CITY STRATEGY

This chapter describes the implementation of car reducing interventions on city scale. The basis for this city strategy consists of interventions that function on city level as explained in the approach decision tree and the lessons learned from the policy analysis and case studies. Furthermore, the lessons learned from the contextual analysis in the previous chapter will be taken into account. This chapter will again use the ten themes to explain the way the city strategy is built up.

Conceptual model

Figure 46 describes the conceptual model that formed the basis of the city strategy. The conceptual model shows four zones that have to be established within the city to make a reduction of cars successful.

Firstly, the car transition zone, at the edge of the city, functions as a large hub for car users. In this area multiple larger car parking's will be located to provide the option to park the car outside of the city boundaries for free and travel into the city of foot, by bus or by bike.

One step closer to the city centre will be a car reduced area. This area is not applicable to car-free or car-low neighbourhoods because of the, relatively large, distance towards train stations and the city centre. The car reduced area focusses on mobility hubs on the edge of the neighbourhood to reduce parking on street by 50%. This creates the opportunity for new design of neighbourhood streets and give priority to cyclists and pedestrians on neighbourhood scale.

The neighbourhoods surrounding the city centre will be car-low neighbourhoods. This means that there are no cars allowed in the neighbourhood and car parking will be located on office parking lots and mobility hubs. Also, the neighbourhoods will have a lower parking norm, meaning that not every resident or household can own a car. The focus is on cyclists, shared mobility, and walking. For residents who do want to own a car, the car transition zone can provide a solution.

Finally, the city centres in and around the city of Arnhem (the city centre, Oosterbeek, Velp, Presikhaaf, Kronenburg and new centres), will be car free and pedestrianized. Cars are not allowed, and the focus of the neighbourhood is on walking. Cyclists are directed to specific cycling paths. Package delivery companies will have to work with package lockers or bike messengers.

This conceptual model further helps specifying the city strategy in detail together with the ten categories derived from the literature review.

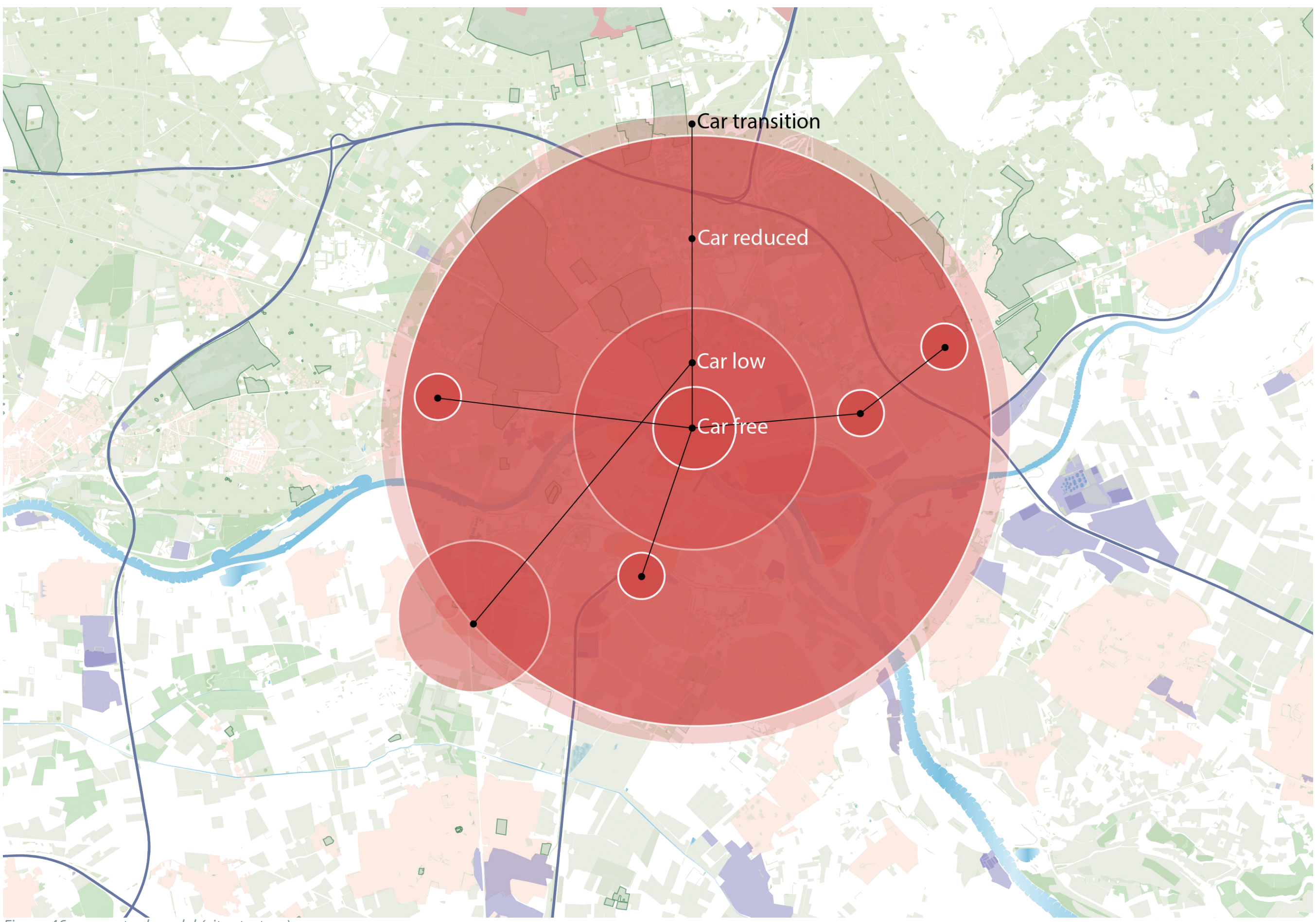


Figure 46: conceptual model (city strategy)

Public transport system

Arnhem Central Station is an important connector of the North and South of the Netherlands in the East. Especially the connection between Nijmegen and Zwolle is of importance (trajectory of Roosendaal towards Zwolle). Arnhem Central Station also is of importance connecting the Netherlands to Germany. The ICE international connects Amsterdam to Frankfurt. On city scale, the public transport of Arnhem consists of trains and busses. Four train stations: Arnhem Central Station, Arnhem Zuid, Arnhem Velperpoort and Arnhem Presikhaaf, serve a large part of the city (mostly North of the river Rijn). To further improve the public transport system of Arnhem, a transport mode that balances between the fast train and relatively slow bus must be introduced. The trolleybus is an important part of the history and future of Arnhem. These electric busses serve almost all of Arnhem but stop at many stops before reaching important amenities and facilities. Therefore, a HOV (Hoogwaardig Openbaar Vervoer) connection should be established. This connection serves all important places within city boundaries and provides a fast connection towards the train stations. Figure 47 shows the suggested HOV network on city scale. Figure 48 shows the serving area of the HOV line, compared to the service area of the train station and figure 49 shows the decision tree of the public transport toolbox. The measures that have been addressed in this part of the strategy are the improvement of public transport (the new HOV line), the aim to cycle for maximum of 10 minutes towards one of the stations (also HOV stops) and the increase in frequency of the bus (due to the introduction of the HOV line).

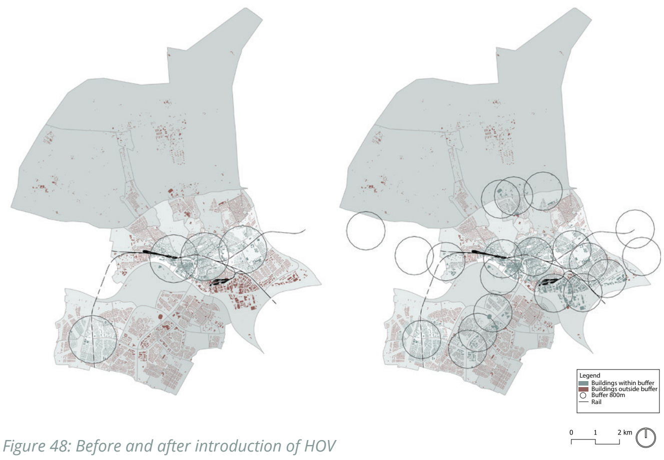


Figure 48: Before and after introduction of HOV

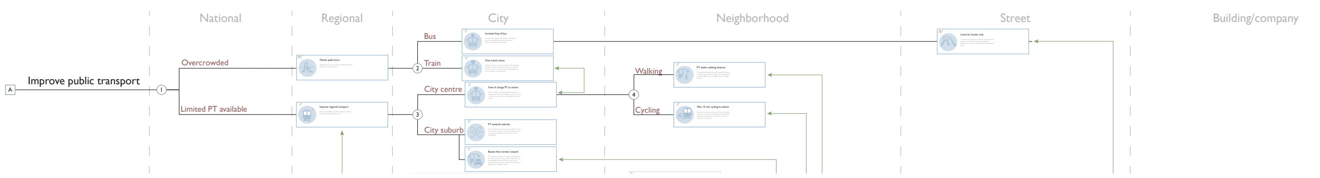


Figure 49: Decision tree public transport

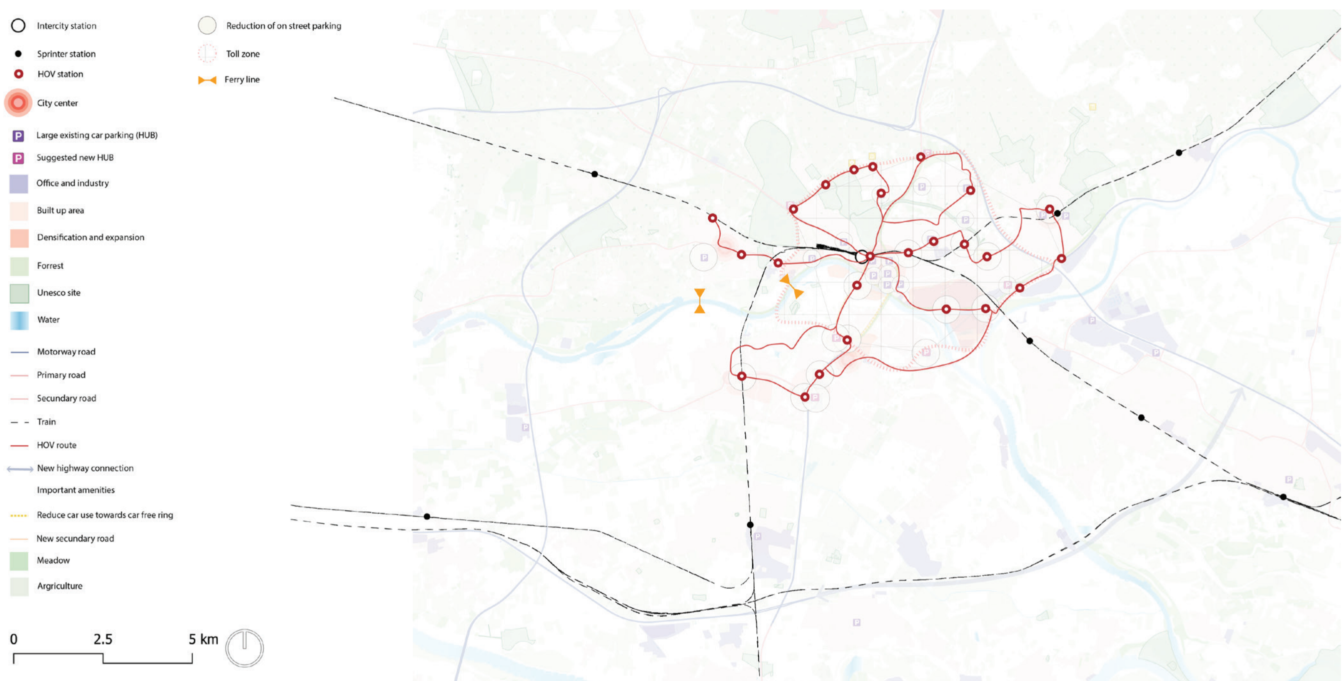


Figure 47: City strategy (Public transport system)

Road network

The A12 is an important barrier between the built-up city of Arnhem to the South and the southern region of national park de Hoge Veluwe to the North. This motorway crosses the middle of the Netherlands, connecting Den Haag to Arnhem and further East towards Germany. West of Arnhem, the A50 connects the A12 to the South of the Netherlands. The other motorway near Arnhem, the A325, connects Nijmegen to Arnhem. This motorway end in the centre of the South of Arnhem.

As explained in the analysis part, the lack of a ring road around the city of Arnhem creates problems for reducing cars out of the city. Currently, the fastest connection South to East and South to North requires passage through the city centre of the city. To solve this problem, a new highway, connecting South to East is established (see figure 51). Although this strategy aims to reduce cars from the city, alternative has to be provided to ensure the continuation of freight transport and other motorized transport. This is also one of the suggestions from the measures from literature (see figure 52).

By providing a new ringroad, the ringroad around the city centre can be reduced in terms of car usage and therefore cycling can be stimulated. Figure 50 shows the current traffic nuisance in the city of Arnhem, which is also one of the reasons for reducing motorized traffic on the centrumring.

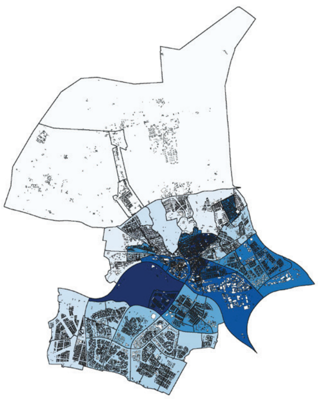


Figure 50: Nuisance per neighbourhood

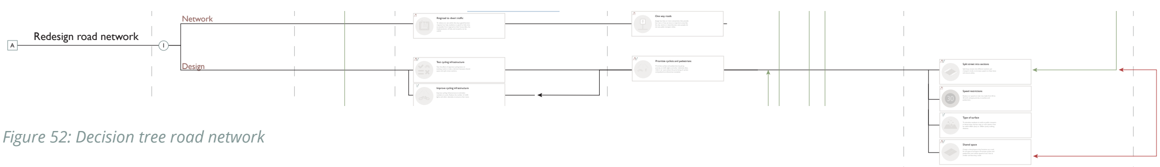


Figure 52: Decision tree road network

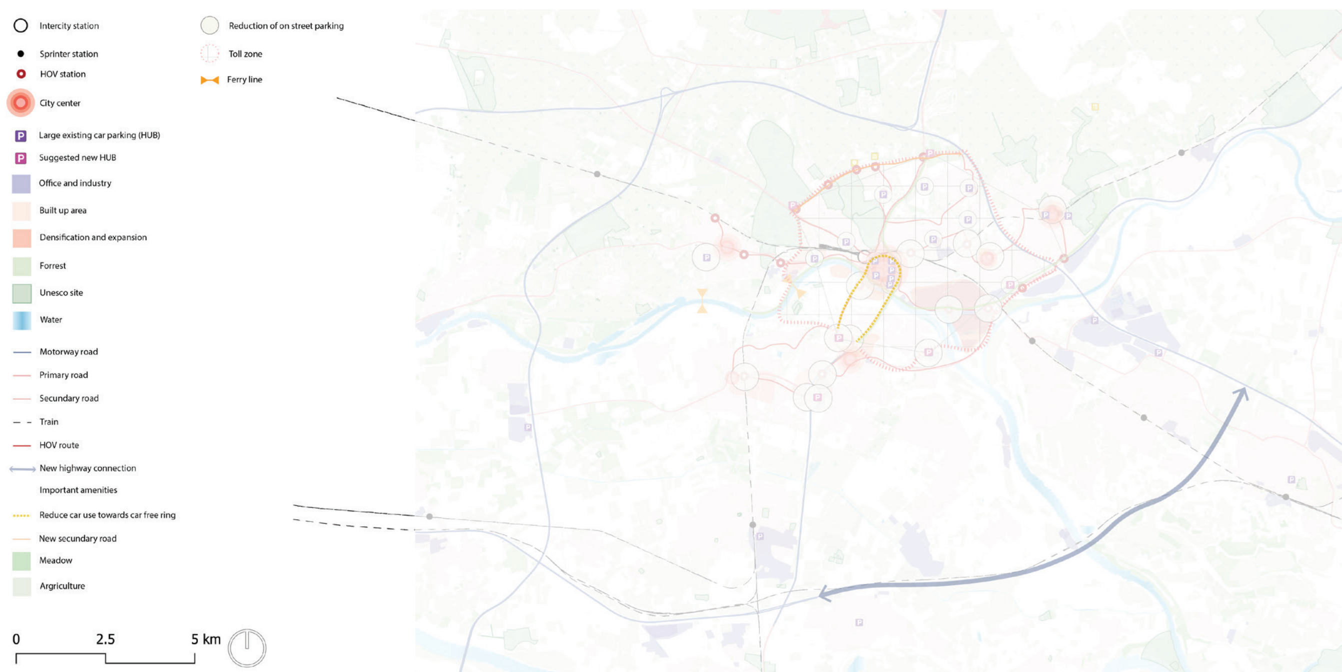


Figure 51: City strategy (Road network)

Active transport

When it comes to active transport, the increase of physical activity levels is the key goal. A second important effect of increased active transport is the reduction of car and bus usage within the city, decreasing the pressure on the city ring. Arnhem is known for its bike paths, connection Wageningen, Apeldoorn, Nijmegen and East of the Netherlands. In terms of regional cycling infrastructure, the city has performed well the last years, however on city scale, two important links in cycling infrastructure are missing. The north-south connection is missing a link between Olympus and the John Frost bridge and between the city centre and the Apeldoornseweg. The East-West connection is guided through the city centre, diverging the cyclists into pedestrianized zones and complicated routes.

This city strategy suggests connecting the missing links of the North-South connection and to use the Rijnkade as direct cycling route for the East-West connection. This implies that the Rijnkade must become car free, which is currently not the case. These missing links do not suggest that there is no cycle path on these roads, but only show that it is not part of the city's main bike paths and therefore less included in safety measures and prioritizing of cyclists.

Figure 53: Current en suggested cycling network

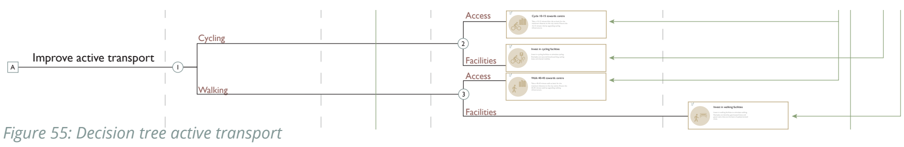


Figure 55: Decision tree active transport

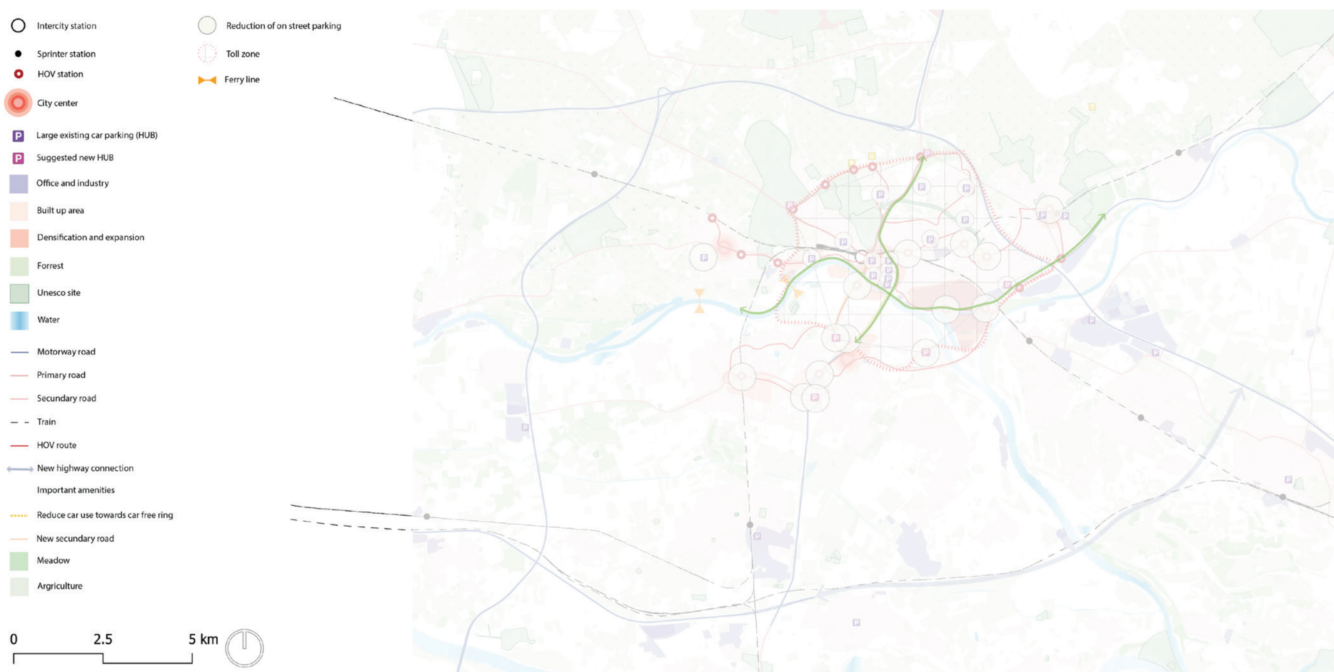


Figure 54: City strategy (Active transport)

Parking management

Most measures of the parking management toolbox are classified as push methods (see figure 56). Therefore, the suggested measures need to be implemented with care and balanced by various pull measures in different categories.

As mentioned in the previous sections, the car transition zone is important to reduce the number of on street parking. Therefore, existing and new large parking hubs around the city are suggested (see figure 57). Furthermore, the existing parking garages in and around the city will be no longer in use for visitors parking only. Normally, these parking garages will be empty for most of the time during the night.

These places provide the option to transfer on street parking towards parking garages within walking distance in each neighbourhood.

As shown in figure 57, areas around large public transport stops, and parking garages will provide (almost) no on street parking for residents (with exception of elderly and disabled). This example of pull measures (parking garages and improved public transport stops) and push measures (reduction and relocation of on street parking) will provide more space for activities and greenery on street level.

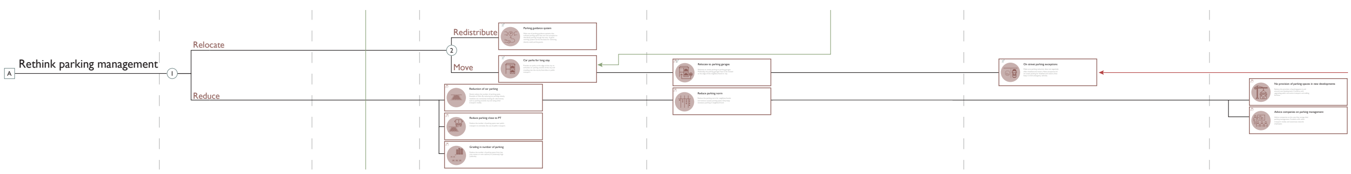


Figure 56: Decision tree parking management

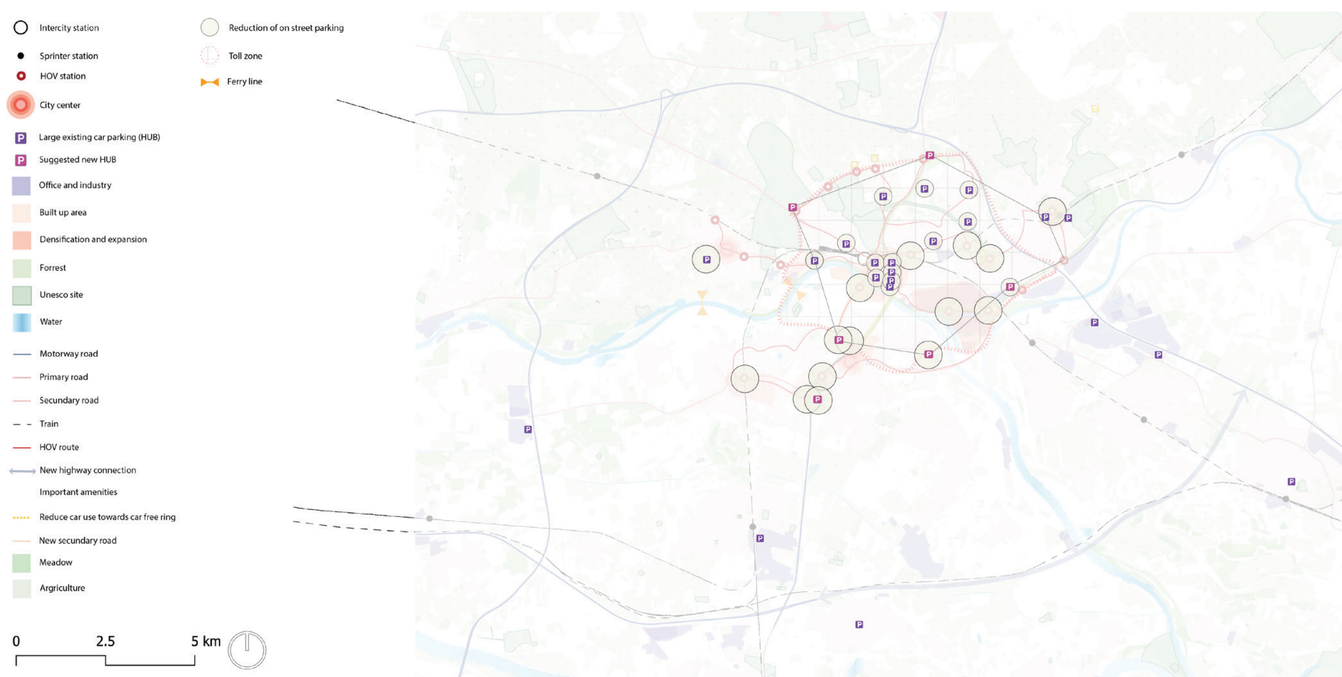


Figure 57: City strategy (Parking management)

Accessibility

Reducing car dominance, directly relates to the degree of densification of a location. One of the densest areas in Arnhem is the city centre, not because of the number of residents per km2 (which is relatively high) but mainly because of use of streets for retail and commercial activities. Therefore, the city centre needs to be pedestrianized (see figure 58). A large part of the city centre is already only accessible for walking (and partly cycling), but a larger part of the centre is qualified. As previously mentioned, the ring around the city centre is an important road in the city of Arnhem and therefore a barrier between the centre and the rest of the city. The number of vehicles that use this road need to be reduced, which can create space for cyclists, pedestrians and green around the city centre, reintroducing the green park around the city centre.
Furthermore, the other centres in and around the city of Arnhem need to be (further) pedestrianized. These are shopping centre Kronenburg, around station Arnhem Zuid, shopping centre Presikhaaf and the adjacent villages of Oosterbeek and Velp (see figure 59).

Figure 58: Decision tree accessibility

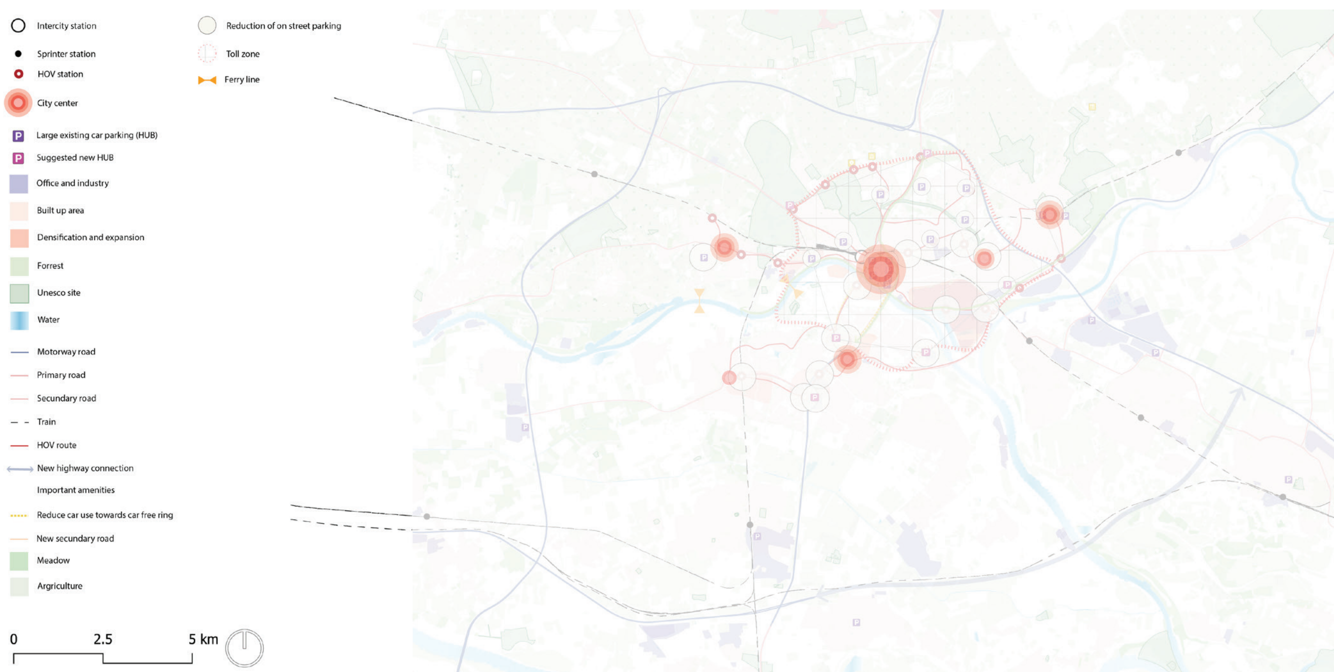


Figure 59: City strategy (Accessibility)

Pricing system

Measures like creating a new ringroad, providing a new HOV connection and redesign of streets have proven expensive. A pricing system is of importance to stimulate governments to act.

On national level, congestion charge is already implemented and will be further extended resulting in a ban on the production of petrol and diesel driven cars from 2035 onwards (EU Ban on Sale of New Petrol and Diesel Cars From 2035 Explained | News | European Parliament, 2022).

On city scale, various measures have been suggested (See figure 60). The most successful measure, but at the same time criticized in various cities, is the introduction of a toll system in the city. Cars that want to enter the city have to pay a certain amount of money, these profits are directly used for upgrading public transport and providing alternatives for the car. The city of Oslo has successfully implemented this measure (RYDNINGEN, U., HØYNES, R. C., & KOLLTVEIT, L. W., 2017)., but the city of London received a lot of objections of residents who are concerned of the social component of the measure (Raghavan & Calian, 2003). Therefore, it is of importance to think this measure through and make exceptions for certain groups to keep the city accessible for most residents. Secondly, provide alternatives and enough parking garages around the city. The toll ring tracks the ring of parking garages in the car transition zone (see figure 61), providing free parking garages and therefore an alternative for paying toll to enter the city.

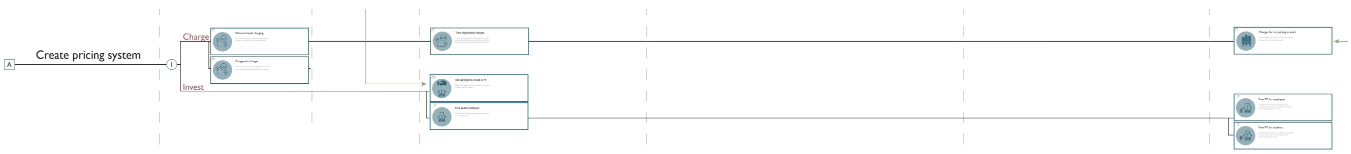


Figure 60: Decision tree pricing system

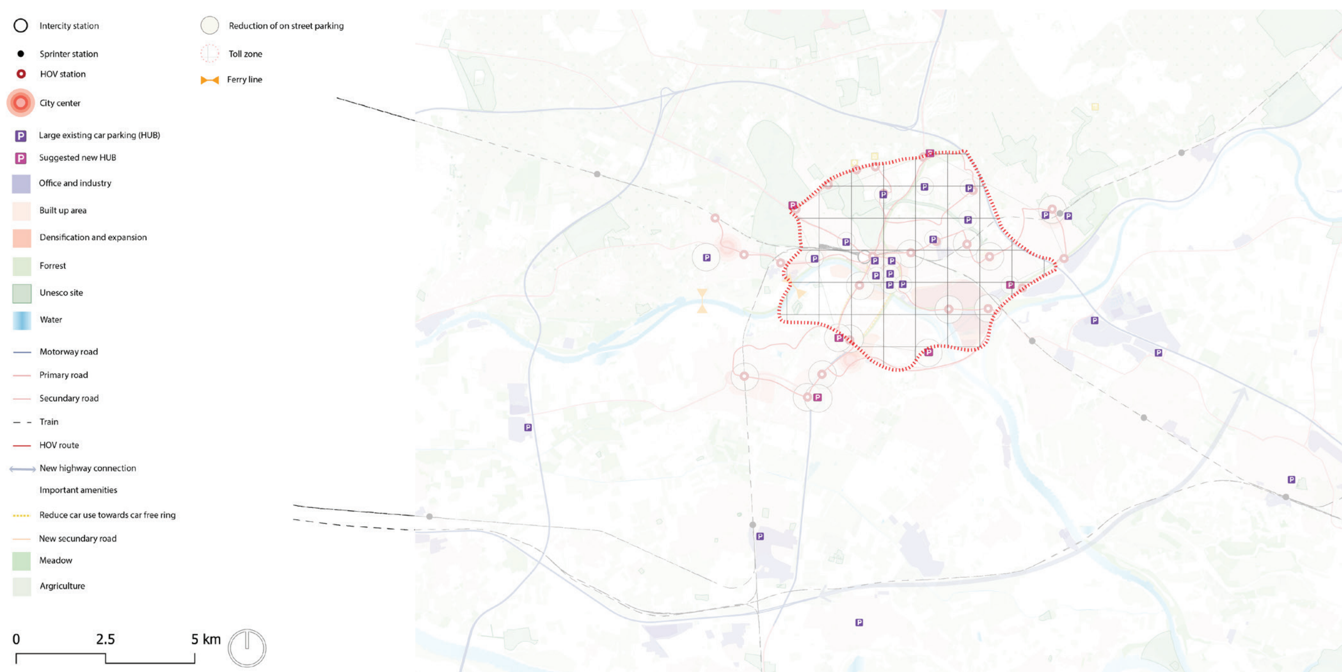


Figure 61: City strategy (Pricing system)

Awareness

Three important measures that focus on creating awareness have to be implemented (see figure 62). Firstly, inform residents about new measures that have been taken (see figure 63) and show the balance between push and pull measures. This ensures that residents know why things happen and what the future effect is of, for example, road work.
Secondly, promote cycling and walking. The basis for a healthy and car reduced city is walking and cycling. The maximum distance from the Northern to the Southern part of (the built-up area) Arnhem is 10km, which makes the city highly applicable for cycling. Although the elevation profile of the city should be taken into account, especially in the Northern part. This reduces the percentage of people who cycle in Arnhem drastically, unfortunately the introduction of e-bikes hasn't resulted in an increase in cycling (Duurzame Mobiliteit - CROW, n.d.).
Lastly, as suggested in the concept, multiple neighbourhoods have to become car free in the near future. To prepare residents for this radical change, car free days need to be introduced in the years before the final change. These days show residents what happens when the car is banned from their streets and the space that becomes free to be use for green and activities.

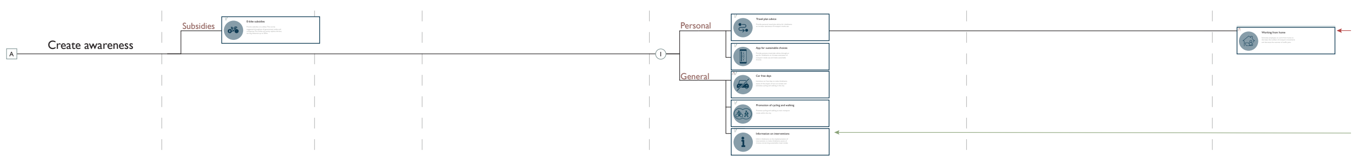


Figure 62: Decision tree awareness

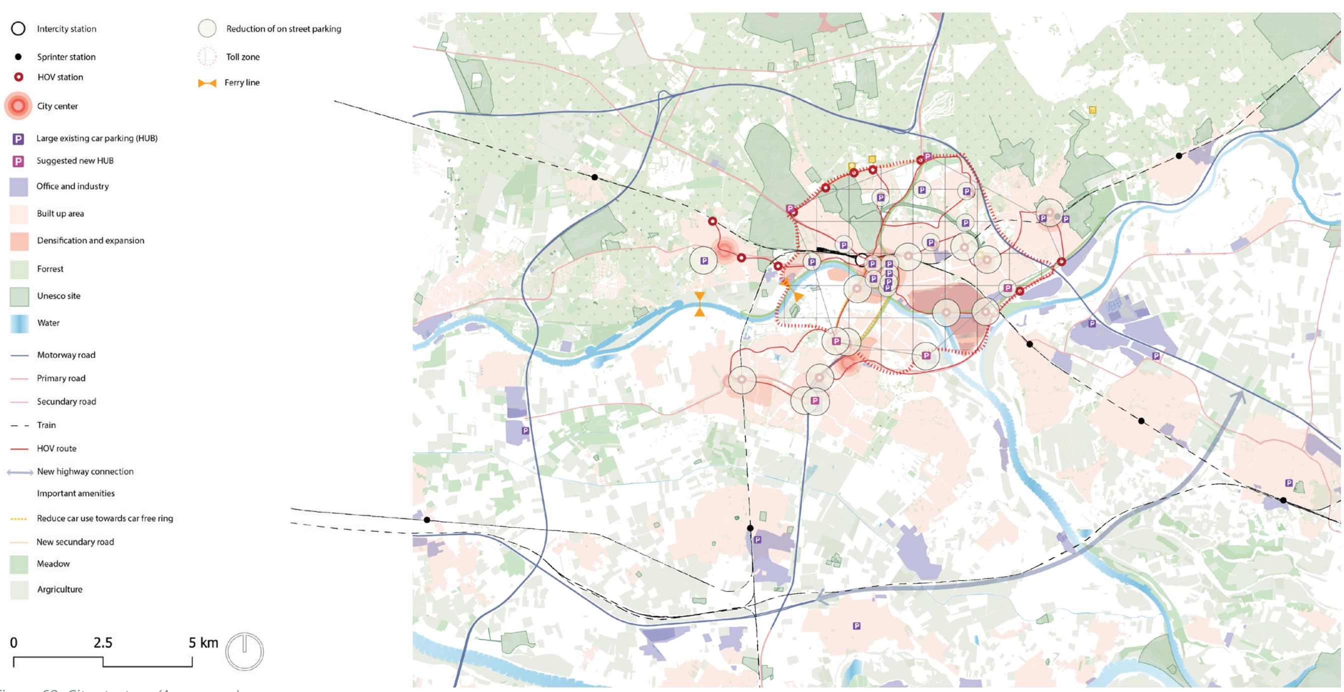


Figure 63: City strategy (Awareness)

Facilities

On national scale, car sharing can be an important facility to reduce car dominance. Although this measure requires street- and neighbourhood level implementation, national government needs to set the ground rules for the implementation throughout the country. On city scale level, the main measure in the facilities category is the introduction of large car parking around the city centre and mobility hubs in and around neighbourhoods (see figure 64). This has been discussed in the section 'parking management' in this Chapter. The way the mobility hub can be realised will be discussed in the neighbourhood scale design. The map (See figure 65) shows the location of these car parking and hubs. Combing existing private parking garages and implementing new hubs and garages.

Figure 64: Decision tree facilities

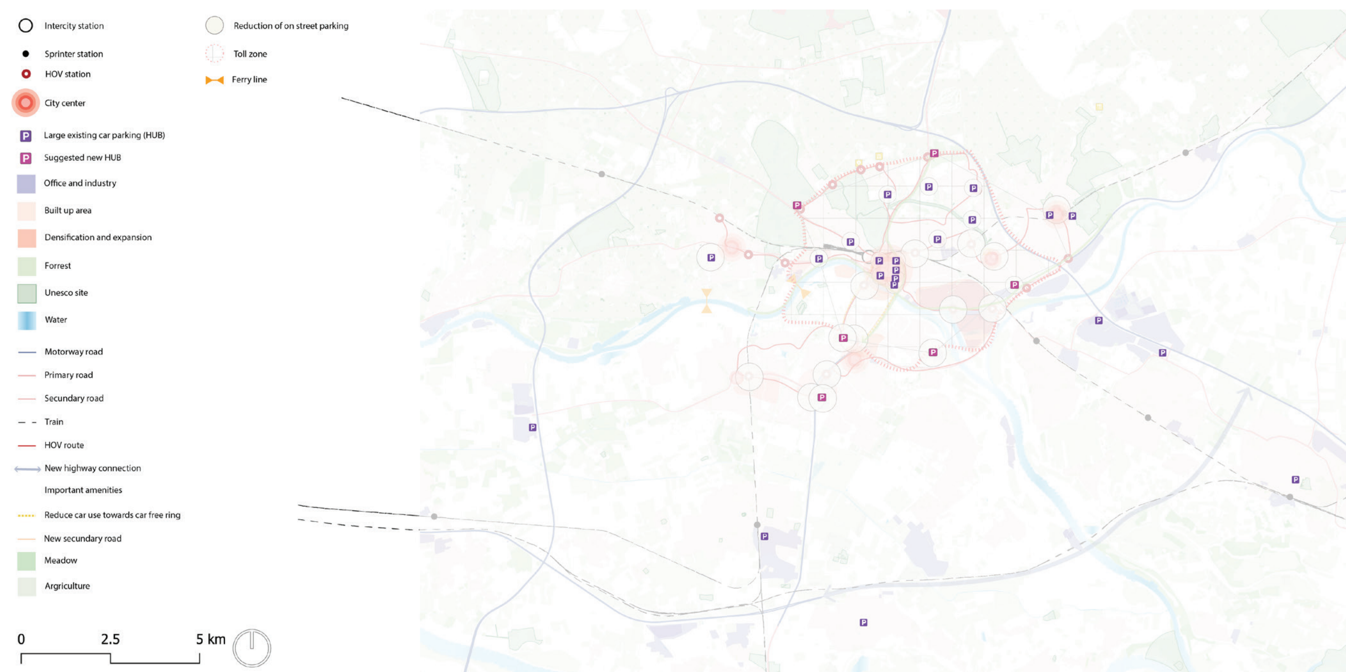


Figure 65: City strategy (Facilities)

Densification

In terms of densification, the most suitable places to densify are near public transport (See figure 66). Secondly, the main bike routes can be another important direction to define suitable densification areas.
This city strategy takes into account the densification areas that are defined in the omgevingsvisie Arnhem (Ontwerp omgevingsvisie Arnhem 2040., 2022) and adds a couple of other areas that have a good combination of public transport facilities and bike paths. Figure 67 shows the suggested densification areas. Crucial for these areas is the implementation of the HOV line, as suggested earlier in this chapter.
The areas are (See figure 67): in and around train station 'Arnhem Zuid', in and around industrial area the Overmaat and Kronenburg, around the Gelredome, Stadsblokken, Arnhems buiten. Meinerswijk Noord, industrial area North and the IPKW terrain.

Figure 66: Decision tree densification

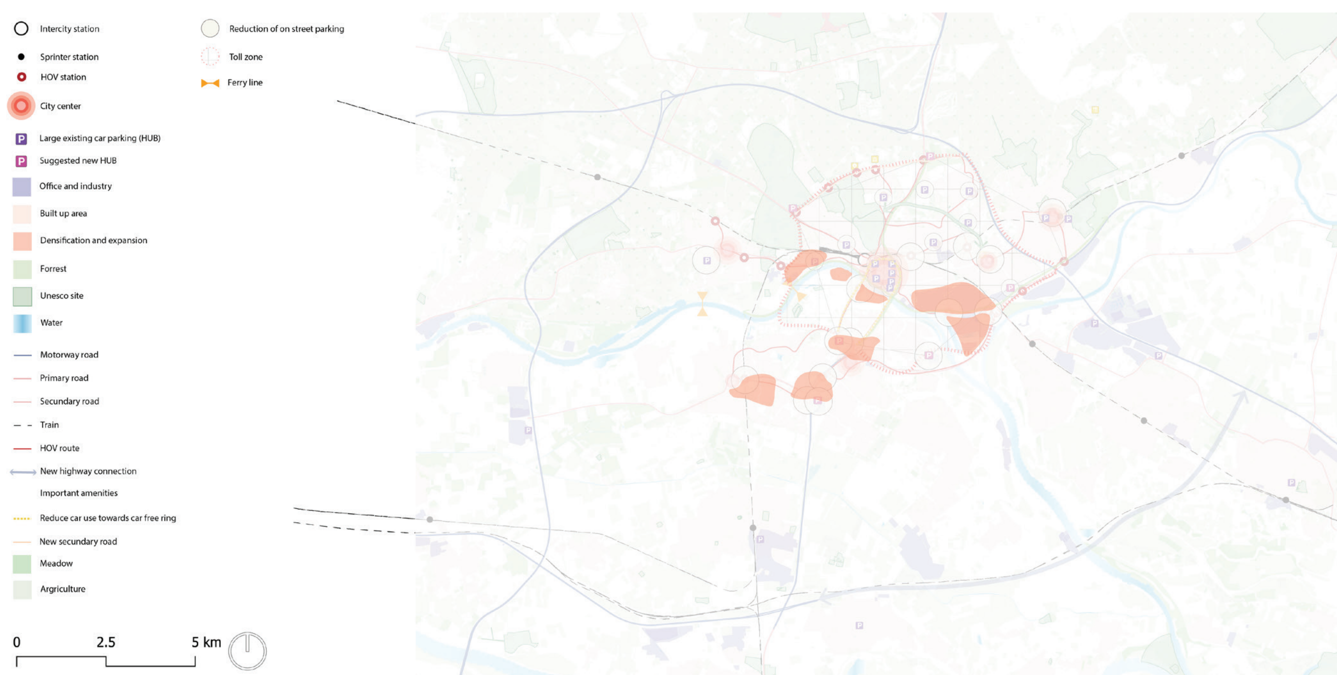


Figure 67: City strategy (densification)

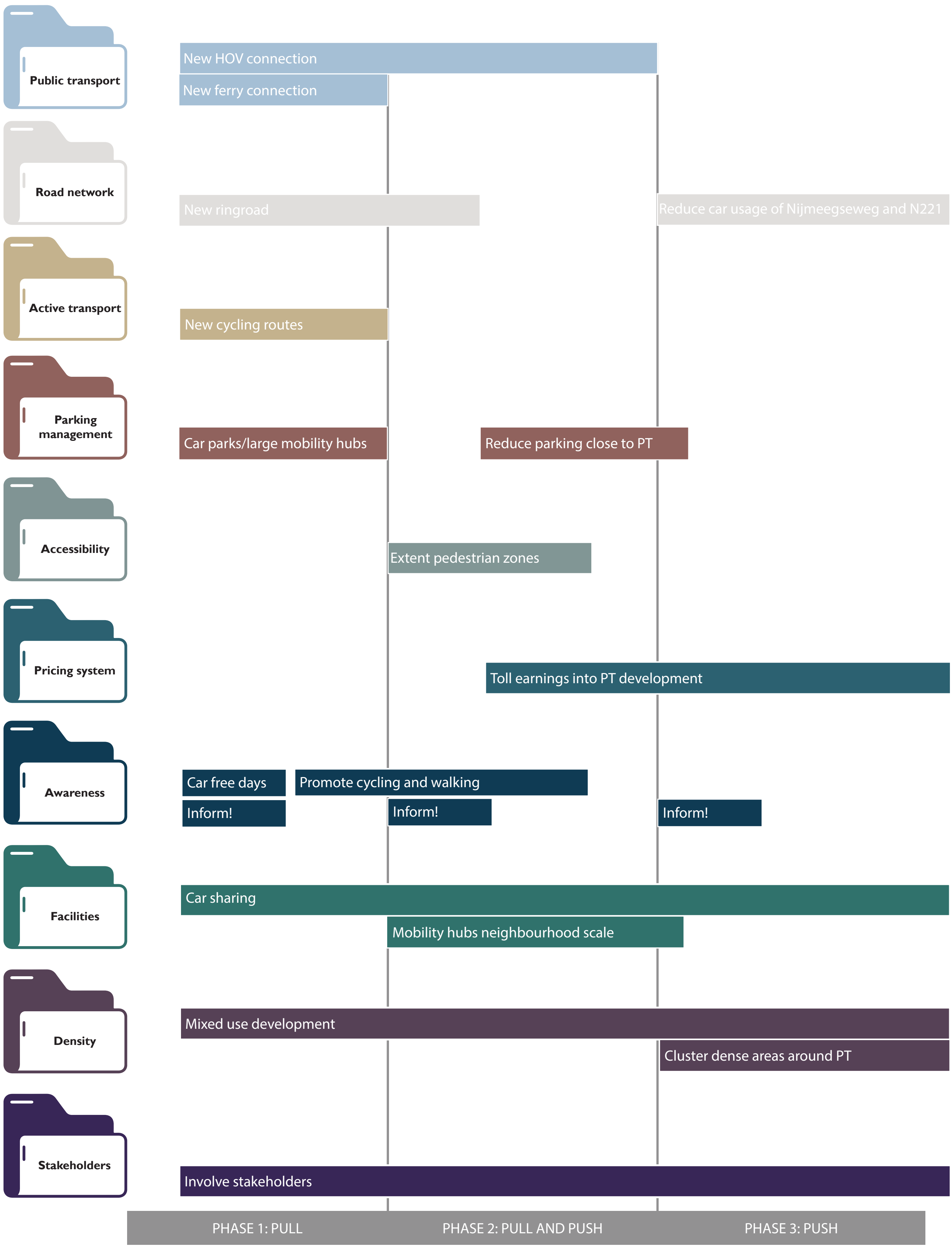


Figure 68: Transition approach

Transition approach

To show the effect of push and pull measures, and the way they can complement each other, a transition approach has been developed (see figure 68). This figure shows which interventions are pull interventions and therefore should be implemented first. And it shows which push interventions can work aside the pull interventions. The final push interventions can only work when the pull interventions are implemented and have proven to work.

Reflection on city scale strategy

To review the suggested city strategy, a presentation and discussion with the neighbourhood collective of the centre of Arnhem (Bewonersvereniging Arnhem6811, 2022) has been organized. After presenting the literature review and city strategy, a couple of suggestions and comments have been made. This paragraph describes the comments and suggestions and the way it changed the city strategy and story.

Firstly, a suggestion to add a map to the historical development of the city of Arnhem, showing the effect of the destruction of large parts of the city after the second world war was made. This map can show the effect of the century of the car on the development of the inner city. Both Arnhem and Rotterdam had space and opportunity to introduce carparking and large roads in their city centre due to the destruction of large parts of the city. This suggestion has been implemented in the historical development chapter.

Secondly, the South of Arnhem has never been an attractive place to live. The first developments of neighbourhoods in the South resulted in failure. The municipality offered free wall covering and lighting to move from the North of the city to the South. This shows the disconnection between the North and South even more. This suggestion has been implemented in the historical development chapter.

Figure 69: Neighbourhood collective 6811

Thirdly, the introduced ring around Arnhem has been suggested by the municipality quite a long time ago, but has never been construction. Another suggestion of the municipality, around 2005, was to introduce the Westtangent to connect Schuytgraaf to Oosterbeek. This project required to demolish the green area of Mariëndaal or built a gigantic tunnel. Both ideas have never been realized (Vries, De, n.d.). The suggestion has been used as example during the presentation.

Fourthly, a suggestion of the group was to introduce a ferry to transfer cyclists over the river Rijn as a solution for the, relatively, high bridges that cyclists have to climb to move from the North to the South of the city. It can be interesting to locate a small ferry to connect Oosterbeek and the Schuytgraaf. This suggestion has been implemented in the city scale strategy.

Fifthly, the group recommended to read the ontwikkelperspectief Spoorzone by Bura. This vision shows how bureau Bura suggests to introduce a new neighbourhood South of het Broek. They also mentioned OV2040, the national vision for public transport in the Netherlands. During the design part of this work, the vision of Bura will be taken into consideration.

Sixthly the group expressed their concerns about the introduction of a toll system in the city. They mentioned the protests of the city of London when this idea got introduced in their city. The article mentioned proved to be from 2003. The toll system now works in London and has reduced car usage within the city centre successfully. Nevertheless, the social component of this measure should be taken into account.

CAR FREE ARNHEM
DESIGN

06

This chapter describes the implementation of car reducing interventions on city scale. The basis for this city strategy consists of interventions that function on city level as explained in the toolbox decision tree and the lessons learned from the policy analysis and case studies.

Photo VI: Cobercokwartier (DPG Media Privacy Gate, n.d.)

LOCATION DECISION

In order to refine the city strategy, three specific neighbourhoods will be chosen for customized design. Several factors were taken into account to make this decision, such as high car density per square kilometre, high resident density per square kilometre, proximity to a train station, high levels of traffic nuisance, and low levels of liveability (see figure 70). These five factors and the decision process will be elaborated on in the following paragraph.

Indicators

To identify a suitable neighbourhood for implementing car reduction measures, five indicators were used. Firstly, the number of cars per square kilometre was calculated to indicate the amount of space required for parking and the limited use of public transportation (see figure 71). Secondly, the number of residents per square kilometre was considered because of the importance of density when implementing car reduction measures (see figure 75). Thirdly, the average distance to a train station was calculated because public transport is crucial in reducing car usage, and expansion of the train network in Arnhem is limited (see figure 72). Fourthly and fifthly, indicators for traffic nuisance (see figure 74) and liveability (see figure 73) were used to determine the current state of the neighbourhood. The municipality of Arnhem calculated the liveability score by surveying local residents on nine different aspects, such as proximity to amenities and satisfaction with the quality of life. These five indicators relate to the four main aspects of the conceptual model: densification, car reduction, built environment, and liveability.

Weight

To compare the five indicators, a weight was assigned to each of them. Liveability was given the highest weight as the focus of this research is to increase liveability by reducing car dominance. On the other hand, the number of cars was assigned the lowest weight as it generally corresponds to the wealthiest neighbourhoods, which are the most difficult to change. The results for each neighbourhood and indicator, as well as their standardization and final conclusion score, can be found in the appendix (see appendix IV).

Final decision

The aim is to find a neighbourhood (out of the highest scoring neighbourhoods), that is close to a train station (suggesting mobility hub implementations), has a high potential for densification (suggesting new built-up areas within the city of Arnhem) and is close to a train station (providing the opportunity to reduce car usage on a large scale). The total score can be viewed in figure 76.

Type of design

To show the effect of car reducing measures in different neighbourhoods, two neighbourhoods will be roughly design with a sketch design and matrix that show the ten categories. One neighbourhood will be fully designed to show the effect of the measures more detailed.

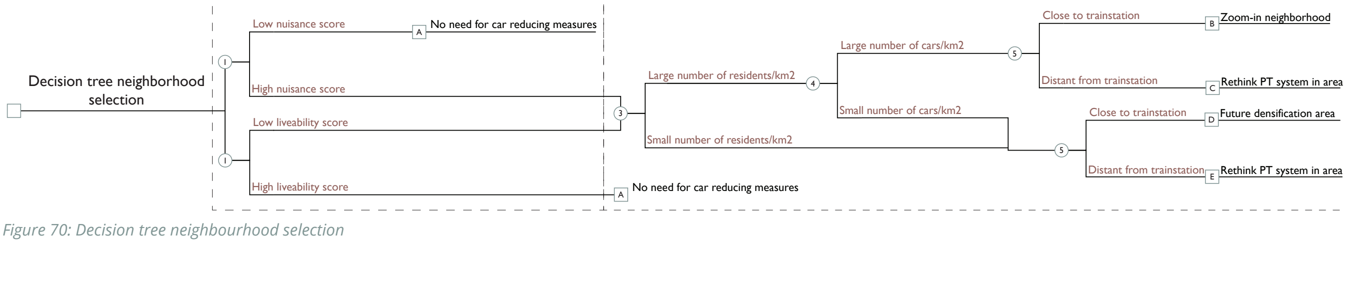


Figure 70: Decision tree neighbourhood selection

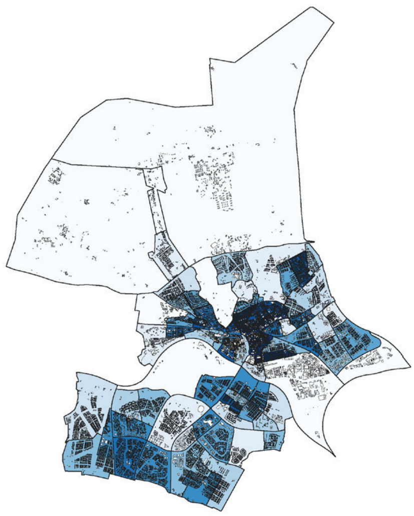


Figure 71: Number of cars per km2

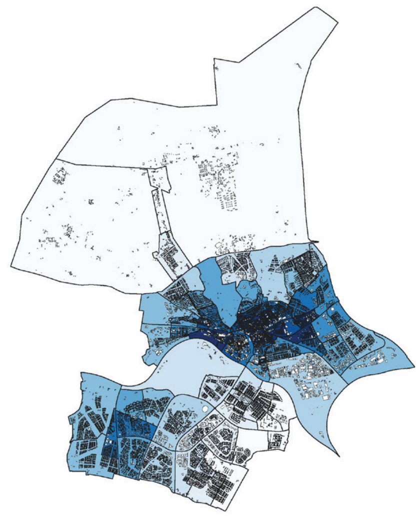


Figure 72: Distance to trainstation

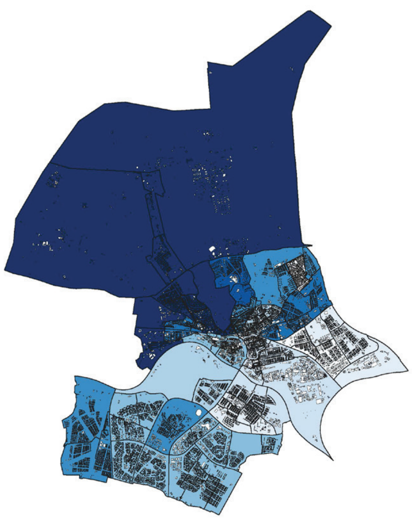


Figure 73: Liveability score

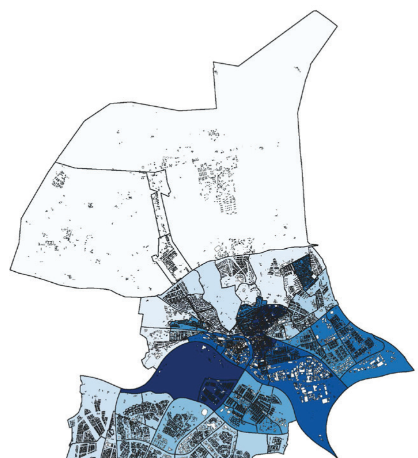


Figure 74: Traffic nuisance

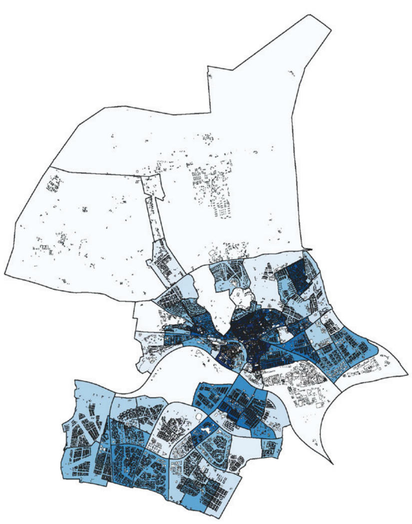


Figure 75: Number of residents per km2

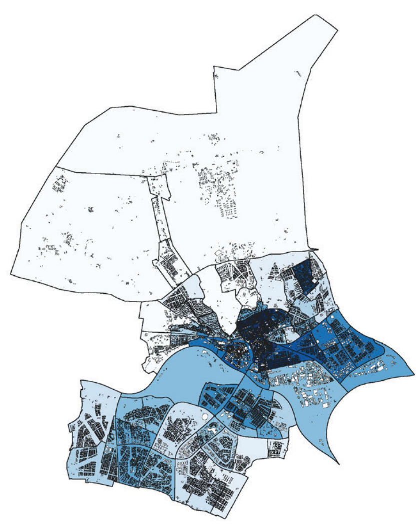


Figure 76: Total score

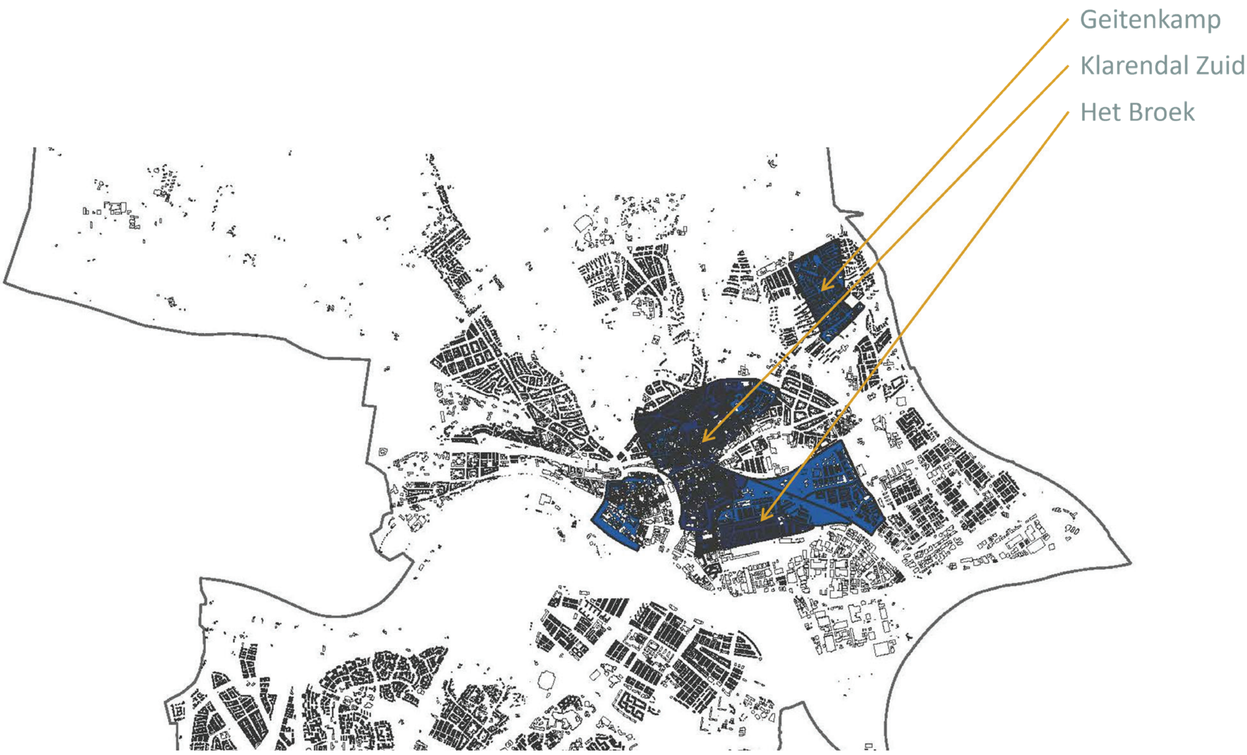


Figure 77: Highest scoring neighbourhoods

Geitenkamp
The first neighbourhood that will be further elaborated is the neighbourhood 'Geitenkamp'. This neighbourhood is located in the North-East of Arnhem (see figure 77) and relatively far away from a train station. Nevertheless, the neighbourhood scored high on the other indicators and is therefore interesting to further dive into. This neighbourhood will be further elaborated in a sketch design.

Klarendal- Zuid
The second neighbourhood that will be further elaborated is the neighbourhood 'Klarendal-Zuid', part of the district 'Klarendal'. This neighbourhood is located North-East of the city centre (see figure 77) and is close to public transport and other important amenities. This neighbourhood will be further elaborated in a sketch design.

Het Broek
The third neighbourhood that will be further elaborated is the neighbourhood 'Het Broek'. This neighbourhood is located South-East of the city centre (see figure 77) and scores low on liveability and number of cars and residents. An interesting part of this area is the adjacent industrial area located South of het Broek, which is pointed out as a densification area in the city strategy. This neighbourhood will be further elaborated in a more detailed design.

NEIGBOURHOOD DESIGN
GEITENKAMP

Photo VII: Geitenkamp (Talen, 2022)

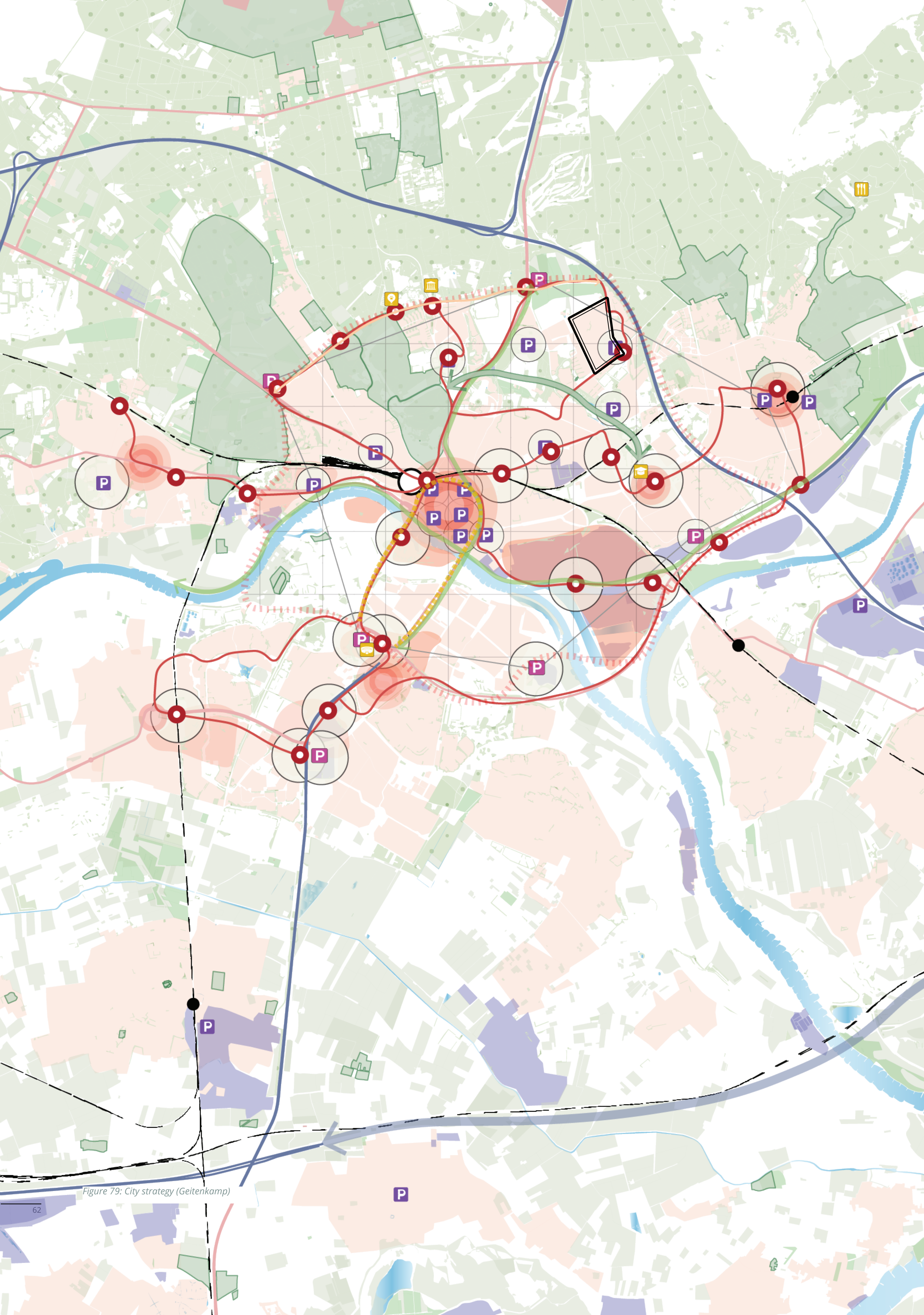


Figure 79: City strategy (Geitenkamp)

SITE CONTEXT


Figure 80: Location Geitenkamp


Figure 81: Landuse Geitenkamp


Figure 82: Green Geitenkamp

The Geitenkamp is a neighbourhood located relatively far from the city centre and public transport. It is close to the village of Velp and close to the access roads onto the motorways (see figure 83), which makes it a suitable neighbourhood to own a car. The neighbourhood is located in between three on other neighbourhoods and agricultural land to the North (see figure 80). The neighbourhood and its surroundings all have a residential function, apart from the few stores in the centre of the neighbourhood (see figure 81 and 84). There is a lot of green within walking distance of the neighbourhood, although within the neighbourhood there is no recreational green to be found (see figure 82). Two bus lines connect the neighbourhood to the city centre but have a lot of stops in between (see figure 85).
The city strategy provides a HOV line stop next to the mobility hub in the neighbourhood. This HOV line will provide a fast connection to the city centre and train station. Figure 86 shows the design matrix for the Geitenkamp neighbourhood. This matrix uses the 10 categories to describe the sketch design of the neighbourhood. To the south of the neighbourhood, a mobility hub will be located. This hub will be partly underground, providing space for recreational green on top of the hub. The hub is connected to the city centre with the HOV-line and therefore provides parking for residents and visitors of the city centre. The neighbourhood will be car-free for approximately 50%. Providing cycle streets and pedestrianized areas. The other 50% of the streets provide on street parking and roads for cars. The accessibility diagram shows the different areas. Two buildings will be demolished to connect the North of the neighbourhood to the South with a green vein as shown in the concept.
Appendix V shows the sketch design for the neighbourhood.


Figure 83: Main infrastructure Geitenkamp


Figure 84: Amenities Geitenkamp


Figure 85: Public transport Geitenkamp

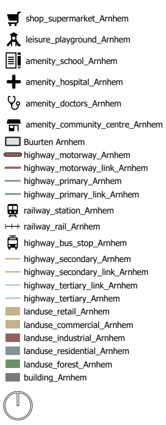


Figure 86: Matrix Geitenkamp

NEIGBOURHOOD DESIGN
KLARENDAL

Photo VIII: Klarendal (Klarendal, 2023)

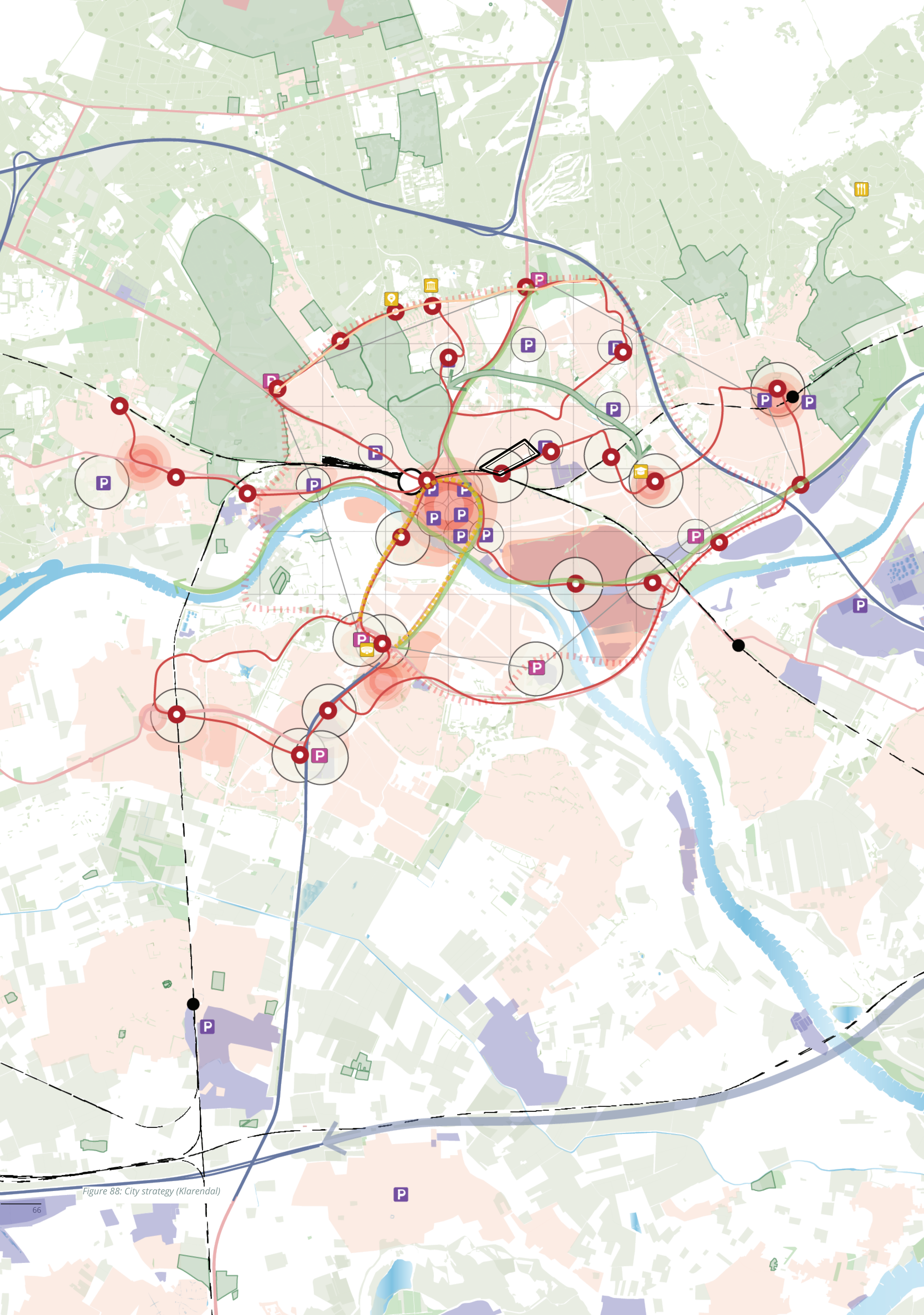


Figure 88: City strategy (Klarendal)

SITE CONTEXT

Figure 89: Location Klarendal

Figure 90: Landuse Klarendal

Figure 91: Green Klarendal

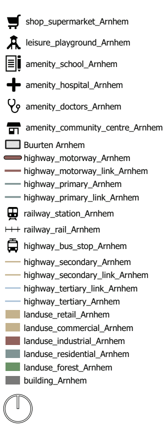
Klarendal is a neighbourhood located close to the city centre and directly linked to Velperpoort station. It is relatively far away from access to the motorway (see figure 92), which makes it suitable for car reduction. The neighbourhood is located in between four neighbourhoods (see figure 89) and therefore relatively far away from recreational green (see figure 91). The neighbourhood and surrounding neighbourhoods have a residential function, but all buildings around the Velperweg have a commercial and/or office function (see figure 90). Most amenities are located outside of the neighbourhood, but are still within walking distance due to the relatively close city centre (see figure 93). The public transport system consists of a train station and multiple bus stops, connecting the area sufficiently to other parts of the city.

The city strategy (see figure 88) provides a HOV line stop South of the neighbourhood. This HOV line will provide a fast connection to the city centre and train station, but also towards important amenities and functions within the rest of the city. Figure 95 shows the design matrix for the Klarendal neighbourhood. This matrix uses the 10 categories to describe the sketch design of the neighbourhood. To the South of the neighbourhood, office parking will be used to provide parking for residents. This office parking will be in use by people who work there during daytime and in use by residents of the neighbourhood during nighttime. The neighbourhood will be car-free, only the Southern office part will be accessible by car. A small part of the neighbourhood will be redesigned (a new large-scale building will be placed). Furthermore, a playground will be established in the hidden green vein, that follows the centre of the neighbouhood and provide a quite walking path straight through the area. The existing shared street will also be car free and become a large bike path, connection the city centre with the three high schools North-East of the area. Appendix VI shows the sketch design of the neighbourhood.

Figure 92: Main infrastructure Klarendal

Figure 93: Amenities Klarendal

Figure 94: Public transport Klarendal



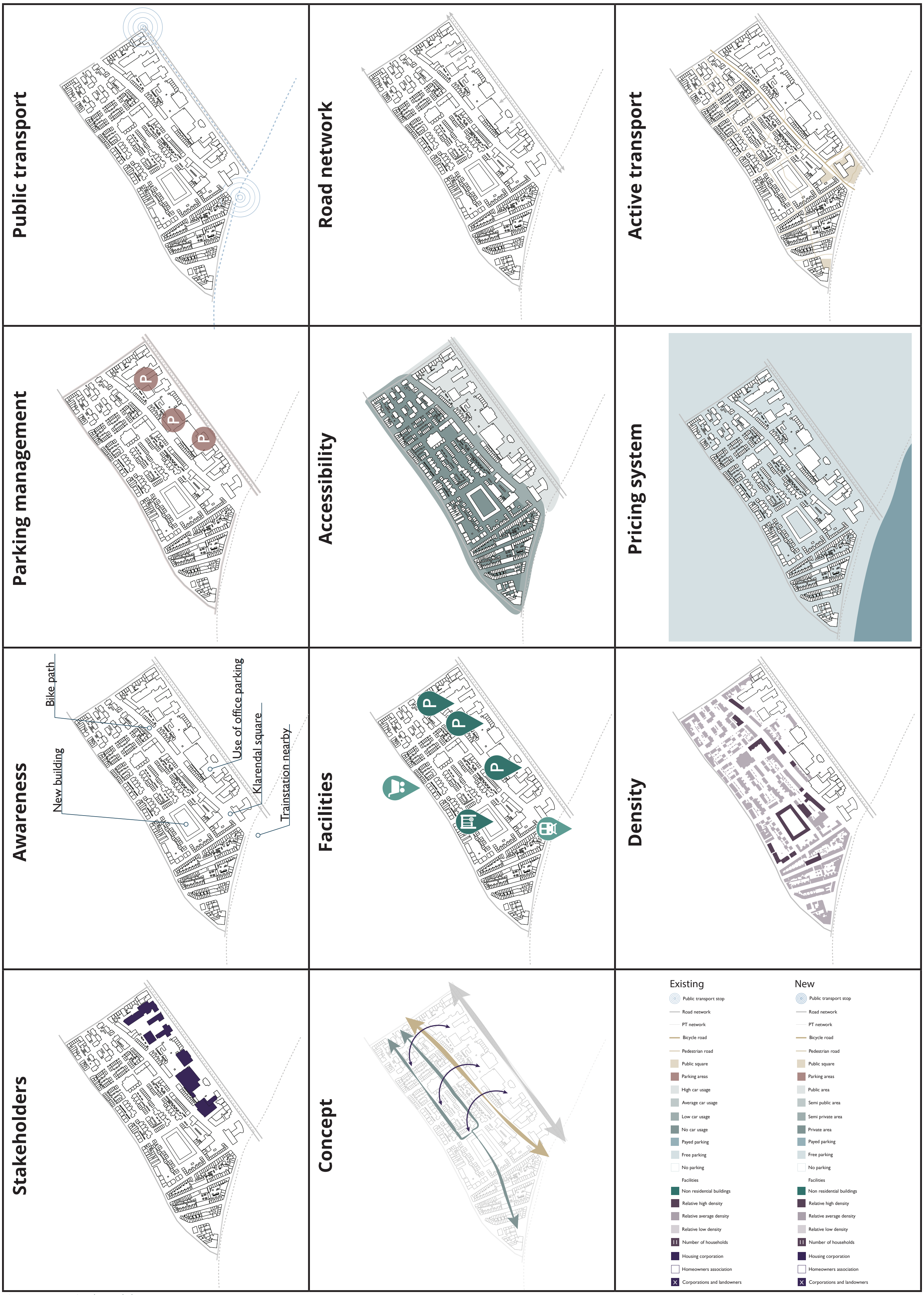


Figure 95: Matrix Klarendal

NEIGBOURHOOD DESIGN
HET BROEK & HET ATLASKWARTIER

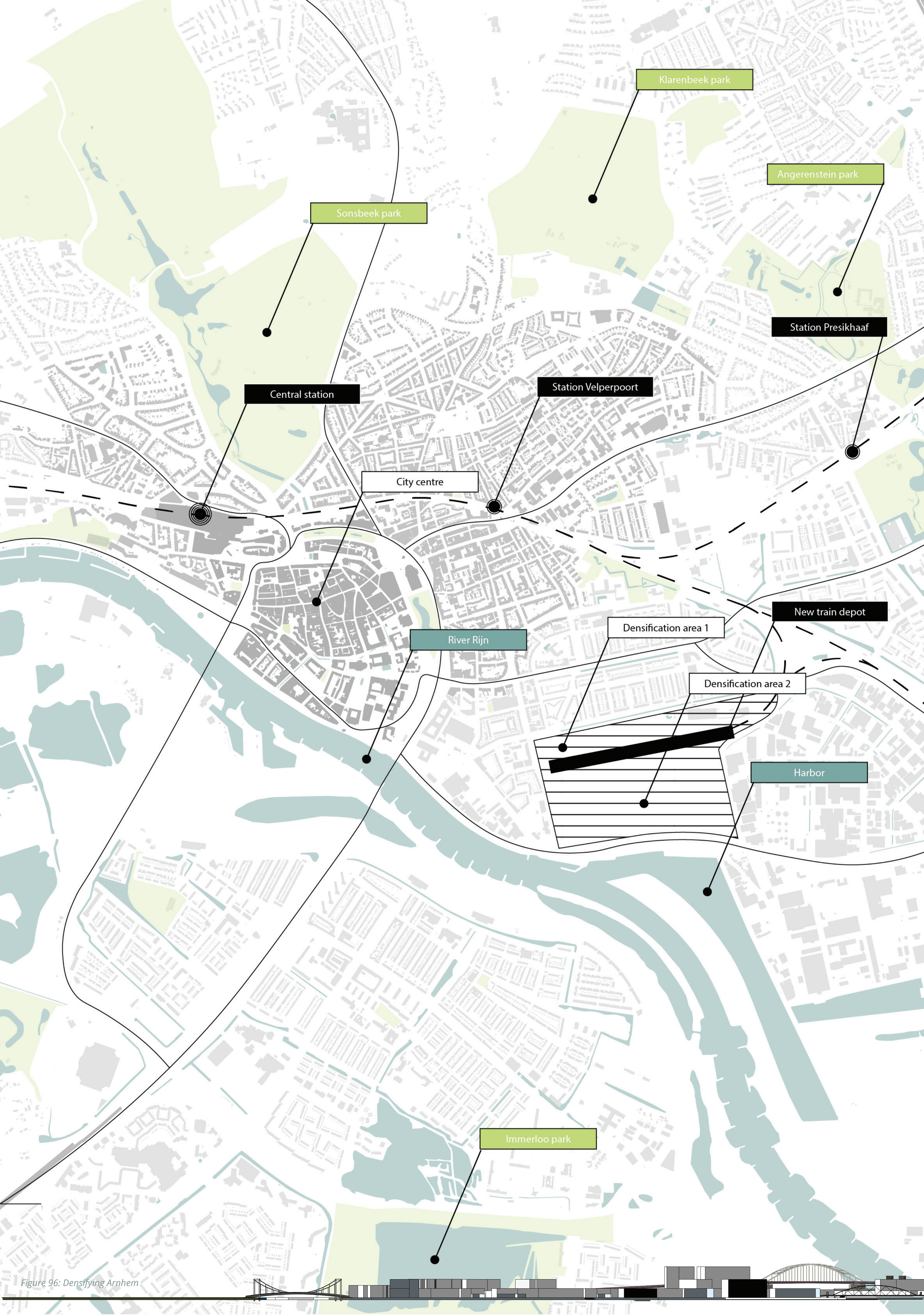


Figure 96: Densifying Arnhem

DENSIFYING ARNHEM

The area of Arnhem and Nijmegen is growing rapidly in terms of inhabitants and housing as well as the increase in companies that settle their businesses in the area. The city of Arnhem was expected to grow from 154.000 inhabitants in 2016 towards 168.000 in 2030 (Gemeente Arnhem, 2016), but currently (2023) Arnhem already has 166.000 inhabitants and keeps developing. In combination with the tight labour market, there is need for a further expansion of the number of houses in the city of Arnhem. As mentioned in the contextual characteristics chapter, the city has reached its city limits and needs to refocus towards densification.

The omgevingsvisie (Ontwerp omgevingsvisie Arnhem 2040., 2022) pointed out various areas that are suitable for (further) densification within the city limits. One of the areas that was suggested by the municipality and has also been pointed out in the previously described city strategy, is the industrial site, located South-East of the city centre (North of the river Rijn)(see figure 96). This area is currently in use as industrial zone and work location (offices). There are limited houses and therefore the area is not in use during nighttime. The location of the industrial zone blocks the connection between the city centre and the South-East of the city. Therefore, this area has to be improved with mixed functions and has to function as a connector between the city centre and the industrial area (see figure 97).

This area will become the first car-free neighbourhood of Arnhem. The city strategy (See chapter 5) serves as basis for this urban design project as well as the approach (see Chapter 4) which features a toolbox with design and policy interventions and a decision tree. These three elements lead to a new neighbourhood typology were humans are the first priority (instead of the car).

'Once the need of automobiles (and their forebears, carriages) can be neglected, a remarkable degree of design freedom arises, allowing us to return to quirky, fine-grained, human-scaled urban areas that reflect the demands of the site and the needs of its users. (Crawford, 2008)'

Context to the city

This new area 'the Atlaskwartier' is surrounding the newly built train depot. North of the area is the neighbourhood 'het Broek' located, South the river Rijn and the old industrial harbor, East the second part of the industrial area and West the city centre and adjacent newly constructed neighbourhood 'Nieuwe Kadekwartier'. In terms of recreation and green, the area is missing a park nearby. Therefore, it will not only become a mixed functions neighbourhood, but also provide green areas for residents of the neighbourhood and surrounding neighbourhoods.

This Chapter will describe the urban design of this new neighbourhood in detail.

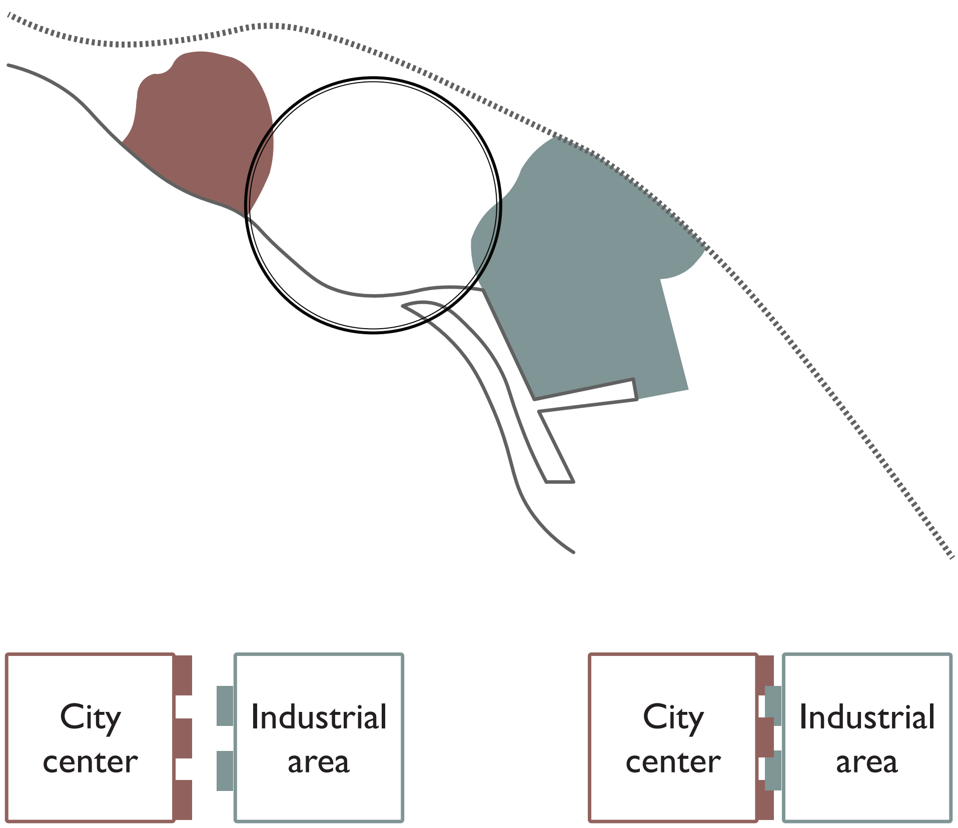


Figure 97: 'Atlaskwartier' as a connector

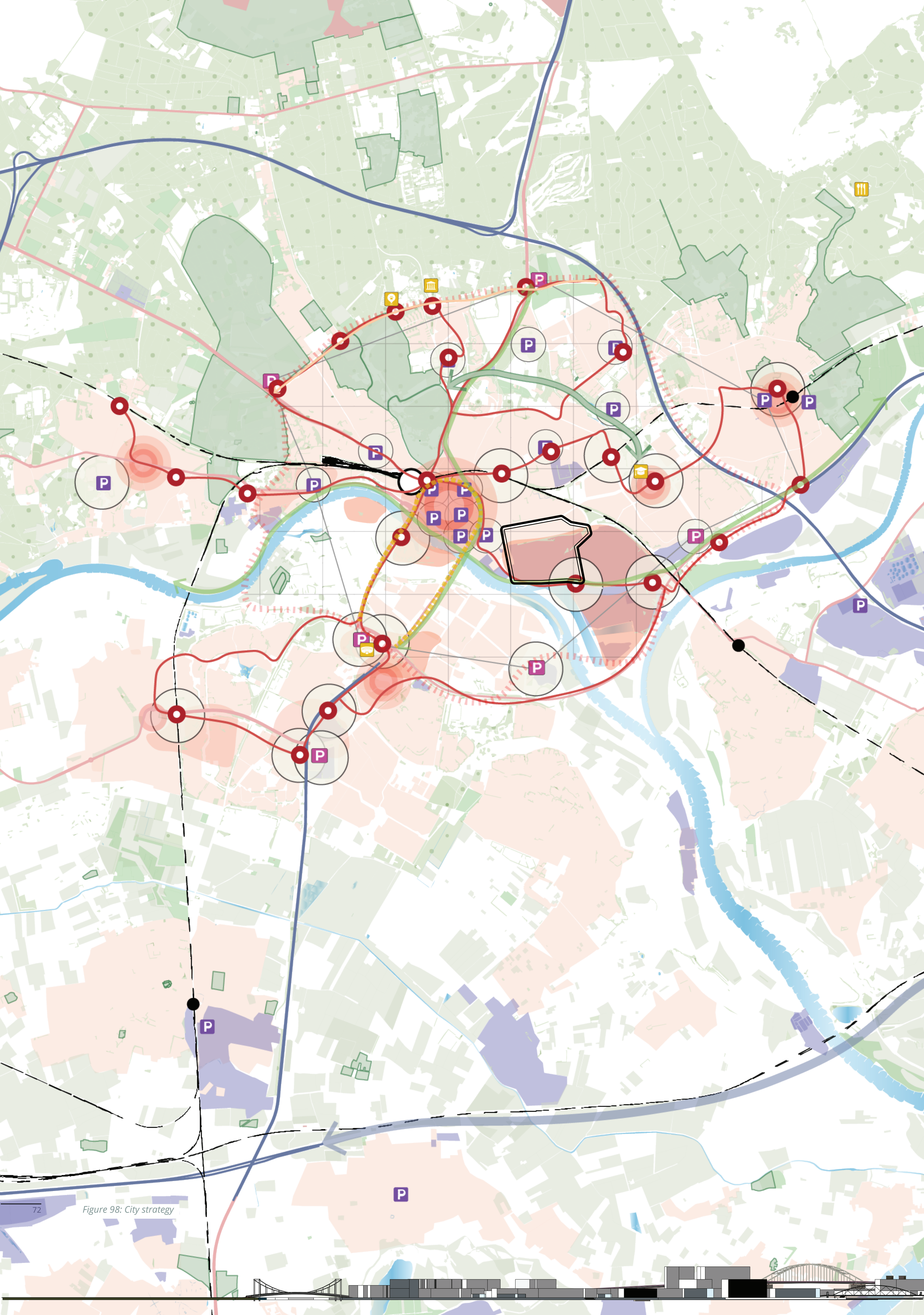


Figure 98: City strategy

CITY STRATEGY

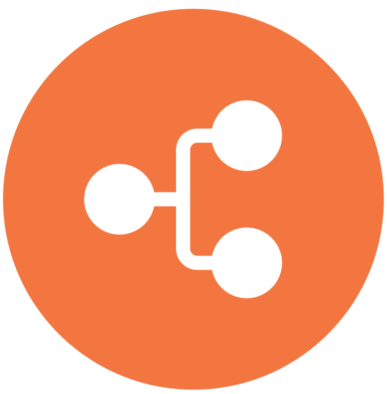
The city strategy serves as a basis for the urban design of 'the Atlaskwartier' neighbourhood. Figure 98 shows the city strategy and the frame that represents the boundaries of the new 'Atlaskwartier' neighbourhood. To understand choices that have been made in the detailed design, the role of the new neighbourhood in the city scale strategy needs to be explored.

The new neighbourhood does not directly connect to one of the train stations in Arnhem North. Some exploring research has proven that there is no space for another station between Arnhem Velperpoort Station and Duiven Station. Therefore, the city strategy provides the new neighbourhood with a HOV (Hoogwaardig Openbaar Vervoer) connection, located South-East of the neighbourhood. This connection not only provides a direct connection towards the city centre and central station, but also connects the neighbourhood with the South of Arnhem. Together with the existing bus stops in the neighbourhood, the area is well connected to the city centre and main train station 'Arnhem Centraal'. Because of the car-free potential for the neighbourhood, the road network is not seen as a first priority, There are road that surround the area and have the capacity to serve the new neighbourhood. But the goal for the neighbourhood is a car user percentage of 25%, making it highly reliable on public and active transport. Therefore, the city strategy provides a new East-West cycling connection. Together with the existing bike path in the 'Het Broek' neighbourhood, the neighbourhood is very well connected to the city centre.

In terms of facilities and parking management, the neighbourhood needs to develop a strategy that focuses on facilities and parking within its boundaries. The neighbourhoods surrounding the area have limited facilities and rely on on-street parking. The parking garages in the centre are reserved for visitors and residents of the area. Therefore, smart use of office parking in the adjacent industrial area is of high importance. In terms of green, the neighbourhood needs to create a new park and recreation area. This is currently lacking in the area and in surrounding neighbourhoods.

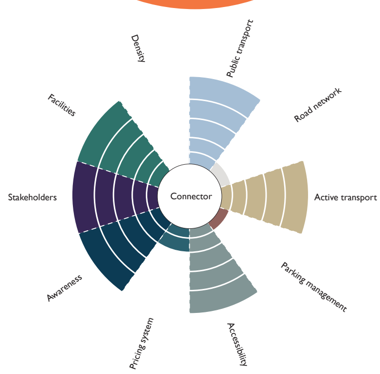
ACTIVE MOBILITY

The first goal of the neighbourhood is to stimulate the use of active transportation. Providing shared mobility, bicycle parking and shared cargo bikes, the neighbourhood wants to stimulate its residents to use active transportation when commuting within the city. The new bicycle road following the river Rijn and the existing bike path through the neighbourhood 'Het Broek' both stimulate the use of bike as main transportation mode.



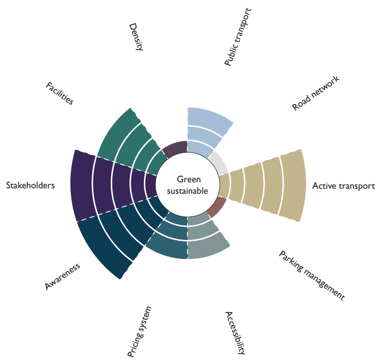
CONNECTOR

Secondly, the neighbourhood serves as a connector. A connector between the industrial area and the city centre. Providing a cycle route that cuts through the neighbourhood, connecting the inner city and the IPKW terrain. A connector in terms of amenities and green. The surrounding neighbourhoods will use the 'Atlaskwartier' as a place to recreate and do their groceries and other shopping. A connector that connects the North-East of Arnhem and the river Rijn.



GREEN AND SUSTAINABLE

The neighbourhood will also focus on sustainable and circular development. Buildings that can be reused will be transformed and the existing road structure will set the basis for the new neighbourhood. The mobility will be electric or active, reducing the carbon footprint of the neighbourhood compared to other neighbourhoods in the area. Lastly, the design will take into account the developments that might happen in the future, keeping a connection with the industrial area East of the 'Atlaskwartier'.



MIXED FUNCTIONS

Lastly, the neighbourhood will combine different functions. Primarily, the neighbourhood is focussed on residential areas. These areas provide housing, recreation, and amenities to the residents. To stimulate working close by, the neighbourhood provides both office locations and remote working spots. The combination of working, living and commerce creates a neighbourhood that can function circular in terms of mobility. Together with the industrial areas close by, it will be a suitable location for labourers.

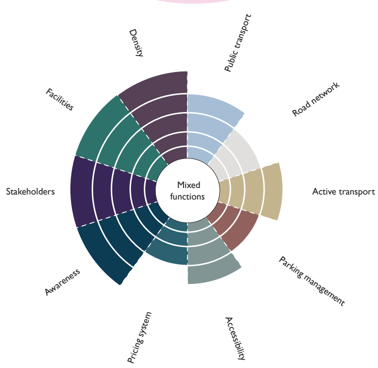


Figure 99: Existing situation


depot
Supermarkets
Industrial area
Harbour
Industrial harbour

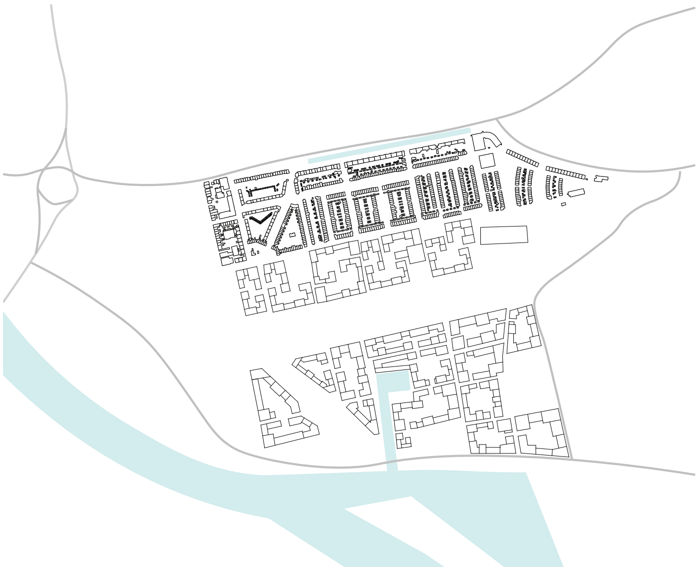


Figure 100: Road network 'Atlaskwartier'

Figure 101: Public transport 'Atlaskwartier'

Figure 102: Parking 'Atlaskwartier'

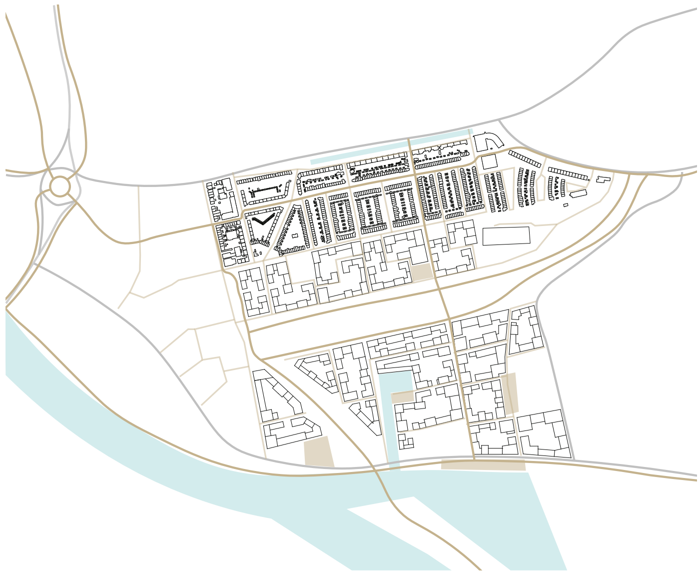


Figure 103: Active transport 'Atlaskwartier'

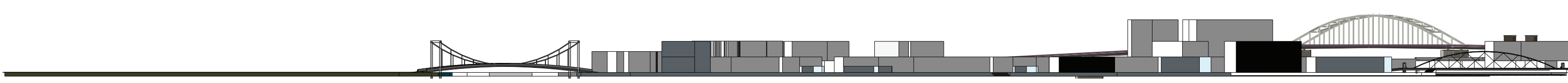
Figure 104: Pricing system 'Atlaskwartier'

Existing

- Public transport stop
- Road network
- PT network
- Bicycle road
- Pedestrian road
- Public square
- Parking areas
- High car usage
- Average car usage
- Low car usage
- No car usage
- Payed parking
- Free parking
- No parking
- Facilities
- Non residential buildings
- Relative high density
- Relative average density
- Relative low density
- Number of households
- Housing corporation
- Homeowners association
- Corporations and landowners

New

- Public transport stop
- Road network
- PT network
- Bicycle road
- Pedestrian road
- Public square
- Parking areas
- Public area
- Semi public area
- Semi private area
- Private area
- Payed parking
- Free parking
- No parking
- Facilities
- Non residential buildings
- Relative high density
- Relative average density
- Relative low density
- Number of households
- Housing corporation
- Homeowners association
- Corporations and landowners



MOBILITY

The new neighbourhood will be dependent on public- and active transport. The neighbourhood will be an example of car-free living, focussing on reclaiming the public domain by pedestrians, cyclists and recreational elements. Therefore, only the streets surrounding the neighbourhood will be accessible by car (see figure 100). With the addition of a HOV-line connection for the Southern part of the neighbourhood, the area is sufficiently connected to the cities bus network (See figure 101).

There are four underground parking garages, to provide parking for elderly and disabled. Residents who do want to own a car can park their car on various parking spaces on the industrial site, East of the area (see figure 102). This solution is temporally, with regards to the upcoming redesign of that area. Other places to park the car are pointed out in the city strategy. To prevent residents from using other neighbourhoods to park their car, all areas in Arnhem will have paid and subscription parking. The bike lines and paths for pedestrians are the main infrastructure of the area, connecting important amenities and other neighbourhoods (see figure 103).

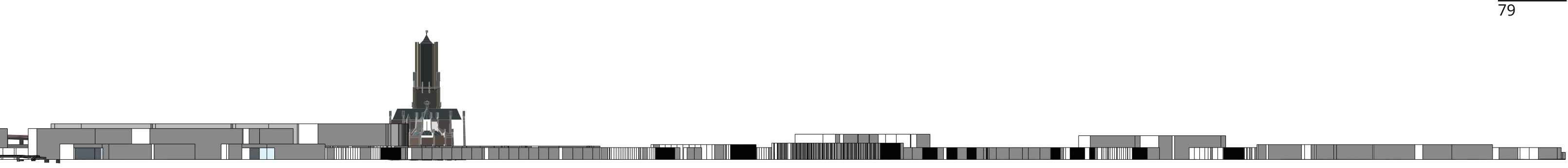
Every building block is equipped with a small mobility hub (see figure 106). This hub is not focussed on cars, but on other modes of transportation. It provides rental cargo bikes (for doing groceries, moving furniture, etc.), electric bikes and parking for bikes. Hubs that are located aside the road network also provide shared cars and parking spots for delivery vehicles. This way, the inside of the neighbourhood can function without cars. Only cars that are allowed are moving trucks, disabled and handicap vehicles and emergency vehicles.

CONNECTOR

The neighbourhood functions as a connector. Figure 105 shows the different places and functions that stimulate this connection. The bike paths in and around the neighbourhood are connecting the neighbourhood North, East and West, towards the neighbourhood ‘het Broek’, the industrial area and the city centre. These bike paths follow green strokes, making it easier to locate these paths.

The different squares all have various functions that attract residents from within the neighbourhood, but also from other neighbourhoods. Especially the Southern part of the ‘Atlaskwartier’ provides recreational elements (such as the river Rijn and harbour) with facility functions (such as restaurants and shopping areas), bounded by a square. The combination of good accessibility, customers from the industrial are and facilities will stimulate retailers to settle in this area.

The cycling bridge, connecting the neighbourhood ‘Het Broek’ and the ‘Atlaskwartier’ also has a high value in terms of connectivity. Due to the train depot, the North-South connection has been a problem for many years, which is solved with the introduction of this bridge.



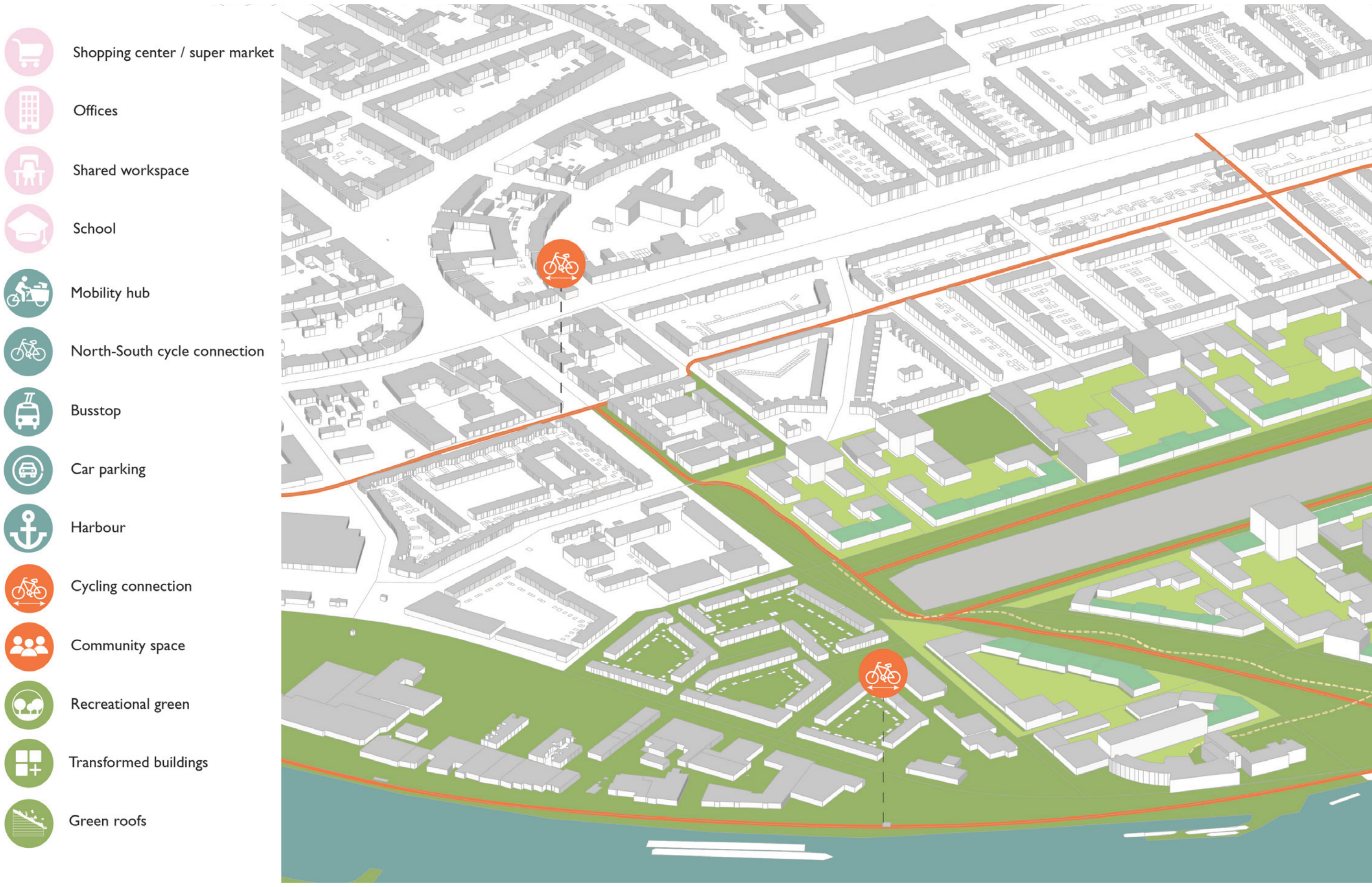


Figure 105: Connector elements 'Atlaskwartier'

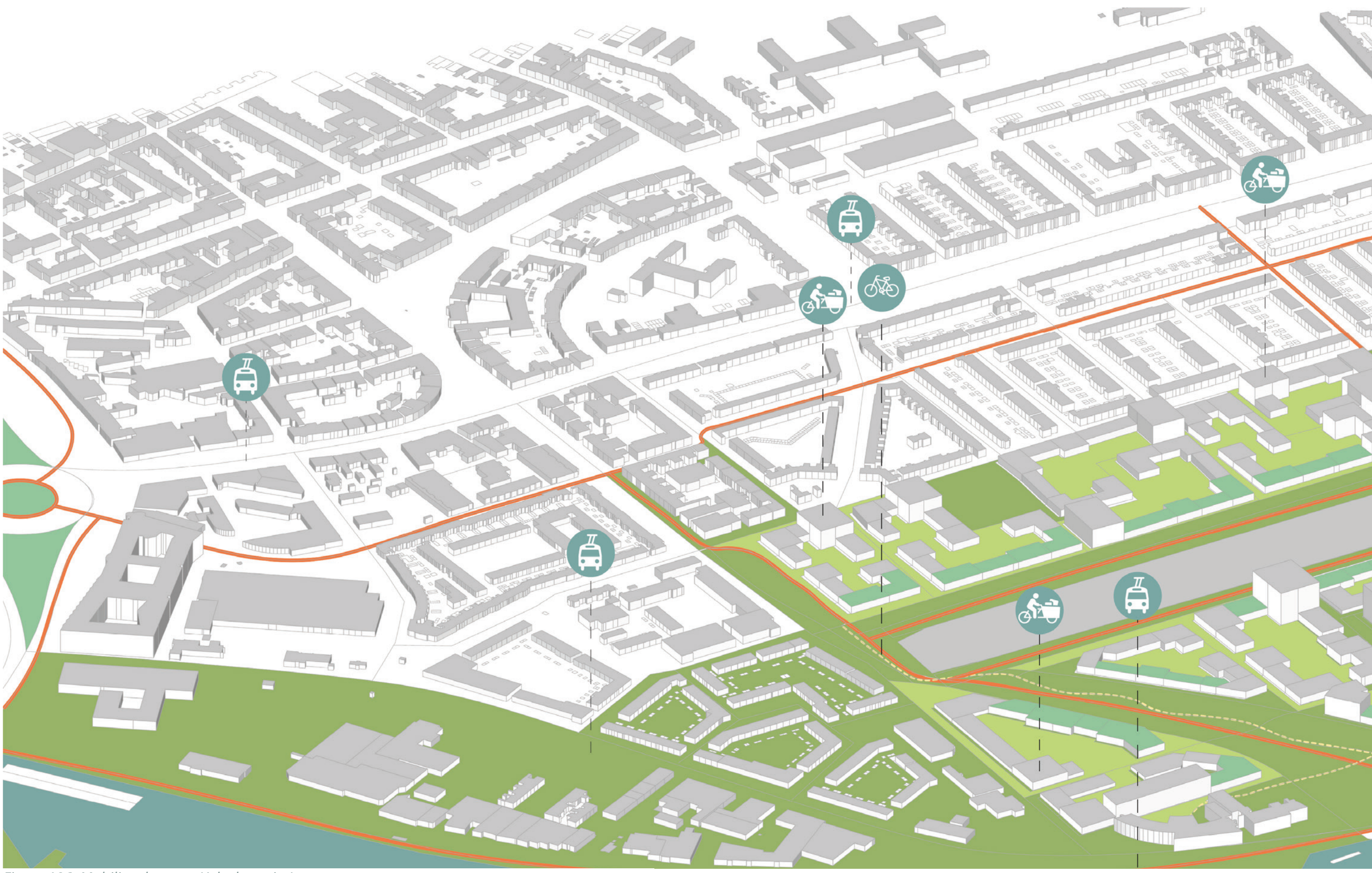


Figure 106: Mobility elements 'Atlaskwartier'

Figure 107: Facilities 'Atlaskwartier'

Figure 108: Accessibility 'Atlaskwartier'

Figure 109: Density (hight differences) 'Atlaskwartier'

Figure 110: Awareness 'Atlaskwartier'

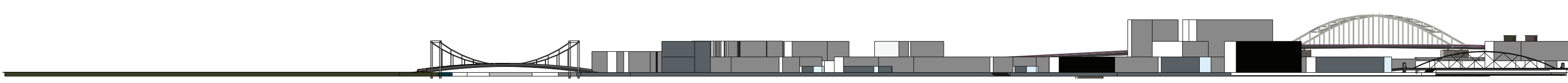
Figure 111: Stakeholders 'Atlaskwartier'

Existing

- Public transport stop
- Road network
- PT network
- Bicycle road
- Pedestrian road
- Public square
- Parking areas
- High car usage
- Average car usage
- Low car usage
- No car usage
- Payed parking
- Free parking
- No parking
- Facilities
- Non residential buildings
- Relative high density
- Relative average density
- Relative low density
- Number of households
- Housing corporation
- Homeowners association
- Corporations and landowners

New

- Public transport stop
- Road network
- PT network
- Bicycle road
- Pedestrian road
- Public square
- Parking areas
- Public area
- Semi public area
- Semi private area
- Private area
- Payed parking
- Free parking
- No parking
- Facilities
- Non residential buildings
- Relative high density
- Relative average density
- Relative low density
- Number of households
- Housing corporation
- Homeowners association
- Corporations and landowners



MIXED FUNCTIONS

Figure 112 shows the most important functions in the area, figure 107 shows the combined functions of the different categories. The neighbourhood will have two supermarkets, one in the North of the area and one in the South.

The neighbourhood will have a variety of office spaces, partly existing buildings, partly existing buildings that have been transformed and partly new buildings. The existing buildings will keep the same function and companies. Therefore, the new buildings will be designed for shared office space. Providing space for small businesses and residents who need a quiet space to work from home. An elementary school will be located next to the park, providing a playground and a quiet area to study. This school will also have space to create some allotment gardens.

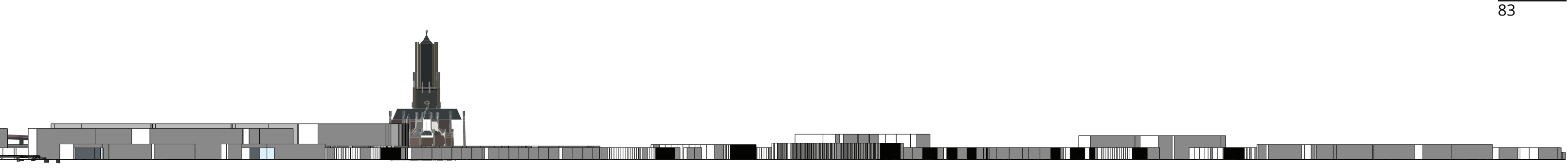
The neighbourhood will not be a high rise area, but instead gradually advance up to the industrial area. Figure 109 shows the hights of the buildings (low, medium and high), to give an indication of the balance of the area. The typologies will provide more information. To ensure a safe feeling, the area has been divided into three 'accessibility' areas (see figure 108). 1) open to everyone, 2) open to residents of the neighbourhood and 3) open to residents of the building block. This way, the area can be experienced as open and welcoming, but also safe and controlled.

GREEN AND SUSTAINABLE

Lastly, the neighbourhood will be a green and sustainable area. Companies that are of importance for the area and fit within the new design will be maintained (see figure 111). A number of offices and the large shopping mall will be part of the new neighbourhood, as well as the PostNL building, which will be transformed into an shared office building.

Figure 110 shows the elements in the neighbourhood that are part of the four goals (active mobility, connector, mixed functions and green and sustainable). Figure 113 shows the green and sustainable elements in the area. The green route, connecting the inner city to the Rijn, is the most important element. This route provides a place for recreation, cycling and walking. All lower roofs, connected to the part and other green strips, will have a green roof to ensure a climate resilient area.

Figure 114 shows all elements together.



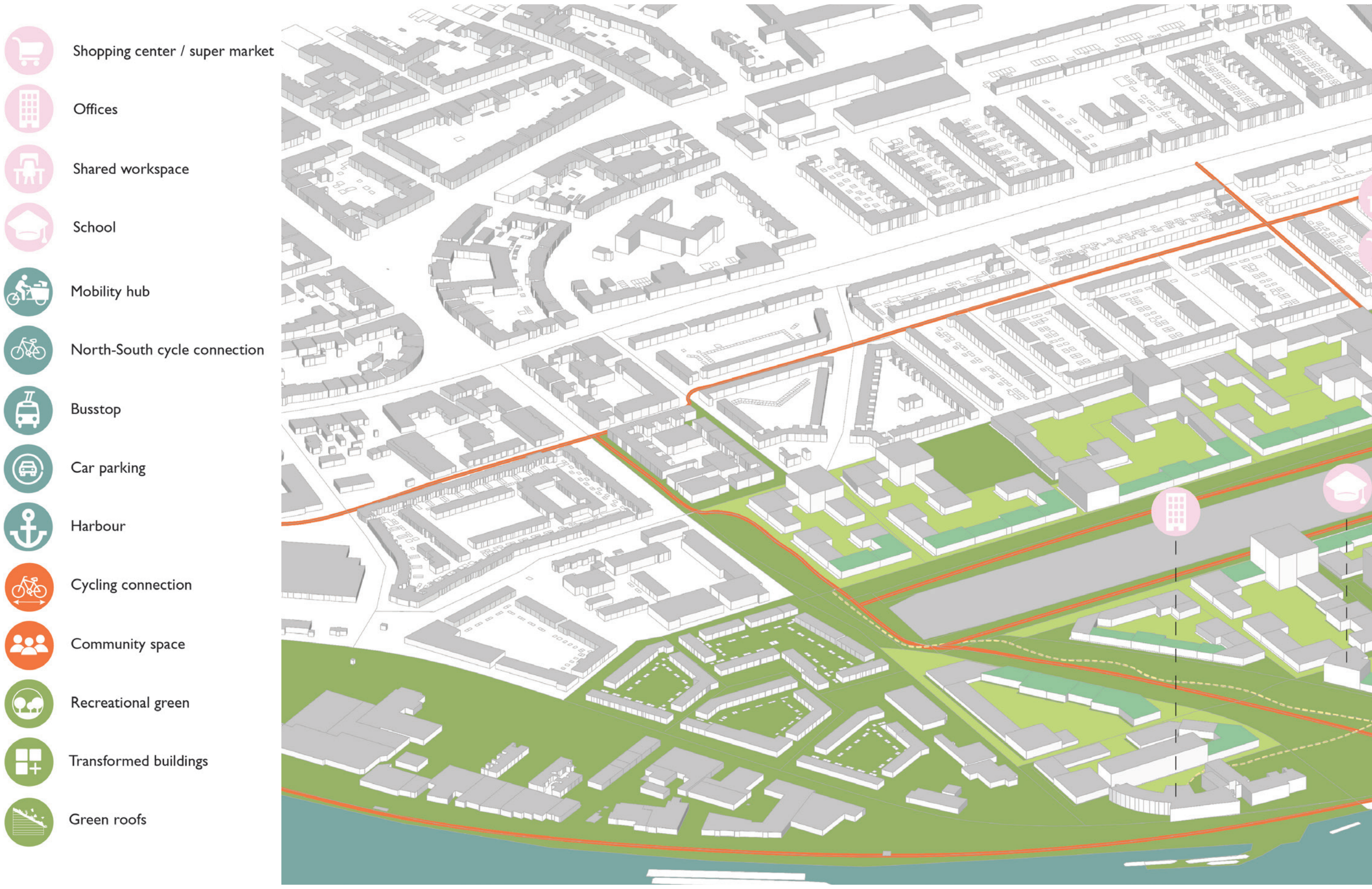


Figure 112: Mixed functions 'Atlaskwartier'

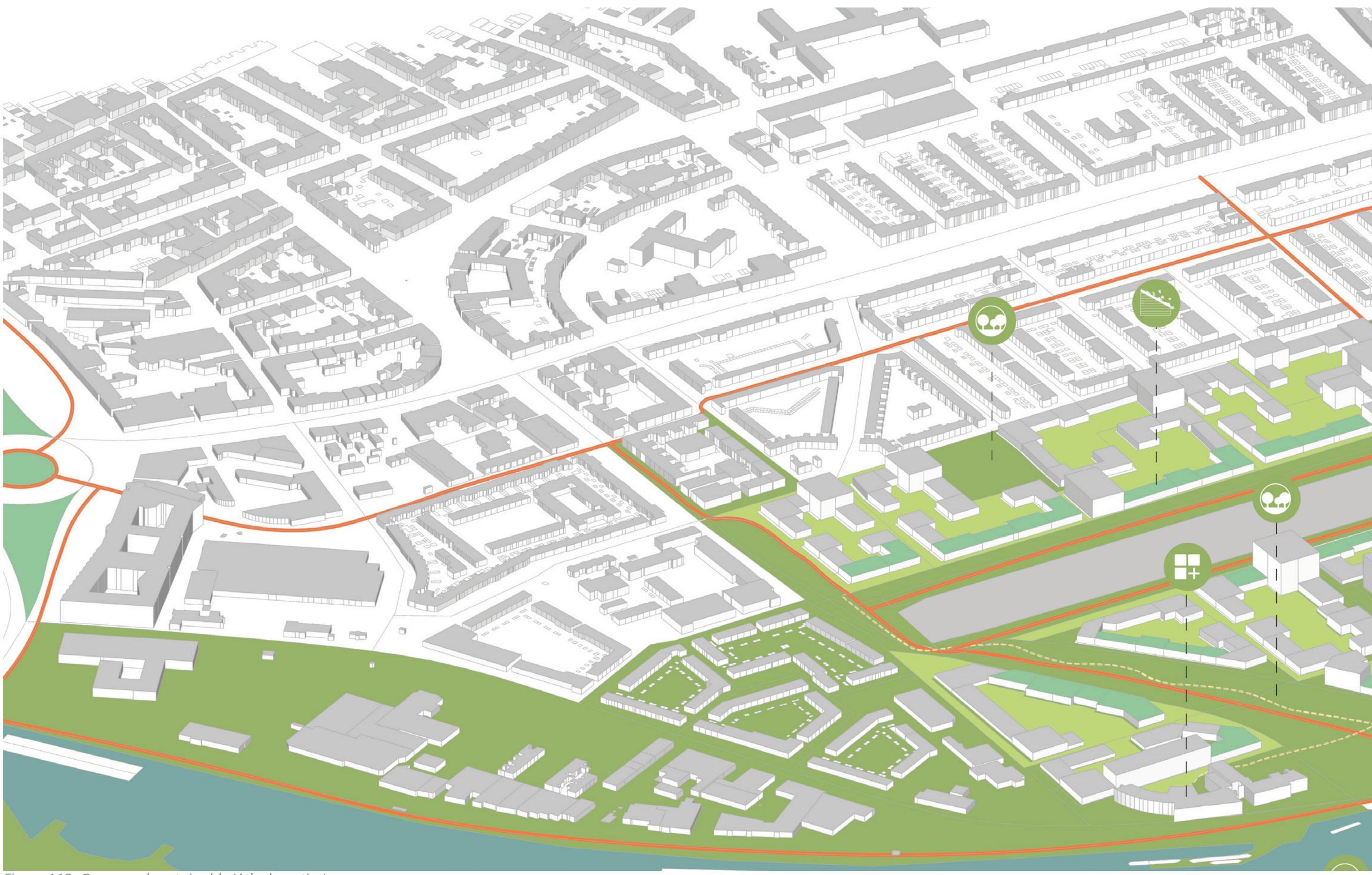
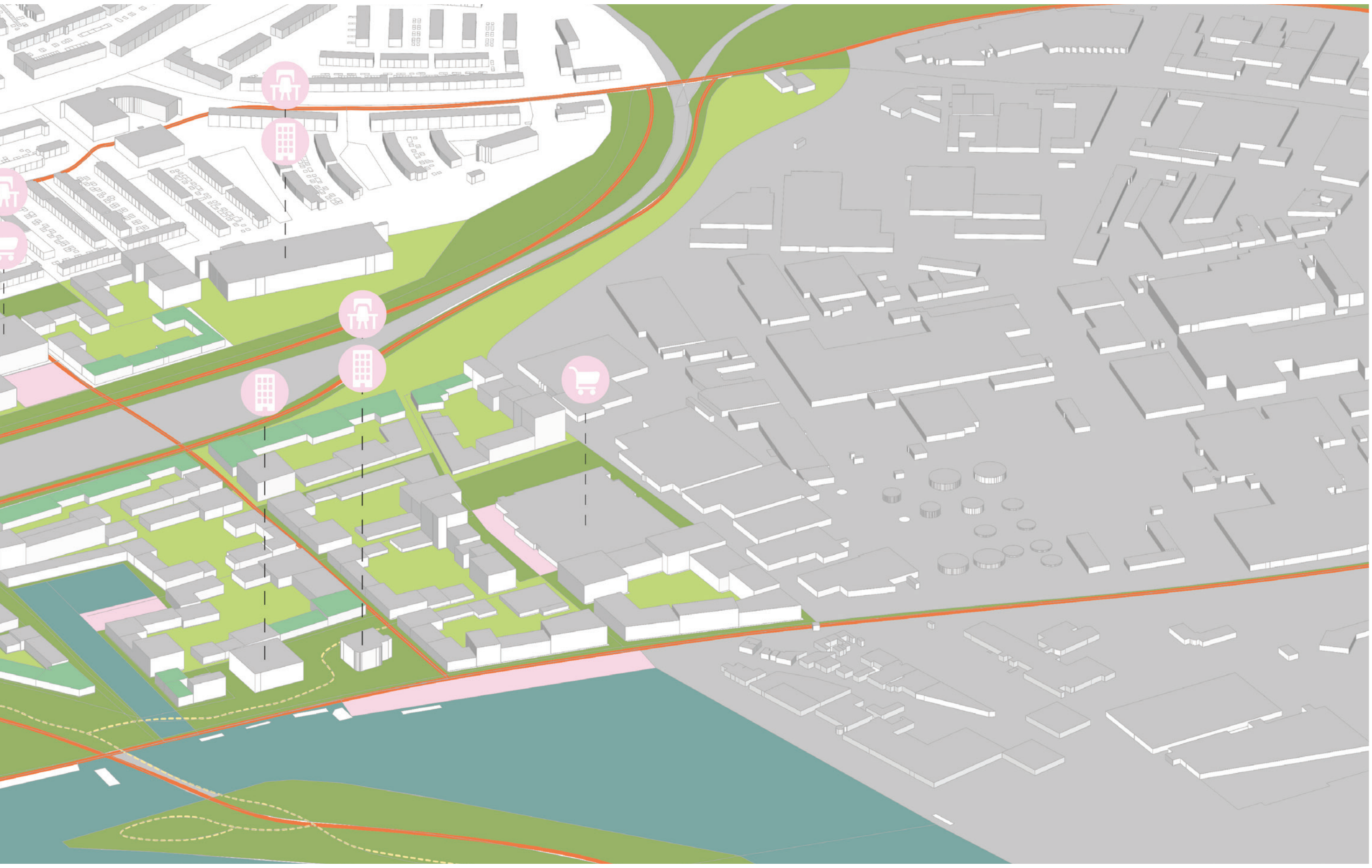
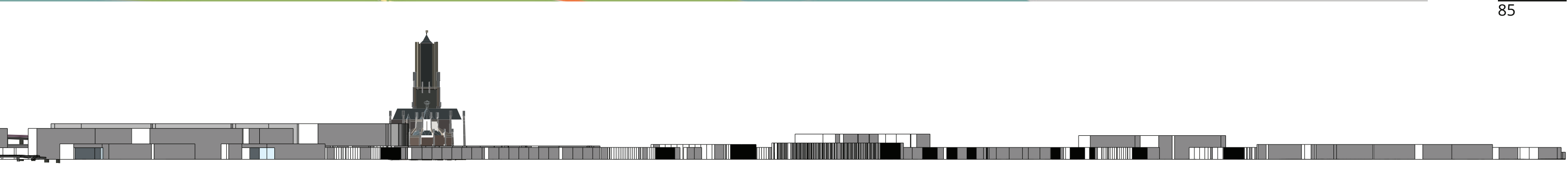


Figure 113: Green and sustainable 'Atlaskwartier'





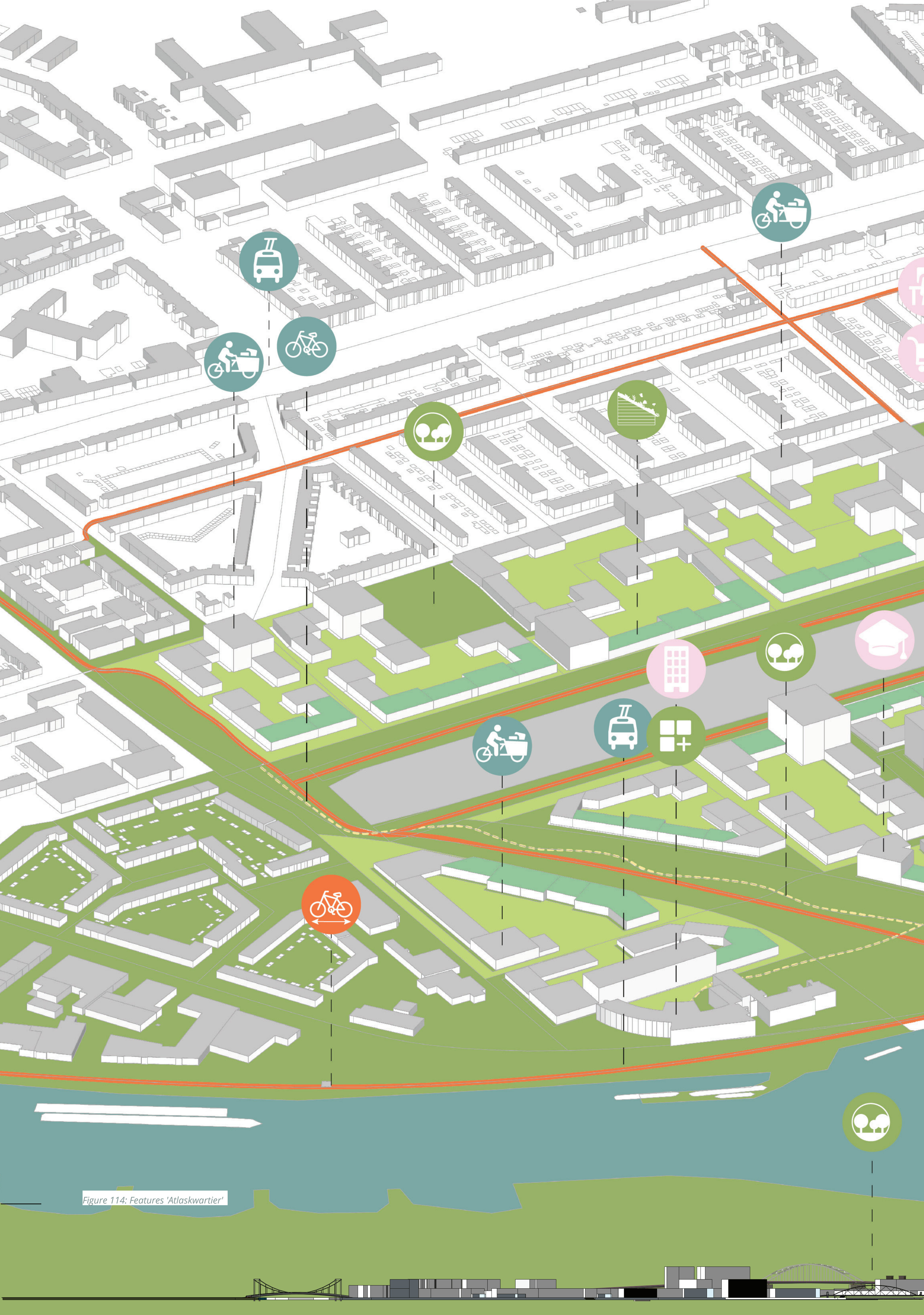


Figure 114: Features 'Atlaskwartier'

Figure 115: Existing situation

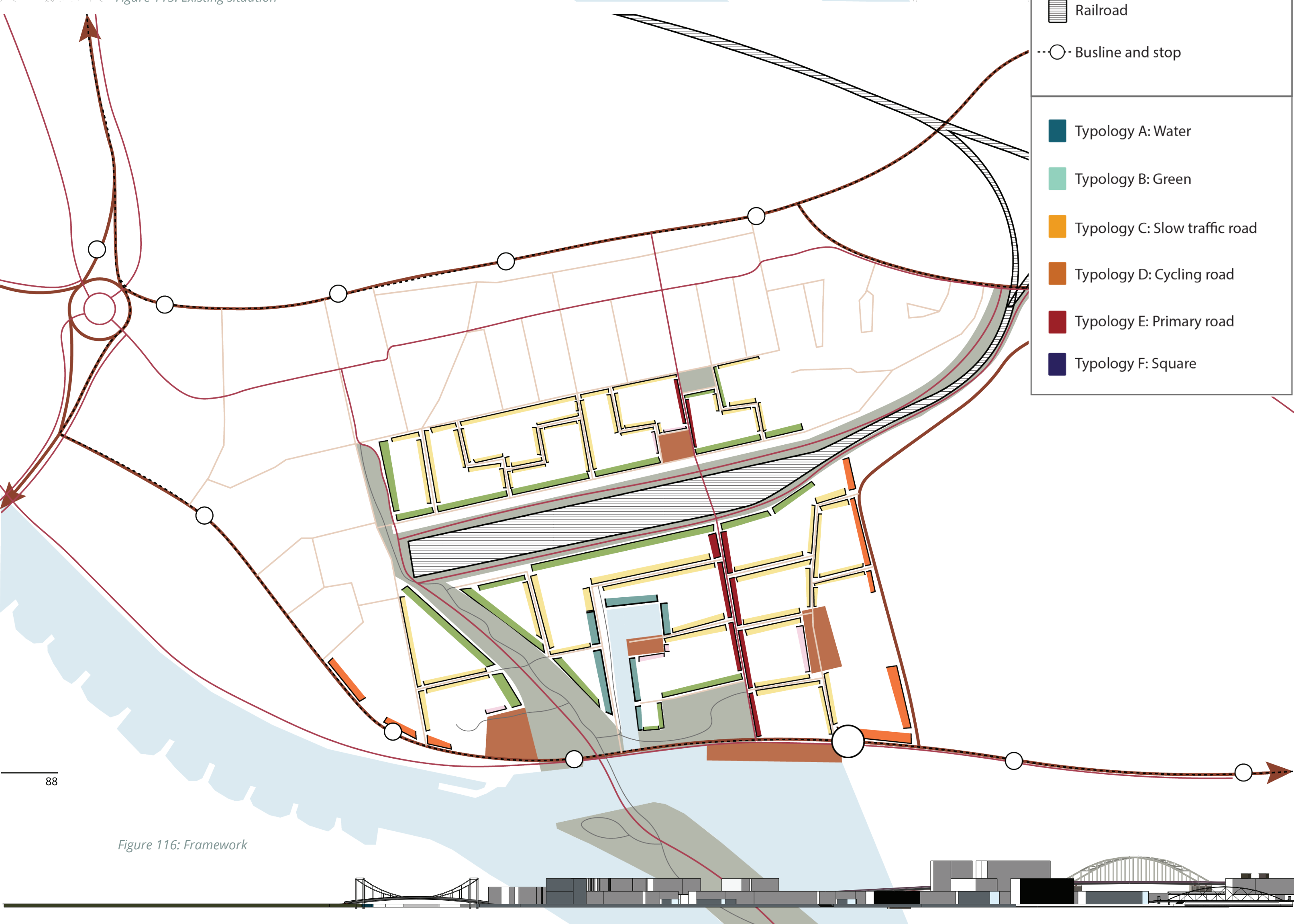


Figure 116: Framework

TYPOLOGIES

To give an indication of the type of buildings that will be established in the area, six typologies will be introduced. Figure 115 shows the existing situation, where figure 116 shows the new situation with the typologies. The goal of the typologies is to let the building types mirror the function of the area that they are facing. All building blocks have a courtyard that will be shared with the residents of that block, providing safe green space. The typologies focus on the expression of the building on the outside of that block.
Typology A: water. This typology is located around the small harbour. The typology consists of single-family houses, with a front door facing the harbour. The building will be approximately 7.8m high (three floors), with a flat roof. The buildings will have a balcony that faces the water and make use of the 'gray' water in terms of toilet flushing and cooling down during the summer.
Typology B: Green. This typology is located aside the green strips and the park. The typology consists of single-family houses. With a front door facing the green area. The building will be approximately 5.8m high (two floors with a slanted roof). The buildings will have a balcony that faces the green and will make use of the green outside as a recreational space.
Typology C: slow traffic. This typology is located aside the shared streets. The typology consists of single-family houses, with a front door facing the street. The building will be approximately 5.8m high (two floors with a slanted roof). The buildings will have a balcony that faces the street and will have no front garden. They do have small patches of grass to plant trees that move up on the walls.
Typology D: Cycling. This typology is located aside the cycling streets. The typology consists of a mix of houses, offices and stores, with a front door facing the street. The building will be approximately 7.8m high (three floors with a flat roof). The buildings will have a balcony that faces the courtyard and will have no front garden. Part of the buildings will only have half of the ground floor (the part facing the courtyard), because the other half will be in use by stores and offices.
Typology E: Primary road. This typology is located aside the primary roads. The typology consists of a mix of houses and apartments, with a front door facing the street. The building will be approximately between 15.6-20.8m high (6-8 floors). The buildings will have a balcony that faces the courtyard and will have no front garden. They do have small patches of grass to plant trees that move up on the walls. The focus of this typology is towards the courtyard, because of the car dominated street on the front of the house or apartment.
Typology F: square. This typology is located around the squares. The typology consists of apartments and offices, with a front door facing the street. The building will be approximately 15.6-20.8m high (6-8 floors). The buildings will have a balcony that faces the courtyard and/or square and will have no front garden. The apartments and offices have a direct connection to the square, creating a safe place during day and nighttime.

SECTIONS

To give a better view on the way the area functions, four sections will be used to explain the design. Firstly, the cyclestreet (see figure 118), functions as an important connector between the North and South of the area. The street will have some shops and a wide cycle street, providing enough space on busy moments of the day. Secondly, the harbour (see figure 119) will play an important role in the area. It provides a combination of shops, recreation and living. Thirdly, the park (see figure 120) will have a public function for the residents of the area and surrounding neighbourhoods. A wadi in the centre of the park will transport water towards the river Rijn, making it an important area for the climate resilience of the neighbourhood. Lastly, the train depot still functions as a barrier (see figure 121). The section shows how the depot is shield of from the neighbourhood by large green walls and trees.

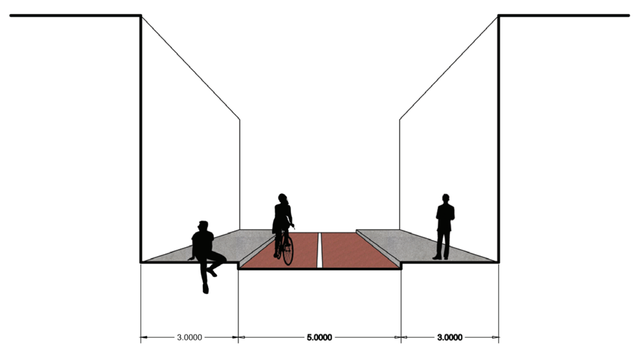


Figure 118: Section - cyclestreet

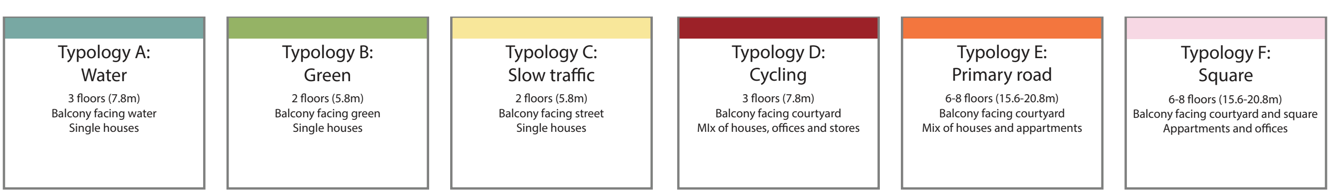
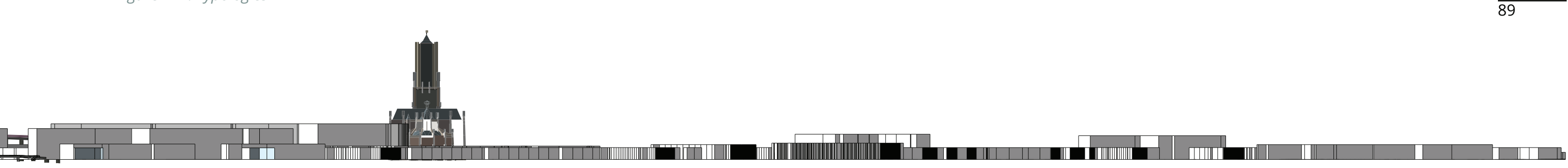


Figure 117: Typologies



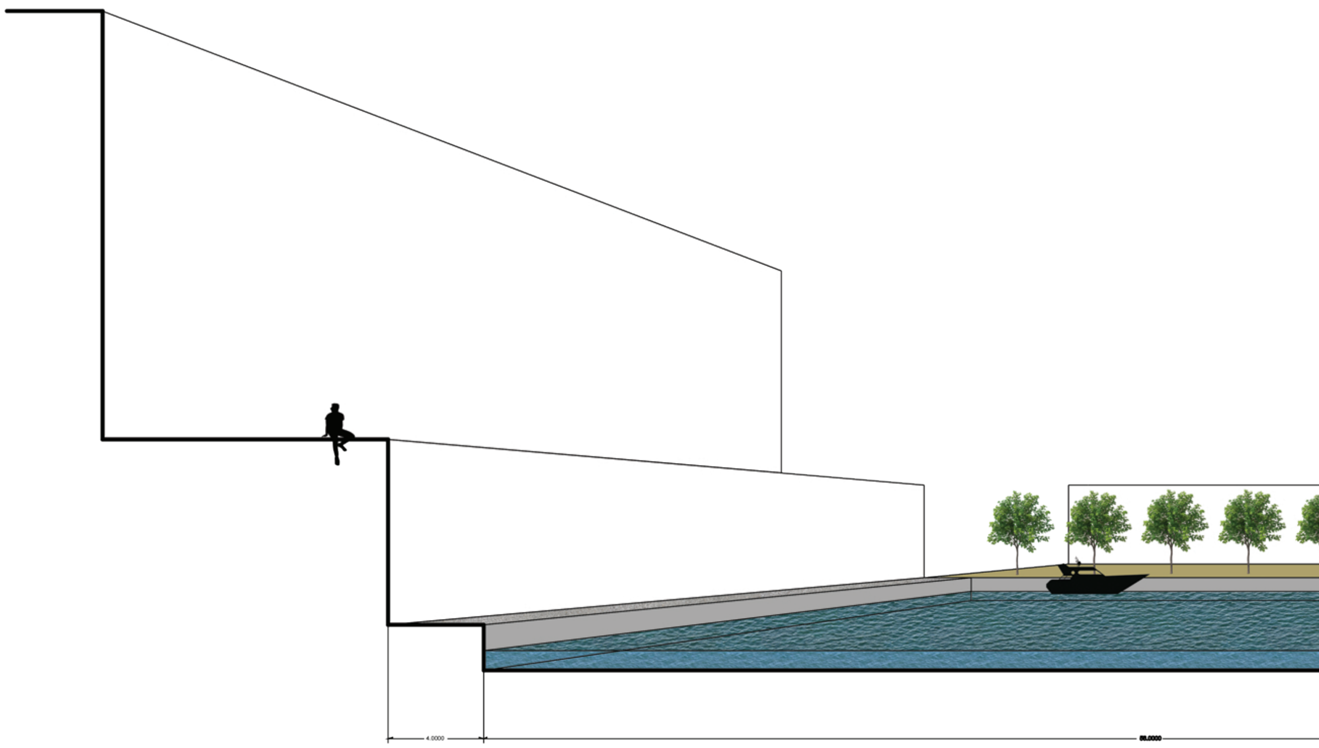


Figure 119: Section - Harbour

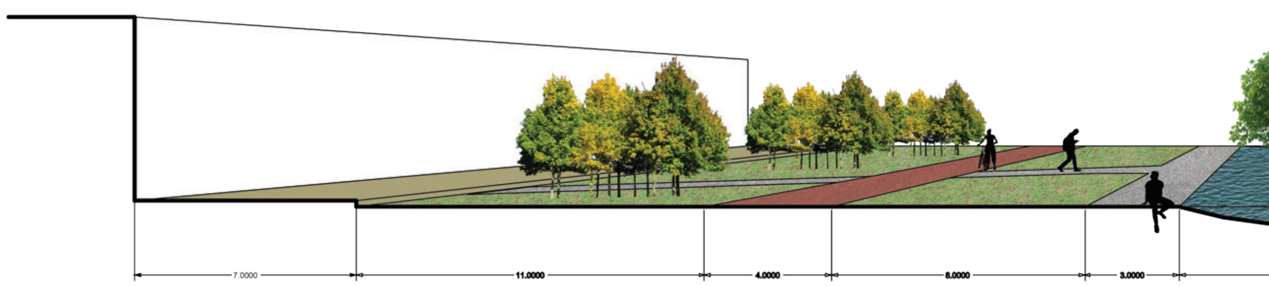


Figure 120: Section - park

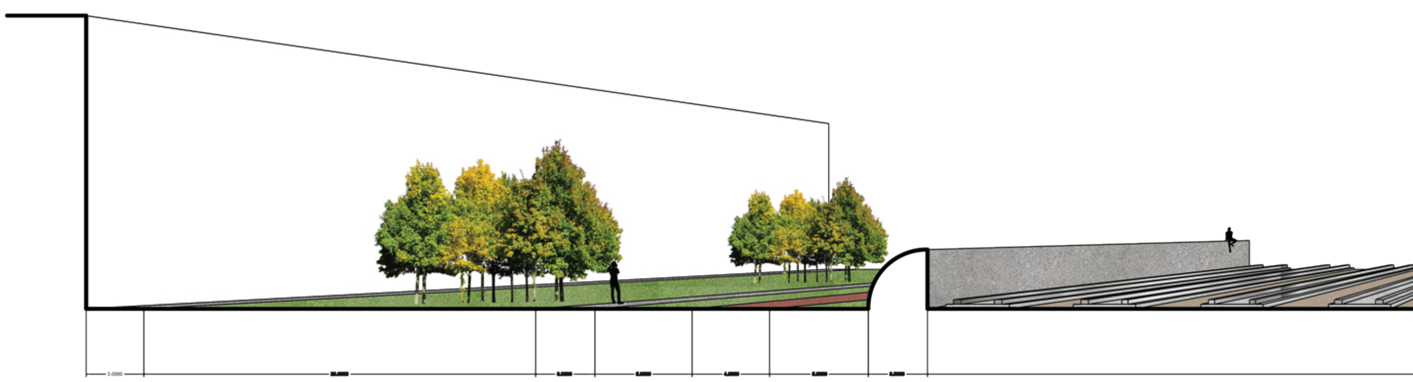
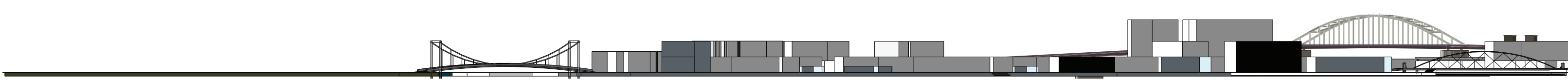
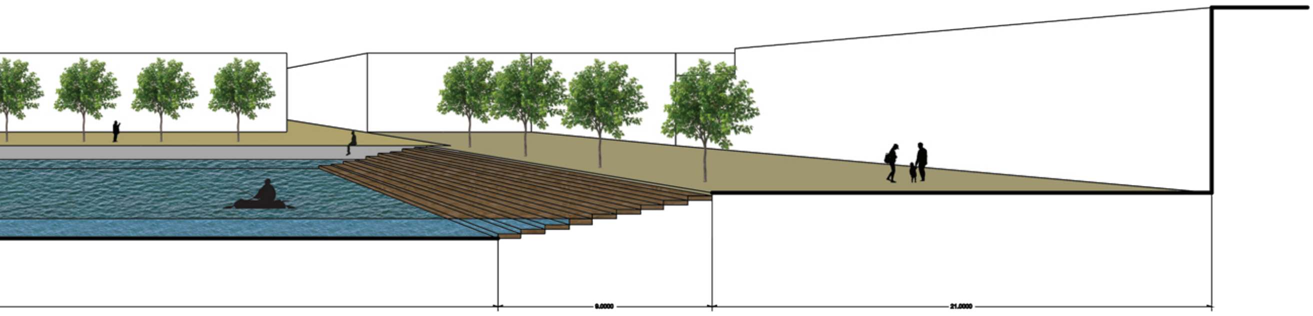


Figure 121: Section - train depot

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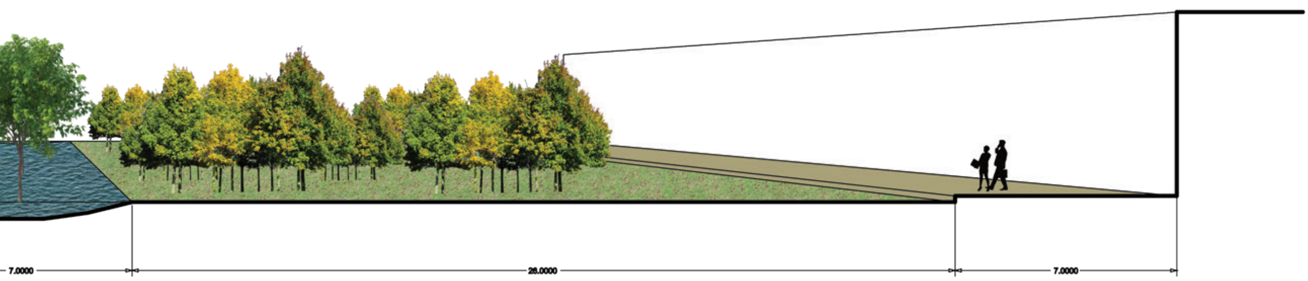
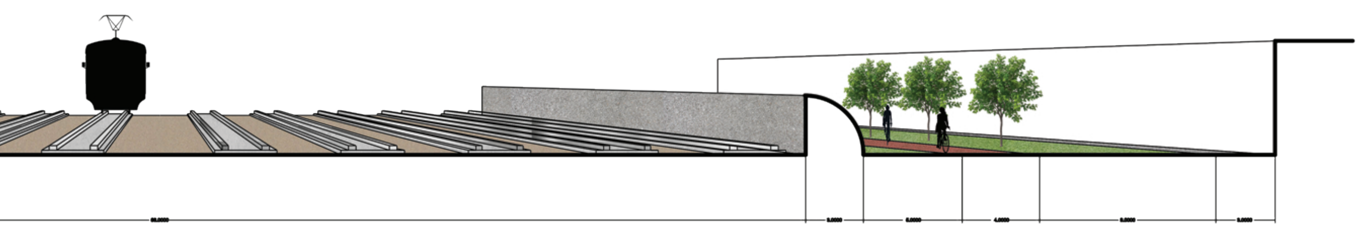

7.0000
26.0000
7.0000



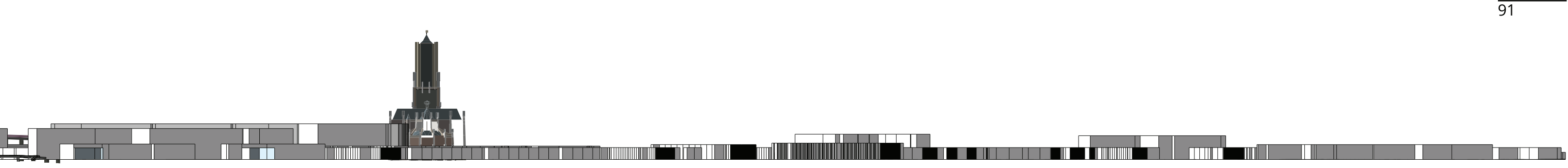
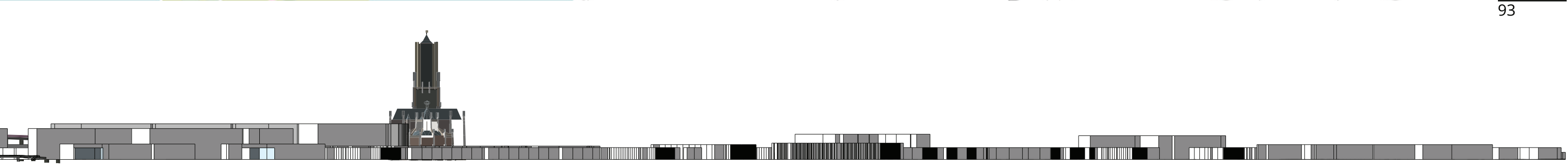


Figure 122: Design



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08

CAR FREE ARNHEM
APPENDIX

APPENDIX I: DENSITY PER CASE STUDY

CODE	City	Population	Km^2	Inhabitants/km^2	Comparison
0	Arnhem	164096	101.5	1616	0
1	Bologna	388367	140	2774	1158
2	Lubeck	217198	214.1	1014	-602
3	York	209893	687	306	-1310
4	Aachen	245885	160.9	1529	-87
5	Rome	2873000	1285	2236	620
6	Cologne	1086000	405.2	2680	1064
7	Darmstadt	159174	122.	1304	-312
8	Zurich	415215	91.9	4519	2903
9	London	8799800	1572	5598	3982
11	Copenhagen	602481	179.8	3351	1735
12	Helsinki	610000	213.8	2853	1237
13	Rotterdam	588490	319	1845	229
14	Fremantle	9251	19	487	-1129
15	Nottingham	331297	74.61	4440	2824
16	Tel Aviv	435855	52	8382	6766
17	Syndey	5312000	12368	429	-1187
18	Bern	133115	51.6	2580	964
19	Brighton & Hove	290395	82.7	3513	1897
20	Norwich	141137	39	3619	2003
21	Grenoble	160649	18.1	8861	7245
22	Lyon	513275	47.9	10716	9100
23	Montpellier	295542	56.9	5196	3580
24	Olso	702543	480	1464	-152
25	Edinburgh	518500	264	1964	348
26	Singapore	5454000	728.6	7486	5870
27	Utrecht	361924	99.2	3648	2032
28	Catania	311584	180	1731	115
29	Tallinn	444702	159.3	2792	1176
30	Bristol	467099	110	4246	2630
31	San sebastian	187415	60.9	3078	1462
32	Amsterdam	905234	219.5	4124	2508
33	Bremen	566573	326.7	1734	118

$$\frac{Inhabitants}{km^2} = Population/km^2$$

$$Comparison = \frac{Inhabitants}{km^2} - 1616$$

APPENDIX II: LITERATURE REVIEW (FULL TABLE)

Code A-Z	Authors	Case study	Scale level	Policy type	Policy instrument	Strategy type	key words	+ or - ?	Description	Succes and critique	Stakeholders involved
A	Topp, H., Pharoah, T.	Bologna	City centre	Substantive	Regulatory	Push	Access control, parking management	+	Access control to the old town + limited parking space	The Bologna concept has shown that success is possible: the total number of vehicles entering and leaving the old town was reduced by about 50%, from 177,000 vehicles per day in 1981 to 87,000 in 1989. Related to passenger cars (excluding taxis) the reduction was more than 60%. This was achieved without major traffic increases on the ringroad. Traffic flow and safety were improved. Public transport achieved shorter journey times because of less traffic on the bus routes, and in 1989 the trend of decreasing patronage was broken for the first time. Most people visiting the old town take the bus (78%), only a few use the car (11%), and 8% go by bike or motorbike.	Municipality
		Bologna	City	Substantive	Public goods & services, economic	Push	Parking management	+	Parking management		
		Bologna	City centre	Substantive	Public goods & services	Push and Pull	Access control	+	Extention of the pedestrian zone		
		Bologna	City	Substantive	Public goods & services	Pull	Public transport system	+	Improvement of public transport		
		Bologna	Neighborhood	Substantive	Regulatory	Push	Parking management	-	residents are allowed to park only within the quarter where they live		
		Bologna	City	Substantive	Public goods & services	Pull	Parking management	+	Large carpark for long stay		
		Lubeck	City centre	Substantive	Regulatory	Push	Access control	+	car ban; covers the entire old town, excluding the access roads to parking garages. It is closed from 10 am to 6 pm for private car traffic except for residents and deliveries and hotel access.	After installing the car ban, 40% to 80% less cars (depending on the time of day) were counted on the access points to the city centre. Out of those who formerly drove by car into the city centre, 58% still use the car to get as near as possible to their destination (but there are no parking problems within the adjoining residential areas), 30% use park-and-ride, and 12% switched to the "environment association" of public transport, cycling and walking. The number of pedestrians and cyclists within the centre increased considerably. The decrease in car traffic resulted in remarkable reductions of noise and exhaust fumes.	Municipality and retailers
		Lubeck	City	Substantive	Public goods & services, regulatory	Pull	Public transport system	+	frequency of bus services increased		
		Lubeck	City	Substantive	Information & Education, Public goods & Services	Pull	Parking management	+	Provisional parking guidance system was installed; Private parking spaces of firms outside the inner city that were vacant during the weekend were included into the park-and-ride scheme.		
		Lubeck	City centre	Substantive	Regulatory, Public goods & Services	Pull	Public transport system	+	Free of charge transport to city center, special baggage-carrying buses		
		Aachen	City centre	Substantive	Regulatory	Push	Access control	+	Shop Saturdays from 10 am to 5 pm, city center closed for cars	Proportion of travel on foot and by bus increased.	Municipality and retailers
		York	City centre	Substantive	Regulatory, Public goods & Services	Push	Access control	+	Cycling is prohibited and servicing vehicles also are not allowed. Two traffic-calmed streets at the edge of the area provide access for buses and service traffic only.	As with the other case study cities, the York "footstreets" scheme has found wide support in the community. But traders have issues with reduction of accessbility.	Municipality and traders
		York	City centre	Substantive	Regulatory	Push	Access control	-	Every day: Car-free from 10am to 5pm, city center closed for cars		
		York	City	Substantive	Regulatory	Push	Access control	–	Within larger area there is a permanent ban on tourist coaches and there are no facilities for commuter (long-stay) parking except in private car parks over which the city has no control		
B	Bonnel, P.	Zurich and Bern	City	Substantive and procedural	Regulatory, Public goods & Services	Push & Pull	Road design	+	Deviding up roads into different sections per transport mode. Priority to busses and cyclists.	Other transport modes have priority over cars. Thanks to coherence with other sector-based policies general consensus of the population has been obtained and therefore the level of private car trips is of little importance.	Municipality and public transport provider
		Zurich and Bern	City	Substantive and procedural	Regulatory, Public goods & Services	Push & Pull	Road system	+	One way roads to ensure use of dedicated roads and channeling traffic		Municipality
		Zurich and Bern	City	Substantive and procedural	Regulatory, Public goods & Services, Information & Education	Push and Pull	Road design	+	Protection of residential zones or 'traffic' calming. Speed restriction, special surfaces, prioritize cyclists and pedestrians and removing sidewalk to create impression that the highway belongs to every user		
		Bologna and Milan	City centre	Substantive	Regulatory	Push	Access control	-	Bans on driving in the city centre at certain times of the day.	50% of the population has welkcomed the policy. Positive effect on car traffic in the banned zones.	Municipality
		Bologna and Milan	City	Substantive	Regulatory	Push	Control of usage	-	Cars with nuber plates with an even number are authorised to be used on even days of the month and vice versa.	No, stimulated people to buy a second car	Municipality
		Grenoble, Lyon, Montpellier	City	Substantive	Regulatory, Public goods & Services	Pull	Road system	+	New ringroads to divert traffic. Focus on free choice for the resident	Shift of problem. Ringroads also have a maximum capacity.	Municipality, civil society
		Oslo	City	Substantive	Regulatory, economic	Direct push and indirect pull	Pricing system	+	Earnings of the toll go into investments in roads (70-80%) and PT (20-30%). Price change according to time of the day (to balance road usage)	georgraphical situation of Oslo made it possible to create a ring around the city. Price change encourage people to travel out of busy hours.	Municipality, public transport provider
		Grenoble, Lyon, Montpellier	City	Substantive	Public goods & services	Pull	Parking management	?	Introduction of public car parks.	Unknown, future research	Municipality, private
		Zurich	City	Substantive	Regulatory	Push	Parking management	+	forbidden the provision of parking spaces in new buildings in certain parts of the city centre.	withdraw 10000 parking places over a few years. Poisitive effect in terms of modal split and economic, commerical and enterainment viatlity. Policy is acompanied by very high parkng prices and strict limits on parkiung time	Municipality, civil society, private
		Cardiff and Liverpool	City	Procedural	Regulatory		Public transport system	-	Deregulation of PT	lowering of the contributions made by the local authorities. The only expected outcome of deregulation which was actually achieved was the lowering of the contributions made by the local authorities. However one should also take into account the extra costs caused by the increase in car traffic as a result of the decrease in public transport provision	Municipality, public transport provider
C	Nicholson, D.	Fremantle	City	Substantive	Public goods & Services, economic	Pull	Public transport system	+	Free transit zone. Local residents were provided with a pass which allowed free use of PT. Funds were raised through increase in parking cost.	Encouraged use of PT by 51%. Scheme had negligible effect on car usage, parkijg and GHG emissions. Ceased in January 1998 because of lack of financial support by the council	Municipality, civil society, public transport provider
		Fremantle	City	Substantive	Public goods & Services	Pull	Public transport system	+	Busses connecting car parkings on the periuphery of the city centre, railway station and other mahor destinations during weekends	Movement between popular destinantions within city centre was facilitated. There was no increase in the usage of underutilised car parks on the periphery of thye city centre while the service was in operation.	Municipality, public transport provider
		Fremantle	Street	Substantive	Regulatory	Push	Access control	-	Trail closure of south terrace on Sundays, an important shopping street in the city centre.	No, Cars are part of the culture and make a postive contribution to the atmosphere.	Municipality
D	Stubbs, M.	York, London	City	Substantive	Regulatory	Push	Parking management	+	all standards are applied to a maximum ceiling and that each development proposal will be assessed downward according to site conditions using the maximum as a starting point. changes previous minimum to maximum standards, while accepting, in policy, that it may be possible to set aside parking standards altogether where matters of historic/architectural or townspace importance dictate.	Yes, in terms of reduction of parking spots. on the basis of this evidence, parking standards and their reduction in the next few years may be much more of an urban than a rural priority.	Municipality
E	Shepherd, S.P.	Edinburgh	Region	Substantive	Economic, regulatory	Push	Pricing system	+	distance-based charging	The introduction of a road pricing system has been shown to significantly increase the social welfare of the residents of Edinburgh and to play a key role in creating an "integrated" strategy. However forming the optimal "integrated" strategy requires alternative systems to be considered.	Muicipality, civil society
F	Vande Walle, S., Steenberghen, T., Paulley, N., Pedler, A., Martens, M.	Cologne	City	Substantive	Regulatory, Public goods & services	Push	Parking management	+	Reducing parkingspots. Conditions to reduce the number of parkings: the land should be no more than 300 m away from a public transport stop; the public transport stop is served by various public transport lines or the frequency is 20 minutes minimum.		Municipality, civil society
G	Klementschitz, R., Stark, J., Sammer, G.	Aachen, Berlin, Bremen, Erfurt, Hamburg, Munich, Rostock, Stuttgard	Building	Substantive and procedural	Regulatory, economic	Push	Parking management	+	Limitation of number of parking places is integrated in the local building laws. Location and type of use always form the basis for calculating the maximum number of parking spaces.	Advantage of this measure is the simple and less complex application. On the other hand, this measure must go hand in hand with on-street parking management to avoid a shift from off-street to on-street parking only and an efficient mass transit supply to avoid destination changes.	Municipality, civil society
		Copenhagen, Helsinki, Rotterdam	City	Substantive and procedural	Regulatory, economic	Push	Parking management	+	Limitation of number of parking places is integrated in the land use or city development plan. Location and type of use always form the basis for calculating the maximum number of parking spaces.		Municipality, civil society
		Berlin	City	Substantive	Regulatory	Push	Parking management	+	the historic city center always forms the most restricted area and the grade of restriction decreases with distance from this center.		Municipality, civil society
H	Olszewski, P.S.	Singapore	City	Substantive	Regulatory	Push	Ownership restraint	+	Impose high costoms duty on cars. Registration fee. Road taks (dependend on engine capacity.	The taxes on car ownership drastically reduced the growth in vehicle numbers. However, except for a brief economic slowdown in 1985–1986, the growth picked up again despite high car prices.	National government
I	Rydningen, U., Høyl	Oslo	City	Procedural	Information & education	Pull	Stakeholders	+	Pay attention to needs of various stakeholders: residents, travelers, parking, Public transport trade and service industry, goods devilveries, craftsmen, disabled people	There will always be exeptions for certain user groups and stakeholders in terms of car usage. Changes should not come overnight, but be carefully planned and discussed with stakeholders	residents, travelers, parking, Public transport trade and service industry, goods devilveries, craftsmen, disabled people
J	Kuss, Nicholas (2022)	Gothenburg, London, Milan, Stockholm	City centre	Substantive and procedural	Economic, public goods & services	Push and Pull	Pricing system	+	Time dependend charges for cars in defined charging zone, invested in public transport or infrastructure	All 12 interventions have proven succesfull	National-, regional government
		Nottingham, Rotterdam	Building	Substantive and procedural	Economic, public goods & services	Push and Pull	Pricing system	+	Charges for car parking spaces at workplaces, invested in PT and employees to use PT		Company
		Rome	City centre	Substantive and procedural	Regulatory, Public goods & Services	Push and Pull	Access control	+	Time- and weekday dependent access restrictions in city centre, only access for residents or with special fee, revenues for PT		Municipality
		Oslo	City centre	Substantive	Regulatory, Public goods & Services	Push and Pull	Parking management, road design	+	Removal of parking spaces, introduction of car-free streets, Alteration of traffic routes, new bikes + pedestrian lanes		Municipality, civil society
		Utrecht	Building	Substantive and procedural	Economic, public goods & services, Information & Education	Pull	Pricing system	+	Free PT pass, bus shuttle and communication plan for employees		Employees, Company
		Catania	Building	Substantive and procedural	Economic, public goods & services	Pull	Pricing system	+	Free PT pass and bus shuttle for students		Students, Company, public transport provider
		Bremen, Genoa	City	Substantive and procedural	Public goods & services, Information & Education	Pull	Car sharing	+	Car sharing + awareness		Public transport provider, national government, civil society
		Brighton & Hove, Graz, Nantes, Norwich, 20 cities in GB	City	Substantive and procedural	Information & Education, Regulatory, Economic, Public goods and services	Push and Pull	Parking management, road design, pricing system	+	Advice for companies, parking management, company shuttle bus, discount for PT, improvement of bike infrastructure		Company, public transport provider
		Brighton & Hove, Norwich	City	Substantive and procedural	Information & Education, Public goods & Services	Pull	Awareness, road design	+	Travel plan advice, Promotion of biking and parking, improved infrastructure for bikes, promotional event and awareness		Company, public transport provider
		Bristol, San Sebastián	City	Substantive and procedural	Information & Education, Regulatory, Economic, Public goods and services	Push and Pull	Awareness, road design, parking management, pricing sys	+	Travel plan advice, promotion of public infrastructure, parking management, bike infrastructure, discount for PT, awareness		Municipality, Regional government, Public transport provider
		Marseille, Munich, Maastricht, San Sebastián	City	Substantive and procedural	Information & Education, Economic	Pull	Awareness, pricing system	+	Personal travel advice, PT discount		Municipality, Regional government, Public transport provider
		Bologna	City	Substantive and procedural	Information & Education, Economic	Pull	Awareness, pricing system	+	App to rewards sustainable choices		Private
K	Glazener, A., Wylie, J., van Waas, W., Khreis, H.	Literature review		Procedural	Information & education	Push & Pull	Awareness	+/-	Car free areas or days to promote use of other transport methods and create awareness of negative point of car usage	Depends on goal. The impacts of car-free days and events are highly variable and seem to depend on the scope (frequency, duration, and geographic size) and goals of each car-free day and event. Most of the existing literature measures impacts in terms of air and noise pollution and some studies focus on physical activity metrics. In some cases, car-free days and events were successful in reducing the concentration of certain air pollutants but had little or adverse impacts on the concentration of others. Often, traffic is diverted from cordoned areas to surrounding streets, displacing traffic congestion and adverse environmental exposures to other areas of a city, with potential understudied implications to environmental justice. Takes a lot of planning to incorporate	Municipality
L	Vélez, A.M.A., Plepys, A.	Amsterdam	City	Substantive and procedural	Economic, public goods & services	Pull	Car sharing	+	Implementation of car sharing opportunities	When individuals with car-free travel habits engage with car sharing, their transport emissions increase, but it is also possible that these individuals will never buy a vehicle or will postpone buying one. When individuals with car-free travel habits engage with car sharing, their transport emissions increase. Although still marginal, new transport modes like car sharing have wider socioeconomic effects, such as the production of vehicles and fuels, as well as the development and maintenance of infrastructure.	

M	Nikitas, A., Tsigdinos, S., Kar		Street	Procedural	Information & Education, Regulatory, Public goods and services	Push & Pull	Road design	+	Tempoary cycling langes to test functionality and usage of permanent lanes	There will be some wins and some losses in terms of their ability to work in a permanent basis but nonetheless they can be an apparatus, even if short-lived in some cases, for actively prioritising bikes over automobiles	Municipality
			City	Substantive	Public goods & services	Pull	Services	+	Cycling parking, bike storage, e-bike charging stations		Municipality, public transport provider
			Building	Substantive	Public goods & services	Pull	Services	+	Workplace showers		Company
			City	Procedural	Information & Education	Pull	Awareness	+	Information and communication on new (cycling) measures		Municipality
		Policy review of cities around the world	National/regional/city	Procedural	Regulatory	Pull	Subsidies	+	Subsidies on e-bikes	Increase popularity. Suitable for longer trips.	Nationa government, regional government, municipality
N	Mitsakou, C., Ada		City	Procedural	Regulatory	Push & Pull	Control of usage	+	Air pollution is bigger during morning rush hour than afternoon rush hyour. Non-rush hours were the lowest. By flattening peak hours, exposure to air pollution is reduced.		Municipality
			Building	Procedural	Regulatory, Information & Education	Push	Control of usage	+	Working from home		Companies
		Literature review	Region	Substantive	Public goods & services	Pull	Public transport system	+	Improvement of public transport		National goverment, regional government, municipality
O	Selzer, S.		Neighborhood	Substantive	Public goods & services, regulatory	Pull	Public transport system	+	Public transport within walking distance (preferably 2 stops)	Both bottom up and top down approaches work well in reducing car dominance. Residents without a car serve as example for others. In terms of parking management, always the entire city parking should be examined.	Municipality, civil society, housing developers, local planners, mobility service providers, policy makers, consultants for urban and transport planning
			City	Substantive	Public goods & services, regulatory	Pull	Public transport system	+	Direct connection to city centre and central railwaty station		
			City	Substantive	Public goods & services, regulatory	Pull	Public transport system	+	Travel time towards central railway station and city centre approx 10 min		
			City	Substantive	Public goods & services, regulatory	Pull	Walking and cycling accessbility	+	Travel time cycling towards central railway station and city centre approx 10-15 min		
			City	Substantive	Public goods & services, regulatory	Pull	Walking and cycling accessbility	+	Travel time walking towards central railway station and city centre approx 40-45 min		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	€-car sharing		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	(cargo e-) Bike sharing		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	Supermarkets and schools within walking distance		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	Recreation psace within walking distance		
			Neighborhood	Substantive	Regulatory	Push	Road design	+	Home zones		
			Neighborhood	Substantive	Regulatory	Push	Road design	+	Speed limit (30km/h)		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	Covered and secured places for bicycle parking		
			Neighborhood	Substantive	Public goods & services	Pull	Services	+	Playgrounds within walking distance		
			Neighborhood	Substantive	Public goods & services, regulatory	Push	Parking management	+	Relocate parking from on street to collective garages,		
			Neighborhood	Substantive	Regulatory	Push	Parking management	+	Reduce compulsory number of parking spaces per housing		
		Darmstad (neighborhoods of Lincoln and K6)	Neighborhood	Substantive	Public goods & services	Pull	Parking management	+	On street parking for visitors and disabled		
P	Aldred, R., Verlinghieri, E., Sharkey, M., Itova, I., Goodman, A.	London	Neighborhood	Substantive	Regulatory	Push	Road design	+	Low traffic neighbourhoods	We conclude that LTN implementation has been broadly equitable at the city and micro levels, but the picture is more mixed at district level.	Municipality
Q	Štraub, D., Jaroš, V.		City	Procedural	Regulatory, economic	Pull	Public transport system	+	Free public transport	As part of other measures to reduce car dominance. Size of city is of importance (mainmly used in medium sized cities, introduction is easier)	
			City	Procedural	Regulatory, economic	Pull	Public transport system	+	Abolished fares for students, employees and visitors		
			City	Procedural	Regulatory, economic	Pull	Public transport system	+	Abolished fares for people over 60 and physical disabeled		
			City	Procedural	Regulatory, economic	Pull	Public transport system	+	Free PT during off peak hours (9-15h)		
			City	Procedural	Regulatory, economic	Pull	Public transport system	+	Free public transport during weekdays		
			City	Procedural	Regulatory, economic	Pull	Public transport system	+	Free public transport during special events		
		Compilation of different forms of free fare public transport	City	Procedural	Regulatory, economic	Pull	Public transport system	+	Specific fare-free bus lines		
R	Cats, O., Reimal, T., Susilo, Y. Gabaldón-Estevan, D., Orru, K., Kaufmann, C., Orru, H.	Tallinn	City	Procedural	Regulatory, economic	Pull	Public transport system	+	Free fare public transport service (FFPTS)	As part of a larger group of measures to increase the usage of PT. FFPTS increased the m,obility of the most cost-sensitive population groups (elderly, people on low incomes, etc). But it failed to draft the motorised people, due to lack of push measures?	Civil society, public transport provider, municipality
S	Arcidiacono, D., Pais, I.	Milan	City	Substantive	Public goods & services	Pull	Car sharing	+	Car sharing	Most frequent users are young, male, with higher education, resident in the city and with limited mobility needs related to the family. Attracted by the flexibility and convenience of the service in terms of free parking and accessto limited traffic areas/	Civil society, company, municipality
T	Katoshevski-Cavari, R., Bak, N., Shiftan, Y.	Tel Aviv	City	Substantive	Public goods & services	Pull	Parking management	+/-	Free park-and-ride facilities alongside free shuttle services	A combination of attributes, including free access to the fast lane, time saving, cost saving, and a relaxed ride, make this service attractive, but time saving is a significant predictor for using the shuttle. However, the results indicate that the facility is also attracting public transportation users to shift to multi-mode travel, where a car is used to commute to the park-and-ride facility.	Civil society, municipality, public transport provider
U	Hickman, R., Ashiru, O., Banister, D.		City	Procedural	Regulatory, economic	Push	Pricing system	+	Congestion charging or area-wide road pricing	This would give clear signals to consumers to switch to more efficient cars or to other modes of transport.	
			City	Substantive	Public goods & services	Pull	Public transport system	+	Investment in PT by adding routes towards suburbs		
			City	Substantive	Public goods & services	Pull	Walking and cycling accessbility	+	Investment in walking and cycling facilities and streetscape and public realm.	Mainly affects short journeys.	
			City	Substantive	Public goods & services	Pull	Landuse	+	Cluster higher density development around PT	Requires complemetary heavy investment in PT, walking and cycling	
			City	Substantive	Public goods & services	Pull	Landuse	+	Mixed use developments	Requires complemetary heavy investment in PT, walking and cycling	
			City	Procedural	Information & education	Pull	Awareness	+	Travelplans for workplace and school	Requires funds. As supporting measure for other policies	
		London	City	Procedural	Regulatory	Push	Road design	+	Reduce driving speed	Need to be combined with awareness programms	
V	Tirachini, A., Hensher, D.A., Rose, J.M.	Sydney	City	Procedural	Regulatory, Public goods & services	Pull	Public transport system	+	Bus only lanes	We find that optimal bus frequency results from a trade-off between the level of congestion inside buses, i.e., passengers' crowding, and the level of congestion outside buses, i.e., the effect of frequency on slowing down both buses and cars in mixed-traffic roads.	

TOOLBOX
Public transport

Flatten peak hours
Reduction of peak use of PT and pulling towards less busy trains and busses.

PT towards suburbs
To connect the city centre to the suburbs of the city, a public transport connection between the city centre and high density suburbs can be established.

Improve regional transport
Increase availability of public transport in areas that are mainly accessible by car.

Busses that connect carpark
To stimulate residents to change travelmode the last miles of their journey, a bus connection can be established between the city centre and carparks. This stimulates people to park their car outside their neighbourhood.

Increase freq. of bus
Increase the frequency of busses in the area to serve more people. Less busy busses will motivate people to take the bus.

PT within walking distance
To stimulate residents to walk to public transport in dense areas, the bus stop or train station must be within 400m (bus) or 1000m (train) walking distance.

Free transit zones
Assign bus lines or train connections that provide low cost or free services to important areas like the city centre or towards areas were people do not use public transport often.

Max. 10 min cycling to station
Ensure that all dense areas are within a distance of 10 min cycling of a trainstation. If not possible, make sure of good bus connections (10 min) towards train stations.

Free of charge PT to centre
Free of charge transport by public transport towards city centre to stimulate residents of city to leave the car at home when going to the city centre.

Lanes for busses only
To reduce time spend in traffic by busses, provide lanes that are only for busses (and emercy vehicles) for a fast connection between important stops.

TOOLBOX
Active transport

Cycle 10-15 towards centre
Take a 10-15 minute bike ride as basis for the maximum distance to the city centre. Ensure the 10-15 minute ride by upgrading cycling infrastructure.

Walk 40-45 towards centre
Take a 40-45 minute walk as basis for the maximum distance to the city centre. Ensure the 40-45 minute walk by upgrading walking infrastructure.

Invest in cycling facilities
Invest in cycling facilities to stimulate cycling. Examples are secured bicycle parking, cycling lanes and shared mobility.

Invest in walking facilities
Invest in walking facilities to stimulate walking. Examples are benches, good paved lanes and green veins that are the basis of pedestrianized areas.

TOOLBOX
Road network

Ringroad to divert traffic

To reduce car use within the city, a good function ringroad can help residents to spend as little time as possible from ringroad to their house. Also, the implementation of hubs and carparks can be usefull.

Improve cycling infrastructure

Improve cycling infrastructure to stimulate residents to cycle. Reduce the number of traffic lights and other obstacles to ensure a fast route.

Test cycling infrastructure

Test the effect of seperate cycling lanes on existing roads to make a decision between shared space and split street sections.

One way roads

Assign bus lines or train connections that provide low cost or free services to important areas like the city centre or towards areas were people do not use public transport often.

Prioritize cyclists and pedestrians

Prioritize cyclists and pedestrians by giving priority at traffic lights and other obstacles. Also, inform car users about this prioritzing of cyclists and pedestrians (fietsstraat example).

Split street into sections

Split busy streets into different sections per transport mode. to increase speed on these lanes and ensure safety.

Speed restrictions

30

Reduce car speed on main city roads from 50 to 30 km/h and give priority to cyclists and pedestrians.

Type of surface

To stimulate residents to walk to public transport in dense areas, the bus stop or train station must be within 400m (bus) or 1000m (train) walking distance.

Shared space

Create a shared space that functions as a road for all types of transport. Prioritize cyclists and pedestrians and reduce speed of cars. Use at smaller and less busy roads.

TOOLBOX
Accessibility

Disallow cyclists and service vehicles

Make the inner city only accessible for pedestrians. Disallow cyclists and service vehicles during shopping hours and focus distribution of stores in early morning and evening. Always make sure emergency vehicles have access

Access control to old town

The city centre (also refered at as the old town) is most suitable for car free development. Make sure to control access to the centre. Only allow cyclists and pedestrians and use this basis for further expansion of car free areas.

Closed centre

Close the city centre during shopping hours to stimulate residents to go shopping by bike or walking. Extend these car free periods over time.

Extent pedestrian zone

Extent the pedestrian zone and take more space for walking and cycling around the city centre.

Time dependent

Make the city centre accessbile during certain times by car for distribution of stores and residents.

TOOLBOX
Pricing system

Distance based charging
Let car users pay per driven km and invest the profits in improvement of public transport.

Free public transport
Provide free public transport on certain routes or time dependend.

Congestion charges
Let car users pay for their congestion and invest the profits in improvement of public transport.

Charges for car parking at work
Let employees pay to park at work to stimulate the use of other transportmodes.

Time dependend charges
Let car users pay more during peak hours and less during off-peak hours to balance car use on busy streets. Invest earnings in public transport.

Free PT for employees
Provide free PT passes for employees to stimulate the use of bus and train connections and discourage the use of cars.

Toll earnings to invest in PT
Raise toll to enter the city and invest the profits in better public transport.

Free PT for students
Provide free PT passes for students to stimulate the use of bus and train connections and discourage the use of cars.

TOOLBOX
Facilities

Car sharing
Stimulate the use of car sharing opportunities. Reducing the number of cars in an area.

School walking distance
Make sure schools are within walking distance of residential areas. This decreases the use of cars.

Mobility hub
Introduce park and ride areas where people can transit from car to public transport or active transport. Preferably at the city edge.

Recreation walking distance
Make sure recreation areas are within walking distance of residential areas. This decreases the use of cars.

Bike storage
Implement bike storages around the city centre to stimulate the use of bicycles and increase security of bikes.

Playground walking distance
Make sure playgrounds are within walking distance of residential areas. This decreases the use of cars.

Cargo (e-) bike sharing
Provide cargo bike sharing in car low or car free neighbourhoods for transport of large things like garbage, groceries and others.

Workplace showers
Make sure companies offer the opportunity to shower at work. This can stimulate employees to use the bike to come to work, even when living an hours ride away.

Supermarkt walking distance
Make sure supermarkets are within walking distance of residential areas. This decreases the use of cars. Combine with cargo bike sharing opportunities.

TOOLBOX
Awareness

Travel plan advice

Provide persona; travel plan advice for inhabitants to increase awareness of transport mode use.

Promotion of cycling and walking

Promote cycling and walking as main transport mode within the city.

App for sustainable choices

Provide persona; travel plan advice through an app for inhabitants to increase awareness of transport mode use and make sustainable choices.

Information on interventions

Inform inhabitants on the implementation of interventions to make inhabitants aware of choices concerning sustainable travel modes.

Car free days

Introduce car free days to make inhabitants aware of the impact of cars on streets and stimulate cycling and walking in the city.

Working from home

Stimulate employees to work from home to decrease the number of transport movements and decrease the nummer of traffic jams.

E-bike subsidies

Balance density and amount of traffic. When an area is dense, decrease the amount of traffic in a neighbourhood. When an area is less dense, provide roads for traffic.

TOOLBOX
Density

Low traffic neighbourhood

Balance density and amount of traffic. When an area is dense, decrease the amount of traffic in a neighbourhood. When an area is less dense, provide roads for traffic.

Mixed use development

To reduce the number of trips, make sure to make use of mixed use developments: residential, commercial and industrial (offices).

Cluster around PT

Cluster high density areas around public transport and reduce car usage around public transport.

TOOLBOX
General aspects

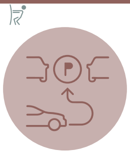
Stakeholders

To reduce the number of trips, make sure to make use of mixed use developments: residential, commercial and industrial (offices).

TOOLBOX

Parking management

Parking guidance system

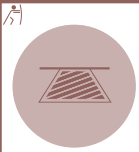


Make use of parking guidance systems that indicate parking spots that are not occupied to distribute parking trough the area. A good working system can be the basis for removing (barely used) parking spots.

Car parks for long stay

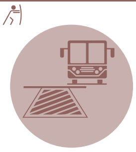
Provide car parks at the edge of the city to stimulate car parking outside of the city and traveling into the city by foot, bike or public transport.

Reduction of car parking



Slowly reduce the number of parking spots. Example of Oslo. By reducing car parkings slowly, residents are constantly looking for alternatives, such as parking outside city and using other transport modes.

Reduce parking close to PT

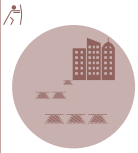


Reduce the number of parking spots near public transport to stimulate the use of public transport.

Advice companies on parking management

Advice companies on the way they arange their parking management. Combine with other transport modes and awareness towards employees.

Grading in number of parking

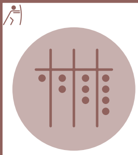


Reduce the number of parking spots from low (city centre or train station) to (relatively) high (suburbs).

Relocate to parking garages

Relocate on street parking to parking garages. Preferably, the parking garages have to be located at the edge of the neighbourhood or city.

Reduce parking norm

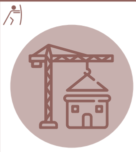


Reduce the parking norm for neighbourhoods and remove surplus parking spots. Only keep necessary parking in neighbourhood.

On street parking exceptions

Make sure parking reduction does not negatively affect disabled and visitors. Make exceptions for on street parking for disabled and visitors. Also keep in mind emergency vehicles.

No provision of parking spaces in new developments



Reduce the provision of parkingspots in and around new development. Combine with upgrading public and active transport and adding facilities.

APPENDIX IV: NEIGHBOURHOOD DECISION

	District	Alteveer-Cranevelt	Velperweg e.o.	Monnikenhuizen	Arnhemse Broek	Schaarsbergen e.o.	Malburgen-Oost (Noord)	Arnhemse Broek	Spijkerkwartier	Heijenoord/Lombok	Burgemeesterswijk/Hoogkamp	De Laar	De Laar	Rijkerswoerd	Malburgen-Oost (Zuid)	Elden	Elderveld	Elderveld	Elderveld	Presikhaaf-Oost	Velperweg e.o.	Geitenkamp	
Factor	**Neighbourhood**	Alteveer-Cranevelt	Angerenstein	Arnhemse Allee	Arnhemse Broek	Bakenberg	Bakenhof	Bij de John Frostbrug	Boulevardwijk	Brouwerijweg e.o.	Burgemeesterswijk	De Laar-Oost	De Laar-West	't Duifje	Eimersweide	Elden	Elderhof	Elderveld-Noord	Elderveld-Zuid	Elsweide	Fabrieksterrein Enka	Geitenkamp	
Nuisance (grade of multiple factors)		3.7	4.4	3.7	5.6	3.3	4.8	5.6	6	5	4.1	4.2	4.2	4.2	5.1	4.5	4.4	4.4	4.4	5.4	4.4	5.5	5
Liveability		8.1	7.8	7.7	6.7	8.4	6.7	6.7	6.8	7.9	8.3	7.2	7.2	7.3	6.6	7.6	7.2	7.2	7.2	6.6	7.8	6.2	7
Number of residents per ha		32.1	35.9	32.4	105.5	10.7	24	19.4	119	86.3	68.6	48.8	55.2	44.8	25	16.2	36.9	32.7	50	17.5	10.5	80.7	179
Number of cars per km2		1526	1540	1536	3835	606	1064		4183	3216	2926	2309	2498	1714	1041	723	1847	1281	2154	925	598	2963	681
Distance to a train station (km)		2.8	1.1	2.5	1.5	3.5	4.2	1.5	1	0.9	1	2.5	1.4	5	3.9	2.4	2.2	1.6	1.1	1.3	0.8	2.4	0

	District	Schaarsbergen e.o.	Arnhemse Broek	Klarendal	Presikhaaf-Oost	Rijkerswoerd	Velperweg e.o.	Velperweg e.o.	Presikhaaf-West	Presikhaaf-West	Presikhaaf-West	Rijkerswoerd	Rijkerswoerd	Rijkerswoerd	Centrum	Schaarsbergen e.o.	Schuytgraaf	Schuytgraaf	Schuytgraaf	Klarendal	St.Marten/Sonsbeek	St.Marten/Sonsbeek	
Factor	**Neighbourhood**	N.O. van Schaarsbergen	Nieuwe Kadekwartier	Onder de Linden	Over het Lange Water	Overmaat	Paasberg	Plattenburg	Presikhaaf I	Presikhaaf II	Presikhaaf III	Rijkerswoerd-Midden	Rijkerswoerd-Oost	Rijkerswoerd-West	Rijnstraat	Schaarsbergen	Schuytgraaf-Centrum	Schuytgraaf-Noord	Schuytgraaf-Zuid	Sint Janskerkstraat e.o.	Sint Marten	Sonsbeek-Noord	
Nuisance (grade of multiple factors)		3.3	5.6	6.1	5.4	4.2	4.4	4.4	5	5	5	4.2	4.2	4.2	5.8	3.3	4.1	4.1	4.1	6.1	5.5	5.5	4
Liveability		8.4	6.7	6.9	6.6	7.3	7.8	7.8	6.4	6.4	6.4	7.3	7.3	7.3	7.1	8.4	7.6	7.6	7.6	6.9	7.7	7.7	8
Number of residents per ha		0.1	15.4	88.7	49.1	18.8	28.5	74.3	64	80.3	53.7	50.3	28	35.7	97.1	2.9	52.9	29.5	39.7	78.9	151.7	45.7	0
Number of cars per km2		4	973	3648	2127	1124	1255	2894	2073	2755	1949	2284	1304	1720	2899	226	2129	1203	1635	3409	5016	2005	
Distance to a train station (km)		6.5	1.7	1	2.2	3.1	1.3	0.4	0.6	1	1.6	4	4.5	3.2	0.9	5.4	1.1	1.9	2	0.9	0.7	1.2	1

Graaf Ottoplein e.o.	St.Marten/Sonsbeek	.5	.7	.4	16	.9
Groene Weide	Malburgen-Oost (Noord)	4.8	6.7	56.5	2385	3.2
Gulden Bodem	Burgemeesterswijk/Hoogkamp	4.1	8.3	42.1	1970	1.7
Hazegrietje	Alteveer/Cranevelt	3.7	8.1	5	265	1.7
Heijenoord	Heijenoord/Lombok	5	7.9	45.8	1968	1.4
Het Dorp, Mariëndaal	Klingelbeek e.o.	3.8	8.2	2.4	72	2
Holthuizen	Vredenburg/Kronenburg	4.4	7.1	11.8	698	4.8
Hommelstraat	Spijkerkwartier	6	6.8	117.8	3843	0.6
Hoogkamp	Burgemeesterswijk/Hoogkamp	4.1	8.3	24.8	1149	2.3
IJsseloord	Presikhaaf-Oost	5.4	6.6	0.1		2.2
Immerloo I	Malburgen-Oost (Zuid)	5.1	6.6	64.1	2084	3.7
Immerloo II	Malburgen-Oost (Zuid)	5.1	6.6	53.8	1366	4.4
Industrieterrein	Arnhemse Broek	5.6	6.7	0.2		2.5
Janssingel	Centrum	5.8	7.1	53.3	2819	0.9
Kamillehof	Malburgen-Oost (Noord)	4.8	6.7	60.8	2156	3.8
Klarenbeek	Monnikenhuizen	3.7	7.7	6.5	253	2.3
Klarendal-Noord	Klarendal	6.1	6.9	120.1	3693	0.6
Klarendal-Zuid	Klarendal	6.1	6.9	137.7	4274	0.3
Klingelbeek	Klingelbeek e.o.	3.8	8.2	13	646	2
Kronenburg	Vredenburg/Kronenburg	4.4	7.1	65.4	2362	3.6
Lombok	Heijenoord/Lombok	4.4	7.9	60.2	2580	1.3
Malburgen-West	Malburgen-West	6.1	6.9	55.6	2140	3.1
Markt	Centrum	5.8	7.1	47.3	1481	1.1
Meinerswijk/De Praets	Malburgen-West	6.1	6.9	0.6	34	2.6
Middelgraaflaan e.o.	Malburgen-Oost (Zuid)	5.1	6.6	61.3	1940	3.1
Molenbeke	Velperweg e.o.	4.4	7.8	56.2	2422	0.7
Monnikenhuizen	Monnikenhuizen	3.7	7.7	46.6	2091	2.2
Sonsbeek/Zijpendaal	Burgemeesterswijk/Hoogkamp	.1	.3	.1		.5
Spijkerbuurt	Spijkerkwartier	6	6.8	138.1	4279	0.6
Statenkwartier	Arnhemse Broek	5.6	6.7	55.8	1830	1.3
Stationsplein	Centrum	5.8	7.1	18.6	1796	0.4
Sterrenberg	Burgemeesterswijk/Hoogkamp	4.1	8.3	41	1952	1.9
Transvaalbuurt	Burgemeesterswijk/Hoogkamp	4.1	8.3	80.7	3509	0.9
Utrechtsestraat	Centrum	5.8	7.1	50.2	1438	0.3
Van Verschuerbuurt	Arnhemse Broek	5.6	6.7	135.2	5184	1.4
Velperweg-Noord	Velperweg e.o.	4.4	7.8	94.3	4075	0.8
Vredenburg	Vredenburg/Kronenburg	4.4	7.1	47.5	1961	4
West van Schaarsbergen	Schaarsbergen e.o.	3.3	8.4	0.4	12	4.9
Weverstraat	Centrum	5.8	7.1	107.2	3715	0.9
Winkelcentrum Presikhaaf	Presikhaaf-Oost	5.4	6.6	33.1	932	1.2
Zeegsingel e.o.	Malburgen-Oost (Zuid)	5.1	6.6	81.8	2963	3.3
Standard dev		0.8	0.6	39.0	1308.7	1.4
Average		4.8	7.3	51.9	2104.7	2.1

APPENDIX V: SKETCH DESIGN GEITENKAMP

APPENDIX VI: SKETCH DESIGN KLARENDAL-ZUID