MASTER

The Potentials of Densification in Aiding the Mobility Transition

Strategies for the redevelopment and planning of dense neighborhoods applied in the context of Eindhoven

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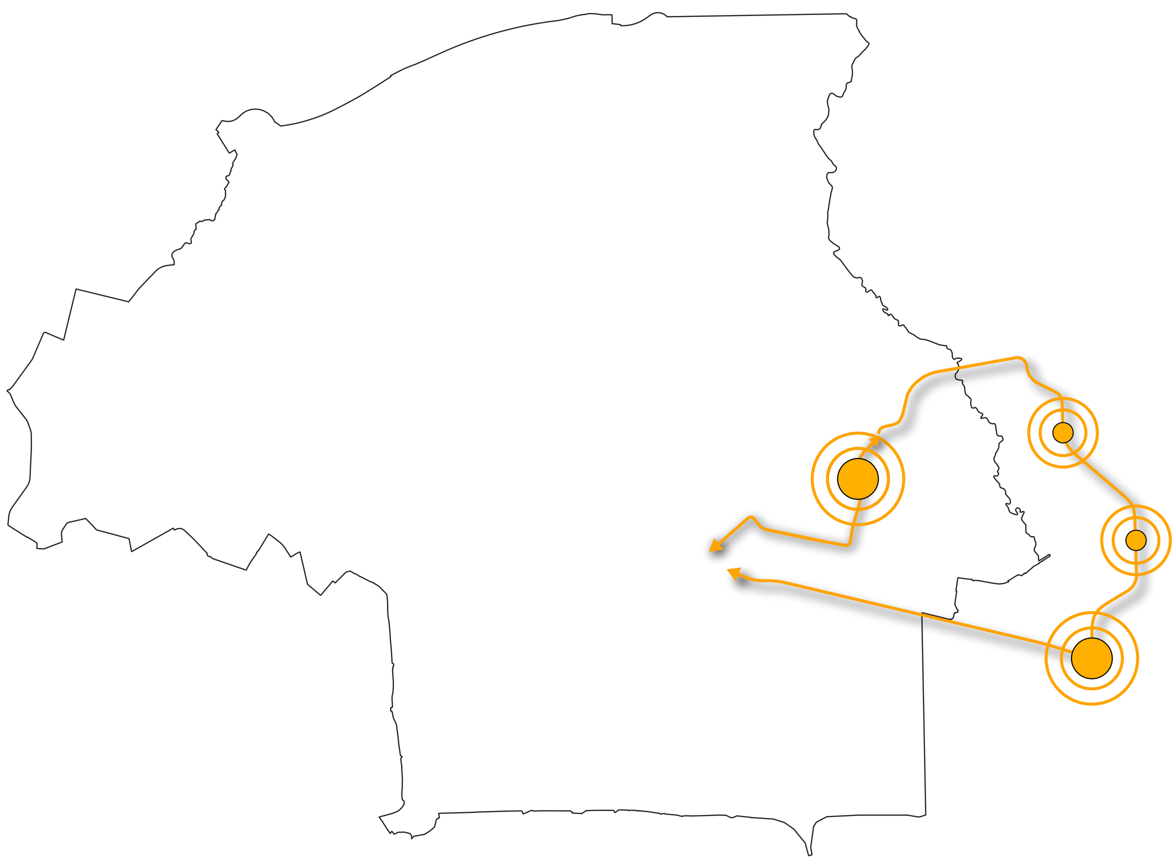
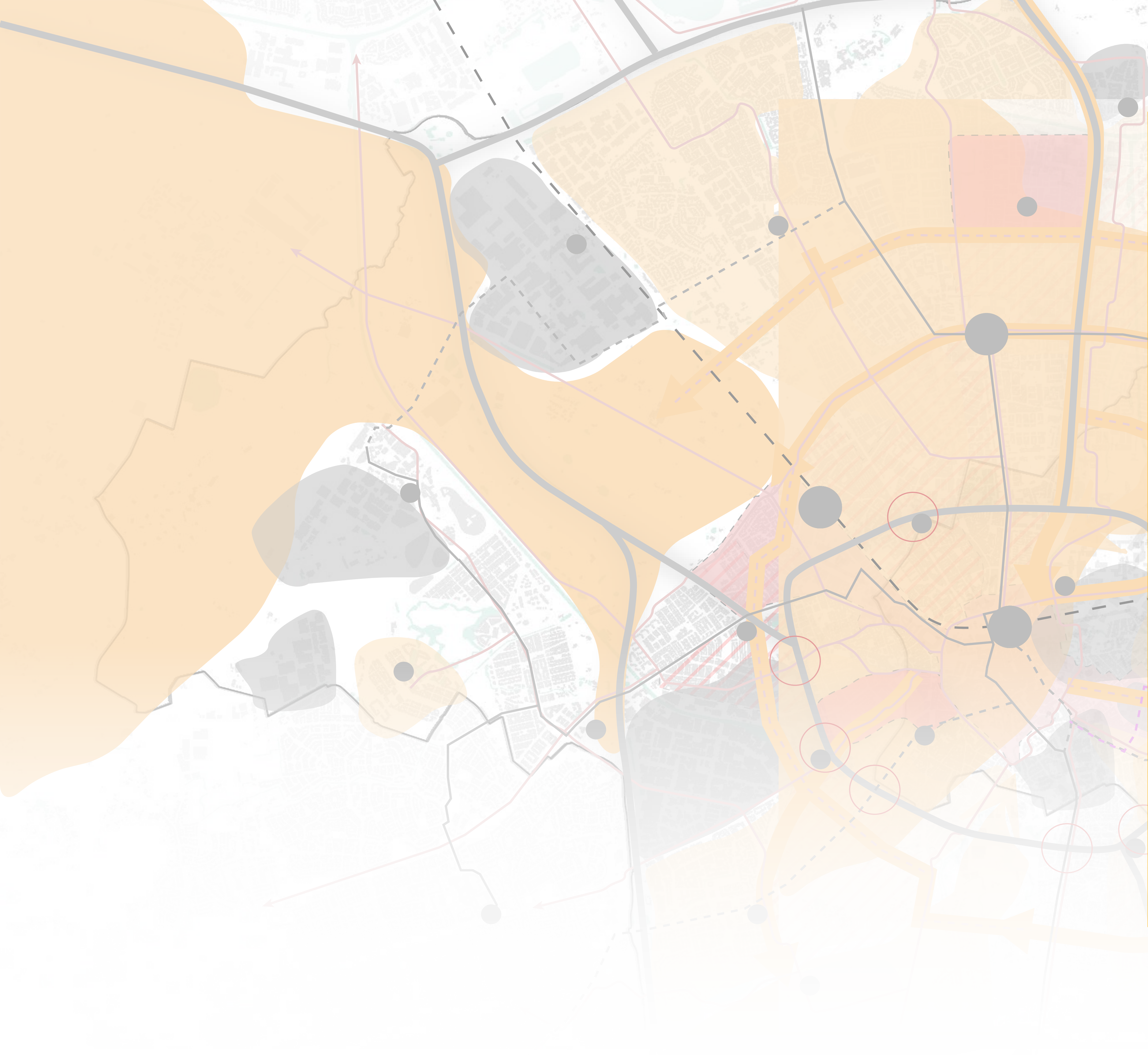
Master thesis

Tom Rous



June 2023

Eindhoven University of Technology (TU/e)
Department of the Built Environment



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Master thesis

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Graduation studio 'Density and Other Matters' 2022 - 2023

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Preface

"The potentials of densification in aiding the mobility transition, Strategies for the redevelopment and planning of dense neighborhoods applied in the context of Eindhoven" is written as the final product of my master program Architecture, Urbanism and Planning at the Technical University of Eindhoven. Presented within this report is the work performed during the studio "Density and other matters", which started in September, 2022 and will come to an end in June, 2023. The topic of transportation and networks has always been one of great interest to me, and the mobililty transition is a relatively new and exciting prospect for many cities. Limited research to date has been performed in order to study the effects and benefits of travel modes associated with the mobility transition, especially shared mobility. Personally, I think that designing cities in such a way that private car use becomes non-essential would be a great aid in alleviating not only congestion and strain on the transportation system, but also creating more liveable and sustainable cities in general.

I want to thank my tutors during this studio, Dena Kasraian and Gamze Dane for their enthusiasm, involvement and shared knowledge in our nearly weekly sessions. I also want to thank Pieter van Wesemael for his valuable feedback and suggestions during key moments within the studio. Furthermore, I did not take part in this studio alone, and would like to express my gratitude to my fellow students for their helpfulness and insights, especially in the first half of the studio. Lastly, I would like to thank my family for their encouragement and support.

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The potentials of densification in aiding the mobility transition

Strategies for the redevelopment and planning of dense neighborhoods applied in the context of Eindhoven

Key words: mobility transition, urban plannin, modal choice, densification,

Cities all over the world are in need for a more sustainable transport system, as is often highlighted in research and publications on the subject of transportation and mobility. Lowering greenhouse gas emissions, creating a safer environment, and encouraging people to live a healthier lifestyle are all goals attributed towards the mobility transition. Policies, information and awareness, but also the built environment can influence this process. The densification of cities puts the mobility sector under even more stress, as a larger amount of people have to use the same public domain. However, this also provides opportunities as population thresholds for services such as larger scale public transportation or centralized shared mobility infrastructure can be reached. A review of established systematic literature is performed to determine the most important factors and indicators on satisfaction and modal choice of more sustainable transportation methods, suitable for a dense city. Spatial analysis will investigate on these findings in the context of Eindhoven and provide the basis for the creation of a strategy to aid urban planners in the development of dense neighborhoods, with the aim to aid society in the mobility transition. The findings of the research will be used to develop a city-scale planning approach for Eindhoven, with a particular focus on the Eastern part and connections to surrounding employment and residential hubs. The type of interventions are focussed on strengthening green and transportation networks in Eindhoven, and creating a safer mobility system. A section of the neighborhood of Doornakkers will be further investigated, and used to display a proof of concept.

Introduction

Cities globally are making the transition to a more sustainable transportation system, but are as of yet often doing so via smaller scale initiatives (Nikolaeva et al., 2019). The reasoning behind this change is multidimensional. Firstly, the pressing need to reduce global greenhouse gas emissions is a driving factor across all sectors of society, and mobility is most certainly one of them, being responsible for over half of all emissions in European cities (Kuss & Nicholas, 2022). Recent research has shown that a reduction in car usage has the highest potential of reducing emissions in cities. Secondly, active transport has been shown to greatly contribute both to physical and mental health, especially when done in an attractive environment (De Oliveira, 2017). Lastly, the growing awareness that the increased densification in European cities cannot be supported by a society that is overly reliant on the private car as a primary means of daily travel. Car users require on average 3.5 times more physical public domain space than non-car users (Creutzig et al., 2020).

The mobility transition is a radical, systematic transition towards more sustainable forms of mobility, defined based on a need for reductions in greenhouse gas emissions, while also being affordable and accessible to the full population, including goals for health benefits associated with active travel modes (Axsen & Sovacool, 2019)(Nykvist & Whitmarsh, 2008)(Kuss & Nicholas, 2022).

Several factors, including the built environment, affect what mode of transport an individual chooses to use for their transportation. Currently, a majority of the built environment in cities is built to accommodate the car and its users, often to the detriment of walkability or cycling infrastructure (Creutzig et al., 2020). Environments that are made to support fast and efficient car travel are not enjoyable, safe, or interesting for pedestrians and cyclists (Southworth, 2005). Environments that are easy to read, pleasant to walk through, and offer a variety of visual activity and functions are vital when it comes to the walkability of a city, and large parking infrastructure for cars can seriously hamper these qualities.

The increasing densification of European cities calls for a new approach to dealing with personal transportation. Densification can be defined as a set of indicators related to floor space usage and land use intensity (Pont et al., 2010), but also as a means to counteract the effects of urban sprawl, by providing higher density housing, mixed use, well-functioning public transport and the promotion of active travel modes (Haaland & Konijnendijk, 2015). The city of Eindhoven in the Netherlands is currently aiming to densify, with several initiatives and visions in place to achieve this (Gemeente Eindhoven, 2020b). These plans include the addition of between 35000 and 40000 new living spaces. Out of these, the municipality has concluded that only 20000 of those can feasibly be realised in the city's center, meaning that an additional 20000 will have ot be realised in neighborhoods outside of the city ring (Gemeente Eindhoven, 2020b). While densification puts more pressure on the current transport infrastructure in the sense that more people will have to utilize the same amount of available road space, it also brings a lot of potential when it comes to land use and mixed-use development. The presence of local facilities and amenities such as restaurants, cafés, shops and job opportunities has been shown to be one of the main driving factors for an increase in walkability and cyclability (Wang et al., 2016). This is shown to be especially important for older adults, a demographic group that is only projected to become larger in the near future (Luiu et al., 2018).

Whilst mobility patterns and the need for a more sustainable transport system are meticulously documented and researched, the impact of the built environment on the wide range of sustainable transport methods across society is lacking. Research is often based on a specific demographic target group, including but not limited to older adults, disabled people, or even gender and sexuality (Barnett et. Al. 2017) Furthermore, research is often focussed on a specific mode of transport, and not all-encompassing (Axsen & Sovacool, 2019). A combination of all findings across the fields is often superficial and lacking in depth, with little direct and specific design takeaways. The established systematic literature reviews on transportation and more specifically modal choice, often state that their findings could be useful for design and policy making, but don't specify how exactly, understandably so, given that that is not their primary objective. On top of this, even if such measures and guidelines were to be given, they would undoubtably not be directly applicable to the city of Eindhoven, the focus of this research.

One concept that has gained a lot of attention recently is the implementation of mobility hubs. Throughout policy and strategic visions from municipalities, the mobility hub is proposed as a solution to pressure on the transportation network and congestion, poor livability in cities and limited urban space in dense areas (Rongen et al., 2022). Within the mobility transition, mobility hubs could serve as an important intervention since it enables multi-modal transport with increased conveniency. Literature on how effective they are is currently limited however.

Through a review of systematic literature, the aims of this research will be to find out to what extent the built environment has been proven to have an effect on the satisfaction and modal choice of a variety of transportation modes. Particularly those modes promoted by the mobility transition, while simultaneously comparing these objective findings to perceived findings from surveys included in the findings of the literature reviews, to see if there are any significant differences. The review also identifies the most important positive and negative indicators for the choice of each mode of transport, and how they could possibly aid or clash with each other in a set of design guidelines for the built environment. These guidelines will be the ultimate goal of this research, and will provide the basis for a city-scale strategy for Eindhoven based on improving transportation networks and accessibility, including new opportunities for shared mobility. This will lead into a design proposal for the development of a neighborhood in Eindhoven with the desired outcome of aiding the mobility transition, and thus achieving some of the sustainable development goals associated.

This paper then aims to answer the following research question:

"How can the built environment aid the mobility transition in a densifying city in order to achieve sustainable development goals?"

Several sub-questions follow from this main question and are formulated in such a way that they contribute to finding the answers required to properly address facets dealing with the main question:

1. To what extent does the built environment affect on the entire scope of travel?

2. What are the most important indicators affecting modal choice and satisfaction levels of active, public or other forms of sustainable transportation?

3. Could these indicators be used to establish an operationalized conceptual scheme?

4. can a set of guidelines be established to aid in the design of high density neighborhoods when it comes to aiding society in moving forward with the mobility transition in the context of Eindhoven?

5. Could such a set of guidelines be applied to a conceptual neighborhood design in Eindhoven, outside of the inner ring?

Such a set of guidelines could be useful for a wide range of cities who are facing similar issues to Eindhoven. Furthermore, the review and synthesis of literature of different transportation modes combined could aid further research to delve deeper into all-encompassing studies that benefit the entirety of the mobility transition and thus society via sustainability goals and livability in cities. The finalised conceptual design could also serve as a case study and example for what might be possible in neighborhoods with similar features. The outcome of the research could aid design of the built environment in such a way that it improves liveability according to at least three different sustainability goals, as proposed by the UN in 2015 (Sustainable Development Goals | United Nations Development Programme, 2015). Namely; Goal 3, Good health and wellbeing, Goal 10; reduced inequalities, and Goal 11, Sustainable cities and communities.

These sustainable development goals not only aim to achieve a higher degree of social equality, but also making both cities and communities more sustainable. Replacing motorized travel with active transport methods has been proven to have health benefits for both mental and physical wellness (Oliveira, 2017), (Bell et al., 2002). Public transportation and shared mobility have the potential to further decrease the amount of car traffic per person, and alleviate both the pressure on the daily mobility system, as well as alleviating some aforementioned environmental issues (Kuss & Nicholas, 2022).

This paper is structured in such a way that first a theoretical framework combined with a simple visual conceptual scheme is presented, following with an explanation of the methodologies used. A review of established systematic literature reviews is performed, in which the indicators for modal choice and satisfaction of sustainable transport choice are the attention points.

The results of the review will be used to operationalize the conceptual scheme into a more robust version. A policy analysis regarding current and future planning for the municipality and surrounding regions will be discussed. A spatial analysis of Eindhoven will explain the context of the city and together with the takeaways from the research will lead to the finding of most optimal intervention areas. Lastly, the results are discussed and a conclusion is drawn. Figure 1 Displays the steps taken in the research and methodologies used. The design part will be discussed in the last part of this report, and is structured seperately.

Methodological scheme

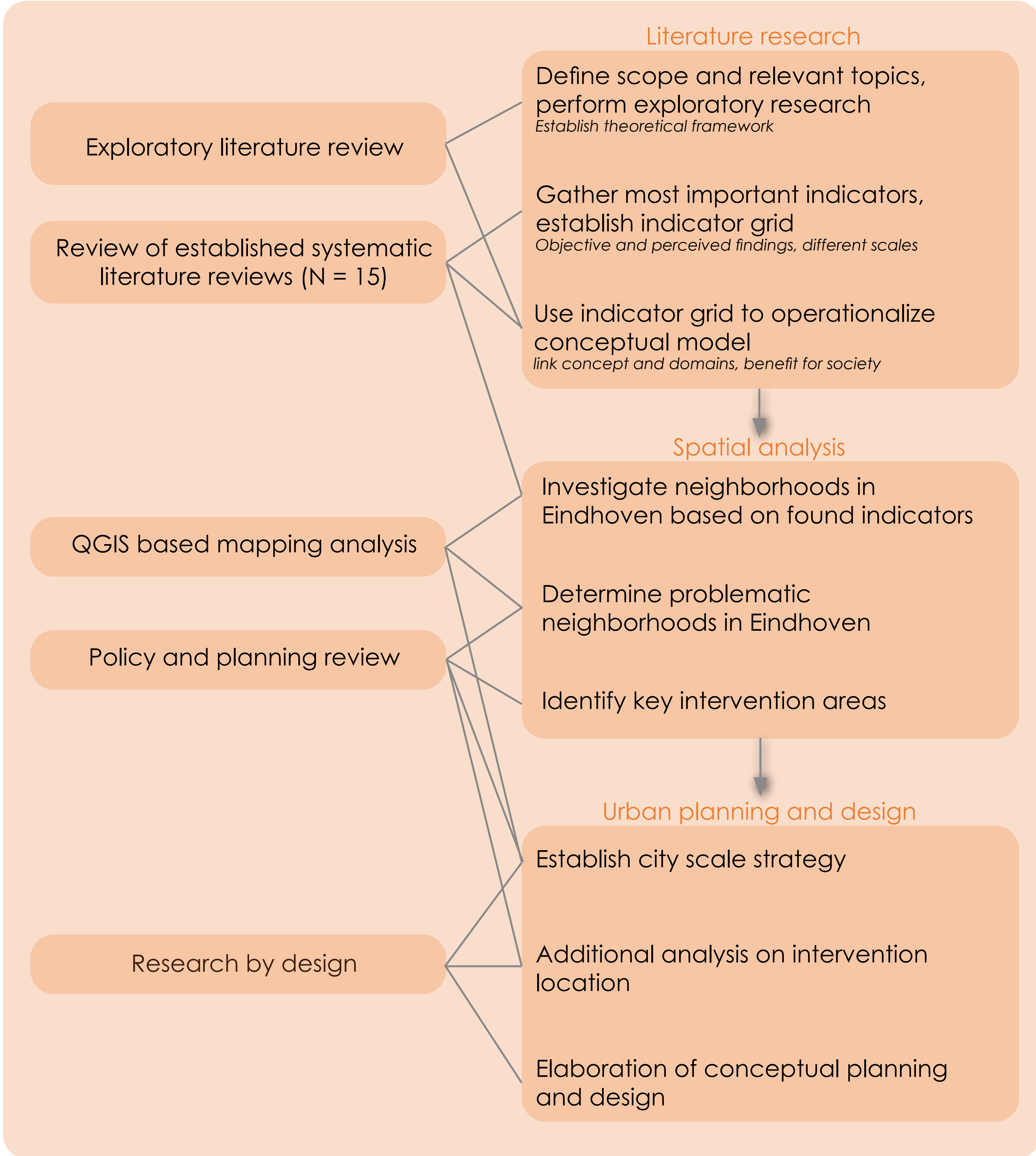


Figure 1, Methodology.

Theoretical framework

For the purpose of establishing a theoretical background the land-use transportation feedback cycle (Wegener, 1995) is considered. The scheme offers a basis for the connections of several important topics in this research paper, as it explains the relations between travel behaviour and features of the built environment, such as land use and accessibility, which are vital for the understanding of how a potential design could aid the mobility transition. The scheme explains that the distribution of activities creates a need for travel, and that the pattern of these travels creates accessibility, which then in turn influences the decision-making process of developers and firms when it comes to choosing a location and affects where people decide to live. This in turn influences the distribution of activities, creating a circular causation pattern. The scheme is displayed in figure 2. A simplified version is displayed in figure 3, as described by Wegener & Fürst (2004). This version was adapted to be used as a baseline version for the research performed in this paper, and to serve as a starting point for the eventual operationalized conceptual model.

One of the major themes in this research, densification, has large implications on this scheme and on both land use as well as transportation and mobility. While density itself is not strongly linked with travel and activities directly, associated factors definitely are. Ewing & Cervero, (2010), analysed effects of the built environment on travel variables, and found that while density itself is only mildly linked to changes in travel patterns, associated variables show a much stronger relationship. They state that the living environments of dense neighborhoods often come with mixed-use settings and centralized service locations, as well as shorter travel distances, all of which were shown to have a larger relationship with travel behaviour. In their research, measures of the built environment were categorised in several variables, called the D's. The first distinction only covered three of such groups, which were density, diversity and design (Cervero and Kockelman, 1997). Further research has expanded these D's, and for this paper, the following five D's will be used to group measures of the built environment; density, diversity, design, demographic and destination accessibility. These D's will be used to group indicators in the literature review performed in the paper.

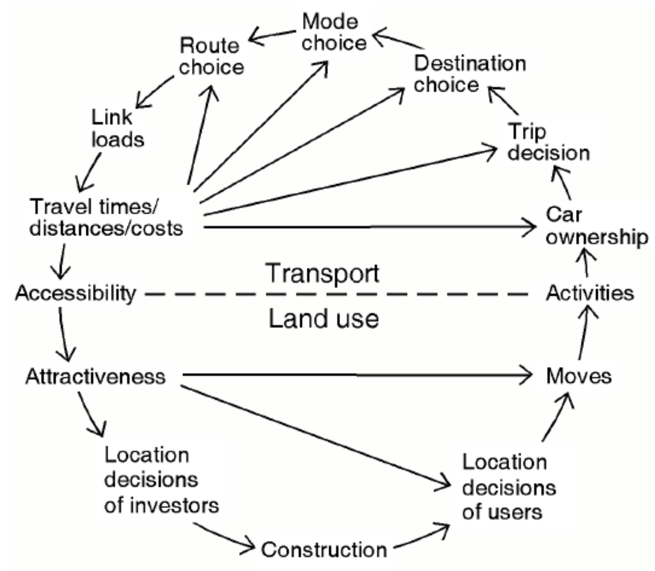


Figure 2, The 'land-use transportation feedback cycle' (Wegener, 1995).

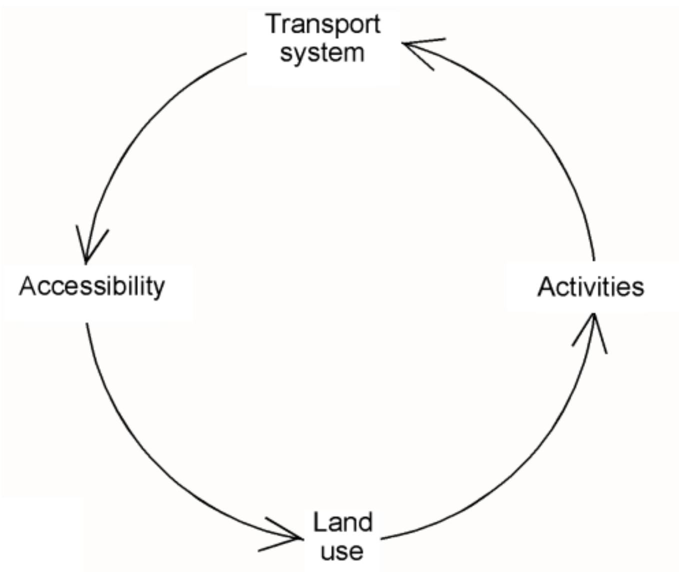


Figure 3, The 'land-use transportation feedback cycle' (Wegener & Fürst, 1999).

Literature review

In order to find the indicators required to operationalize the conceptual scheme, a review of established systematic literature reviews is performed, after which an indicator grid is made which will highlight the indicators mentioned in the literature. The reason a review of established literature is done is due to the fact that the topic of transport and mobility has such a rich and saturated amount of literature already available, but the exact information required needed to be extracted from a combination of sources. To include an even larger amount of information and data, the decision is made to review systematic literature reviews, as each one of these already has a vast amount of data and reference material included. In order to gather relevant conclusions on current affairs and newly introduced transportation methods, only systematic literature reviews from the past 10 years are included in the review. Furthermore, only literature in English was considered.

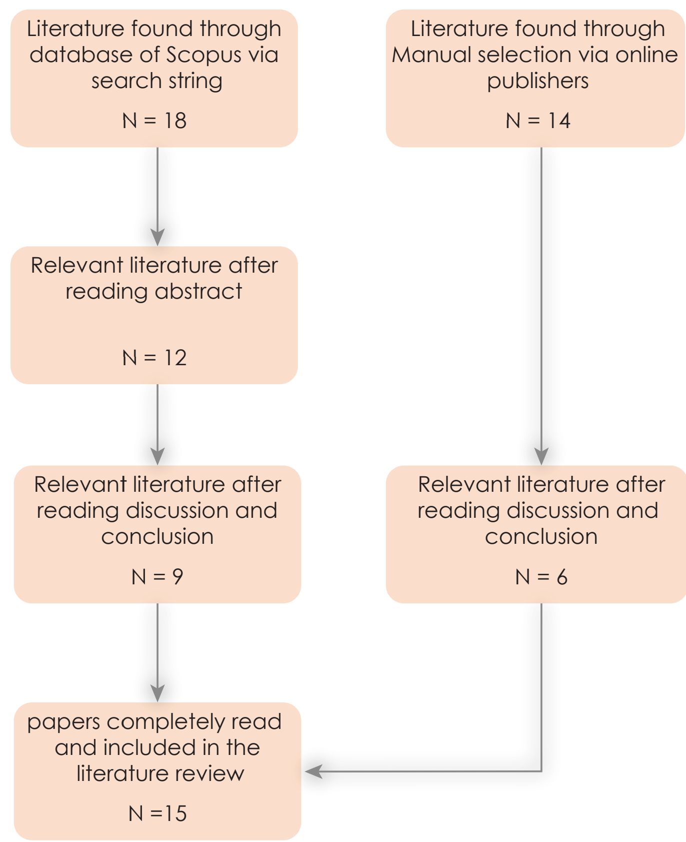


Figure 4, flowchart of the literature selection process.

The search strategy included extraction via the online source of SCOPUS and manual selection of articles from well-known and established journals such as Sustainability or Cities. This resulted in a selection of 31 articles, which after reading the abstract, discussion and conclusion chapters was reduced to 15 relevant papers, which were ultimately included in the literature review. The reason for excluding some literature was because their results did not touch upon modal choice or satisfaction levels or did so in a manner too superficial for this research.

The findings of the literature review will be presented in a literature grid, showcasing the different indicators that are mentioned in the literature to have an effect on travel mode choice or satisfaction of said mode, divided in an established system based on the 5-D's as described by Ewing and Cervero (2010). As mentioned earlier, these categories are Density, Diversity, Design, Destination accessibility and Demographics. This distribution helps with visually separating the indicators into relevant categories for integration in the conceptual scheme as well as making the grid more easily navigable and comprehensible for the reader. Ewing & Cervero (2010), do confess that some ambiguity is present within these distinctions, and that some areas could overlap and might change in the future.

The chosen reviews are all relatively recent and within the last two decades, meaning that findings should still be relevant for the most part. It should be noted however that several forms of transportation such as shared e-bikes and scooters are more recent developments and research into how these modes of transport affect the urban system are still ongoing, perhaps leading to incomplete results or only preliminary conclusions. This review was performed to gain a better understanding in what the most important indicators might be for modal choice and satisfaction of the transportation modes associated with the mobility transition. Furthermore, a distinction is made between objective data-based findings and perception-based data findings through survey and people's responses.

This was done with the purpose of finding out if there was a significant difference between these two sets of results, which could be interesting for the outcome of this research but also further research. The identified literature focusses on several modes of transport, which have been categorised in four different groups, namely; walking, cycling, public transport and sharing principles such as e-bikes, scooters but also carsharing. These are all modes of transport relevant to the mobility transition.

At the top of the grid, which can be seen in table 1, the division based on mode of transport is made, with the columns underneath the headings stating which paper found a connection with that mode of transport and a certain indicator, which are displayed on the left side of the grid, divided within the groups as per the 5 D's. the right side of the grid indicates on which scale this connection is relevant. Positive connections have the reference number of the paper with a '+' sign, negative connections have the '-' sign, again followed by the reference number of the associated research paper. The paper associated with each specific relation found, including the reference number, can be found in appendix 1. If there were only positive connections mentioned in all papers, the box is coloured dark green for easier reading comprehension, the same was done with dark red for only negative connections. A mix of results lead to a gradient of those colours, with mostly positive being light green, equal positive and negative white, and mostly negative pink. The column directly right of the indicator shows if the findings in that row are objective data based, or perceived and subjective. Grey boxes indicate that in the papers no connection between that mode of transport and indicator was found, with dark grey boxes indicating that such a relation most likely does not exist or is not applicable in the context of this research. For example, the affordability of "walking", since this is an essentially free mode of transportation at it's core. Another case would be the "comfort of service" of walking, since a main aspect influenced by the built environment is already covered by "quality of infrastructure".

Density

the indicators associated with density are shown to have an overall positive relation with travel modes connected to the mobility transition. (Abduljabbar et al., 2021) found that having to travel shorter distances was positively related with people choosing to walk or cycle to their destination, and that shared mobility, especially e-bikes and e-scooters, were highly suitable alternative travel modes for shorter distances. Saelens et al. (2003) found that for both cycling and walking, a higher degree of urban density and shorter distances from departure to destination had a strong positive relation with people choosing to walk or cycle instead of using a private motorised vehicle. On the other hand, other shared forms of mobility, such as private carsharing, were found to be more suitable for travelling longer distances, and the time it took to set up travel in such a manner was often unproportional to the time saved compared to walking or cycling for shorter distances (Mitropoulos et al., 2021). Higher urban density often meant that the distance from a person's residence to a public transportation stop or dedicated cycling infrastructure was lower, resulting in a higher degree of participation in these travel modes (Luiu et al., 2018) (Mitropoulos et al., 2021).

Diversity

The found indicators associated with diversity are proximity of green space and facilities at destination. The term "mixed-use" could be applied to the latter of these, however many of the source literature reviews do not specifically call it as such. Barnett et al. (2017) found that for older adults the use of active modes of transport was strongly related to having a range of services available at their destination, meaning that it was crucial for their physical activity to have the services they used be within cycling or preferably walking range from their homes. One of the research papers included in their review does however state that while higher urban density tends to bring facilities and services closer to people's homes, it may not always be beneficial for the cyclability of the area,

"D" variable	Indicator	O/P	cycling	walking	public transport	Shared mobility	regional	city	nbh.	street	importance
Density	Shorter distances	o	+ [1, 14]	+ [14]		+ [1, 12], - [5]	X	X	X		++
		p	+ [4, 11]	+ [11]		- [12]					
	High urban density	o	+ [14]	+ [7, 14]		+ [3, 5, 12, 13], - [12]	X	X	X	X	++
		p	+ [4, 11]	+ [11]							
	shorter Distance from departure to dedicated infrastructure	o	+ [4]			+ [3, 5]		X	X		+
		p			+ [11, 12]						
Diversity	Facilities at destination (Shops, recreation, education, work)	o	+ [4, 12, 14]	+ [2, 12, 14]	+ [12, 15]	+ [1, 5, 13]	X	X	X	X	+++
		p	+ [1]	+ [2]	+ [15]	+ [3]					
	Proximity of green space	o	+ [4]	- [7]				X	X	X	+
		p		+ [2]							
Design	Separation from other traffic modes	o				+ [1]		X	X	X	++
		p	+ [4, 11]	+ [11]	+ [11]						
	Dedicated infrastructure	o	+ [1, 4, 9, 14]	+ [2, 9, 14]		+ [1, 5, 13]	X	X	X	X	+++
		p	+ [10]	+ [2, 10, 11]	+ [6]						
	Quality of infrastructure	o	+ [1]				X	X	X	X	+
		p	+ [9, 11]	+ [9, 11]							
	safety from crime	o		+ [2]		+ [1]	X	X	X	X	++
		p	+ [10, 11]	+ [2, 10, 11]	+ [11]	+ [12]					
	Traffic safety	o		+ [11]		+ [1]	X	X	X	X	++
		p	+ [6, 10]	+ [10], - [6]							
	Steep inclines	o	- [1, 11]	- [11]		- [1]			X	X	+
		p									
	Protection from weather	o					X	X	X	X	+
		p	+ [10]	+ [10]							
Demographic	Age of user	o	- [11]	- [11]	- [11]	+ [12], - [1, 5, 12]	X	X	X	X	++
		p	- [10]	- [10]							
	(Long-term) Health issues	o	- [11]	- [7, 11]	- [11]		X	X	X		++
		p			+ [11]						
	Gender (female)	o				+ [12]	X	X	X		+
		p				+ [1]					
Destination accessibility	Affordability	o	+ [8]		+ [9, 11]	+ [1, 5, 12]	X	X	X		++
		p			+ [8, 11]						
	Monetary Incentive	o			+ [9]			X			+
		p									
	Reliability of service	o			+ [9, 11]	+ [5]	X	X	X		+++
		p			+ [11, 15]	+ [12]					
	Availability of service	o			+ [2, 8, 9, 11]	+ [1, 5, 9, 13]	X	X	X		+++
		p			+ [2, 6, 11, 15]	+ [12]					
	Comfort of service	o				+ [12]	X	X	X		+
		p			+ [11, 15]	+ [12]					
	Awareness and information	o	+ [9]	+ [9]	+ [9]	+ [9, 12, 13]	X	X	X	X	+++
		p	+ [1, 8]		+ [11]						

- positive relation
- mostly positive relation
- neutral relation
- no relation found
- negative relation
- mostly negative relation
- not applicable
- [N] paper reference number

Table 1, Indicator grid from literature review.

especially for older adults (Van Cauwenberg et al., 2012). For the feasibility of public transport and shared mobility, it was almost a necessity to have facilities be present at their major stops and end destinations. (Saif et al., 2018) Furthermore, Dibaj et al. (2021) found in their review that shared mobility was often used as a first-mile and last-mile trips, essentially bridging the gap between the more static and inflexible public transport system and their final destination. The main incentive for doing so was found to be because it was a significant timesaver. Green space is an indicator that is very open to interpretation, but for the purpose of this research, green spaces are defined as anything from parks, open green spaces, gardens or streetside trees (Haaland & Konijnendijk, 2015) (Kabisch & Haase, 2014).

Design

The indicators associated with design are naturally highly interesting for the field of urban design and planning. Separating distinct types of transportation on their own travel lanes was found to be positively influential on people's modal choice and satisfaction level for every transport mode considered. It should be noted that separation from traffic is not inherently the same as having dedicated infrastructure, as a bike lane can still be directly adjacent to a car lane with no physical barrier or space separating the two. Fraser and Lock (2011) found separating bike traffic from other modes of traffic was positively influential for people's decision whether or not to use a bike, but also found that having dedicated infrastructure in place, I.E., bike lanes, was even more beneficial. Luiu et al. (2018) also found this to be the case for walking and cycling amongst older adults, and it also goes hand in hand with older adult's perception of traffic safety. Especially for older adults, ensuring bike lines are made of sufficient quality was essential, as it made them feel safer and more comfortable in electing to use active travel modes. Lorenc et al. (2008) found that in households with children and parents, dedicated cycling lanes made them feel both more safer as well as more confident in choosing to cycle to work or school.

66% of the included literature reviews discussed dedicated infrastructure in some regard, and the entire spectrum of travel modes is included, making it the most common type of indicator included in the grid. High quality bike lines and pedestrian walkways were mentioned for active travel, but also shared mobility was found to benefit from having some permanent and centralized infrastructure in place to service people (Golbabaei et al., 2021). Traffic safety and safety from crime were cited by five literature reviews as important indicators for people choosing to use a certain mode of transport or not. Barnett et al. (2017) state that they their reviewed literature pointed out that especially women found the shared mobility form of e-scooters to be interesting because it made them feel safer travelling from both traffic and crime as opposed to regular public transportation and active travel modes. Having steep inclines or hilly landscapes was found to be hugely detrimental for people deciding whether to cycle or walk to their destination (Abduljabbar et al., 2021) (Mitropoulos et al., 2021). Additionally, bad weather conditions were found to be a major factor when considering to cycle or walk (Lorenc et al. 2008). Protection from weather in bike storage places or mobility hubs could alleviate some of the discomfort.

Demographic

in terms of demographics, only a small number of indicators was included in the scope of the research. For instance, neighborhood household income and employment levels were not considered, and when research pointed out that more wealthy residents preferred a certain mode of transport, that was instead sheared under affordability of transport in the destination accessibility category. The main findings regarding demographics state that health issues are often found to be detrimental when it comes to satisfaction and modal choice of transport modes associated with the mobility transition. For example, Jardim and De Castro Neto (2022) found that in some research neighborhood walkability and people choosing to walk was related with the overall physical wellbeing in the area. Furthermore, while long term health issues were found to negatively affect people's decision to walk or cycle, making changes to enhance walkability and cyclability in neighborhoods was found to have a much larger effect on people with a disability, and even encouraged those people to use public transport more (Jardim & De Castro Neto, 2022) (Luiu et al. 2018). Two reviews also pointed out that women were more likely to use certain modes of shared mobility (Abduljabbar et al., 2021) (Mitropoulos et al., 2021).

Destination accessibility

This category is the most ambiguous, and concerns not only built environment and physical indicators, but primarily policy related variables. The most commonly found indicators concern reliability and availability of public transport and shared mobility. People were hesitant to rely on public transportation when timetables did not suit their travel pattern or if the service often had issues. Naturally, people were found to use modes of transport more often if such a service was in place in the vicinity of their homes. More importantly here is the fact that four different literature reviews synthesised that survey results showed people would use public transport if they were able to, but that a convenient system was not in place for them currently (Barnett et al., 2017) (Hoffmann et al., 2017) (Mitropoulos et al., 2021) (Van Cauwenberg et al., 2012).

Awareness and campaigns to promote certain types of transport were also found to be generally positively related to people using a certain mode of transport. For example, Kuss and Nicholas (2022) found that both monetary incentives to bike to work from people's employers as well as promotion campaigns to use active modes of travel had a positive impact. With shared mobility and micro-mobility as a concept being relatively new, the availability and accessibility of information was found to be a large barrier to entry, as users were often unaware or unsure of how to find or apply to bike sharing programs, or found the software related to the mobility program too complicated and difficult. (Kong et al., 2021) (Mouratidis et al., 2021)

Conceptual model

Through the findings of the literature review and the established literature grid, important indicators associated with satisfaction levels and modal choice of transportation modes associated with the mobility transition were gathered in such a way that they could be grouped more easily. This in essence sets the basis for an operationalizable conceptual scheme. The land-use transportation feedback cycle (Wegener, 1995) was used as a basis to work from, and the relations of density, diversity, design, demographics and destination accessibility could be deduced from the scheme, as well as from the literature reviewed in this research. As a starting point, the conceptual scheme was altered in such a way that densification and the mobility transition were directly opposite to each other, while still showing how they were cyclically related. This new simple scheme can be seen below.

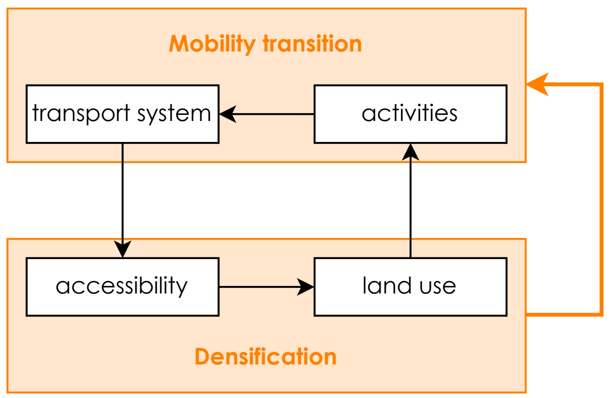


Figure 5, simple conceptual model adapted from land-use transportation feedback cycle (wegener, 1995).

This simple version of the conceptual scheme shows how through densification, the mobility transition can be affected. How exactly this happens, and what direct benefits for society can be gained is explained via the operationalized conceptual scheme, visible in figure 6. Through densification, several different design principles and increased (local) diversity lead to a change in the transportation system and travel methods. Stimulation by policy can change destination accessibility via the indicators seen in the indicator grid, and has a wide ranging effect on the entire system. One variable in this grid that has so far not been mentioned specifically is the electric car. Electrification of the transportation sector is often cited as a means to reduce global greenhouse gas emissions. However, it goes directly against some of the goals associated with the mobility transition, and a much better approach is a large scale reduction of car-usage in general (Winkler et al., 2023)

Not only do electric vehicles directly require more urban space to function because of additional infrastructure requirements, In order to make them actually sustainable and contribute to a reduction in greenhouse gasses, the energy used to power them must come from renewable sources. Electrifying only the current fleet of private cars would require an area of up to twice the size of the Netherlands to be filled with wind turbines for Europe alone. (Orsi, 2021)

The model shows how the different indicators and their domains affect each other, and several individual links have been highlighted where of relevance, like the relation of the electric car mentioned earlier. The goals associated with the mobility transition are shown on the right of the model, and lead to an increase in human wellbeing on both physical and mental health.

However, this conceptual model alone can not provide a direct answer to a design question or a problem within the city. The concepts are too broad and the links are near impossible to quantify or directly relate to other links. On top of this, the built environment is always highly contextual. Therefore, a spatial analysis is required to be able to use it and to see which interventions are required.

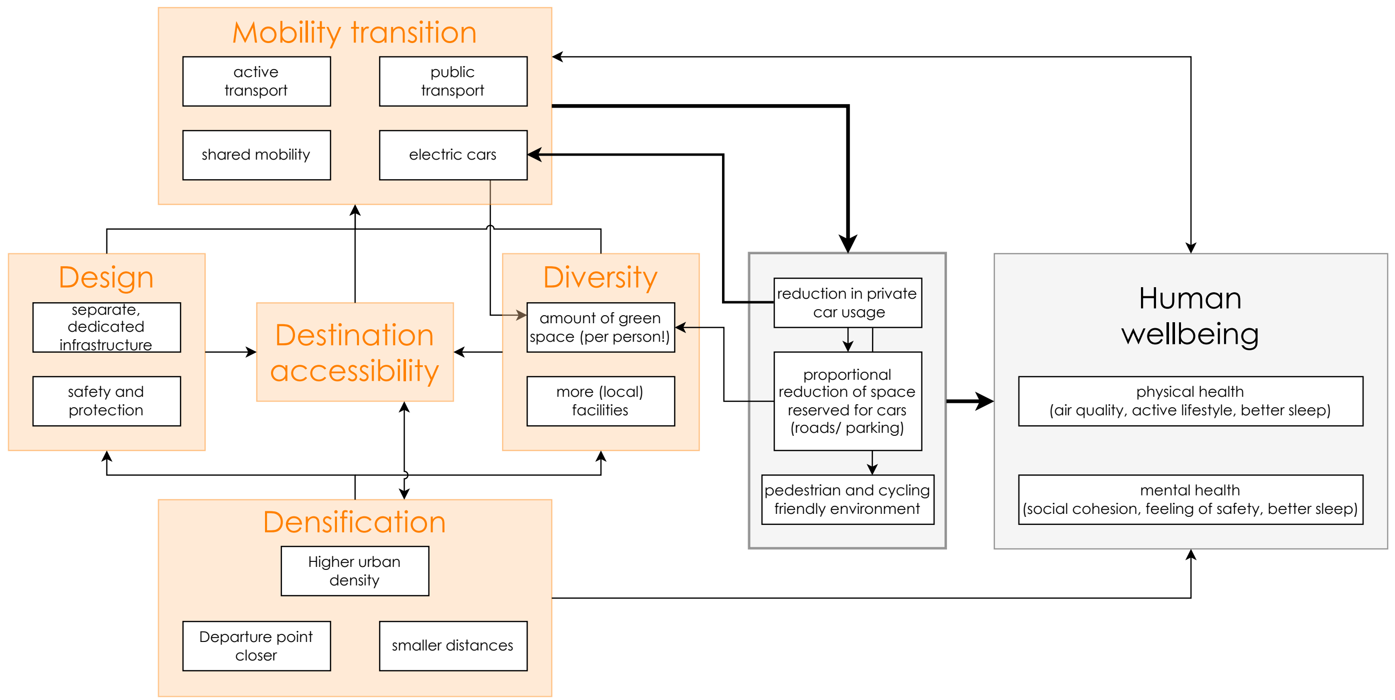


Figure 6, Conceptual model with indicators from literature review.

Spatial Analysis

The software of QGIS will be used to make data-based maps on several topics uncovered during the literature review. Using the conceptual model as well as the indicators found in the indicator grid, a spatial analysis is performed on the context of Eindhoven's neighborhoods. The relative importance of the indicators is judged based on the frequency of that indicator being found within the reviewed literature. For example, the demographic indicator of "gender" was mentioned far less frequent (n=2) compared to the design indicator "dedicated infrastructure (n=15).

Eindhoven is subdivided based on the geographic division of neighborhoods, resulting in 109 different sections. For closely related indicators, such as "age of user" and "health issues", maps were combined into composite maps to more quickly compare districts on similar topics. The data-based QGIS mapping is supplemented by a regular spatial analysis of Eindhoven on relevant aspects, such as the current state of the transportation network. A neighborhood will be deemed problematic if it falls in the group that score in the worst 20th percentile on a given indicator. Ultimately, the most problematic neighborhoods that consistently score poorly on the analysed indicators will be given a closer inspection. Figure 7 to 13 shows the composite map and state of the current transportation network. Individual maps can be found in appendix 2

Data required for the physical objects on the maps predominantly came from OSM (openstreetmap contributors, 2022) and PDOK (2022), such as road networks and public transport infrastructure. For demographic data and survey results for community perception of the built environment, data was gathered from Eindhoven in cijfers (2023), an open data source from the municipality. Google Earth (Google, n.d.) was used to manually check the built environment and add to the mapping analysis whenever this was required. The data source for every map is found in appendix 3

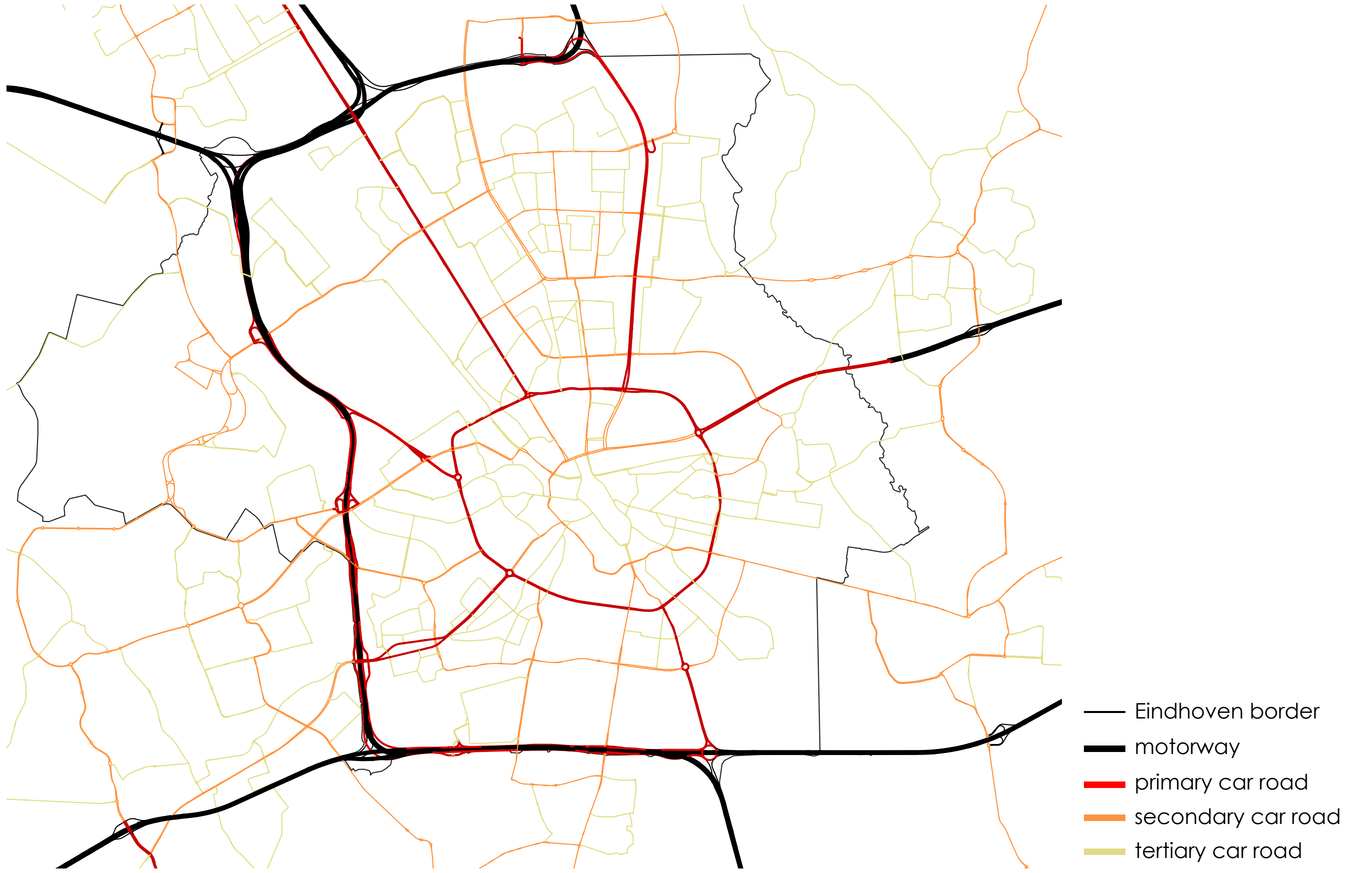


Figure 7, Car infrastructure network.

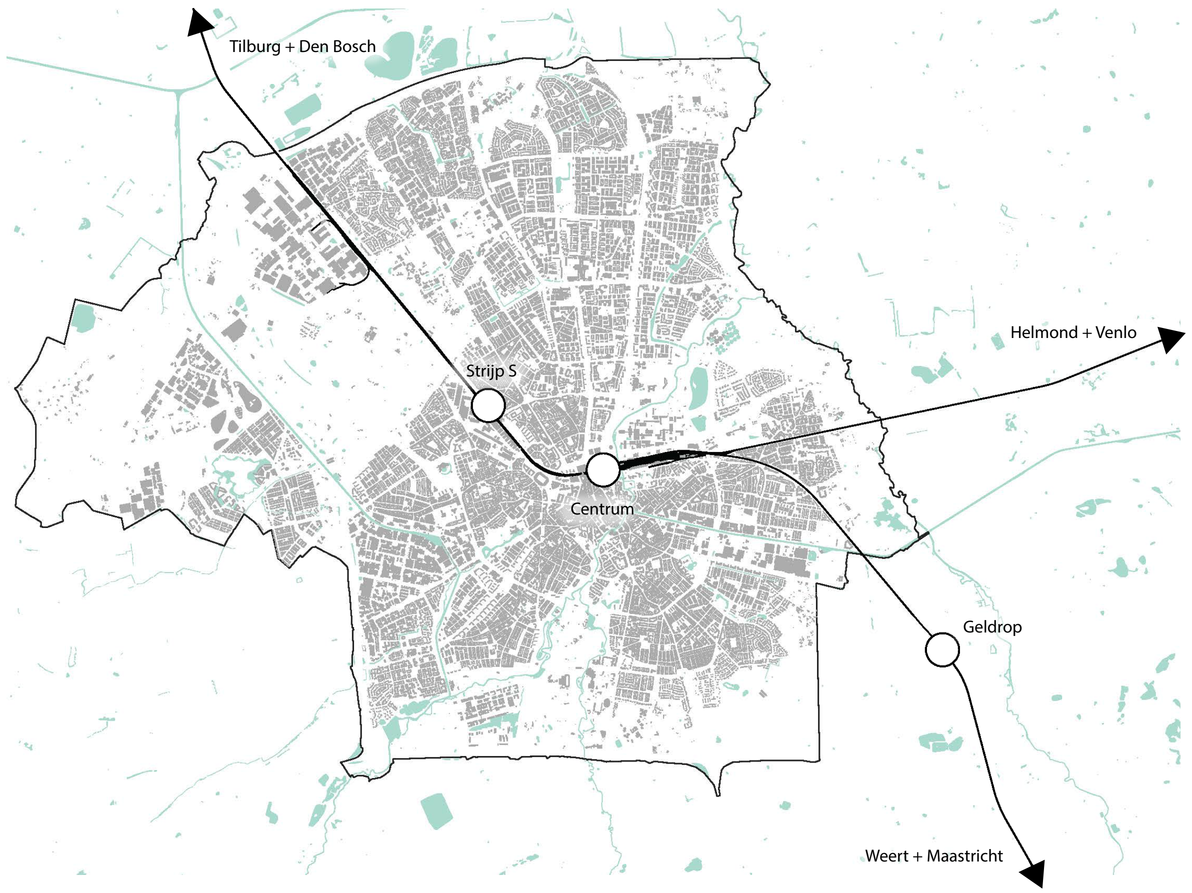


Figure 8, Train track and stations location.

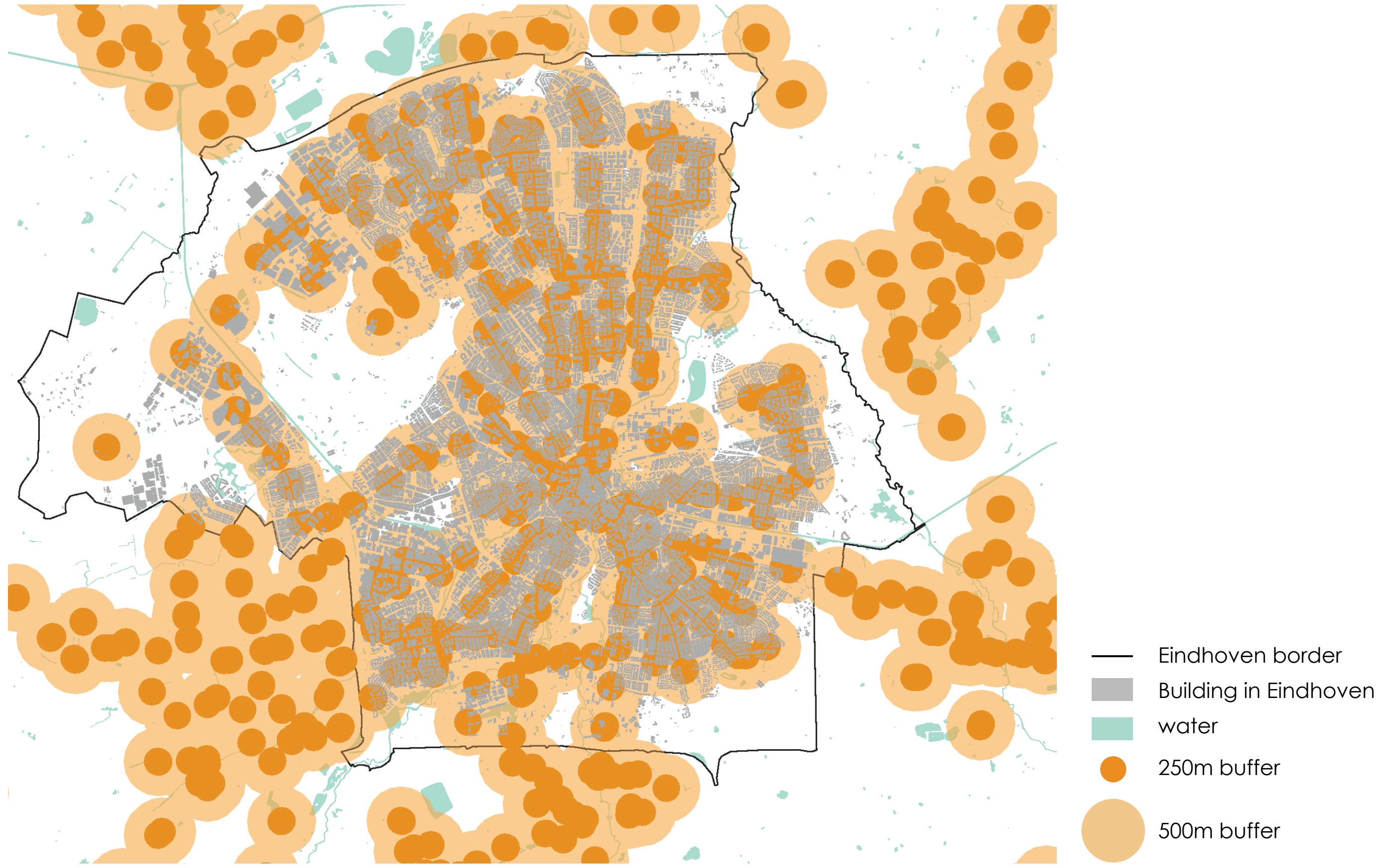


Figure 9, Bus coverage in Eindhoven.

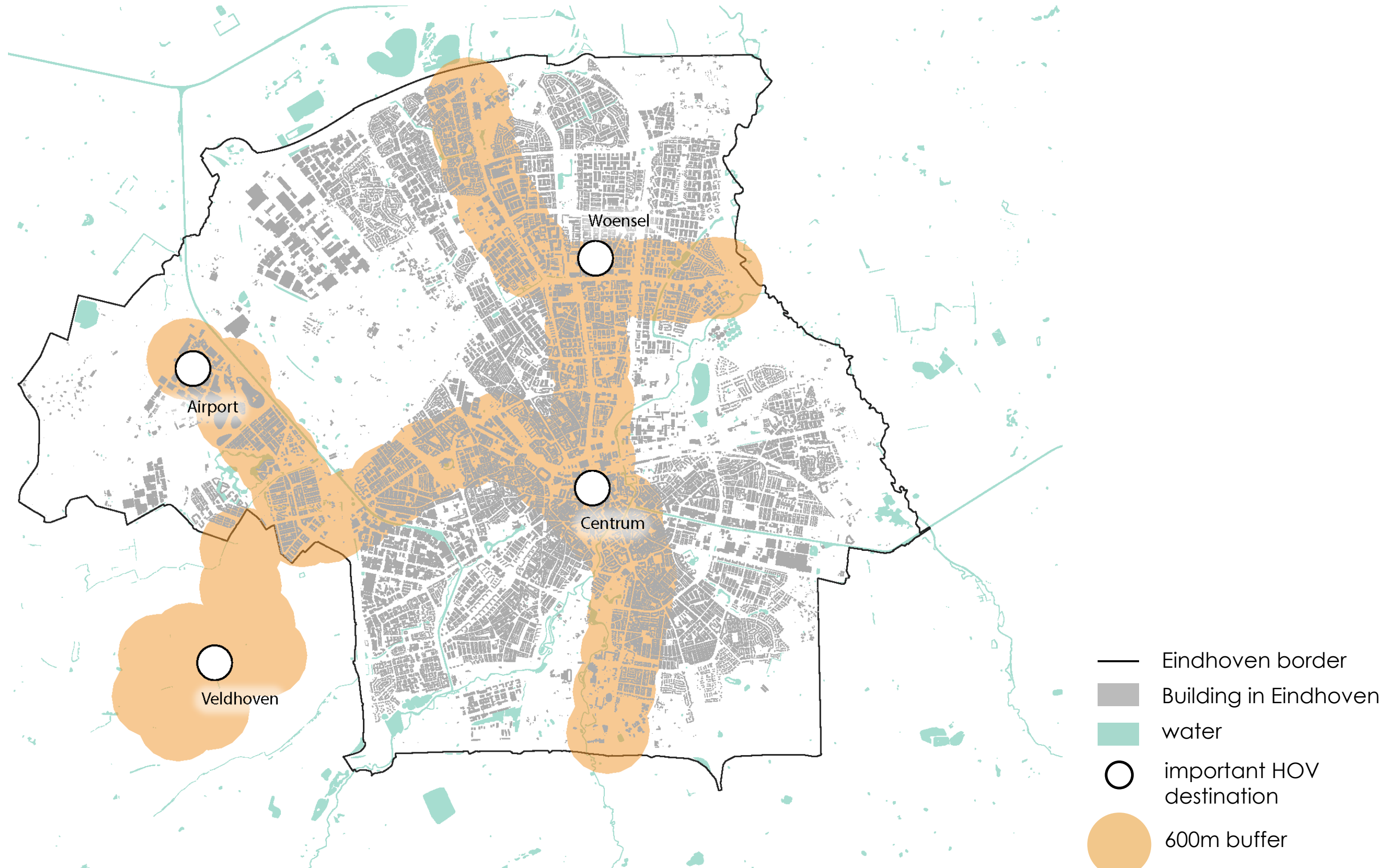


Figure 10, HOV bus coverage in Eindhoven.

Figure 11, permanent sharing infrastructure coverage in Eindhoven.

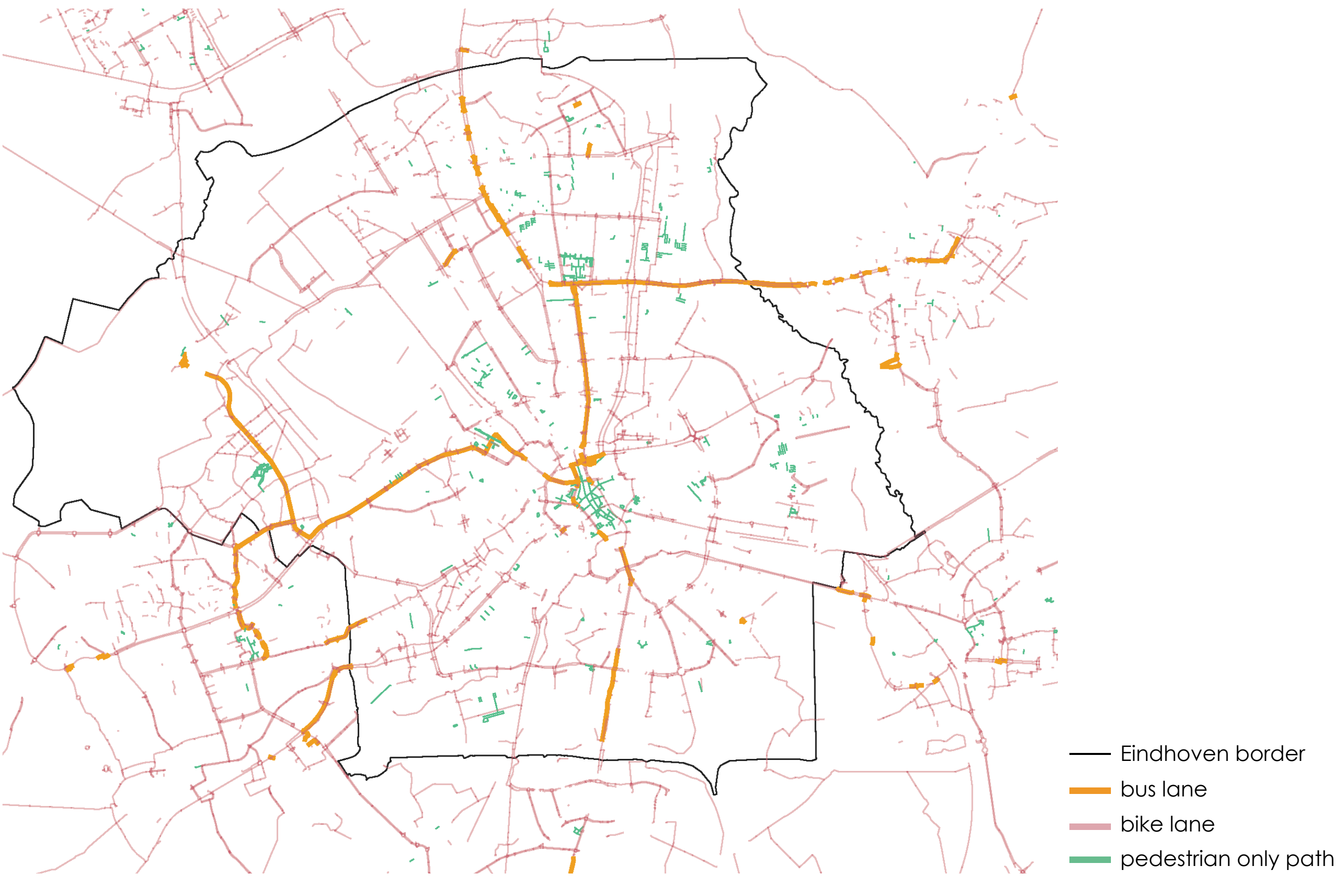


Figure 12. Dedicated infrastructure in Eindhoven.

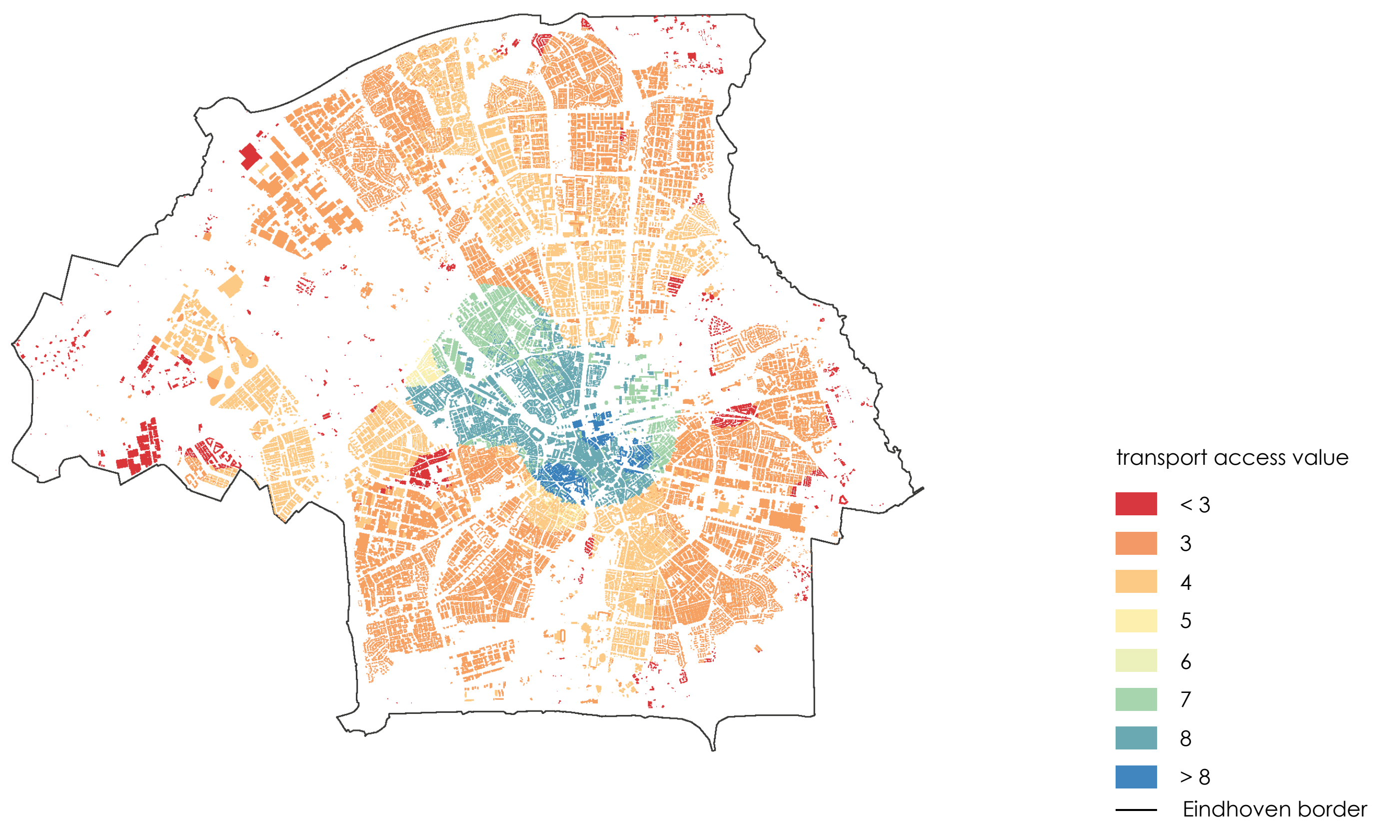


Figure 13, Transport accessibility values in Eindhoven.

	Train station	Bus stop	HOV bus stop	Car sharing	Bike sharing
Effective service coverage range	1200m	500m	600m	500m	250m
Transportation accessibility value	5	3	4	1	1

Table 2, Transport accessibility values and coverage range.

In order to create a map with transport accessibility values for buildings in Eindhoven (Figure 13), all the found infrastructure related to transportation modes associated with the mobility transition was gathered and given a buffer zone in QGIS based on the effective service range of those services (Gemeente Eindhoven, 2019). The value given by each mode of transportation is based on several factors, such as regional connectivity, frequency and capacity. This results in a map that shows which buildings are lacking in terms of transportation options that can deliver people to their destination within the effective service range of that specific mode of transport, or for residences that do not have access to certain transportation modes. In order to calculate the value of each individual building, a vector analysis with the option of summarizing attributes by location within QGIS is performed. HOV bus stops were given a higher degree of transportation value over regular bus stops, as literature states that these kind of stops provide a larger degree of capacity, frequency and reliability over regular busses, especially in Eindhoven due to the priority lanes given to the HOV busses. For car- and bike sharing, only permanent infrastructure was considered. Companies such as greenwheels promise city wide coverage for shared mobility, but do not have any permanent or centralized infrastructure in place (Greenwheels, n.d.) During this research, the city of Eindhoven is working on improving the infrastructure in place for shared mobility, but currently only the areas around the central train station and city center were found to have permanent facilities in place.

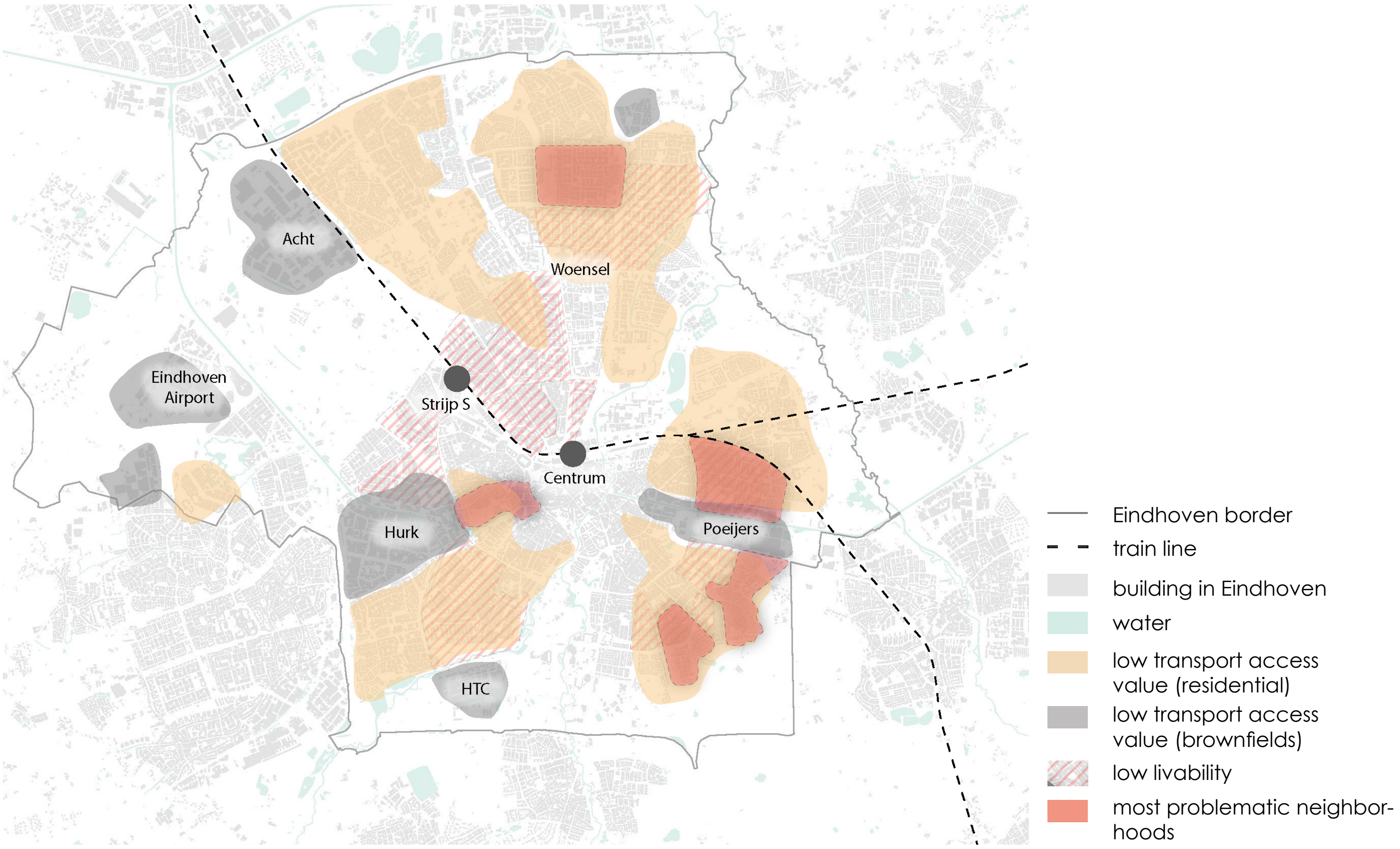


Figure 14. Most problematic areas in Eindhoven.

Combining the different indicator themes and built environment analysis leaves us with a map indicating which areas in Eindhoven are deemed most problematic, show in figure 14. In darker red are those neighborhoods that consistently scored poorly on the analyzed themes, and in lighter orange are those areas that are experiencing transportation deficiency when compared to other neighborhoods within the city. The areas in grey indicate the business parks and industrial sites that similarly do not have proper coverage from public transport and shared mobility, while being major employment centres and trip destinations, especially by car users (Smartwayz, 2020). The areas indicated by the dashed lines are areas defined by the municipality of Eindhoven as needing additional attention in the coming years to ensure livability and safety remain at a level appropriate for a Dutch city. It is at this point that it is worth noting that for most of the analyzed themes, Eindhoven does relatively well overall. survey results generally indicate people enjoy living in the city and find public transport and traffic safety to be at least satisfactory. However, even when this is the case, relatively some areas score significantly worse than others, and do so consistently, indicating that there are definitively areas and neighborhoods that would benefit from attention and improvements on the themes and indicators relevant to the mobility transition. Broadly, the areas directly in between the green wedges of Eindhoven (appendix 4) score the worst, and the city center and those areas surrounding the HOV lines score relatively well on most themes. One notable aspect is naturally that the city center and the western part of Eindhoven have access to a train station with Central station and Strijp S, while the eastern part of the city does not. Bus coverage in Eindhoven is near perfect, however problems start to arise when looking into the individual lines and their timetables, which can be traced back to survey results about people's perception of the transport network and city center accessibility. When a person has a bus stop nearby, but the line servicing that stop takes a very indirect route, it can be assumed that using that mode of transport is less desirable if using a car is simply faster. Similarly, the cycling network is not at the same level of quality throughout the city (Figure 12).

Policy and planning analysis

After looking into the current state of the built environment and demographic themes related to the mobility transition, it is necessary to consider what the municipality of Eindhoven is currently developing or what their current approach towards the mobility transition entails. On top of this, it is important to know what the current densification policies are and what the demand of increased housing is.

The Verdichtingsvisie binnenstad (Gemeente Eindhoven, 2020b), entails in what way Eindhoven is aiming to densify, but predominantly covers the inner parts of the city. On top of this, the densification principles are centered around architectural qualities and location choices. On the topic of mobility, the main points of attention are that no new parking places on the ground floor are to be realized, and that new developments should come with a plan on how to attract shared mobility for its users. Furthermore, the report states that only 21000 out of the proposed 40000 new dwellings to be constructed by 2040 can be realized in the area within the city ring. This means another 19000 dwellings will have to be constructed in outer neighborhoods.

In terms of mobility, there are two main avenues Eindhoven is exploring at the moment. An expansion of the HOV network is underway, and would see at least two entirely new lines created. (Gemeente Eindhoven, 2020b)(Gemeente Eindhoven, 2022) Furthermore, the ring road would become an important barrier from outside, and the municipality is looking into creating several locations along the ring road that would allow visitors to leave their car at the ring, and continue towards the inner city on a shared bike. Lastly, the brainport region is looking into creating larger scale mobility hubs, multifunctional spaces aimed at alleviating pressure on the regional network by providing users an opportunity to swap to a different mode of transportation, and even creating a dedicated brainport connection (Gemeente Eindhoven, 2022) Furthermore, the most important cycling routes throughout the city should become more important in servicing top employment locations.

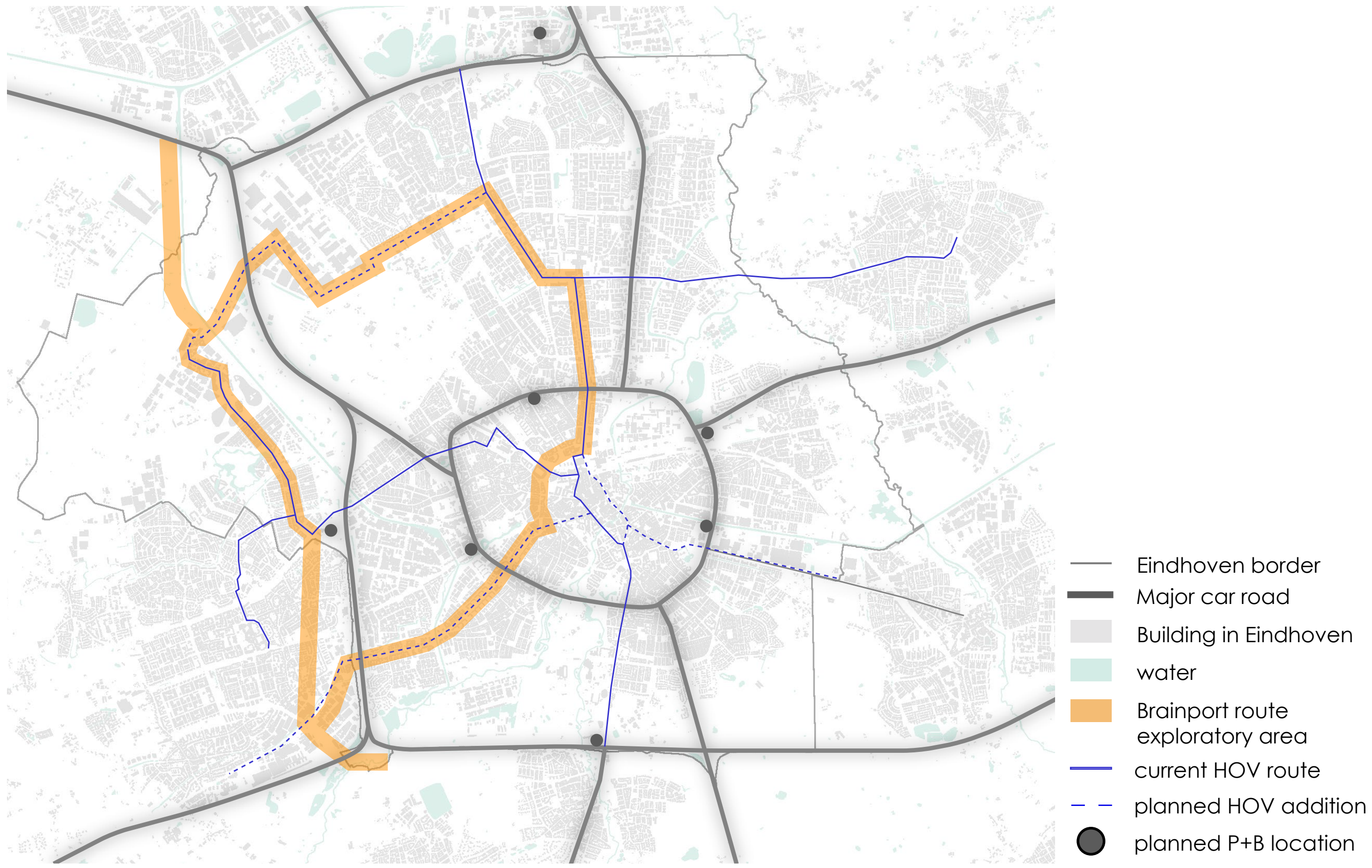


Figure 15. Proposed HOV network in Eindhoven with P+B locations (Park and bike).

The literature reviewed in this research provided plenty of policy related indicators that could aid the mobility transition. While affordability and monetary incentives are not the main dimensions of this research, it is worth noting that Eindhoven as a city does not have a system in place that provides monetary benefits to using active travel modes or public transport. However, many institutions and companies do so. Reliability and accessibility of public transport can be analysed however, and while Eindhoven seemed to have excellent coverage in terms of bus stops, the system does not work as well as it could. Like many other cities, Central station is the main departure and destination point, meaning there is very little cross-traffic between neighborhoods, and in order to get to your destination, it is more than likely you will first have to travel to Central station. This naturally means a massive increase in travel time, and generally means that the public transport system is not faster than cycling or using a personal car. Figure 16 displays some example routes (Traveltime, n.d.).

While most inhabitants score their accessibility to the centre quite high, accessibility to other regions of the city is not well documented and surveyed. While the coverage from central station is quite good, the reach from a neighborhood outside of the city centre is quite a lot worse. Figure 17 displays the areas you can reach from a central point within the neighborhood of Doornakkers and Central station within 20 minutes of departure. The maps have 12 different layers overlaid, with each 5 minute interval for a full hour providing a transparent coverage map. By overlaying these layers it is possible to distinguish that certain areas are only accessible within 20 minutes for a very brief period each hour, and are therefore not even accessible within 20 minutes on average. Increasing the frequency of busses on lines and implementing more bus-friendly infrastructure such as the implementations used for HOV lines could greatly increase the public transport effectivity in Eindhoven, as well as the addition of lines between neighborhoods.

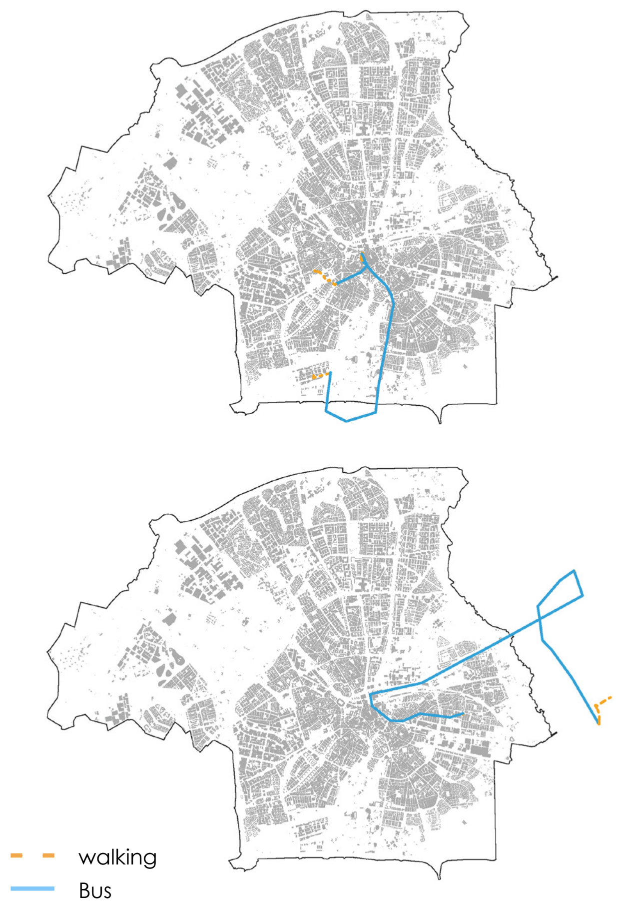


Figure 16, the routes of public transport required to reach example destinations from within an outer neighborhood.

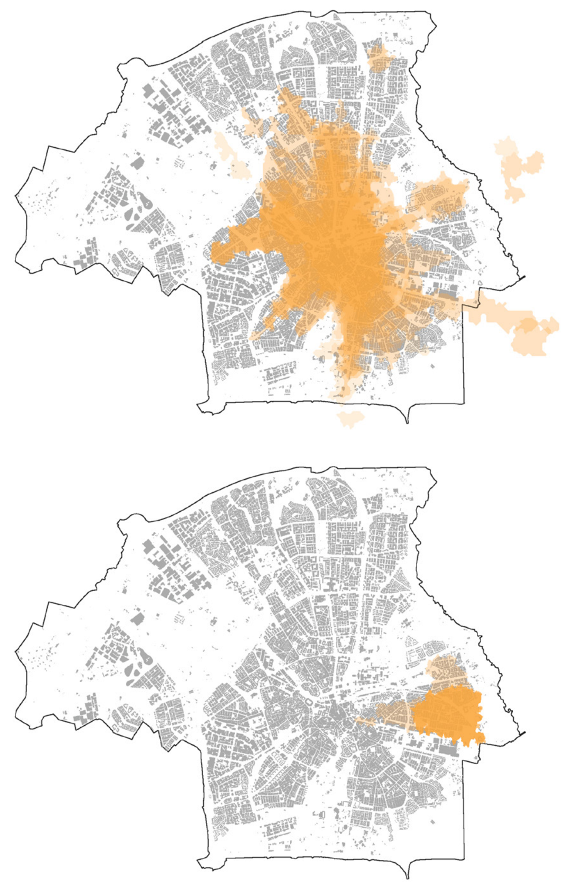


Figure 17, 20 minute service area of busses from a certain location (top, Central Station, bottom, Doornakkers).

Discussion and conclusion

Discussion

Due to the broad nature of the subject and research question, some discussion points and limitations are raised. While one of the aims of the research was achieved by comparing the entire scope of travel modes associated with the mobililty transition, this left some ambiguity. While the indicator grid now covers a wide range of transportation options and indicators, it was not possible within the scope of this research to go very in depth on each of them, leaving some of the findings slightly superficial. Ewing and Cervero (2010) also admit that the subdivision of built environment indicators in the D's leaves room for interpretation. This is most apparent in the dimension of Density. Not only are the indicators here ambiguous, due to the structuring of the grid, shared mobility has some conflicting outcomes. This is primarily due to combining several different modes of shared mobility in a combined header, as well as the interpretation of indicators differing from research paper to research paper.

Some of the findings from the indicator grid are very clear however. From a design perspective, the most common measure to increase both satisfaction levels and participation rates of travel modes associated with the mobility transition was to give each mode of transportation their own dedicated infrastructure, separated from other traffic streams when possible. This was backed by both objective and perceived sources. This is primarily due to the fact that it also has positive impacts on other indicators such as traffic safety, comfort and reliability.

Generally, objective and perceived data had little difference on whether or not an indicator was positive or negative for a certain travel mode. One of the themes where it differs is "Shorter distances" in the Density dimension. However, this can be attributed to the aforementioned limit of the research, in that this theme in itself is ambiguous as well as the combining of several transport modes under the same header of "shared mobility". Next to that, there was a single conflicting outcome when it came to "proximity of green space" in the Diversity domain. This came due to a strong difference in context between the different literature sources, and should not be used as an example of a clear clash between objective and perceived findings.

This meant that at first sight, the process of separating objective and perceived indicators appeared a bit moot, however an important outcome can still be considered. Given that there were no strong differences or clashes, this means that people's perception of the built environment and what they would want to be improved are closely linked to what would actually happen. For example, if a survey reveals that people would use a certain mode of transport if they had access to it, that would mean that after providing that access, the usage of that transportation mode would also actually increase, according to findings in the indicator grid.

While the indicators found in the Destination accessibility domain are all found to generally have a positive influence on satisfaction levels and modal choice on transportation options associated with the mobility transition, they are also not the most unexpected outcomes. Naturally, a survey respondent would indicate that a lower price would suit them more, and that increased comfort and reliability of public transport, as there is no reason the opposite would be true. However, since there is also objective data backing this up in some cases, this gives the finding increased relevance and believability.

As mentioned, in the research the decision was made to combine all modes of shared mobility into a single header in the indicator grid. While this generalizes the results perhaps a bit too much, one of the reasons for doing this was the fact that very little research has definitive data and research outcomes on this subject, especially given how young this development is. While separating this header into for example shared bikes, e-scooters, carsharing etc., would have given more in depth and detailed results, it would also have made the findings very sparse and made for an uninteresting indicator grid as most options would simply be greyed out due to a lack of data. Furthermore, by combining all of them together, the findings are applicable to the entire scope of shared mobility, and one of the main aims of the research was to find out if indicators between different modes of transport would be similar and could if improvements for a certain mode of transportation had effects on another.

No strong evidence was found to support this argument however, and seemingly many improvements made share mutual benefits between different transportation modes. Only in the domain of Density were there some conflicts between travel modes, but as stated, this is primarily due to the fact that a wide range of travel modes is grouped under shared mobility, including shared (electric) cars. The relation between the different travel modes could have used a more in-depth analysis. However, research indicates that improving the cyclability and walkability of cities has also shown to increase public transportation usage, as these forms of transport are used as first-mile, last-mile travel combined with public transportation. On top of this, shared (e)bikes and scooters naturally benefit from an increase in cyclability and dedicated infrastructure to support this, as they often share the same roads. Further research is encouraged to gather more contemporary literature, especially as new research is published on the relatively new concepts of mobility hubs and shared mobility, as insights from those forms of transport and infrastructure are currently often unconclusive and premature.

The spatial analysis of Eindhoven gave some interesting results, and gave definitive outcomes on which areas in Eindhoven are the most interesting when it comes to finding solutions to aid the mobility transition. One big limitation of the research was that some relevant demographic facts were not considered, such as employment levels and social status. Further research should include this in the analysis stage, since several indicators found in the grid are associated with income levels, and one of the main drivers for daily transportation is the need to get to work. From the policy analysis, it was clear that Eindhoven is already looking into several initiatives aimed at the mobility transition. However, the proposed solutions do not yet address all the found issues, and some of the areas found to be most problematic do yet have direct intervention strategies in place, and a new strategy and design proposal would benefit those areas greatly. This could be combined with a new approach to solve the densification goals outside of the inner city ring.

Conclusion

After performing the exploratory research into the conceptual framework, and the reviewing of systematic literature reviews on the topic of satisfaction levels and modal choice of transportation modes associated with the mobility transition, an indicator grid was possible to be made. While not serving as a toolbox exactly, it provides measures and initiatives to be taken in order to positively influence the mobility transition. While the research had some limitations in terms of depth and ambiguity, it still provides a basis to a combined approach towards every relevant travel mode. While many of the indicators are closely related to policy and regulation, there are definitively built environment design and planning take-aways from the research, as well as interesting findings that could benefit from further research.

While Eindhoven is well on the way to improve accessbility and transportation networks of car alternative travel modes, areas outside of the city centre and Brainport route lack some attention, especially the eastern region of Eindhoven. The indicators found during this research combined with the spatial analysis can form the foundation of a densification approach outside of the city centre that simultaneously aims to aid those neighborhoods with the mobility transition, and due to the broad scope of the research could be applied to other contexts as well.

Strategy and planning outcomes

Strategies for the redevelopment and planning of dense neighborhoods applied in the context of Eindhoven

Strategy

In order to demonstrate how the identified indicators can be used to analyze a transportation network in a city and provide a direction towards a strategy or design, two scenario's for densification and the improvement of networks and infrastructure associated with the mobility transition are devised. The first of these scenario's will build on the current vision of the municipality of Eindhoven, and will use the areas found through the QGIS mapping analysis to bring the entire transportation system to a higher standard. The second scenario takes a more large scale approach and goes beyond current vision and planning for Eindhoven. Since no in depth analysis of costs or budget is performed in this research, the plans will assume sufficient funding is secured, and serve more as a conceptual strategy that can be used as an example for future urban planning.

Based on the QGIS mapping analysis, it is shown that Eindhoven is doing relatively well for the most part, but several neighborhoods lack facilities and infrastructure to be able to properly utilize public transportation, active travel modes, and do not have access to permanent infrastructure for shared modes of transportation such as mobility hubs or centralized parking or storage of shared bikes and scooters.

First, a set of conceptual plans to improve accessibility to large scale green spaces via active travel modes is shown. Then, a proposal to include the eastern section of Eindhoven and surrounding employment centres in the HOV network is displayed, Followed by a city-wide implementation of local and regional mobility hubs in order to bring more modes of transportation within reach of outer neighborhoods.

Following the city scale strategy, three key areas of intervention are found, which are explained in slightly more detail. Afterwards, one area deemed most interesting and rich of potential is used as an example of what interventions would be possible, and how this could look like spatially. For this purpose, the neighborhood of Doornakkers is chosen. An additional layer of analysis is performed on the location, to be able to apply the knowledge found from the research.

The street and transportation network is analysed, and local amenities are mapped. A brief demographic overview of the neighborhood is given. First, the scenario is explained where densification is performed through key interventions on specific locations, aiming to bring the least amount of disruption to the local built environment, and only seeking to use those spaces that are currently underutilized or empty. The street network and infrastructure is altered to bring more opportunities for public transportation and a more enjoyable and functional active travel network.

The second scenario will take a larger scale into consideration, and will cover not only Doornakkers but a larger part of East Eindhoven, aiming to connect the section of the city to employment centres and turn much of the industrial sites along the canal into highly urban environments, continuing the densification corridor from the city centre. This will be combined with a green corridor along the canal, and will see the implementation of a new train station to serve as a large scale central mobility hub. The main stakeholder in this process will be the municipality, and cooperation between neighbouring cities is required.

Green infrastructure and active travel

One of the main large scale planning elements in Eindhoven are the green wedges, a result from decades of garden city planning and expansion. Nowadays, these wedges ensure that green space is not only found at the perifery of the city, but makes it's way all the way towards the city centre. However, the areas defined in the mapping analysis are blocked off from these large scale green spaces by either large car roads and the train tracks, and generally are situated in the middle of these green wedges, indicating that perhaps the lack of access to these spaces leads to worsened conditions.

Next to the green wedges, Eindhoven also has a system of green corridors and lanes. Especially in the northern part of the city, these lanes are quite well established and of decent quality, but not all areas seem to share this luxury, as especially the east seems lacking in this regard, with little to no quality green lanes being present at the moment, or only in small disconnected sections.

In order to bring the green infrastructure system of Eindhoven to a higher level, the main cycling infrastructure is also considered, and is combined with an expansion of the green corridor network. This will ensure that a larger population is connected to the green spaces in Eindhoven, while simultaniously bringing green spaces and cycling infrastructure together, which has been proven to increase the usage of active travel modes.

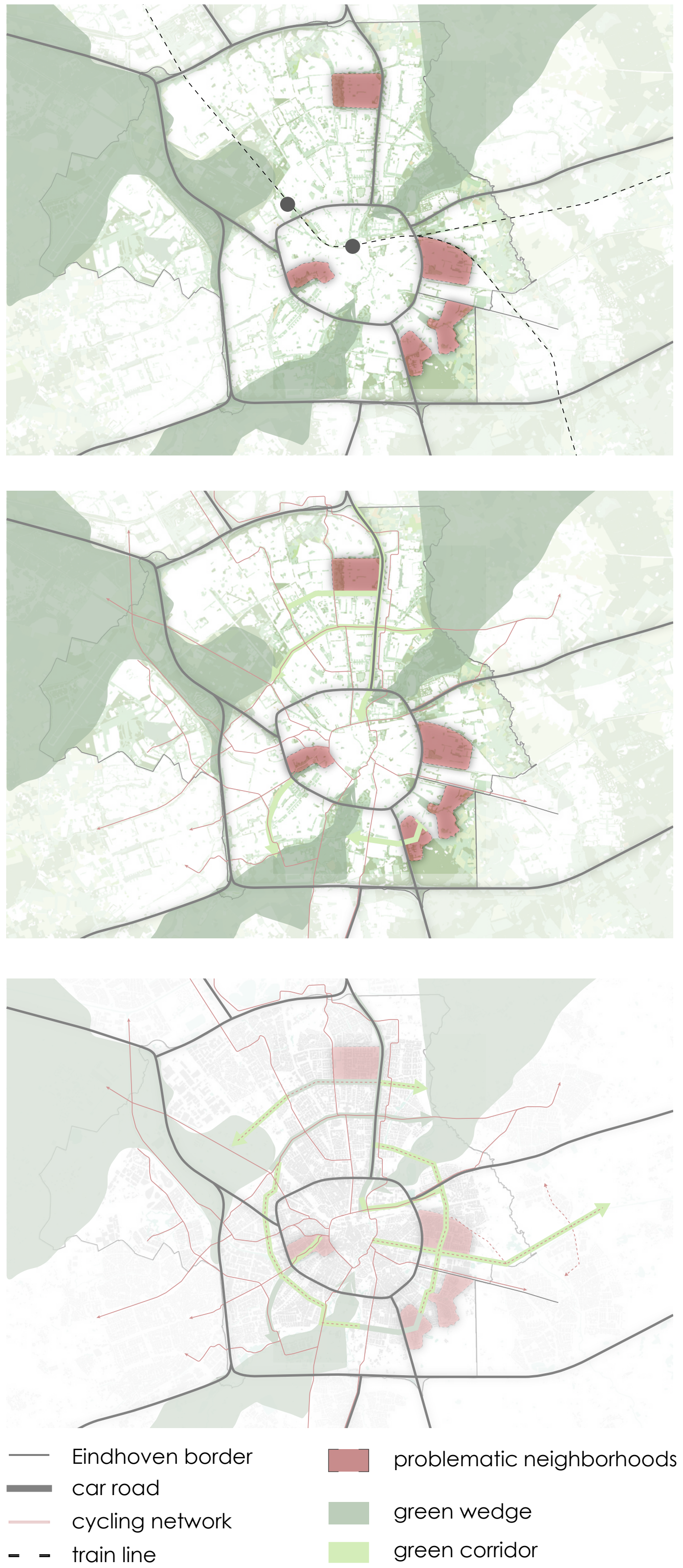


Figure 18, showing top to bottom;

- Current green wedge placement in Eindhoven and large physical barriers;
- The current most important green corridors in eindhoven;
- A proposed system to bring the different corridors together in a coherent system.

Public transport and mobility hubs

In transitioning to more sustainable modes of transport, the HOV network in Eindhoven presents a prime opportunity to attract more people to using public transportation, due to increased reliability, speed and capacity compared to regular busses. Several new lines are already being considered, but again the eastern part of Eindhoven is left largely left behind thus far.

A new line would be added in the eastern part of Eindhoven, connecting surrounding municipalities to the city centre as well. Currently, the HOV network is it's own separate entity, but the addition of mobility hubs along the routes where the network intersects with others, such as the cycling or car network could increase the conveniency and availability of multi-mode travel. Close attention is paid to large scale employment locations such as business and industrial areas.

Lastly, the HOV network enjoys the privilege of having policies in place that aim to bring grade-separated crossings with the ring road in Eindhoven, aiming to reduce the disruption in travel time as much as possible by congestion and traffic. In figure 19, these crossings that have already been modified in this way have been circled in green. However, not all crossings have been addressed as such, and a large amount of ring road crossings with HOV and cycling remain dangerous and inconvenient, and are circled in red. A strong relation appears to be in place with the more dangerous crossings being situated close to the areas experiencing unsafe traffic situations and reduced accessibility. Aiming to improve these crossings in a manner similar to the others will alleviate these issues, especially for the newly proposed HOV connections.

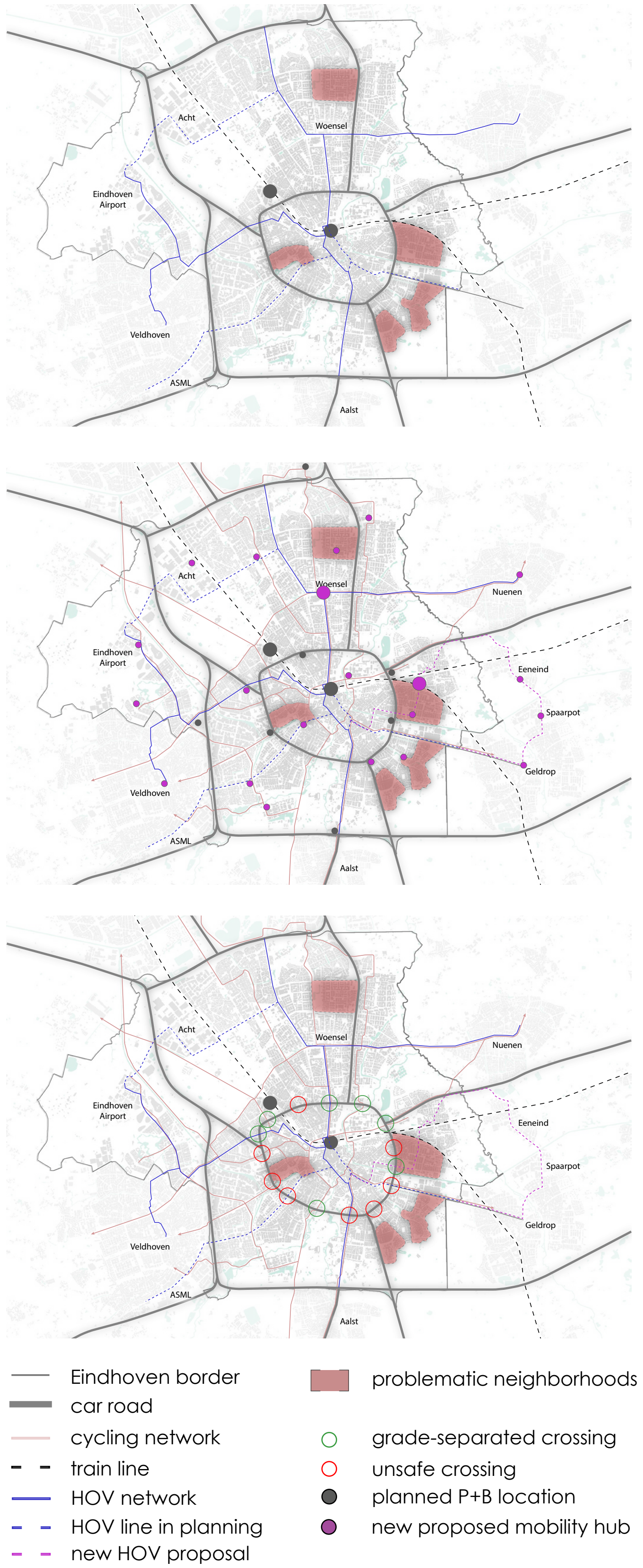


Figure 19, showing top to bottom:

- The current and planned HOV network;
- A proposed program of mobility hubs along important routes and locations where multiple transport modes come together with a new HOV route;
- The most important crossings with the ring road.

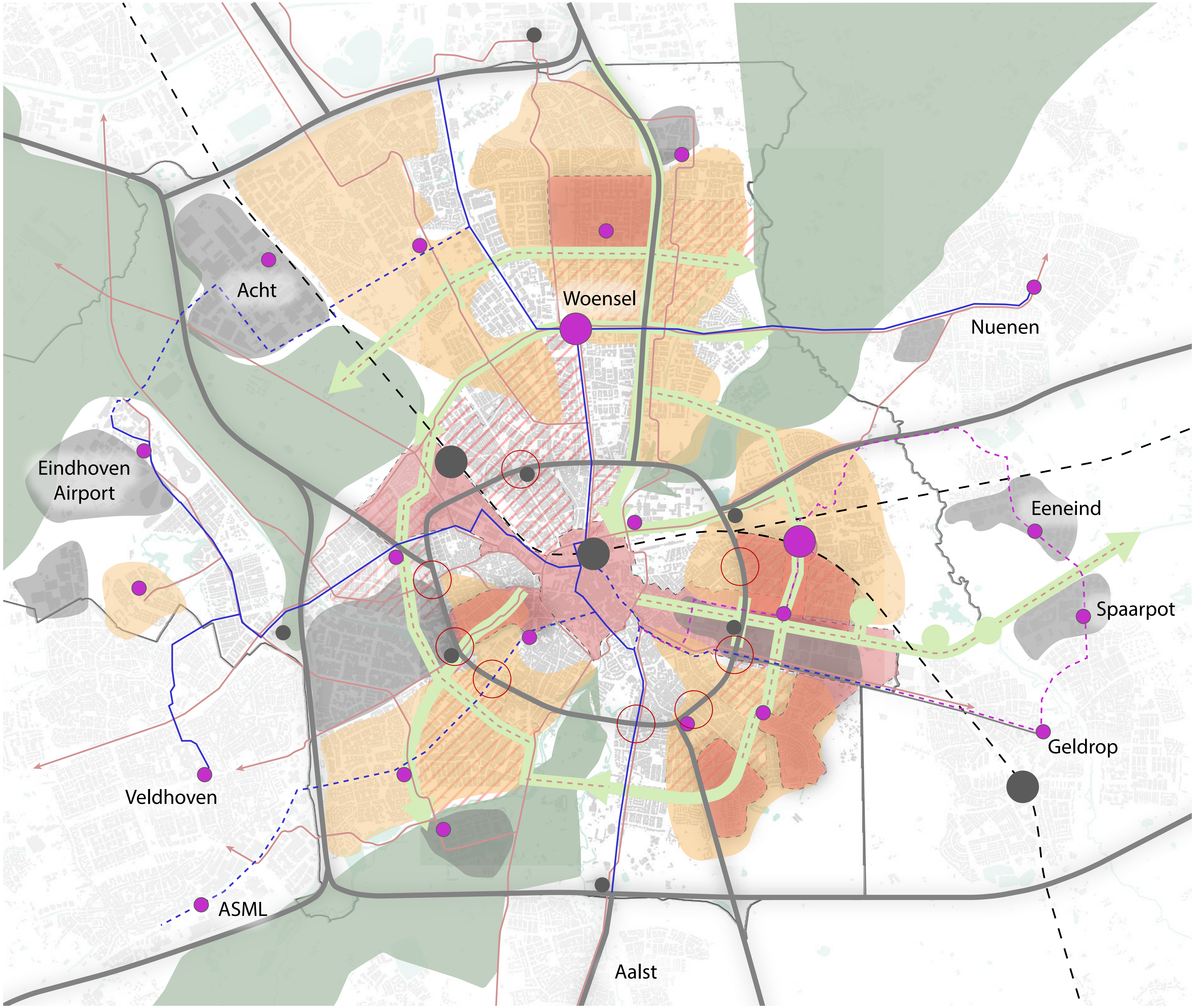


Figure 20, Full city scale strategy

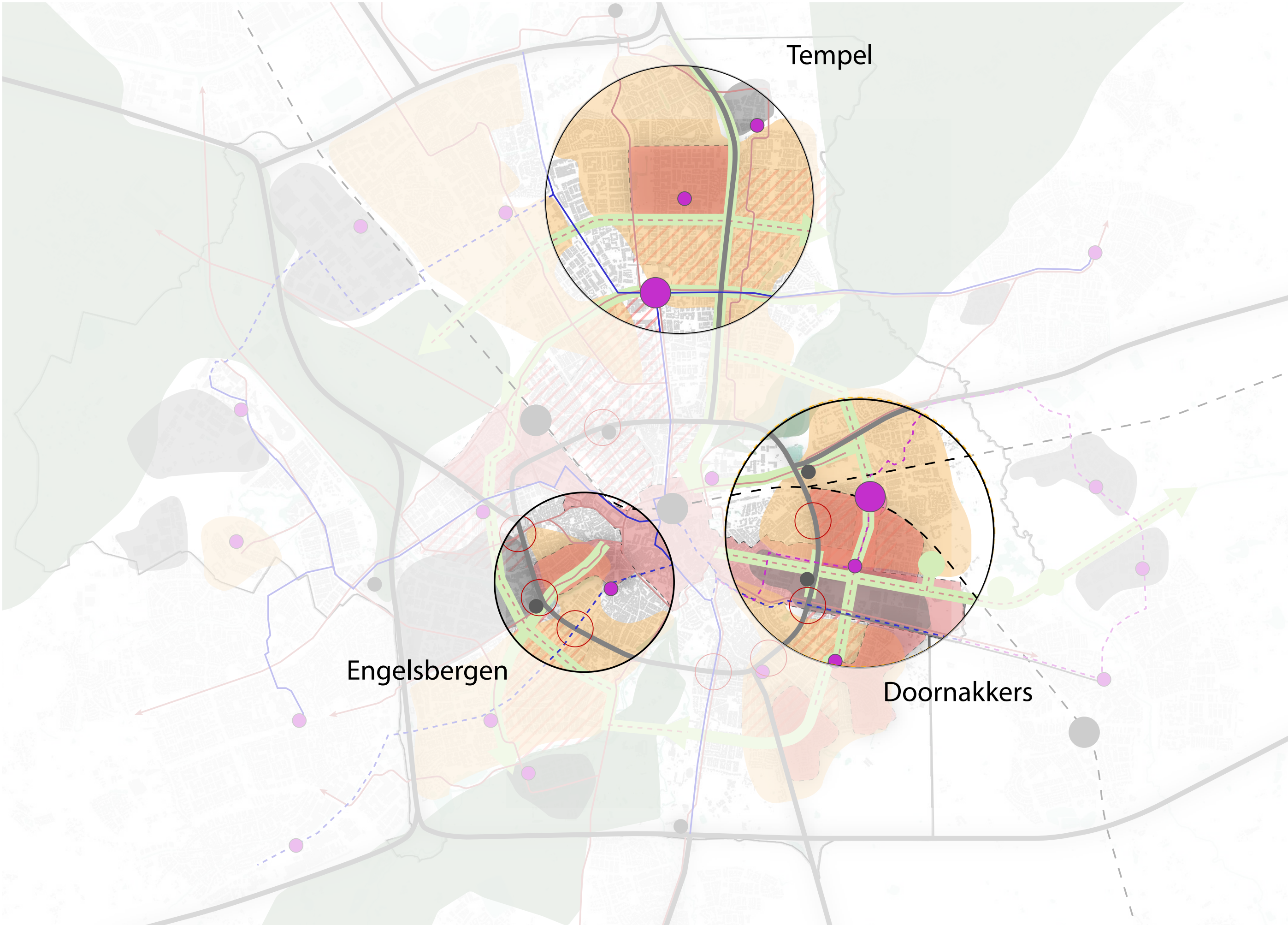


Figure 21, Three most interesting intervention areas.

Implementation

From the city strategy, three different intervention areas are deduced. The first of these, Tempel, is situated in the northern part of Eindhoven, and is the furthest away from the city centre. For this particular area, most problems seem to stem from the fact that the city centre is too far away to reach conveniently by bike within 15 minutes, and instead residents use the nearby WoensXL shopping mall for their daily needs. On top of this, the area is very inwards focused, and little connections to the city wide network are easily accessible.

Secondly, Engelsbergen is considered. This neighborhood is interesting because it is in fact very close to the city centre, but still experiences accessibility issues. The closely situated ring road has no safe crossings, and the green network connected to this area is therefore currently cut off from the city-wide network. One of the newly proposed HOV lines will hopefully bring this area increased accessibility.

The third area, Doornakkers, was deemed by far the most interesting to investigate and make a proposal for, as it incorporates every single aspect of the city scale strategy, and experiences transport deficiency and a lack of attention from future planning. This neighbourhood is right outside the city ring, and is located next to the canal, an area with a lot of potential due to the possibility to turn the waterfront into a high quality green corridor and cycling avenue. On top of this, much of the neighborhood is currently very mono-functional, and houses a large section of old and outdated industrial sites, which take little advantage of the beautiful location and proximity of the canal. Lastly, this area is in a prime location to continue the densification policies in Eindhoven towards the outer regions, and bring a highly urbanised environment closer to surrounding municipalities.

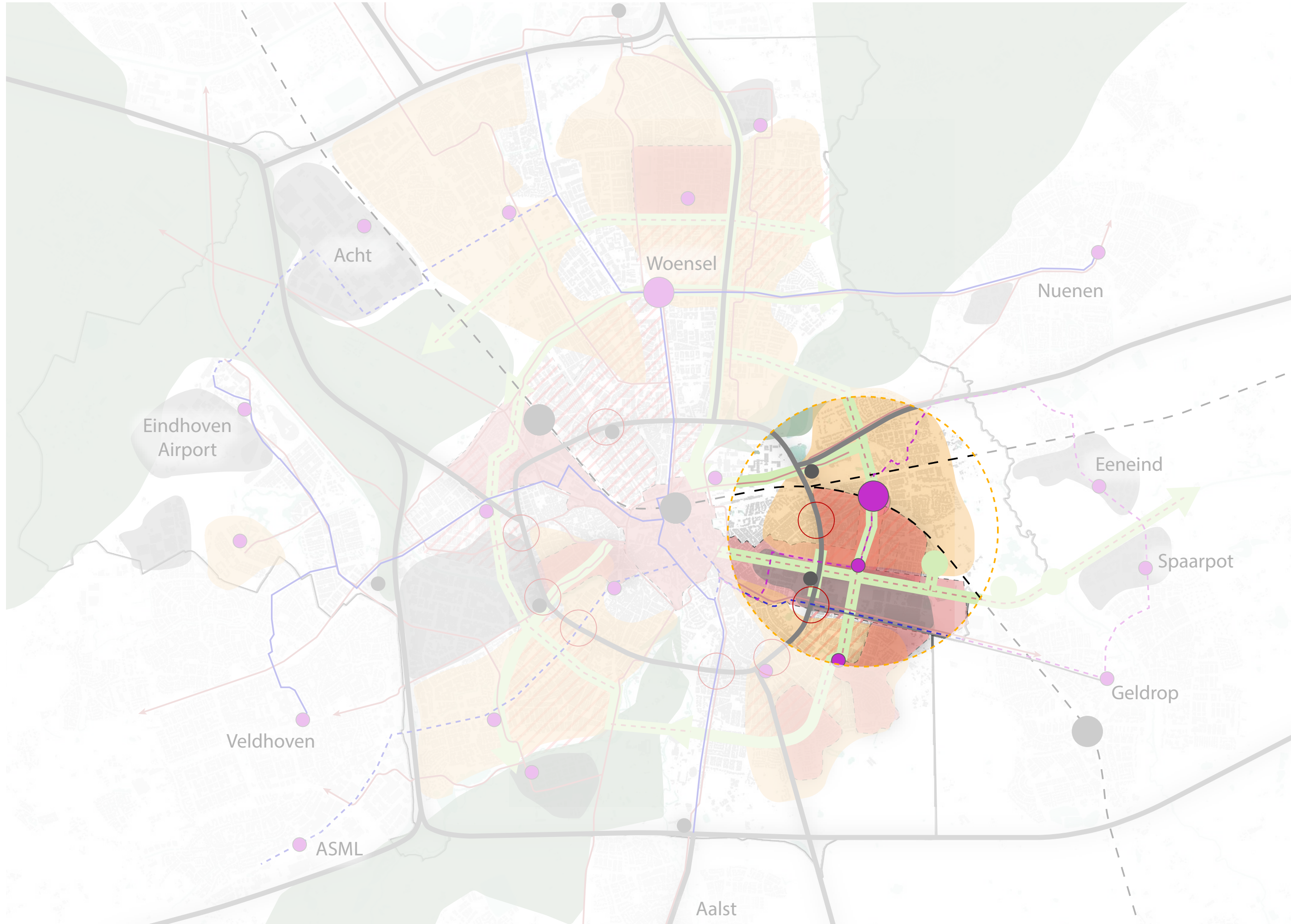


Figure 22, Location choice of Doornakkers.

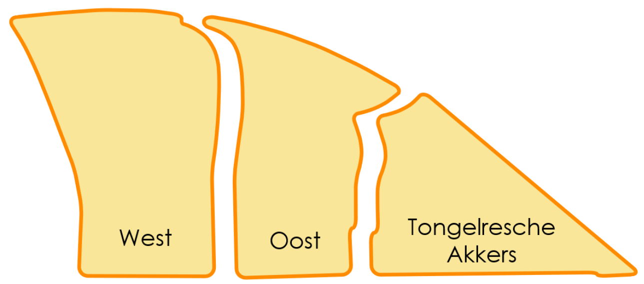


Figure 23, Districts in Doornakkers.

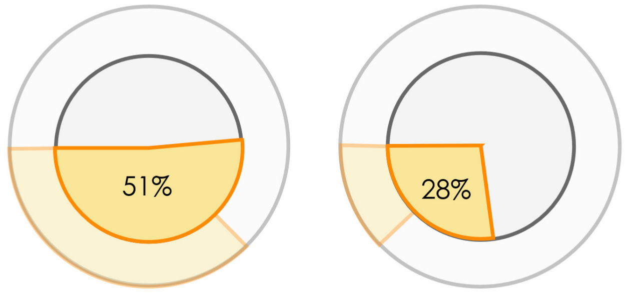


Figure 24, % of housing that is social rent (left) and % of residents over the age of 65 (right) vs. Eindhoven average.

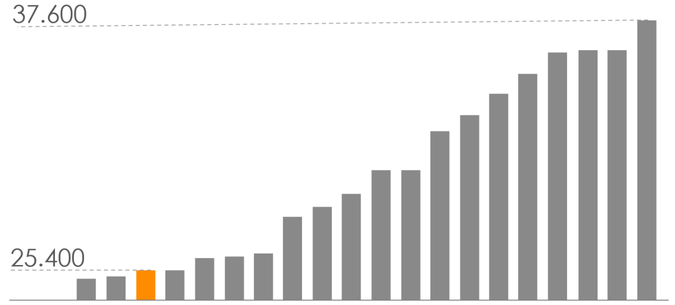


Figure 25, Average income of Doornakkers vs Eindhoven.

Source: Allecijfers (2023)

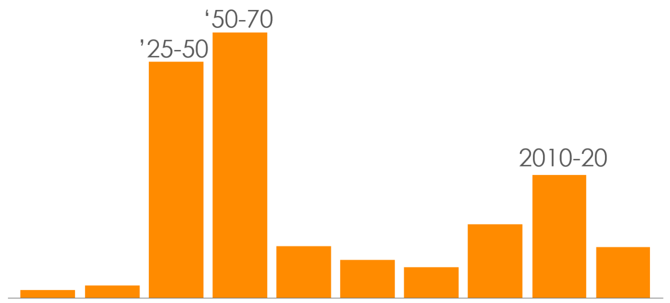


Figure 26, building years of residences in Doornakkers, showing three distinct spikes around World War II and new recent development in Tongelresche Akkers.

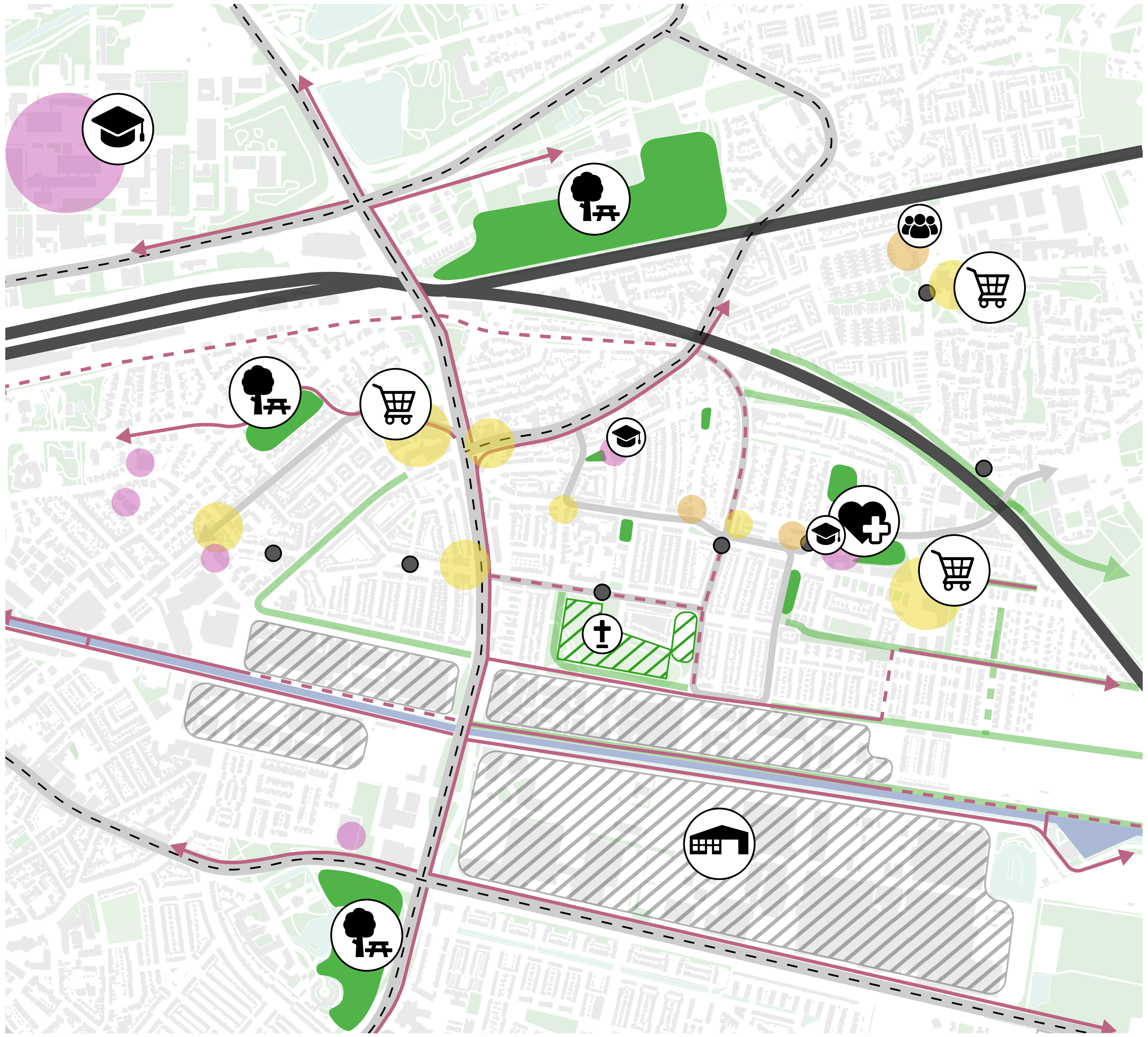


Figure 27, additional analysis on most important networks and amenities in Doornakkers on a local scale, functions are described by icons.

Design principles

In order to apply the measures and interventions found in the literature research contextually, an additional analysis on the context of Doornakkers is performed. This analysis is displayed in figure 27. Doornakkers has quite some services available, but they are all relatively small scale, and the larger green spaces are situated outside of the neighborhood. New developments in the eastern side of the neighborhood have introduced green corridors and cycling lines, however these are currently isolated and not properly connected to the city-wide network. In the older parts of Doornakkers, cycling lanes are often present, however they are not separated from the car road and share the same space. The train tracks and ring road manifest as quite large physical barriers to surrounding areas. The area around the canal is predominantly used for warehouses and low quality buildings.

Derived from both this analysis and the city scale strategy, design principles are created to guide the planning process in a conceptual manner. Three leading principles are the introduction of both a radial and cross connection to green space with improved and interconnected green corridors, the displacement of main car roads towards the edges of the neighbourhood, and densification along the HOV route and waterfront created by the canal. These areas have the most available room and potential to integrate the buildings in a high quality public space and mobility system. Lastly, newly added amenities and functions should be centered around the introduced mobility hubs for mutual benefit and interactivity. Amenities will be added based on what is missing in the area as well as the introduction of an increased population size.

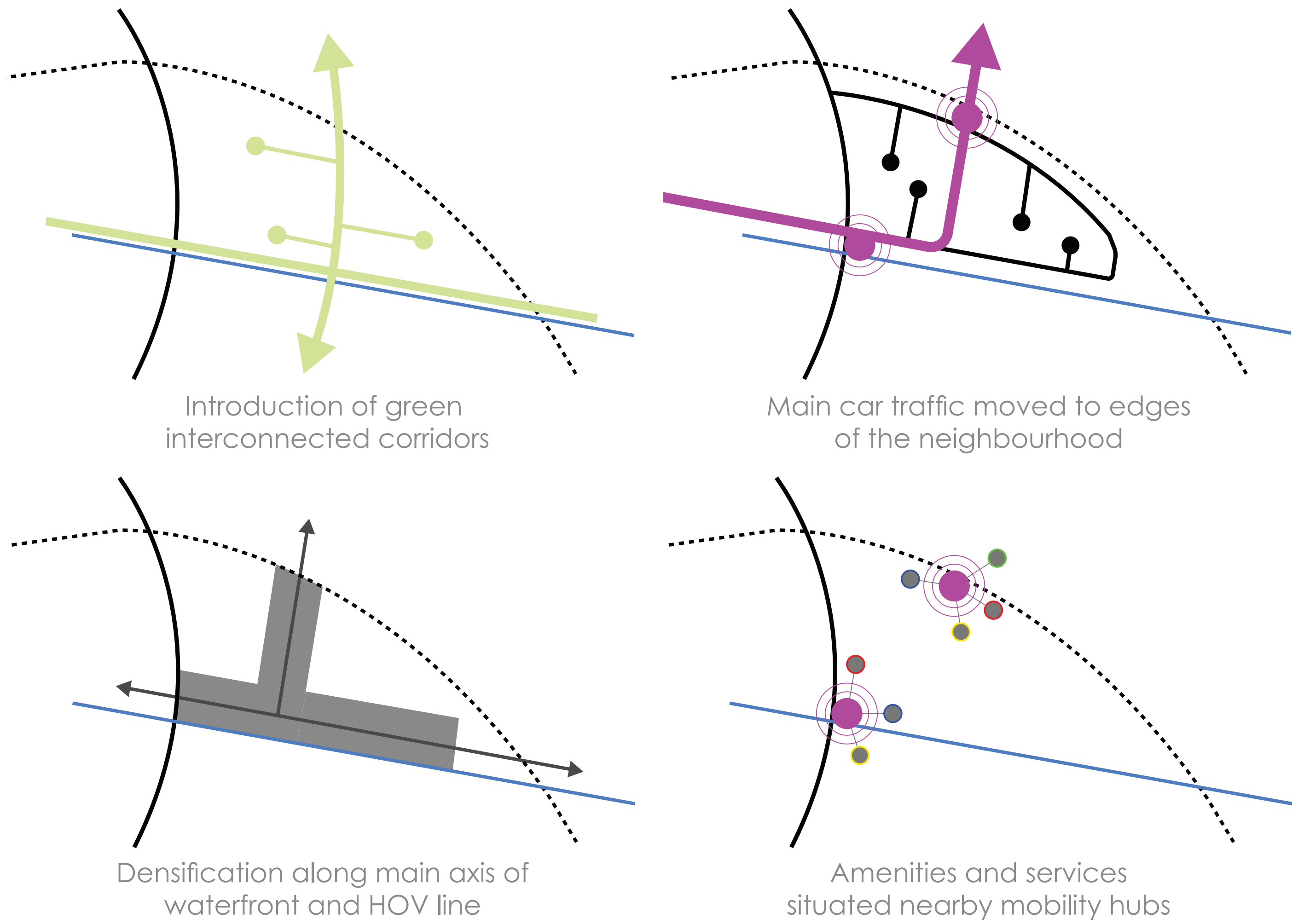


Figure 28, Design principles.

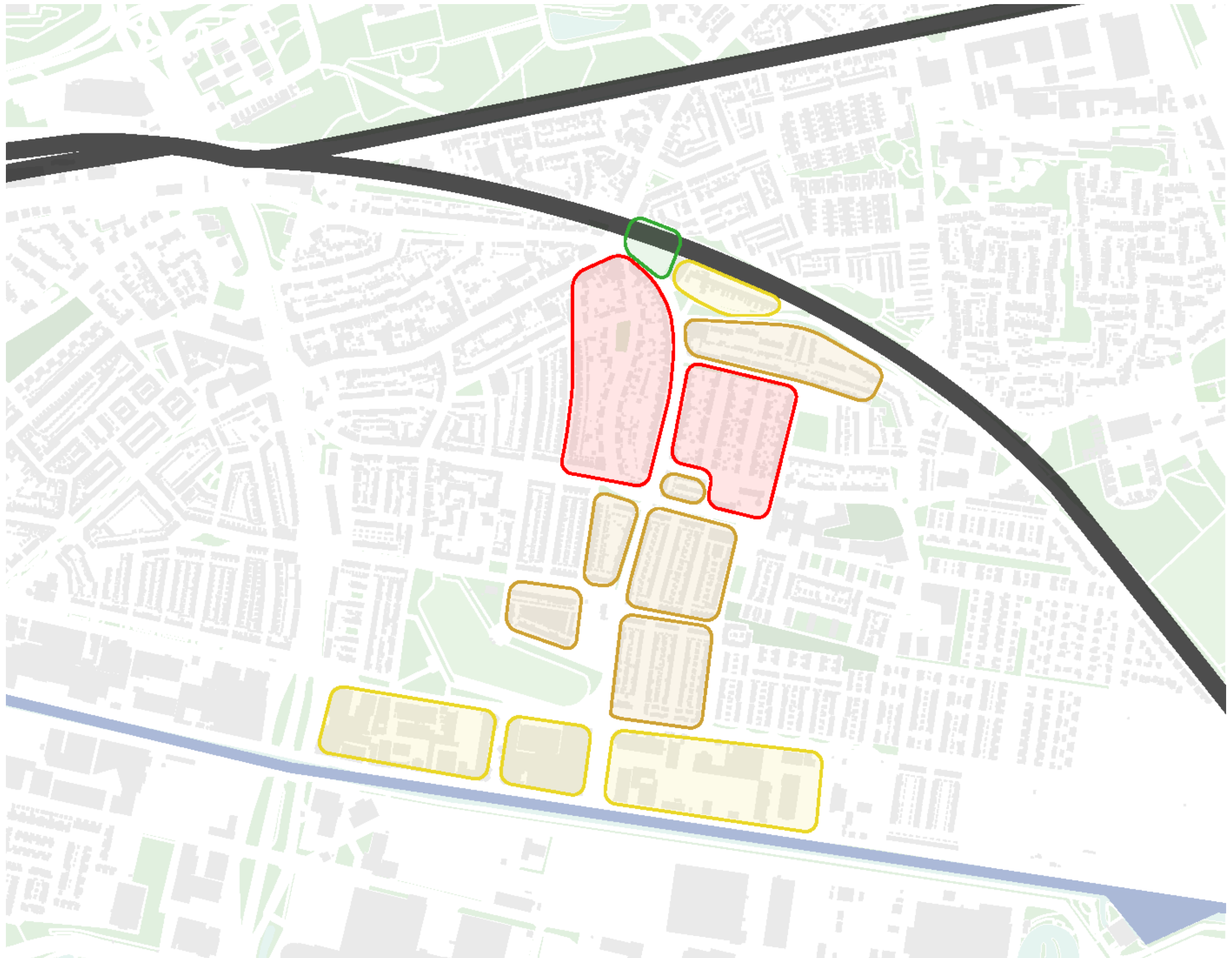


Figure 29, Potential densification opportunities, graded by feasibility.

Densification opportunities

Doornakkers has a range of different characteristics and quality of the built environment. In order to propose a densification strategy, several areas are analysed to see what their current quality is, and how disruptive it would be to redevelop them into highly urban areas.

Only one area in the neighborhood was distinguised as non-disruptive and given the color green. This area is currently used as a large scale temporary parking place, and seems underutilized. Furthermore, this space is especially interesting as it is situated right next to the crossing of the proposed HOV line with the rail road, creating a bottleneck of mobility lines. A space like this that is currently underutilized and where many traffic streams come together is a prime location for a mobility hub, especially since it would serve multiple neighborhoods.

The second category entails spaces that are currently used by low-value warehouses or old low-functioning buildings. These areas are marked in yellow. These areas are once again very interesting as they are situated next to the canal and proposed green corridor, allowing for a high quality urban space to be created, suitable for dense developments. The third category is marked in orange, and entails low-quality social houses from the post-war period. These houses are nearing the end of their lifespan, and are currently situated in a low quality environment. Displacing current residents makes this redevelopment quite disruptive however, but there are many cases where buildings such as these were redeveloped in other areas in Eindhoven. Lastly, the fourth category is marked in red, and contains high quality houses, as well as cultural heritage. These areas are preferably left alone and kept unaltered, besides improvements to the pedestrian and cycling infrastructure.

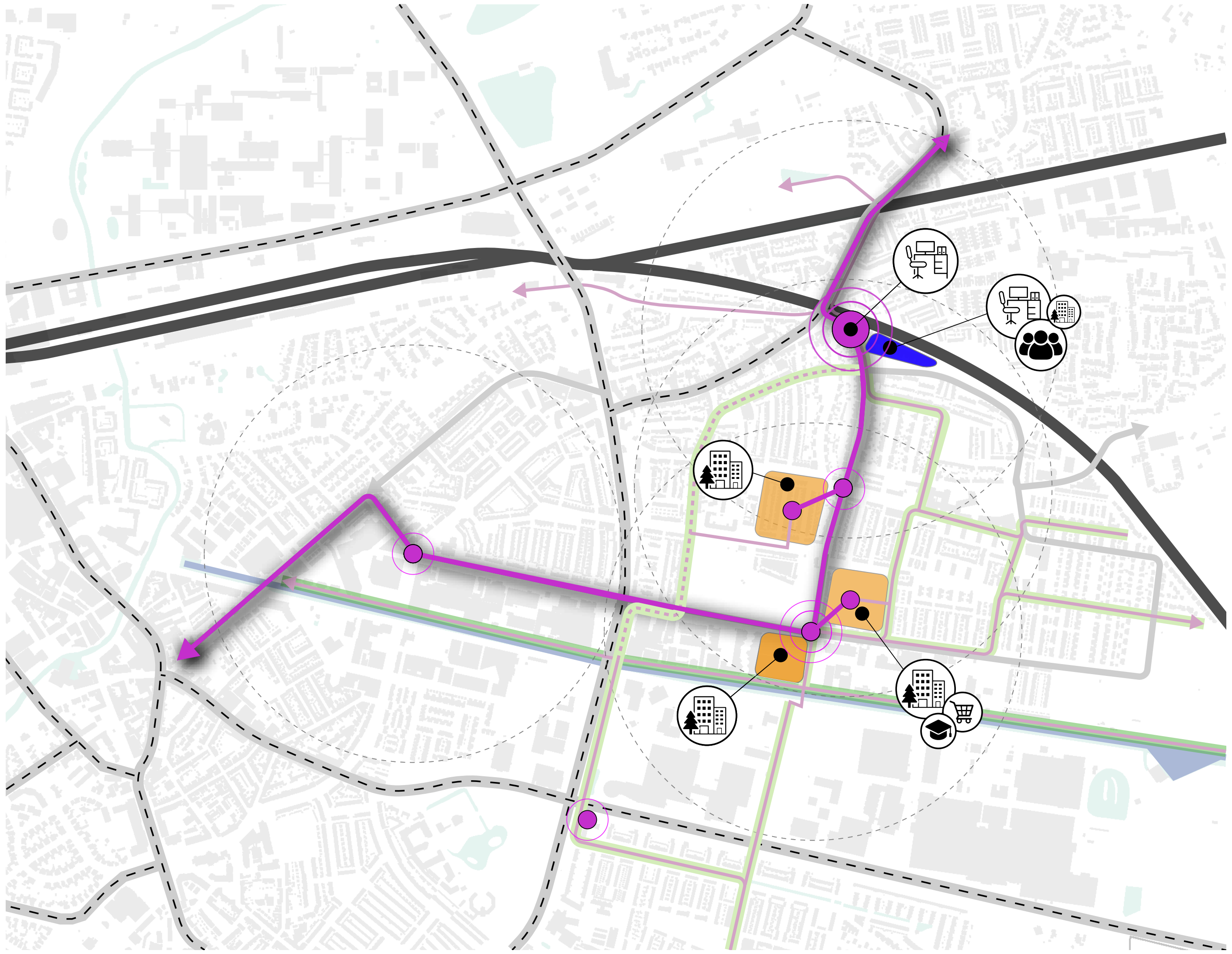
category 1, severely underutilized space

category 2, space inefficient low-qualty buildings and warehouses.

category 3, old social housing

category 4, cultural heritage and higher quality housing

Figure 30, reference images from areas in Doornakkers (Google, n.d.)

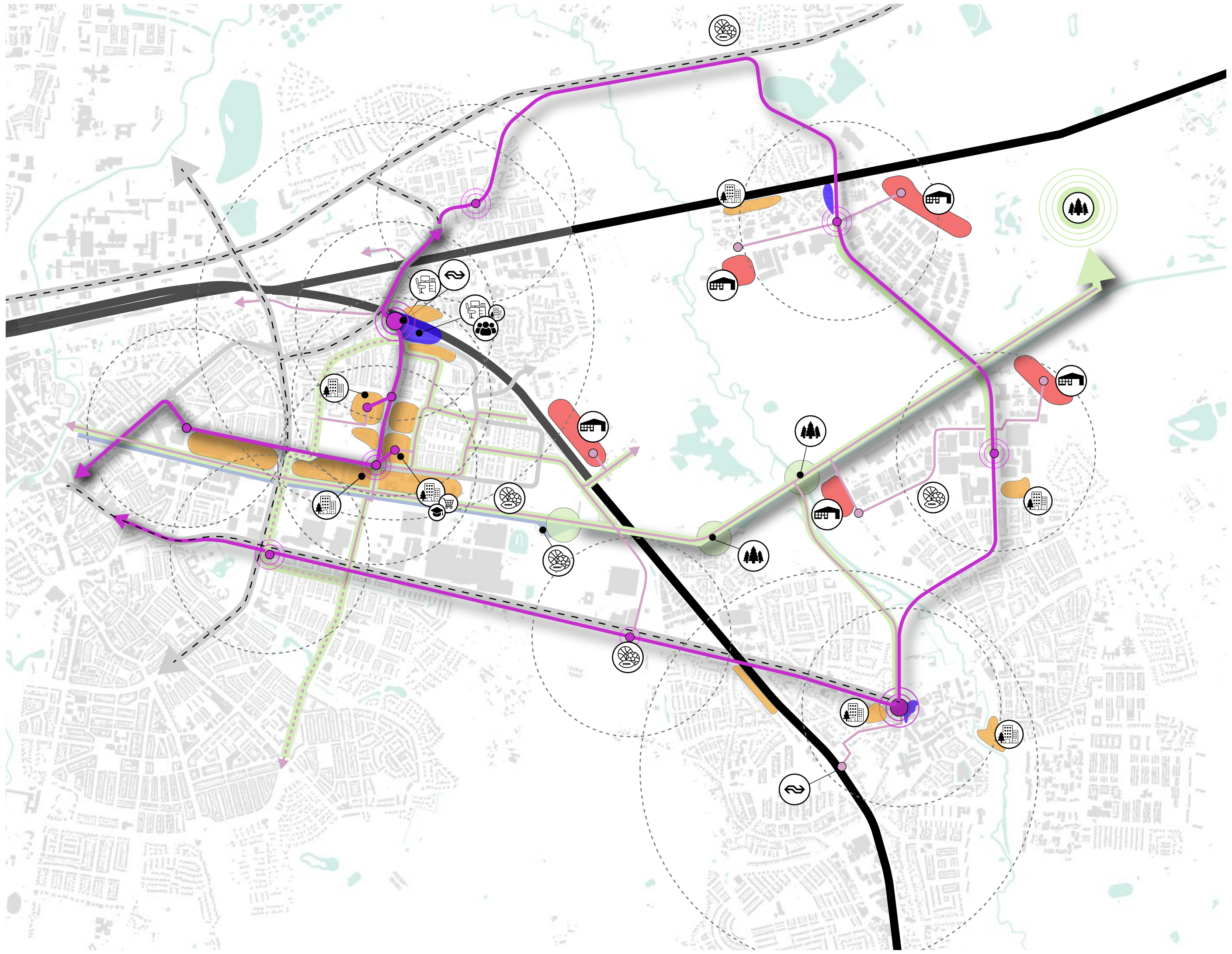


Bike lane
Shared road with cars
Important internal car road
Primary car road
Green corridor
Train tracks
Canal
HOV-bus line
Mobility hub
Redevelopment area with primarily residential function
Redevelopment area with primarily office function
Service range of mobility hub or public transport stop
Iconography:
- Residential
- Retail
- Education
- Offices
- Communal function

Figure 31, Scenario 1 elaboration, Doornakkers as focus area.

	Total area considered	Current estimated residences on site	Estimated proposed residences on site	Amount of new residences
Brownfields	2,5 ha	0	250	250
Old social housing	7,75 ha	155	430	275
Greyfields	0,9 ha	0	60	60
				total : 585

Table 3, Assumed addition of new residences per intervention area in scenario 1.



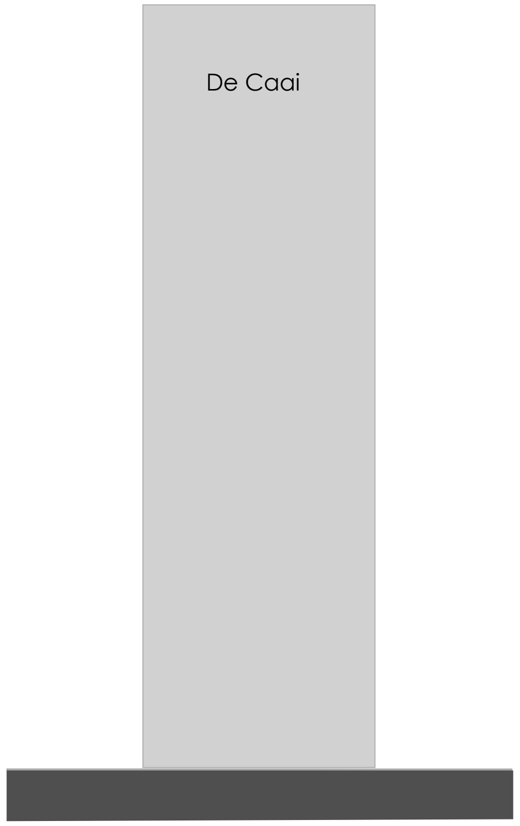
Bike lane
Shared road with cars
Important internal car road
Primary car road
Green corridor
Train tracks
Canal
HOV-bus line
Mobility hub
Redevelopment area with primarily residential function
Redevelopment area with primarily office function
Space for displaced industrial and warehouse buildings
Service range of mobility hub or public transport stop
Iconography:
- Residential
- Retail
- Education
- Offices
- Communal function
- Train station
- Natural green
- Sports

Figure 32, Scenario 2 elaboration, East Eindhoven as focus area

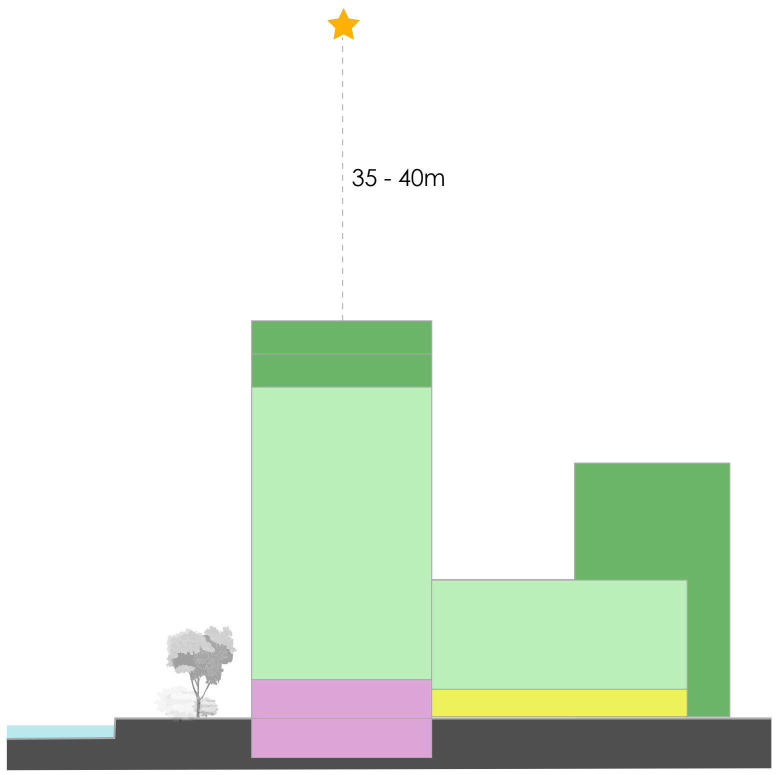
	Total area considered	Current estimated residences on site	Estimated proposed residences on site	Amount of new residences
Brownfields	22,5 ha	0	2250	2250
Old social housing	15,25 ha	320	1020	700
Greyfields	6,15 ha	5	370	365
				total : 3315

Table 4, Assumed addition of new residences per intervention area in scenario 2.

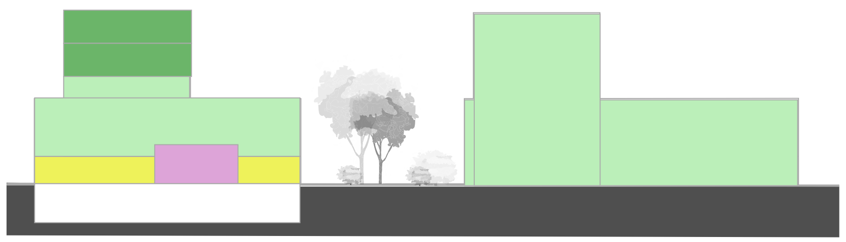
Conceptual local implementation



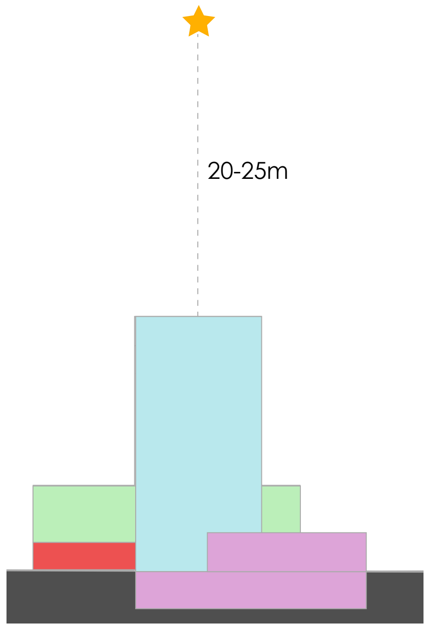
Reference height of tallest building in nearby development.



Larger recognizable building near waterfront combined with mobility hub and services in plinth.



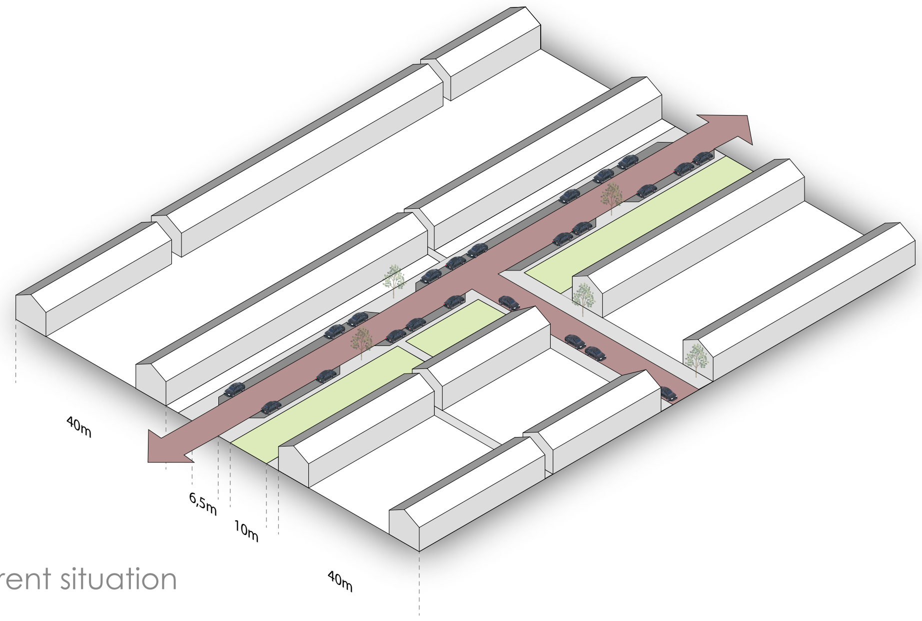
Inner areas have only some larger buildings, with most of them maxing out at three layers.



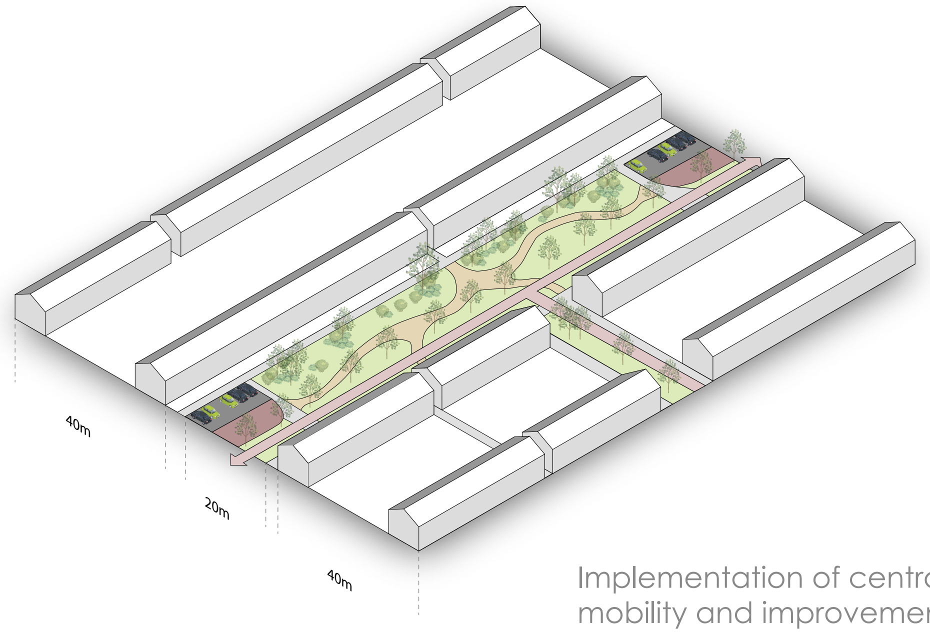
Recognizable building near large scale hub integrates office spaces.

Affordable housing
Higher cost housing
Retail
Offices
Mobility hub
Communal function
Underground parking

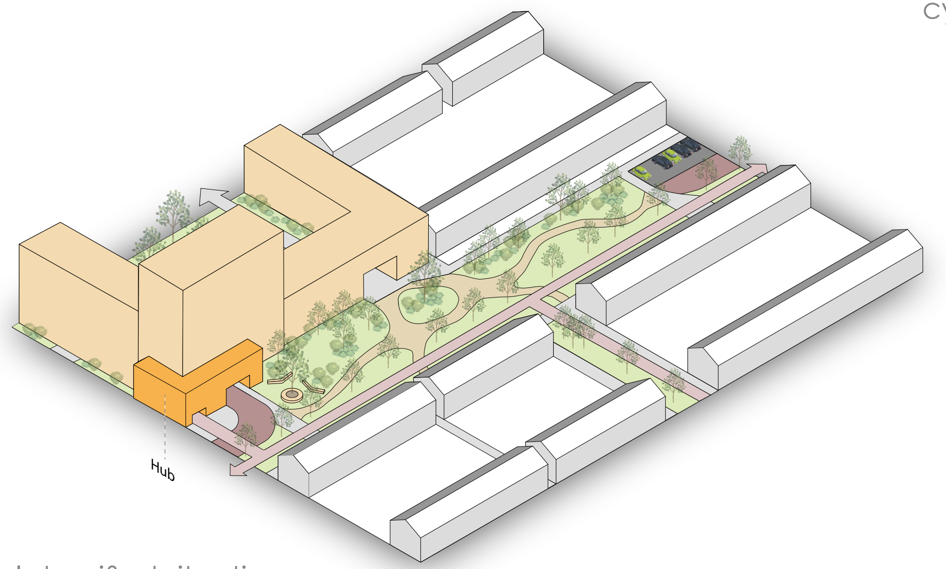
Figure 33, Sections showing building rules for densification in Doornakkers



Current situation

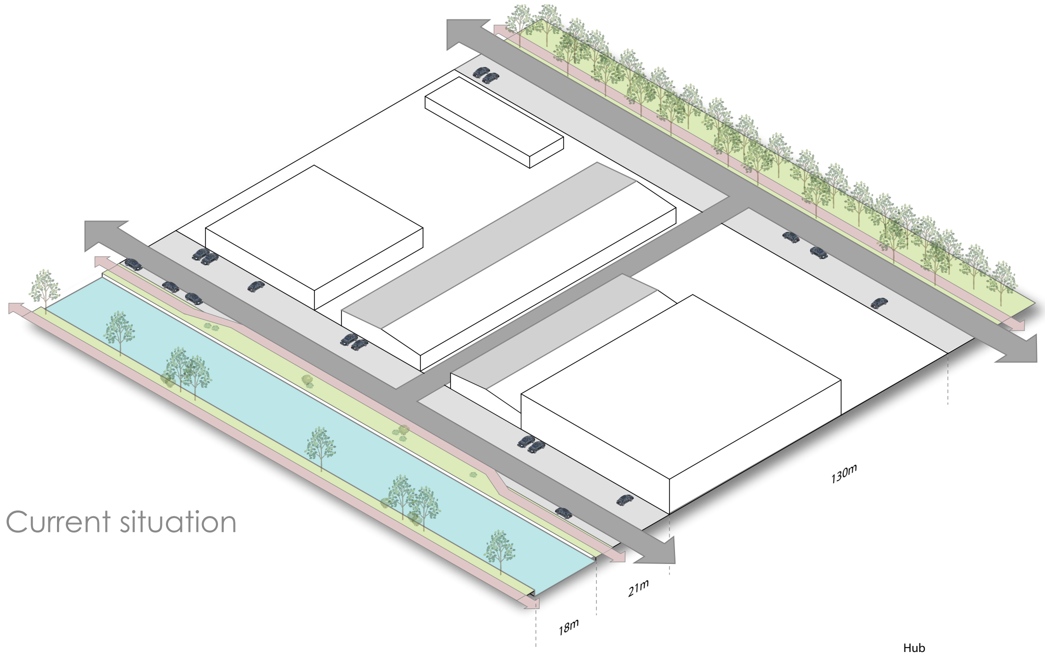


Implementation of centralized mobility and improvement of cycling and walking networks

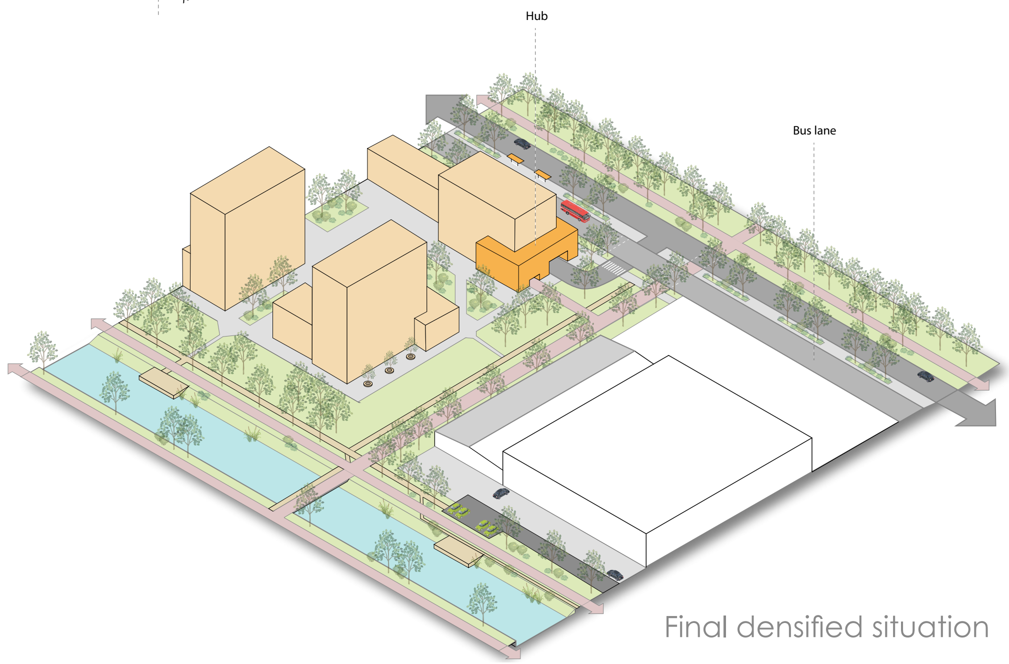


Final densified situation

Figure 34, Conceptual sketches of possible design interventions applied to a context in Eindhoven.



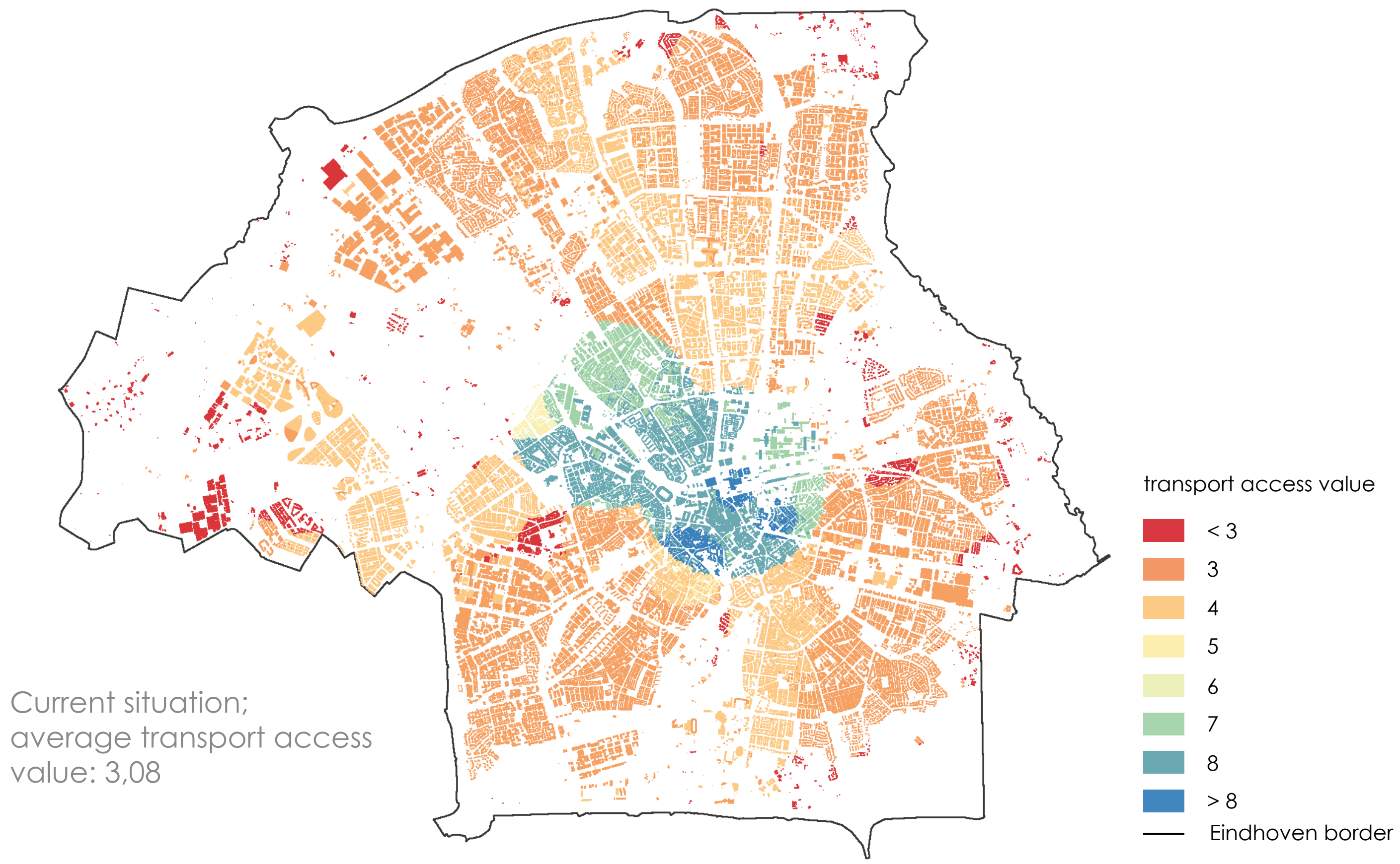
Current situation



Final densified situation

Figure 35, Conceptual sketches of possible design interventions applied to a context in Eindhoven.

Implementation assesment on Eindhoven



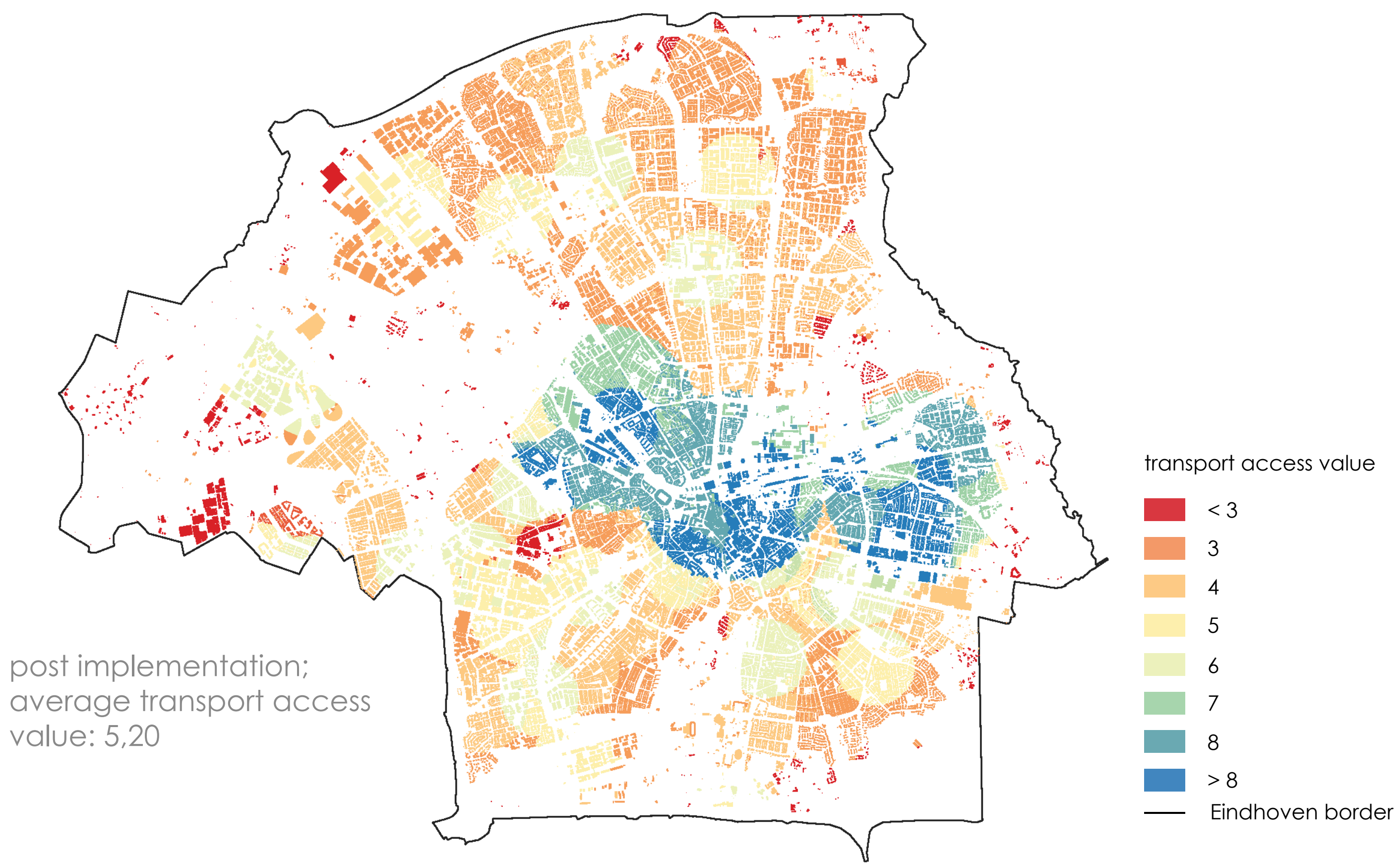


Figure 36, current and post-implementation transportation values

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Appendix

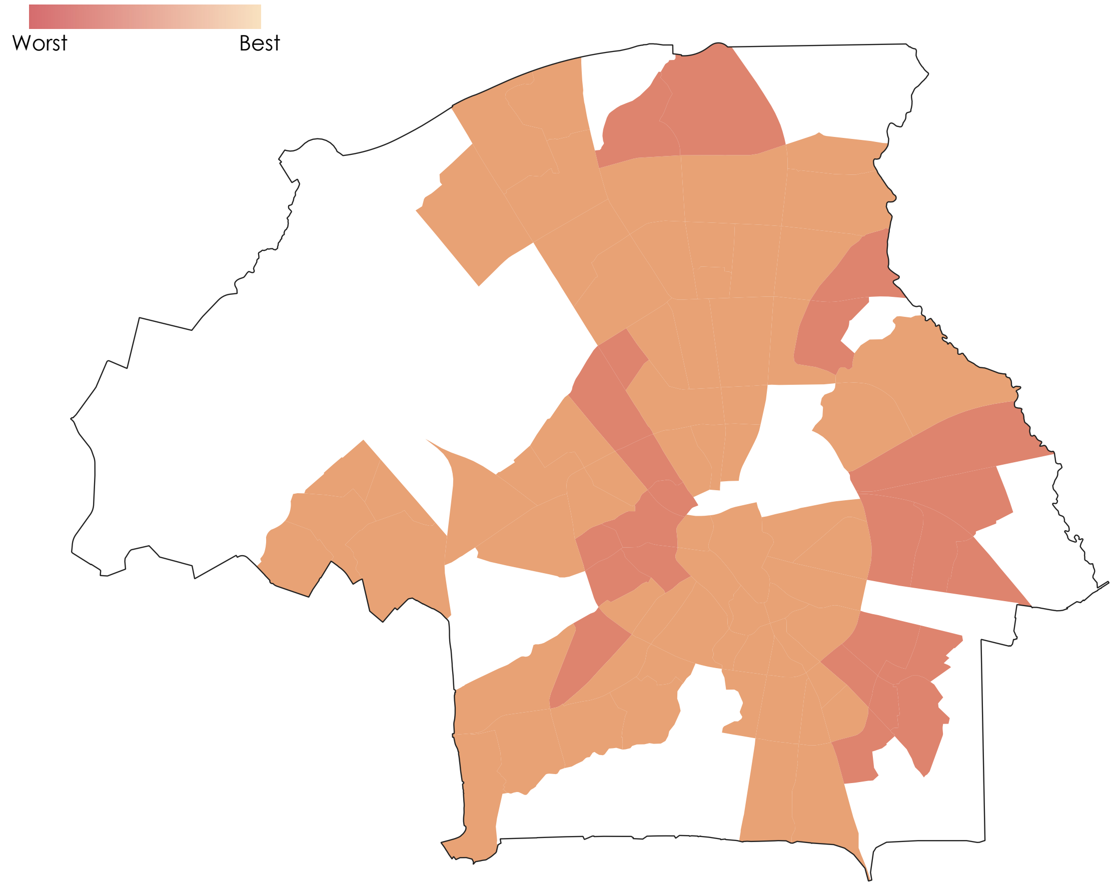
Appendix 1, overview of indicators found in literature

rererence source number	Author(s)	year	title	positive relations found	negative relations found
1	Abduljabbar, R. L., Liyanage, S., & Dia, H.	2021	The role of micro-mobility in shaping sustainable cities: A systematic literature review	cycling - shorter distances (o) - facilities at destination (p) - proper infrastructure (o) - awareness campaigns (p) shared mobility - shorter distances (o) - dedicated infrastructure (o) - seperation from traffic (o) - safety from crime (o) - traffic safety (o) - user is a woman (p)	cycling - steep inclines (o) shared mobility - steep inclines (e-bikes) (o) - age of user (o) - availability of service (o)
2	Barnett, D., Barnett, A. H., Nathan, A., Van Cauwenberg, J., & Cerin, E.	2017	Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis	walking - facilities at destination (o/p) - proximity of green space (p) - dedicated infrastructure (o/p) - safety from crime (o/p) public transport - availability of service (o/p)	
3	Dibaj, S., Hosseinzadeh, A., Stead, D., & Kluger, R.	2021	Where Have Shared E-Scooters Taken Us So Far? A Review of Mobility Patterns, Usage Frequency, and Personas	shared mobility - high urban density (o) - shorter distance from departure to dedicated infrastructure (o) - facilities at destination (p)	
4	Fraser, S. D., & Lock, K.	2011	Cycling for transport and public health: a systematic review of the effect of the environment on cycling	cycling - shorter distances (p) - high urban density (p) - shorter distance from departure to dedicated infrastructure (o) - proximity of green space (o) - seperation from other traffic modes (p) - dedicated infrastructure (o)	
5	Golbabaei, F., Yigitcanlar, T., & Bunker, J. M.	2021	The role of shared autonomous vehicle systems in delivering smart urban mobility: A systematic review of the literature	shared mobility - high urban density (o) - shorter distance from departure to dedicated infrastructure (o) - facilities at destination (o) - dedicated infrastructure (o) - affordability (o) - reliability of service (o) - availability of service (o)	shared mobility - shorter distances (o) - age of user (o)
6	Hoffmann, C., Abraham, C., White, M. P., Ball, S., & Skippon, S.	2017	What cognitive mechanisms predict travel mode choice? A systematic review with meta-analysis.	cycling - traffic safety (p) public transport - dedicated infrastructure (p) - availability of service (p)	walking - traffic safety (p)
7	Jardim, B. A., & De Castro Neto, M.	2022	Walkability Indicators in the Aftermath of the COVID-19 Pandemic: A Systematic Review.	walking - high urban density (o)	walking - proximity to green space (o) - health issues (o)

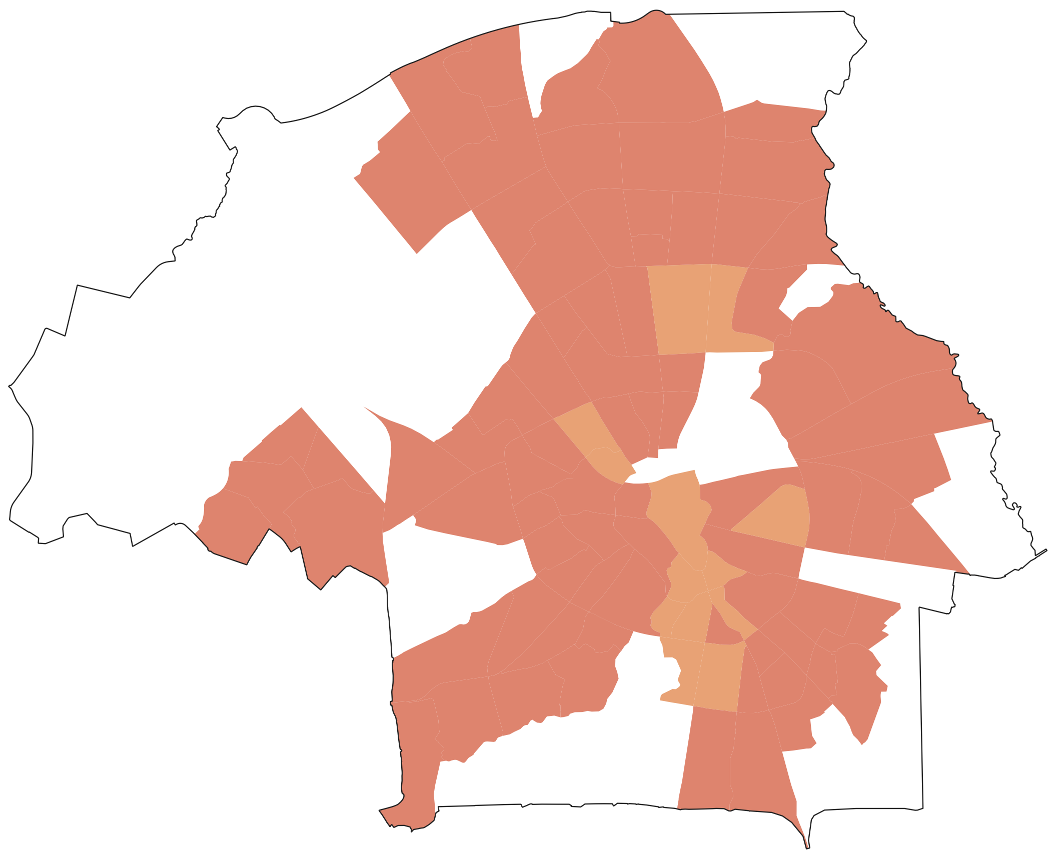
reference source number	Author(s)	year	title	positive relations found	negative relations found
8	Kong, W., Pojani, D., Sipe, N., & Stead, D.	2021	Transport Poverty in Chinese Cities: A Systematic Literature Review.	cycling - affordability (o) - awareness and information (p) public transport - affordability (p) - availability of service (o)	
9	Kuss, P., & Nicholas, K. A.	2022	A dozen effective interventions to reduce car use in European cities: Lessons learned from a meta-analysis and transition management.	cycling - dedicated infrastructure (o) - quality of infrastructure (p) - awareness and information (o) walking - dedicated infrastructure (o) - quality of infrastructure (p) - awareness and information (o) public transport - affordability (o) - monetary incentive (o) - reliability of service (o) - availability of service (o) - awareness and information (o) shared mobility - availability of service (o) - awareness and information (o)	
10	Lorenc, T., Brunton, G., Oliver, S., Oliver, K., & Oakley, A.	2008	Attitudes to walking and cycling among children, young people and parents: a systematic review.	cycling - dedicated infrastructure (p) - safety from crime (p) - traffic safety (p) - protection from weather (p) walking - dedicated infrastructure (p) - safety from crime (p) - traffic safety (p) - protection from weather (p)	cycling - age of user (p) walking - age of user (p)
11	Luiu, C., Tight, M., & Burrow, M. F.	2018	Factors Preventing the Use of Alternative Transport Modes to the Car in Later Life.	cycling - shorter distances (p) - high urban density (p) - separation from other traffic (p) - quality of infrastructure (p) - safety from crime (p) walking - shorter distances (p) - high urban density (p) - separation from other traffic (p) - dedicated infrastructure (p) - quality of infrastructure (p) - safety from crime (p) - traffic safety (o) public transport - shorter distance from departure to dedicated infrastructure (p) - separation from other traffic (p) - safety from crime (p) - health issues (p) - affordability (o/p) - reliability of service (o/p) - availability of service (o/p) - comfort of service (p) - awareness and information (p)	cycling - steep inclines (p) - age of user (o) - health issues (o) walking - steep inclines (p) - age of user (o) - health issues (o) public transport - age of user (o) - health issues (o)

reference source number	Author(s)	year	title	positive relations found	negative relations found
12	Mitropoulos, L., Kortsari, A., & Aifadopoulou, G.	2021	A systematic literature review of ride-sharing platforms, user factors and barriers.	cycling - facilitie at destination (o) walking - facilities at destination (p) public transport - shorter distance from departure to dedicated infrastructure (p) - facilities at destination (o) shared mobility - shorter distances (o) - high urban density (o) - safety from crime (p) - age of user (o) - user is a woman (o) - affordability (o) - reliability of service (p) - availability of service (p) - comfort of service (o/p) - awareness and information (o)	shared mobility - shorter distances (p) - high urban density (o)
13	Mouratidis, K., Peters, S., & Van Wee, B.	2021	Transportation technologies, sharing economy, and teleactivities: Implications for built environment and travel.	shared mobility - high urban density (o) - facilities at destination (o) - dedicated infrastructure (o) - availability of service (o) - awareness and information (o)	
14	Saelens, B. E., Sallis, J. F., & Frank, L. D.	2003	Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures.	cycling - shorter distances (o) - high urban density (o) - facilities at destination (o) - dedicated infrastructure (o) walking - shorter distances (o) - high urban density (o) - facilities at destination (o) - dedicated infrastructure (o)	
15	Saif, M. W., Zefreh, M. M., & Török, Á.	2018	Public Transport Accessibility: A Literature Review.	public transport - facilities at destination (o/p) - reliability of service (p) - availability of service (p) - comfort of service (p)	

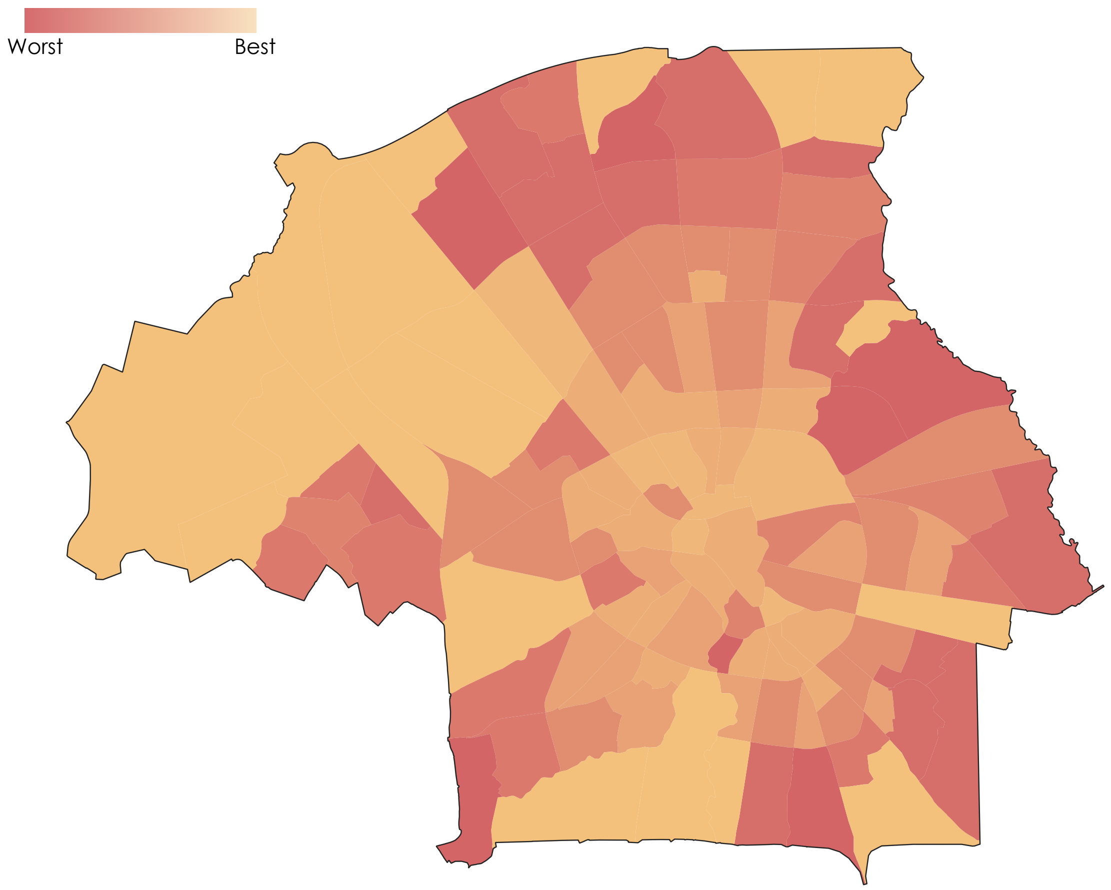
Appendix 2, overview of QGIS maps



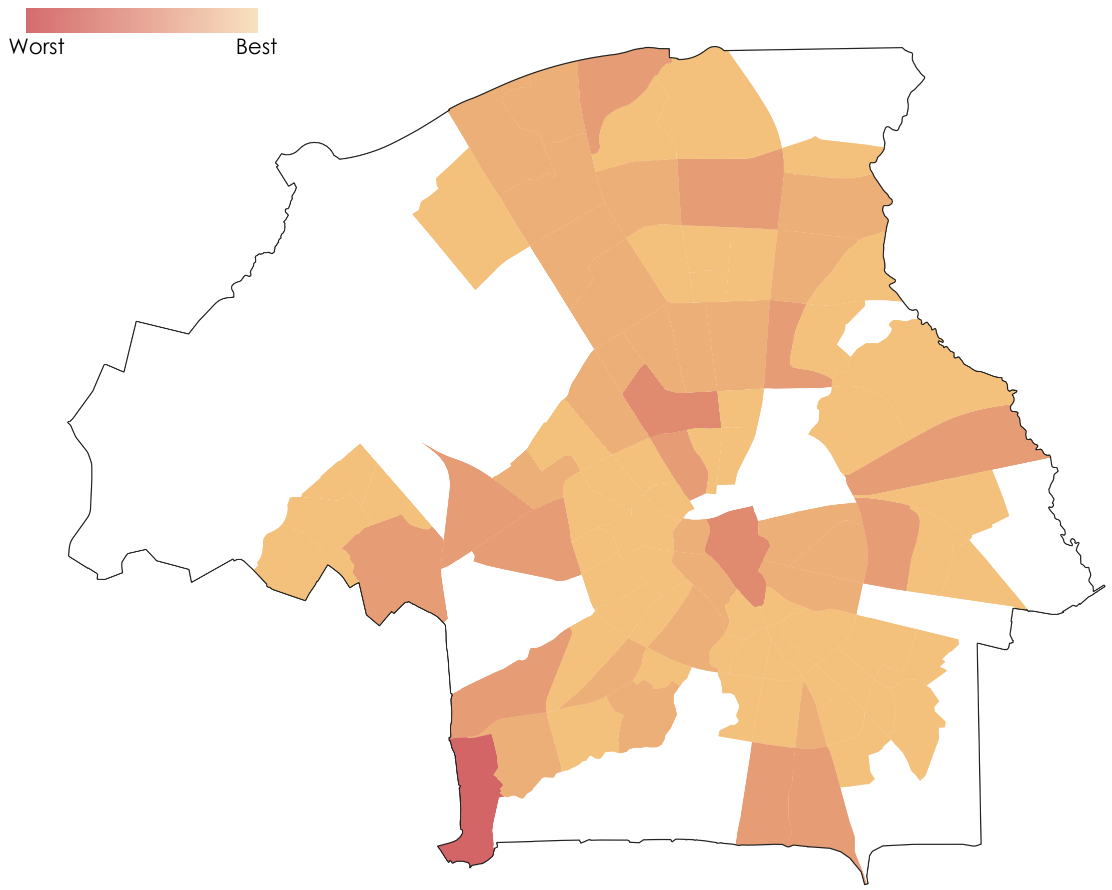
Appendix 2A, City centre accessibility by bus



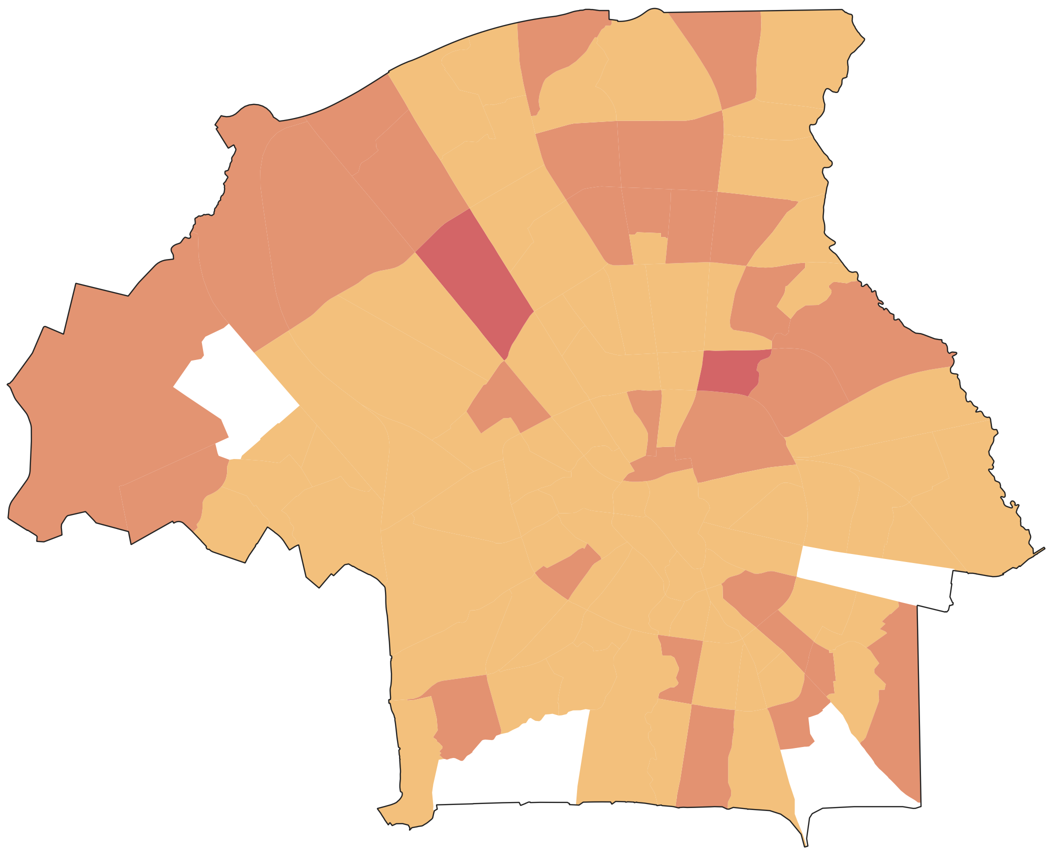
Appendix 2B, City centre accessibility by bikes



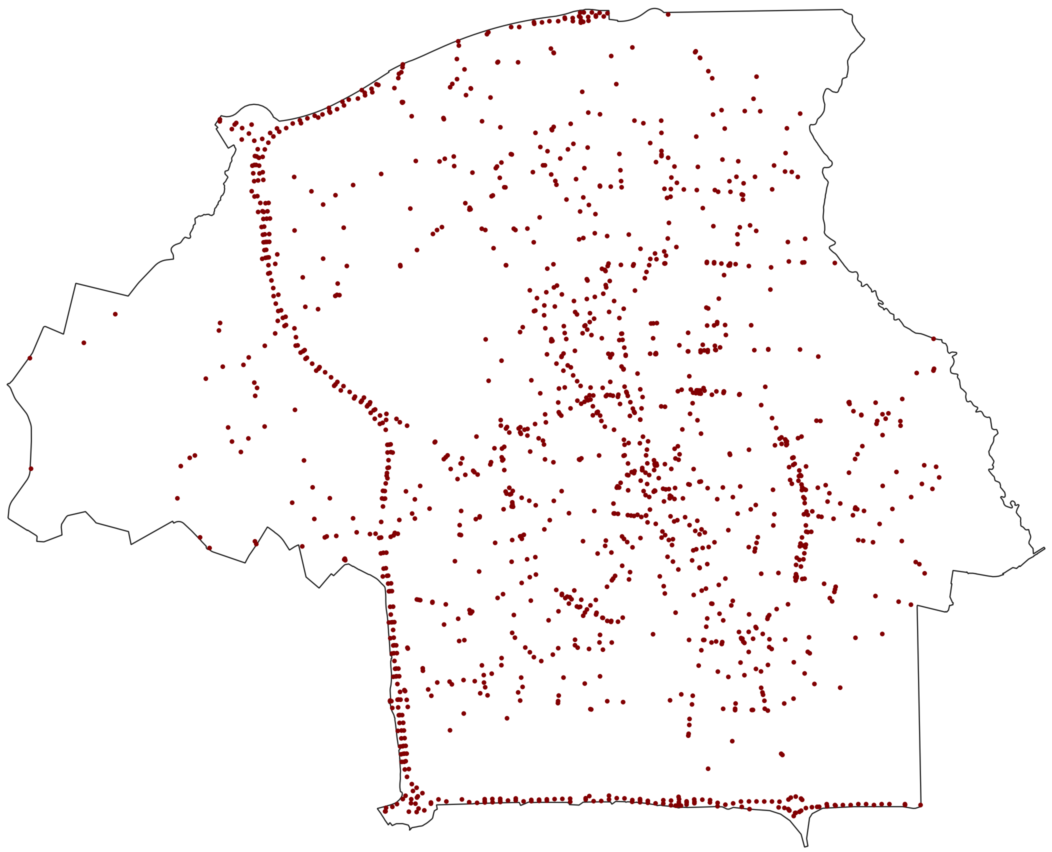
Appendix 2C, Car ownership per neighborhood (most cars = worst)



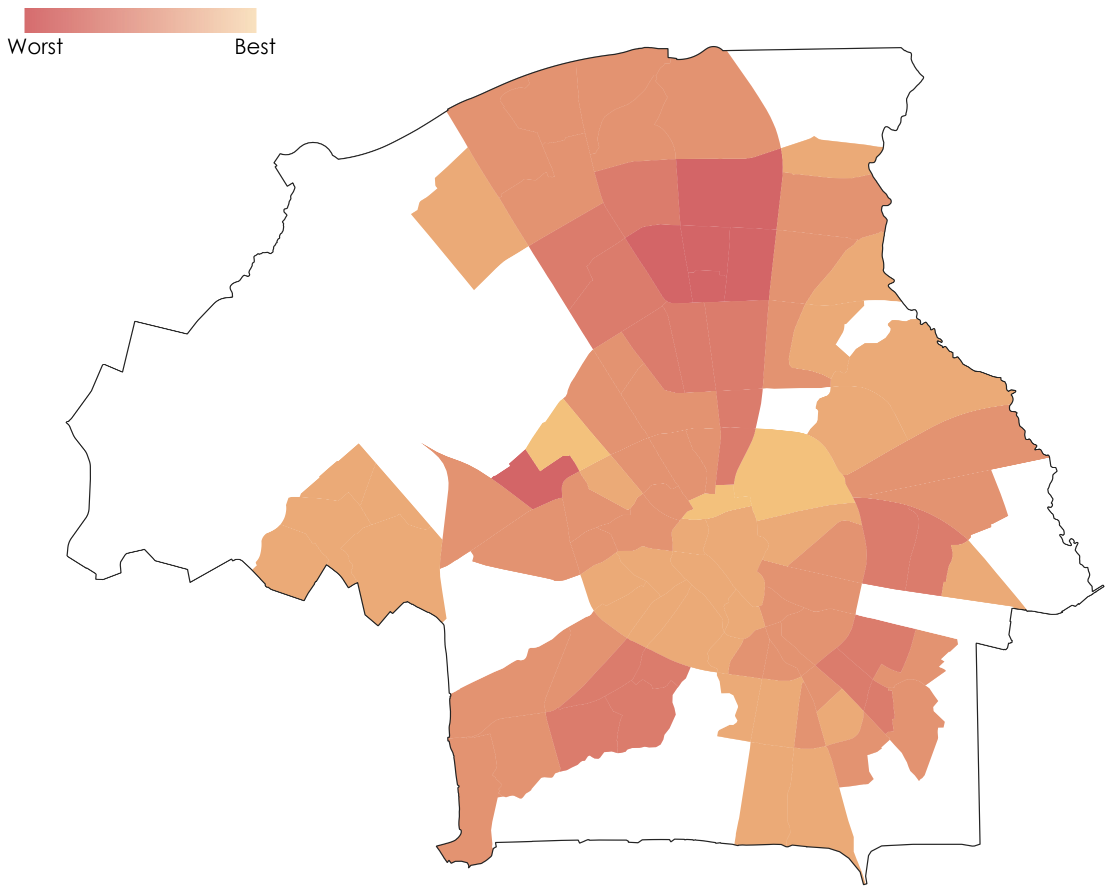
Appendix 2E, Traffic accidents per neighborhood



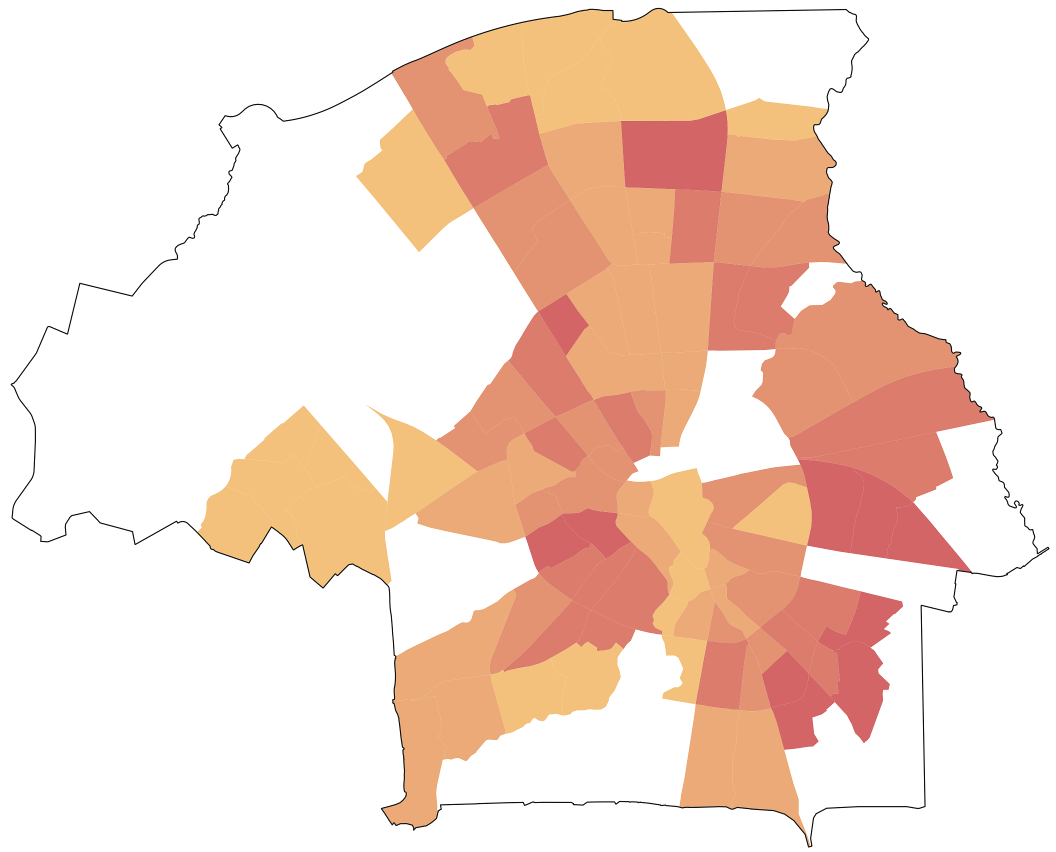
Appendix 2D, Gender discrepencies



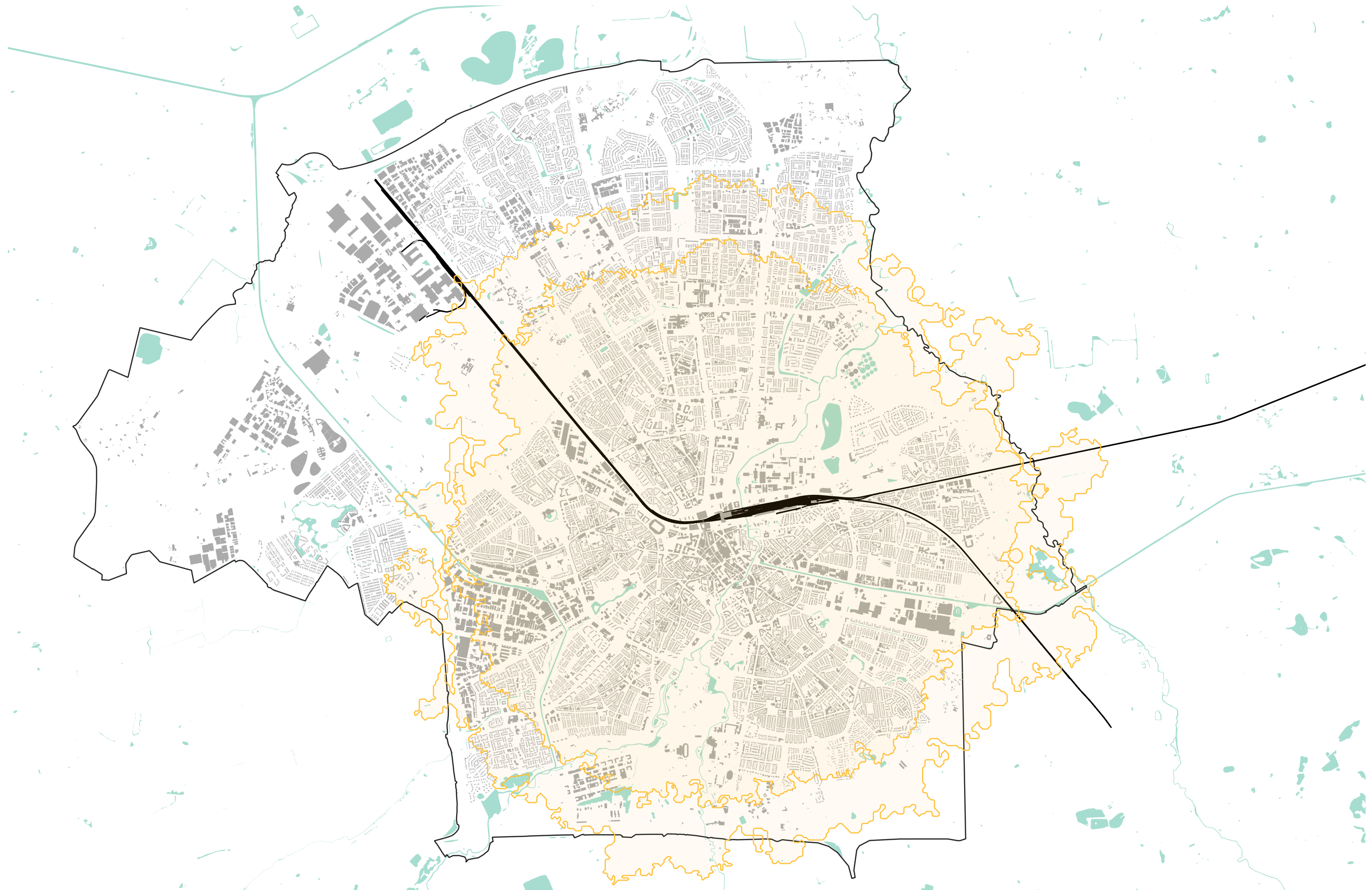
Appendix 2F, (reported) traffic accidents in 2022



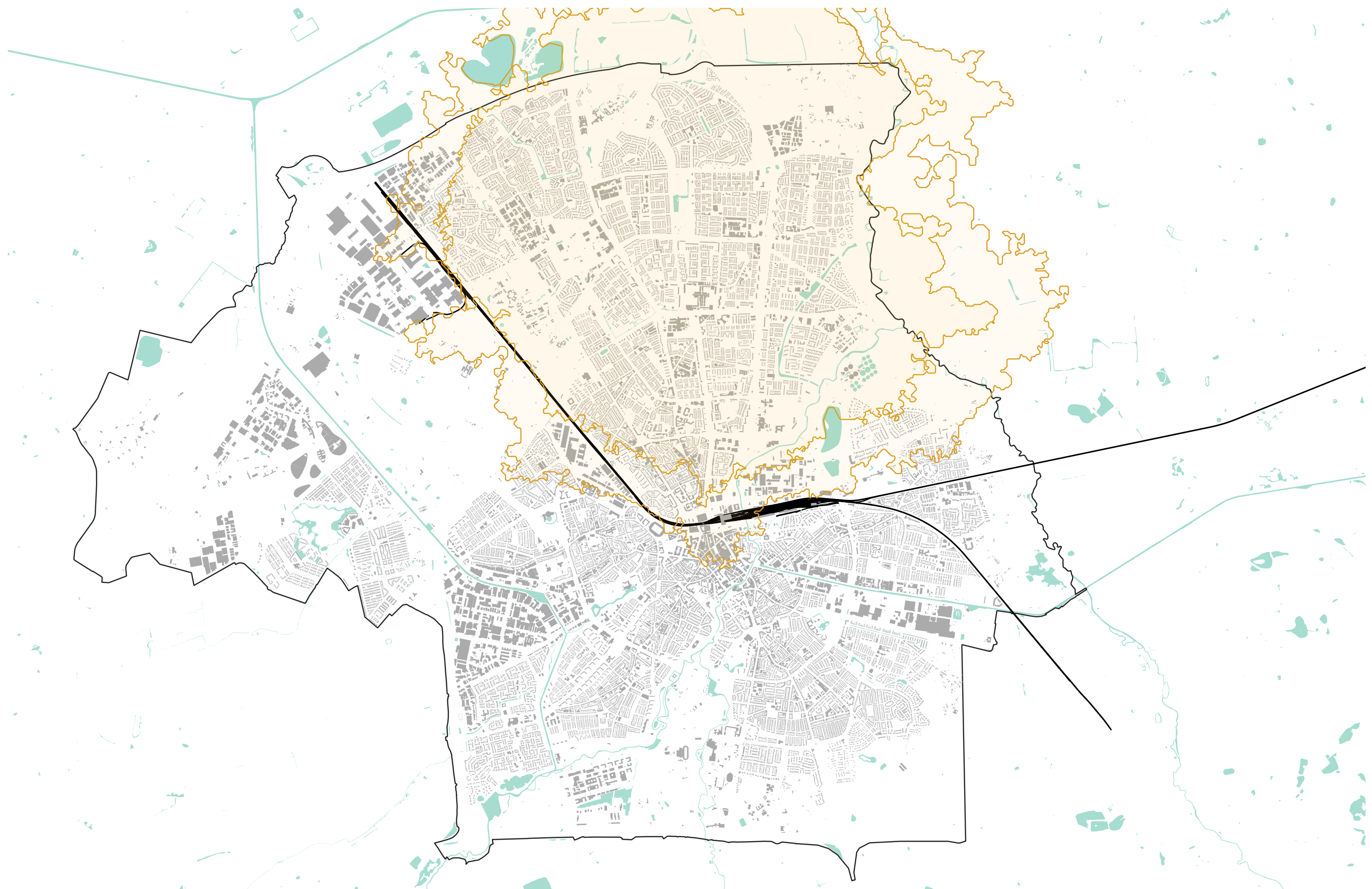
Appendix 2G, perception of own health



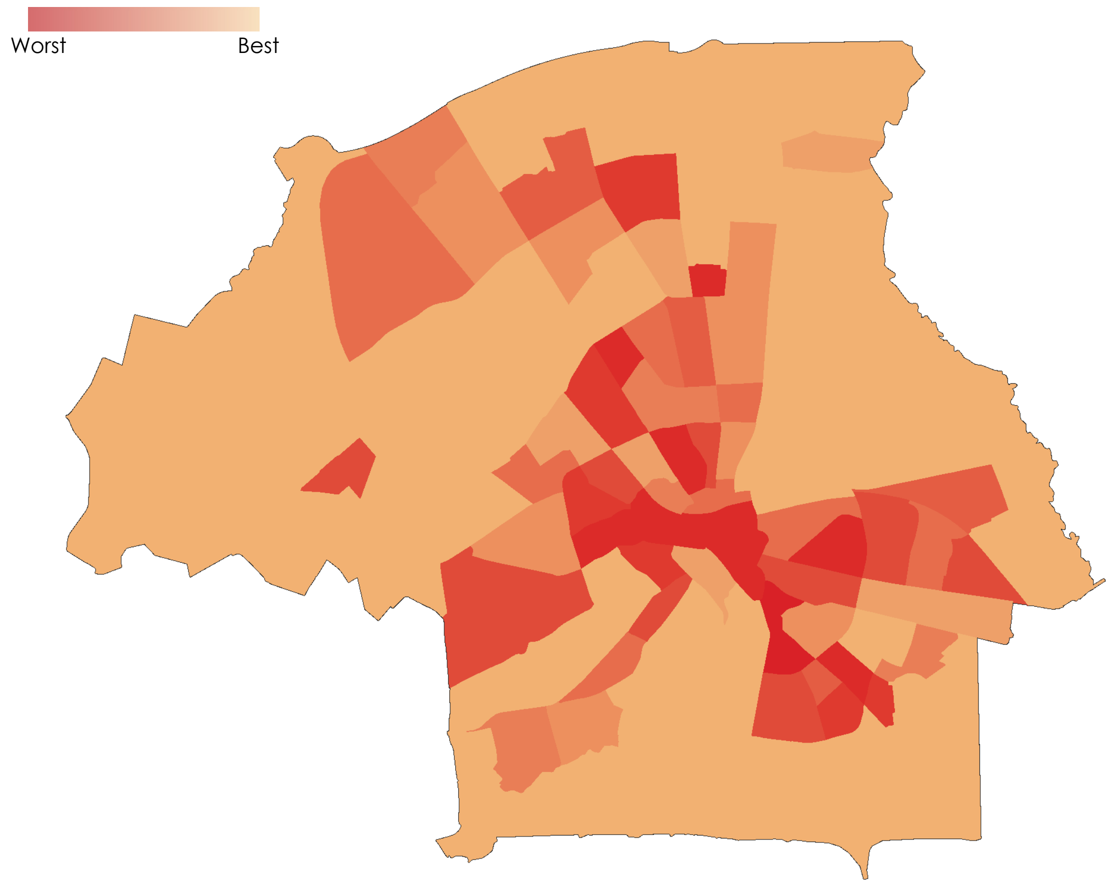
Appendix 2H, Percentage of people that feel unsafe in traffic



Appendix 2I, 15 min bike range from central station, regular vs E-bike



Appendix 2J, 15 min bike range from Tempel, regular vs E-bike



Appendix 2K, % of neighbourhood used as green space.

Appendix 3, Data sources for maps

map theme	data	data source
dedicated infrastructure	public transport stops	OSM / PDOK / Gemeente Eindhoven
	Bike lanes	OSM / PDOK / Gemeente Eindhoven
	pedestrian paths	OSM / PDOK / Gemeente Eindhoven
	Car roads	OSM / PDOK / Google Earth / Gemeente Eindhoven
	(HOV) Bus lanes	PDOK / Google Earth / Gemeente Eindhoven
travel time / PT coverage	20-min coverage of PT	Traveltime / Google
	routes to take by PT	Traveltime / Google
	city centre accessibility (survey)	Gemeente Eindhoven
livability	low livability defined by municipality	Gemeente Eindhoven
	car ownership	Gemeente Eindhoven
	gender	Gemeente Eindhoven
	traffic accidents	Rijkswaterstaat
	perception of own health	Gemeente Eindhoven
	long term health problems	Gemeente Eindhoven
	perception of traffic safety	Gemeente Eindhoven
	perception of safety from crime	Gemeente Eindhoven
	proximity to green space	PDOK / Gemeente Eindhoven

Appendix 4, Eindhoven green wedges