SUSTAINABLE MOBILITY IN POST-INDUSTRIAL DEVELOPMENT

A research to sustainable mobility in post-industrial development applied to Merwe-Vierhavens, Rotterdam

MSc Graduation thesis report | **Stefan Vermeulen** | 4604881

COLOFON

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01 Introduction

In this chapter an introduction of the thesis project and an explanation of the research structure is given.

This thesis project starts with two problems, which are rather called ‘challenges’. The first challenge is the transition towards sustainable mobility. In the 20th century, the transportation network was dominated by vehicles with internal combustion engines. However, the use of these vehicles causes different environmental problems like excessive CO_2 emission (Fulton et al., 2017). This calls for a change in mobility use. Electric, hybrid, shared, and autonomous vehicles could be technological revolutions to engage towards a sustainable way of mobility use. Besides that, the stimulation of public transport use and non-motorized transportation, like walking and cycling, could contribute to enhancing sustainable mobility (Transport & Environment, 2019).

Another urban trend is the redevelopment of industrial areas. The (heavy) industry is moving out of the cities, which leaves these sites prime for redevelopment (Van der Knaap, 2002). However, with the heavy industry moving out, small-scale businesses find their way back into the city. Another urban challenge is the densification of the cities, as the province of Zuid-Holland must densify with 1 million homes (Ruimte + Wonen, 2018).

The two challenges come together in the Merwe-Vierhavens (M4H), Rotterdam, an industrial site prime for redevelopment, displayed in figure 1.1. This thesis project addresses the following research question: ‘How can sustainable mobility principles influence the redevelopment of post-industrial sites, towards a sustainable environment?’.

This report consists of five parts. In the first part, the problem field is defined, explaining and diving into the different challenges that form the base of this thesis. The next part, methodology, explains the research structure of the project. The theoretical research elaborates the different concepts with the theoretical background. These theories form the basis of the fourth part, the analysis. In this part, further research of the concepts is done and the theory is applied to the case of M4H. In the final part, strategy, an approach towards sustainable mobility is given, consisting of infographics, patterns, and a strategic framework.

Figure 1.1 | Aeroview M4H *(Dick Sellenraad, n.d.)*

02 Problem field

In this chapter will describe the problem field of this thesis research. It starts with a problem analysis which introduces the two main challenges: the sustainable mobility shift and the industrial shift. It also introduces the project location. The problems field is concluded by the problem statement, research aims and research relevance.

2.1 Problem analysis

2.1.1 Introduciton sustainable mobility shift

Urban areas are constantly facing different challenges in adapting to the current needs of the people in these areas. The urban challenges arise from social, economic, or environmental perspectives.

A challenge in the mobility and transformation department is the adaptation or shift towards sustainable mobility. The mobility demands in urban areas are rising because of population and economic growth. This rising demand will lead in 2050 to three to four times as many passenger-kilometers traveled than in the year 2000 (Cervero, 2013). Most of the trips, at the beginning of the 21st century, are done by private motorized vehicles, powered by internal combustion engines (ICEV). These engines run on gasoline or diesel, non-renewable fossil fuels, which contribute to excessive CO_2 emissions. This influences the environment in a negative perspective and could therefore be stated as an unsustainable way of transportation (Transport & Environment, 2019).

To tackle the environmental problems, caused by the current mobility network, a shift towards sustainable mobility principles is needed. A sustainable mobility network focuses on the de-carbonizing of fuel supply and prioritization of sustainable mobility forms, such as public transport and non-motorized transportation. This transition of mobility network can be divided into a technical and a spatial component. The technical transition consists of a redevelopment of ICEV into sustainable alternatives, like electric vehicles. The responsibility of the spatial component in this mobility shift rests with the urban developers. The design of urban fabric has a major role in guiding this shift by spatially stimulating sustainable mobility principles.

To completely understand sustainable mobility, the relation to sustainable development should be researched. The World Commission on Environment and Development (1987) defines sustainable development as follows: 'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. An important component is an effect it has on future generations, in order to achieve sustainable development, the future implications must be considered.

To achieve sustainable development, the 2030 Agenda for Sustainable Development (UN General Assembly, 2015), has set up 17 development goals (SDGs) which act as a blueprint. The SDGs are approved and acknowledged by the UN and act as a call for action. The 17 SDGs have a large range in categories, considering the 'five Ps' (people, planet, prosperity, peace, and partnership).

The role of transportation in sustainable development is acknowledged by the UN in several documents over the years, as it enhances economic growth and accessibility, and improves social equality, health, and resilience of cities (United Nations, 2012). However, in the broad scope, there is a lack of an SDG standalone considering sustainable transportation. The aspect of transportation is reflected in multiple SDGs and targets, such as goal 3 (good health and well-being), goal 9 (industry, innovation, and infrastructure), and goal 11 (sustainable cities and communities).

In order to state the importance of sustainable transportation in relation to sustainable development, the initiative of SuM4All was started by the World Bank Group (2016). SuM4All

(Sustainable Mobility for All) is a platform that focuses on international cooperation on transport and mobility issues (SuM4All, 2017). The concept consists of four elements:

- a commonly agreed vision for sustainable mobility, which is articulated around four global objectives (see below).
- a global tracking framework (GTF) to measure progress towards these objectives.
- a global program of actions.
- a global governance structure to support the implementation of the first three components.

In order to achieve sustainable transport and mobility, the initiative distinguished four global objectives. The first objective is equitable mobility. This ensures equal opportunities for everyone, leaving no one behind. This would be represented in transport that connects people and communities to schools and health care and delivering goods and services to all areas. The second objective is efficient mobility. This ensures that the increase of mobility is met at the least possible cost for society, including non-motorized transport. The third objective of safe mobility ensures safety across all modes of transport, by reducing crashes, injuries, and fatalities. The final objective is green mobility and focuses on lowering the environmental footprint of the transport sector by reducing amongst others pollution.

The European Commission (1992) defines sustainable mobility as: 'To ensure that our transport systems meet society's economic, social and environmental needs whilst minimizing their undesirable impacts on the economy, society, and the environment'. The undesirable impacts should not go to cost while meeting society's needs. In order to achieve this way of mobility, a transition is

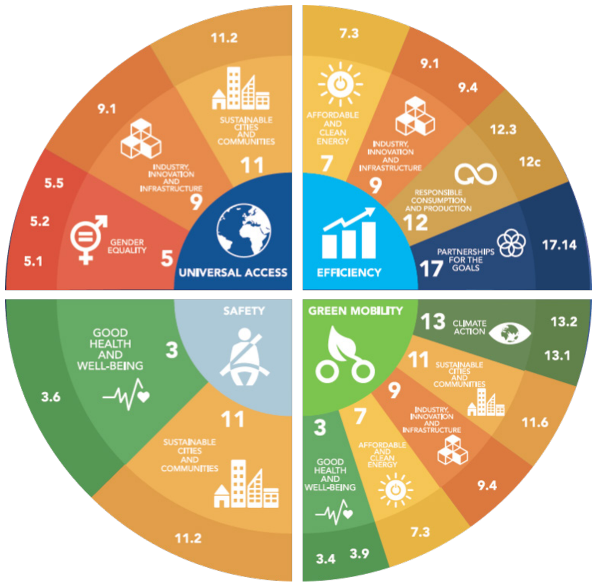


Figure 2.1 | SDGs mobility *(UN, 2015)*

2.1 Problem analysis

needed. The SuM4All initiative provides a tool, which shows points of improvement for each country. The Netherlands ranks third out of 183 countries on the list, regarding sustainable mobility, just behind Germany and Sweden. This is a great achievement; however, the tool also provides policies that need further action. For the Netherlands important action plans regarding universal urban access are for example the implementation of Mobility as a Service packages, providing effective car- and bicycle-sharing systems, and implementing awareness and behavior change strategies.

Policies considering sustainable mobility in the Netherlands derive from the Paris Agreement. The goal is carefree mobility, for everything and everyone in 2050. This would result in a reduction of environmental damage. An infographic is developed to provide an overview of the most important agreements in the mobility sector, see figure 2.2. The agreements are divided into four subcategories:

- sustainable energy carriers
- electric (passenger) traffic
- more sustainable logistics
- more sustainable personal mobility

With these agreements the Dutch government strives to cut emissions, guarantee affordable, safe, and comfortable accessibility for everyone in smart, sustainable, and compact cities (Ministerie van Economische Zaken en Klimaat, 2019).

The municipality of Rotterdam is active in the transition towards sustainable mobility. Several goals considering this transformation are distinguished, in official documents of the municipality (2016) it is stated: 'This means that we focus on clean transportation and more and better alternative transport choices, like walking, cycling, and public transport'. Besides this, the city of Rotterdam has the challenge to decrease its CO_2 emissions by 30% in 2025 and 50% in 2030. To achieve this, they decided to take measures to cut these emissions and accelerate the mobility transition. In the transition, cycling becomes the main mode of inner-city transportation, which asks for an upgrade of the current network. Space in the infrastructure needs to be redesigned to give priority to pedestrians, cyclists, and public transport. Sharing systems are increasing and ask for more space in the city (Municipality of Rotterdam, 2016)

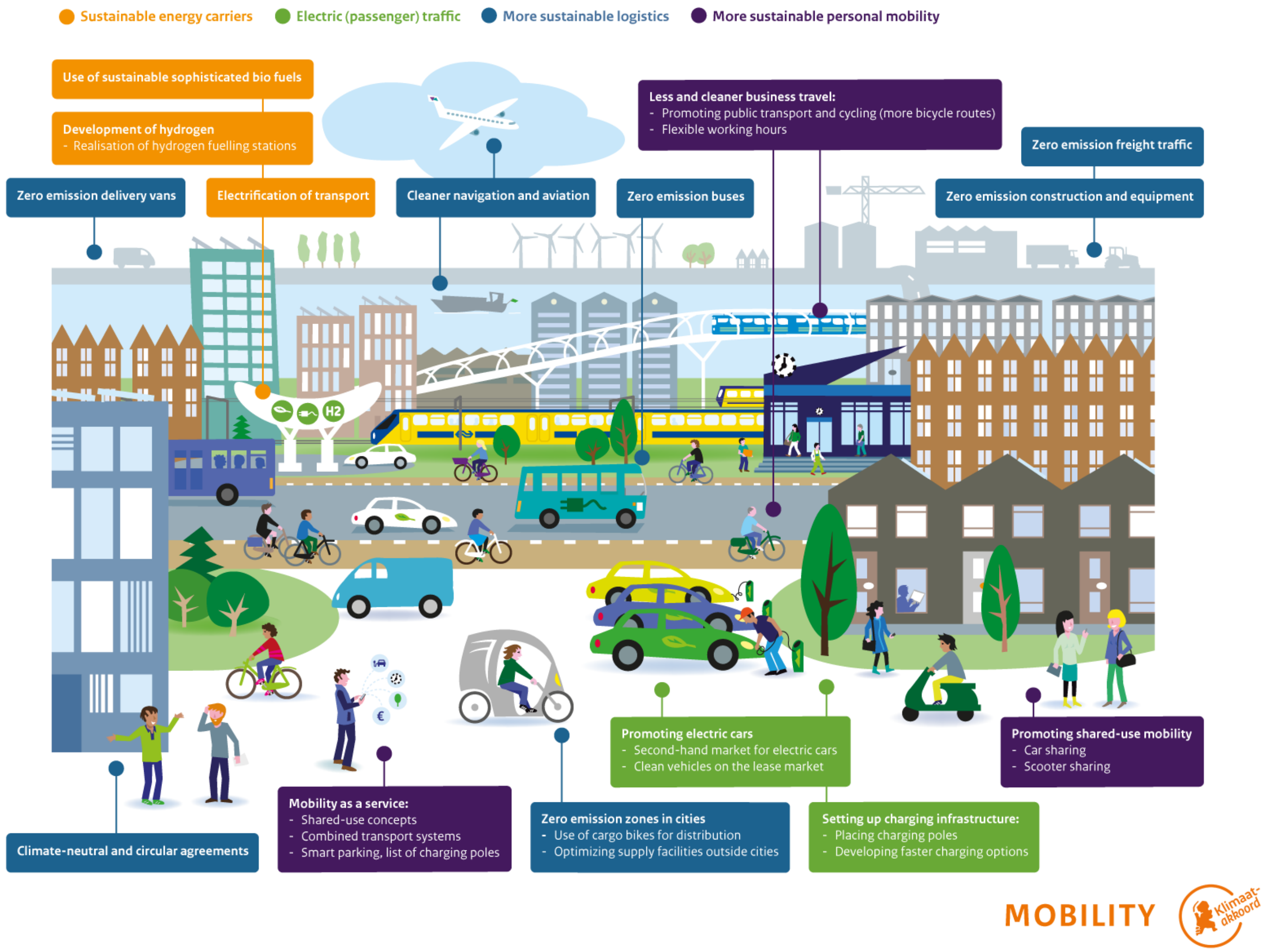


Figure 2.2 | Infographic sustainable mobility *(Klimaatakkoord, 2019)*

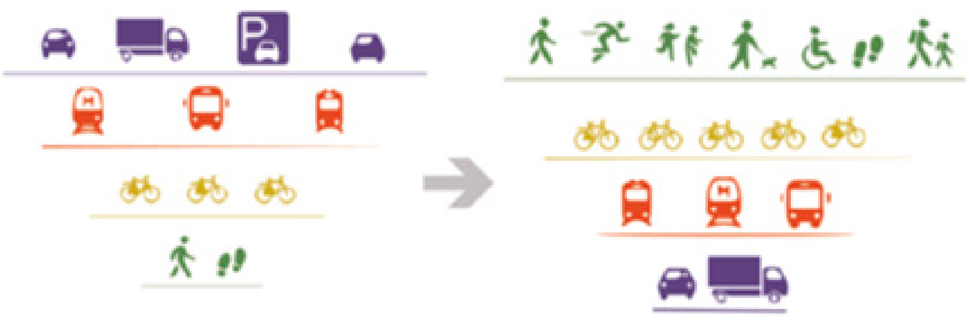


Figure 2.3 | Transition in mobility *(Municipality of Rotterdam, 2016)*

2.1 Problem analysis

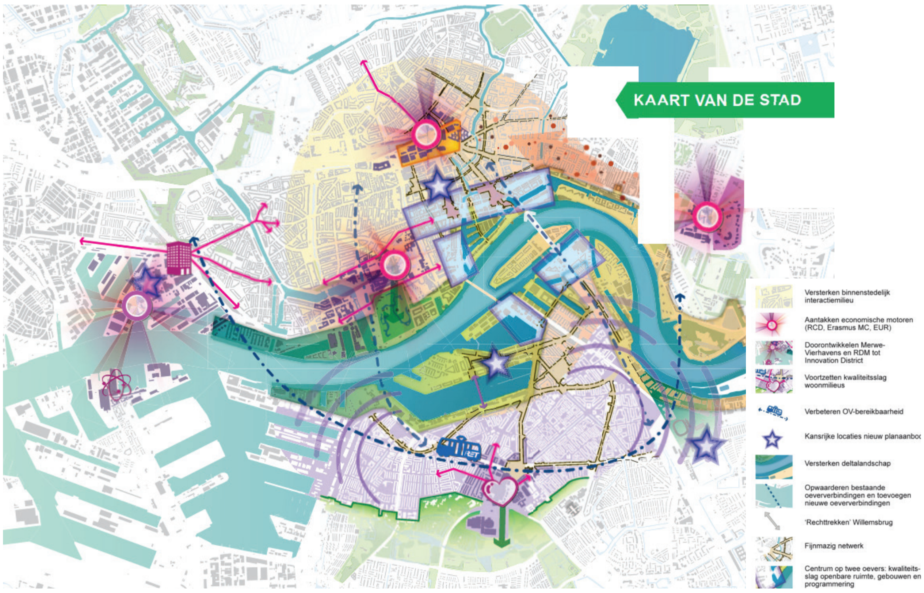
2.1.2 Introduciton industrial shift

Industry is an important diver of the development of cities as it is responsible for a major part of the economy in a city. Therefore, most cities are based around ports and other factors that stimulate industrial activity. However, the growth of industry within the city center is limited, which is why there is an urban shift with industry moving out of the city center and relocating near cities edges. These locations are better accessible and provides further development opportunities. This leaves the industrial sites in city centers empty and ready for redevelopment (Van der Kaap, 2002). The redevelopment in such post-industrial sites is often focused on residential densification, in combination with other functions, creating a mixed-use area.

The transformation to mixed-use functions derives from another urban challenge, urban densification. Whereas in the early 2000s new homes were created by large city extension, the so called Vinex-wijken, a shift occurred where urban growth is now more focused on inner-city densification. The city of Rotterdam strives to realize more than 50.000 houses within its urban borders before 2040. Within this densification the municipality aims on densifying areas near stations, the city center, and post-industrial sites. (Municipality of Rotterdam, 2019).

The area of interest is the city of Rotterdam. This city, known as the largest port city of Europe, is constantly developing. The development of the first ports started in 1400-1800 at the north side of the city. Over the years, the industrial activity increased, and bigger ports were needed, causing the industrial shift downstream towards the North Sea (figure 2.5). With the industrial activity moving out, the post-industrial areas near the city center needed to be redeveloped. The redevelopment started with the Oude Haven (Old Port), followed by the Wijnhaven, Leuvehaven and Zalmhaven. In these ports the industrial activity is replaces with leisure, housing, and offices. Next is the redevelopment of the Kop van Zuid (Head of South). This area is transformed into a vibrant extension of the city center to the south side of Rotterdam, connected by the famous Erasmusbrug.

Next in line the focus of the municipality is on transformation the Stadshavens (CityPorts), developed in 1906-1922. The industrial activity is slowly moving out and a strategy for urban transformation is needed. The development strategies of the municipality of Rotterdam show they focus on the development of the Merwe-Vierhavens (figure 2.4). The Merwe-Vierhavens (M4H) is part of the Stadshavens area, located on the north side of the river. Within the Stadshavens structural vision the M4H is designated as mixed-use densification area, because of its prime location near the city center.



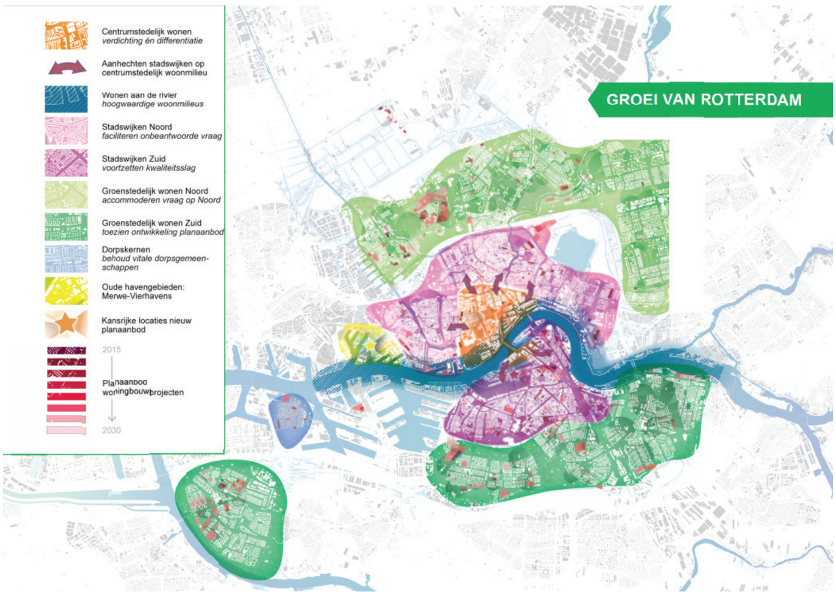
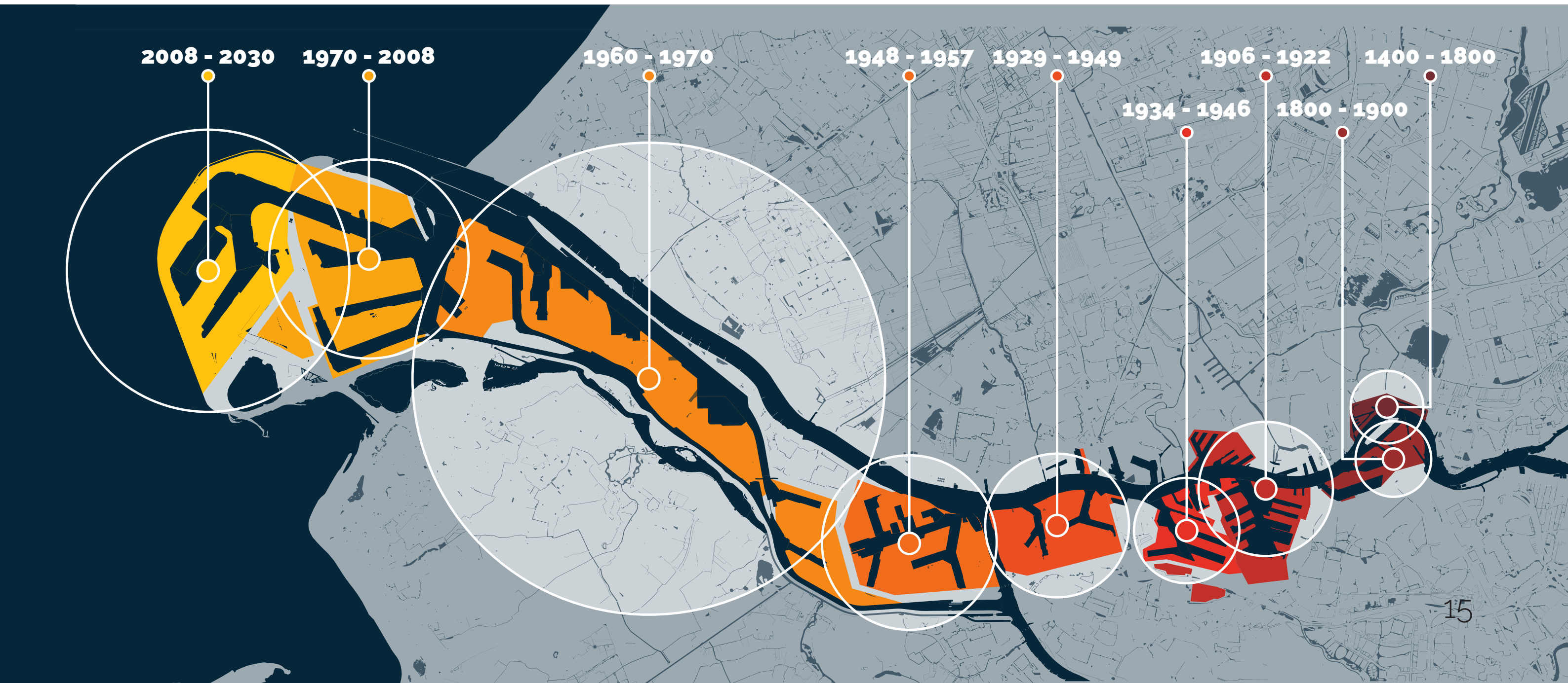


Figure 2.4 | Structural vision development in Rotterdam *(Municipality of Rotterdam, 2016)*

Figure 2.5 | Development Port of Rotterdam *(Port of Rotterdam, n.d.; adapted by Vermeulen, 2020)*



2.1 Problem analysis

2.1.3 Introduciton Merwe-Vierhavens

The area of interest is the Merwe-Vierhavens (M4H). This location in Rotterdam, is a post-industrial area ready for redevelopment, dealing with the challenges introduced before (see figure 2.6). The M4H is a former port area at the north side of the Maas (figures 2.7 and 2.8). It was once one of the largest fruit ports worldwide, storing and transporting various fruits every day. Nowadays, the approximately 100 hectares large port area is expanding and transforming into a Makers District.

To accomplish this a transformation of the urban fabric is needed. This urban transformation creates the opportunity to investigate possibilities to incorporate the mobility shift in this area. Rotterdam Makers District is a cooperation of the municipality of Rotterdam and the Port of Rotterdam, together they investigate the possibilities of redeveloping M4H. DELVA (2019) constructed a framework 'Toekomst in de maak' in which they propose several principles which would guide a sustainable urban development. This framework also addresses the topic of mobility as one of the principles. This thesis project will therefore use some of the stated principles, however a different perspective on the mobility approach will be done. As post-industrial sites generally consist of large infrastructural elements and the opportunity to implement sustainable mobility measures in an early stage present itself. Research is needed to investigate the relation between the different components, to see how mobility can be a guide to steer the development towards a sustainable environment.

Figure 2.6 | Pictures M4H *(Google maps, 2016)*

Figure 2.7 | Location M4H in city perspective *(Authors own, 2020)*

Figure 2.8 | M4H

2.2 Problem statement

2.2.1 Problem statement

The research of the topics related to the problem field consists of two different parts. On the one hand, research is done to generate knowledge about the stated concepts of mobility, development, and environment (figure 2.9), to create an overview of principles in relation to other spatial concepts. The second part consists of a specific case study on the M4H, to generate case-specific knowledge about the concept of mobility and post-industrial redevelopment. The topics described in the problem field lead to the following problem statement:

'Industrial sites need to be redeveloped as the industry is moving out and the current urban structure is not fit for the new functions. This, together with densification and other environmental challenges causes pressure on open space, which results in social, economic and environmental unsustainability'.

As the problem statement not directly touches the topic of sustainable mobility, a hypothesis is needed to relate the two challenges. The hypothesis for this research reads:

'The mobility shift towards sustainable principles can be a way to steer the development of post-industrial sites towards a sustainable environment'.

This states that the implementation of sustainable mobility principles will influence the development. This hypothesis derives from the statements that mobility is one of the key players in the sustainable transition of a city and that the concept of mobility is related to a large factor of other urban conditions.

The diagram in figure 2.9 shows the three main concepts: mobility, development, and environment. These three concepts all have a sustainable component in them and are therefore interrelated to each other. The diagram shows that the focus of this research starts from a mobility perspective.

Figure 2.9 | Diagram problem statement

2.2.2 Research aim

Multiple aims are formulated to show the purpose of this research. The aims are related to the different sub-questions, explained in paragraph 3.2. The first research aim is to find the relation between sustainable mobility principles and development challenges. Another aim is to find ways to translate mobility concepts into urban design principles. This aim shows the importance of an interrelation between research and design. The project also aims to reveal the potentials of urban development in M4H. This aim relates the research to the case location. The final aim of the project is to translate case-specific design elements into a general framework. This is an important aspect to aim for, as it makes sure the research is not only focused on the specific case but also considers the larger scope.

2.2.3 Research relevance

The research on these topics has its relevance on both social and scientific levels. As research showed that the transport and mobility sector is responsible for a large part of the environmental issues, the sector also has the potential to contribute largely to making cities more sustainable (Cervero, 2013). This shows the relevance and importance of understanding the role of (sustainable) mobility in this urban transition. Another aspect of the relevance of this research is visible in practice. A clear understanding and specific knowledge are needed in realizing successful redevelopment projects in post-industrial sites, as these locations are often strategic focus points in the city's development vision.

03 Methodology

In this chapter the methodology of the thesis research is explained. It shows the research framework and discusses the research questions and methods. The conceptual framework is described and a timeline overview is given.

3.1 Research framework

The structure of the research in this thesis project is shown in the research framework in figure 3.1. This framework shows the important elements of this research and explains the relations between these different elements. The research starts at the personal motivation and relevance, which lies in the infrastructural elements. The problem field consists of two urban challenges, the mobility shift, and post-industrial development. These two urgent challenges are further researched and explained in the conceptual framework. Through problem analysis, the problem field is converted into a concise problem statement which reads the following: *'Industrial sites need to be redeveloped as the (heavy) industry is moving out and the current urban structure is not fit for the new functions. This challenge, together with densification and other environmental challenges causes pressure on open space. This results in social, economic and environmental unsustainability'.* The hypothesis following the problem statement states that the mobility shift towards sustainable principles can be a way to steer this development towards a sustainable environment. In this way, the two elements from the problem field are the center of research. The representative case of M4H is used in this thesis to answer the research question. The main research question of the thesis project is *'How can sustainable mobility guide the redevelopment of post-industrial sites towards a sustainable environment?'*. To answer this question, four sub-questions are formulated. Four research aims, related to these questions, are distinguished to guide the research. Different methods are used to answer the four sub-questions. Through these methods, the questions are answered, leading to the research output of a sustainable mobility framework. This framework consists of specific development strategy and spatial design interventions for the case M4H, and a general decision-making tool. These outcomes are then evaluated and revised to see if they answer the main research question of the thesis project.

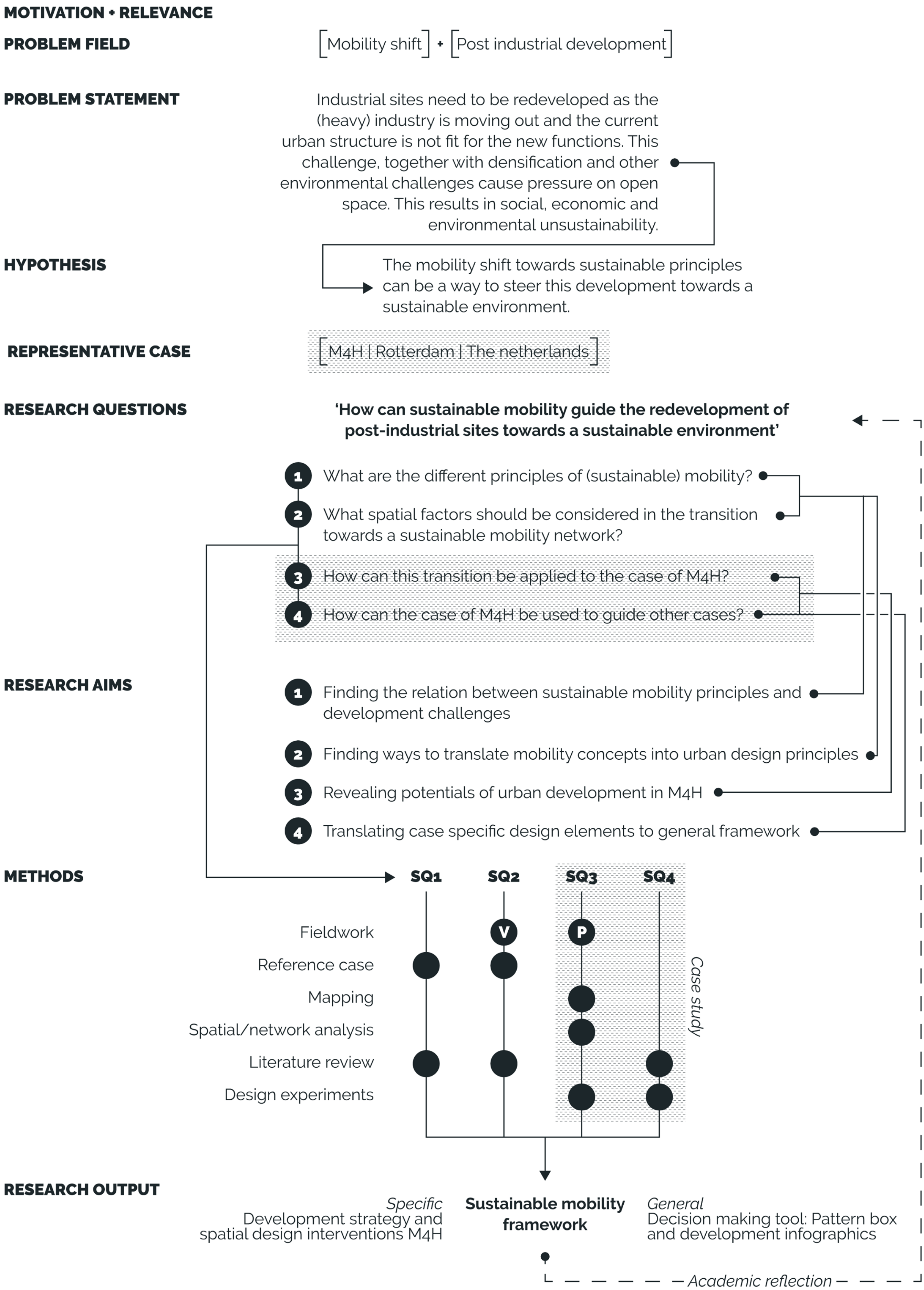


Figure 3.1 | Research framework

3.2 Research questions

To research the problem statement and check the hypothesis the following main question has been formulated: '*How can sustainable mobility principles influence the redevelopment of post-industrial sites towards a sustainable environment?*'. This question consists of three components: mobility, development, and environment. All three components are related to the overarching component of sustainability.

To answer the main research question, four sub-questions have been formulated. The first question: *'What are the different components of (sustainable) mobility?'* dives into the topic of sustainable mobility. Research on this topic is needed to provide basic information of the principles, which set the base of the thesis project. With the second question: *'What factors should be considered in the transition towards a sustainable mobility network?'* the urban transition is further analyzed. This question provides in-depth research and tackles the different factors that influence the transition. An understanding of these factors is needed to relate the topic of sustainable mobility to other concepts. This is further elaborated in the third question: *'How can this transition be applied to the case of M4H?'*. The final question: *'How can the case of M4H be used to guide other cases?'* provides the opportunity to look beyond the case study. It creates the opportunity to provide research applicable to other cases and broadens the research's relevance.

3.3 Research methods

RESEARCH QUESTIONS	METHODS
'What are the different components of (sustainable) mobility?'	- Reference cases - Literature review
What factors should be considered in the transition towards a sustainable mobility network?'	- Fieldwork (virual) - Reference cases - Literature review
How can this transition be applied to the case of M4H?	- Fieldwork (physical) - Mapping - Spatial analysis - Network analysis - Design experiments
How can the case of M4H be used to guide other cases?	- Literature review - Design experiments

Figure 3.2 | Research methods

EXPLANATION	EXPECTED OUTCOME
These methods are used because this question is about generating knowledge about the different mobility principles. This can be done by a literature review as there is much research done by others on these topics, which then can be used for this research. If the literature review lacks on generating a complete overview of knowledge, reference cases will be used to complement.	Decison making tool: a pattern box
In this case, the method of fieldwork is used, to visit different project locations and research the spatial transition. The fieldwork for answering this question will be, because of travel limitations, mostly done virtually. The other methods overlap with SQ1.	Decison making tool: a pattern box
In fieldwork in this case can be done physically. Fieldwork is used to analyze and research the project location. This is also done by mapping and spatial/network analysis, to research the other spatial urban conditions related to the transition. The use of quick design experiments on the location is used to analyze different effects and search for other relations.	Development strategy and spatial design M4H
The literature review is needed to research possible ways of translating specific case outcomes to a general framework. The design experiments are again used to research how different factors influence the location.	Academinc evaluation and reflecion

3.4 Conceptual framework

Figure 3.3 shows the conceptual framework for this thesis project. The research starts with the two concepts of mobility transition and urban development. The mobility concept consists of the transition from the use of internal combustion engine vehicles to sustainable alternatives. The urban development concept arises with the concept of densification and the industrial shift. The concept of densification is all about increasing the density of people living in urban areas. The concept is, together with the concept of industrial shift, the main driver for urban development in this research.

The two concepts, mobility transition, and urban development are challenges that are spatially related in post-industrial sites. These challenges affect the pressure on open space. This pressure could be distinguished into a social, environmental, and economic component. The concept of pressure on open space is in this project then related to the renewal of the urban structure, as a transition in this structure could provide a way to handle the ongoing challenges in post-industrial sites. The renewal of the urban structure is elaborated into two outcomes, a development toolbox, and inclusive design interventions.

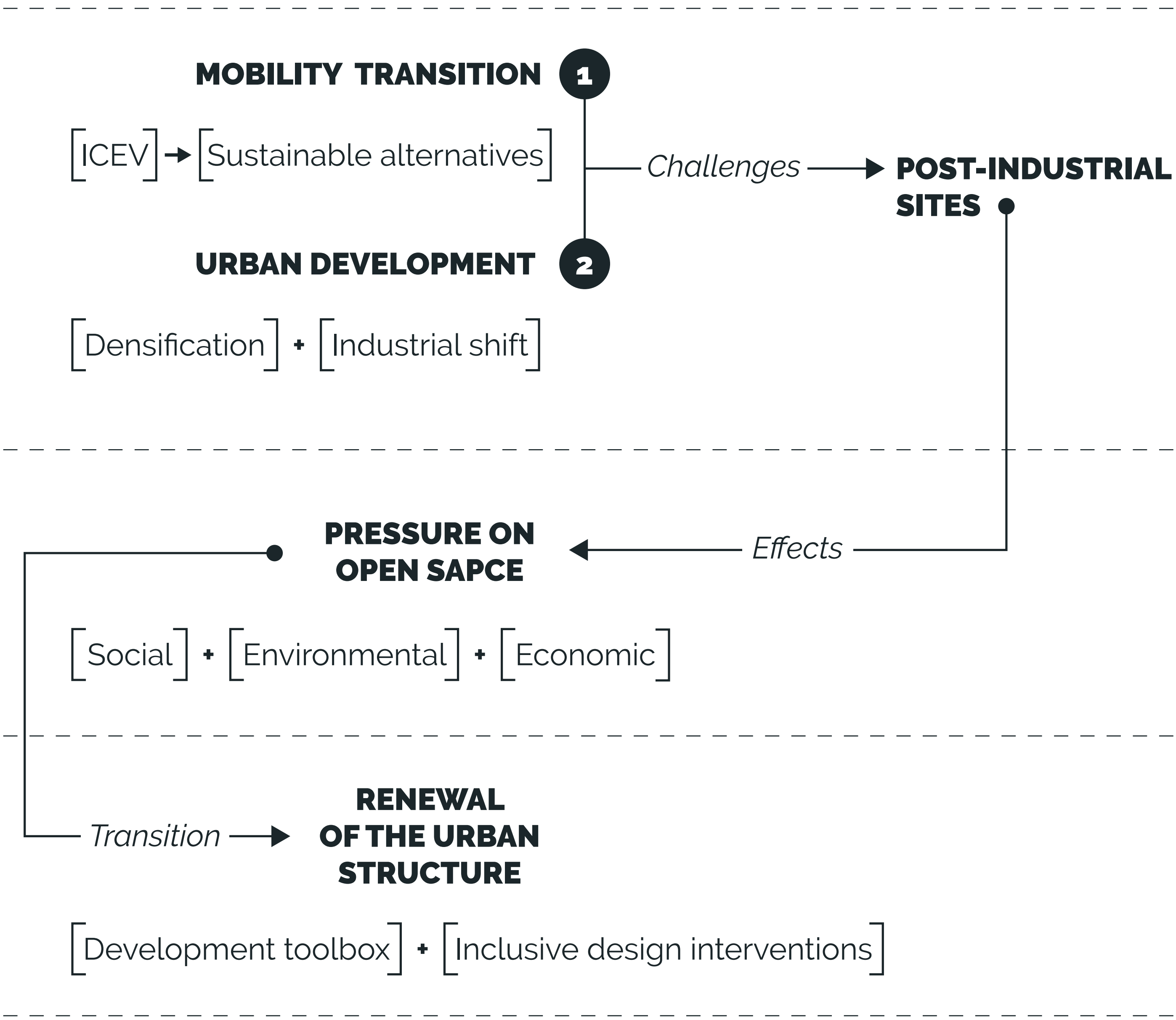


Figure 3.3 | Conceptual framework

04 Theoretical research

In this chapter, the theoretical background is given to the different concepts. The concept of sustainable mobility is explained by the written paper. The theory of two strategies is given: the strategy of transit-oriented development and the strategy of the two networks.

4.1 Theoretical framework

The concept of mobility stands central in this research topic and is therefore the focus point of the theoretical framework. Different theories are used to research and elaborate the concept of sustainable mobility on its own, but also in combination with two other concepts (figure 4.1). The first combination is mobility and development, leading to the strategy of transit-oriented development which connects sustainable mobility to urban redevelopment. The combination of mobility and environment is researched through the strategy of the two networks, connecting to urban resilience. The two strategies are the starting points to further research the different concepts and guide further analysis.

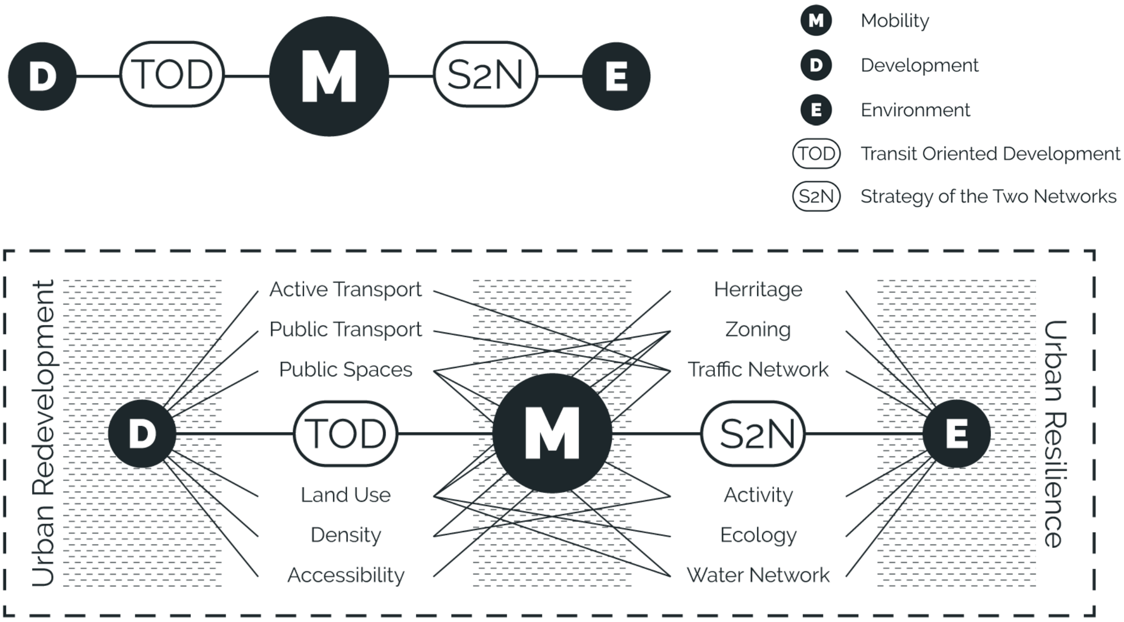


Figure 4.1 | Theoretical framework

4.2 Theory on sustainable mobility

The concept of sustainable mobility is elaborated and further researched through a paper (Vermeulen, 2019) with the main research question being: 'In which way do sustainable mobility principles contribute to increasing environmental issues in urban areas?' (see appendix 9.1). The paper by Vermeulen reaches into the different ways of sustainable mobility and its relation to environmental issues. The main conclusions will be summarized in this section.

The concept of sustainable mobility could be divided into two categories, a technical transition of motorized vehicles and a transition in the mobility usage of people. The first category investigates the technical revolution of cars, while the second category investigates stimulating the use of other mobility types. Both transitions result in a decrease in vehicles with an internal combustion engine.

A technical transition towards sustainable mobility is electrification. Compared to internal combustion engine vehicles, electric vehicles emit less over their lifetime and are cheaper to run (Transport & Environment, 2019). Further research showed that a transition towards electric vehicles contributes to improving the air quality in urban environments. Electric vehicles are a realistic alternative in the long term (Soreta et. al, 2014). A hybrid vehicle contributes less to environmental aspects as it partly still runs on internal combustion engines. However, it could be an attractive alternative in the electrification process (Šarkan et al., 2019).

A transition in mobility use can also lead to a reduction of environmental impact. Instead of predominantly private passenger use, a decrease in car use can be achieved by encouraging sharing transportation options. By sharing vehicles, the number of cars will reduce, resulting in fewer emissions. Although automated vehicles have no direct impact on environmental issues, it allows redesigning urban structure. Together with sharing options, a decrease in parking spaces could be achieved. In this way, space could be redefined for other purposes (Transport & Environment, 2019).

Public transport and non-motorized transport are forms of sustainable mobility that exclude car usage. Over the years the use of public transport is increasing, as it is a worthy alternative. Different factors play a role in the stimulation of public transport use, with service quality being one of the largest (Mugion et al.,2018). The stimulation of non-motorized transport has also a positive effect on the decline of car use. The pedestrian activity could be stimulated by improving the walkability of a city (Southworth, 2005). A clear cycle network also contributes to encouraging non-motorized transport as cycling is not only for recreational purposes (Cervero, 2013).

4.3 Strategy of transit-oriented development

The strategy of transit-oriented development (TOD) is relevant to this thesis research as it combines two of the main concepts: mobility and development. In this strategy, the main development is spatially focused around transit stations to integrate transit and land use (Zhang, 2007). The contribution of TOD in urban design results in the coordination of transportation modes, mix land uses, and public spaces (Pojani & Stead, 2015). Several research documents provide an overview of guiding principles that arrive from the TOD strategy. The following principles are stated by Calthorpe Associates (2011):

- Maximize the use of existing urbanized areas.
- Reduce consumption of non-urban areas.
- Link land use with transit.
- Reduce the number of auto trips and regional Vehicle Miles Traveled (VMT).
- Reduce air pollutant emissions.
- Provide a diversity of housing types.
- Design the urban area efficiently

The TOD strategy offers different principles for different urban conditions. 'Urban TODs' would focus on transit points with an orientation to job development and commercial activity. 'Neighborhood TODs' on the other hand would focus on a transit system with an orientation to retail, services, and housing. In 'secondary areas' TODs would be focused on the connection between low-density housing and transit stops (Calthorpe Associates, 2011).

Key components of successful transit-oriented developments are density, transit accessibility, and pedestrian friendliness (Dittmar & Ohland, 2012). These components should be considered while designing with the TOD strategy. These components result in social and economic benefits, like the reduction of CO_2 emission, prevention of urban sprawl, and higher property prices (Zhang, 2007). However, in other conditions, these 'benefits' could act as drawbacks. Other outcomes are urban compactness and pedestrian/cycle friendliness.

To implement the TOD strategy successfully Thomas et al. (2018) elaborate on the different factors which should be considered. A cooperative relationship between the involved actors, a long-term vision, and a multidisciplinary approach is needed for successful implementation. Besides that, site-specific tools and instruments and a focus on small-scale design are needed to connect the strategy to the existing architectural framework and street networks.

4.4 Strategy of the two networks

The strategy of the two networks (S2N) is a guiding model for planning and design by Tjallingii (2005) considering carrying structures of the urban landscape. The strategy is relevant to this research as it combines the two concepts of mobility and environment.

As the name suggest, the strategy of the two networks consists of two carrying networks: the water network and the traffic network. These two networks create conditions for two multi-functional environments of synergy (Tjallingii, 2015).

The first network is the fast network, with the traffic network as its carrier. The fast network consists of a profit-oriented zone where efficient production comes first. The slow network has the water network as its carrier and consists of a non-profit oriented zone, where biodiversity, recreation, landscape, and heritage are brought together. Whereas the fast network is often predominant in urban design and suppresses the slow network, the S2N treats these networks equal. As one of the important aspects is that the two networks are interrelated. The slow network enhances the development of the fast network (Tjallingii, 2005).

The slow lane is related to landscape ecology, industrial activity however changed the natural landscape. This results in a competition for space in industrial areas like M4H. The S2N gives opportunity to combine the industrial and landscape ecology strategy (Tjallingii, 2015).

4.5 Conclusion

Both the strategy of transit-oriented development and the strategy of the two networks are related to mobility and applicable to the research topic. The two strategies are brought together by deriving different concepts. These concepts are connected over the topic of mobility, see figure 4.2. These concepts are further analyzed and elaborated in the next paragraphs. In this way, the two strategies form the base of the analysis but are not literally applied as they might not fit the project location 100%.

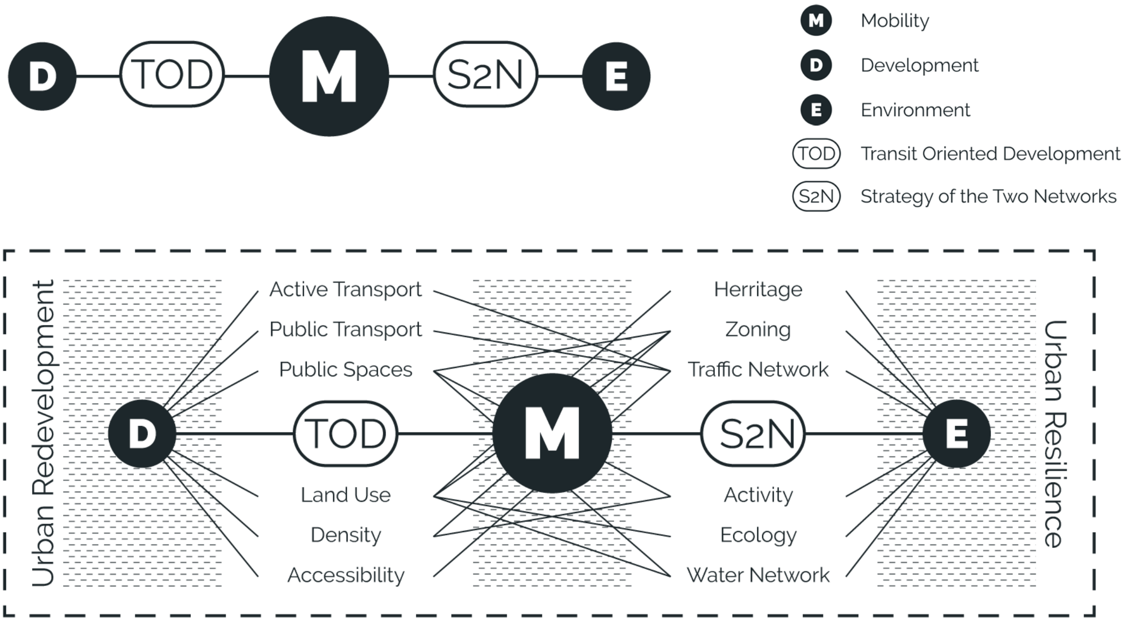


Figure 4.2 | Theoretical framework


THE LEE TOWERS
IN M4H

05 Analysis

This chapter shows the analysis of the project location, M4H. It is devided into three parts, TOD, S2N and Sustainable Mobility.

5.1.1 Introdution

In this chapter, analysis is done where the theories on sustainable mobility are applied in the case of M4H. The analysis is divided into three parts. First, the concept of transit-oriented development is applied to the M4H. The same is done for the strategy of the two networks. The analysis on these topics results in conceptual drawings which reveal the potential of M4H. This forms the basis for the strategic spatial framework elaborated in chapter 6. The final part of the analysis consists of further analysis on sustainable mobility. In this analysis, several mobility components are distinguished and applied to the M4H. This forms the basis for the infographics and patterns which are also elaborated in chapter 6.

5.1 Analysis on TOD

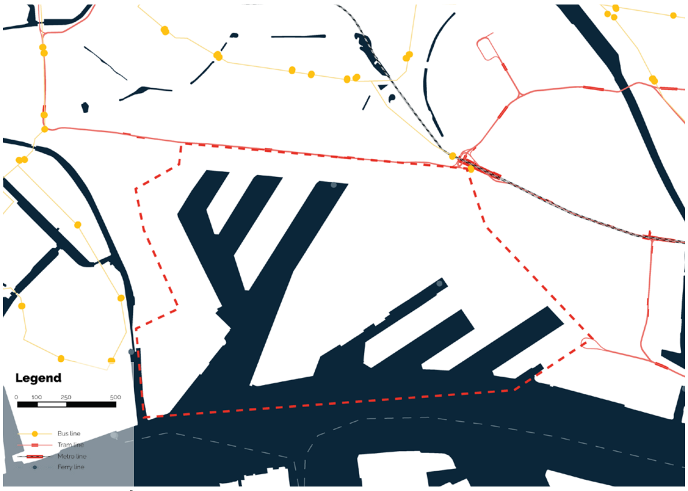


Figure 5.1 | Public transport M4H

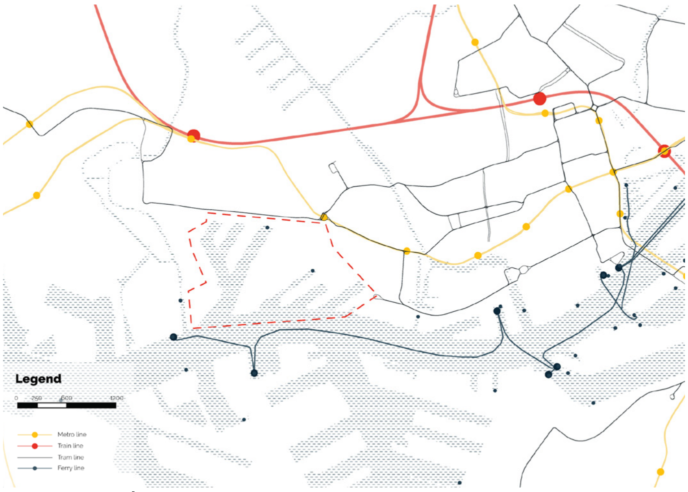


Figure 5.2 | Public transport M4H

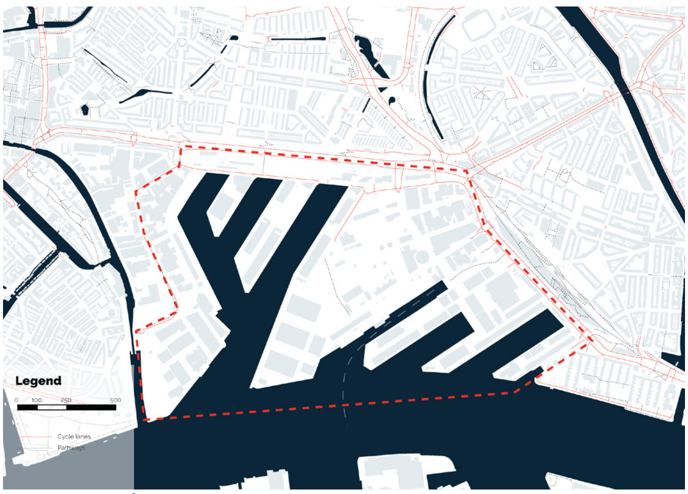


Figure 5.3 | Active transport M4H

5.1.1 Accessibility public transport

An important aspect of transit-oriented development is the accessibility to public transport. The map in figure 5.1 shows how the area of M4H is connected to the public transport network. Metro station Marconiplein is located on the northeastern side of the area. This metro station acts as a public transport hub as it also connects several tram and bus lines. The tramline, connecting Marconiplein and intercity station Schiedam Centrum, travels at the northern side of M4H. On the city scale (figure 5.2) the public transport network connects M4H to the rest of Rotterdam with several metro and tramlines. The public transport network over water does not directly connect to M4H, however, there are two water taxi stops.

The active transport network, shown in figure 5.3, consists of pedestrian and cycle paths. Separate cycle lanes run along the major road, connecting the surrounding areas to each other. The pedestrian and cycle paths cross the major traffic roads on the same level.

Figures 5.4 and 5.5 show problem areas considering the accessibility of public transport. To reach the metro station, pedestrians must cross approximately 100 meters of roads, grass patches, and tramlines. The tram stops are well connected to the neighborhood in the north, but not to M4H.

Figure 5.6 shows a diagram considering the current accessibility of public transport. The public transport stops are not connected to M4H. Figure 5.7 shows a potential extension of the network, to serve the whole M4H better. The accessibility is increased by connecting the stops to M4H.

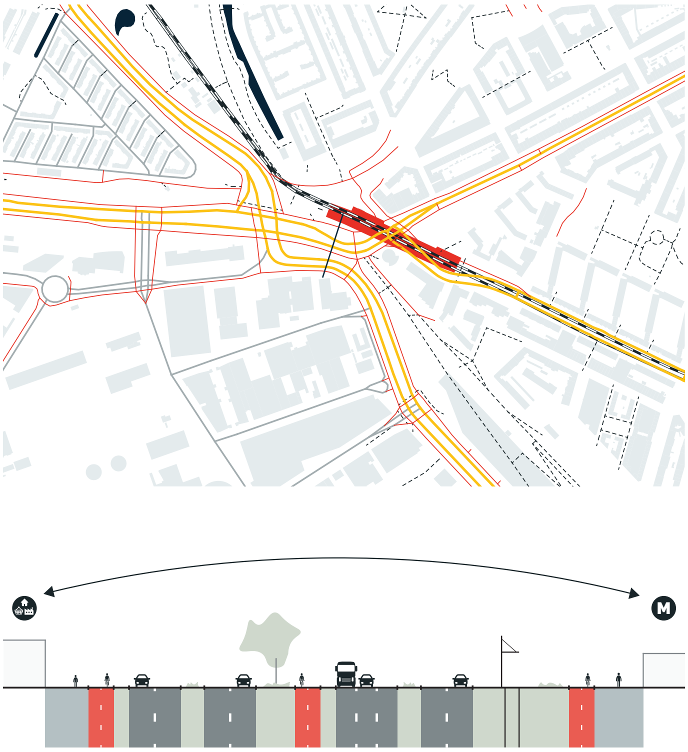


Figure 5.4 | Accessibility metro station

Figure 5.5 | Accessibility tram stops

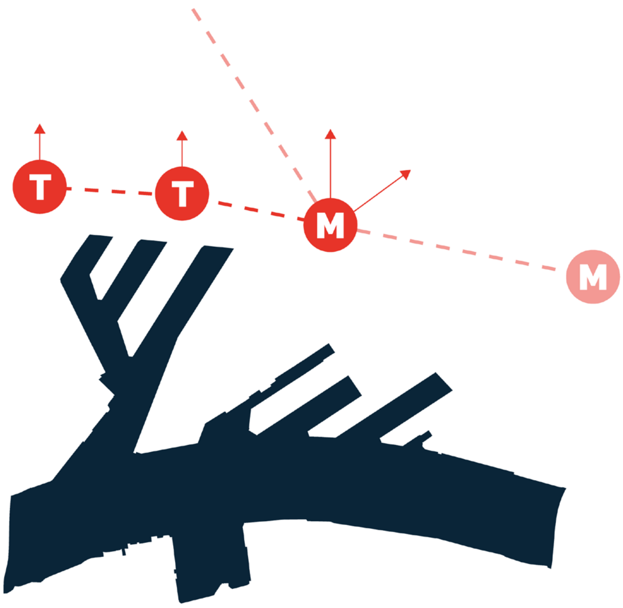


Figure 5.6 | Accessibility M4H current

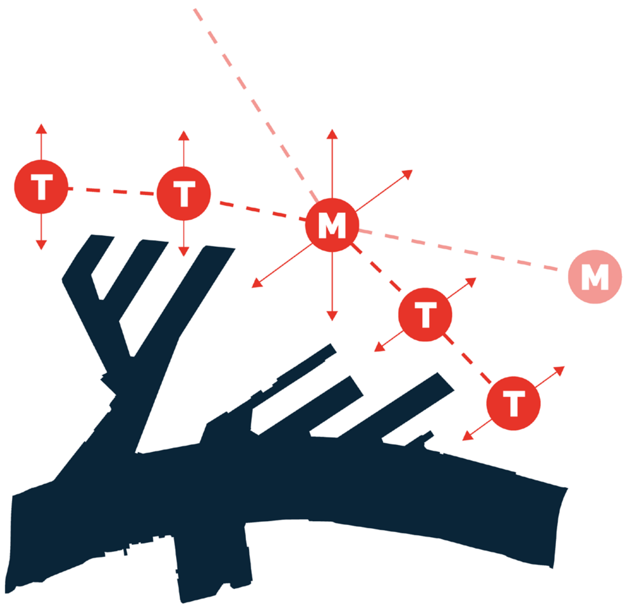


Figure 5.7 | Accessibility M4H potential

5.1 Analysis on TOD

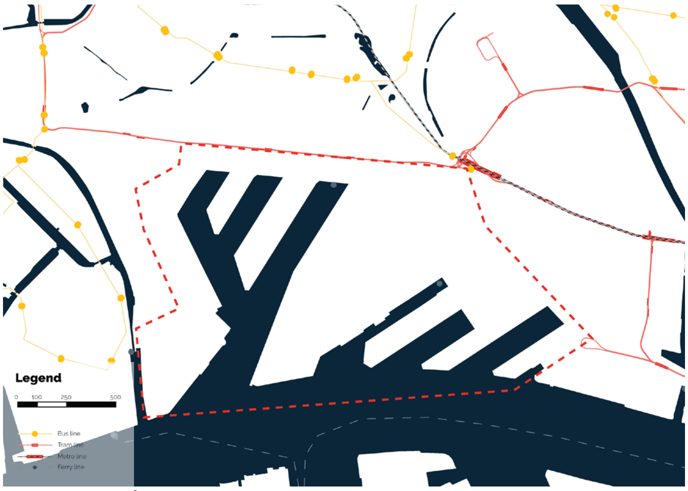


Figure 5.8 | Public transport M4H

Figure 5.9 | FSI M4H

Figure 5.10 | Buildings function M4H

5.1.2 Function and density development

Important to transit-oriented development are building density and function diversity. The map in figure 5.9 shows the FSI in M4H and its surroundings. It can be seen that the FSI in M4H is low compared to the surrounding neighborhoods, the FSI increases near Marconiplein, the transportation hub. The diagrams in figures 5.11 and 5.12 show the principles considering density, where it shows the potential of increasing density towards the public transport stations. This concept increases the people, and thereby the activity in the area. The further away from the public transport, the density decreases.

Figure 5.10 shows the current functions in M4H. Most building functions in the area are related to industrial activities, such as warehouses and factories. The buildings in neighboring areas are mostly residential. Commercial activities such as shops, cafes, and retail are scattered near the main roads bordering the areas. The diagrams in figures 5.13 and 5.14 summarize the main principle of functional diversity in combination with density. The function is more diverse in the areas surrounding the transportation hubs. With this, different people are attracted to and use the area. The further away of the public transport, the diversity decreases.

Figure 5.11 | Density M4H current

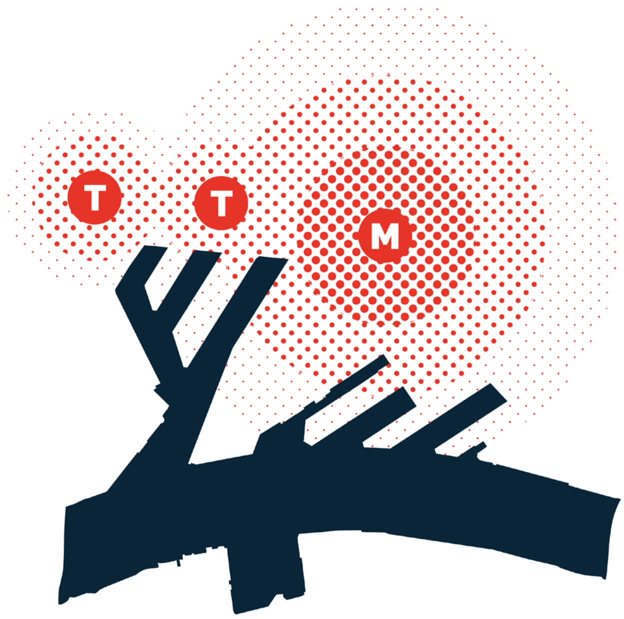


Figure 5.12 | Density M4H potential

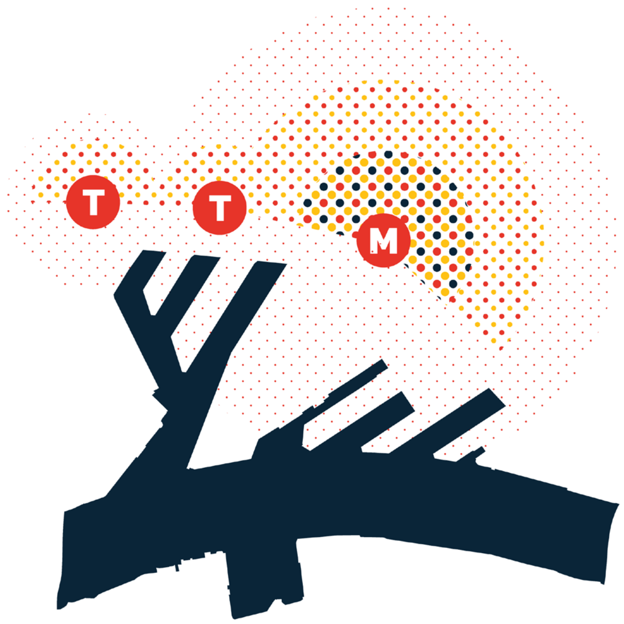


Figure 5.13 | Functions M4H current

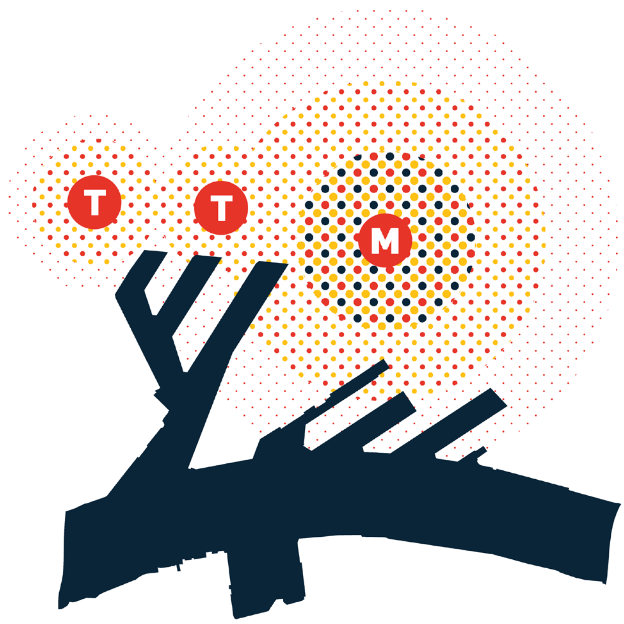


Figure 5.14 | Functions M4H potential

5.1 Analysis on TOD

5.1.3 Conclusion TOD

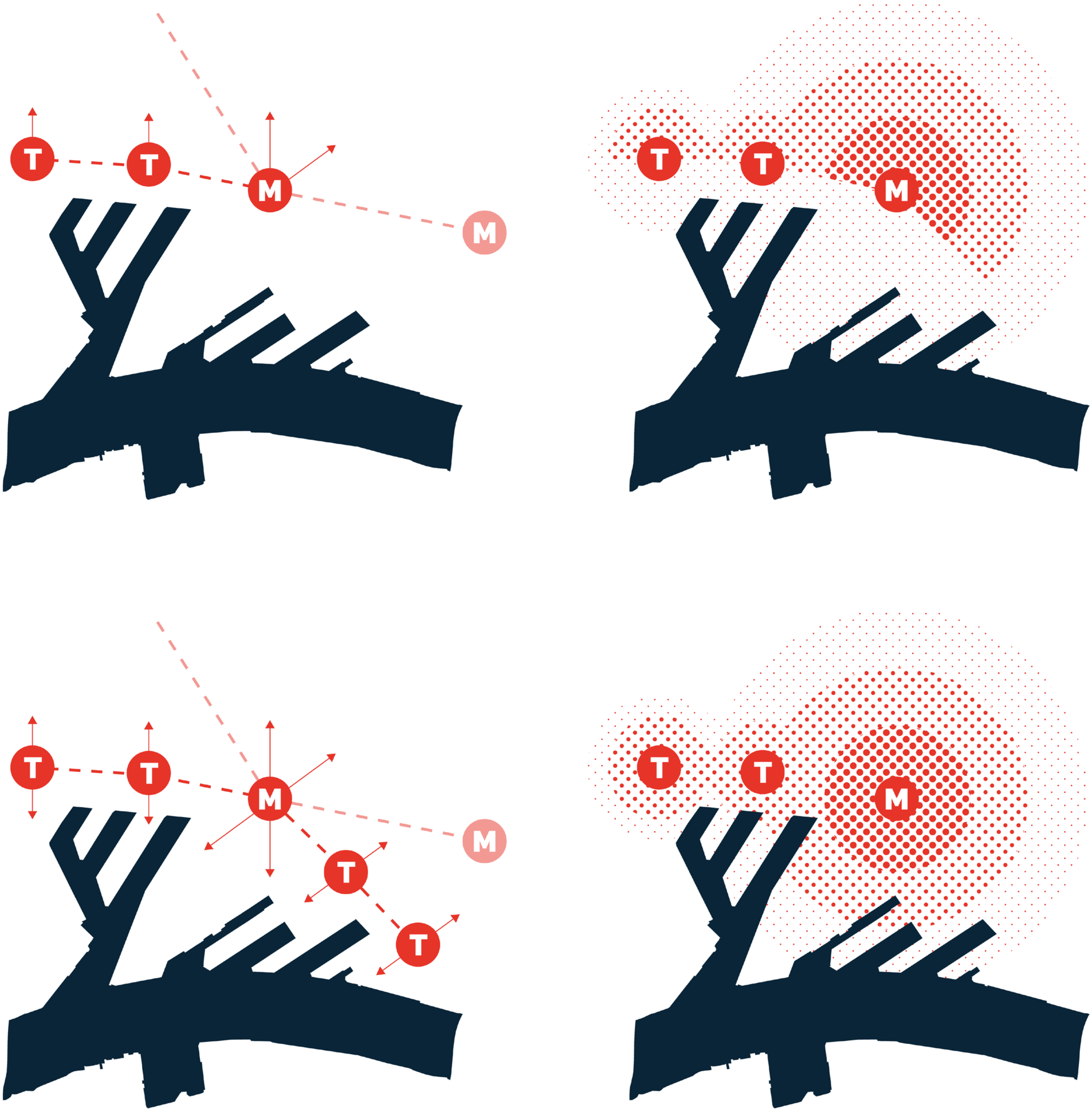
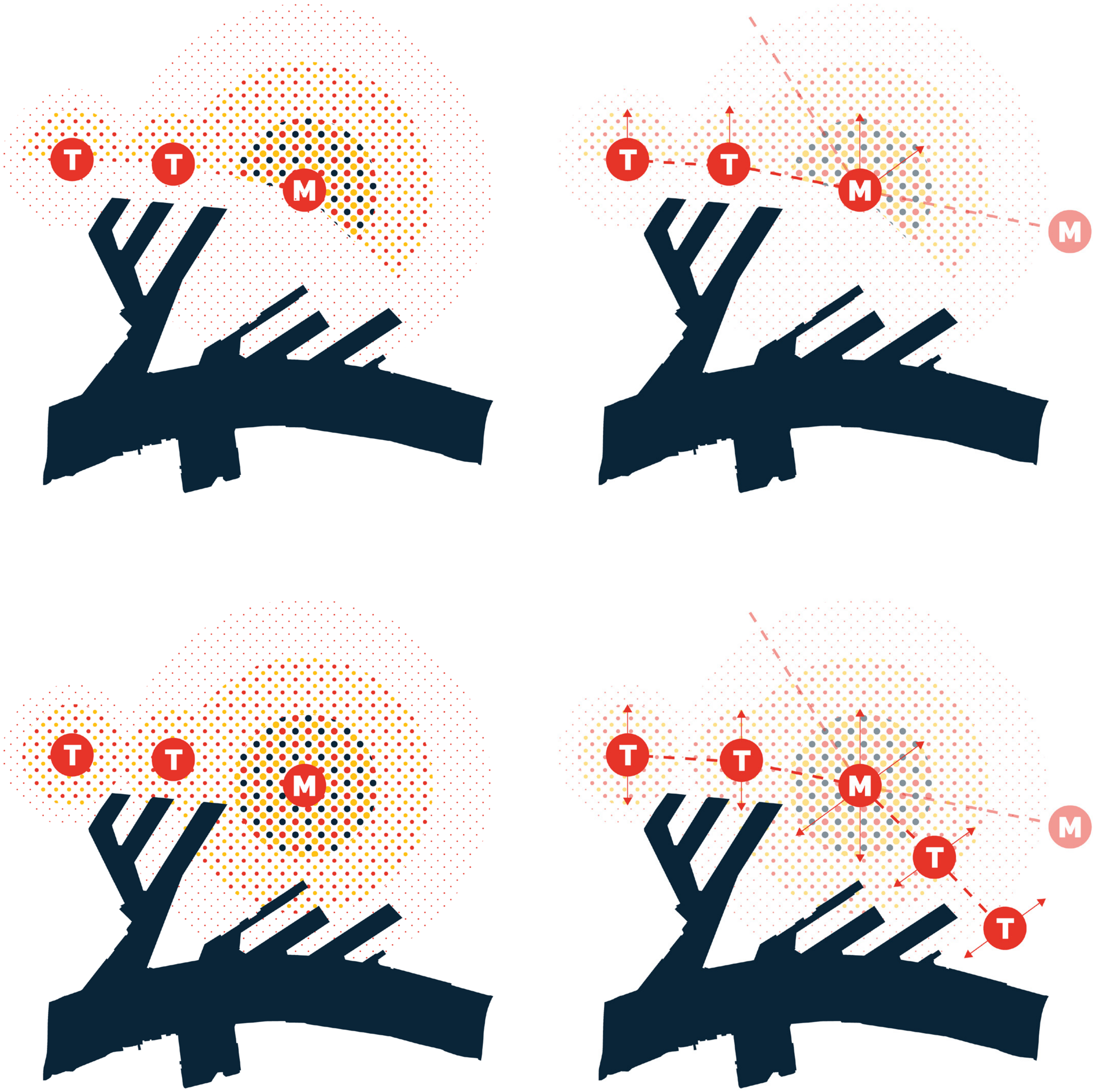


Figure 5.15 | Conclusion current (top) and potential (bottom) diagrams TOD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5.2 Analysis on S2N

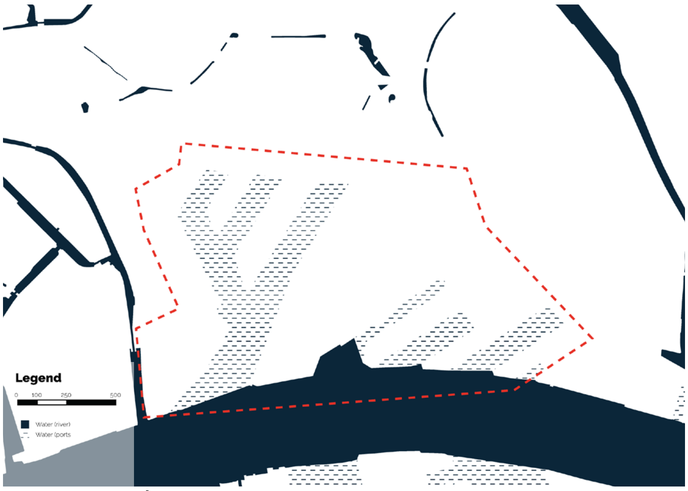


Figure 5.16 | Water network M4H

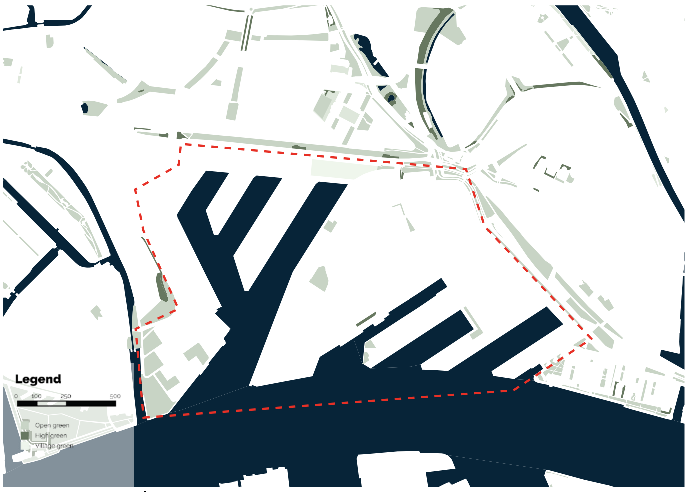


Figure 5.17 | Green structure M4H

Figure 5.18 | Brownfields M4H

5.2.1 Slow network

As stated before, the strategy of two networks consists of a slow and a fast network. The slow network has the water network as its base. Figure 5.16 shows the water network in M4H, the area is located along the river the Nieuwe Maas. The main water structures in the area are the ports, which can be separated into two: the Merwehavens (west) and the Vierhavens (east). These ports provide the accessibility of water in the area. However, because of the former industrial activity, they are not part of the slow network yet.

Figure 5.17 shows the green structure in and around M4H. In the area itself, there is a lot of paved area and hardly any greenery can be found, which is a result of the industrial function there used to be. The area is bordered by major roads, green strips act as a divider between the two directions. However, this greenery is not usable by the people.

There are a few open spaces in the area, see figure 5.18. These areas are brownfields, also a result of industrial activity. These areas are currently not in use but provide the opportunity for further development.

Figure 5.19 shows a diagram of the slow network in M4H. The ports on the southern side act as arms that reach into the area. Green strips in the northern part are not connected and usable. The open areas in between are not connected to and used in the network.

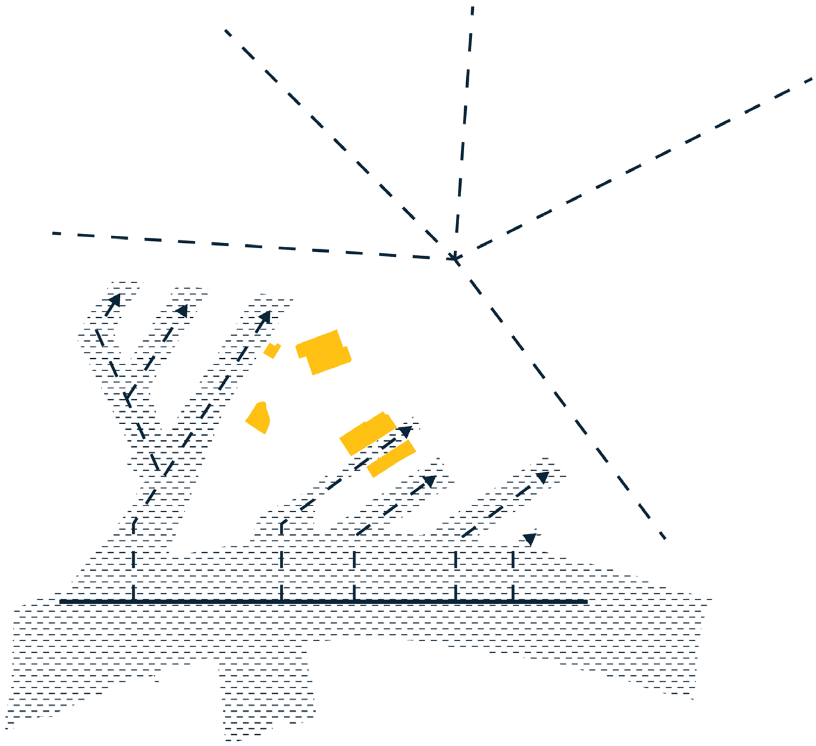


Figure 5.19 | Slow network M4H

5.2 Analysis on S2N

Figure 5.20 | Infrastructure M4H

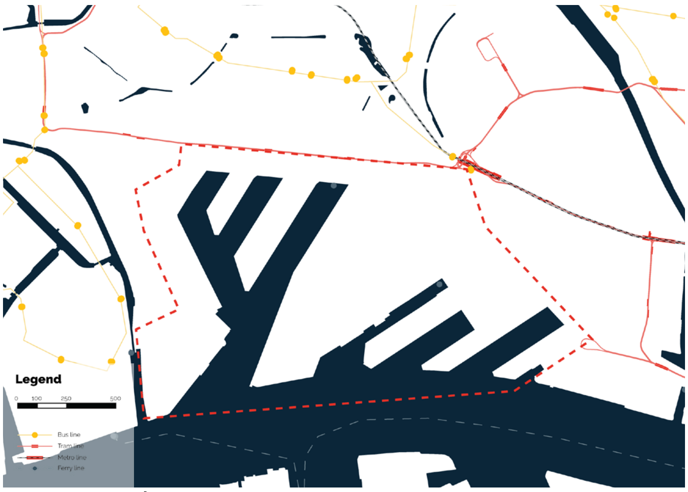


Figure 5.21 | Public transport M4H

Figure 5.22 | Buildings functions M4H

5.2.2 Fast network

The second network is the fast network. This network is based around the traffic network, which can be seen in figure 5.20. As stated before there are several main roads bordering the area. These large roads come together at the Marconiplein. These large roads provide accessibility to the area for motorized traffic. However, these infrastructural elements also act as a barrier between the different neighborhoods.

Next to the traffic network is the public transport network. This network is discussed before, but important for this paragraph is that the public transport lines also surround the area and come together at the Marconiplein.

The map in figure 5.22 shows the building functions, as profit is also part of the fast network. The commercial activity is mostly surrounding the Marconiplein, industrial activity is scattered around the whole M4H.

Figure 5.23 shows a diagram of the fast network in M4H. As for the fast network it is mostly focused on the northern side of M4H, near the Marconiplein. From this hub several roads are leading into the area.

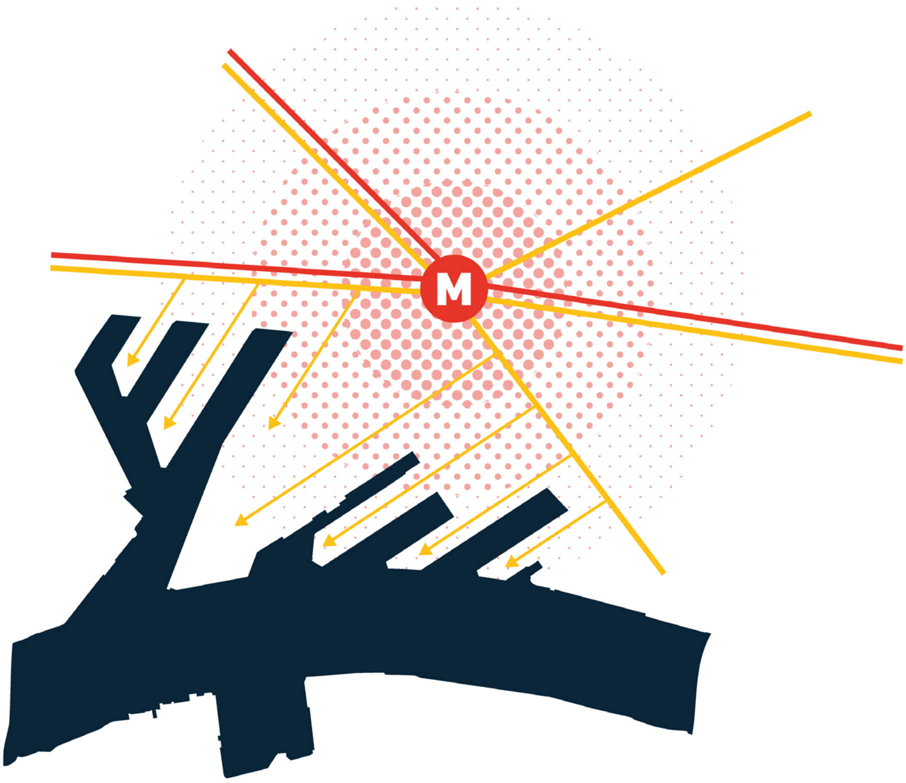


Figure 5.23 | Fast network M4H

5.2 Analysis on S2N

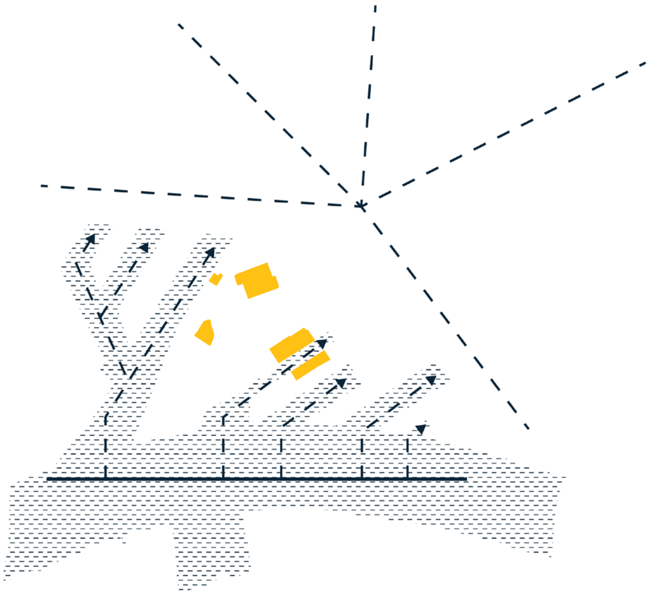


Figure 5.24 | Slow network M4H

5.2.3 Conclusion Sn2

In the previous paragraphs both the slow and fast networks in M4H are analyzed. Figure 5.26 shows the two networks merged. In general, it could be stated that the fast network is more dominant in the northern part, while the slow network is predominant in the southern part. This explains why there is little green in the northern part, as it is suppressed by the large roads of the traffic network. Both networks reach into the area, which creates the possibility for a connection in the middle. Currently there is no connection between the two networks, as the open spaces are not related.

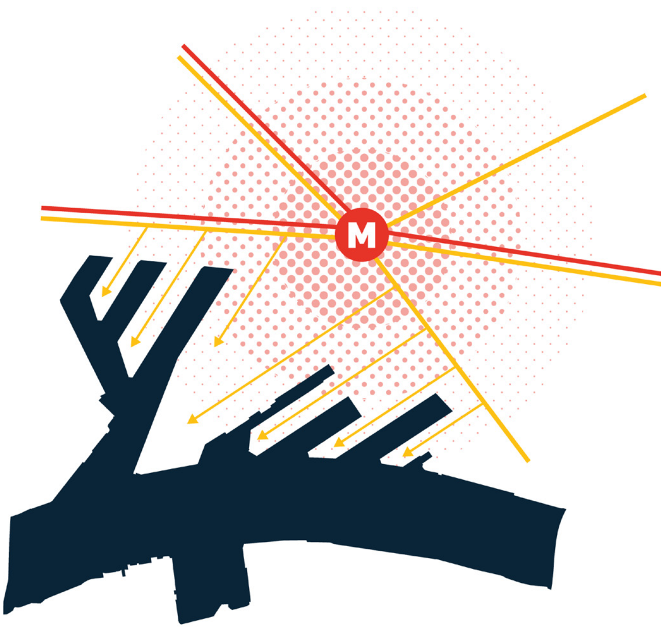


Figure 5.25 | Fast network M4H

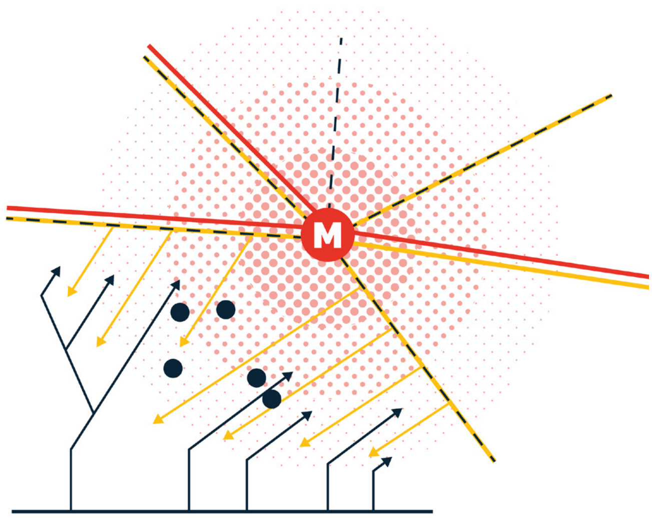


Figure 5.26 | S2N M4H

5.3 Conclusion

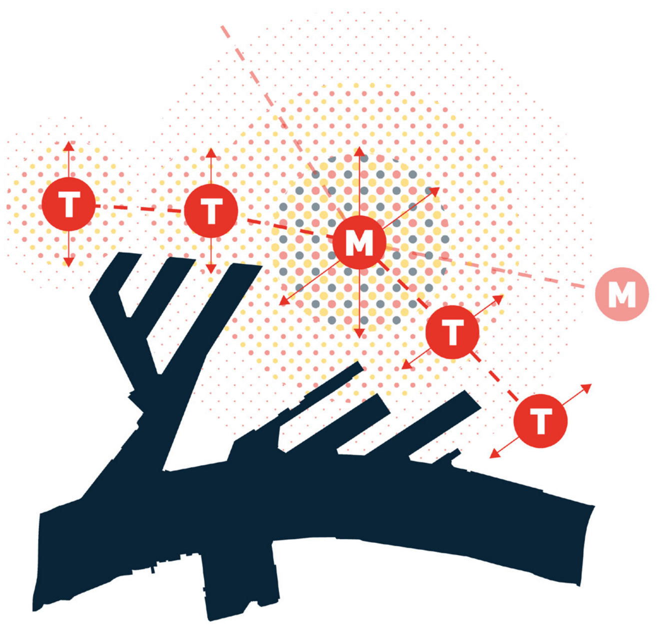


Figure 5.27 | TOD M4H

In the previous paragraphs two different strategies are applied on M4H. Figure 5.29 shows a combination of the two conclusion maps. It can be concluded that the strategy of transit-oriented development mostly overlaps with the fast network, which is part of the strategy of the two networks. The TOD strategy creates the potential to enhance the fast network. An important factor to consider is that the slow network should not be suppressed by this.

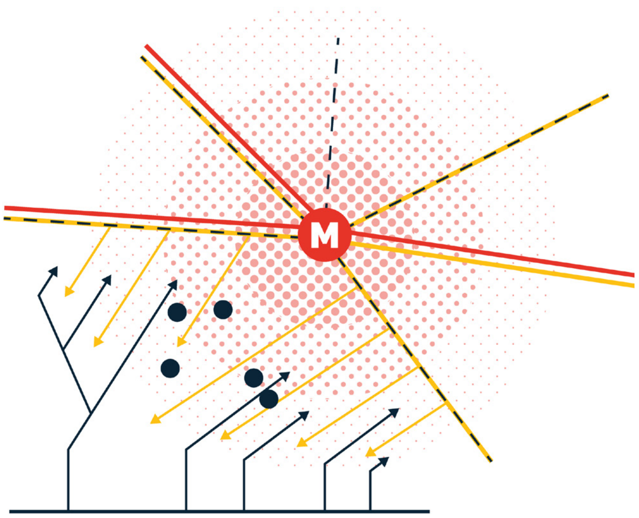


Figure 5.28 | S2N M4H

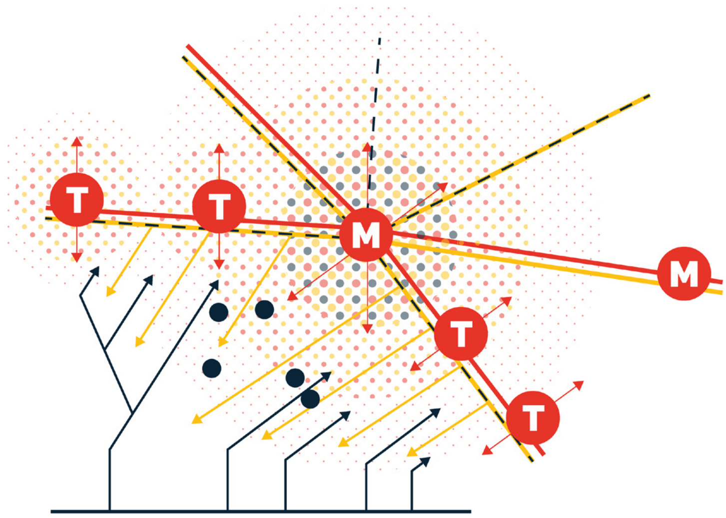


Figure 5.29 | Conclusion strategies M4H

5.4 Analysis on sustainable mobility

5.4.1 Public transport (PT)

Public transport is passenger transport that is publicly accessible, which means that everyone can make use of it. Public transport in the Netherlands consists of urban transport, regional transport, and rail transport (Ministry of Infrastructure and Water Management, 2019). Public transport is a sustainable way of transportation as it provides alternative ways of transportation besides car use. It focuses on collective transportation, which results in a decrease in car use. The Ministry of Infrastructure and Water Management (2019) distinguishes four main categories for public transport in the Netherlands.

The train is a transportation mode that has its main focus on transportation of travelers on large distances. The train network could be distinguished into different categories, such as high-speed trains (HSL), intercity trains, regional trains, or suburban trains. The train has already become more sustainable over time, with the transition from coal as fuel towards electrification (Baggen & Ham, 2019). Future improvements for the train network are to increase the number of trains to accommodate the number of passengers. Together with better travel information and travel comfort, the train provides an attractive alternative to the car (Ministry of Infrastructure and Water Management, 2019).

The metro is a mode of transportation that operates in a closed system, mostly situated underground or on an overpass. This ensures a conflict-free track, as it is completely separated from other (road) traffic. The metro has its strength in high frequency and large passenger capacity. This makes the metro an effective way of traveling in large cities and dense areas. To increase efficiency and frequency the metro is slowly transforming into autonomously driven vehicles. In the Netherlands, the metro is often extended (in the form of a light rail) into the city's suburbs. This provides a quiet living environment within reach of the city center (Baggen & Ham, 2019).

The tram is a fine-meshed transport system focused on local transport, which fits into the urban scale. The tram has a large passenger capacity and is one of the oldest forms of public transport in cities. The tram tracks could be distinguished into two types. In a closed tram track construction, the rails are incorporated in the road surface, tram and other road traffic share the same traffic area. An open tram track construction consists of a separate tram track and could be combined with grass (Baggen & Ham, 2019).

A bus is a vehicle for transporting more than 8 people, it uses the public road or designated bus lanes. Bus lines could be distinguished into different types such as city buses for inner-city transportation, regional buses for transportation between city and villages, and long-distance buses. HOV (Hoogwaardig Openbaar Vervoer) is a term for city and regional transportation which meets the high flow and frequency requirements (Baggen & Ham, 2019). This ensures connectivity and accessibility between city centers and the agglomeration boundary. Buses come in different types and sizes. Hybrid and elective buses are becoming the standard to ensure a sustainable way of transportation (Ministry of Infrastructure and Water Management, 2019).

Besides the four main modes of transportation, the public transport network could be supplemented by other modes of transportation. The monorail (hanging) is a sustainable mode that comes close to a metro. Waterbuses and ferries are a way to ensure connectivity over water and cable cars for bridging heights. Taxies operate as an on-demand transportation mode (Baggen & Ham, 2019).

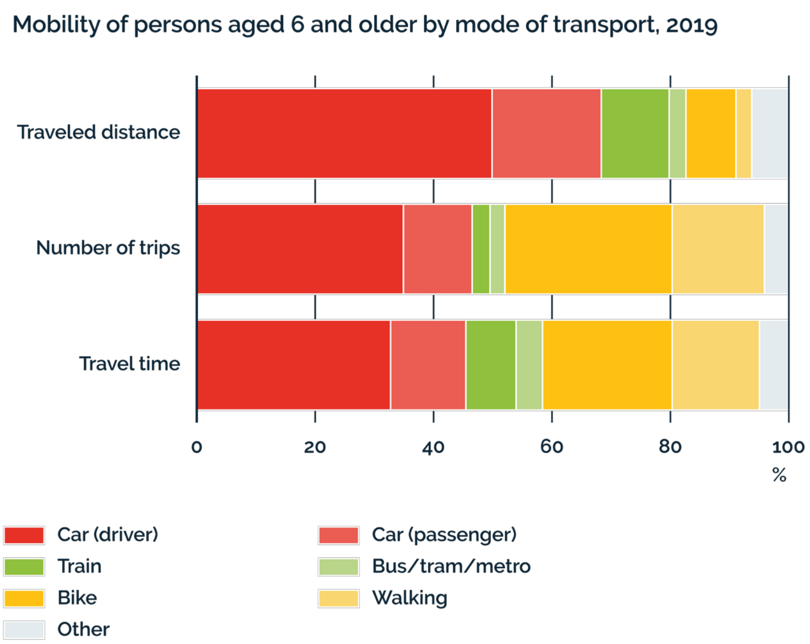


Figure 5.30 | Mobility use *(Ministry of Infrastructure and Water Management, 2019)*

5.4 Analysis on sustainable mobility

5.4.1 Public transport (PT)

To stimulate the use of public transport different spatial implications could be addressed. An important factor is the interconnection of the public transport lines and/or modes (Adamski, 1993). If conducted in a clear network hierarchy, the public transport modes support each other in passenger use. In an efficient network, the public transport lines are connected to provide transfer points and to increase the serving area (Cats et. al, 2020).

The concept of Transit Oriented Development (TOD), further elaborated in chapter 4.3, also relates to public transport use. In this concept main development is spatially focused on transit stations to increase urban activity and the demand for public transport (Zhang, 2007). In order to work with the strategy of TOD, four different density zones could be distinguished for the matching transport mode (see figure 5.31). As train and metro operate on a large city scale, a high-density zone, with a mixed-use function is suited. This density zone has an urban and public character. The mid-high-density zone is supported by tramlines, as they operate on a local scale. In this zone the buildings are midrise and a variety of functions cluster around the stops. In the mid-low zone, the buildings are supported by bus lines, as mostly residential, low-rise buildings are fit for this zone. The low-density zone has an open character with lots of public space. The density zones are situated around the public transport lines to form a gradient (Ingvardson & Nielsen, 2018).

The public transport network is constantly in transition, becoming more efficient and sustainable. The infographics shown in chapter 6.2 implicate the transformation of public transport toward sustainable mobility in 2050.

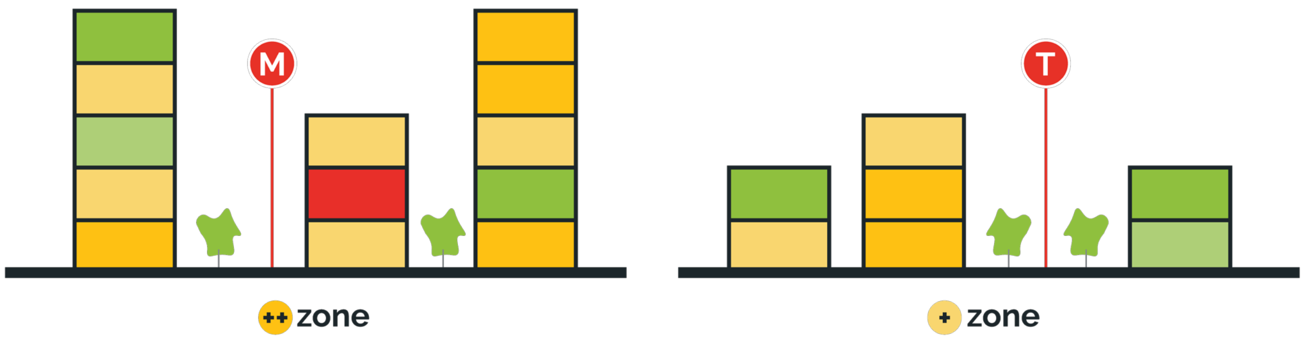


Figure 5.31 | Density zones

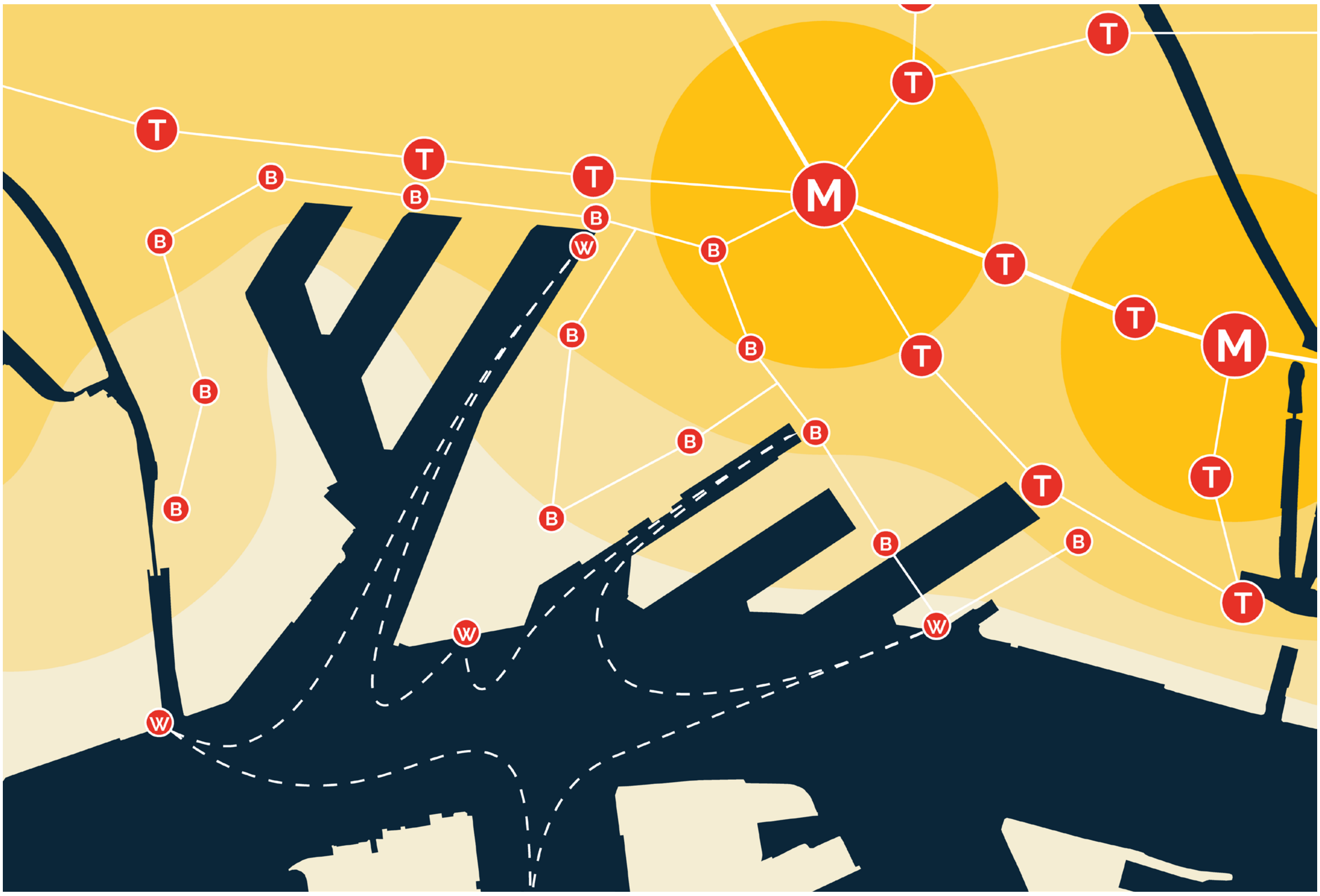
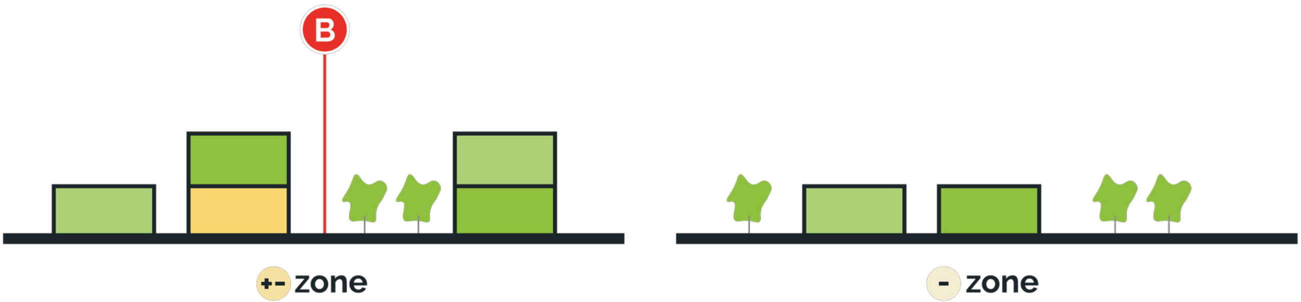


Figure 5.32 | Public transport applied on M4H



5.4 Analysis on sustainable mobility

5.4.2 Slow mobility (SM)

Slow mobility is a way of transportation that consists of non-motorized transport, such as cyclists and pedestrians. This way of mobility contributes to a reduction of the number of cars and car-travels.

The majority of slow mobility consists of pedestrians, a person walking from starting point A to their destination point B. Pedestrians make use of sidewalks, pathways, or pedestrianized areas. Pedestrians are also allowed on cycle paths in absence of the previously stated roads. Pedestrians are a vulnerable type of transportation, so safety is an important factor (Baggen & Ham, 2019). Different types of movements could be distinguished for pedestrians. The first one is a movement completely done by walking. Another type is pre- and post-transport. In these cases, walking is part of a chain, for example, walking-train-walking (CROW, 2019).

Cyclists are also part of slow mobility, often used in the same way as walking, but with cycling, larger distances can be crossed (CROW, 2019). Cyclists are allowed on designated cycle paths, which could be completely separated from the car traffic. In residential streets cyclists are allowed on the road, often indicated by a cycling zone or lane. To ensure safety and stimulate cycling safety from large traffic should be taken into consideration. This can be done by creating bicycle tunnels or overpasses at major crossings. At a level crossing, cyclists should get priority over cars. An 'auto te gast' street (car as a guest) acts as a cycling path but also allows cars. The cars should give priority and stay clear from the cyclist (Baggen & Ham, 2019).

Besides walking and cycling other forms of mobility also classify as slow mobility. People skating or on scooters also make use of the same network and should be taken into consideration (Baggen & Ham, 2019).

To stimulate the use of slow mobility, several spatial design principles could be used (figure 5.33). The design of a clear slow mobility network could enhance the connectivity in an area. A network would consist of key destinations which are connected by routes. The destinations could be public transport nodes, public spaces, or key buildings (figure 5.34). The network supports the use of slow mobility modes for these transportations.

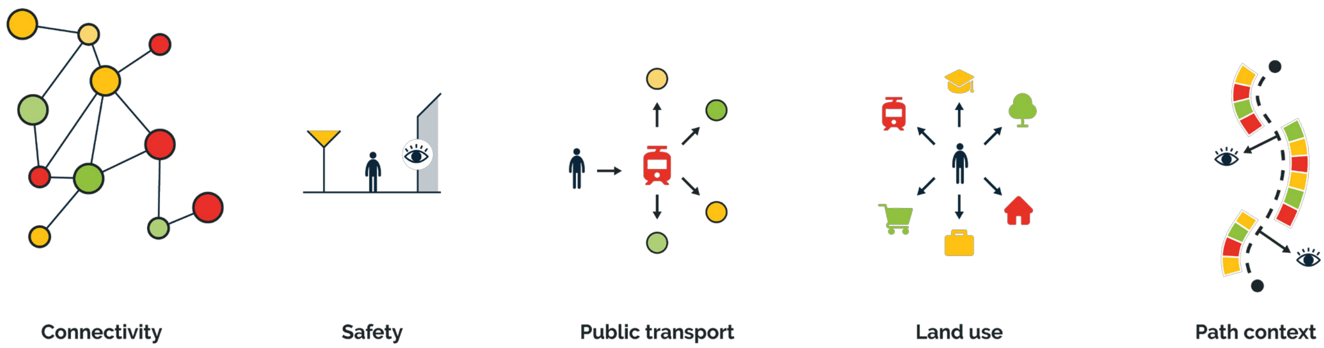


Figure 5.33 | Walkability stimulation

Figure 5.34 | Key destinations

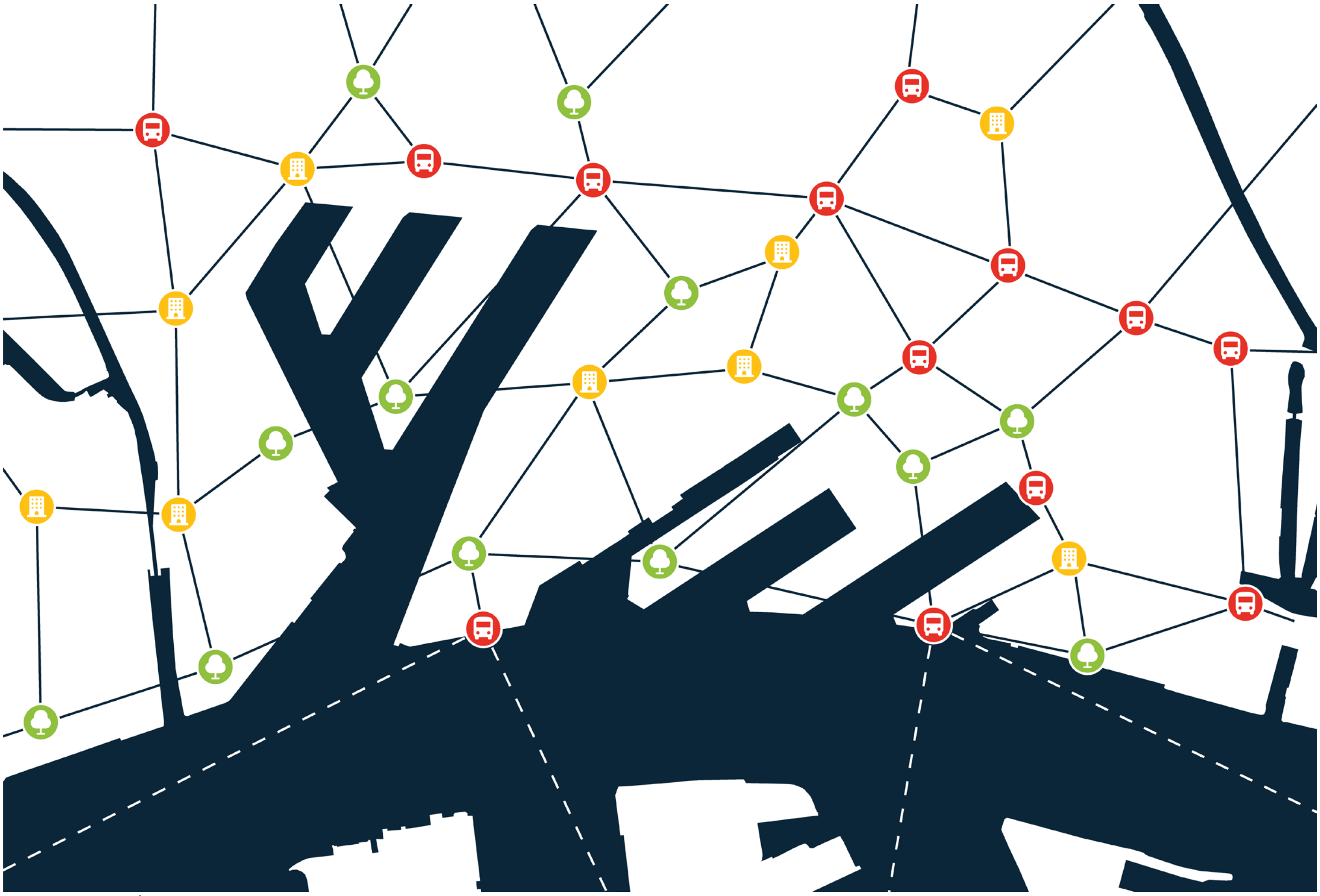


Figure 5.35 | Slow mobility applied on M4H

5.4.3 Sharing network (SN)

A sharing network consists of hubs in which vehicles can be shared amongst different people. Important in this network is the change in focus from vehicle ownership towards vehicle use. Various types of vehicles qualify for being shared in this system (Crow 2016).

Car sharing is becoming more popular amongst mobility use. Several different types of car sharing could be distinguished. There is the classic way of car sharing in which providers have cars with a fixed parking spot. These cars are 24 hours per day available and are one of the most used forms of car sharing. Companies considering this type are for example Greenwheels, ConnectCar, and MyWheels. One-way carsharing is a form in which you pick up a car and leave it at your place of destination. An example of this is Car2Go, which operates in the region of Amsterdam. In peer-2-peer carsharing private individuals rent out their own car via an online platform. As this type does not require investment in new cars and fixed parking, which makes it possible to increase widely. The final type is private car-sharing, which uses the same principle as peer-2-peer. However, in this case, it is without the meditation of an online platform or organization. People share their cars with neighbors, friends, or family without official documents. They could become a member of the Shared Car Use Association to get special car sharing insurance shut down (Crow, 2016).

Crow-Fietsberaad (2020) uses the following definition considering bicycle-sharing: 'Shared bicycles are bicycles that are offered for a short period (time) and at low cost (payment) in a network of publicly accessible distribution points. The bicycle-sharing system is easily accessible, easy to use, and forms part of the daily mobility demand, in addition to the train, bus, car and your own bicycle'. Five different systems could be distinguished in appearance. Urban or district/region-based systems are executed with a lot of locations in the urban network, which have a high ease of use. Public transport-related systems are locations near public transport stops and focus on the public transport user. The bike is often used for the last mile to reach their destination. Park&Bike systems focus on people who park their cars at the cities edge and continue their trip on their bike. Tourism systems are traditional rental systems in which bikes can be rented for longer periods. Locations are often near highlights of the city. Corporate or business zone bound systems are closed systems that focus on a specific target group. In all five systems, there are three types of return possibilities (Crow, 2020). There is back-2-one (B21) in which bikes need to be returned to the same location as departure. In this system, space is controllable but rather not flexible. In back-2-many bikes can be returned to multiple locations without extra charges. This system is more flexible but a fine-meshed network of return locations is desired. The third system is free-floating (FF) and does not require specified stations. In this case, there is nuisance from wandering bicycles and a lack of controllability.

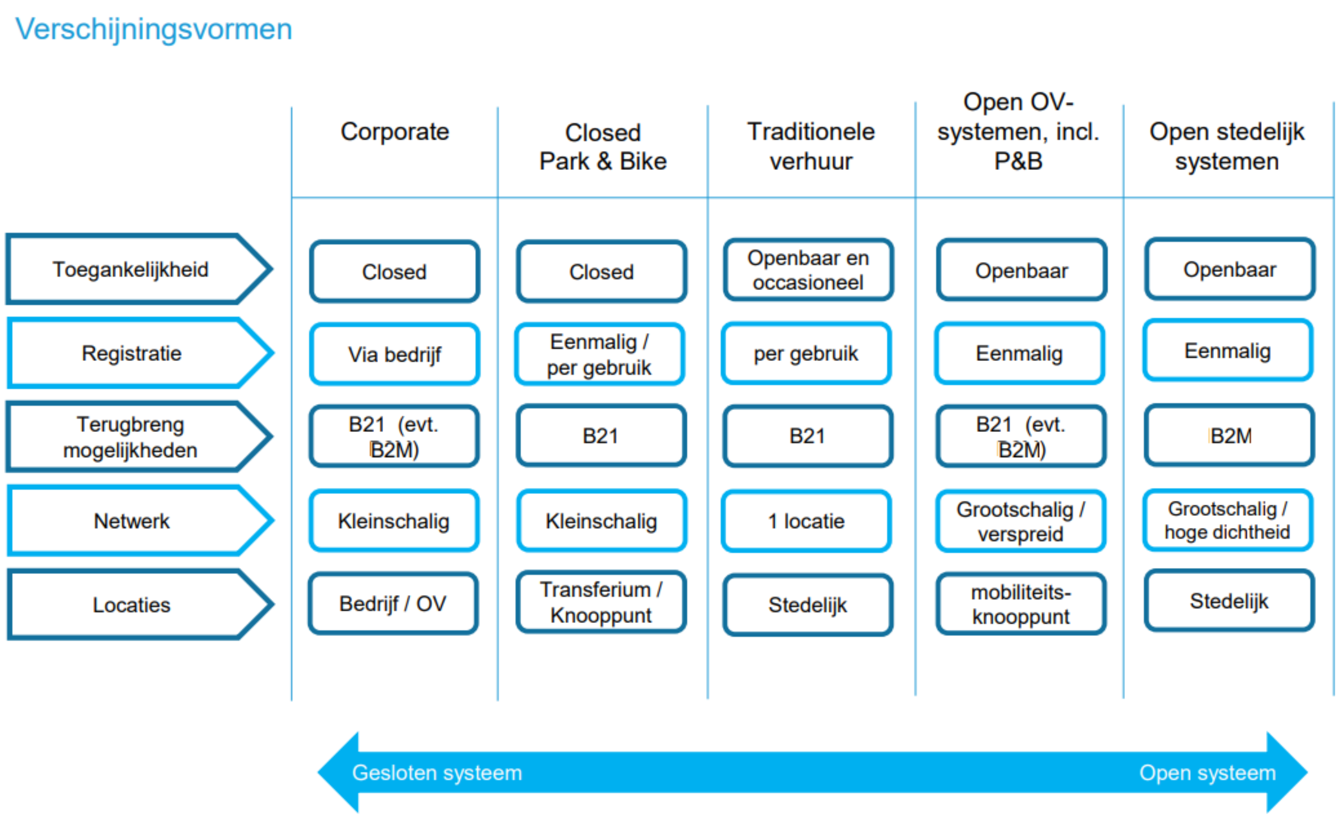
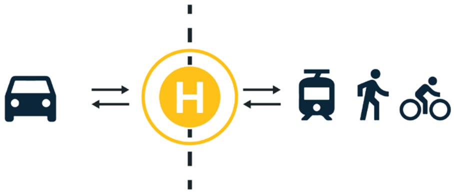


Figure 5.36 | Different types of sharing systems (CROW, 2016)

5.4.3 Sharing network (SN)

The implementation of the sharing network has some spatial effects on the urban form. Figure 5.37 shows some concepts considering the placement and use of sharing hubs. Sharing hubs are places where the vehicles are parked and the journey of a shared trip starts. To support the use of shared mobility, the location of the sharing hubs is essential. When places near key locations the number of usage increases (Snel, 2020). Key locations which could be beneficial are for example public spaces, parks, commercial areas, or transit stations. In these locations, the activity of people is high which is increases the demand for mobility use (Saberi, et al., 2018).

Sharing hubs also provide the opportunity to switch between different mobility systems. Figure 5.38 shows how a sharing network would look like applied to the M4H. In this case, two different systems, inside and outside, are connected by transfer entrances. In these hubs, a switch between sustainable and normal mobility uses can be made. These are special types of sharing hubs.



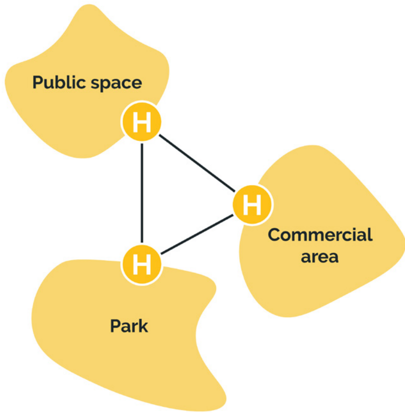


Figure 5.37 | Sharing principles

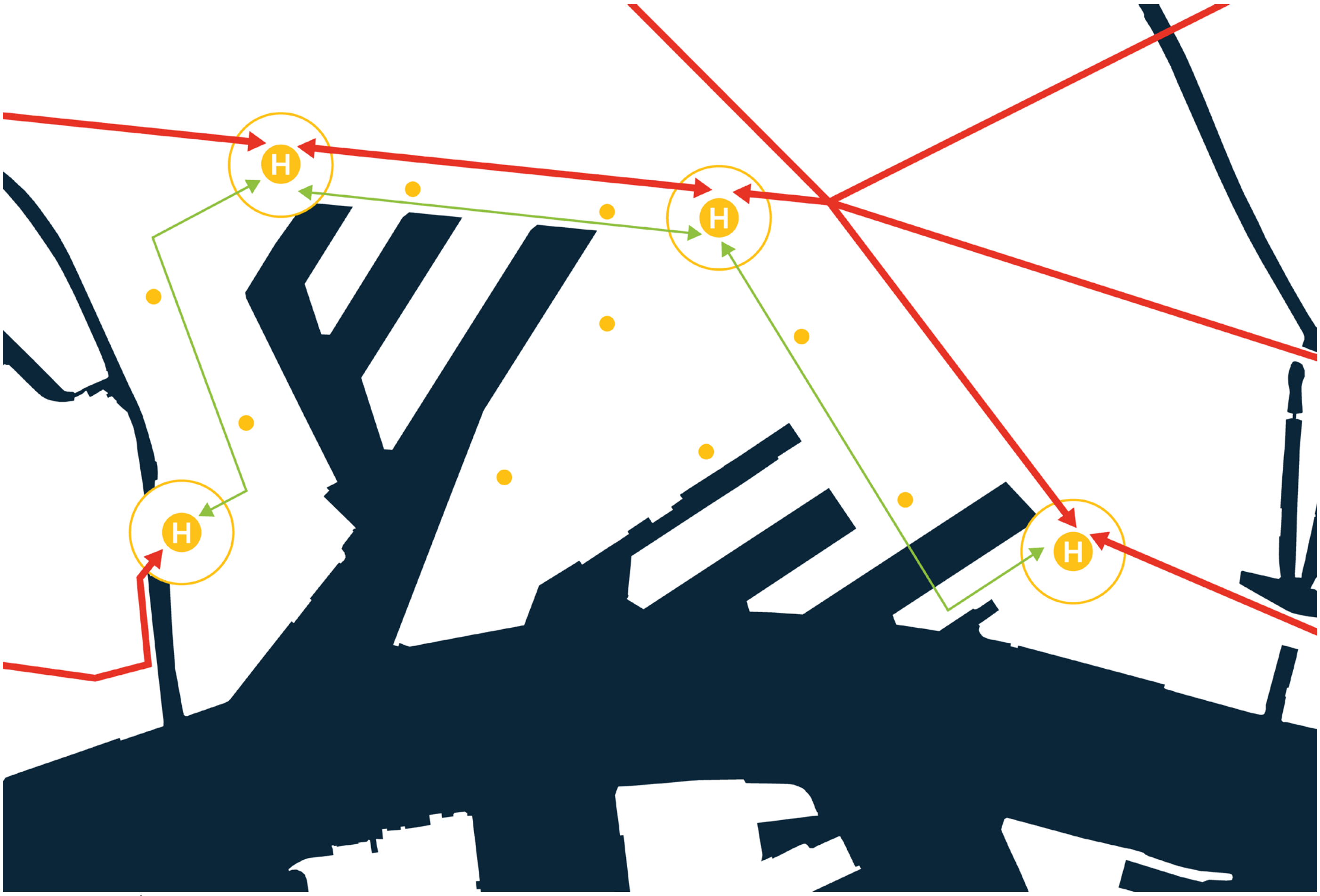


Figure 5.38 | Sharing network applied on M4H

5.4 Analysis on sustainable mobility

5.4.4 Clean mobility (CM)

The topic of clean mobility focuses on stimulating the technological transition from ICEV to sustainable alternatives. The transition mostly considers cars, as public transport vehicles are often already electrically driven. Several concepts concerning clean mobility are stated by the European Commission (2019). Smart road charging is a concept that can be introduced in certain areas. Several principles are proposed in order to make sure it has the desired outcomes. Firstly, discrimination should be avoided, so citizens shall not be unfairly treated based on their nationality, for example, road pricing. Secondly, the actual usage and pollution are best reflected in the driven distance (tolls) rather than on time (vignettes). A change in this system will support less driven kilometers and therefore less pollution. The third principle is to reward environmentally-friendly vehicles based on their performance to stimulate their use. Besides smart road charging the availability and acceptance of alternative fuel-powered vehicles also participates. In order to stimulate the use of for example electric vehicles, charging should be as easy as filling the tank (European Commission, 2018).

The implementation of clean mobility in the urban fabric comes with some spatial complications. Figure 5.40 shows two principles considering clean mobility, the availability of electric charging in a neighborhood and the street layouts. Figure 5.41 shows clean mobility applied to the M4H. The neighborhood is transformed into a car-free zone, which eliminates most of the pollution and emissions in the area. To get a car-free neighborhood several implications need to be done. The street layout focuses on slow mobility instead of car mobility. This also makes space free for natural elements. A dense charging network ensures the use of electric vehicles in places where car use is unavoidable.

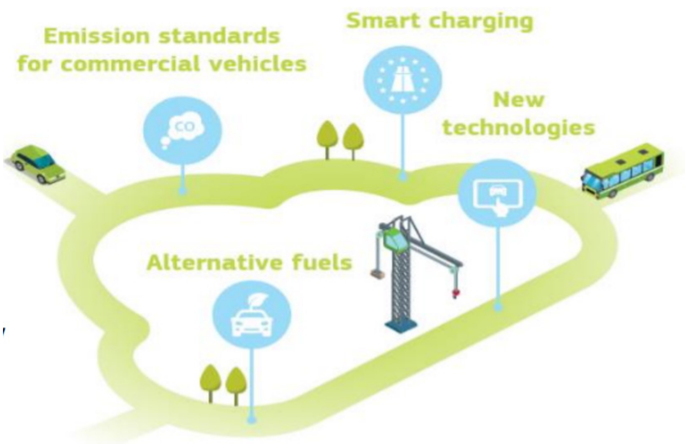


Figure 5.39 | Clean mobility principles *(European Commission, 2019)*

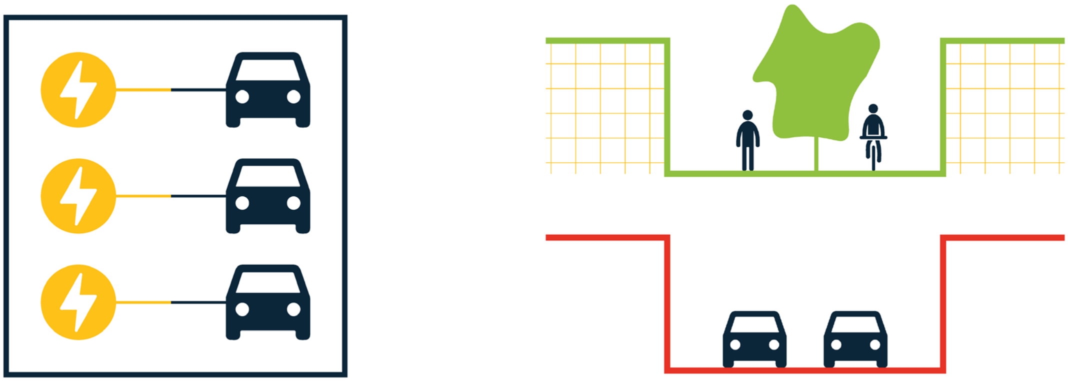


Figure 5.40 | Clean mobility principles

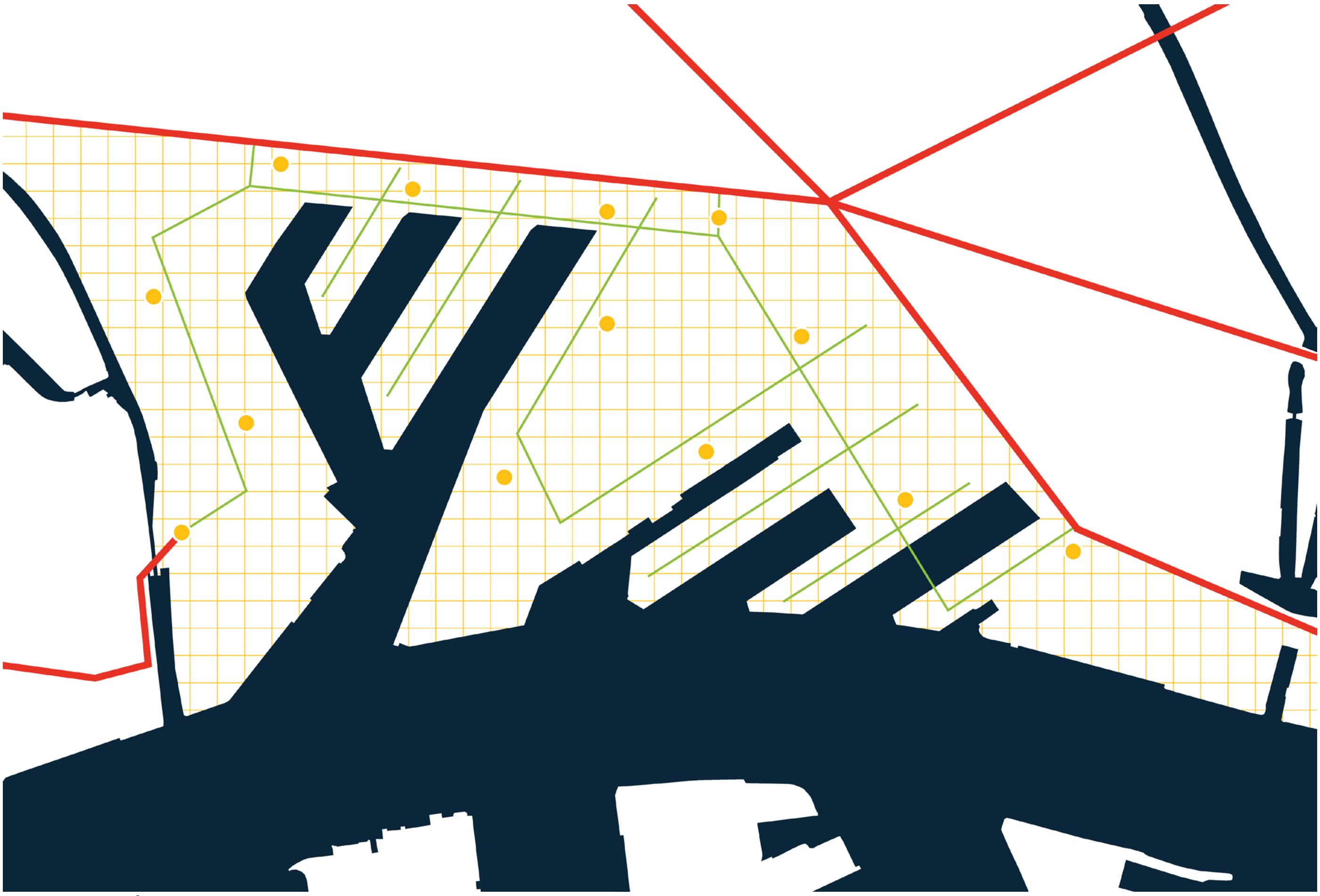


Figure 5.41 | Clean mobility applied on M4H

06 Strategy

This chapter shows the elaboration of the strategy. It consists of four infographics, a patternbox and a strategic spatial framework.

6.1 Introduction

From the analysis on sustainable mobility, transit-oriented development, and the strategy of the two networks the next step is made. This part consists of three elements, tackling sustainable mobility in three different ways. First, there are four infographics, containing a vision of the mobility components involved in the transition. These infographics contain general information on the trends. The second part consists of a pattern box. The pattern box is a translation of the infographics into design and development principles. The pattern box consists of a deck of cards, each card describing a different principle. The final part consists of a strategic spatial framework. In this part, the concept of sustainable mobility is applied to the case of M4H. This framework derives from the analysis in chapter 05. The framework consists of key elements on different scales, stakeholders, development timeline, and design interventions. The pattern cards are used while designing the interventions.

6.2 Infographics

As stated before, the concept of sustainable mobility can be divided into four different categories: public transport, slow mobility, sharing network, and clean mobility. These four components all serve the main goal of reducing car traffic and its bad effects on the environment. Over the years the components are constantly developing and adjusting to the current status. The four components are already further elaborated in previous chapters; however, the infographics display a conclusion and vision for a future transition. An infographic consists of different elements. Central on the infographic is a visualization of what the future considering this component would look like. This vision is supported by text and diagrams. Also on the infographic is a future expectation per transportation mode involved. Besides mobility, the connection to development and environment considering the mobility elements is also made. In this way, a clear overview of the mobility types is given. This infographic could be used in further research or development, summarizing, and transmitting knowledge about sustainable mobility. On the next pages, the four infographics are displayed.

Next pages:
Figure 6.1 | Infographic public transport
Figure 6.2 | Infographic slow mobility
Figure 6.3 | Infographic sharing network
Figure 6.4 | Infographic clean mobility

Infog

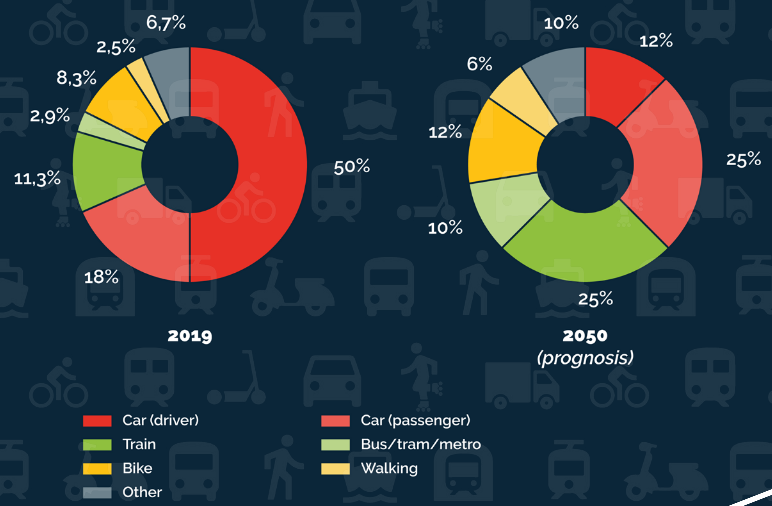
PUBLIC TR

as part of Susta

PROGNOSIS

Currently, still more than half of all passenger-kilometers are still made by car mobility, either as driver or passenger. To move towards sustainable mobility, in 2050 a shift in mobility use must be made. The prognosis for 2050 shows a reduction in halving car use. This provides the opportunity for public transport to expand and take up about 35 percent of passenger-kilometers.

Passenger-kilometer by mode of transport aged 6 and older *(CBS, 2019)*



TRAIN

In 2050, the train network consists of the following elements. The stations are designed as nodes where all kinds of mobility intersect. A station hub is a key location in the urban fabric, which accommodates a high-density environment. The rail network is extended to facilitate a high usage frequency, consisting of intercity, regional, and suburban trains. The energy is generated in a closed system within the train network.

METRO

In 2050, the metro system is extended to connect the suburbs to the city center. The metro is still an easy and quick way of traveling in urban areas. Autonomation of the metro provides the opportunity to increase the frequency and shorten the travel time. Metro stations are designed in a way to connect to other public transport modes and provide easy accessibility for pedestrians and cyclists.

TRAM

In 2050, the tra
experience the fo
The trams se
transportation nee
are extended, as th
of the main forms
since bus lines
anymore. Tram
autonomous to
frequency. Tram t
in green environm
the use of space.

raphic

RANSPORT

ainable Mobility

DEVELOPMENT

The public transport network transforms into one of the main backbones of the urban structure. Stations are important, active nodes in the city. In these key locations, mobility, development, and environment come together. The city densifies around station areas to facilitate mixed-use areas and public spaces. The station areas are tied together by public transport lines. The lines operate on different scales and levels, according to the mode of transportation. The efficient lines with high frequency provide quick connections to increase accessibility.

ENVIRONMENT

By the prioritization of public transport, the usage of the private car is reduced. This results in fewer emissions and environmental pollution. The different kinds of transportation modes run on locally generated power. The environmental aspect is represented in the design of stations. These areas exist in a green environment where the pedestrian and cyclists experience stand central.

am network will
llowing transition.
erve the local
ed. Tram networks
he tram is now one
s of transportation
are not sufficient
vehicles drive
increase travel
racks are situated
ments to optimize

BUS

In 2050, the bus system is transitioned into a sustainable way. The current way of using buses is completely surpassed by the trams. The bus network is now an on-demand service, in this way it meets the travelers' needs. The buses are only electric power-driven and rely on sustainable resources. Just like the other modes, busesa are also autonomously drivena to ensure safety in use.

OTHER

In 2050, other modes of transportation make their appearance, these modes are specific to the different environments. For example, the use of cable cars in mountainous areas or ferries and waterbuses in cities based around water. Adjusting to the characteristics of the city ensures optimization of land use. Other modes of transportation also include monorails and hyperloops.

Infog

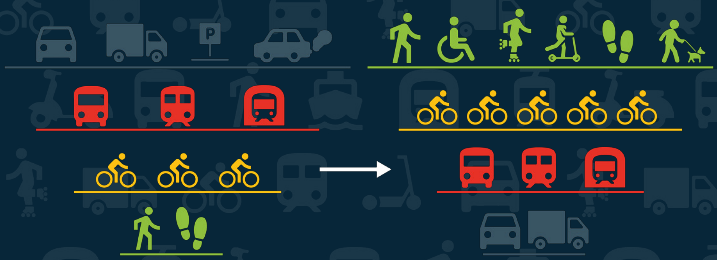
SLOW M

as part of Susta

PROGNOSIS

With the reduction of cars on the streets, the car-dominated environment shifts towards slow mobility use. In 2050, the shift in mobility towards slow mobility prioritizes the use of bicycles as the main mode of transportation in cities. The slow mobility network connects to public transport to support sustainable mobility on a large scale. This results in both an increase in walking, cycling, and public transport use.

Slow mobility as the priority mode of transportation
(Gemeente Rotterdam, 2020)



PEDESTRIANS

In 2050, pedestrians take an active role as a mode of transportation. The design of the urban fabric stimulates walkability by focusing on pedestrian activity. The reduction of cars ensures more space for pedestrians in neighborhoods, streets, and central locations. The reservation of space for pedestrians crucial for a pleasant walking environment that stimulates movement. In this way, active mobility and social participation are enhanced by walking in the immediate living environment. The streets in cities are redesigned with more green and attractive walking routes to important destinations, such as facilities or public spaces, which are created. The pedestrian network is well connected to the public transport network. This connection is important as public transport provides a way for pedestrians to travel larger distances.

CYCLISTS

In 2050, cycling
major modes
used in urban
short distances,
effective than car
cycling in urban a
is expanded and
ensures safe and
accessibility for
cycling network c
routes connecting
and destinations.

raphic

IOBILITY

ainable Mobility

DEVELOPMENT

The implementation of slow mobility affects the design of the urban fabric. The slow mobility network consists of routes, connecting important key destinations in the neighborhood. Key destinations are, for example, public transport stops, parks, public spaces, or commercial buildings. The development in a city is centered around the slow mobility network to guaranty accessibility for cyclists and pedestrians. High-density and mixed-use buildings provide all facilities and amenities within walking distance. The slow mobility routes are separated from other traffic to ensure physical safety. Social safety is ensured by the path context.

ENVIRONMENT

The prioritization of slow mobility results in a reduction in car use. This change has a positive effect on the environment, as CO_2 emissions are lowered. In the design of streets focused on slow mobility, more space for greenery is available. This is visible in the large rows of trees, semi-permeable pavement, and green strips. In this way, slow mobility accommodates greenery in the street sections.

is one of the of transportation environments. On cycling is more use. To support areas, the network d densified. This d efficient cycling all locations The consists of cycling g important nodes On these routes, cyclists are separated from other traffic to ensure safety.The electric bike gains popularity besides the regular bike. With the rise of electric bikes further distances can be crossed. To support the use of electric bikes, bicycle parking is upgraded with electric charging stations. A network of bicycle-sharing stations encourages cycling in the absence of a private bicycle.

OTHER

In 2050, slow mobility does not only consist of pedestrians and cyclists. Other modes of transportation considering slow mobility are for example skaters and scooters. These types share in the use of the pedestrian areas and should therefore also be taken into consideration. To stimulate the use of bicycles and scooters, these vehicles could be shared. This is further explained in the 'Sharing Network' infographic

Infog

SHARING

as part of Susta

PROGNOSIS

The implementation of sharing in the mobility network reduces the number of cars on the roads. The sharing network consists of two types: vehicle sharing and ride-sharing. Both types have a huge impact on the behavior of people, as it makes individual car ownership obsolete. The sharing network consists of sharing hubs that are distributed over the neighborhood, providing accessibility for everyone.

CARS

In 2050, cars are less prominent in the urban environment, as individual car use is cut down. However, the use of cars might sometimes be unavoidable. In cases where there still is car use, dense sharing systems are laid out to still reduce the number of vehicles. The sharing network consists of people who share cars on individual rides, or people who share a car on the same ride. The sharing hubs consist of parking and charging for the vehicles, as all vehicles are electrically driven. In this way, the cars are emission-free and safe for the environment. Sharing hubs are located near important locations, such as facilities, public spaces, and transit hubs. A sharing hub in a neighborhood enhances community as it gathers people. It causes interaction between people by the implementation of a communal area.

BICYCLES

In 2050, bicycles
part of the sharin
slow mobility co
explains, cycling i
forms of mobility i
use of bicycles is
by a shared cyc
system consists c
people can re
sharing stations c
to important key

raphic

NETWORK

ainable Mobility

DEVELOPMENT

Within the sustainable mobility network, sharing hubs are important nodes. The hubs are intensely used by the residents, so the hubs are designed in a way to act as a key location in the neighborhood. These central points are accompanied by some commercial amenities and public activities. In order to succeed as an efficient hub, several options of sharing are provided. In this way, there is a suitable ride for everyone.

ENVIRONMENT

The implementation of a sharing network in a neighborhood significantly reduces car use, and therefore also benefits environmental impacts. The vehicles that are part of the sharing network are executed as electric vehicles in order to support clean mobility. The charging of electric vehicles is done by locally generated power. Together with the implementation of greenery, sharing hubs become key locations in the environmental network.

are an important
g network. As the
omponent further
s one of the main
n urban areas. The
further supported
ling system. This
of stations where
nt bikes. Such
are situated next
y locations such

as public transport stops, public spaces, and important buildings. These sharing stations could be extended with the possibility of sharing other types of vehicles. In order to stimulate the use of bikes on longer distances, they are exploited with charging points for electric bikes. The bikes can be returned at every station, to make the journey as efficient as possible.

OTHER

In 2050, not only cars and bicycles are part of the sharing network. Other types of transportation are introduced in sharing hubs to fit more types of tips. Modes of transportation that are added to sharing hubs are for example scooters, motorcycles, and Segways. These operate mostly in urban areas for recreational purposes, however, with future developments they are now part of the system as a full-fledged alternative.

Infog

CLEAN M

as part of Susta

PROGNOSIS

At the center of the shift towards sustainable mobility stands clean mobility, as it states that all vehicles need to be clean and free of emissions. The transformation is guided by several design principles, which make sure all vehicles in 2050 are clean. In the clean mobility principle vehicles are driven by electric power, as this is a renewable energy source. Clean mobility cuts pollution and provides clean air which positively influences the living environment.

VEHICLES

In 2050, vehicles are part of clean mobility in the way they are powered. The electrification of public transport has continued, as their energy is generated in a closed system. Cars are completely electrified or running on a hybrid system. This cuts down pollution from the streets. The autonomation of vehicles also contributes to efficient energy use.

ZONING

In 2050, the zoning of mobility has become standard. Zones that are established in urban areas to contribute and support sustainable mobility are no emission zones and low emission zones. In these areas, cars with internal combustion engines are prohibited and sustainable mobility modes are given priority. These zones regulate the use of mobility in cities.

raphic

MOBILITY

ainable Mobility

DEVELOPMENT

The implementation of clean mobility in a neighborhood also considers development. Part of clean mobility is a dense charging network and these stations should be located near important locations, as well as in sharing hubs. In order to further elaborate clean mobility, locally generated power can create closed energy systems. Energy generated by for example solar panels on roofs, can be used in charging electric vehicles.

ENVIRONMENT

The environmental impact of clean mobility over time is large, considering that mobility is responsible for a large part of the CO_2 emissions. With the implementation of clean mobility in a neighborhood the emissions and pollutions are cut, reflecting positively on people's health and livability.

STREETS

In 2050, the layout of a street influences clean mobility. A hierarchy in streets provides the opportunity to ban certain types of mobility in certain streets. The most common street design consists of sustainable mobility modes like trams, busses, and slow mobility lanes. These types of mobility take up less space in the street, which provides the opportunity to implement more greenery, like trees, bushes, and grass. In this way, there is a less paved area and more permeability.

CHARGING

In 2050, an electric charging network stimulates the use of clean mobility. Charging points are installed in sharing hubs and parking stations. The visibility of electric charging introduces sustainable services in the urban network. When connected to a closed energy system, the charging points can be connected to local networks.

6.3 Pattern box

6.3.1 Use of the patterns

To expand the use of the mobility framework, a translation into a pattern language is made. A pattern language is a method to deal with complexity in design and planning, developed by Christopher Alexander (1979). A pattern presents a bridge between a problem and a solution. With the combination of several patterns on different levels a pattern field is created (Rooij & van Dorst, 2020).

In this thesis project, the patterns are used to create a translation of the theory into design and development. In this way the results of the research on sustainable mobility fiends a way to be used in practice. The pattern box consists of a deck of cards containing the design/development patterns. Each card describes a principle that stimulates the transition to sustainable mobility. The total deck also includes a set of empty cards. These cards are there to further expand the framework in the future, as sustainable mobility is continuously developing. New, missing principles might be discovered and be added to the set of cards. In this way, the pattern box is a dynamic design/development tool.

The pattern cards are designed to be useful in a variety of ways, by different target groups. The first type of users are urban designers and there are several ways they can make use of the pattern cards. In their design projects, the pattern cards could be used to stimulate the use of sustainable mobility in the different stages. The patterns are a way to assess a location, investigating the problems and opportunities considering sustainable mobility. In this way, the cards set the development assignment. Next to that, the cards can be used in prioritizing and decision making, as the deck of cards gives an overview of all different principles and their effects. By prioritizing the principles in development, a timeline and/or planning could be a result. At the end of a design project, the cards are an easy way to evaluate a project, considering the amount and kind of principles used to incorporate sustainable mobility.

Besides urban designers, the pattern cards are also of value for stakeholders engaged in development projects. The cards can act as a way to transfer knowledge and information about sustainable mobility principles to those people. This creates better awareness of the challenge and a better understanding of ongoing development. When used in the early stages of a development project, the patterns are a way to generate participation and engagement. The cards are a way to stimulate discussion between the involved people and provides the opportunity for stakeholders to give input for the development and influence by for example setting priorities.

The cards are designed in a way to create a balance between generality and specificity. This ensures the use of the cards by the different target groups. For example, urban designers might be familiar with the principles on the cards, and the pattern box would be used more in a brainstorming workshop session to encourage exploration and experimentation. For other stakeholders, the cards contain a certain level of information to teach and bridge the knowledge gap. This balance is also needed to make sure the cards can be used in different situations and design stages. To achieve that, they do not contain literal design proposals for specific locations. Instead, they are created on a conceptual level, to steer and guide the development.

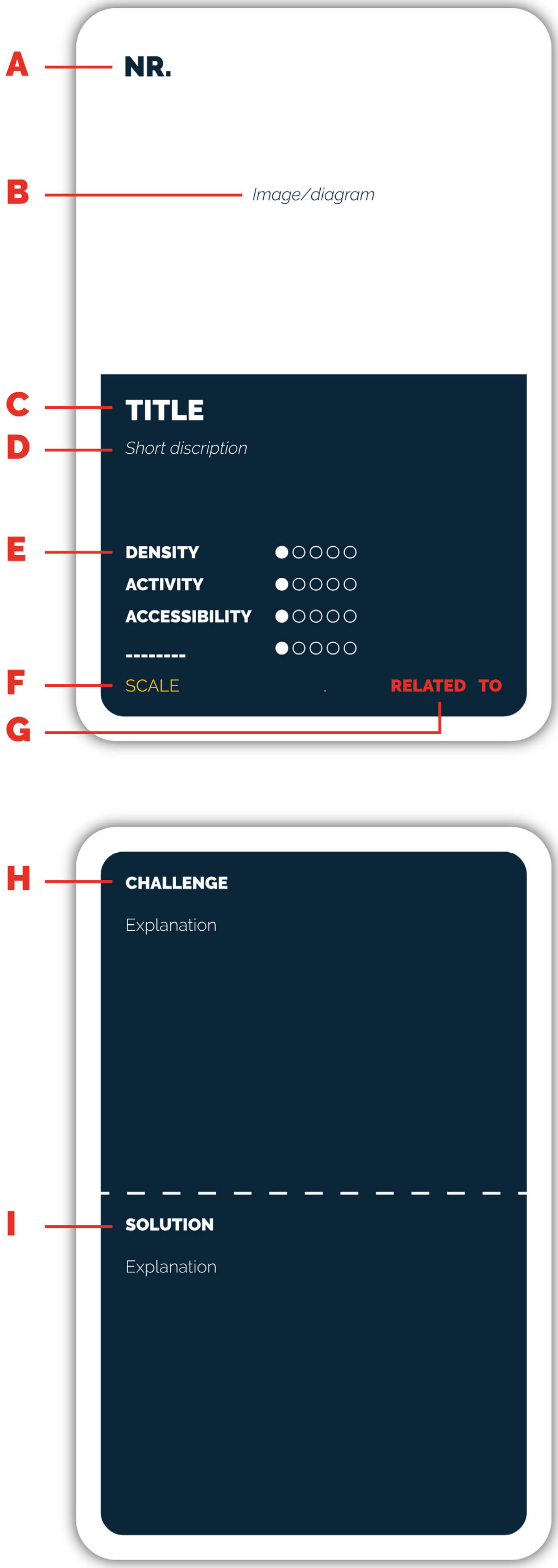


Figure 6.5 | Basic pattern card

6.3.2 Basic card layout

Each card consists of three elements, information, explanation, and elaboration. The basic layout of a card can be seen in figure 6.5, consisting of a front- and a backside. The frontside is used to give a quick overview of the pattern and consists of the following elements from top to bottom.

At the top of the card, the mobility category and number are shown (A), which provides an easy classification. The top half consists of visualization, image, or diagram (B), which represents the principle and attracts attention. On the bottom half, the given title (C) of the pattern, together with a short description (D) is shown to introduce the pattern. The rating (E) on density, activity, and accessibility provides an evaluation of how the principle deals with these concepts. On the bottom, the scale (F) of the pattern is highlighted and important connections (G) to other cards are visible. The backside of the card further elaborates the principle. It describes the challenges (H) which explain the problem to tackle, and the solution (I) which explains the implementation.

6.3 Patternbox

6.3.3 Example cards

The figures on the following pages show some elaborated pattern cards. The cards shown give a clear example of how they supplement each other. In the case of PT1 and PT2, the relation is clear. Card PT2 explains the concept of hierarchy in public transport networks, an important principle to address the different types of mobility to certain contexts and establish the relation between them. A transfer hub (explained in PT1) can be used to connect the different hierarchy layers, as they intersect on this node. When experimenting with the 'hierarchy network' card, the 'transfer hubs' card can be an addition and next step in the process.

A full overview of the pattern box is given in the figure on the next page. This overview can be used to quickly check the patterns and chose which one would be applicable. The small icon of a card can also be used to show the use of a card in a design. After the overview, the next figures give an elaboration of each card in detail, with the front side on the left, and the back side on the right.

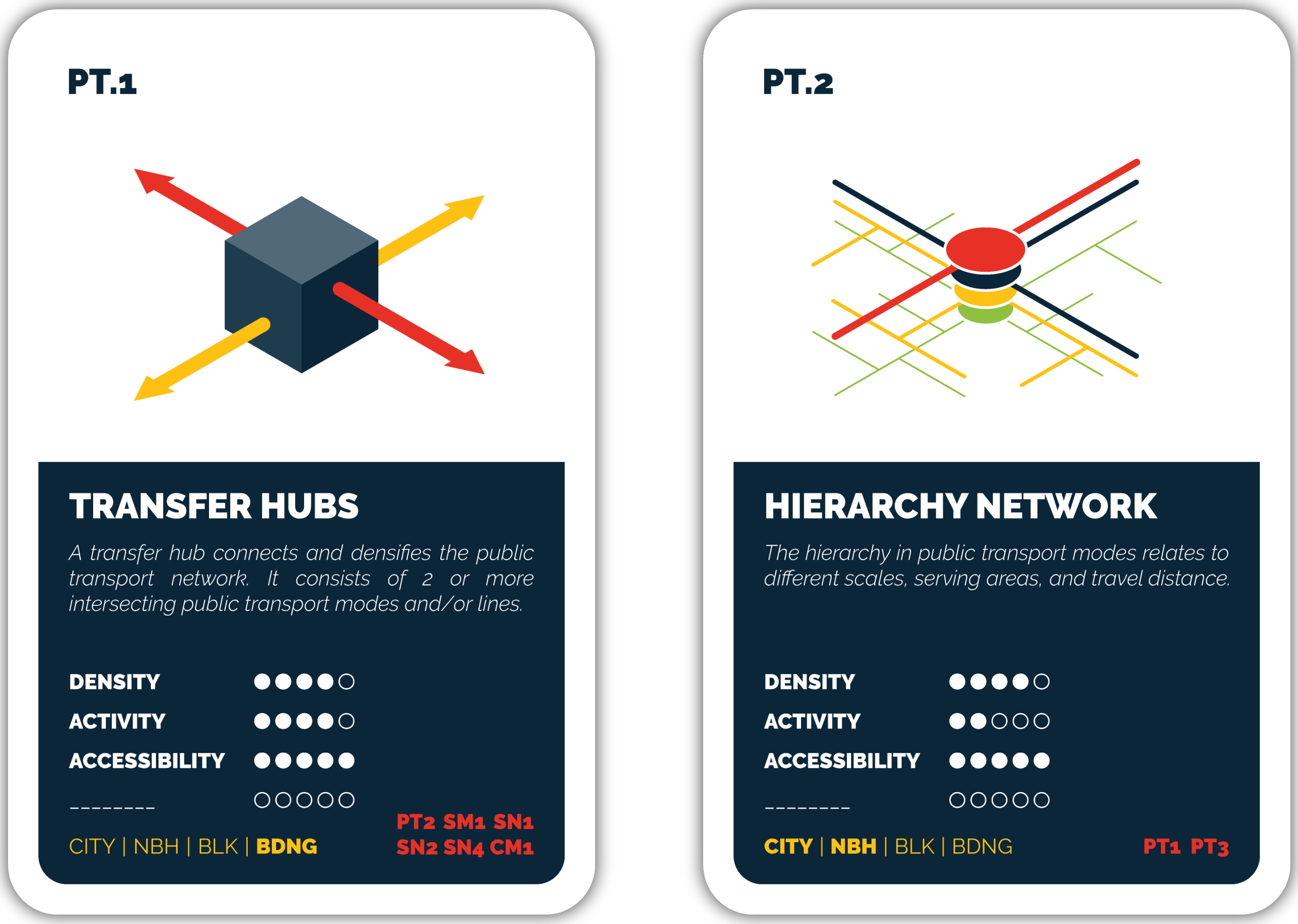


 Figure 6.6 | Relation between cards

6.3 Patternbox

PUBLIC TRANSPORT (PT) SLOW MOBILITY (SM)

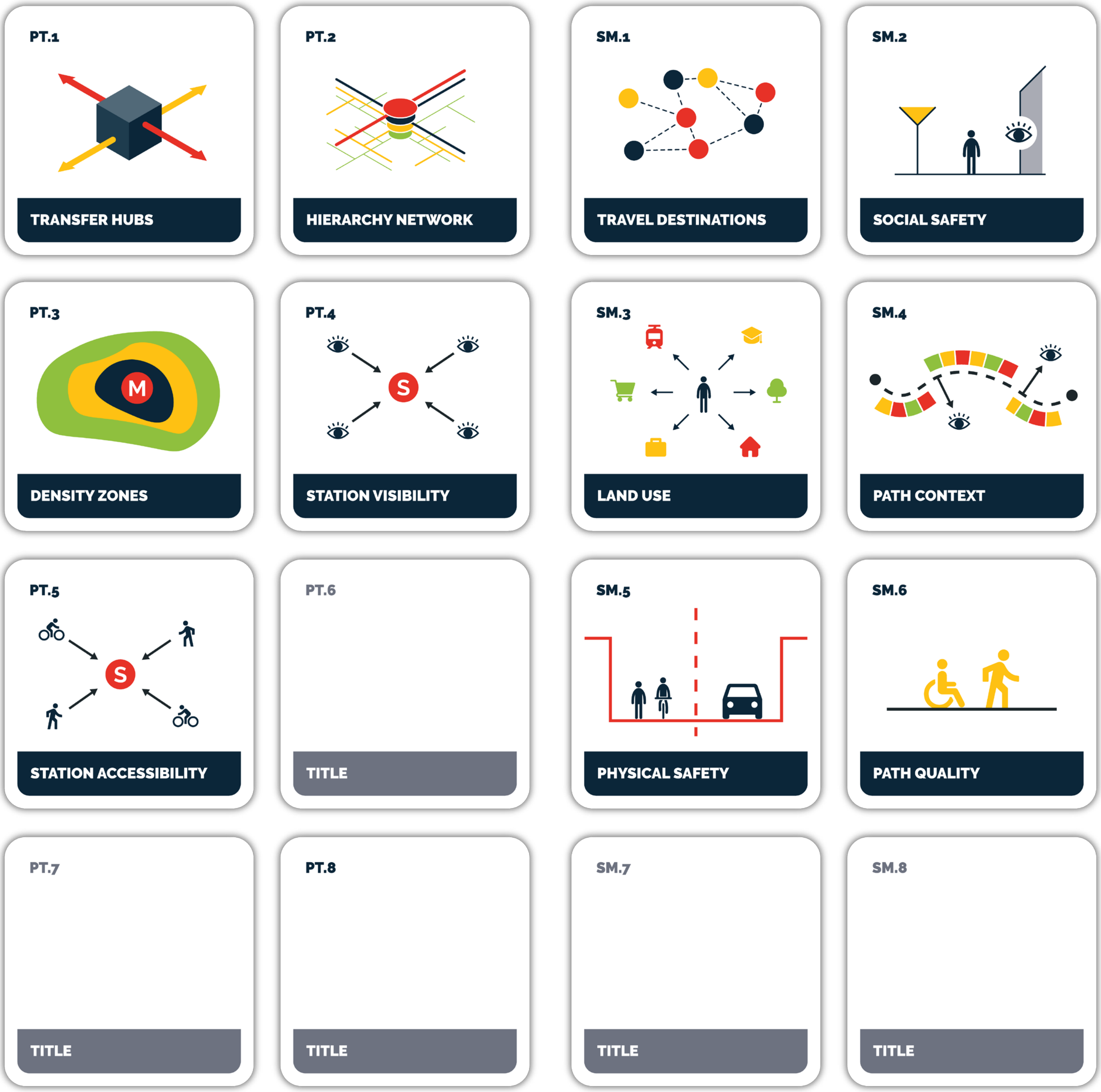
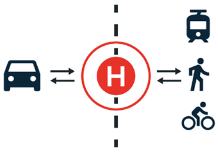


Figure 6.7 | Overview pattern box

SHARING NETWORK (SN)

SN.1



TRANSITION ZONES

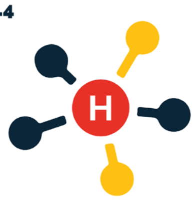
SN.2

PARKING HUBS

SN.3

COMMUNITY

SN.4



CENTRALITY

SN.5

TITLE

SN.6

TITLE

SN.7

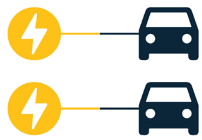
TITLE

SN.8

TITLE

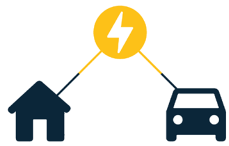
CLEAN MOBILITY (CM)

CM.1



CHARGING NETWORK

CM.2



LOCAL POWER GENERATE

CM.3

NO EMISSION ZONE

CM.4

TITLE

CM.5

TITLE

CM.6

TITLE

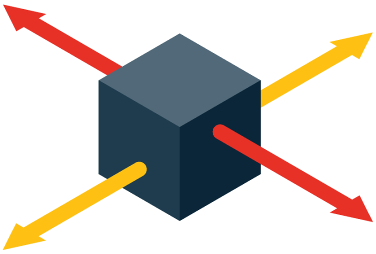
CM.7

TITLE

CM.8

TITLE

PT.1



TRANSFER HUBS

A transfer hub connects and densifies the public transport network. It consists of 2 or more intersecting public transport modes and/or lines.

DENSITY ●●●●○
ACTIVITY ●●●●○
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | BLK | **BDNG**

PT2 SM1 SN1 SN2 SN4 CM1

CHALLENGE

Public transport lines are linear elements that are limited in size and directions. To enhance the use, an interconnected public transport network is needed.

SOLUTION

A transfer hub in a public transport network provides the possibility for travelers to transfer easily between transport lines and/or kinds of transportation modes like trains, trams, and busses. At a transfer hub, various lines are connected which extends the public transport network of the given location. A transfer hub creates more options for travelers to reach different destinations.

Figure 6.8.1 | Card: Transfer Hubs

PT.2

HIERARCHY NETWORK

The hierarchy in public transport modes relates to different scales, serving areas, and travel distance.

DENSITY ●●●●○
ACTIVITY ●●○○○
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | **NBH** | BLK | BDNG

PT1 PT3

CHALLENGE

Public transport consists of various modes which all have their characteristics in relation to scale, serving area, and travel distance. To enhance the public transport, use a clear relation between the different networks is needed.

SOLUTION

The design and use of a clear hierarchy network ensure optimization of public transport use. In this network, the various transportation modes are connected to the correct scales and context. Starting at the largest scale the basic hierarchy is as follows: train-metro-tram-bus. An interconnected network with the correct use of hierarchy ensures that travelers can use public transport to travel between destinations on all scales.

 Figure 6.8.2 | Card: Hierarchy Network

PT.3

DENSITY ZONES

Development in urban areas is related to the public transport network. Density increases towards transit stops, to meet the passenger demand.

DENSITY ●●●●○
ACTIVITY ●●○○○
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | **NBH** | BLK | BDNG **PT2 SM3**

CHALLENGE

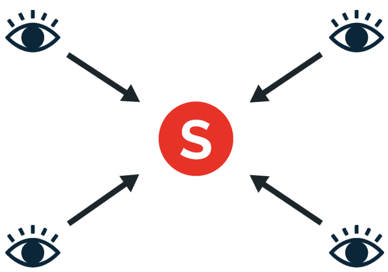
Different public transportation modes accompany different amounts of users. Metros and trains are for example designed to accommodate a high number of passengers. In order to match the passenger demand, development density should be coordinated.

SOLUTION

To match de passenger demand, density zones surround transit stops. The density decreases further away from the station. A high-density zone consists of high rises, mixed-use functions, and a public character. Low-density zones are focused on residential areas with a more private character. The zones act as a graduate with smooth transitions between the different zones.

Figure 6.8.3 | Card: Density Zones

PT.4



STATION VISIBILITY

To increase the use of public transport, station visibility plays an important role. Visibility could be enhanced by the design of the urban fabric or the design of the building itself.

DENSITY ●●○○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | **BLK** | **BDNG** **PT5 SM1 SM4**

CHALLENGE

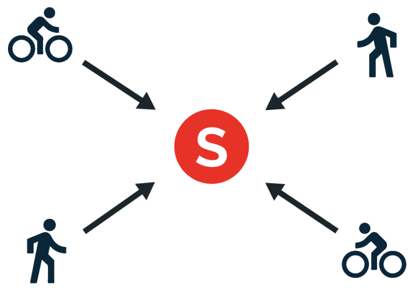
The use of public transport is related to how the station is situated in the neighborhood. The presence of a station does not guarantee its use, as this is related to how centralized it is. To ensure the central status of station visibility is important.

SOLUTION

Station visibility could be a way to increase the use of public transport in an area. The visibility could be enhanced in different design ways. On the neighborhood scale, visibility comes together with the design of the urban fabric. Sightlines and main roads leading to the station highlight the presence of the transport stop. The design of the building in the form of a landmark could also attract attention.

Figure 6.8.4 | Card: Station Visibility

PT.5



STATION ACCESSIBILITY

In order to be a functional station, the building should be easily reachable for everyone, including pedestrians and cyclists.

DENSITY ●●○○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | **BLK** | BDNG

PT4 SM1 SM5 SM6 SN4

CHALLENGE

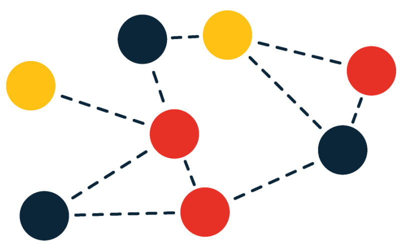
Pubic transport operates on a network level, which connects different places together. However, the journey of a traveler often extends further than the station itself. To fulfill a complete trip the transit station needs to be well connected to the destinations.

SOLUTION

To connect stations to the urban context, accessibility should be reached on different levels. To increase accessibility for slow mobility, the station needs to be connected to cycle- and pathways, as well as facilities like bicycle parking.

Figure 6.8.5| Card: Station Accessibility

SM.1



TRAVEL DESTINATIONS

A clear network of various destinations enhances the use of slow mobility as it connects different key locations.

DENSITY ●●○○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | **NBH** | BLK | BDNG

PT1 PT4 PT5 SM2 SM4

CHALLENGE

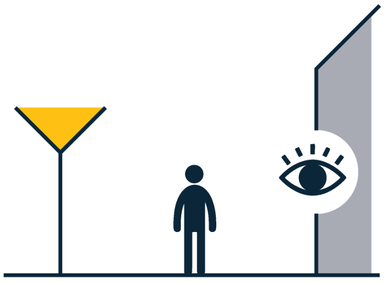
Slow mobility consists of people going from one place to the other, but the lack of destination does not support the use of the network. To enhance the use of slow mobility principles a clear network of locations is needed.

SOLUTION

Key locations for slow mobility should be designed and defined in a clear network. This ensures the use of the slow mobility network as it connects to destinations for travelers. The destinations could be divided into categories such as public spaces, mobility hubs, or commercial buildings.

 Figure 6.8.6 | Card: Travel Destinations

SM.2



SOCIAL SAFETY

The use of slow mobility principles is stimulated by social safety. Social safety can be achieved by street lights or eyes on the streets.

DENSITY	●●○○○
ACTIVITY	●●●●●
ACCESSIBILITY	●●●●○
--------	○○○○○

CITY | NBH | **BLK** | BDNG **SM1 SM4 SN3**

CHALLENGE

Pedestrians and cyclists are vulnerable travelers considering social safety. The use of slow mobility modes can be diminished by an unsafe social context. In such situations, people might prefer car use as it is considered quicker and safer.

SOLUTION

In order to enhance slow mobility use, several principles considering social safety could be taken into consideration. The first one is the presence of good and enough street lights. In a lighter street, people can see each other and see what is happening, which decreases criminality. Another aspect is what is happening in the buildings adjacent to the pathways. Active ground floors, with windows and residential functions, provide eyes on the street. This also ensures social safety.

Figure 6.8.7 | Card: Social Safety

SM.3

LAND USE

The classification of land use is a way to provide different functions and amenities within walking/-cycling distance.

DENSITY	●●●●●
ACTIVITY	●●●●●
ACCESSIBILITY	●●○○○
--------	○○○○○

CITY | NBH | **BLK** | BDNG **PT3 SM4**

CHALLENGE

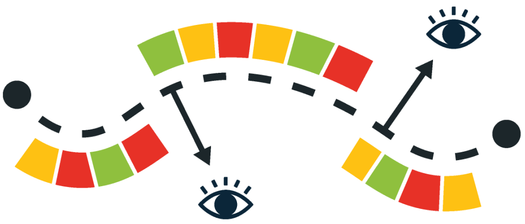
Designate areas with one function of land use provide large travel distances between them. In order to reach the destination, the use of a car is unavoidable. Ways should be discovered to avoid the use of cars.

SOLUTION

ar use becomes unnecessary if there is differentiation in land use, as they are within walking/cycling distance. With this classification, people can walk to the store or park, and cycle to for example the station and their work. Land use can be optimized by the introduction of mixed-use buildings, as they house several functions.

Figure 6.8.8 | Card: Land Use

SM.4



PATH CONTEXT

The path context contributes to the stimulation of slow mobility. Sightlines, routing, and building diversity are ways to improve the path context.

DENSITY ●●●○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | **BLK** | BDNG **PT4 SM1 SM2 SM3 SN4**

CHALLENGE

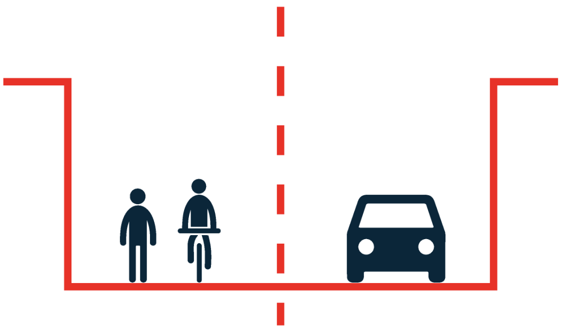
Walking distances can be measured in meters or time, however, the experience of people might differ. Distances might feel larger when there is little variety in path context, like a repetition of buildings or the absence of sightlines to trigger the eye.

SOLUTION

Variety in path context is a way to increase the use of slow mobility modes. An interesting path context influences the walking/cycling experience. This can be achieved by alternating buildings, both in façade and use. Sightlines and vistas to important locations or destinations provide an interesting context. Altogether the walking and cycling route should be well designed.

Figure 6.8.9 | Card: Path Context

SM.5



PHYSICAL SAFETY

A separation of the different mobility modes in traffic ensures physical safety for slow mobility.

DENSITY ●●○○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | BLK | **BDNG** **PT5 SM6 SN1**

CHALLENGE

Slow mobility modes, like pedestrians and cyclists, are vulnerable road users. As they share the same street an interference between different modes provides unsafe situations. Measures should be taken to ensure physical safety and create a safe environment.

SOLUTION

Physical safety can be achieved by separating traffic flows. Pedestrians and cyclists are vulnerable road users and should be protected. In a street section, the different flows of mobility are separated, according to size and speed. In this way, there is less interference between the different modes, which ensures physical safety for slow mobility modes.

Figure 6.8.10 | Card: Physical Safety

SM.6

PATH QUALITY

In the design of pathways the quality is an important factor. The quality is enhanced by the used material and the connections to other elements made.

DENSITY ●●○○○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | NBH | BLK | **BDNG** **PT5 SM5**

CHALLENGE

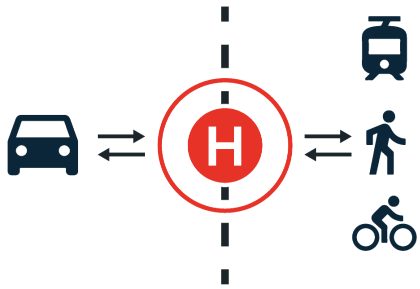
Pathways in a mobility network are heavily used, which is why good path quality needs to be ensured. All different users should be taken into consideration in the design to ensure accessibility for all.

SOLUTION

Path quality is important to slow mobility as it ensures accessibility for everyone, good path quality consists of several elements. The material used influences the quality of the path, as hard pavement creates a stable underground, opposite to sand or pebbles. The relation of paths to other streets is important, as safe crossings need to be realized. Steps and stairs need to be designed in a way to also ensures accessibility for disabled travelers. The paths should be well maintained through the years.

Figure 6.8.11 | Card: Path Quality

SN.1



TRANSITION ZONES

Entrances to areas with a focus on sustainable mobility are designed as transition zones. Sharing hubs in these zones provide a way to transfer between mobility modes.

DENSITY ●●●●○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●●●
-------- ○○○○○

CITY | **NBH** | BLK | BDNG **PT1 SM5 SN2 CM3**

CHALLENGE

The use of sustainable mobility ways should be prioritized over individual car use. However, in certain situations the use of cars is still unavoidable, so a way to transfer between the different systems is needed.

SOLUTION

Transition zones are designed for people to transfer between different mobility systems. A transition zone consists of a sharing hub which is the entrance to the area, as people can change their way of mobility in this hub. In this way, the car use can be banned as much as possible, and sustainable mobility can be prioritized in certain areas.

Figure 6.8.12 | Card: Transition Zones

SN.2

PARKING HUBS

Parking hubs gather cars in a designated area and provide possibilities to repurpose the taken areas in streets.

DENSITY ●●●●●
ACTIVITY ●●●○○
ACCESSIBILITY ●●●●○
-------- ○○○○○

CITY | NBH | BLK | **BDNG** **PT1 SN1 SN3 CM1**

CHALLENGE

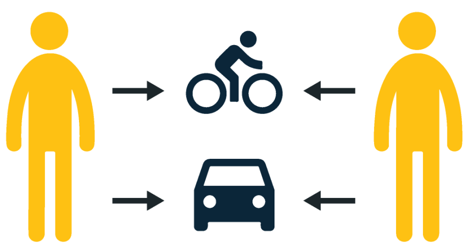
Cars dominate the street scene when there is on-street parking. Possibilities need to be found to hide cars, to deprioritize the use.

SOLUTION

Parking hubs are created to hide vehicles from the view in streets. In this way, the cars are gathered in a designated area. Parking hubs need to be diverted around the area and work best if located near public amenities. To support sustainable mobility parking hubs can be combined with electric charging and transfer possibilities. The street parking which is of no longer use can be transformed into green spaces.

Figure 6.8.13 | Card: Parking Hubs

SN.3



COMMUNITY

Implementing the sharing network encourages community in a neighborhood.

DENSITY ●●●●○
ACTIVITY ●●●●●
ACCESSIBILITY ●●●○○
-------- ○○○○○

CITY | NBH | **BLK** | BDNG **SM2 SN2 CM2**

CHALLENGE

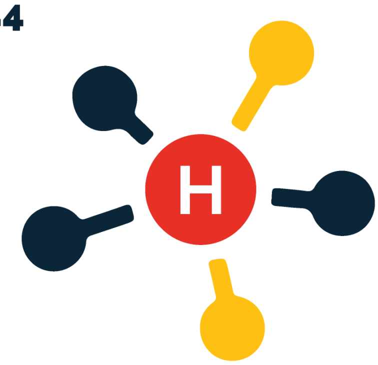
Lack of community in urban neighborhoods and blocks needs to be challenged by the implementation of sustainable mobility principles. Mobility not only needs to relate to environmental aspects but also to social aspects in a neighborhood.

SOLUTION

Implementing the sharing network encourages community in a neighborhood. In the sharing network rides and vehicles are shared between the residents. While sharing, possibilities to meet are created and interaction between residents is needed. The implementation of sharing hubs near key locations also influences interaction.

 Figure 6.8.14 | Card: Community

SN.4



CENTRALITY

Popular central locations in a neighborhood are equipped with sharing hubs, this supports the use of the sharing network.

DENSITY	●●●●○
ACTIVITY	●●●●●
ACCESSIBILITY	●●●●●
--------	○○○○○

CITY | **NBH** | BLK | BDNG **PT1 PT5 SM4**

CHALLENGE

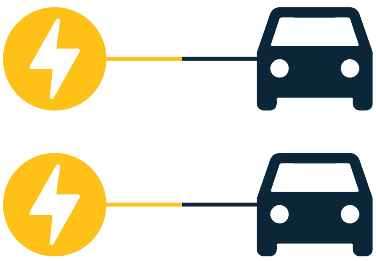
For a sharing hub to operate successfully, the location should be related to the context of the neighborhood. The use of the sharing network is reliant on the accessibility for the passengers.

SOLUTION

Sharing hubs are located near central locations in a neighborhood. A central location can be a public space or park, a commercial center, or public transport station. These central locations are heavily used and high in activity which supports further use of the sharing network. The concept of centrality ensures the reachability of popular destinations, which also contributes to the use of these locations.

Figure 6.8.15 | Card: Centrality

CM.1



CHARGING NETWORK

The use of electric vehicles needs to be stimulated by the implementation of a charging network.

DENSITY	●●○○○
ACTIVITY	●●●○○
ACCESSIBILITY	●●●●●
--------	○○○○○

CITY | **NBH** | BLK | BDNG **PT1 SN2 CM2 CM3**

CHALLENGE

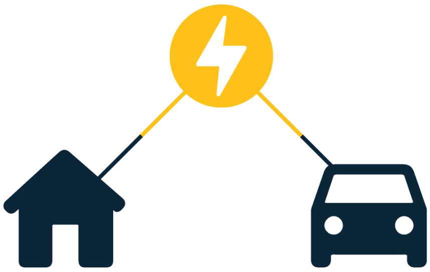
Cars with internal combustion engines are bad for the environment which is why the use of alternative vehicles needs to be stimulated. With the introduction of electric vehicles in a neighborhood, several new services need to be installed.

SOLUTION

A dense charging network in a neighborhood stimulates the use of electric vehicles. The amount of charging points needs to be in relation to the density of a neighborhood. Electric charging points work best in combination with parking hubs.

Figure 6.8.16 | Card: Charging Network

CM.2



LOCAL POWER GENERATION

Individual or communal power generation on a local scale can be used to charge electric vehicles.

DENSITY ●●○○○
ACTIVITY ●●●●○
ACCESSIBILITY ●●●○○
-------- ○○○○○

CITY | **NBH** | **BLK** | **BDNG** **SN3 CM1 CM3**

CHALLENGE

Ways to generate power need to be found, as clean mobility also considers the way power is generated. The generation of power should be done on a local scale.

SOLUTION

In order to support clean mobility local power generation can be used to charge electric vehicles. This can be done on an individual scale, but also on a community basis. Solar panels in for example bus stops or stations can also be used to make sure vehicles use clean mobility.

Figure 6.8.17 | Card: Local Power Generation

CM.3

LOW EMISSION ZONE

The prohibition of cars that emit excessive CO_2 can be regulated by a low emission zone.

DENSITY ●●○○○
ACTIVITY ●●●○○
ACCESSIBILITY ●●●○○
-------- ○○○○○

CITY | **NBH** | BLK | BDNG **SN1 CM1 CM2**

CHALLENGE

Cars with an internal combustion engine have a bad influence on the environment as they emit excessive CO_2. Ways need to be found to lower the use of these types of vehicles

SOLUTION

In a low emission zone several types of cars can be banned. In this zone sustainable mobility modes have priority and the CO_2 emissions are cut as much as possible. In order to stimulate these zones, there needs to be an easy transition between inside and outside.

 Figure 6.8.18 | Card: Low Emission Zone

6.4 Strategic spatial framework

6.4.1 Introduction

In this paragraph, the research on sustainable mobility is applied to the M4H (figure 6.26 and 6.27). Paragraph 2.1 already introduced the case location as a post-industrial site in Rotterdam. The location is in transition as the industry is moving out, and the city needs to densify. The M4H is transformed into a mixed-use environment for working and living. In this paragraph, the transition of M4H is further elaborated from a mobility perspective. Key elements in this transformation on both the city and district-scale are distinguished and explained, as well as stakeholder engagement and the development timeline. Design interventions zoom in on specific locations to show the implementation of the key elements. Several goals are taken into the redevelopment assignment, as a relation between port and city needs to be created. The current infrastructure needs to adapt to slow mobility and the M4H needs to be connected to the context. Densification to a mixed-use area needs to create a pleasant living/working environment. All these goals contribute to sustainable development and need to be achieved through a mobility perspective.

Figure 6.26 | Location M4H in city perspective *(Authors own, 2020)*

Figure 6.9 | M4H

6.4 Strategic spatial framework

6.4.2 Key elements (city scale)

The redevelopment of the M4H is embedded into the context of the city of Rotterdam in several ways. As the transformation is centered around sustainable mobility, the connection to public transport is of high value. A metro stop near the edge of M4H connects the site to the rest of the city. Local public transport connections which reach into the area connect the district to the metro station. On a larger scale, public transport over water also connects the M4H to its context. The M4H is also connected to the city's slow mobility network. A network of cycling routes along the river crosses M4H, connecting the existing structures at both sides. Green structures reach from the area into its surrounding neighborhoods in the form of parks and street designs. In the city of Rotterdam, the M4H is a new development project which houses new inhabitants, providing a mixed-use working/living environment. The district sets an example for the rest of the city by implementing innovation and sustainable mobility principles.

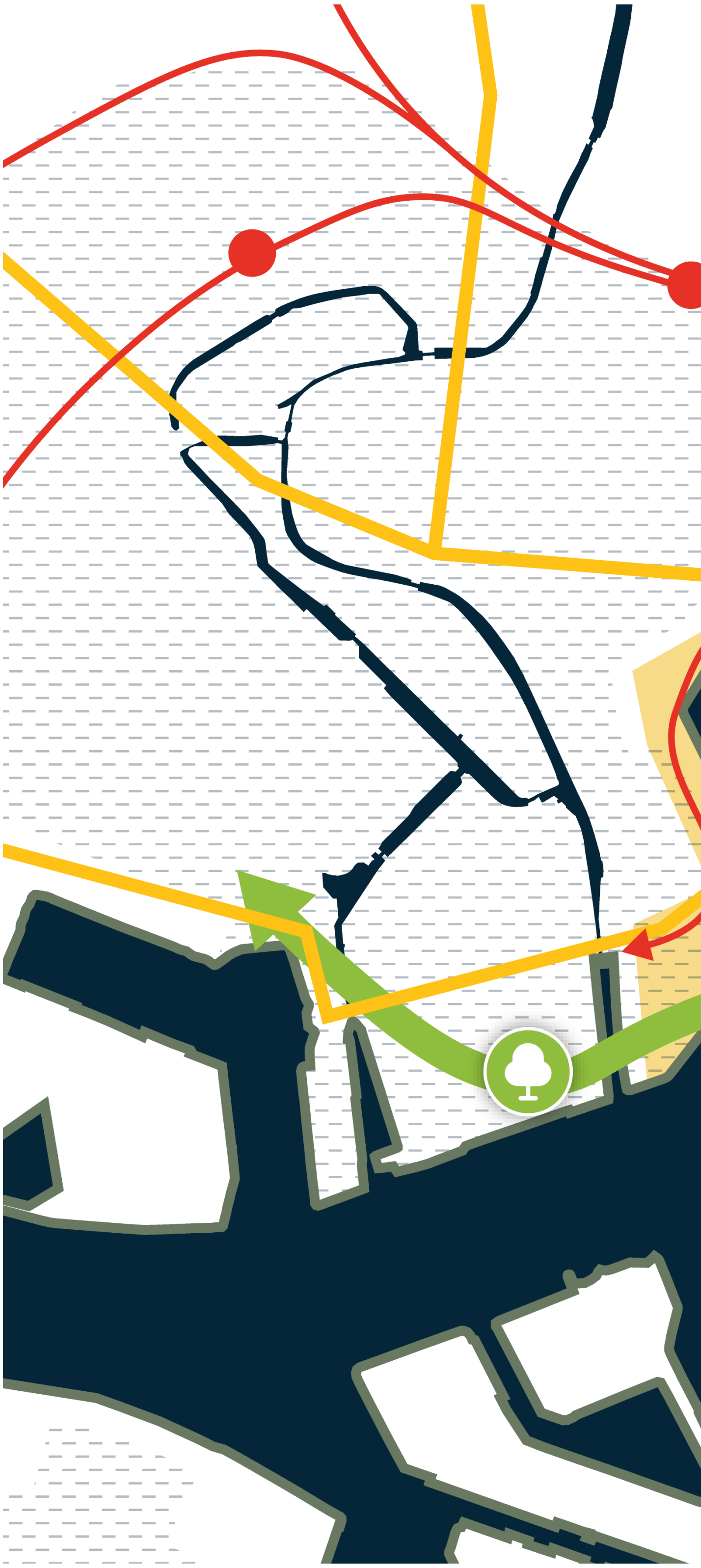
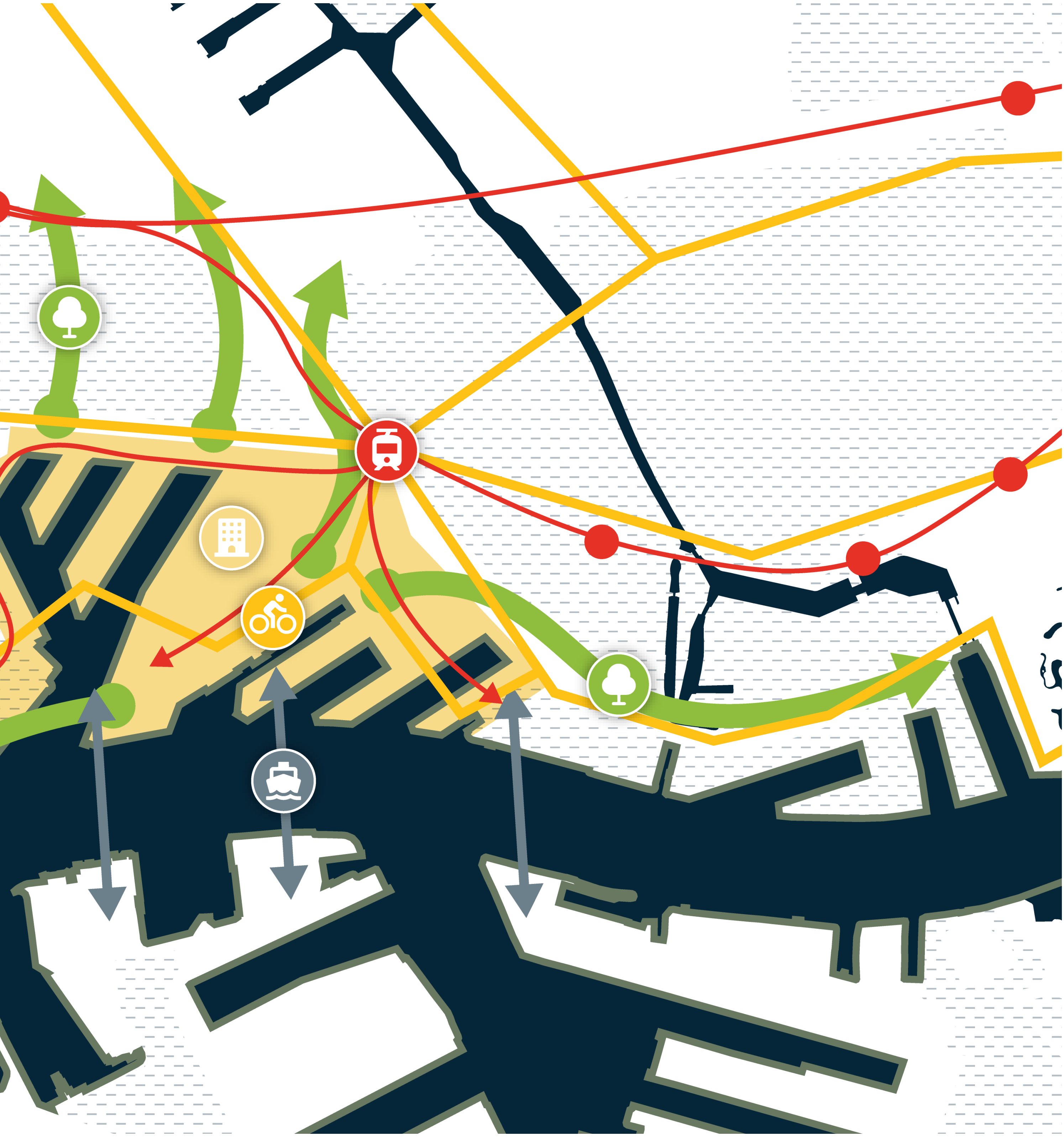


Figure 6.10 | Key elements city scale



6.4 Strategic spatial framework

6.4.3 Key elements (local scale)

The redevelopment of M4H, shown in figure 6.11 could be divided into five key elements, guiding the transformation. Those elements are interrelated to each other, creating a coherent story in implementing sustainable mobility, development, and environment.

The five key elements are:
- the main road
- the local roads
- the green network
- the water network
- the buildings

The different key elements will be highlighted in the next paragraphs, where each concept is further explained.

LEGEND

- Entrance hub
- Sharing hub
- Central activity
- Slow road
- Local public
- Tram line
- Metro stop
- Waterbus line
- Monument
- Iconic buildings
- Build up area
- Water
- Greenery
- Active waterfront

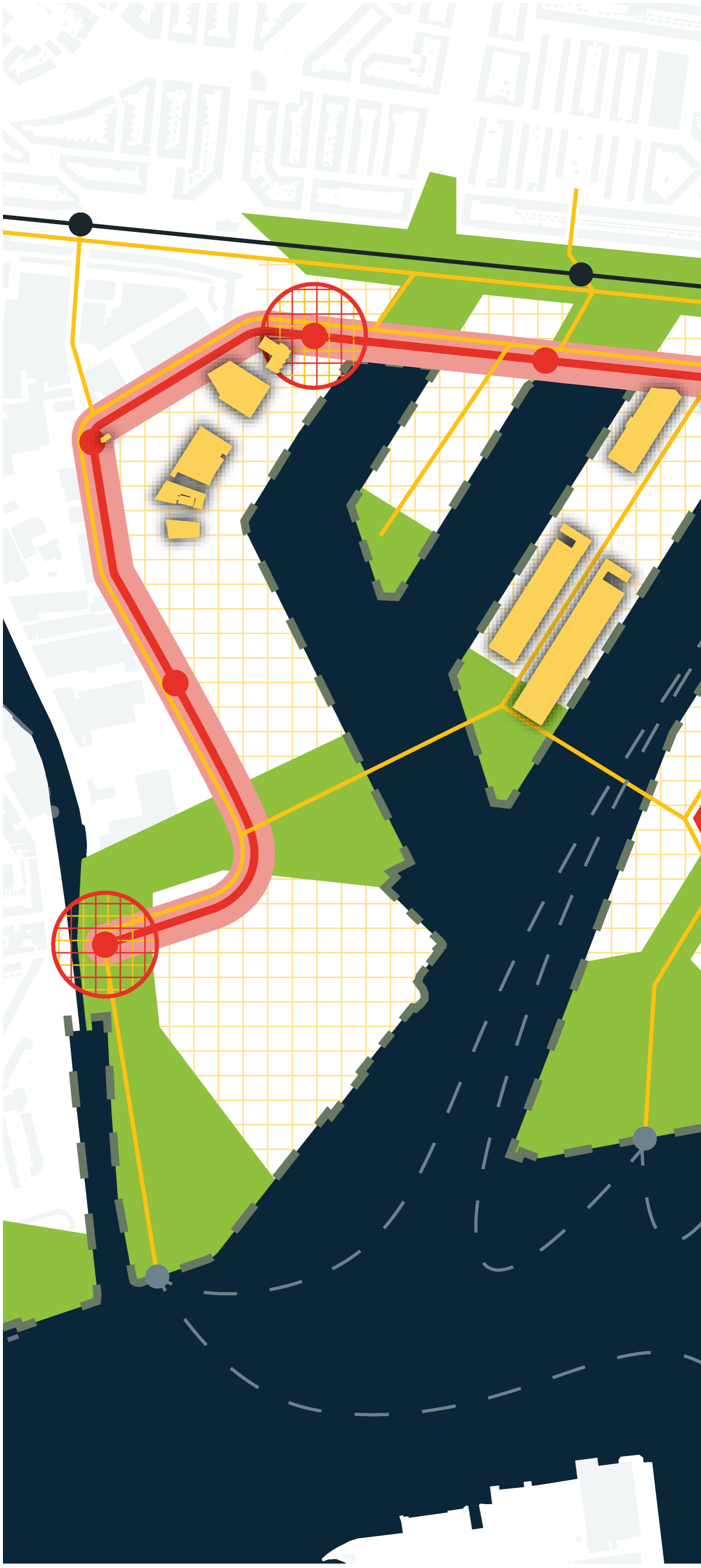


Figure 6.11 | Key elements local scale

6.4 Strategic spatial framework

6.4.3.1 Key elements: Main road

The first key element in the spatial transition of the M4H is the main road. This road acts as the connecter of the area in different ways.

The main road connects the M4H to the rest of the city of Rotterdam through four entrance points. These entrances are, from east to west, located near the IJsselhaven, Marconiplein, Merwehaven-East, and Schiedam. These locations are the main points where people enter the M4H. An entrance is designed as a mobility hub, where the transition can be made between sustainable mobility usage in the M4H and 'normal' mobility outside the M4H. An entrance hub consists of the following parts. It connects to public transport to facilitate mobility on a large scale. It facilitates parking spaces for car-sharing possibilities, together with electric charging points. Entrance hubs are well connected to the slow mobility network and accommodate a higher building density.

The main road also connects M4H on a local scale, as it creates a vein of activity through the whole area. It connects the seven ports, as well as the public spaces/parks and characteristic buildings. The main road facilitates a mixed-use of functions, such as commercial, retail, workspaces, and residential. In this way, a vibrant, active street is created. In the section of the street (figure 6.12) large spaces for pedestrians and cyclists are shown, as well as greenery in the form of trees. Besides that, space is reserved for a local transport system, consisting of automated vehicles. This transport system operates on the main road, connecting to the different entrance hubs. This cancels the need for private cars and creates the possibility to travel to your destination as close as possible by public transport. The stops of this transportation line are executed as sharing hubs for the local community. A local sharing hub consists of a public transport stop and bicycle parking and charging, creating public meeting places.

Figure 6.12 | Sections main road

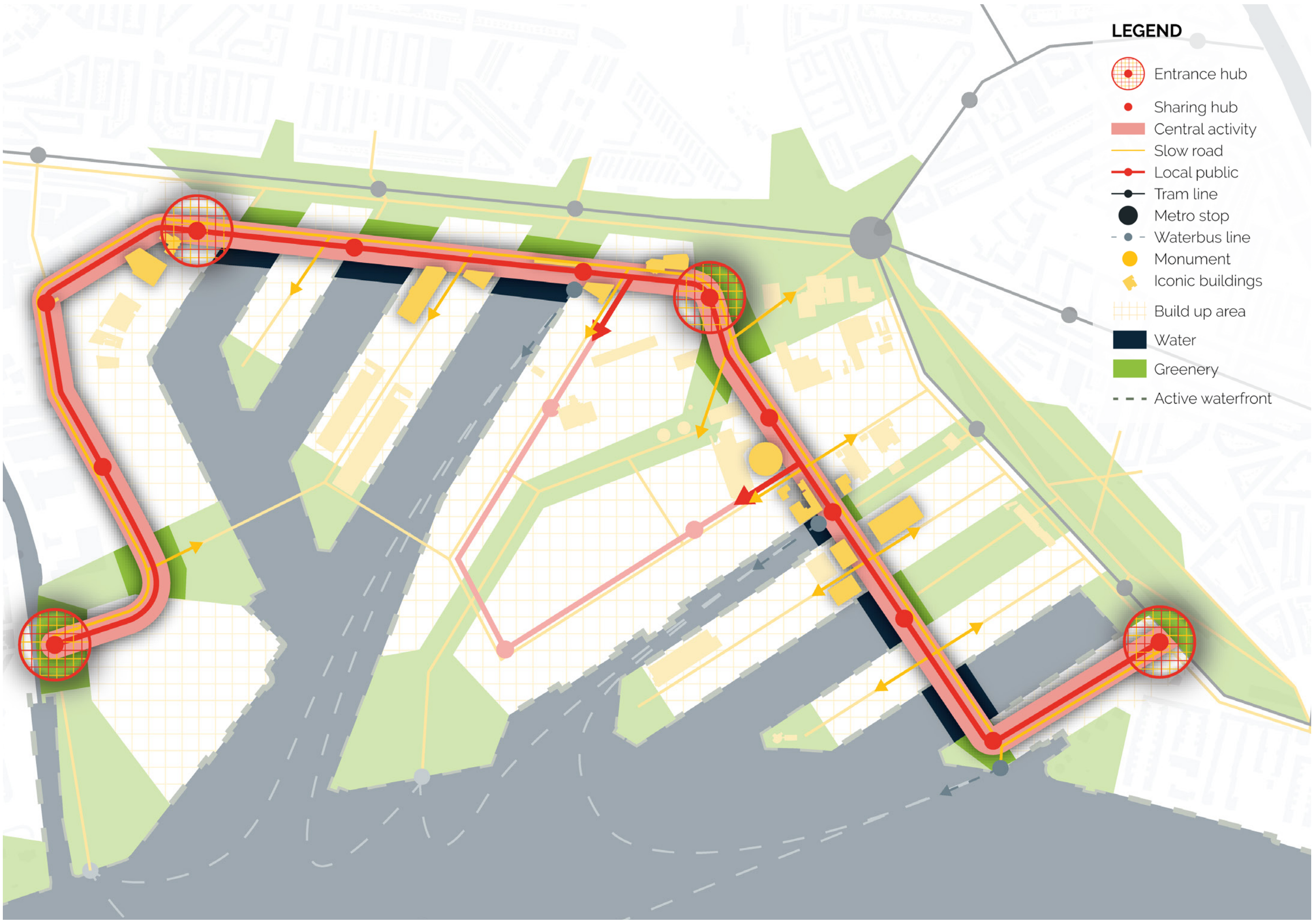


Figure 6.13 | Key element main road

6.4.3.2 Key elements: Local streets

The second key element in the spatial transition of the M4H is the network of local roads. These roads are soft, green roads designed to get local traffic to their destination.

The local streets run parallel to the ports, providing access to development on the peninsulas. Access is granted by a connection to the main road, which runs perpendicular to the local roads. Where development on the main road focuses on generating activity, the local roads are quieter and lay-back. This reflects in the functions, as most of the peninsulas are designed for residential purposes, creating a pleasant living environment. The local roads are designed for slow traffic. In the section (figure 6.14) the central cycling road is shown. This road is designed as a so-called 'fietsstraat' or 'auto te gast' (car as a guest) street. In this concept other traffic gives priority to the cyclists, creating a pleasant cycle atmosphere. However, the road is wide enough to allow other vehicles. This provides the possibility for delivery, service, and emergency vehicles to access the location when needed.

The local streets are executed as green streets to create an environmentally friendly atmosphere. The absence of cars in the street scenery provides more space for the implementation of greenery. These green areas have a positive environmental effect as fewer pavement increases permeability. Trees and bushes contribute to increasing biodiversity and lowering the urban temperature. The local streets are green connectors as they are connected to park areas on both sides. This provides the opportunity for residents to have easy access to nature, to escape the urban landscape.

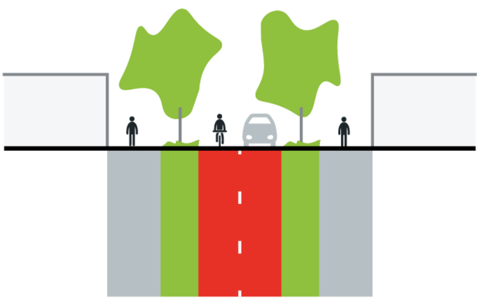


Figure 6.14 | Section local street

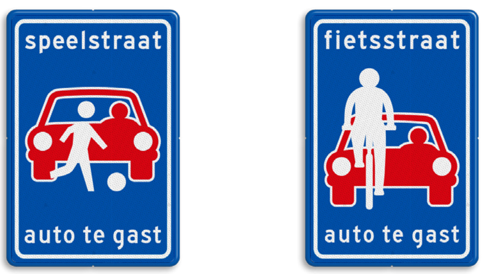


Figure 6.15 | Title *(Source, 2020)*

Figure 6.16 | Key element local streets

6.4.3.3 Key elements: Green network

The third key element in the spatial transition of the M4H is the green network. This network transforms the industrial area into a sustainable green environment.

The green network introduces nature, in the form of parks and routes, into the M4H. This green network consists of two elements. At first, there are the parks that connect the greenery on the borders of the north/eastern side of the area to the water. The ports of the Merwehaven and the Vierhavens are extended by public parks, to support a continuous flow of nature into the city. These parks connect to the surrounding neighborhoods, providing access to the M4H. In these parks, mobility stands central, as they connect inside and outside transportation.

The second type of park is the 'koppark', situated on the heads of the peninsulas. These areas are contractionary to the other type, less central, and more secluded. These parks focus on escaping the urban environment and are primarily accessible for the local inhabitants. An exception to this is the park located on the head furthest in the Merwehaven. This park acts as a connecter to both pedestrian bridges connect in this area. The largest koppark is located in between the Merwehavens and the Vierhavens. This park is connected to the Marconiplein park by a green connecter. This route leads through the main area, connecting Marconiplein to the waterbus stop at the park. In this way, the green network follows the strategy of the two networks as it intersects the fast and slow lane.

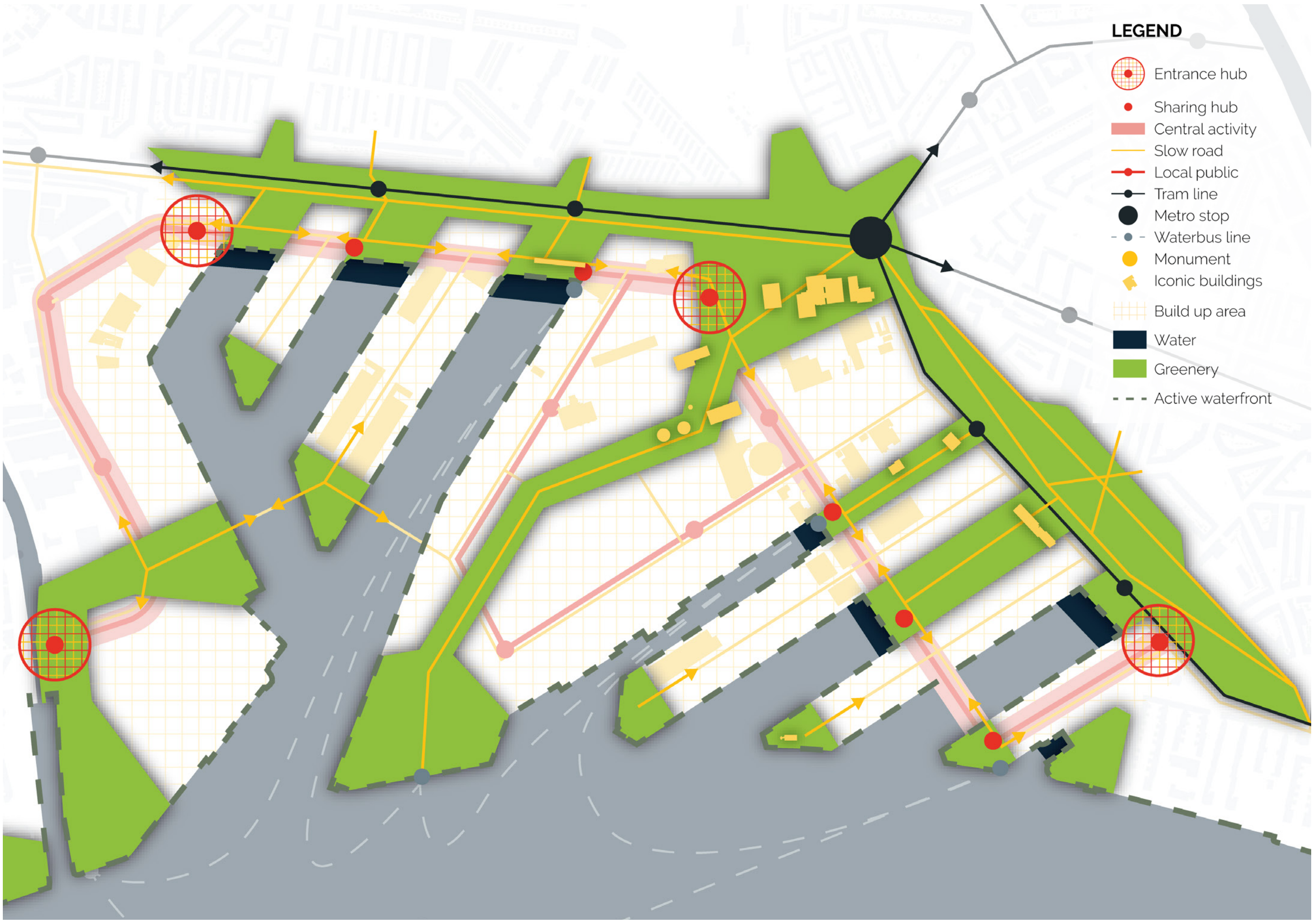


Figure 6.17 | Key element green network

6.4.3.4 Key elements: Water network

The fourth key element in the spatial transition of the M4H is the water network. This network integrates the characteristic ports as an active element.

The water network consists of the two port areas, the Merwehavens and the Vierhavens. These ports reach into the area, cutting out land and creating several peninsulas. The water provides a lot of open space, which is currently hard and industrialized. The water network creates both segregation and connections

The water network can be used as a connecter as it provides the opportunity for an extension of the public transport network on water. The waterbus network is extended with new stops in the Merwehaven, the koppark, and near the Ferro Dome. This connects the M4H over water to Rotterdam South and Rotterdam Center. The water also connects to the park areas, which act as an extension of nature into the city. Redevelopment of the quays activates the area by providing accessibility to the waterfronts. The waterfronts are focused on recreation for slow mobility and urban development. The quays incorporate the local scale through street furniture, greenery, and elevation changes.

Besides connection, the water network also segregates areas. Several bridges are constructed to connect the areas and increase accessibility. A bridge over the IJsselhaven extends the main road and connects it to the western entrance hub. The Merwehaven is bridged by a pedestrian bridge to shorten travel time between these areas. However, several obvious connections are not made. In these places, the absence of bridges is desired to create secluded quiet areas. Examples of this are in the Merwehaven east and on the Keilehaven and Lekhaven.

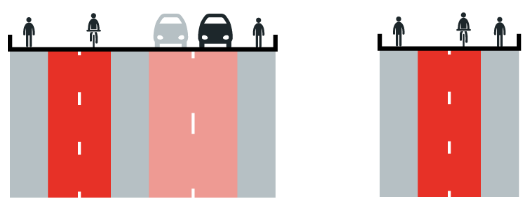


Figure 6.18 | Section bridges

Figure 6.19 | Key element water network

6.4 Strategic spatial framework

6.4.3.5 Key elements: Buildings

The fifth key element in the spatial transition of the M4H is the buildings. The layer of the buildings could be split into two parts: buildings that remain and new development. Both are further explained in the next sections.

Several buildings important to the M4H remain in the redevelopment. First, there are the buildings which are listed as a monument by the municipality of Rotterdam. These buildings are protected as they are designed by famous architects, have historic meaning, or are characteristic of the area. An example of a monument in M4H is the Ferre Dome, this former gasworks has an iconic appearance and is currently an event center. Other monuments are the Citrusveiling, the Katoenveem, and the Keilepand.

Besides monuments, there are also other buildings which are important to the area. These buildings are iconic in their architectural style, façade appearance, or building heights. Examples of iconic buildings are the Marconitorens, three high-rise buildings near the Marconiplein, or the chimney and silos, which were part of the energy building. Other buildings are the warehouses on the Merwehaven and buildings which house local businesses (Local people, 2021; DELVA, 2019).

Next to the monuments and iconic buildings, there is also room for new development. This development is situated on the local streets, consisting of mixed-use functions. In this redevelopment, a makers district is created, which consists of a mix between working and living, between local and non-local businesses, and between city and industry.

Figure 6.20 | Key element buildings

6.4.3.5 Key elements: Buildings

The new development is guided in such a way that it connects to the local context of the M4H. Different density zones are established to achieve the desired built environment. The distribution of the density zones is determined by several aspects. First, it relates to the ratio city/nature, as the density increases towards the northern city side and decreases towards the river. Another indicator is the relation to public transport stations. The density also increases towards transit hubs, which is why the areas surrounding the main street and towards the tram lines are denser. Figure 6.21 shows the different density zones, with the darkest yellow being the densest area and the lightest yellow having the lowest density. The density zones apply to new development, existing development may deviate from the set conditions. Figure 6.22 show how new development adjust to a warehouse in the different density zones. .

Figure 6.21 | Density zones new development

The lowest density zone, figure 6.22.1, consists of most park areas. In this area, the building of a warehouse might be unnecessary, so the building could be transformed into a park/ public space area. In the mid-low density zone, the area of the warehouse needs to be halved as the density is lower than before. The leftover area could be transformed into private or community spaces. In the mid-high density zone, extra building area is added to increase density. In the high-density zone, the building is topped up to increase the density by building height. Extra new buildings are added in the open space surrounding the warehouse.

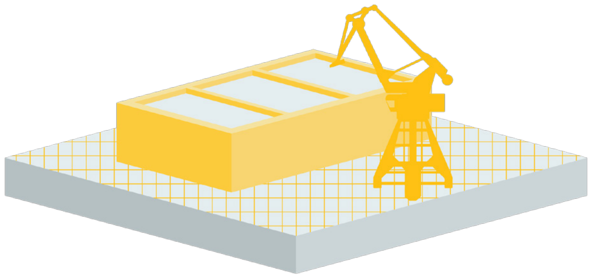


Figure 6.22.1 | Current situation

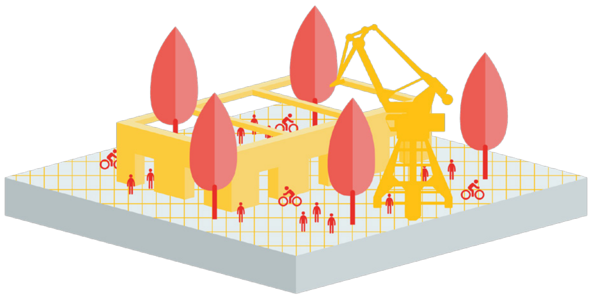


Figure 6.22.1 | Low-density zone

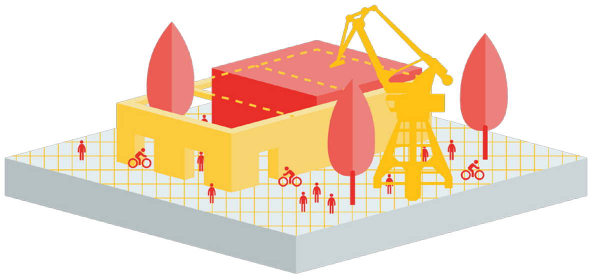


Figure 6.22.1 | Mid-low density zone

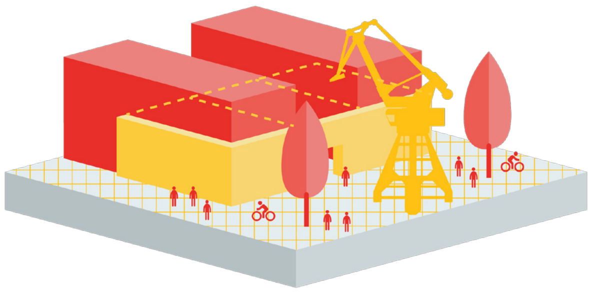


Figure 6.22.1 | Mid-high density zone

Figure 6.22.1 | High-density zone

6.4 Strategic spatial framework

6.4.3.5 Key elements: Buildings

To preserve the industrial character of the M4H in the new development several guiding principles are used, figures 6.24 to 6.32 show the different categories. Each principle highlights one important element (yellow) and shows how this is preserved within the new development (red).

The 5 categories are:
- Non-functional elements
- Plot/building blocks
- Facades
- Open space
- Functions

Non-functional elements:
An element that represents the industrial port character of the M4H is the non-functional elements. These elements were used during the industrial times but lost their function over time. Examples of this are the port cranes, chimneys, silos, or rails. These elements are easily kept and could be well integrated into the new development.

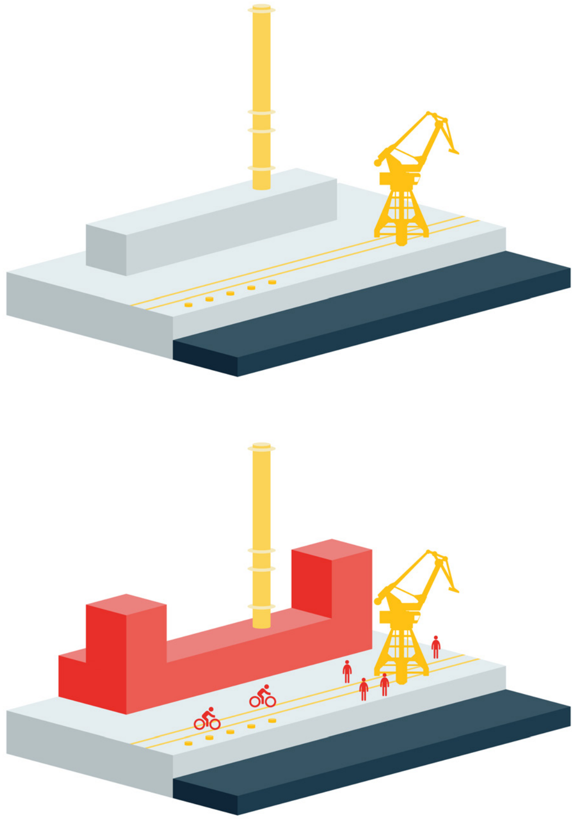


Figure 6.24 | Transformation non-functional elements

Figure 6.23 | Non-functional elements M4H

Facades:
The face of the building is an important characteristic element. Facades of the post-industrial buildings are preserved in the new development. This could be done by literally containing the façade, but the usage of the same materials or structure can also be a way to preserve the same feeling.

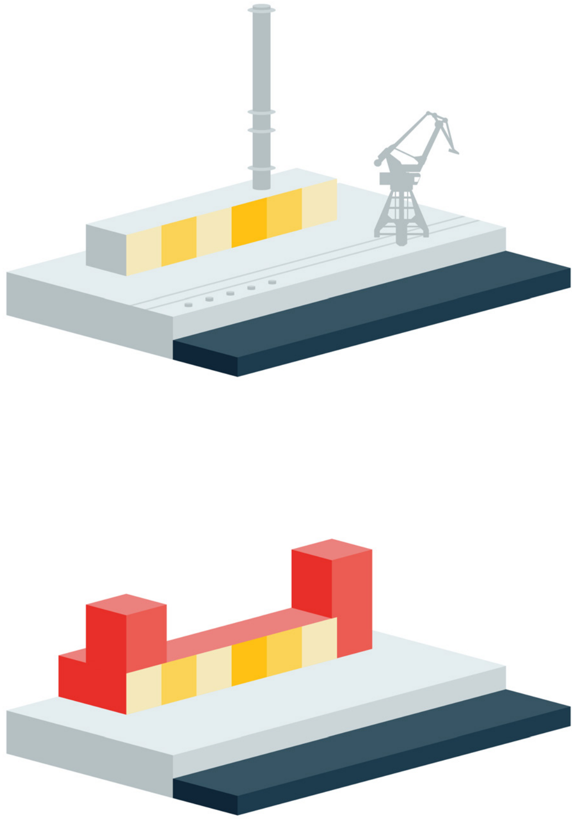


Figure 6.26 | Transformation facades

Figure 6.25 | Facades M4H

Plot size/building blocks

Characteristic to the industrial area is the plot sizes and building blocks. The large industrial blocks represent the huge scale in this area. When the new development is contained within the current plots and block sizes, it contributes to preserving the current character.

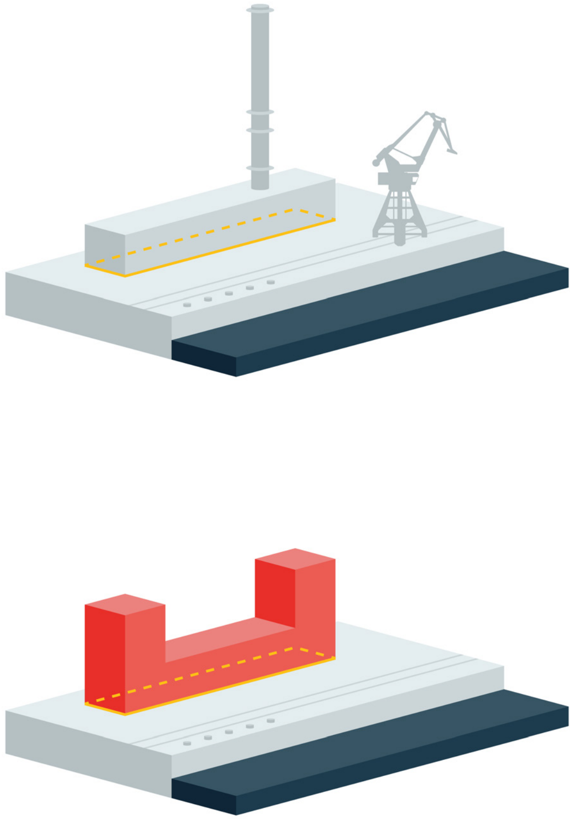


Figure 6.28 | Transformation building blocks

Figure 6.27 | Building blocks M4H

Open space:
Key to industrial areas is the amount of open space. In the M4H this is also the case, as there is a lot of open space due to the ports, large industrial sites, and infrastructure. The way open space is used can also contribute to containing the character, with the focus on the ports and active use of the open space.

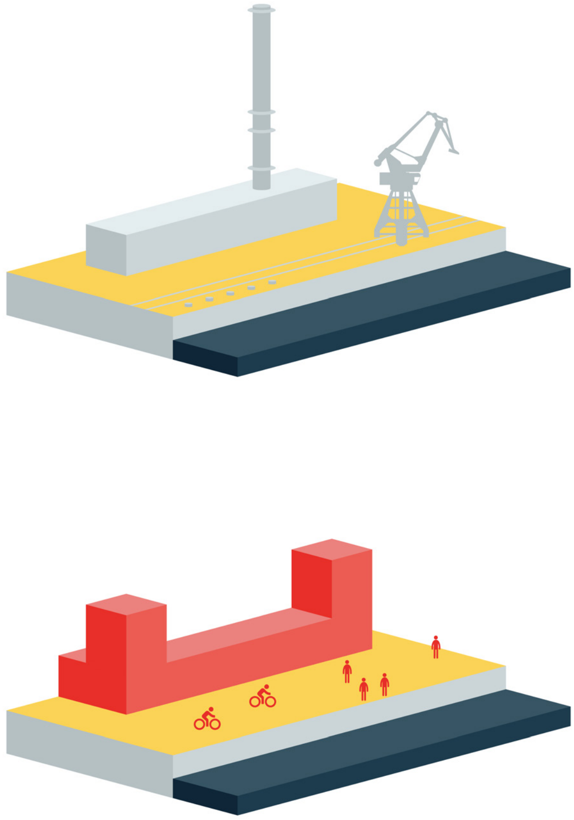


Figure 6.30 | Transformation open space

Figure 6.29 | Open space M4H

Functions:
Besides materialistic elements, the character of an area is also formed by the functions. This is why it is important to provide possibilities to contain certain functions in the area. Local businesses like shops, workspaces, and restaurants can be kept in their current building, but if necessary a replacement to another building might also be possible.

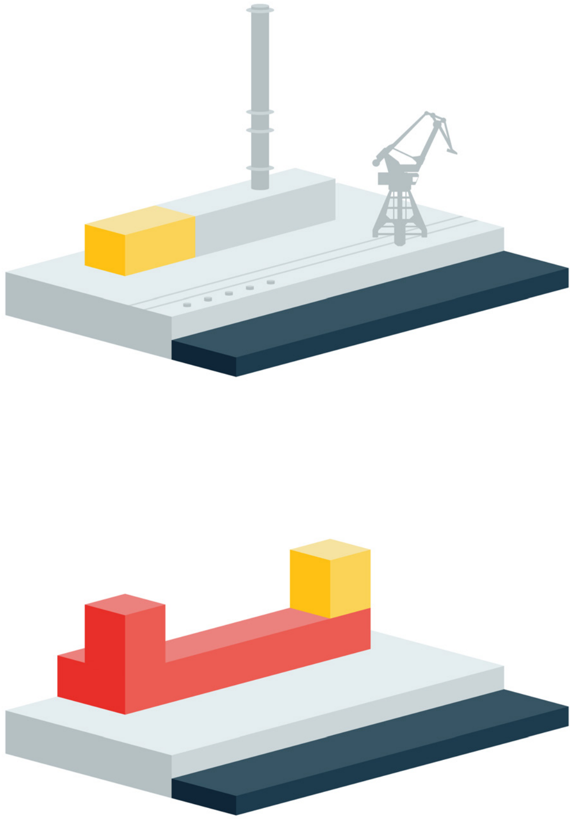


Figure 6.32 | Transformation functions

Figure 6.31 | Funcions M4H

6.4 Strategic spatial framework

6.4.4 Stakeholders

To apply the transformation to the M4H, the current situation should be taken into consideration, exploring the stakeholder situated and involved in this location. A selection of businesses located in the M4H is shown in figure 6.33. These businesses differ from large companies, like Access Rotterdam and Continental Juice, to small local entrepreneurs like De Fruitvis and Autoservice JAKI. Besides the businesses in M4H, two major stakeholders involved are the Municipality of Rotterdam and the Port of Rotterdam. The Municipality of Rotterdam is involved in the redevelopment, investigating possibilities for future transformation. One of the main goals is to densify the area and create a pleasant working/living environment. The Port of Rotterdam is involved by the port activity of the M4H, with the large companies situated in this area. As the focus of the Port of Rotterdam is shifting towards the Maasvlakte, both companies try to work together in transforming the M4H.

Crucial for the redevelopment is the engagement of the stakeholders, in adapting to the transformation. To analyze the engagement in transition, figure 6.34 clusters the businesses in 8 sections. The first three sections are related to the Port of Rotterdam. The Fruit Terminal Rotterdam, Access World, and Continental Juice form the fruit and juices district. There is little room for these companies in the future of M4H, which is why they are not engaged in the transition. With the industrial shift, these companies are slowly moving out towards the western industrial areas. Neutral in engagement in the transition are the soft industrial, retail, and car garages in the western part near Schiedam, and the non-local businesses. There is room for these companies in the future of M4H, however, some parts must move out to make place for other activities. Engaged in the transition are local businesses and mixed-use buildings. These companies already fit the future of M4H and are taken care of in the redevelopment. Space is reserved to attract and house local businesses. Parts of the M4H consist of vacant buildings, which are prime for redevelopment. However, due to the former industrial activities, these sites are polluted and need to be cleaned up before redevelopment takes place.

Port of Rotterdam

Gemeente Rotterdam

Figure 6.33 | Stakeholders M4H

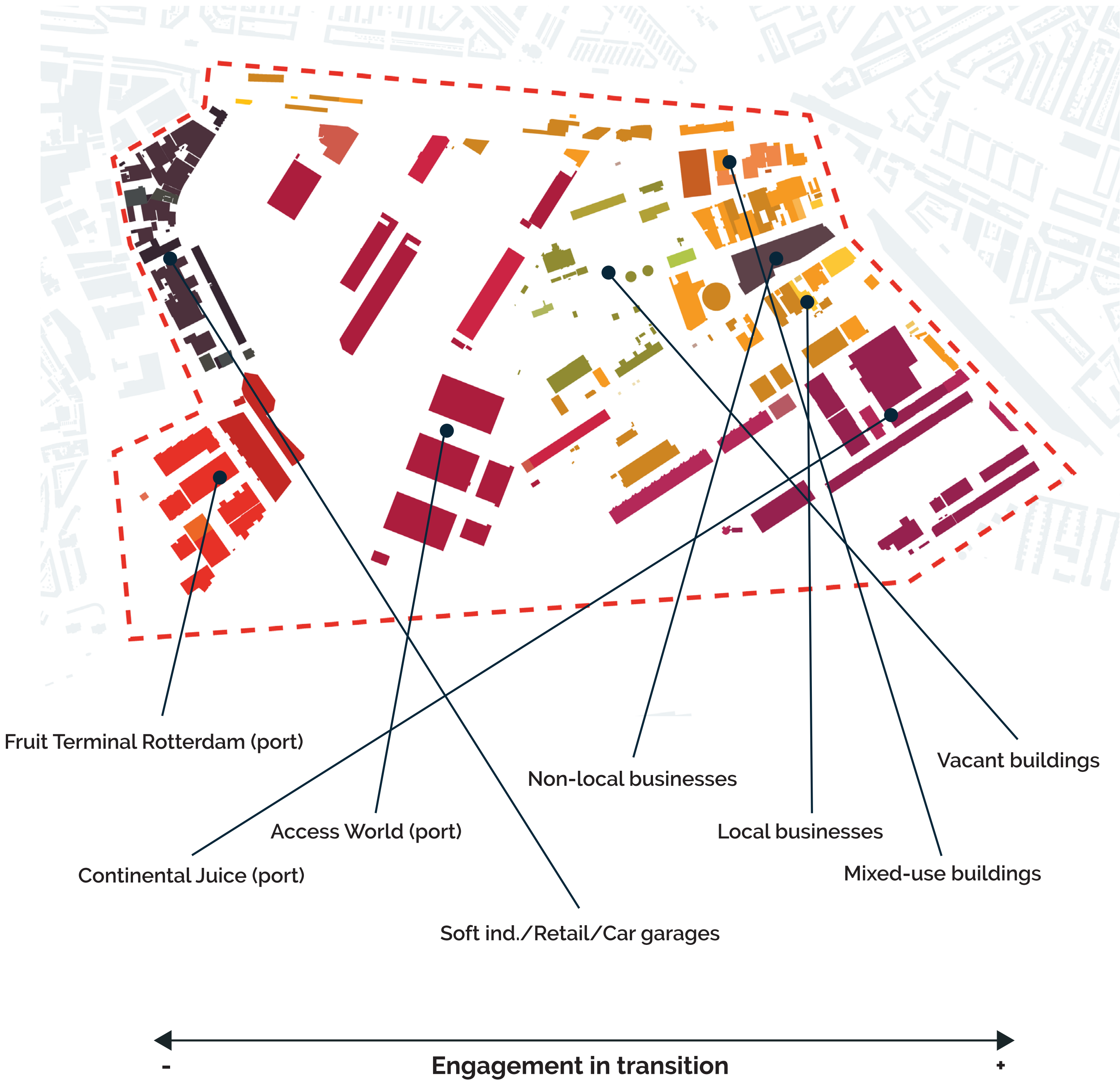


Figure 6.34 | Stakeholder engagement

6.4 Strategic spatial framework

6.4.5 Development timeline

The transition of the M4H takes place in four phases, mostly related to stakeholder engagement. Two approaches are used in the development over time (figure 6.35). The first one is a spatial approach where the redevelopment starts at the northern city side, moving in phases towards the river. In this approach, redevelopment can start before all port activity is moved out. In the second approach, redevelopment is triggered by several starting projects. These projects are key locations in the area, which stimulate further redevelopment. A combination of the two approaches is used in the case of M4H, with the following phases.

Phase one starts with the construction of the two entrance hubs near Marconiplein and the Merwehavens, as sustainable mobility is well represented in these locations. The entrance hubs provide accessibility to the area and eliminate the first car travels. The two entrance hubs are connected, and the first part of the main road is constructed. The main road extends to the Keilehaven, as this part is another key location that triggers further development in this area. The first phase focuses on connecting M4H to the outside, starting the implementation of sustainable mobility and densification near the Marconiplein.

In phase two the third entrance hub is constructed. This entrance connects the M4H to Schiedam and sets the first steps in redeveloping the western side. The constructed main road in phase one triggers further development of the Merwehavens. These peninsulas are connected to the main road and the kopparken are constructed. The first connection to the former energy part is made by constructing the networks reaching into this area.

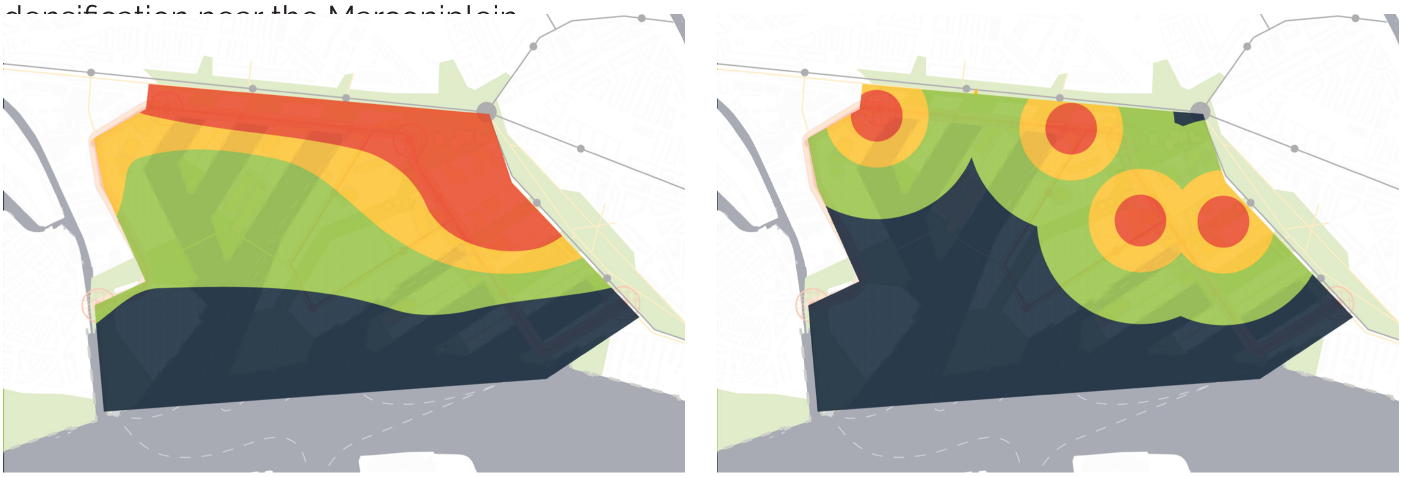


Figure 6.35 | Evolvement of development

Figure 6.36 | Development phase 1

Figure 6.37 | Development phase 2

6.4 Strategic spatial framework

6.4.5 Development timeline

In phase three the main road is completed by the construction of the fourth entrance hub near the IJsselhaven and development of the western part is started. The loop into the middle part is completed which also includes the bridges over the Merwehaven. The green route connecting Marconiplein to the tip is constructed as the pollution of the former industrial activity is cleaned up.

In phase four, the large companies of the Port of Rotterdam are completely moved out. This means the completion of the large park in between the Merwehavens and the Vierhavens. The park extension of the Lekhaven and further development in this area is started. The slow network is completed creating large accessibility for pedestrians and cyclists. The final stage shows a redeveloped M4H where sustainable mobility is the standard, creating a sustainable neighborhood connected to the rest of Rotterdam.

Figure 6.38 | Development phase 3

Figure 6.39 | Development phase 4

6.4 Strategic spatial framework

6.4.6 Design intervention 1

Several design interventions are elaborated to show how the implementation of sustainable mobility in the M4H is executed in detail. The first location is situated at the top of the third Merwehaven. This location is an example of a key location that triggers development by enhancing accessibility.

The current situation, shown in figure 6.43, lacks accessibility and connections. The lack of accessibility is represented in the design of the tram stop. This tram stop, situated between the lanes on the dike, only connects to the neighborhood at the north. A connection to the M4H is currently absent, which does not stimulate the use of public transport and enhances the dike as a barrier between the neighborhoods. The water in the area is not used and accessible for the public, while it is such a valuable element. The current buildings in the area come with fenced-off properties. This influences the accessibility, as it now blocks the route to the tram stop and the quays. The main street running through the area is wide, car-centered, and lacks greenery. The slow mobility is suppressed by the large infrastructure.

Figure 6.40 | Current situation

Figure 6.41 | Current situation

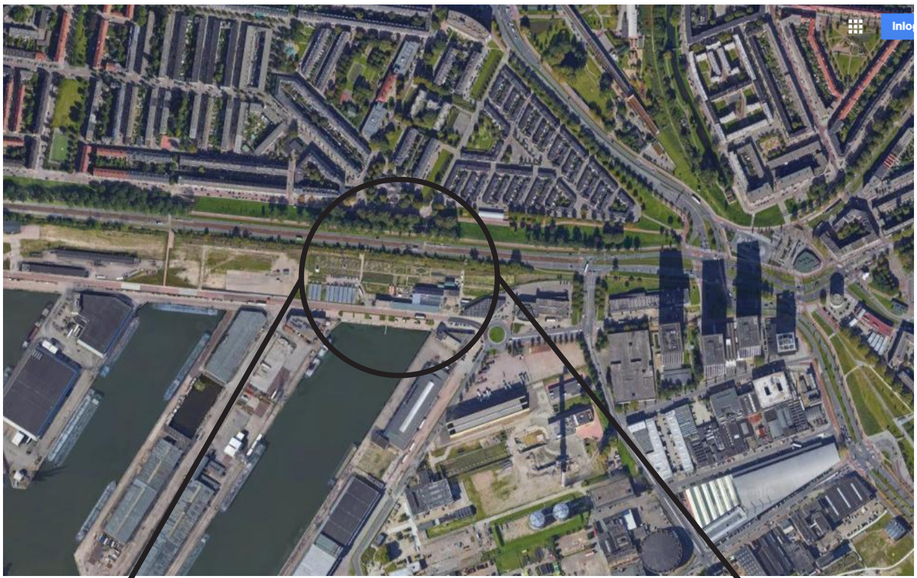


Figure 6.42 | Current situation *(Google maps, 2020)*

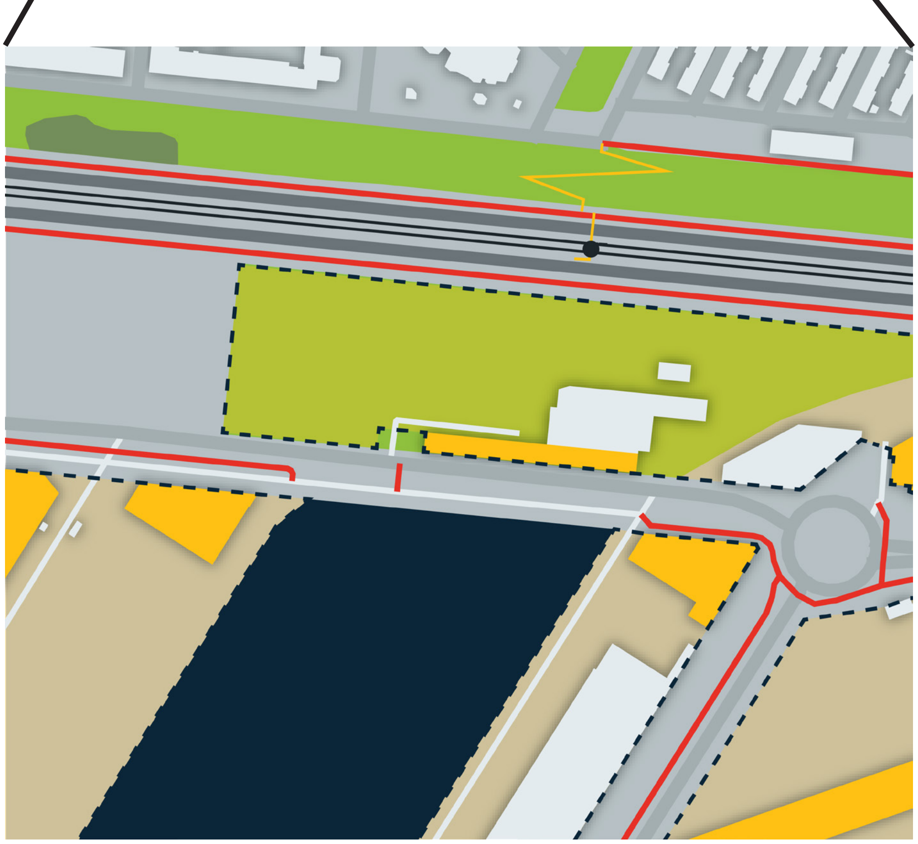


Figure 6.43 | Current situation

6.4 Strategic spatial framework

6.4.6 Design intervention 1

Two main concepts are used in the redesign of this location. The first concept is that the M4H is a transition zone between the city and nature. This is represented in the design by the extension of the port area by parks into the city, and the development at the land areas reaching into the port area. Secondly this location act as a hub in between the fast and slow lane, two concepts deriving from the strategy of the two networks by Tjallingii (2005). A mobility hub is designed at the intersection of the two lanes. The slow lane consists of the water, park, and slow network, leading in the north-south direction. The fast lane consists of the public transport lines and main streets leading in an east western direction. The mobility hub acts as a connecter.

The transformation of this location is happening in one of the early stages of redevelopment. A mobility hub connects all the elements but also connects the M4H to the outside area. The design consists of different layers, which will be explained in the next paragraphs.

The design of this location is supported by the principles of the pattern box (figure 6.45). Following principles are actively used in this design. In the design different mobility lines come together, creating a transfer hub (PT1). This connection between the different modes increases accessibility for slow traffic. Although the different lines do not directly come together in one station, the area is designed in a way to support a fast transfer. The new public transport network is designed with a clear hierarchy (PT2). The tramline has its main function in connecting the neighborhood to other neighborhoods and is therefore situated at the edge of the location. The local transportation line is situated on the main street, as it acts as a local connecter. With the tram stop elevated on the dike and the layout of the park, visibility of this station (PT4) is ensured. This increases accessibility and use by pedestrians and cyclists. Besides the park, pedestrian routes next to the port create an interesting walking context (SM4). The sharing hub is located next to the public park, which is a central location for this area (SN4). This enhances use and reachability for its users.

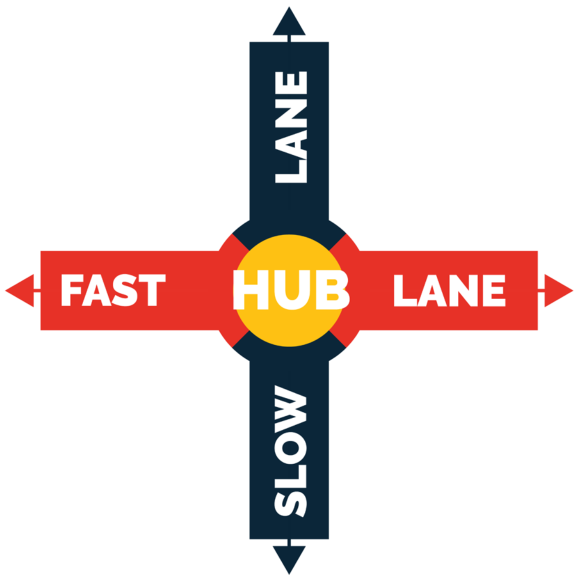


Figure 6.44 | Concepts transformation

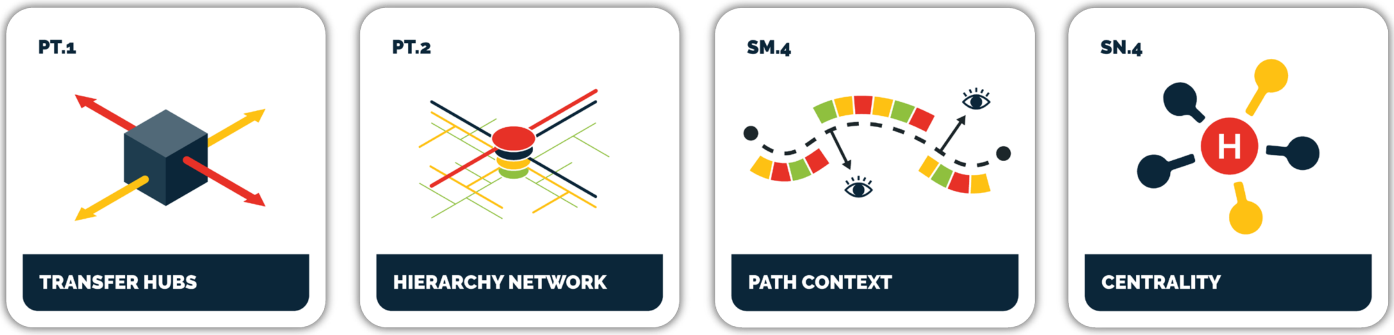
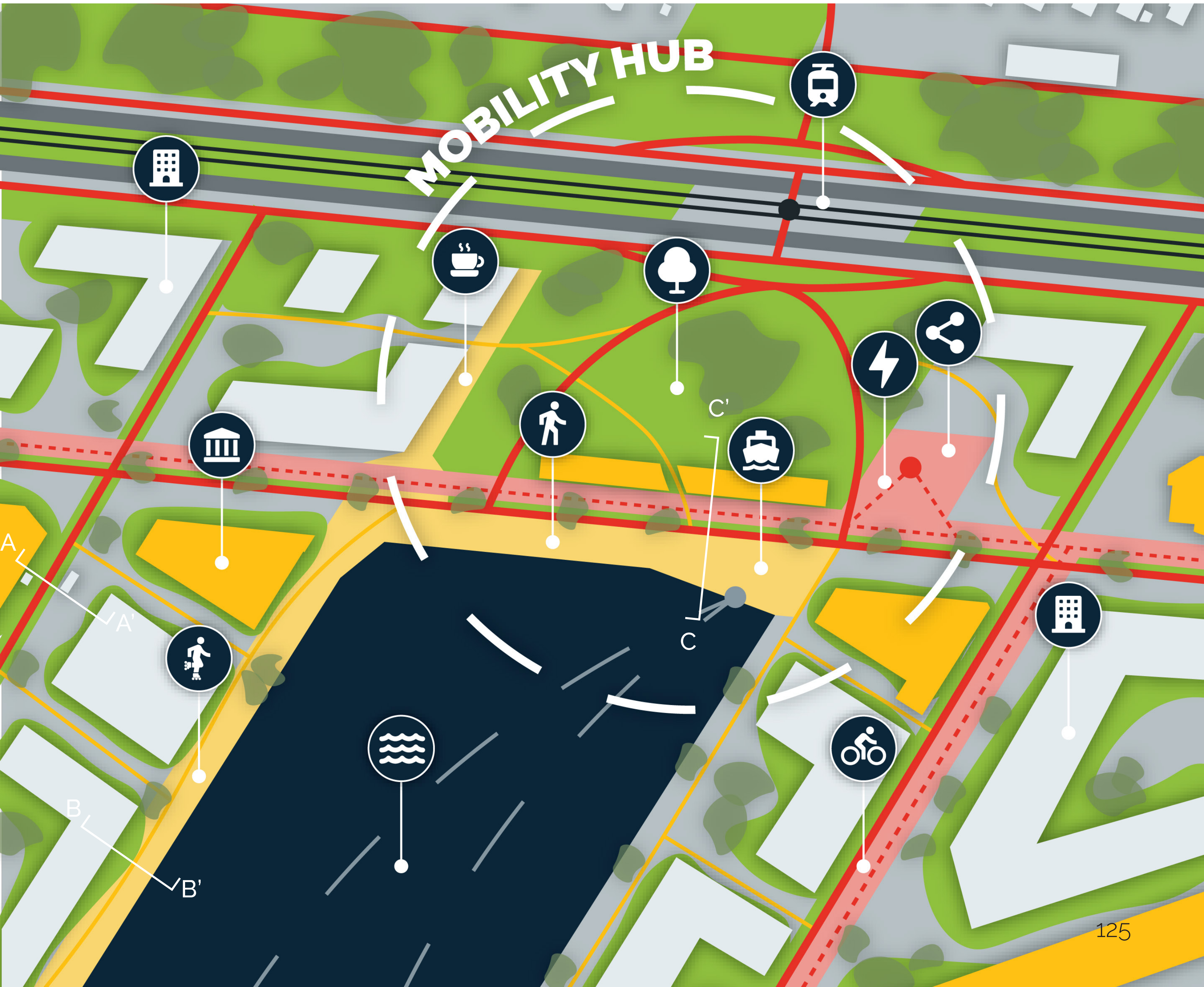


Figure 6.45 | Used pattern cards

Figure 6.46 | Transformation location



6.4.6 Design intervention 1

The first layer important in this design intervention is the layer of public transport (figure 6.47). As this intervention is designed as a mobility hub, different transportation modes come together. On the border of M4H, a tramline is situated. This tramline says the same, however, in the new situation it connects to both sides. The tramline connects the M4H to metro station Marconiplein in the east and train station Schiedam Centrum in the west. The area is also connected on a larger scale by waterbus. The waterbus network is extended into the Merwehaven and connects the site to other parts of M4H, Heijplaat-RDM at the other side of the river, and Rotterdam center. The third type of public transport involved in this mobility hub is the local transportation line consisting of automated vehicles. This line connects on the scale of M4H and provides the opportunity to travel to other parts of the district. This transportation line stops at the sharing hub, where sharing is supported amongst electric bicycles and scooters.

To connect the stops of the different modes of transportation, a dense slow mobility network is constructed. This network consists of cycle paths and pedestrian paths. The slow mobility network connects the tram stop to the waterbus through the park. The cycling network acts on all different scales, as the lanes on the dike connect to the larger scale of cycling in Rotterdam. The cycle paths running in the north-south direction are local streets to provide accessibility to the developed buildings. The quays of the port are upgrades to active waterfronts to provide access to the water. These pedestrianized areas connect to the heads of the peninsulas, where a wide view of the river is granted. The main road leading through the area is also supported by slow lanes to make sure pedestrians and cyclists can travel efficiently in the M4H.

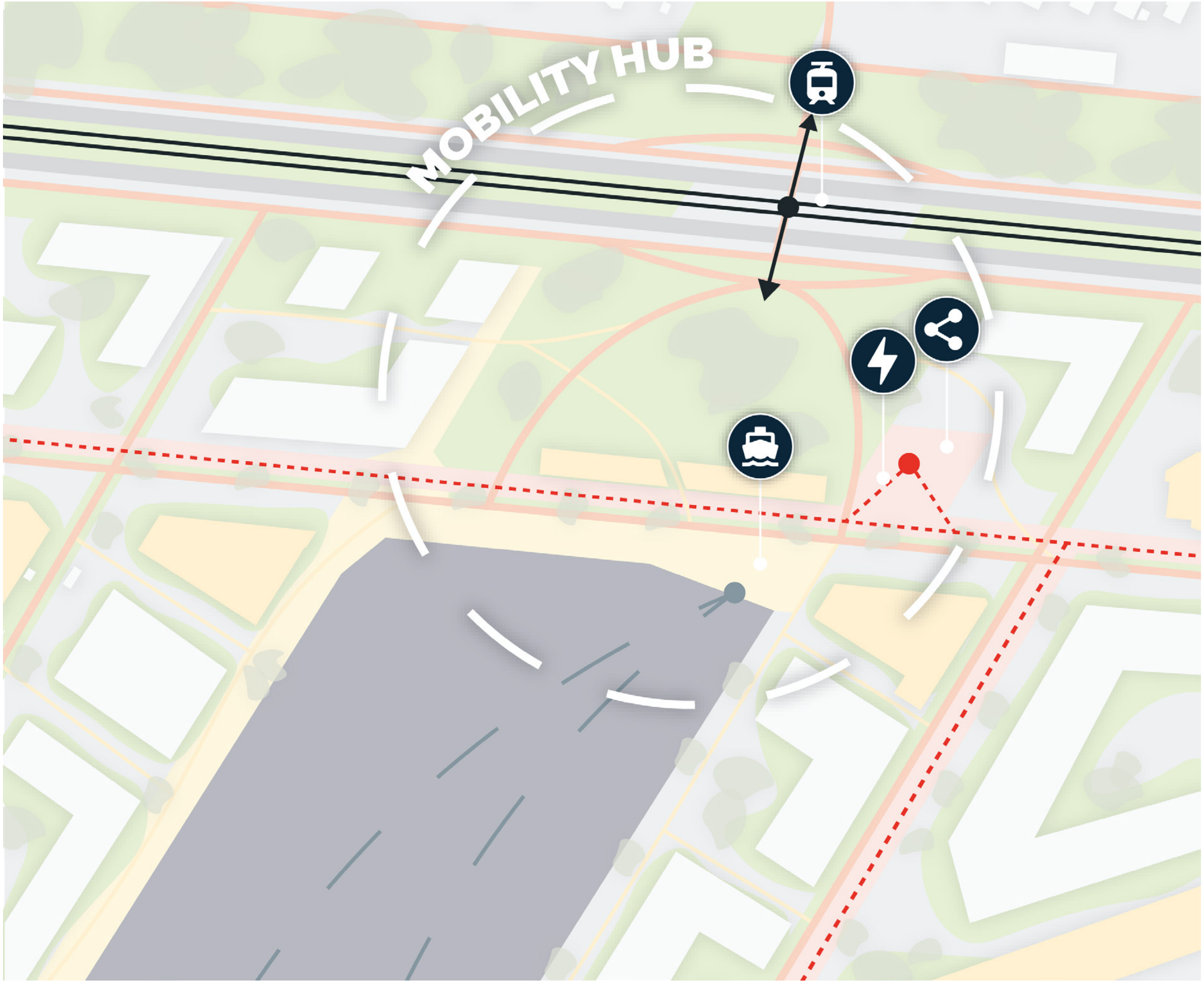


Figure 6.47 | Public transport

Figure 6.48 | Slow network

6.4 Strategic spatial framework

6.4.6 Design intervention 1

Besides networks, the area is densified by the development of new buildings (figure 6.49). The development is focused on the natural areas of the port and park. Accessibility to the buildings is granted by the local streets running behind the buildings. Buildings that are valuable for the current character of the M4H are preserved and kept in the redevelopment process. The development contains a variety of functions and building heights. The buildings near the mobility hub contain a mixed-use function (grey) and are more high-rise. Along the main street commercial functions are situated to generate activity, with cafes and restaurants surrounding the park area. The development along the peninsulas is further from the mobility hub, which relates to the mid-low-density zone, consisting mainly of residential areas.

One of the major changes is the network of green and blue (figure 6.50). Whereas in the current situation there is hardly any greenery in this part of the M4H, the new situation shows a dense green network. This network consists of a park area which is an extension of the port area over land. This public park is the center of the mobility hub and is one of the main public spaces for development in this area. The park extends over the dike, connecting to the green structures in the adjacent neighborhood. The local streets are network connections as they house trees, bushes, and grass. The main road is executed with a large row of trees to represent its status as the main street by giving it a clear repeated structure for the whole M4H.

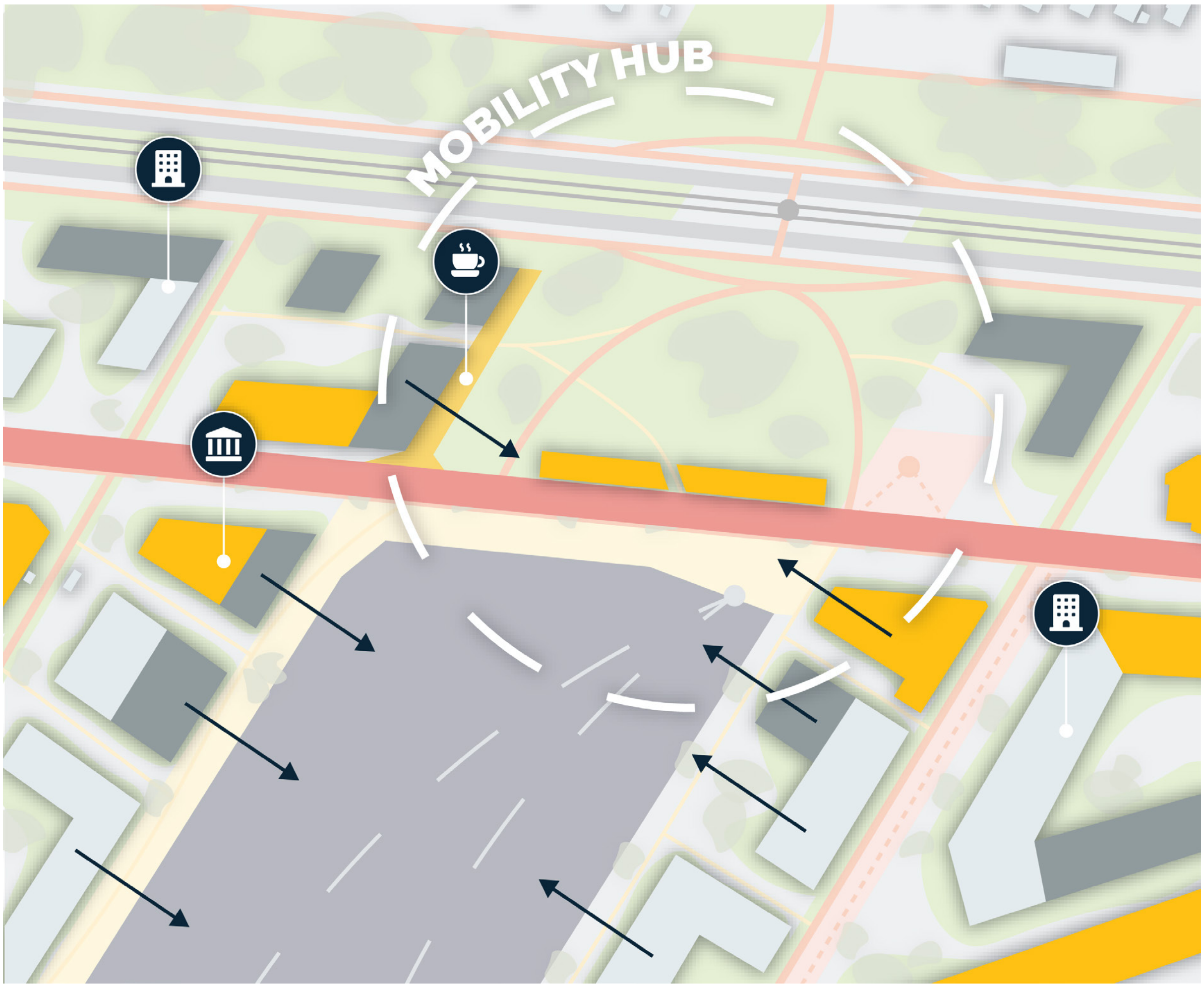


Figure 6.49 | Development

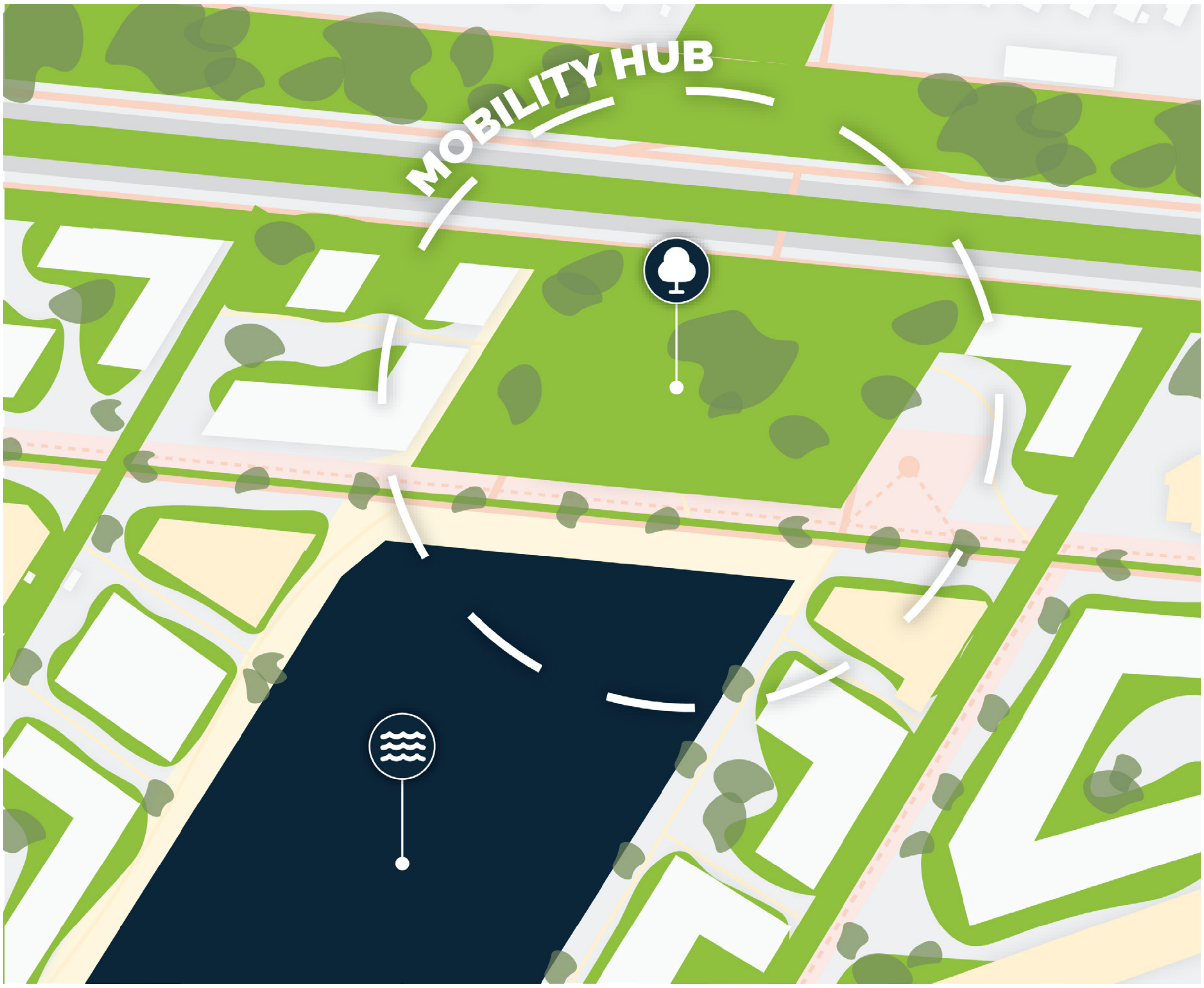


Figure 6.50 | Greenblue network

6.4 Strategic spatial framework

6.4.6 Design intervention 1

The map in figure 6.51 shows different routes people use while traveling through the mobility hub in this part of the M4H. The yellow route shows a person living in one of the buildings going to another part of the M4H. He travels by foot to the sharing station where he picks one of the shared bicycles to be able to travel quicker and further. On the red route, a person is leaving the building and going to the city center. He chooses to travel by waterbus, as it is an efficient and scenic way to reach the city center. While walking to the waterbus, a stop is made at one of the commercial buildings to grab some drinks on their way. The green route represents someone working in M4H and escaping the urban environment for a lunch walk along the waterfront. For the pink route, the mobility hub is a destination in itself, enjoying and relaxing in the natural environment of the park. The light blue line shows how someone might live and work in the same area, easy access between both destinations is granted by the main road. The dark blue route shows someone leaving M4H by tram, the tram is easily accessible through the park. These routes are a set of examples of how people use the mobility hub in different ways.

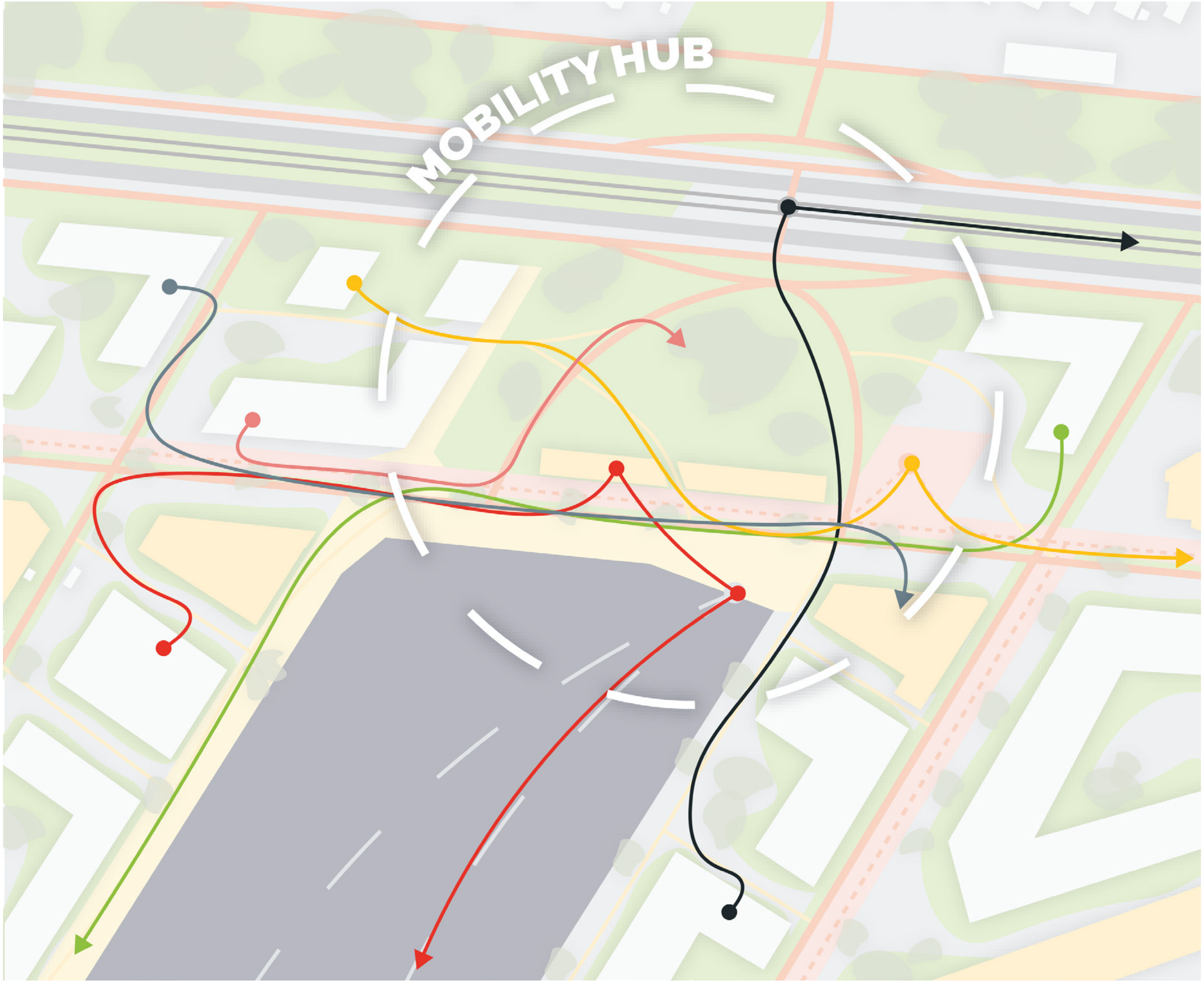


Figure 6.51 | Activity

6.4.6 Design intervention 1

Section AA' (figure 6.52) shows the local street. In this street now slow mobility has priority, which is represented by the central position of the 'fietsstraat'. Besides bicycles, this street also provides accessibility for delivery and emergency vehicles. The 'fietsstraat' is bordered by two green sections. Threes, bushes, and grass introduce nature and biodiversity back in the M4H. The redeveloped industrial buildings are connected by wide pedestrian paths. Front gardens create a transition between public and private.

Section BB' (figure 6.53) is taken at the port and shows the newly redeveloped waterfront. The quay is materialized with the same pavement as the other waterfronts in Rotterdam. In this way, the M4H connects to the rest of the city's waterfront. Level changes at the quay provide the possibility to reach the water and can be used as a place to stay. Industrial elements, like the cranes and rails, are kept in the design to preserve the character of the M4H. The waterfronts are completely pedestrianized and are a pleasant walking environment.

Section CC' (figure 6.54) is also taken at the waterfront and is more focused on mobility. The section shows the new dock for the waterbus stop. The stop is facilitated with bicycle parking and charging and a pleasant waiting area. The main road which cuts through this area connects the location to the rest of the M4H. the main road consists of a cycle path, a row of trees, and a road for the local transportation system. The section cuts through a local restaurant, which has the opportunity for outside seating at the park side. The park connects to the tram stop and is an extension of the port area.

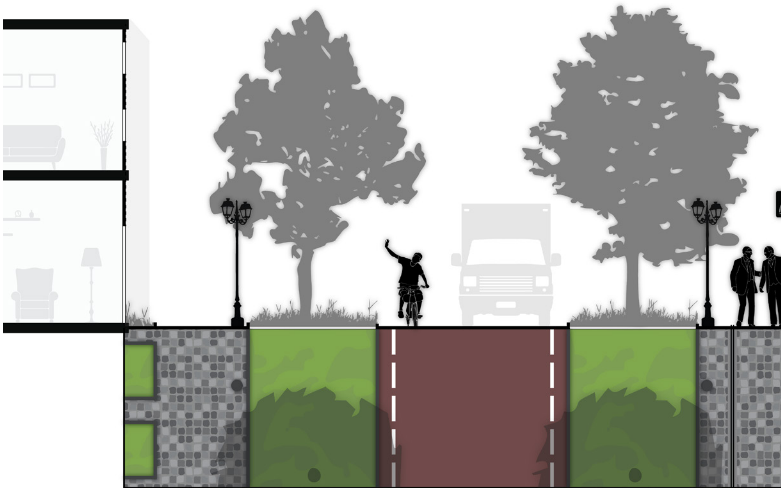


Figure 6.52 | Section AA'

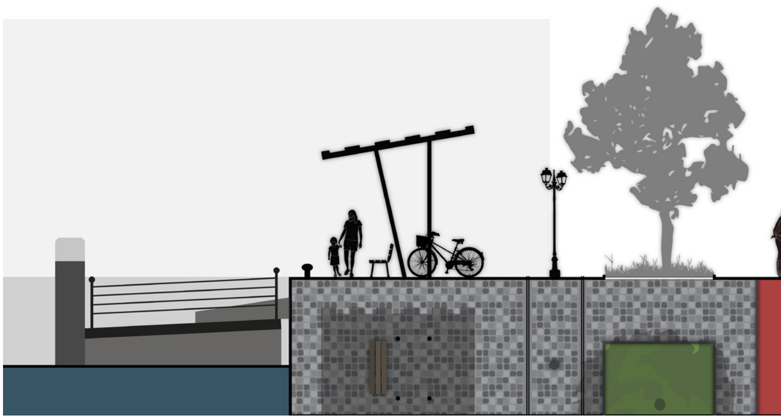


Figure 6.54 | Section CC'

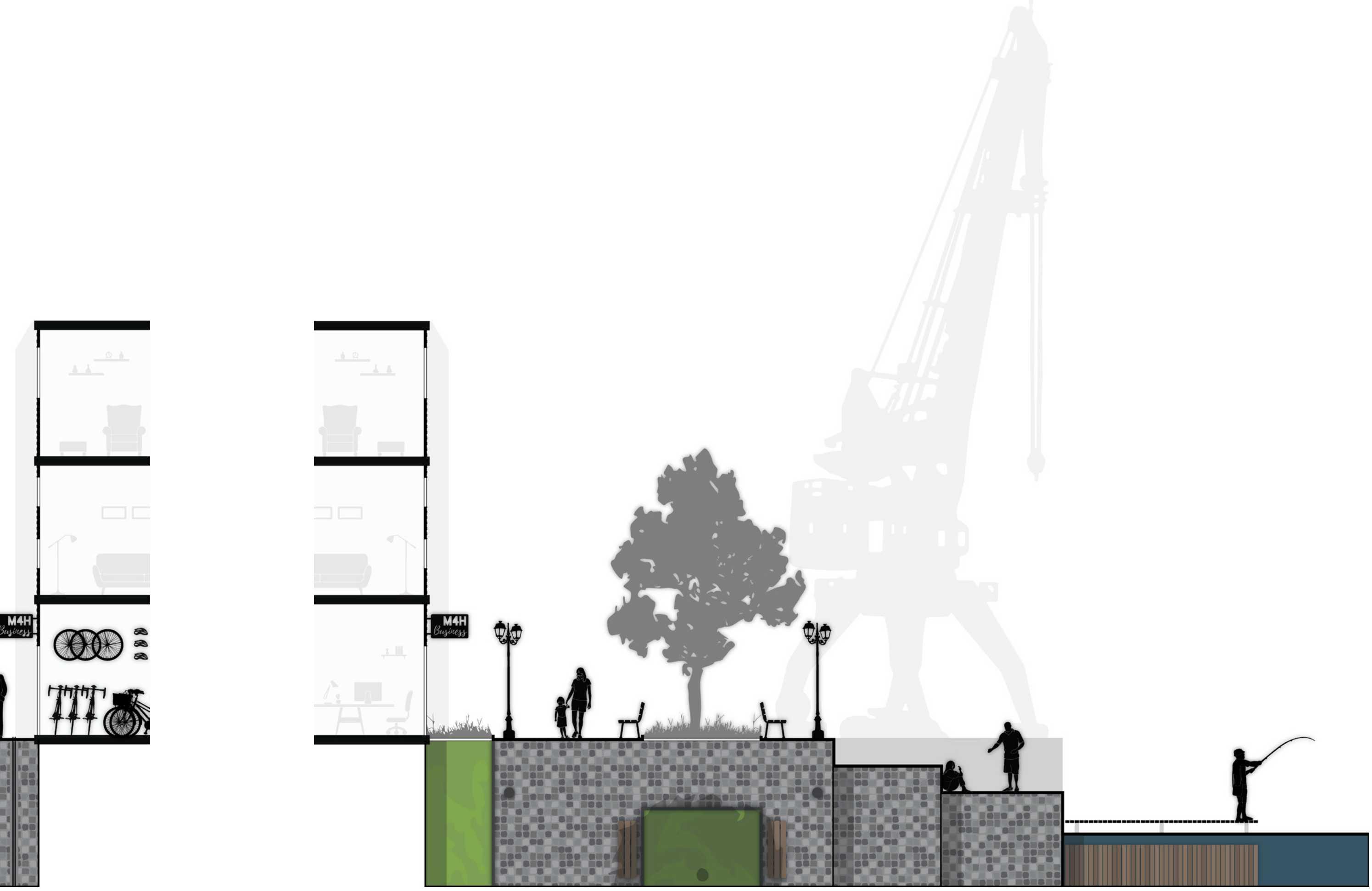
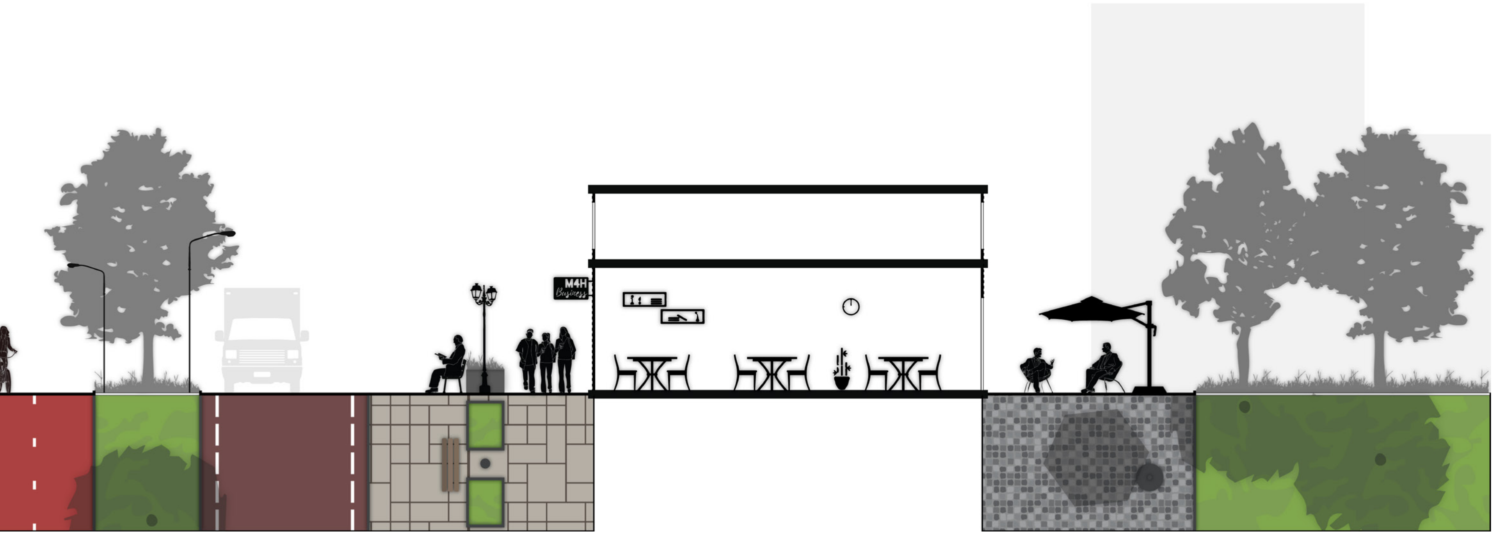
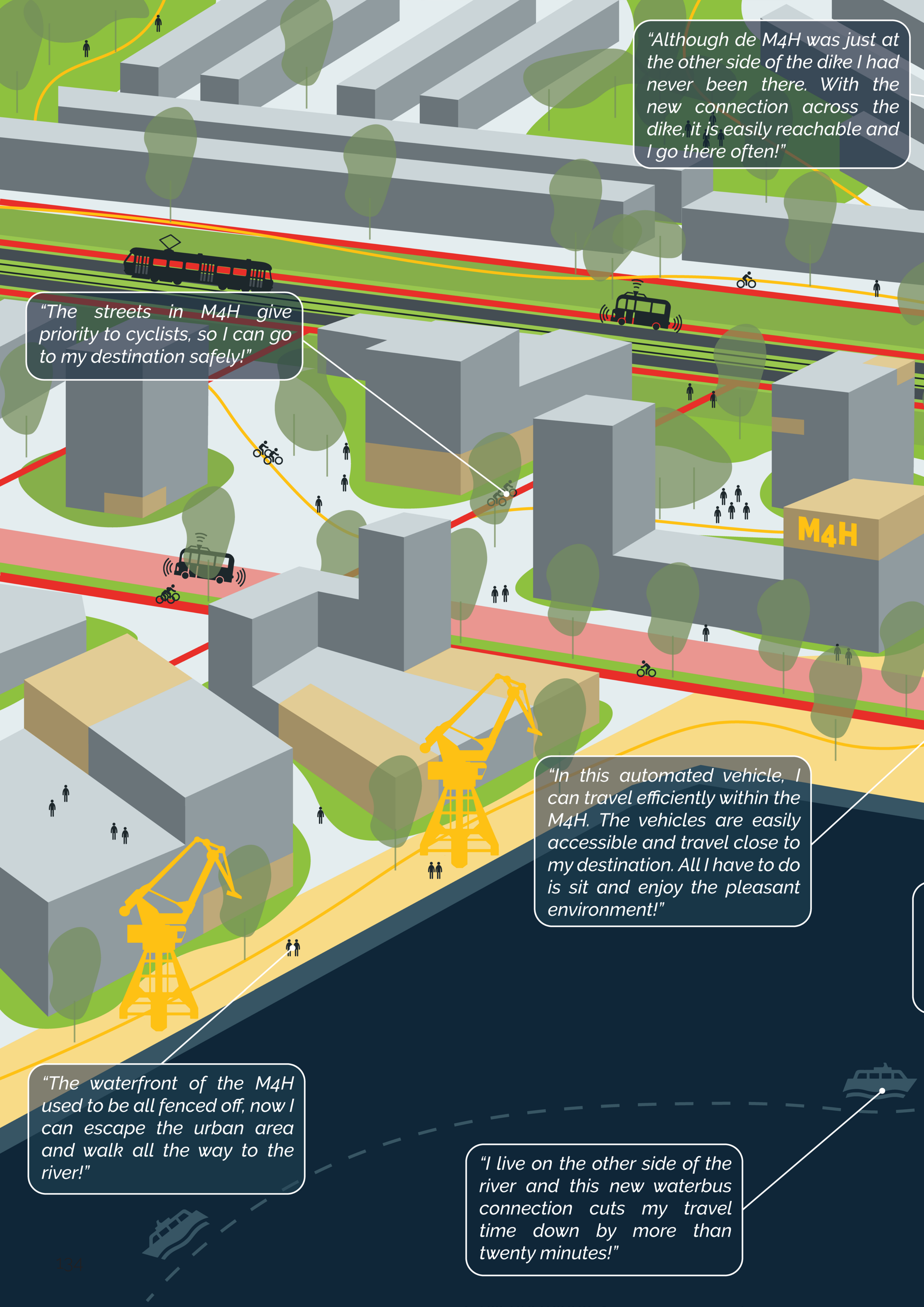
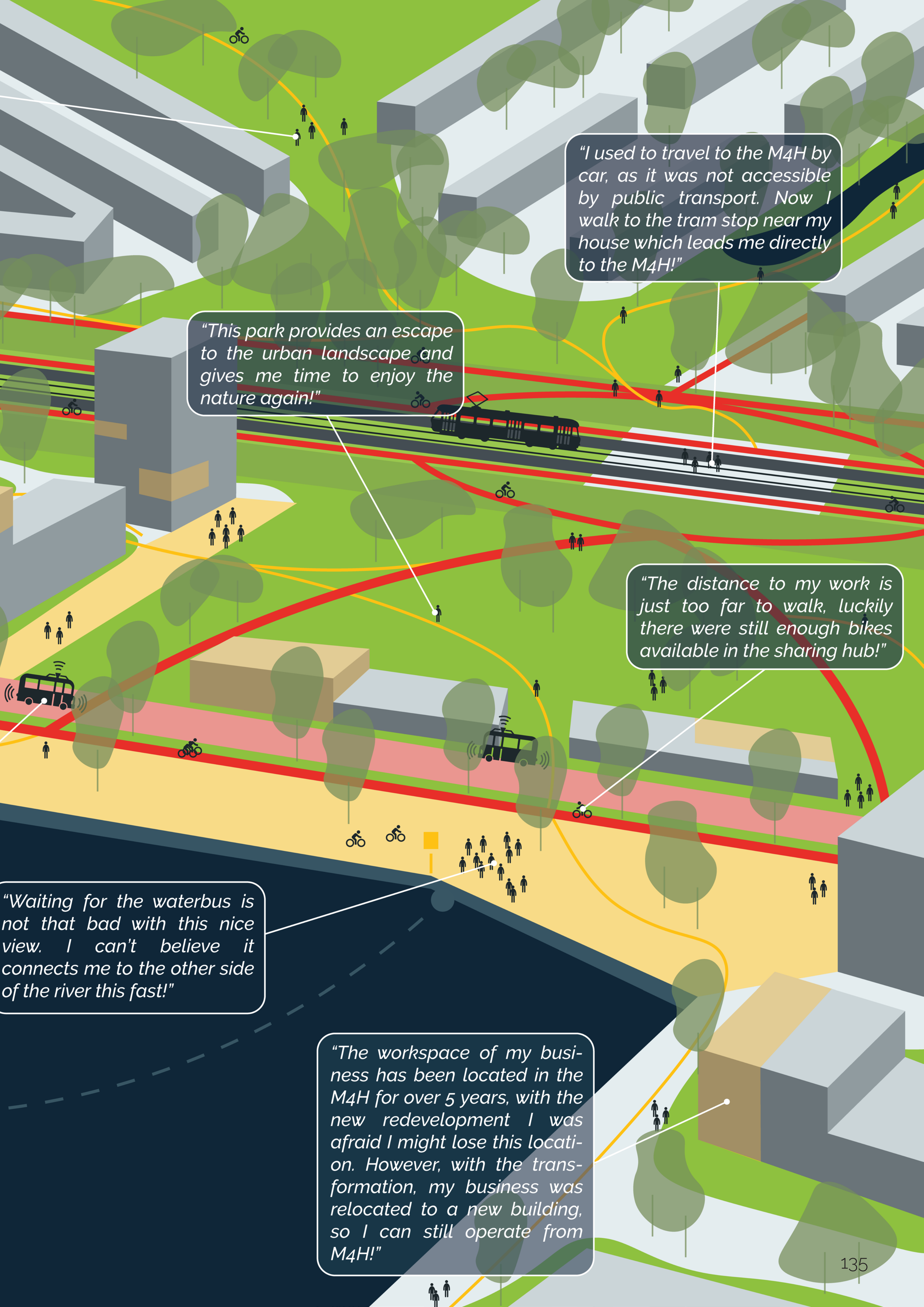


Figure 6.53 | Section BB'




"Although de M4H was just at the other side of the dike I had never been there. With the new connection across the dike, it is easily reachable and I go there often!"
"The streets in M4H give priority to cyclists, so I can go to my destination safely!"
M4H
"In this automated vehicle, I can travel efficiently within the M4H. The vehicles are easily accessible and travel close to my destination. All I have to do is sit and enjoy the pleasant environment!"
"The waterfront of the M4H used to be all fenced off, now I can escape the urban area and walk all the way to the river!"
"I live on the other side of the river and this new waterbus connection cuts my travel time down by more than twenty minutes!"



"I used to travel to the M4H by car, as it was not accessible by public transport. Now I walk to the tram stop near my house which leads me directly to the M4H!"
"This park provides an escape to the urban landscape and gives me time to enjoy the nature again!"
"The distance to my work is just too far to walk, luckily there were still enough bikes available in the sharing hub!"
"Waiting for the waterbus is not that bad with this nice view. I can't believe it connects me to the other side of the river this fast!"
"The workspace of my business has been located in the M4H for over 5 years, with the new redevelopment I was afraid I might lose this location. However, with the transformation, my business was relocated to a new building, so I can still operate from M4H!"

6.4.7 Design intervention 2

A second design intervention, as an example of the redevelopment, is done at the area near the Ferro Dome. In contrast to design intervention 1, this location is not situated at the edge but in the center of M4H. This location can be seen as one of the locations which trigger further development, as the transition is already going on near the Keilehaven.

However, in the current situation, the urban fabric still presents some challenges which should be dealt with. As the map in figure 6.59 shows, also a lot of plots in this area are still fenced off, which results in a lack of accessibility. The large building which contains the Praxis and Leen Bakker is not in relation to the scale of the surrounding blocks.

Figure 6.56 | Current situation

Figure 6.57 | Current situation

Figure 6.58 | Current situation *(Google maps, 2020)*

Figure 6.59 | Current situation

6.4 Strategic spatial framework

6.4.7 Design intervention 2

The design intervention is led by two concepts. The first concept is that the M4H is a transition zone between the city and nature. This is represented in the design by the parks and other green elements which surround the development in this area. Secondly, the concept of a hotspot is applied to this area. A hotspot is an area in which there is a high level of activity. The activity has its center at the Ferro Dome, which consists of an event center surrounded by public space and commercial activities.

The transformation of this area is happening in one of the early stages of redevelopment, as this location can be considered as one of the starting locations which triggers further development. This location is stated as such an area, as current development is already happening in this location.

The design of this location is supported by different principles of the pattern box (figure 6.61). Amongst others, the following principles are used in this design. The main road, connecting on a local M4H scale, runs through this area. At this road several sharing hubs are located, two in this case. The hubs are connected to key locations, the Ferro Dome, and the waterbus stop at the Keilehaven (PT1), which increases the centrality (SN4). The public space connecting the Ferro Dome is one of the public hotspots of the neighborhood. In this area people gather, both because of the mixed-use functions (SM3) and the connection to mobility. This enhances the community (SN3). In the new development the Praxis block is split, to increase connectivity and provide an interesting walking environment. Together with several sightlines to the water, the overall use of slow mobility is increased by the path context (SM4).

Figure 6.60 | Concepts transformation

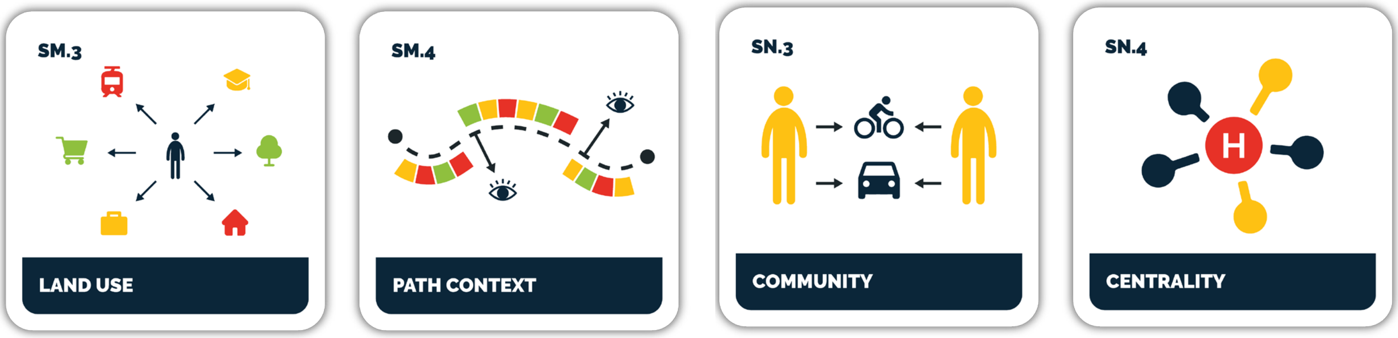


Figure 6.61 | Used pattern cards

Figure 6.62 | Transformation location

6.4 Strategic spatial framework

6.4.7 Design intervention 2

The main road of M4H also runs through this location. The main road is about 10 meters wide and consists of a cycle path, a road for automated vehicles and delivery trucks, and a green buffer. The green buffer provides permeability during rainfalls and decreases the Urban Heat Island effect. The row of trees also contributes as a recognition factor.

A sharing hub is connected to this location, it contains amongst others bicycles and scooters. The electric vehicles are charged in this station and make it possible for people to travel close to their destination.

The sidewalks are expanded to about 7 meters in width. They serve as a route, but also as a destination, as the path is detailed with benches and street furniture and provides accessibility to the adjacent buildings. Green elements are executed in the form of front gardens and planters. Streetlights ensure social safety when it gets darker.

Part of the main road is a local public transport system. This system consists of automated vehicles which transport people within the M4H. A stop is located near the public square of the Ferro Dome. The stop provides shelter and a waiting area.

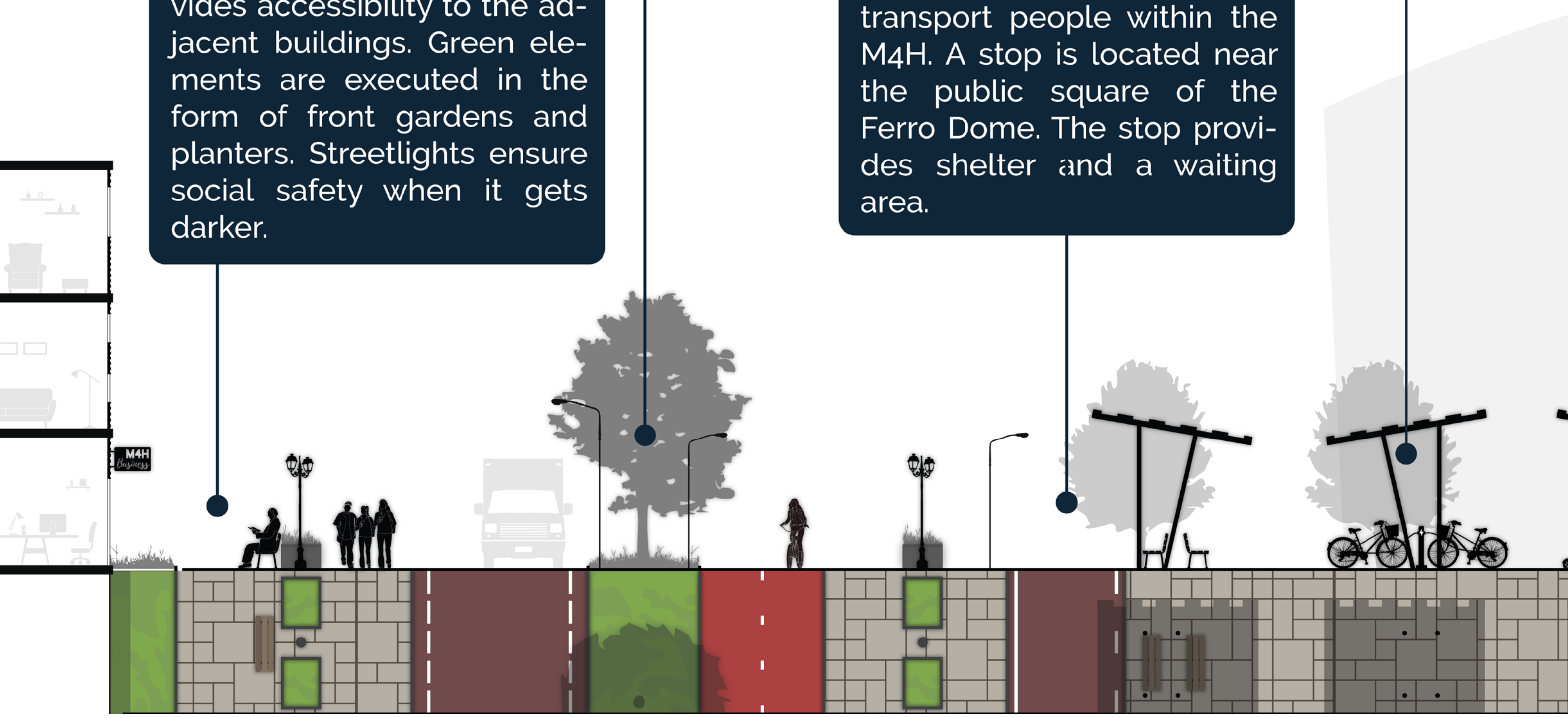
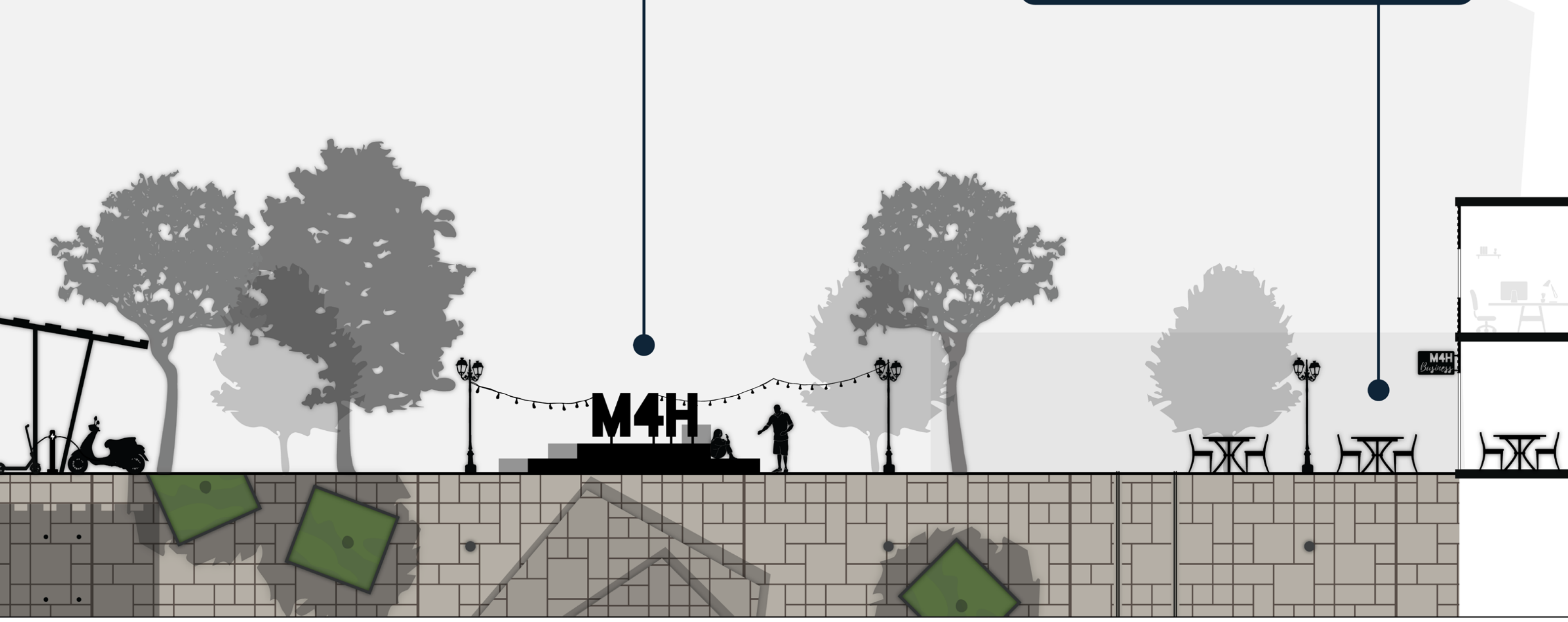


Figure 6.63 | Section AA'

The hotspot of this area is the newly realized public space. Where most public spaces are executed as a park, this particular area is transformed into a public square. It provides a location for people to gather and is easily reachable as it is connected to several mobility modes. The public square is located next to the Ferre Dome and makes it possible to also have events outside.

In order to preserve the public character of this location different functions are situated on the buildings' ground floors. The plinth consists of public functions, such as stores, restaurants, and cafes. This also connects the square to the buildings as it provides the possibility for outside seating areas.



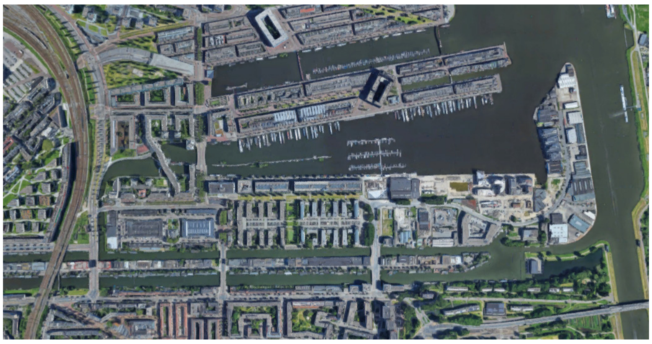

MOBILITY HUB

6.5 Transferability to similar sites

The case of M4H is one example of an industrial location that undergoes redevelopment. Within the Netherlands, the challenge of the industrial shift is also happening in other (large) cities like Amsterdam, Utrecht, and Delft. Figure 6.65 gives some examples of similar locations to the M4H and shows how they compare to each other scale-wise. In a first observation, the sites look quite similar, as there is the presence of water in the form of ports or canals. Other similarities can be seen in building sizes and structures, the road layout, and placement in the context of the city. However, there are some differences between the M4H and the other cases, as they for example differ in scale. Other differences may be present in the desired outcome of transformation, the current stage of transformation, and the context of the transition.

Transferability to other cases is an important part of the research to the M4H. Within the redevelopment of other cases, the same steps can be followed to create the strategic spatial framework. This framework consists of key locations, a stakeholder analysis, a development timeline, and design interventions, elements which are also applicable to other cases. The generalization of the pattern box also concerns transferability. The patterns used in the example of the M4H can also be used in other cases, but with the analysis done first, other patterns might be more suitable. The diversity of patterns presented ensures the possibility to implement sustainable mobility in all different kinds of ways in the redevelopment of industrial sites in the Netherlands.

Merwe-Vierhavens, Rotterdam



Cruquiusgebied, Amsterdam

RDM, Rotterdam

Merwedekanaalzone, Utrecht

Schieoevers, Delft

Haven-Stad, Amsterdam

Figure 6.65 | Similar loctions *(Google maps, 2020)*

07 Conclusion + Reflection

7.1 Conclusion

The main research question for this thesis project regarding sustainable mobility is:

'How can sustainable mobility guide the redevelopment of post-industrial sites towards a sustainable environment?'

The following four sub-questions help in answering the main research question.

1. 'What are the different components of (sustainable) mobility?'

2. 'What factors should be considered in the transition towards a sustainable mobility network?'

3. 'How can this transition be applied to the case of M4H?'

4. 'How can the case of M4H be used to guide other cases?'

The conclusion as an answer to the main research question will consist of the four small conclusions on the sub-questions.

1. 'What are the different components of (sustainable) mobility?'
Sustainable mobility could be defined as 'To ensure that our transport systems meet society's economic, social and environmental needs whilst minimizing their undesirable impacts on the economy, society, and the environment'. Central in this definition is our transport system which currently consists mainly of internal combustion engine vehicles. These types of vehicles have a bad effect on the environment. In order to create sustainable mobility a transition of our transport system is needed. The transition focuses on a reduction of cars, by stimulating the use of alternative modes. In this transition four mobility components are distinguished: public transport, slow mobility, sharing network, and clean mobility.

2. 'What factors should be considered in the transition towards a sustainable mobility network?'
The concept of mobility is spatially related to other concepts such as development and environment. In the transition towards sustainable mobility, a synergy between these concepts can be created. In the combination of mobility and development factors like density, accessibility, connections, and functions are important. A large transit station could go together with high-density development and mixed-use functions. In this way mobility and development supplement each other in attracting activity. Environmental factors are also represented in the mobility transition. Emissions are cut in the electrification of clean mobility. A mobility transition has also effect on the urban scale, as it requires a redesign of the urban fabric. In this redesign large car infrastructure could be replaced by green environmental implementations.

3. 'How can this transition be applied to the case of M4H?'
The case of M4H shows an example of a post-industrial site in redevelopment. The case has the potential to implement sustainable mobility in the early development stages. Sustainable mobility is applied to the M4H by creating new public transport lines and enhancing the slow mobility network. Several entrances and sharing hubs create the possibility to remove car traffic from this district. This provides opportunities to implement more greenery in street design and public spaces. Altogether a

sustainable neighborhood is created, where working and living come together. Sustainable mobility is well represented in all different urban elements.

4. 'How can the case of M4H be used to guide other cases?'
The case of M4H is used in applying the different sustainable mobility principles. However, this transition sets an example for other redevelopment projects. In order to achieve transferability of the gathered knowledge infographics and a pattern box are developed. The infographics contain and summarize knowledge about the different mobility components. It shows the vision for future transformations and forms the basis for the pattern box. The pattern box consists of a deck of cards, containing different mobility principles. The cards are used as a decision-making tool, helping in setting priorities in urban development. The pattern box is used in the design interventions in M4H, which shows the use and implementation of the tool.

7.2 Reflection

Relation studio/urbanism
The master thesis project is executed within the Urban Fabrics studio, as part of the master track Urbanism. The master focusses on analyzing urban environments and urban development in a critical way, while proposing new solutions for an efficient, sustainable, and livable organization and management of the built environment. This thesis project achieves this by researching the transition of mobility in applying and designing with sustainable alternatives in the urban built environment.
The main focus of the Urban Fabrics studio is the topic of 'Urban transformation & qualities of density'. The case of Merwe-Vierhavens, Rotterdam, is used as a representative case for this thesis project. The Merwe-Vierhavens is an industrial redevelopment site in urban transformation. This transformation is one of the key factors in which the transition towards sustainable mobility will be applied. The urban transformation of the Merwe-Vierhavens is accompanied by densification, on which this thesis project tackles the quality of the urban environment. Another important aspect of the Urban Fabrics Studio is the multiscale approach and design on eyelevel, which are achieved by connecting the neighborhood on the city scale and developing detailed design interventions on the small scale.

The relation between research and design
Different aspects of the thesis project visualize the relation between research and design. In the development of the project research and design are used back and forth to support each other. The research in the beginning of the project has mainly focused on the theoretical background of sustainable mobility and the supporting principles, while the design aspect became visible by the use of the case Merwe-Vierhavens. As the research is focused on the spatial aspect, it could be easily applied by designing in the case study. The design in the case study on the other hand provided further knowledge and findings which feeds directly back into the theoretical research. One of the research outcomes, the pattern box, also acts as a representation of the relation between research and design in this project. The pattern box consists of theory considering the transition towards an increase in use of sustainable mobility modes. The patterns can then be used as a way to visualize and describe the development and design process. It also has the function of a participation tool to bridge the research and design. In this way there is a tight interrelated relation between research and design throughout the whole process.

Societal relevance
The mobility transition towards sustainable alternatives carries with it the transformation and improvement of urban environments. As stated, the mobility transition consists of a technological and behavioral transition. The behavioral transition is dependent on the acceptance and change of society. However, research showed that people are still attached and dependent to the unsustainable way of mobility. This thesis project therefore contributes to the societal change and acceptance of sustainable mobility.

Scientific relevance
As several sources conclude, the current way of mobility is unsustainable and contributes largely to climate change. Thus, there needs to be a transition from vehicles with an internal combustion engine and private car ownership

to more sustainable alternatives. This transition is already becoming more visible as a side effects in urban development projects. However, in this thesis the transition stands central, and it shows a way of incorporating sustainable mobility as a starting point for urban (re)development. This is executed in a case study with guidelines and examples.

Ethical issues
Part of the thesis project revolves around the redevelopment of the Merwe-Vierhavens in Rotterdam. This location is an industrial site in transformation, which involves a lot of stakeholders. Small businesses and local entrepreneurs are vulnerable to large, top-down redevelopment plans. The same goes for the composition of the inhabitants of this part of Rotterdam, as the Merwe-Vierhavens should be integrated in the context of the Rotterdam neighborhoods.

Advantages and limitations chosen methodology
At first the focus was intended to be more on the development of the pattern box, to translate research into design. Several cases would be analyzed and used to achieve this. However, over the course of time the focus directed more towards the case of Merwe-Vierhavens, and the relevance of other case studies declined. An advantage of this redirection is that the case of Merwe-Vierhavens is really elaborated in depth and the research used for the thesis became more specific. But it also made it more difficult to include aspects that are not relevant in the case of Merwe-Vierhavens to the pattern box. The relevance and quality of the pattern box could have been enlarged by the input of several other cases, but this opportunity is still available in future elaboration and exploration.

Transferability
The transferability of the thesis project is taken in consideration in its early stages, as one of the sub research questions specifically addresses this. In the sub question touches upon the issue of how this thesis can be used for other cases than the Merwe-Vierhavens which is used in the design part. The transferability is increased through the development of a patter box. This tool act as a bridge between research and design. The different patterns are carefully developed to create a balance between being too specific and too general. This provides the possibility to use the pattern box, and thereby a major part of the thesis outcome in other (re) development cases.

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09 Appendix

Sustainable Mobility

Decreasing Environmental Issues through Sustainable Mobility

AR3U023 Theories of Urbanism
MSc Urbanism | Graduation studio Urban Fabrics | Delft University of Technology

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25-11-2020

Abstract
There is an ongoing trend in change of mobility. Where in the early years of the 21st century the main cars were either gasoline or diesel, nowadays more sustainable alternatives are becoming more and more popular. This change towards a sustainable way of transportation evolves mostly form an environmental perspective as vehicles with internal combustion engine contributes to a large part of CO_2 emissions. This essay researches the question: ''In which way do sustainable mobility principle contribute to increasing environmental issues in urban' In the answering of the research question the outcomes will be divided amongst two different approaches, a technical transition and a transition in the use of mobility. All modes of sustainable mobility contribute to lower the number of vehicles with internal combustion engine used. Sustainable alternatives are electric and hybrid powered vehicles, shared and automated systems and a stimulation of public transport and non-motorized transport modes.

Keywords: Sustainable mobility, electric cars, autonomous driving, shared driving, public transport, walkability

1. Introduction

The demands for urban mobility and transport in urban areas is rising, because of population and economic growth. This rising demand will lead to three to four times as many passenger-kilometers travelled in the year 2050, than in the year 2000 (Cervero, 2013). In the beginning of the 21st century most of the trips were made by private motorized vehicles, fueled by either gasoline or diesel. This way of mobility is unsustainable, as the use of fossil fuels is not unlimited and non-renewable. However, nowadays sustainable alternatives are becoming more and more popular as alternatives for vehicles with internal combustion engine (Transport & Environment, 2019).

This change towards sustainable mobility alternatives is part of the transition on sustainable cities. It is commonly known that cities need to adapt to be more sustainable, the mobility and transportation sector contributes to a large part in this transition. Worldwide there is a shift towards cleaner, economically viable and just cities of the future. This shift is visible in the de-carbonizing of fuel supply, and prioritization of sustainable mobility forms like public transport and non-motorized vehicles (Cervero, 2013). An aspect of the sustainable cities is inclusiveness, which is also reflected in transportation. In a car-dependent city, those without car lack in accessibility, whereas the use of sustainable mobility forms could provide a more inclusive use.

The change towards a sustainable way of transportation evolves mostly form an environmental perspective. The benefits of for example electric or hybrid driving are a reduction in emissions and therefore less pollution (Helmers & Marx, 2012). However, the advantages and disadvantages of sustainable mobility principles do extend beyond. This essay will answer the main research question of 'In which way do sustainable mobility principle contribute to increasing environmental issues in urban areas?'. In answering this question, the following sub questions are used: 'What are the different principles of sustainable mobility and how can they be divided?, to distinguish the different measures. The second sub question, 'How do these principles influence the environment?' contributes by elaborating the environmental impacts of the different principles. The third sub question 'How do these principles relate to spatial design', rises the opportunity to implement these principles in urban design. The research is elaborated per category of sustainable mobility.

2. Research

2.1 Sustainable mobility principles

To analyze the effects of sustainable mobility principles the broad concept of mobility needs to be subdivided first. A distinction could be made between two different approaches. The first way of reducing the use of internal combustion engine vehicles is a technological change. The transition is focused on using a sustainable source as fuel, instead of the unrenewable fossil fuels. This new form of mobility would replace the vehicles that run on benzine and diesel over time. Another approach in reducing the use of internal combustion engine vehicles is a transition in the way people use mobility. This transition focuses on a change in behavior of the users. This shift results in less car usage in general and more use of public transportation modes and non-motorized options.

2.2 Technical transition of motorized private vehicles

Research has proven that the use of vehicles with an internal combustion engine have a bad influence on the environment and contributes to climate change. This is because the fossil fuels are a limited resource, and it contributes to a large part of the CO_2 emissions. To make a shift to green alternatives a technical transition is needed. The technological revolution of the electric car is commonly known as the sustainable replacement of a car with internal combustion engines. According to research done by Helmers & Marx (2012), the electric car is four times more energy efficient as conventional cars, which is why it is seen as an innovative solution. Electric vehicles also emit less over their lifetime and are cheaper to run (Transport & Environment, 2019).

Research done by Soreta, Guevaraa and Baldasano (2014), shows the effects of electric vehicles on the environmental aspect of air quality. The research is applied on the case of Barcelona and Madrid, the two largest cities in Spain. The research concludes that the transition towards electric vehicles has potential on improving the air quality. However, there are certain factors that need to be considered. It first states that although the transition towards electric vehicles shows significant change in air quality, it is not sufficient to ensure proper air quality. It also states that the transition to full electrification requires a contribution of all actors. A complete transition will therefore take up at least a decade, in which the impact on air quality is limited. A third factor is the implementation of electrification on all different modes of transportation, such as buses, two wheelers, heavy-duty vehicles, and passenger cars. A research to the impacts of electric vehicles on climate change and air quality in Dublin (Brady & O'Mahony, 2011) supports the conclusions of the research in Barcelona and Madrid. The main conclusions match as this research also states that the transition towards electric vehicles contribute to urban air quality and the reduction of climate change. However, in the conclusion it is also stated that the effects will not be sufficient in the next decade, but it supports the statement that electric vehicles are a realistic alternative for internal combustion engine vehicles in the long term.

Another technical transition from internal combustion engine vehicles towards a more sustainable alternative are hybrid vehicles, or hybrid powered vehicles. These vehicles are equipped with a propulsion system composed of two or more components (Capata, 2018). A hybrid vehicle could for example have an electric motor with a thermal engine, because of this combination hybrid cars still use fuels like benzine and diesel. A hybrid powered vehicle, however, uses less fossil fuels than a regular ICEV, and can therefore be considered as a more sustainable option. While there is still CO_2 emission, this vehicle does contribute to the environmental impacts, but considerably less than a fully electric powered vehicle (Šarkan et al., 2019). However, other policies and measures are needed, as technology alone will not have enough influence in the transition (Transport & Environment, 2019).

2.3 Transition in mobility usage

The other approach to reduce the environmental effects of vehicles with internal combustion engine is a shift in the use of mobility. Whereas the current mobility use is predominantly private passenger cars, a transition to more sustainable ways of mobility is needed. More sustainable alternatives could be achieved by sharing the transport mode, so the usage is no longer private, this will reduce the number of vehicles. Another sustainable alternative is the stimulation of non-motorized mobility.

The first alternative of reducing the number of cars is shared mobility. The concept of shared mobility is mostly known in public transports concepts. However, this concept is nowadays also applied to shared car ownership. Sharing cars have the potential to improve the mobility system in efficiency and reducing the need for private cars, as the concept of sharing cars only allows users to access them when needed. A research by Transport & Environment (2019), with the topic of a reduction of cars, also addresses the shared driving concept. It states that the deployment of 344 car sharing vehicles let to a reduction of 5000 privately owned cars. To achieve shared mobility, the option of shared ownership should be more attractive than private ownership. Regulations plays an important role in the attractiveness of car sharing, as these cars are required to be emission free by 2030. Mandatory car equipment, like the implementation of certain technologies for sharing, makes the service more expensive. However, the implementation of car sharing contributes to enhancing the electric vehicle network. Electric charging infrastructure is dependent on a high use rate, which can be reached, as sharing vehicles increases the time vehicles are in use.

As shared vehicles decrease the number of cars, it also influences the parking demand. A study by Zang et al. (2015), researches the impact of shared vehicles on the urban parking demand. Parking demand has relation to the number of vehicles in the system, a reducement of the number of vehicles results in a decline in parking demand. However, the total number of vehicles in the system needs to be large enough to ensure short waiting times. Another factor which influences the parking demand is the level of willingness to share rides. The parking demand declines if there is a high willingness to share rides. The willingness to share rides can be increased through low travel costs. With automated shared vehicles a scenario with empty cruising vehicles can reduce parking demand the most. However, this increases the distance each vehicle travels. The research concludes that by comparing different models, 90% of the parking demand can be eliminated. With this change most of the urban parking spaces are no longer needed and can therefore be transformed and used for other purposes.

The upcoming of automated vehicles, briefly mentioned before, is also an urban trend in mobility. As automation already exists in other modes of transport such as planes and metros, the principle is also implemented on cars. There are several benefits attached to automated driving, with the largest being reducing the road fatalities. Automated vehicles have not directly impact on environmental issues, other than that the urban structure could be redesigned. Automated vehicles take less road space and parking. The use of automated vehicles could be enhanced if combined with the sharing option. In this way it could be another form of public transportation (Greenblatt & Shaheen, 2015). An example of such service is MaaS (Mobility as a Service). This service has a positive effect on the environment, as it enhanced the travel efficiency. This results in lower CO_2 emissions and more efficient use of space (Kramers et al., 2018). The impact of automated or autonomous vehicles is largest in combination with shared on demand mobility (transportation (Greenblatt & Shaheen, 2015).

As stated before, the reduction of the use of internal combustion engine vehicles could also be achieved by stimulating alternative modes of transportation besides cars. An example of such alternative mode is public transport. In the early 2000s the use of public transport was far less popular than the use of private cars. A study, done by Steg (2003), compared the use of the two types of mobility through a survey. In the outcome, cars score higher than public transport on almost every criterion, except for traffic safety. The car is also seen as a status symbol and has therefor social value. However, over the years the image of car use shifted. The unsustainable aspect of CO_2 emissions and fossil fuels became aware. This positively affected the use of public transport as it became known as a more sustainable alternative use of mobility. Mugion et al. (2018), researched the topic of public transport in relation to sustainable mobility, in the case study of Rome. It investigated the role that service quality play in promoting sustainable mobility behavior, and thereby reducing the private car usage. To stimulate the use of public transport, the satisfaction of the users should be enhanced. One of the main conclusions of the research is that there is indeed a relation between service quality and overall satisfaction. An improvement of the service quality could therefore stimulate the use of public transport. The main components that influence the service quality are security, reliability, travel time, comfort and waiting conditions. The services need to be designed to fit the customer needs and expectations. The research also concludes that 'public transport service quality of public transport influences users' intention to use public transport more' which results in a decrease of private car use.

The stimulation of non-motorized transport, like cyclist and pedestrians, also contributes to a reduction of cars. One of the effects of an increased walkable city is the reducement of car travels. Walking is a replacement of the car on a short distance (Talen & Koschinsky 2013). There are several ways to improve the walkability of an area, a research done by Southworth (2005) distinguishes six criteria. The first criterion is connectivity of path network, pedestrians need to be able to have easy access and a continuous flow on their journey. To enhance and stimulate walkability it needs to be linked to other public transport modes. In this way pedestrians are also supported on a larger scale. Land use plays an important role in the pedestrian network. With the daily functions in a walkable reach (10 min) people are less likely to go by car. Land use also relates to the safety aspect, as the functions on the ground floor act as eyes on the street. Safety can also be achieved by separating the traffic flows. Another, rather obvious, criterion of walkability is the quality of the pathway. People are more likely to choose pathways with smooth surfaces, that are well maintained. The final criterion is path context. This relates to the experience of people on their journey. Monotonous, repetitive structures should be avoided. The use of sightlines, vistas and landscape elements contributes to the satisfaction of the users.

Another form of non-motorizes mobility is cycling. Cycling could be distinguished into two purposes, recreational cycling and cycling as a form of transportation. The use of bicycles differs a lot along the world, as it highly depends on the cycling infrastructure available. In some Dutch and Danish cities cycling takes up to 40% of trips (Cervero, 2013). Technological revolutions, like electrification, can also be applied on bicycles, an example is the e-bike. The use of e-bikes in the Netherlands is researched by de Kruijf et al. (2018). For the research, the use of e-bikes is stimulated by an incentive program in which commuters could earn monetary incentives when using their e-bike. The results show that the program was highly effective, as the use of e-bikes increased up to 68%. This use of e-bikes has partly benefit on the environment, congestion, and health issues, as half of the e-bike trips substitutes car trips. However, the other half of e-bike trips substitute conventional cycling, which has fewer benefits on issues regarding environment, congestion, and health. The use of e-bikes is dependent on travel distance, but also on factors like age, gender, and physical condition. The concept of sharing could also be applied on cycling, in this way the service could be an extend to public transport (Transport & Environment, 2019).

3. Conclusion

The following main question is researched in this essay: 'In which way do sustainable mobility principle contribute to increasing environmental issues in urban areas?'. The results of this research are divided by sustainable mobility category. For answering the main question, the main conclusions of each section are summarized.

The use of internal combustion engines has negative effects on the environment. The internal combustion engine runs mainly on benzine or diesel, which are non-renewable fossil fuels. Another effect is the large amount of CO_2 emissions and pollution. To decrease the environmental impacts, a transition towards sustainable mobility is needed. The concept of sustainable mobility could be divided into two categories, a technical transition of motorized vehicles and a transition in the mobility usage of people. The first category investigates the technical revolution of cars, while the second category investigates stimulating the use of other mobility types. Both transitions result in a decrease of vehicles with an internal combustion engine.

A technical transition towards sustainable mobility is electrification. Compared to internal combustion engine vehicles, electric vehicles emit less over their lifetime and are cheaper to run. Further research showed that a transition towards electric vehicles contributes to improving the air quality in urban environments. However, to improve the air quality, other measures are also needed and a compete transition towards electric vehicles will take over a decade. Electric vehicles are therefore a realistic alternative in the long term. A hybrid vehicle contributes less to environmental aspects as it partly still runs on internal combustion engines. However, it could be an attractive alternative in the electrification process.

A transition in mobility use can also lead to a reduction of environmental impact. Instead of predominantly private passenger use, a decrease in car use can be achieved by encouraging sharing transportation options. By sharing vehicles, the number of cars will reduce, resulting in less emissions. The implementation of car sharing also contributes to enhancing the electric vehicle network, as the charging infrastructure is dependent on high use rate. Although automated vehicles have no direct impact on environmental issues, it gives the opportunity to redesign urban structure. Together with sharing options, a decrease in parking spaces could be achieved. In this way space could be redefined to other purposes. Services like MaaS (Mobility as a Service) uses automated vehicles as a form of public transport.

Public transport and non-motorized transport are forms of sustainable mobility which exclude car usage. Over the years the use of public transport is increasing, as it is a worthy alternative. Different factors play a role in the stimulation of public transport use, with service quality being one of the largest. The service quality is influenced by factors as security, reliability, travel time, comfort and waiting conditions. The stimulation of non-motorized transport has also positive effect on the decline of car use. Pedestrian activity could be stimulated by improving the walkability of a city. Different criteria, like connectivity, accessibility, quality, and context are influencing the walkability. A clear cycle network also contributes to encouraging non-motorized transport as cycling is not only for recreational purposes. Concepts as sharing network and electrification could be applied on cycling as well, to connect the service to public transport.

Overall, the essay shows different modes of sustainable mobility and distinguishes the effects and suggest ways to improve. However, to reflect, this essay addresses only the main forms of sustainable mobility, further research could dive into other forms. This essay has a focus on the environmental effects of mobility, mostly on reducing CO_2 emissions. However, the suggested transition of mobility could also affect other social and economic topics. This could also be elaborated in further research.

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