Urban fast charging stations

A design of efficient public charging infrastructure for large numbers of electric vehicles in cities

Graduation report

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COVER:
A potential city location in The Hague

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FINAL PROJECT GRADE: 9.0

"The horse and carriage era did not end because we ran out of horses.

It ended because horse transportation was disrupted by a superior technology, the internal combustion engine, and a new 20th century business model."

[Seba, 2014]

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PREFACE

At the start of 2014, I traveled to Amsterdam to visit Fastned, at this time a startup company that operates in the new and fast growing market of electric driving and charging. We discussed about the graduation project, that would complete my master degree of civil engineering at Delft University of Technology. Graduating is about applying the knowledge you have gathered during your study. Second, it is about learning new things. I was enthusiastic to start a research project in an upcoming market where still many things are to be discovered.

My first experiences with electric cars taught me a few things. No noise, no vibrations, and an amazing continuing acceleration! But there is a downside as well. The driving range is limited and recharging takes a lot of time. A network of fast chargers along the highway is now under construction. But how can we prepare cities for charging large numbers of electric vehicles in the future?

In the past few months I enjoyed working on that. I am grateful for becoming part of the Fastned team. A group of enthusiastic and motivated people, looking for opportunities and innovations, and building on the future with dedication. My special thanks go to Joost Hoffman and Maria Garcia, who were always open for good discussions, new insights and ideas.

My thanks go to the graduation committee: Rob Nijsse, Roel Schipper, Jan Anne Annema, and Geert Ravenhorst. I want to thank family and friends for their contribution and support. All these ideas and input have contributed to this report, which hopefully will learn you something new as well. Jouke Lutgendorf and Jasper Keuning, thanks for your critical review and good suggestions for improvements.

If you have any questions regarding the content of this report, or if you like to share ideas about this topic, feel free to contact me at any time!

Pieterjan Nijhuis

ABSTRACT

The urban environment will greatly improve when all vehicles are fully electric, because of the strong reduction of CO2, NOx, particulate matter, and noise. The number of electric vehicles (EV's) in the Netherlands is growing fast, and the Dutch government aims for 1 million electric cars in 2025. A large-scale network of chargers is needed to charge the batteries of all these cars. Public chargers are accessible for everyone, and are essential for the majority of people who cannot charge at home or work.

Municipalities started financing the first public chargers in cities. However, the majority of municipalities has no further budget or policy for realizing new public chargers. The increase in the number of new public chargers is stagnating. A majority of EV drivers in cities already experiences an increasing shortage of chargers. This might be an indication that the capacity of the public charging infrastructure is not sufficient for the rapidly increasing number of EV's. Public chargers are essential for urban areas, because private parking places for charging at home are available for only 10% of all cars. This causes the following research question to arise:

How could urban areas provide public charging infrastructure for the rapidly increasing number of electric vehicles?

The objective of this research is to develop a tool that helps municipalities and market players to understand the need for public charging infrastructure, and to design an efficient solution for charging large numbers of electric vehicles in an urban area.

First, the developments and trends in the market of electric driving and charging are examined. A full electric vehicle with a battery capacity of 24 kWh can drive approximately 120 kilometers. At present, 80 % of this battery can be recharged in six hours with a 3.7 kW slow charger, or in 30 minutes with a 50 kW fast charger. Technical improvements in battery technology will increase the battery capacity of EV's, and therefore further increase the driving range. Advances in charging technology increase the capacity per charger and enables to charge EV's faster. These developments are expected to change the strategy and structure of a public charging network.

Second, this research includes the development of a scenario model. This model is presented as a tool that helps to gain insights in the required capacity of public chargers, by generating various scenario's. The total demand and supply for chargers in one city is compared on the basis of an energy balance in kWh. A method is developed to distribute the energy demand based on where EV users want to charge, and where

they can charge. Four user types are distinguished, that have different preferences for charging at three type of locations (home, destination, and public). With this tool, municipalities and market players can create various 'what-if' scenarios for various cities. Data is collected to examine scenario's for Amsterdam, Rotterdam, The Hague, and Utrecht.

Comparing these scenario's indicates a capacity gap between demand and supply: the current network of public slow chargers can provide significant more energy than is needed for charging all electric cars in these cities. This decentralized network, with slow chargers located at hundreds of parking places, is underutilized and not cost efficient due to high exploitation costs. A more efficient solution is necessary for charging large numbers of vehicles in cities.

The cost efficiency of charging infrastructure can be improved by creating a centralized network, with multiple fast chargers at a limited number of locations. An increase of charging speed and capacity per charger will decrease the costs per supplied kWh. Improvement of the effective use of chargers is therefore necessary, in particular for scenario's with high EV volumes. It is important that EV drivers recognize locations for fast charging as a place to stop, charge, and go. It is essential that drivers clear their position after charging, so other vehicles can start charging.

An efficient solution to prevent the expected shortage of public charging infrastructure in urban areas, is realizing modular and flexible charging stations with multiple fast chargers, at strategic locations along access roads.

First, the demand for charging strongly depends on the number of electric cars, and is therefore uncertain. The modular station can be expanded or reduced with one or more modules, and is therefore flexible for changes in demand. Serial produced modules, with a minimized number of different elements, provide the opportunity for easy, fast, and cheap assembly of many stations.

Second, strategic urban locations with available space are scarce. A station with a small and flexible footprint increases the possibilities for realizing stations at different locations, along access roads and other high traffic density roads in the city.

Finally, the preliminary design of a prefabricated foundation, a modular and light weight timber structure, and the detailing of connections, show how station modules can be repositioned at other locations, or can be completely demounted for re-use.

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INTRODUCTION AND RESEARCH METHODOLOGY

The urban environment will greatly improve when all vehicles are fully electric, because of the strong reduction of CO2, NOx, particulate matter, and noise. In the Netherlands, freight and passenger transport is responsible for 24% of the total emission of CO2. Due to the fact that 70% of the total energy demand of transport is needed for passenger cars [PBL, 2014, WRR, 2013], a transition towards full electric cars will have a strong positive impact on the living environment for citizens.

The Dutch government stimulates the use of electric transportation, and aims to reach European climate targets. The increase of electric vehicles (EV's) and chargers along the roads now becomes visible. Last year alone, the number of electric cars driving on Dutch roads has tripled. The target for adapting EV's in the Netherlands is clear: more than one million electric cars on the road by 2025 [RVO, 2011].

A new network of chargers is inevitable to charge the batteries of all these vehicles. However, charging infrastructure that is prepared for a large numbers of EV's in the future is still under development. Charging infrastructure can be compared with a network of petrol stations, but there are two major differences.

First, electric cars can be recharged at any location with a power connection. People who have their own driveway or garage, can charge their electric car at home. Other possibilities are to charge at work, or at any other destination. Public chargers should be available for the majority of people who cannot charge at these private locations at all times.

Second, there are various charging speeds to recharge electric cars. The required time to fully recharge depends on the power connection and the charging technology. Until recently, completely recharging a full electric car with a regular power connection took at least eight hours. The technological breakthrough in fast charging now enables to recharge a similar battery for 80% in less than fifteen minutes.

Fast charging stations at highway locations

Cars are synonymous with freedom, so not being able to quickly recharge and get back on the road creates a problem. A reliable network of fast chargers is therefore essential for EV drivers on the go. In the Netherlands, Fastned is the first company that installed fast chargers on a large scale along the highways. Fastned was founded in 2011 with the aim to realize a nationwide network of fast charging stations, that only provide electricity that is generated from wind- and solar energy.

One station can accommodate up to eight fast chargers. Figure 1 shows a charge station along the highway near The Hague. Every electric vehicle can charge here, because chargers support all available power connections. Everyone can use the chargers by self-service with use of a mobile phone. In 2012, Fastned acquired concessions to realize fast charging stations at 201 out of 245 service areas along Dutch highways. By the end of 2014, twenty stations were operational, and Fastned prepares for constructing one new station every week.

Slow chargers in cities

Municipalities stimulated the startup of a public charging infrastructure by financing public slow chargers, where the majority of EV's is charging 1 to 4 hours. As figure 2 shows, parking places are retained for charging EV's only. The best occupied public slow charger in the Netherlands charges on average three cars a day.

At the moment, the majority of all municipalities do no longer have budget or policy for realizing new public chargers [Natuur&Milieu, 2014]. Further development of a public charging infrastructure is being left to players in the private market, and the increase in the number of new chargers seems to stagnate.

A large scale user survey provides information about charging behavior and contentment of EV users in main Dutch cities. A majority of 64% of the EV drivers experience a shortage of public chargers, mainly because the chargers are already occupied [G4, 2014]. Despite the clear target of 1 million electric vehicles, there is no solution for charging large numbers of electric vehicles in urban area. This is the motivation for this research project, and the cause for the main research question.

Figure 1 – A public fast charging station at A12-location Knorrestein [fastned.nl]

Figure 2 – A public slow charger at a parking place in Amsterdam [groen7.nl]

1.1 RESEARCH QUESTION

How could urban areas provide public charging infrastructure for the rapidly increasing number of electric vehicles?

1.2 OBJECTIVE

The objective of this research is to develop a tool that helps municipalities and market players to understand the need for public charging infrastructure, and to design an efficient solution for charging large numbers of electric vehicles in urban area.

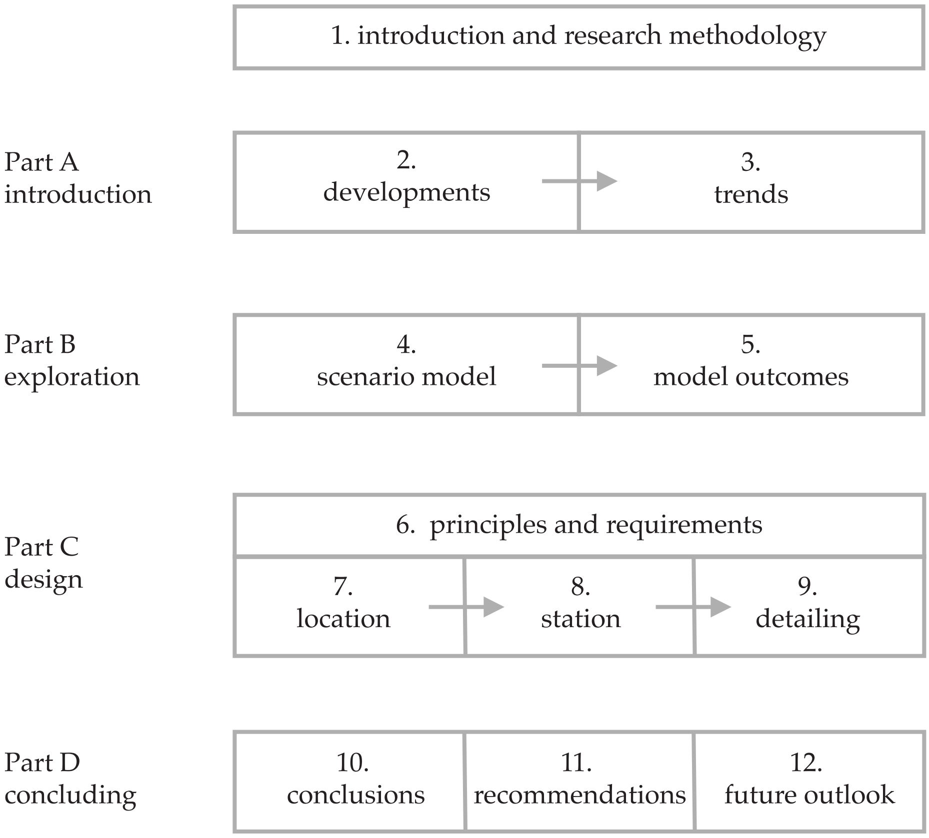


Figure 3 – Schematic view of the research model and the report structure

1.3 RESEARCH METHODOLOGY

Figure 3 shows the research methodology and the report structure with corresponding chapter numbers. The chapters are organized in four parts. The following sections explain the content and research questions for every part.

Part A - Introduction

The purpose of part A is to understand the developments in markets of electric driving and charging. Events and breakthroughs in these emerging markets are categorized in five themes and arranged in chronological order on a timeline. This context information helps identifying trends and creating a model that can compare future scenario's.

Part A addresses the following questions:

- What are important developments in the market of electric driving and charging?
- What are the expected changes in the market for charging electric vehicles?

Part B - Exploration

Part B is an exploratory study, with the aim to gain insights in the required capacity of public charging infrastructure in urban area. First, it explains the method and the design of a scenario model, that can compare the demand and supply of public charging infrastructure. Thereafter, the model results are presented on the basis of the tool that is developed for municipalities and market players. A comparison of different scenario's and costs, indicates what is an efficient solution for a network of chargers that can charge large numbers of EV's in cities.

Part B addresses the following questions:

- Which factors determine the demand for charging electric vehicles?
- Which factors determine the capacity of charging infrastructure?
- How to determine the need for public charging infrastructure in urban areas?
- What is an efficient solution for charging large numbers of EV's in urban area.

Part C - Design

Part C continues with the implementation of a design solution. First, the design principles and requirements are explained. Options and choices in the design are elaborated step by step on the basis of three main design principles. Requirements are derived from a literature study into an Industrial, Flexible, Demountable design approach. Finally, a preliminary design is presented as possible solution for charging a large, but uncertain number of electric vehicles in urban area.

Part C addresses the following questions:

- What are the design principles and requirements for finding a good solution?
- Which design solution is suitable for charging a large, but uncertain number of electric vehicles?
- Which design solution can be realized at a variety of city locations?
- Which design solution is sustainable for the future?

Part D - Conclusions and recommendations

Part D includes the conclusions that are derived from the model (part B) and the design (part C). Recommendations for municipalities and market players are given, and suggestions for further research are provided. Finally, an outlook towards a future perspective is given.

1.4 REPORT INFORMATION

Please note the possibilities for digitally navigating through this report. It is recommended to display the report as two pages on screen. The table of content is linked with all chapters and sections, and references are linked with the sources in the bibliography. When printing this report, beware that all pages should be double-sided. This report is available at the repository of Delft University of Technology. A digital version of the model, and a collection of notes, ideas, design sketches and drawings are available on request via the author.

Part A

INTRODUCTION

2

DEVELOPMENTS IN ELECTRIC DRIVING AND CHARGING

This chapter provides an overview of events and breakthroughs that have influenced the market for electric vehicles and charging infrastructure in the past few years. The goal is to identify and understand the ongoing developments in these emerging markets. The information gathered in this chapter helped to select and correctly apply those factors that are relevant for developing a model that is able to compare the demand and the supply of public charging infrastructure (chapter 3).

A selection of relevant events, facts, and data is visualized and documented in this chapter. The selected information is categorized into five themes, which are represented by the icons below. All information is arranged in chronological order on a timeline. In Appendix **??**, a picture of the complete timeline is included. The following sections show the timeline for every theme within the range 2008 - 2014.

Worldwide developments of electric vehicles and technology are included, because the Netherlands has no extensive automotive industry. However, the Netherlands is one of the leading countries in developing a national charging network. The developments in charging infrastructure and policy are therefore focused on the Netherlands only.

Electric vehicles
Technology
Charging infrastructure
Finance
Policy

2.1 ELECTRIC VEHICLES

The term electric vehicle (EV) can refer to any type of vehicle that is driven by electricity. Within the context of this research, EV refers to electric passenger cars, since Fastned initially aims on providing a fast charging infrastructure for this market segment. Other sources for propulsion, for example hydrogen, are outside the scope. This section explains the different types of EV's, and elaborates on the developments from first to modern electric vehicles.

The first electric cars

The invention of the first electric car was back in the 19th century. n the early 20th century this method for propulsion became increasingly popular. However, further enhancements in the technology of internal combustion engines resulted in a decreased interest for electric cars. The driving range of fuel driven cars was better, refueling was much faster, and a fast developing infrastructure for refueling offered significant advantages. In today's automotive market, these aspects still play a major role in the development of new electric car models.

The development in the technology of electric driven cars stagnated, but in the late 20th century this gained new interest. Changing economical and political situations during this period have influenced the energy market. During the Gulf War in 1990, the price of oil increased significantly. The global economic recession that followed in 2008, led to an oil price that was higher than ever before [Lukoil, 2013]. These price developments, in combination with the growing public awareness of a sustainable future, seem to stimulate the development of cheaper, more efficient, and cleaner cars.

ICE - Internal Combustion Engine
A conventional petrol car uses an ICE, in which the combustion of fuel and air occurs at high temperature and pressure to generate mechanical power.

FEV - Full Electric Vehicle
A vehicle propelled by an electric motor powered by energy that is stored in high capacity batteries on board.

SEV - Semi Electric Vehicle
A vehicle that combines the conventional ICE with an electric propulsion system. SEV refers to all available configurations, such as range extenders and plugin hybrids.

The way towards mass production of new EV models

The timeline in figure 4 highlights two major developments in the market of electric vehicles. First, *new models* of electric cars with improved performances are introduced to the market in recent years. Second, the original equipment manufacturers (OEM's) have started *mass production* of EV's worldwide. The timeline starts in 2008, the year where many OEM's announce their plans to introduce electric car models. Information related to the introduction of new models and corresponding production volumes are collected from the manufacturers websites and a web database [Marklines, 2014]. Nowadays, the majority of car brands have introduced an electric model to the market [Sierzchula et al., 2012]. The timeline includes a selection of car models, that are available for the Dutch market and highlight a breakthrough in technology or sales volume.

The Japanese automotive industry introduced the Toyota Prius in 1997. It was the first commercial hybrid car, and one year after the start of production, 18.000 cars were sold in Japan only. In 2000, this model became available world wide. A few years later, Tesla started to develop the Tesla Roadster in the United States. The model became available to the market in 2008, and introduced new battery technology and different speeds for charging the batteries at home. In the same year, large scale research and development of electric cars starts with other car manufacturers [IEA, 2013]. Up to 2010, the Prius was the only electric model in the European EV market that achieved sales volume of more than 100 vehicles. In 2010, two new models are presented in Japan; the Nissan Leaf, and the Mitsubishi i-MiEV. These are the first cars that are prepared for fast charging.

While the global stock of electric cars in 2011 exceeds a number of 50.000, the first European OEM's start with production tests of their electric car models. In the large German automotive industry, it is BMW that takes the first initiative with the i3 model. Meanwhile, Tesla introduces their Model S, a model that provides a battery pack that

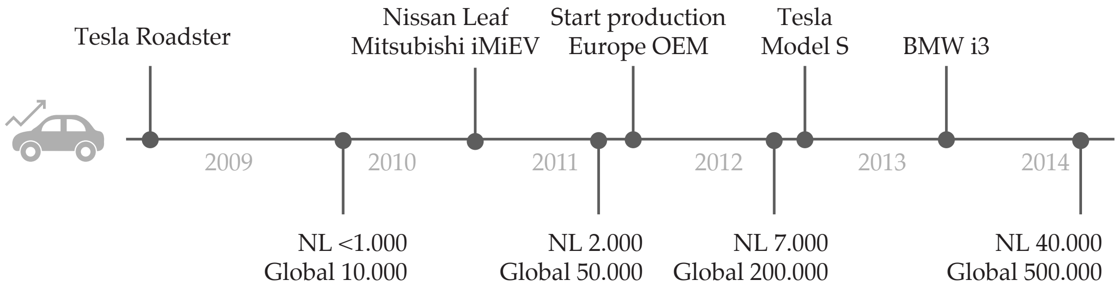


Figure 4 – Timeline: new EV models and total sales volumes

almost doubles the capacity of their previous Roadster model. It is a breakthrough in the process of overcoming the real and perceived driving range limitations so far. Nissan is market leader with a share of 45%, and the Nissan Leaf model achieves a sales record of 50.000 cars worldwide in 2013. One year later, the sales volume is already doubled.

Due to the fast progress in the Dutch EV market, the Netherlands becomes visible as a potential market in 2013. This development is emphasized by the fact that Tesla opens their EV head office in Amsterdam, and locates an assembly plant in Tilburg for serving the West European market. In the same year, BWM presented their new i3 model in Amsterdam. In the Netherlands 7.9 million passenger cars are now registered [CBS, 2014]. At the start of June 2014, almost 36.000 electric cars are on the road, from which 4.800 cars are full electric [RVO, 2014].

2.2 TECHNOLOGY

The automotive industry is a large scale worldwide market, where the car as a product has been developed over more than one century. Technology plays a major role in the development of the electric vehicle market. This section explains which technical aspects are most important. The world wide developments in technology are described, and the technical principles for charging electric vehicles are explained.

The leading technical performance of electric cars

For car manufacturers, most important improvements in technical performances of EV's are those that provide competitive advantages over other (petrol or electric) cars. Full electric vehicles charged with renewable energy lead to significant improvements in terms of energy efficiency and environmental impact, whereas other methods of propulsion lead to no substantial improvements or even higher life cycle emissions [Helms et al., 2010]. The energy efficiency of an electric engine is up to 90%, where the efficiency of an internal combustion engine now has a maximum of 30%. Driving an electric vehicle is emissions free, which reduces the local environmental impact to a minimum. With electric propulsion, there is an opportunity to further reduce the total environmental impact by making use of renewable energy sources. Developments in the technical improvements of the EV's efficiency and environmental impact, are therefore considered less important with respect to an increase in the market share of EV's. The same principle applies for performances related to driving experience, such as speed, acceleration, and handling.

Currently, the two most important aspects for improving the performance and the use of electric cars, are the *battery capacity* and the *charging rate*. Compared to petrol cars, the driving range of EV's is still limited. The electric vehicle with the highest battery capacity, is now approaching the driving range of an average petrol car. Second, recharging of an electric vehicles takes significantly more time than refueling a petrol car. Time for recharging a full battery can range from 15 minutes to more than 12 hours.

The growth of battery capacity

An increase of the battery capacity improves the driving range and therefore helps to overcome the effect of range anxiety. The fear that an EV has insufficient range to reach a destination that has charging facilities, now seems to be a barrier to choose for a full electric vehicle. Second, a higher range means that consumers are required to recharge less frequently. The average full electric vehicle uses 1 kWh for driving a distance of approximately 5 kilometers.

The first commercial hybrid vehicle from 1998 had a lead-acid battery capacity of 1,3 kWh. The lithium-ion batteries became predominant from 2006 due to their high energy density, and excellent storage characteristics compared to conventional lead-acid and nickel-metal batteries. In 2008, the serial production of a full electric car with a lithium-ion battery pack of 53 kW started in the United States. However, the production volume of this model was relative low. From 2010, Japanese car manufacturers started large scale production of a model with a 24 kWh battery.

In the following years, the global EV sales continue to grow and OEM's make additional investments to realize new production facilities for vehicles and batteries. Car manufacturers need a few years to develop and test new car models. The design of today's EV therefore started with the technology of approximately 4-6 years earlier.

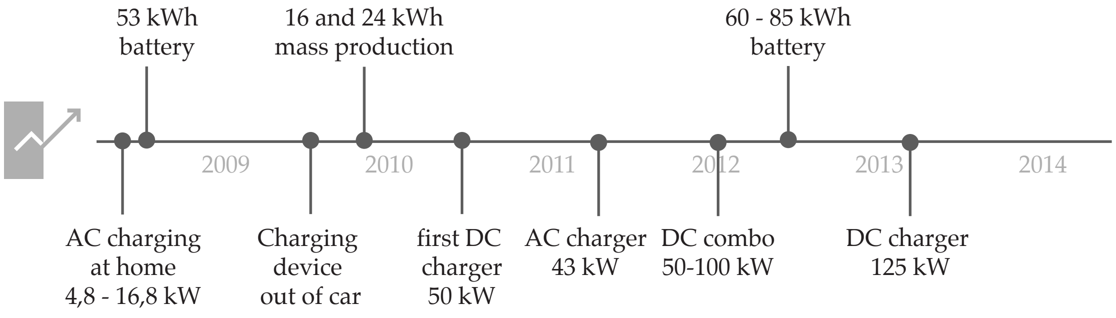


Figure 5 – Timeline: developments in battery and charger technology

Currently, a full electric model from June 2012 has the highest available battery capacity. With a 85 kWh battery, this model can drive at least 400 kilometers.

Slow AC charging versus fast DC charging

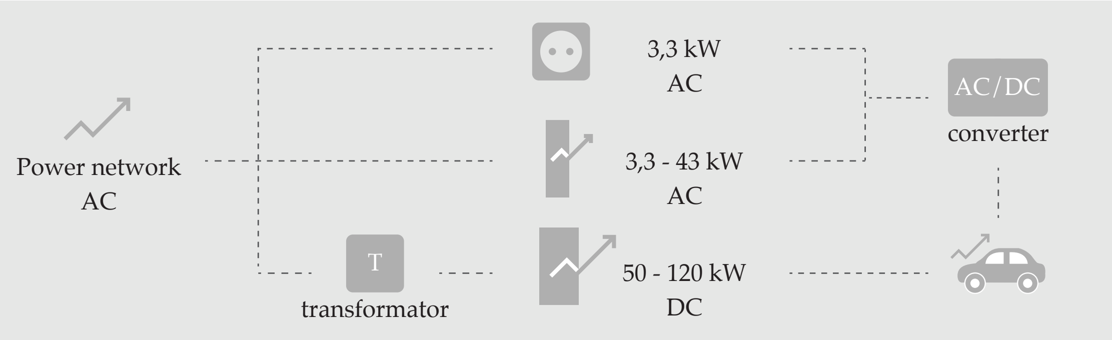
There are various possibilities and charging technologies to recharge the battery of electric vehicles. The input for a basic charger is an electric charge in alternating current (AC). The charger is required to convert this flow of electric charge into a direct current (DC). The battery receives and stores this electric energy, and provides the electric engine the energy in DC when needed.

A regular power connection in households and offices is supplied by the power network in AC. The first electric models have an on-board charger installed. This configuration provides the possibility to recharge the battery anywhere, because the AC is converted to DC in the car [Yilmaz and Krein, 2013]. The charging rate in which an alternate or direct current can be transfered, depends on the power connection. The two basic equations below, explain how the charging rate and time are calculated [Young et al., 2013]. The voltage and current used in this example, represent a regular Dutch power connection.

Power = Voltage x Current
3,7 kW = 230 V x 16 A

Capacity = Charging rate x Time
24 kWh = 3,7 kW x 7 h ±

A regular Dutch power connection can recharge 3.3 kW in one hour. A higher charging rate is possible, but this requires a heavier network connection. A full electric model from 2008 included an on-board charger that offered higher charging rates, with a maximum of 16,8kW with AC. Together with this upgrade in charging rate, the



costs, volume and weight of the on-board charger are increasing as well. With the introduction of two new Japanese models in 2010, the charging configuration changed. The charging rate of the on-board charger is limited, and the batteries were prepared for 50 kW charging with DC. The possibility for faster charging are taken out of the EV, which reduced the costs of the vehicle itself. In the following years, the developments in charging technology resulted in higher charging rates. Pioneer Tesla is open-sourcing patents in 2014 to share knowledge for further improvements worldwide. Currently, the maximum applied charging rates are 45 kW AC, and 125 kW DC. In this report, *fast charging* refers to charging at 43kW or more, and *slow charging* is associated with all other charging rates using AC up to 43kW.

2.3 CHARGING INFRASTRUCTURE

Charging infrastructure is a necessity to facilitate driving electric vehicles. Similar to petrol cars, a supplying network for refueling is required to provide at least nationwide coverage. The main difference with charging electricity, is that power grid connections are available in every street. This section explains the different ways to charge EV's, and shows the development of the charging network of urban area in the Netherlands.

Three options for charging

The possibilities for charging can be characterized by availability, capacity, and location. The availability indicates who can use one particular charger. Three types are distinguished: private (one user, on private terrain), semi public (any or limited users, on private terrain), and public (any user, on public terrain). The capacity mainly depends on the charging rate, which indicates how many EV's can be charged within a certain time. For this research, a categorization is made based on location. Three types of locations are distinguished: *home, destination, and public*.

Charging at home requires a private driveway or garage. Only slow charging is possible here, because the charging speed is limited to the regular AC power connection. The default charging speed is 3,3 kW, and for additional investment and exploitation costs, it is possible to upgrade the power connection for a charging rate up to 22 kW AC.

Charging at destination is considered semi public, thus the charger is positioned on private terrain. A typical destination is the work location, where several users share one charger. The power connection and costs are similar to the facilities for charging at home. However, a shared charger requires a higher charging rate to provide sufficient capacity for multiple users. In contrast, the costs of this charger can be shared over a larger amount of users.

Public charging is available for every user. A variety of locations is possible: residential area, parking locations, along the road, and near highways. Users without access to private or semi-public chargers, are strongly depending on public charging infrastructure. Slow- and fast charging are possible, depending on the investment the initiator is willing to make for the power connection and the necessary facilities.

A growing network of public AC chargers

The development of public charging infrastructure in the Netherlands was initially ahead of the EV volume. Up to 2010, only a limited number of electric models were available for the Dutch market. The demand for public charging infrastructure was therefore still limited. New EV models with trend setting technologies are developed in the United States and Japan. This provides future prospects for the upcoming EV market in the Netherlands. In 2009, one year before new EV models become available for the European and Dutch market, the first public slow chargers are realized.

By June 2011 approximately 500 public slow chargers are installed throughout the Netherlands. By the end of the same year, this number is doubled. Municipalities started with financing the first public chargers in cities. Individual EV drivers can request for a public charger close to home, and the municipality subsidies the charger. The main initiator for installation and exploitation of these chargers, is a form of collaboration between a number of Dutch utilities. Large municipalities, such as Amsterdam and Utrecht, initiated the installation of chargers in their urban area. In 2012, one year after the introduction of fast DC charging, the first fast charger is installed. The realization of fast chargers along the Dutch highways started in 2013. Both the number of EV's as public chargers is increasing significantly. Mid 2014, the RVO [2014] registered 12.500 (semi)public chargers, and the number of private chargers is estimated on 18.000.

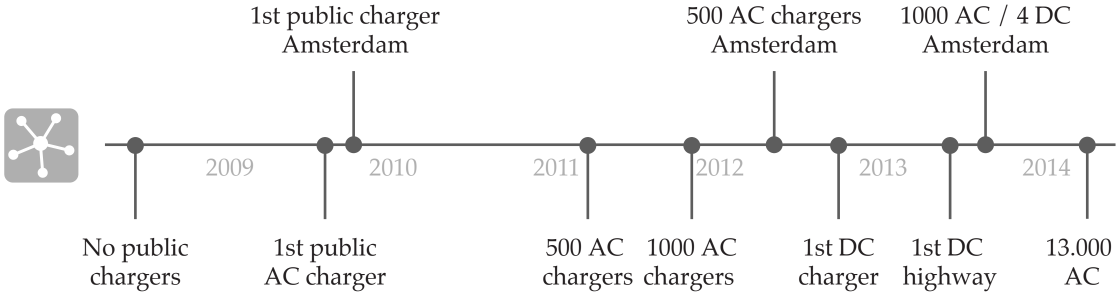


Figure 6 – Timeline: developments in public charging infrastructure

2.4 FINANCE

The automotive industry and governments are increasingly investing to contribute to the further development of electric vehicles, technology, or charging infrastructure. Simultaneously, production costs are decreasing. This section elaborates on the investments of main stakeholders, and on the developments of costs.

From government subsidies towards private investments

The automotive industry is making world wide investments, primarily in the development of new EV models and improvements in technology. After a phase of testing and small scale production, OEM's in the United States and Japan start serial production. Nissan is in 2011 the first manufacturer that invests in a new production plant in Europe. Research and development continues worldwide, and in the same year the European automotive market prepares for producing electric models as well. The investments in technology are characterized by the opening of the first new battery plant for Nissan in the United States.

The Dutch government promotes the adaption of EV's by contributing in the costs for vehicles and charging infrastructure. Currently, the market price for EV's is relative high compared to conventional petrol cars. On a national level, the government promotes consumers to purchase EV's by providing subsidies. Driving EV's is further promoted by the appliance of tax regulations that reduce the yearly costs.

Local governments also have various initiatives to stimulate the adoption of EV's. For instance, the municipality of Amsterdam installed the first public charger in 2009, and provided parking and charging for free. In 2011, a public car sharing program is

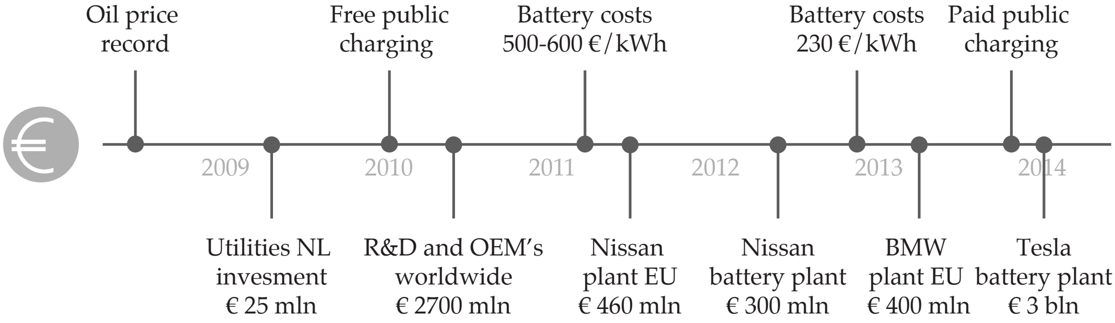


Figure 7 – Timeline: market investments and development in costs

initiated with 200 EV's divided over Amsterdam. Subsidies are available to support in the realization of charging facilities, in particular for (semi) public slow chargers.

Companies and utilities also make investments to expand the charging infrastructure. The first public charger is installed in 2009 by E-laad, an collaborative organization of multiple Dutch utilities. In the following years, E-laad is installing and exploiting the majority of public chargers in urban area. Other companies enter the market in the following years and offer various solutions for public and private charging.

The fall of battery costs

The purchase price and the user costs are important aspects for consumers to consider driving an EV [G4, 2014]. Government subsidies help to reduce the purchase price. This however does not influence the production costs of EV's. A decrease in the costs of batteries makes electric vehicles more cost competitive with conventional cars [Hensley et al., 2012]. The battery costs of EV models in 2010 range from 500 to 600 €/kWh. Technological developments and benefits from scale economies contribute to a decrease in costs [BCG, 2010]. The most recent EV models now have battery costs in between 200 and 250 €/kWh. Recently, Tesla announced the construction a new factory for lithium-ion batteries. With level of scale benefits, the OEM expects to further reduce the battery costs to 100 €/kWh in 2020.

What is the price for charging?

The user price for charging depends on the location and charging rate. The price for slow charging at home is 0,23 €/kWh, and the price for the required private charger is on average 1500 euro. There are approximately twenty providers of public charging, who use different pricing models. On average, the price for slow charging is 0,28 €/kWh, and for fast charging 0,58 €/kWh.

2.5 POLICY

The policy of governments influences the adaption of EV's on different levels of scale. Both national and local Dutch governments apply different measurements to reach their environmental targets. This section explains the motives to stimulate electric transport, and the targets are quantified. Hereafter is briefly explained what measurements are used in general.

National goverment stimulates more EV's

On behalf of EU regulations, European car manufacturers and national governments have to find solutions to meet environmental targets. The electric vehicles help car manufacturers to reduce the CO2 emissions, and meet the norms for 2015. For the Dutch government, EV's are a possible innovation that helps to reduce sound- and emission levels.

Targets set by governments provide an indication for the quantity of EV's that can be expected for the coming years. Germany, which has Europe's largest automotive industry, aims for 1 million EV's in 2020. The Dutch government aims for 200.000 EV's in 2020, and 1 million EV's in 2025 [RVO, 2011]. This corresponds with a EV market share of approximately 14% in 2025.

On national level, the Dutch government stimulates the purchase of EV's by temporary subsidies and tax regulations. Financial incentives, especially subsidies, are identified as being necessary for EV's to reach a mass market [Hidrue et al., 2011]. The subsidies lower the purchase price for consumers significantly, and tax regulation reduce the yearly user costs. Policy measurements are subject to changes and the amount of incentives is changed over the years.

The development of a nation wide charging infrastructure is driven by entrepreneurs and local governments. The governments supported by making changes in the Dutch petrol law. This allows the market to offer electricity for EV's at service areas along all highways in the Netherlands. The tender for building permits of the highway locations dated from 2012, and the years thereafter several new market parties installed fast chargers here.

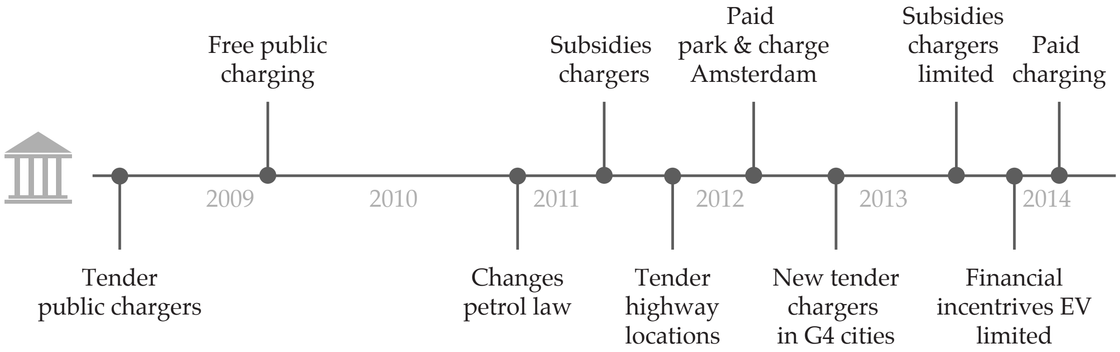


Figure 8 – Timeline: policy measurements in the Netherlands

Municipalities start with public chargers

The regulations and targets for improving the environment also apply for local governments, such as provinces and municipalities. For municipalities, EV's offer the potential to improve urban air quality [Brady, 2011]. The municipality of Amsterdam therefore stimulates electric transport, and aims for 40.000 EV's in 2020 [Amsterdam, 2009]. The G4 municipalities have various initiatives to stimulate EV use. Supporting and enabling the build-up of public charging infrastructure is a feasible and effective policy option for urban area [Sjoerd Bakker; Trip, 2013].

The development of public charging infrastructure in urban area is initiated by provinces and municipalities in 2008. A tender starts for 4.500 public chargers in 70 municipalities. The first chargers are installed one year later and 1000 chargers are realized by the end of 2011. EV users who cannot install a private charger at home, can apply for a public charger. The application is submitted to the municipality, which then starts a procedure to decide if, and where this charger will be placed. Currently, the planning and distribution of public infrastructure in cities is mainly controlled by municipalities [Van der Beesen, 2014].

At the moment, the majority of all municipalities do no longer have budget or policy for realizing new public chargers [Natuur&Milieu, 2014]. Subsidies for installing chargers are limited, and the use of public charging infrastructure is no longer available for free. Furthermore, the Dutch Authority for Consumers and Markets (ACM) states that utilities are no longer allowed to directly facilitate public charging infrastructure. For fair competition, the installation and exploitation of public chargers is gradually assigned to private market parties.

2.6 TRENDS IN ELECTRIC DRIVING AND CHARGING

Growth in demand and supply

The developments of the emerging EV market became visible in the Netherlands from 2011, when the first 1000 EV's are sold. Figure 9 illustrates the increase in volume of registered EV's in the Netherlands for the following years. The volume tripled with an increased of more than 20.000 electric passenger cars in 2013. OEM's worldwide enable further growth by making investments in mass production facilities. By August 2014, the models that represent the top 5 in sales volume, sold together 180 FEV's, and 680 SEV's. The Dutch governments aims for a further increase, and set a target of 1 million EV's on the road by 2025.

The development of public charging infrastructure initially anticipates on the number of EV's in the Netherlands. There is a strong growth in the number of public chargers in the past few years (figure 9). Approximately 2200 new installed public AC chargers in 2013 resulted in a growth of 60%. There is no nationwide target that states the number of public chargers.

Over the past four years, the volume of EV's increased more than the volume of public chargers. The volume of EV's exceeded the number of public chargers in 2012. Currently, the national ratio between public chargers and EV's is approximately 1:3. Publications from media and user survey results [G4, 2014] indicate that respondents (64%) still experience a shortage of public charging infrastructure. There is uncertainty related to the question whether this possible shortage of charging infrastructure will increase in the near future [MEZ, 2014].

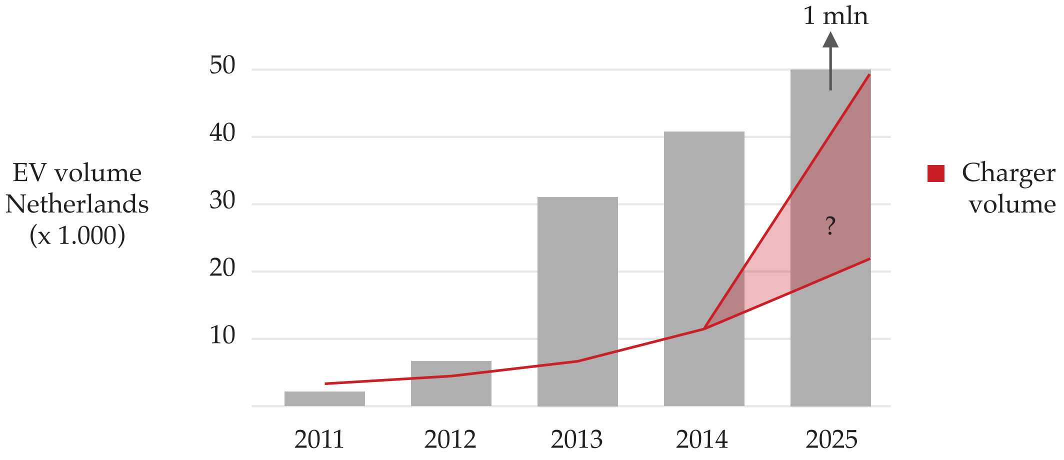


Figure 9 – Quantity of electric vehicles in the Netherlands [RVO, 2014]

Technical improvements enable more and faster charging

There are two main developments in technology that will change charging EV's in the future (section 2.2). First, the increase of battery capacity, which improves the driving range. Figure 10 indicates how much energy can be stored in the EV's with the best battery capacity of each year. EV models that become available in the near future, should technically be able to offer a battery capacity of 85 kWh or more. There is a significant positive correlation between an increase in battery capacity, and an increase in energy transfer per charging session [Spoelstra, 2014]. Considering the charging rate remains constant, the average time to recharge the EV's battery will increase as well. However, the development of DC charging provides possibilities to further increase the charging rate (figure 11). As a result, the time to recharge can be reduced.

2.7 CONCLUSION AND DISCUSSION

The demand for public charging infrastructure strongly depends on the quantity of electric vehicles on the road. The other way around, the availability of charging infrastructure also influences the further growth of the EV market. The adaption of EV's on global and national level are influenced by the described five developments in certain extent.

Literature study learns that technological improvements, charging infrastructure, presence of production facilities, and financial incentives are to be significant and positively correlated to a country's electric vehicle market share. Despite this relation, neither of the developments will guarantee high electric vehicle adoption rates [Sierzchula et al., 2014]. For this research, the future volume of EV's on Dutch roads is considered as an uncertainty. However, the strong growth of EV's, and the technological improvements that allow more and faster charging, indicate that the demand for charging is likely to increase in the near future.

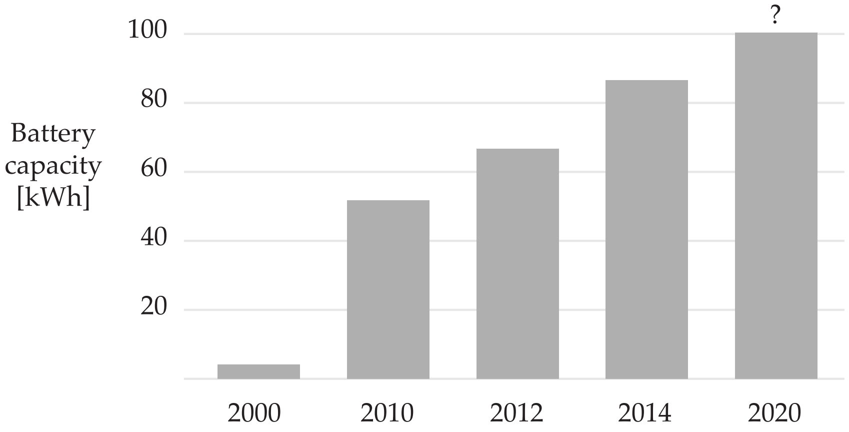


Figure 10 – Worldwide development of battery capacity

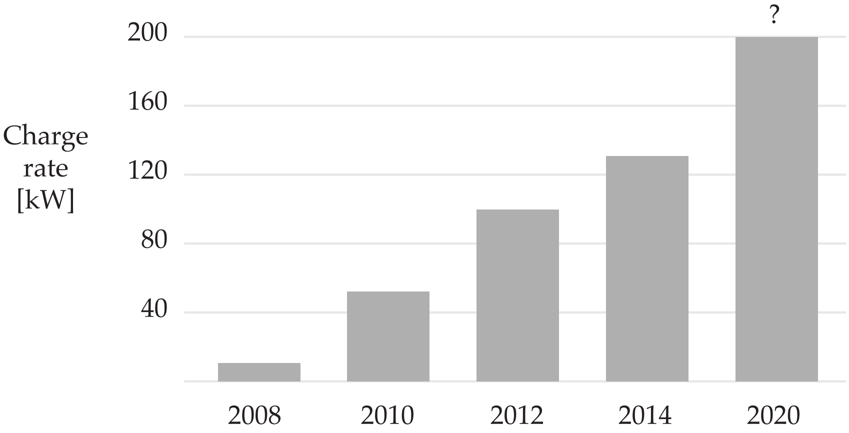


Figure 11 – Worldwide development of charging rate

Part B

EXPLORATION

3

THE SCENARIO MODEL

Currently, both private and public parties are involved with expanding the network of public chargers. On a national level, there are no specific targets set by the government. Municipalities have their own policy regarding the development of public charging infrastructure, and new chargers are installed on demand. A plan for providing sufficient public charging infrastructure in the future is still missing.

This chapter explains the method and the design of a scenario model for public charging infrastructure. Given the variables that determine the demand, the model provides an estimation of how many public chargers are needed in urban area. A method is developed to distribute the total demand and estimate the market share for public charging. The model allows municipalities and market players to create various *what if* scenarios, by changing demand characteristics (for example, EV volume). Comparing what-if scenario's with the current situation, will indicate the size of the *capacity gap*: the difference between demand and supply of public chargers.

First is explored what information is necessary to quantify the demand for charging. The previous chapter explained the various developments that influence the EV market. The uncertainty of certain market developments is taken into account by including variables, that the user can change. A user interface is designed to deliver the model as an easy tool, that is suitable for any user. This allows municipalities and market players to gain access to this information, and gather knowledge and insights as well. The user interface is shown in the next chapter, which also elaborates on the findings that are gained by inserting data in the model.

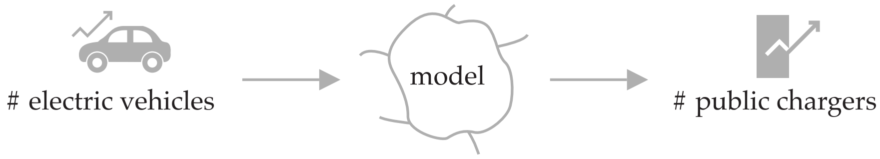


Figure 12 – The basic input and output for the model

3.1 MODEL SCOPE

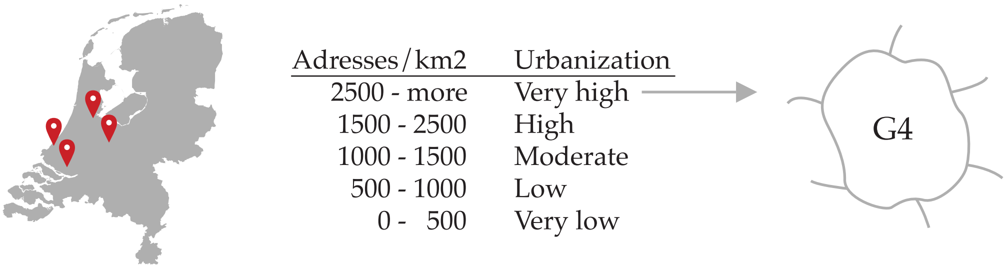
The model is designed in a way that any user can insert data for one particular geographically defined area. The method for calculating demand and supply is universal. The distribution of charging demand to the supplying infrastructure is dependent of urban characteristics. Every model is a simplification of the reality, therefore the number of constant values and input variables is limited.

For this research, the model scope is limited by selecting one type of geographical area in particular. The focus is on areas with a very high degree of urbanization. The Central Bureau for Statistics (CBS) categorizes five classes of urbanization, based on the amount of addresses per surface area (figure 13). For the Netherlands, four cities are selected that have a very high degree of urbanization. The cities of Amsterdam, Den Haag, Rotterdam, and Utrecht, are often referred to as the 'G4 municipalities'. These four cities have the greatest number of inhabitants and electric vehicles in the Netherlands

The model works with the assumption that all EV's for one city in particular, only charge in this city. There is no interaction with any influence outside the boundaries of the model. Realistic is that EV's will charge in various cities.

3.2 MODEL STRUCTURE

The structure of the model can be divided into three parts: demand, distribution, and supply (figure 14). The basis for the model is the energy balance between demand and supply, expressed in kWh. First, the total energy demand for charging all EV's is calculated, given a variable number of EV's. Second, the energy demand will be distributed over the possibilities for charging. These possibilities are categorized by defining three types of locations: home, destination, and public. Common examples of destination are office or retail locations. Two elements for performing this distribution are essential here: where EV users *want* to charge, and where they *can* charge. This determines which share of the total energy demand is attributed to public charging infrastructure. Finally, an estimation can be made for the number of chargers that are necessary to meet the energy demand. Comparing what-if scenario's with the current situation, will indicate the size of the capacity gap: the difference between demand and supply of public chargers.



Adresses/km2	Urbanization
2500 - more	Very high
1500 - 2500	High
1000 - 1500	Moderate
500 - 1000	Low
0 - 500	Very low

Figure 13 – Selection of study area: G4 cities with very high urbanization grade

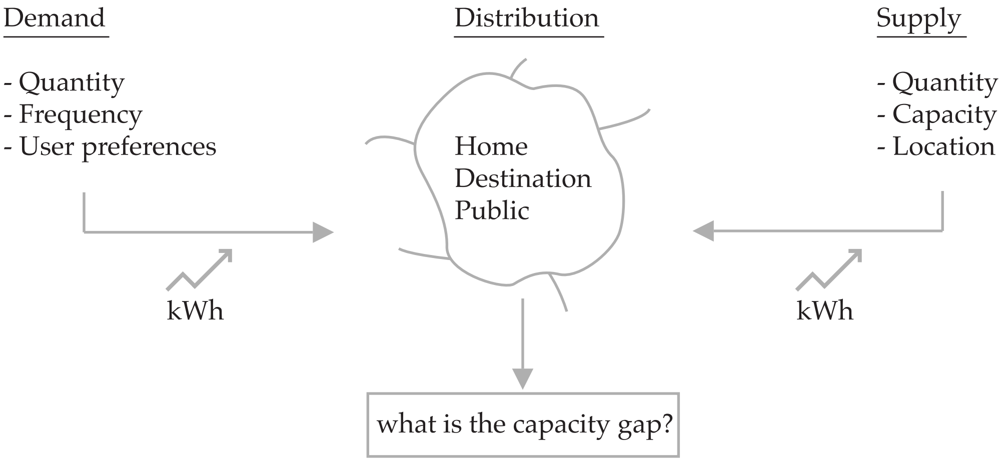


Figure 14 – Model structure based on energy balance between demand and supply

3.3 DEMAND FOR CHARGING

Three aspects are relevant to identify the total demand of charging infrastructure: *how much, how often, and where?* The quantity of energy is the main input factor for the calculation model. The frequency indicates how many charging sessions EV users need. The user preferences are a measure to identify at what type of location EV users prefer to recharge. The following units are consistently applied in the model: [kWh] for energy, [km] for distance, and [months] as default time unit. Figure 15 shows how the quantity and frequency are calculated, and indicates the factors which are relevant to quantify user preferences.

Quantity	Frequency	User preferences
- EV volume	- Battery capacity	- Price
- Distance	- Energy usage	- Time
- Efficiency	- Charging rate	- Availability
		- Distance

Figure 15 – Three aspects to determine demand for charging

Quantity

The quantity of energy is expressed in kWh, and is calculated as a multiplication of the EV volume, the average distance that is driven full electric, and the efficiency of the engine. For the model, the EV volume is the main variable that significantly influences the outcomes. A general distinction is made between FEV and SEV, because input values (for example battery capacity, or electric driven kilometers), are significantly different. Similar to the EV volume, the market share of FEV and SEV depends on many factors (chapter 2). The distribution between FEV and SEV is therefore variable as well. The travel distance is a constant, based on statistics of driving patterns for passenger cars, powered by petrol, diesel, or electricity. The efficiency of the electric engine is a constant average factor. A higher efficiency leads to less energy consumption per kilometer.

Frequency

The frequency is an informative indication of how often an EV user needs to recharge the battery per month. The energy usage is a constant average value, based on the distance and efficiency. The battery capacity is a constant value, calculated as the weighted average of all EV's in the Netherlands.

User preferences

This section is included to gain a better understanding of why users prefer to charge at one type of location over one other. First, the underlying factors are identified. Thereafter, a proposed method to quantify these factors is explained. This exploration is a suggestion for attributing charging demand to a particular type of location, additional to the attribution that is derived from survey data.

Insights in where EV users (would) prefer to charge, or where they can charge, can be explained by analyzing the charging transactions at the present network of chargers. Collected data of charging sessions are therefore input for the model. However, motivation factors that influence users' choice for charging at one particular type of location, are not yet identified.

The charging preference is subjective, and depends on the user's appreciation of price and ease of charging [Spoelstra, 2014, Franke and Krems, 2013]. The price of charging is generally expressed in €/kWh or €/time, including or excluding a startup fee. An quantitative comparison between different providers and price models is therefore possible. The ease of charging can be defined as a collection of factors that influence the user's choice. Three main differences between the charging possibilities are relevant factors: time, availability, and distance.

The time factor covers waiting time and charge time. There is no waiting time for the private charger at home. For public charging, the waiting time depends on the availability of one particular charger. The availability can be expressed as a ratio between the number of EV's that share a single charger, and the capacity of a single charger. Theoretically, the capacity depends on the charging rate. However, reduction factors have to be taken into account to include practical issues (for example charger failure, or parking after charging). The additional distance an EV driver has to travel to reach a charger, can be determined by calculating the coverage rate in [chargers/km2] or [km/charger].

The factors for describing user preferences, and the required data to attribute values to these factors can now be explained. The proposed method for rating the charging alternatives is by performing a multi criteria analysis. Xu et al. [2013] applied this method to select locations of charging stations. Similar influence factors are applied for this approach, but further research is necessary to support the other weight factors for this research. A survey among EV users can help to identify how important EV drivers find these influence factors.

3.4 DISTRIBUTION OF DEMAND

In three steps, the total energy demand is distributed over three type of locations. Charging behavior is not only depending on mobility behavior and personal preferences, but also depends on the physical possibilities to recharge [Movares, 2013]. First, four types of users are defined, based on their possibilities for charging. Hereby, the user preferences are quantified for every user type. Second, the supply constraints for every location type are determined. Finally, the market share for every type of location is calculated.

Users & preferences

Four user types are distinguished, based on the locations where they are able to recharge the battery of their EV. Figure 16 indicates where EV users *want* to charge (first, second or thirth choice), given their situation. For example, user type C can charge at destination, but has no possibility to charge at home. Based on the motivation factors as explained in section 3.3, user C prefers to charge mostly on destination, and a the second best choice is a public charger.

User types		Home	Destination	Public
A	🟩 🟩	1st	2nd	3th
B	🟩 🟥	1st	2nd	3th
C	🟥 🟩	-	1st	2nd
D	🟥 🟥	-	2nd	1st

Figure 16 – Where do user prefer to charge, given their situation.

Supply constraints

Supply constraints limit the possibilities where EV users *can* charge. Using a parking based assignment method, the capacity and location of charging stations can be optimized [Chen et al., 2013]. Home charging requires a private parking space and a charger for personal use. The amount of users that is able to charge at home is therefore limited to the number of private parking spaces. Public charging infrastructure is for every user, and is in particular important for users who cannot charge at home or destination. The model therefore has no constraints included for public charging. For charging at destination, there is not yet an approach to define a solid limitation.

Market share

The market share for public charging infrastructure is determined by combining the user preferences and the supply constraints in relative values. First, the relative quantity of users per type is calculated. For example, the market share of user C (cannot charge at home, can charge at destination) is calculated by (1 - C_{home}) x $C_{destination}$, where where C is the constraint factor.

An estimation of the relative market share is calculated by multiplying the user share with the user preferences. The solution for this distribution is independent from the volume of EV's. The results in absolute values are directly derived from the amount of EV's that is inserted in the model. The total energy demand in [kWh] for public charging infrastructure is the final result.

3.5 SUPPLY OF PUBLIC CHARGERS

The supply of public charging infrastructure that is needed to match the demand, depends on *how* to supply and *where* to supply. Given the total energy demand and the capacity of a single charger, the of number required chargers can be calculated.

Capacity

There are various types of chargers, which vary in connection and charging speed. The majority of public slow chargers now has a charging rate of 7,4 to 11 kW. Fast chargers currently have a charging rate of 50 kW. The possibilities in the model are limited to two options: slow- and fast charging.

Theoretically, the maximum capacity of a charger can be derived by multiplying charging rate and time. The result is the total energy [kWh] one charger can transfer given a specified time. This however, does not take into account reduction factors such as the realistic charging rate, and chargers that are still occupied after charging. Several assumptions have to be made, to determine a realistic capacity. An alternative approach for determining a realistic capacity, is by analyzing the current usage and occupancy of public chargers.

Location

For determining the best location of a charging station, various optimization methods are developed [Xu et al., 2013, Chen et al., 2013, Sadeghi-Barzani et al., 2014]. For the purpose of this research, it is sufficient to have an estimate of the total chargers.

3.6 MODEL RELIABILITY

The EV volume that is inserted in the model is directly proportional to the calculated quantity of energy demand. This also applies for other variables (distance, efficiency, battery capacity, energy use), because the energy demand is the result of a basic multiplication. The quantitative result of the equation can be easily checked by performing this calculation by hand. Naturally, the usability of the model outcomes depends on the values that are given to the input variables. These values are supported in chapter 4. The default values are informative for the user, and the user is able to change this input. In the development process of this model, it appeared that adding more data or variables did not lead to more useful results.

Sensitivity analysis

A sensitivity analysis is performed to evaluate how strong the distribution of market share depends on changes in supply constraints and user preferences. Supply constraints (section 3.4 and 4.2) directly affect the relative share of user per type, and indirectly affect the distribution of market share. The effect of changing the supply contraints is identical for the results in EV volume, energy quantity, and market share. Figure 17 visualizes the changes in market share as a result further limiting the supply constraint for home charging by steps of 10%. Figure 18 is a similar visualization for limiting the supply constraint for charging at destination. Note the differences in scale on the horizontal axis, which indicates the relative deviation compared to a basic *what-is* scenario (home constraint 40%, and destination constraint 50%).

Changing the home constraint with 10% has a strong influence on the distribution of demand (more than 10%). The input value of the home constraint is based on the ratio private parking: public parking, thus can be examined accurately. The effect of changing the user preferences is less significant. User preferences are now based on user survey data. The reliability of this data can be improved by validating with an additional study as proposed in section 3.3.

Figure 19 shows the deviation in outcomes when the preference for home charging is reduced with 10%, and charging at destination and public are both increased with 5%.

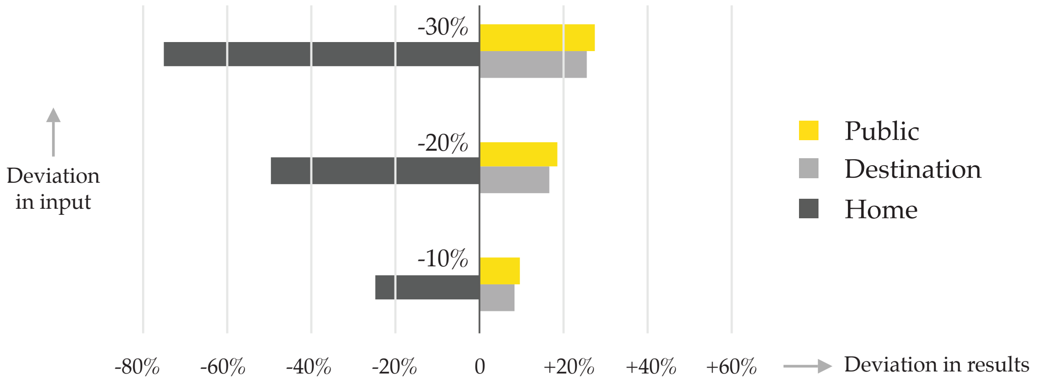


Figure 17 – Deviation of model outcomes as a result of changing *home* constraint

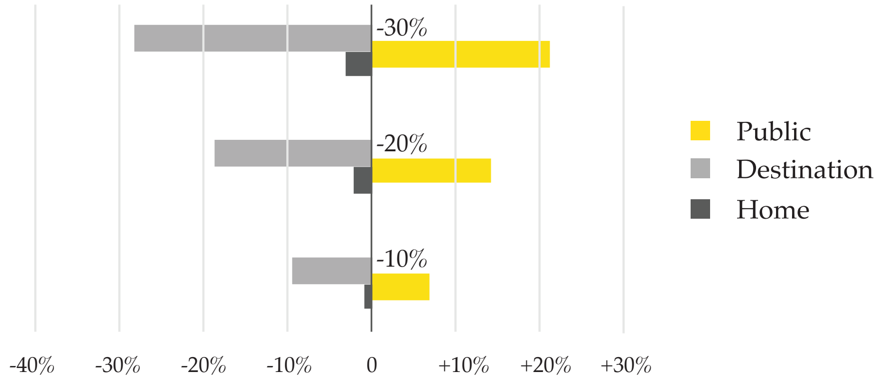


Figure 18 – Deviation of model outcomes as a result of changing *destination* constraint

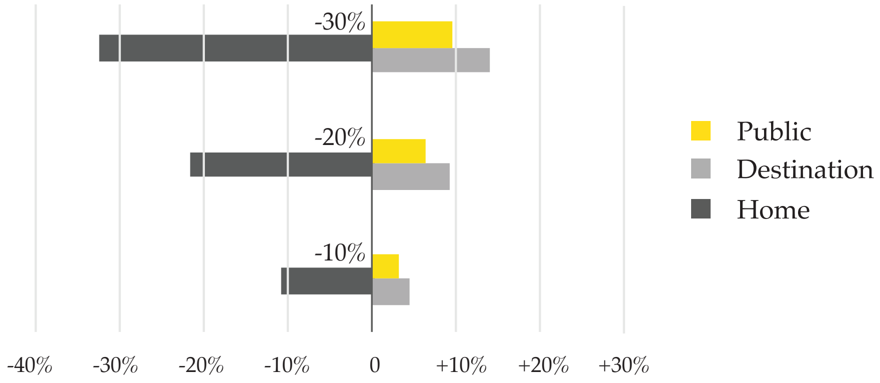


Figure 19 – Deviation of model outcomes as a result of changing *user preferences*

There is a linear relation between any input variable and the model outcomes, because only basic multiplications are used.

The results of the model can be further validated by comparing the results with information that is available from other user surveys and data analysis, which are not used as input source for this model.

3.7 CONCLUSION AND DISCUSSION

An approach for comparing the energy balance between demand and supply of urban charging infrastructure is presented.

This study looked at a city's total charging infrastructure, and excluded the effects chargers outside the model boundaries. Second, the influence of a heterogeneous distribution of charging stations over the study area is not taken into account. Further research into these effects can contribute to an optimization of the sizing and placing of fast charging stations.

The model is generalizable for other geographic areas as well, since the calculations in the energy balance are universal. For other cities with high urbanization grade, obtaining an inventory of private parking places is required to perform a similar calculation. Additional context information can be collected from the CBS database. For less urban or rural areas, additional research is required to determine correct input variables such as distance, and user preferences. Further recommendation regarding the model results are explained in chapter 4.

4

THE CAPACITY GAP

A model is developed that can estimate the demand for public charging, and indicates how many chargers are required to meet this demand. The model is useful to generate *what-if* scenario's, and the outcomes can be compared with the current situation. This enables to determine up to what extend there is a capacity gap between supply and demand.

This chapter explains the result from the exploratory study, by going through the user interface of the model step by step. The user interface is a dashboard where all data is put together, to make the model suitable for any user. The model views in this chapter only show data for a general what-is scenario for 2014. Conclusions drawn upon comparing this scenario with a *what-if* scenario are explained in text for Amsterdam only.

Creating various *what-if* scenarios, and see the effects of changing the input data, is therefore recommended. Blue colored text indicates that the user can change the input. Additional information is provided in extra tabs, which are accessible via the [?] signs. Input values are based on a collection of user surveys and data analysis. Appendix **??** provides additional information this data.

4.1 DEMAND IN THE NETHERLANDS

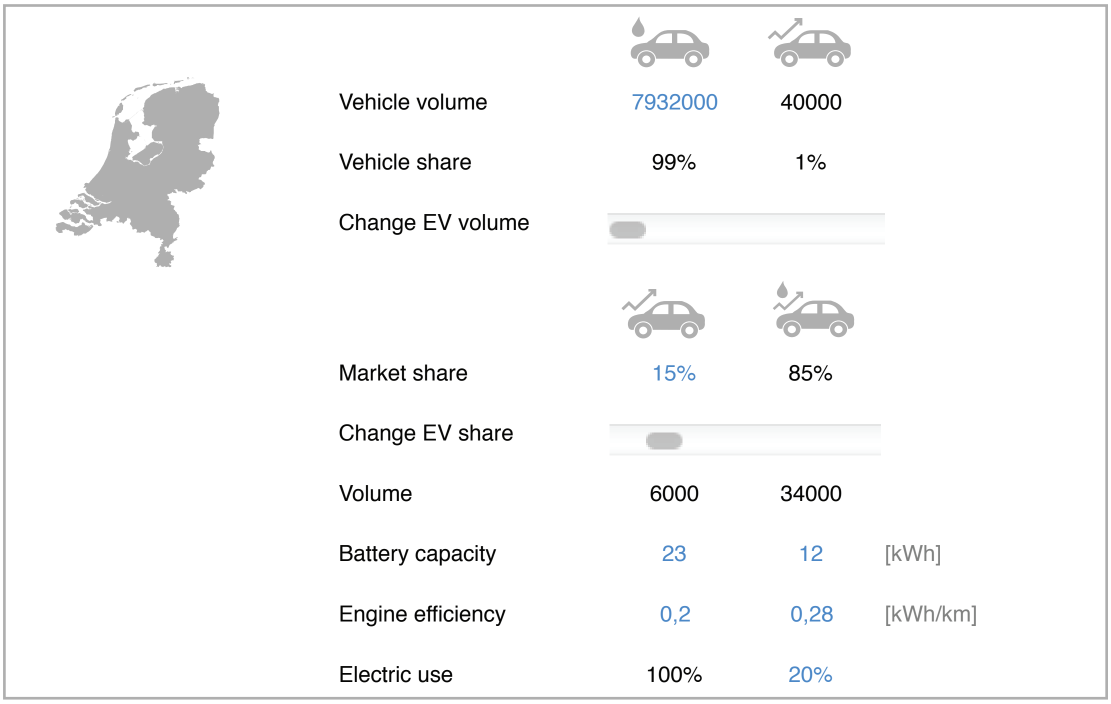
The model starts with input factors that define the energy demand for the Netherlands (figure 20). There are over 7.9 million vehicles in the Netherlands, and approximately 1% is now electric. The stock of EV's is growing faster than the total stock of vehicles. Approximately 15% of all EV's are full electric. The battery capacity and the engine efficiency are constant values, based on a weighted average of the top 5 models in the Netherlands. The average capacity of a FEV now doubles the capacity of a SEV. The engine of the average FEV is more energy efficient than a SEV. Drivers of an SEV make use of electric propulsion for approximately 20% of the distance they drive [G4, 2014].

4.2 URBAN CHARACTERISTICS

After configuring the general data, the model focuses on urban area (figure 21). First, a selection has to be made for one of the G4 cities. Statistics from CBS [2014] are collected, such as the number of inhabitants, households, and cars. This is additional information to understand the context. The national share of G4 cities in inhabitants (13%), households (15%), cars (10%), and EV's (12%) is distributed almost equally. The number of FEV's is relative high in the G4 cities (20%). The number of cars per household in the G4 (0.75) is low compared to the average of rest of the Netherlands (1.1).

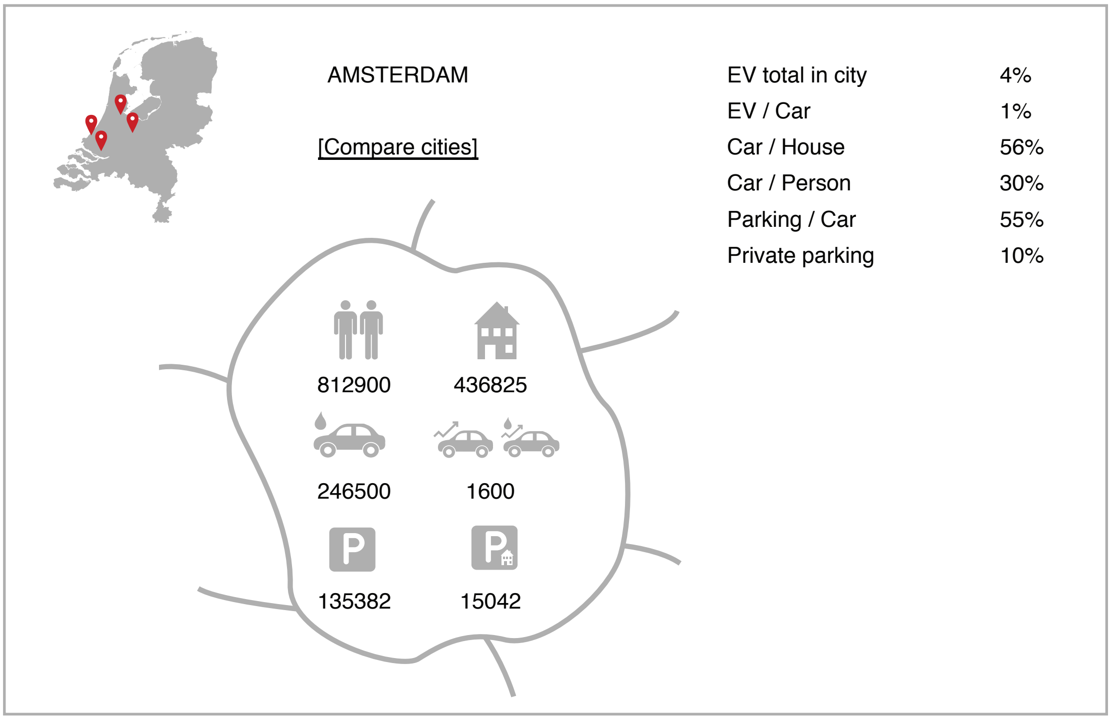
As indicated in section 3.6, the availability of private parking is an important factor for the distribution of demand. Most recent inventory study of parking area in the Netherlands is performed by Van Dijken [2002]. The estimated total parking places in the Netherlands is 16.5 million, that is more than 2 parking places per car. Approximately 9 million parking spaces are identified as public (54%), and there are 7.5 million private parking spaces (46%) [P1, 2011]. This share of private parking is the lowest in a comparison between 7 European countries, where the average is 75% [Bunzeck, 2011].

In urban area, the possibilities for parking are more limited. A preliminary inventory study of parking places is performed for the G4 cities. On average, there is 0.5-0.6 parking place per car. Approximately 10% of the total parking capacity of the four cities, is private parking.



Vehicle volume	7932000	40000	
Vehicle share	99%	1%	
Change EV volume			
Market share	15%	85%	
Change EV share			
Volume	6000	34000	
Battery capacity	23	12	[kWh]
Engine efficiency	0,2	0,28	[kWh/km]
Electric use	100%	20%	

Figure 20 – Demand characteristics for the Dutch EV market.



AMSTERDAM

[Compare cities]

EV total in city	4%
EV / Car	1%
Car / House	56%
Car / Person	30%
Parking / Car	55%
Private parking	10%

Figure 21 – Urban characteristics based on data from CBS [2014] and Amsterdam [2014]

4.3 QUANTITY AND FREQUENCY OF CHARGING

Now the preconditions are set, the quantity and frequency of charging are calculated (figure 22). The EV volume for the selected city is derived from a constant percentage of the total EV volume. RWS [2014] provided current EV volumes for the G4 cities.

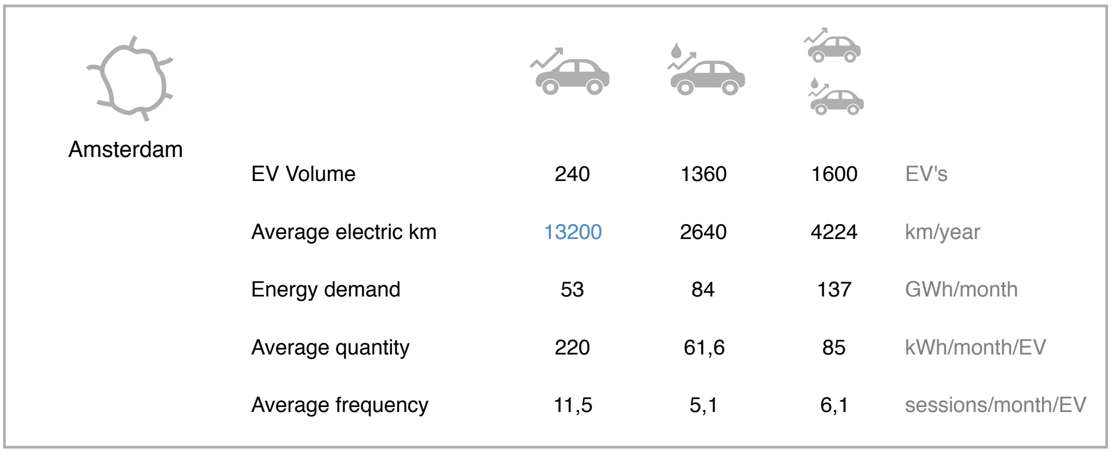
The average electric kilometers that are driven in urban area are considered similar to the national average. CBS statistics indicate that the distance of the average daily trip of vehicles in very urban area drive is 60% less than the average distance for most rural area. In contrast, EV drivers in the G4 cities estimate to drive on average 250 km/week [G4, 2014], which corresponds with the national yearly average for all vehicles (13.200 km/year). A more elaborate analysis of driving patterns, such as Pearre et al. [2011] performed for the U.S. market, could enhance this result.

The majority of EV users (95%) starts charging when the battery state is between 15% and 80% [Smart, 2012, Franke and Krems, 2013]. FEV drivers will not charge their batteries from zero to maximum. SEV drivers can start charging from a 0% battery state, because they can continue driving on petrol. The calculated value for charging frequency is therefore increased with 20%. Data analysis of Spoelstra [2014] indicates that EV drivers that are dependent on public charging infrastructure, have a charging frequency average of around 2,8 times a week. This is in line with the calculated frequency of 11 to 12 charging sessions a month.

4.4 ATTRIBUTION OF CHARGING DEMAND

The interpretation of user preferences is subjective, as explained in section 3.4. The interpretation of the values as presented in figure 23 are supported by an European user survey of Bunzeck [2011]. This survey examines the preferred charging location, taking into account whether the car owners have a private parking place or not. Overall, charging at home is strongly preferred. In the Netherlands, the majority of respondents prefer a combination of home charging and public charging.

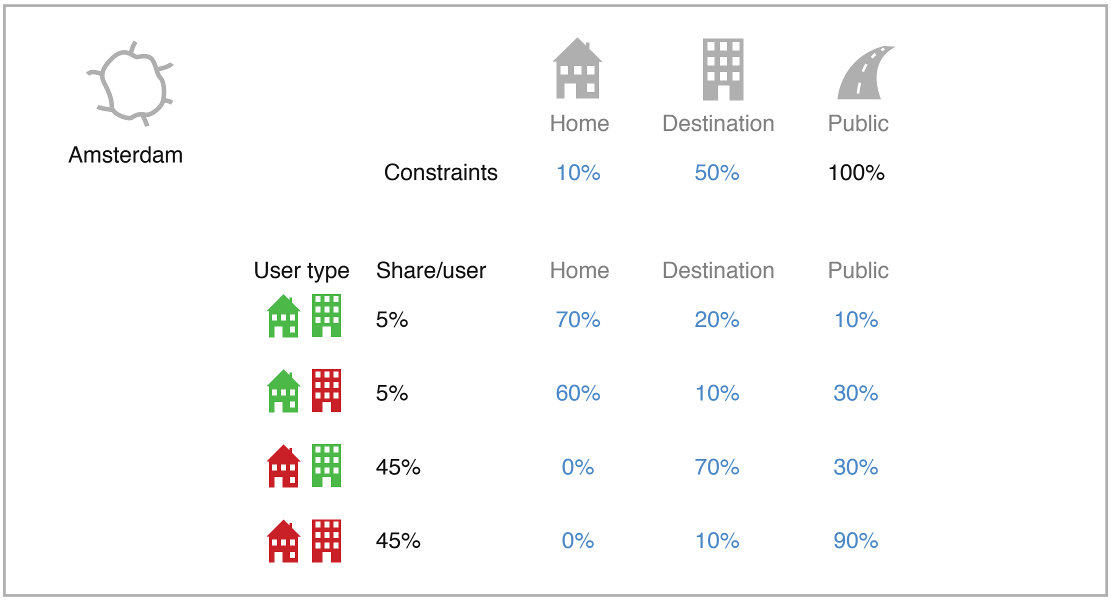
These preferences are consistent with results of the G4 survey. Currently, EV drivers in the G4 indicate to charge 43% at a private charger, 54% at work, and 81% at a public charger [G4, 2014]. There are only minor differences in the results between the four cities. Charging preferences and behavior are reflected on the volume of EV's and the number of private parking places in the four cities. It can be concluded that the share of EV drivers that is able to recharge at home will decrease when the total EV volume is increasing.



Amsterdam

EV Volume	240	1360	1600	EV's
Average electric km	13200	2640	4224	km/year
Energy demand	53	84	137	GWh/month
Average quantity	220	61,6	85	kWh/month/EV
Average frequency	11,5	5,1	6,1	sessions/month/EV

Figure 22 – Quantity and frequency of recharging EV's in selected city



Amsterdam

	Home	Destination	Public
Constraints	10%	50%	100%

User type	Share/user	Home	Destination	Public
🟩🟩	5%	70%	20%	10%
🟩🟥	5%	60%	10%	30%
🟥🟩	45%	0%	70%	30%
🟥🟥	45%	0%	10%	90%

Figure 23 – Attribution of demand over three type of locations

4.5 DISTRIBUTION OF MARKET SHARE

The total energy demand is attributed to four user types, based on the constraints for charging at home and destination. The market share of each user type is then further divided over three possibilities for charging, which depends on the average charging preferences of this user type.

User constraints of 40% for home charging and 50% for destination are applied for the 2014 scenario. This results in 44% market share of public charging. Reflecting this result for Amsterdam, approximately 690 EV's (from which approximately 100 FEV's) are making use of public charging infrastructure. Limiting the home constraint from 40% to 10%, will lead to an increase of demand for public charging to 56% (or 830 EV's).

Naturally, the results of this model are not exactly reflecting the actual situation. The model is a simplification and although all values are supported on surveys or analysis of data, the outcomes are negotiable. However, conclusions can be drawn by comparing the outcome of this model with other studies. Most important result is that this distribution gives an indication of the required public infrastructure for several *what-is* scenario's.

4.6 CAPACITY OF PUBLIC CHARGING INFRASTRUCTURE

The capacity of a public charger is determined by including the capacity that is currently used. A calculated theoretical capacity is not realistic, because several reduction factors apply. For example, more than 50% of the EV drivers does not clear the parking place after charging [G4, 2014]. The average occupancy of public slow chargers is currently about 1.0 EV per charger per day. The best occupied public chargers facilitate around three times as much [Elaad, 2014]. Fast chargers along the highways now have a similar user rate, but for the majority of time those chargers are not occupied.

Amsterdam

	Home	Destination	Public	
Volume	104	600	896	EV's
Quantity	8877	51216	76483	GWh/month
Share	7%	38%	56%	

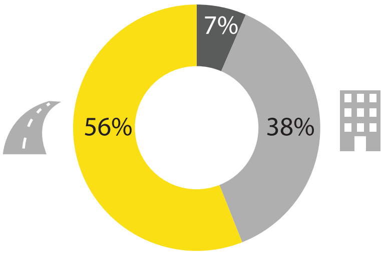


Figure 24 – Distribution of market share

Amsterdam

	Slow	Fast	
Charge rate	11	50	[kW]
Energy/session	7	12	[kWh]
Session/day	1	18	#
Occupancy	8%	54%	
Capacity/day	7,0	216	[kWh]
Chargers	364	12	#
Ratio slow/fast	31	1	

Figure 25 – Required charger capacity and quantity

4.7 CENTRALIZED FAST CHARGERS ARE MOST COST EFFICIENT

The investment and exploitation costs are a critical factor, when rating different ways of realizing large numbers of public chargers. The cost estimation in figure 26 is based on data obtained from market leaders in slow charging (E-laad) and fast charging (Fastned).

For slow chargers, the investment costs include a connection to the current power network, and the installation of a charger with two connections. For fast chargers, investment costs include a new connection towards a high voltage power network, new road infrastructure, a station with solar panels, and two chargers. The comparison excludes the development costs of the chargers and the design of a station.

The investment costs of a fast charging station are significantly higher. In proportion, the exploitation costs of slow chargers are twice the exploitation costs of one fast charging station. A correct comparison in the costs for a public charging infrastructure can be made by calculating the cost efficiency, that is in €/kWh. The costs per kWh are decreasing, when charging rate and capacity per charger are increasing [Schroeder and Traber, 2012].

- A *centralized network*, with multiple fast chargers at limited number of locations, is most cost efficient.
- A *decentralized network*, with many (slow or fast) chargers throughout the city, is not cost efficient for any number of electric vehicles, because of the high exploitation costs.

The profitability of the network strongly depends on the actual use of the capacity that is offered. The current decentralized network of slow chargers is suitable for low EV volumes only, because of relative low investment costs. A centralized network of fast chargers is necessary for high EV volumes, to offer sufficient capacity and facilitate cost efficiently.

4.8 UNDERSTANDING THE MODEL OUTCOMES

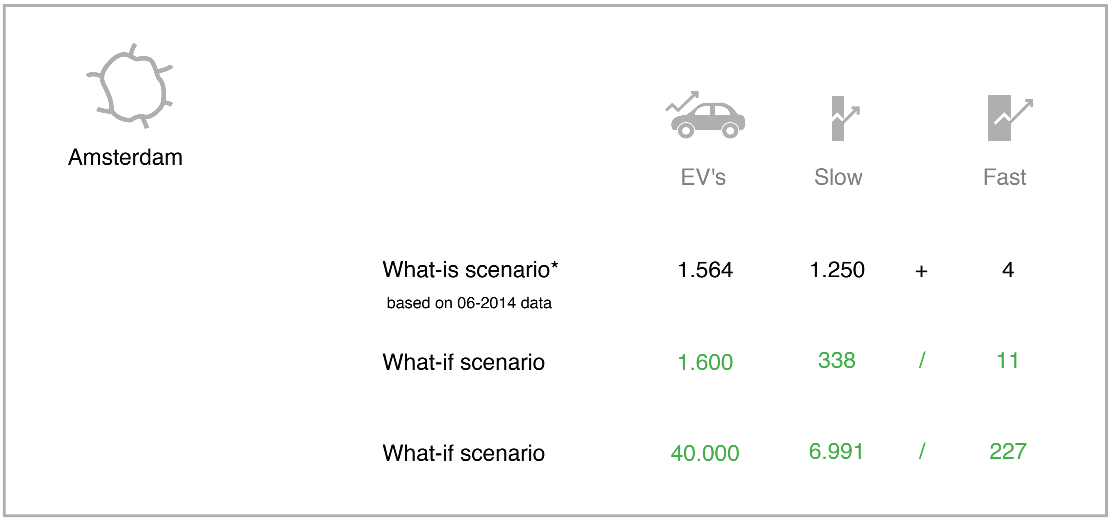
An interpretation of the model outcomes can be made by comparing the calculated number of chargers with the current number of chargers. Figure 27 shows a comparison between three scenarios that apply for Amsterdam.

What-is? Current scenario: Amsterdam counts 1250 public chargers and the number of private sold chargers is estimated on 400-500 (based on main suppliers' sales). That means the current ratio between chargers and EV's is circa 1:1. Remarkable is the discrepancy with the user survey of G4 [2014], where 64% of the interviewed EV drivers indicate there are not sufficient public chargers.

Amsterdam

	Slow	Fast	
Incremental costs:			
Investment	€ 8.000	€ 200.000	
Yearly exploitation	€ 1.200	€ 15.000	
Total costs (incremental x charger volume):			
Investment	€ 2,90	€ 1,18	million
Yearly exploitation	€ 0,44	€ 0,09	million

Figure 26 – Indicative investment and exploitation costs



Amsterdam

	EV's	Slow		Fast
What-is scenario* based on 06-2014 data	1.564	1.250	+	4
What-if scenario	1.600	338	/	11
What-if scenario	40.000	6.991	/	227

Figure 27 – The calculated required public chargers compared with the current situation

What-if? Current scenario: The model estimates that Amsterdam needs approximately 360 public slow chargers to facilitate today's demand. That is a factor 4.5 smaller than the number of chargers that is already installed. Even when the complete energy demand is attributed to public chargers only, the model estimates 650 chargers. Despite the shortage of chargers that the majority of EV users experiences, there are sufficient public chargers available to meet the complete energy demand. So there is a significant capacity gap between supply and demand, caused by underutilized chargers. This conclusion is valid for all G4 cities, and is supported by the results of a data analysis of Spoelstra [2014].

What if? Future scenario's: With a ceteris paribus assumption, the model estimates the numbers presented in figure 28, for a future scenario with 1 million EV's in the Netherlands. The required number of chargers has increased significantly. For similar utilization rates, the capacity gap will grow as well. For large numbers of chargers, as in this scenario, an underutilized and therefore inefficient charging infrastructure is not feasible.

4.9 CONCLUSIONS

The conclusions can be explained with help of the illustrative graph in figure 29.

- Two ways to provide charging infrastructure are distinguished: slow and fast charging. Currently, only slow chargers are provided in urban area. More capacity can be created by increasing the number of slow chargers or fast chargers (figure 29).
- The scenario model indicates a significant capacity gap between supply and demand of public chargers. This is caused by underutilization of the decentralized network of slow chargers at parking places in the city. As a result, EV drivers now experience a shortage of chargers.
- Increasing the effective capacity of public chargers is therefore necessary for providing an economically feasible charging infrastructure for large numbers of EV's.
- A decentralized network of public chargers is not cost efficient, because of high exploitation costs. Further development of a decentralized network of slow chargers requires thousands of cost inefficient chargers.
- A centralized network of fast chargers is a feasible and efficient solution for high EV volumes in cities, because the cost efficiency increases, when charging rate and capacity per charger are increasing. However, this can only be achieved when fast chargers have significantly higher utilization rates than the current chargers.

	Amsterdam	Rotterdam	Den Haag	Utrecht
🚗	40.000	22.000	18.000	40.000
slow	7.000	3.900	3.100	7.000
fast	230	125	100	230

Figure 28 – The outcomes for a 1 million EV scenario

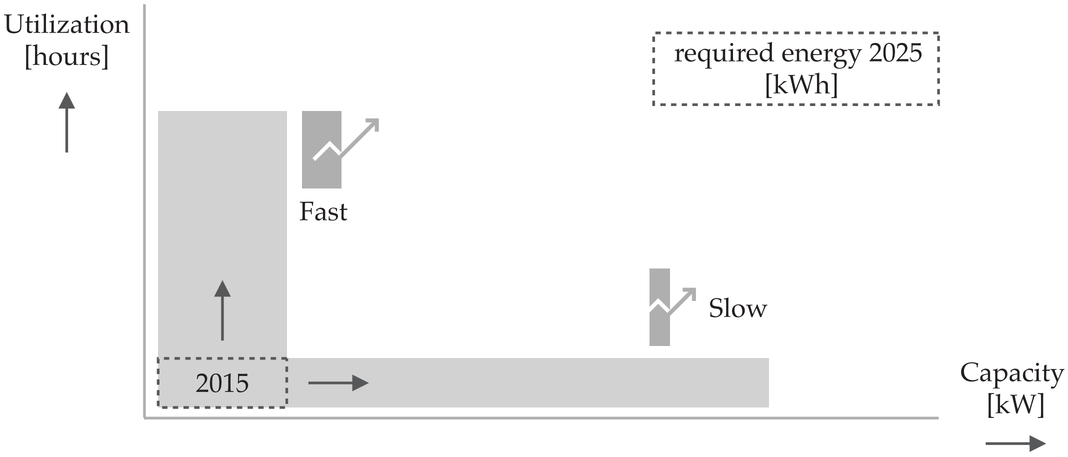


Figure 29 – Two ways to increase the effective energy supply of charging infrastructure

What is an efficient solution for charging large numbers of EV’s in urban area?

Effective energy supply = utilization x capacity

Utilization = actual usage [hours]
Capacity = # chargers x charge rate {kW]

Part C

DESIGN

5

DESIGN PRINCIPLES AND REQUIREMENTS

The scenario model indicated two targets that are important for providing public charging infrastructure for large number numbers of EV's: more capacity, and higher utilization. An efficient public charging infrastructure in terms of utilization and costs, is a network with fast chargers that at centralized locations. A charging station is designed to maximize the utility of fast chargers: EV drivers should recognize locations for fast charging as a place to stop, charge, and go. It is essential that drivers clear their position after charging, so other drivers can start charging.

In the Netherlands, fast charging stations are already realized along highway locations. The design of the stations that are developed by Fastned, require a considerable amount of space. Available space in urban areas is scarce, and therefore an alternative solution is designed.

The design for this solution is based on three main principles. For high EV volumes, a *large network* of fast chargers is necessary for providing sufficient public charging infrastructure. For uncertain EV volumes, flexible charging stations should accommodate a variable number of chargers at various *city locations*. For low EV volumes, *sustainability* is an important aspect that represents the idea of re-using stations for other purposes. Additional, it supports the idea that charging stations accommodate electric vehicles that on are propelled by clean and renewable energy.

This chapter explains the principles and requirements for designing fast charging stations in urban area. The following chapters in this design part, will elaborate on the design solution. The steps in the design process are explained in the next section. This will further explain the content of all chapters in this design part.

large network

city locations

sustainability

5.1 THE DESIGN PROCESS EXPLAINED

This section describes the process that has been followed in designing a fast charging station. Figure 30 illustrates the process of finding design requirement and solutions. Design principles are derived from the scenario model, and design requirements provide direction to the design solution. The design process iterative: requirements further limit the design solutions, and solutions help finding more detailed requirements. The upper levels of the pyramids provide an answer to the *why* question, and the lower level show *how* that is achieved.

The design process starts with working from conceptual principles towards a more detailed list of requirements (left pyramid). Three important starting principles are already explained in the introduction of this chapter. A literature study is performed to learn from a design approach that has similar principles for designing housing projects. This study gives direction to the design requirements. Finally, a list of functional design requirements is presented.

At the end of this chapter, the design principles and requirements are clear. The following chapters will elaborate on the design options, choices, and final solutions. Chapter 6 presents a universal location design, which is based on the idea that a *flexible* design is needed to create a station that fits at a variety of *city locations*. Chapter 7 presents a modular station design, that is based on the idea of *industrializing* the construction of a *large network* of charging stations. Chapter 8 elaborates on the detailing, that supports the *sustainable* idea of repositioning or *demounting* stations.

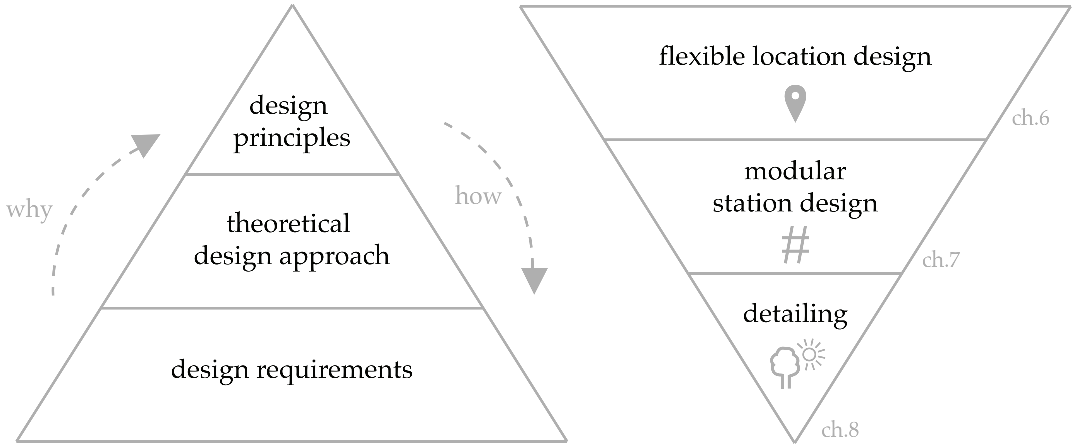


Figure 30 – From concept to detail: process of defining requirements and solutions

5.2 INDUSTRIAL, FLEXIBLE AND DEMOUNTABLE DESIGN

The IFD concept is a way of designing, developing and constructing, where the combination of *industrial, flexible,* and *demountable* aspects play an important role in an integrated approach. It is not a goal on its own, but a tool which serves a strategy for improved control of the product, faster construction and great potential for replacement or re-use in the long term [Crone, 2007].

The concept of this design approach finds its origins in the application of housing projects around 1960. Additional context information about the development of this concept into the IFD approach as it is applied nowadays, can be found in Appendix **??**. From the literature study can be concluded that there is great diversity in the motivation and the application of the IFD approach.

The variety of definitions and interpretations given in literature, provide a useful spectrum of principles that can be used to develop a list of requirements. The process of organizing these definitions revealed that the three IFD aspects represent different phases in the complete lifecycle (as illustrated in figure 31). The following three subsections summarize the findings of the literature study, and explain the link with this design. An overview of definitions and interpretations for each aspect is provided in appendix **??**.

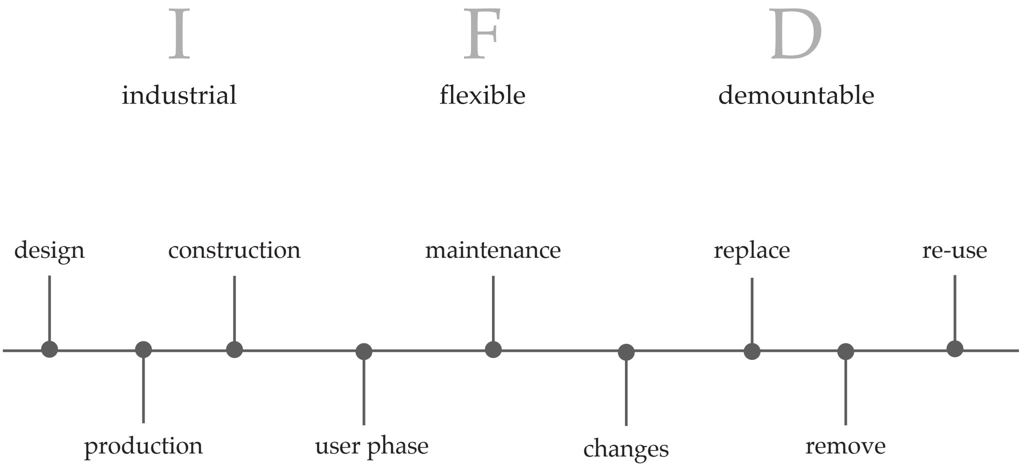


Figure 31 – The IFD aspects cover the total life cycle of a station

Industrial

The basic principle of industrialization is the subdivision of the final product from smaller components, in order to simplify the production process and therefore reducing the costs. The advantages of an industrial approach are mainly gained in the design and construction phase. Considerable advantages can be gained by repetitive use of the design, knowledge, and experience of of the designing parties [Van den Brand and Van Gurchom, 2003]. In production and construction phase, scale of economies can be gained by modular building, prefabrication of building components for assembly on site, and standardization of building elements for detailing [Gann, 1996].

Flexible

Flexibility can be described as the ability to be easily changed. Freedom of choice and the possibility to adapt are considered as the two most important goals. The motivation for providing flexibility is to anticipate on *user* demand. Process flexibility is the extend up to which design choices can be made in the later design process. The product flexibility is the extend up to which the realized project is able to adapt to changing demand of users [Gunst, 2008].

Every location is different, and it is uncertain how many chargers are needed per location. The need for additional services (shop, toilet, new concepts, etcetera) is location dependent as well. Increasing or decreasing the size of a station can help to adapt to different locations, and to changes in demand during the user phase.

Demountable

The demountable aspects reflect one of many approaches towards sustainability. The focus is on the last phase of the building's lifecyle. The aim is to prevent and minimize waste, by re-using components of the building as good as possible. This can be achieved by designing for disassembly. This is in line with the idea of fast assembly on site, or changing the building during user phase. Ultimately, the aim is to re-use all building elements and materials, and leave nothing behind when a station is no longer needed.

IFD summarized

- Serial production and modular construction provides the opportunity for easy, fast, and cheap assembly or many stations.

- A flexible station can adapt to changing demand and can be positioned at different city locations
- A station that is easy to demount, can be positioned at another location, or reused for other purposes.

5.3 DESIGN REQUIREMENTS

A list of functional design requirements allows to check the feasibility of preliminary designs and compare the alternatives. The following sections will briefly explain the most important requirements, which are listed in figure 32.

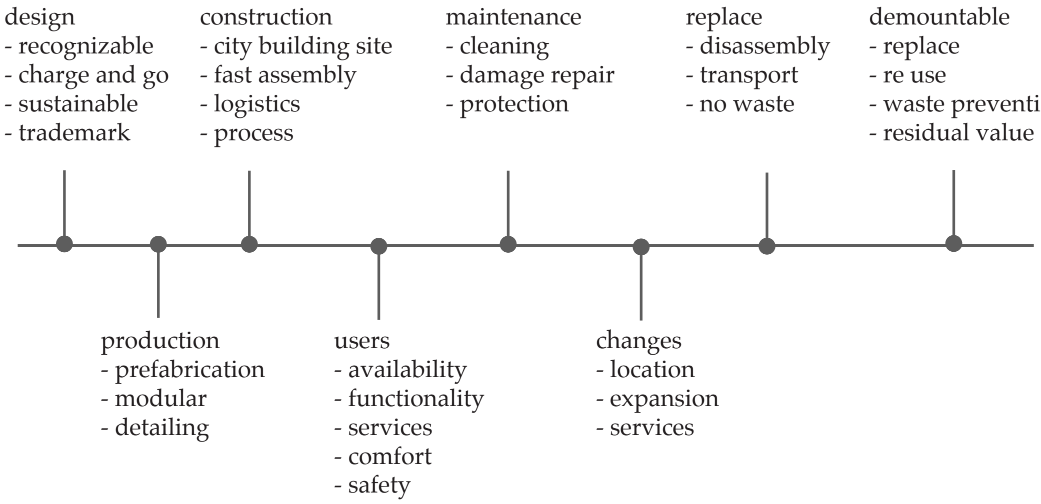


Figure 32 – Overview of design requirements

A Fastned design

The mission of Fastned is building the fastest charging stations for all types of electric cars, and deliver only renewable energy from wind and sun. This sustainable aspect should be represented in the appearance of the station. The concept for fast charging is: stop, charge, and go. It is not a parking place, and people should recognize it as a fast charging station if they drive by. In addition, the trademark of Fastned should be represented in the design.

An efficient production and construction process

A construction site in urban area brings in challenges such as limited space, ongoing traffic, involvement of local residences and other stakeholders. The production process should be centralized by prefabrication. The amount of work on site has to be limited. The target is to assemble all building modules within one week.

The user experience

Availability and functionality are the most important user requirements. All available chargers should be accessible by any electric car at all times. Ongoing traffic flow should be stimulated to improve the availability and to reach high occupancy rates for the chargers. Besides charging, there should be a possibility to offer additional services. Users should have a pleasant and safe stay at the station while charging.

Maintenance of many stations

Stations are exploited large-scale and minimizing or simplifying maintenance is therefore a target. Elements that are vulnerable for damage by accidents or vandalism should be robust or protected. It should be easy to clean or repair parts of the building within one day.

Changing the station per location

There is uncertainty in the demand for charging. The design should offer flexibility in order to change the number of chargers. Providing or removing additional service buildings should be taken into account.

Demount and re-use a complete station

Permits can impose the station's lifetime at a particular location. A lifetime of 15 years should be applied, and thereafter it should be possible re-use most of the building. First priority should be to demount and replace the station. In case of disassembly, waste production should be minimized and the residual value should be maximized.

6

A FLEXIBLE LOCATION DESIGN

If charging stations are to be build in cities, where could they be realized? The goal of this chapter is to find a solution for a flexible location design, that can be positioned at different city locations, and is able to adapt to changing demand.

One universal design should fit for a variety of locations. The most important selection criteria for finding locations, is the availability of sufficient area to design a charging station for at least four cars. Efficient use of the available space in urban area is the starting point for designing charging stations. Optimizing the best distribution of stations over the city, is not part of this study. Neither are other factors (land property, permits, power grid network) taken into account.

This chapter provides an overview of potential city locations in Amsterdam. Based on this selection of location, various possible configurations are identified and organized. Finally, the considerations for making choices in the design are summarized. Two examples of typical city locations are provided to illustrate how the universal solation can fit at different locations.

6.1 VARIOUS CITY LOCATIONS

Lessons can be learned from the positioning and design of the petrol station network. There are over 4200 petrol stations in the Netherlands, from which 5% are located along the highways. A majority of 77% is located in urban area, where the stations are almost equally divided over positions near the urban access roads, in residential area, or in industrial area. The majority of petrol stations is designed for an even numbers of fuel pumps. More than 55% of all petrol stations has 4 or 6 fuel pumps installed.

The scenario model indicates that for 40.000 EV's, approximately 250 fast chargers are needed for the city of Amsterdam. That corresponds with approximately thirty stations with eight fast chargers each. This is a rough approximation, but it provides insight in the number of locations that might be needed.

Potential locations are examined with help of satellite maps, and by driving in- and around cities. Locations with high density traffic are most interesting. However, locations along main access roads are scarce, and the number of potential locations is insufficient (see figure 34). Therefore, charging stations should be realized in the city as well. Figure 35 shows a number of potential locations in the city. Besides providing more locations, these city locations also have more favorable locations for cars that mostly drive in the city only.

6.2 CHARGING AT ALL TIMES

A frequently applied configuration for petrol stations is positioning two cars behind each other. For the coming years, refueling cars is much faster than recharging EV's. Positions for recharging will be occupied for a longer time, ranging from a few to twenty minutes. For charging stations it is therefore important that all available chargers are accessible at all times.

Accessible charging positions

To maximize the use of every charger, every car should be able to reach the charger position, as illustrated in figure 33. Vehicles that are charging, may not block the entrance or exit for other cars.

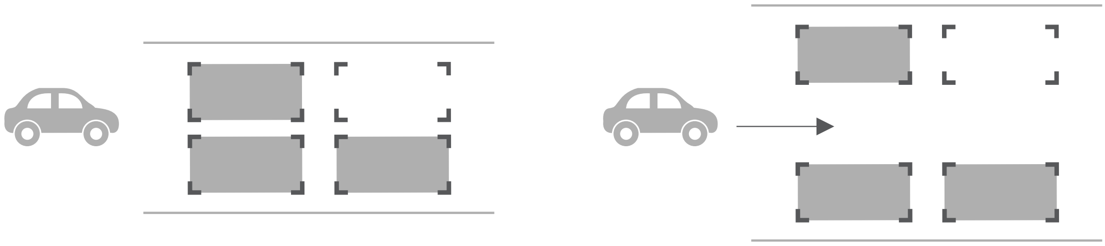


Figure 33 – All positions should be available at all times

The charger position that fits all cars

The position of the charger is decisive to make sure that any EV can charge from any position. The new developed drivetrain configuration for EV's is still sensitive for changes. As a result, the position of the power connection on the vehicle can still change. There are now various positions of these connections, on all sides of the cars.

Figure 34 – Potential locations near the Amsterdam ring are limited [Google Earth,2015]

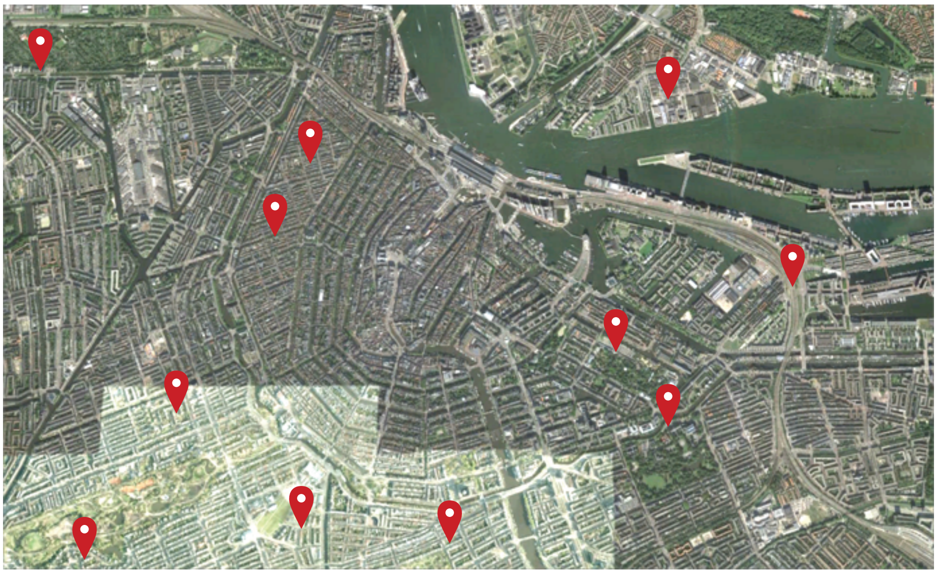


Figure 35 – Potential locations in the city of Amsterdam [Google Earth,2015]

At this moment, one charger can charge one EV using the AC connection, and one EV with a DC connection at the same time. For charging two vehicles using DC, two chargers are necessary. A logical position of the charger is along the side of the car, because the user is able to reach the power connection without turning the car, and the charger does not block the driveway.

Other solutions for charging should be considered as well. The charger cable can increase in diameter and weight for higher charging rates, so possibilities to hang this cable or reduce the cable length can be considered. Possibilities such as wireless charging do not explicitly determine a fixed location.

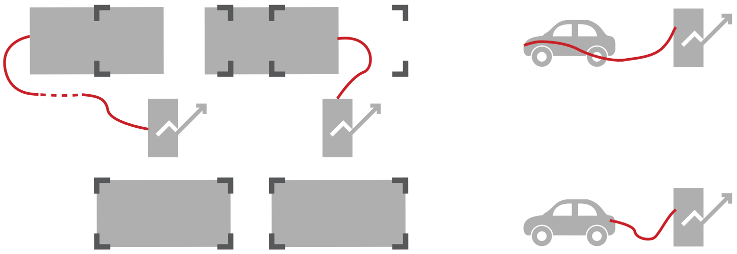


Figure 36 – The charger position that fits all cars

6.3 DIFFERENT LOCATION OPTIONS AND CHOICES

Location options are defined by parking configurations and driveway configuration. All possibilities to position the EV while charging are considered, and the choice for the parking configuration that fits best for charging stations is supported. The driveway configuration depends on the location.

This sections explains the solutions for integrating the selected parking configuration in all possible locations in urban area.

Three options to park a vehicle

There are three main types of parking configurations: parking straight, perpendicular, or under an angle (figure 37). All configurations can be implemented as single or double lines of parking places. The choice for the most suitable configuration is a trade-off between minimum space and maximum ease of driving.

Parking along the road or perpendicular are most common in urban area, and requires the minimum available space for parking. These option requires most effort for parking, and are therefore more suitable for longterm parking. Slow chargers are often positioned in combination with these parking configurations.

Entering and leaving a charging station with minimum effort is desirable to stimulate maximum turnaround and thus allow other vehicles to start charging. Parking straight is therefore the best configuration for petrol- or charging stations. However, this configuration can only be applied when sufficient space is available for connecting with the main road. This does not apply for parking under an angle (30, 45 or 60 degrees), which is therefore a suitable configuration as well.

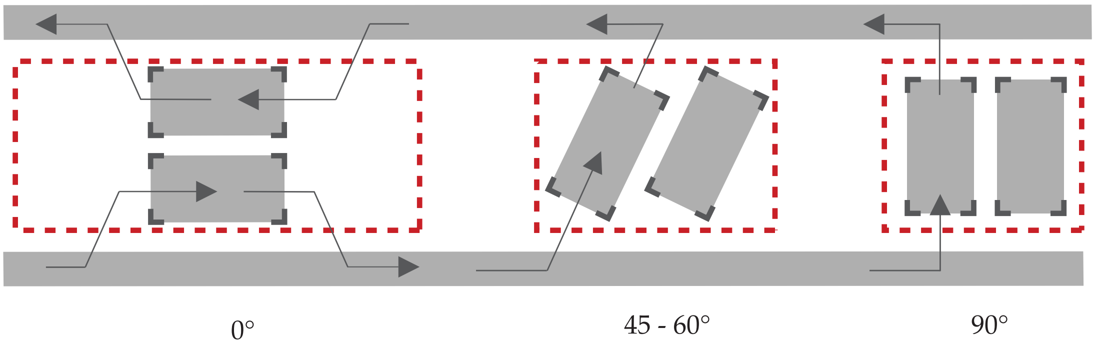


Figure 37 – Three parking configurations

The connection with the main road

The design of the entrance and the exit of charging stations depends on the connection with the road (figure 38). The various configurations can be categorized by distinguishing single and double roads, in combination with speed limits. For single roads, the charging station is positioned on the right side of the road. For double roads, the charging station can be position on the right side, or in between both roads. The speed limit determines whether an additional entrance or exit lane is necessary for traffic safety.

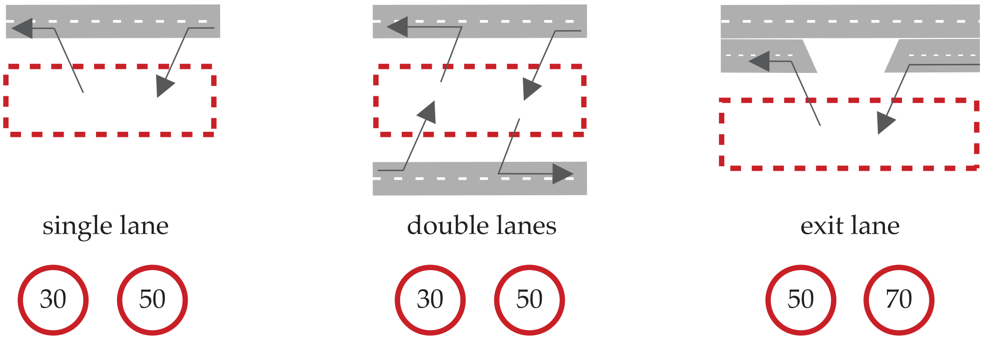


Figure 38 – Road connection and speed limits determine access route

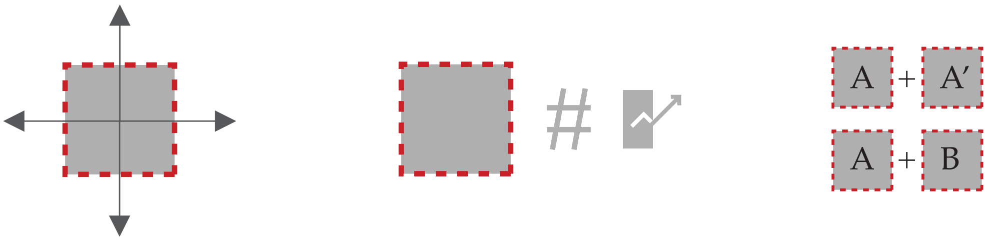
6.4 EXPANDING LOCATION AND CAPACITY

A modular constructed charging station makes the design flexible with respect to locations and capacity. A large capacity station can be realized at spacious locations, and small stations where space is limited. It also allows to start with a small capacity station, and further expand when demand is increasing stronger than expected (and vice versa). Figure 39 illustrates three considerations for expanding a stations.

It should be possible to expand the basic module at least in two directions. When expanding with more than two modules in one direction, a symmetrical shape is required to make identical connections between the modules. This consideration results in a basic module that can be expanded in all directions.

Changing the number of modules can be independent from changing the number of chargers. There are several possible combinations. The realization of one extra module is more expensive than adding one extra charger. One module should therefore allow to accommodate multiple chargers.

The third consideration is choosing between creating similar or different connection modules. Every additional module can have a similar shape, but different size.



how to expand ?　how many chargers / module ?　which modules ?

Figure 39 – Three considerations for expanding a station

6.5 DIMENSIONING

The choice in determining the dimensions of a station are a consideration between minimizing the use of space, and maximizing the ease of driving. The requirements for road design [CROW, 2004], determine the minimum required dimensions for the driveway and parking configurations. The footprint of one station module with two car positions, will require the space of approximately three parking places. The final dimensioning is determined later, in alignment with the station design.

6.6 CONCLUSION: A LOCATION DESIGN

The options and considerations for developing a universal location design are explained. The location designs that represents the these aspects is illustrated in figure 40. This solutions is based on the following design considerations:

- Potential locations are along main access roads and in the city center
- All free available charging positions are accessible at all times
- The position of the charger allows to connect all cars
- No additional road infrastructure required for locations along slow traffic roads
- The basic module can be expanded in all directions
- The basic stations needs 2 modules to accommodate a minimum of four chargers
- The basic module can be expanded by adding a module of with 2 chargers

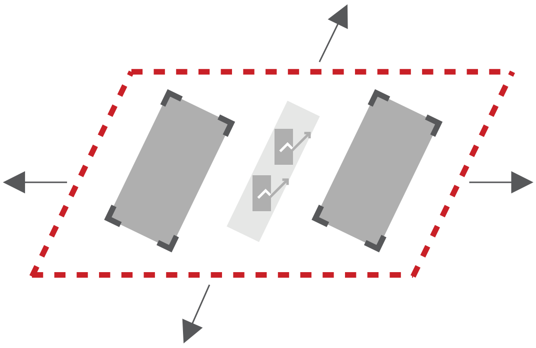


Figure 40 – The base station is constructed with two modules that can be further expanded

6.7 EXAMPLES OF POTENTIAL LOCATIONS

Two typical examples for a main road location (figure 41), and a small space city location (figure 42) in Amsterdam, are included on the next two pages. These examples show how various configurations of the universal location design could fit in a real location.

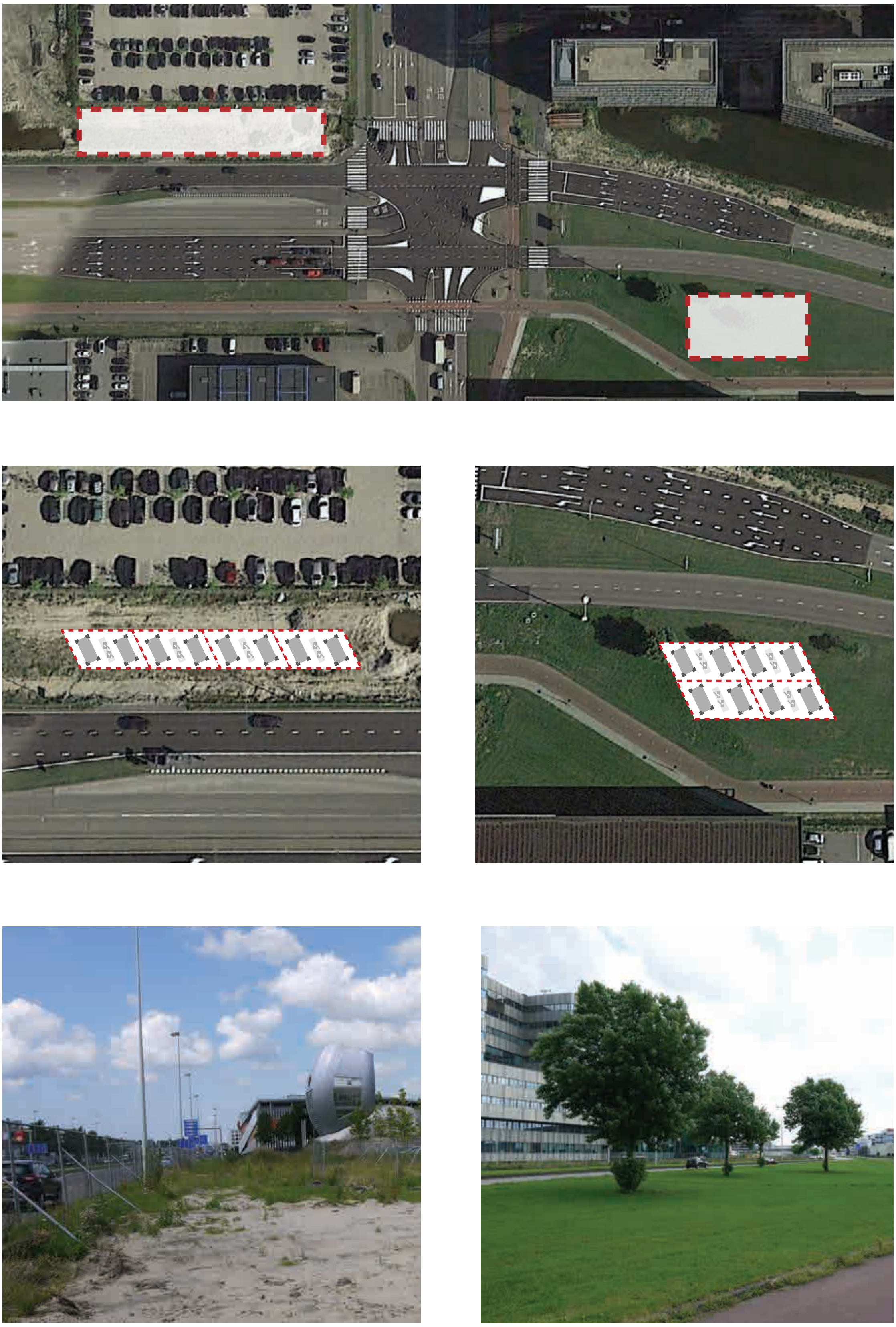


Figure 41 – Potential location with available space along an access road [Google Earth, 2015]

Figure 42 – Potential location with limited space in the city [Google Earth, 2015]

7

A MODULAR STATION DESIGN

The start of a new station design continues on the flexible location design that is elaborated in the previous chapter. The footprint of the station sets boundaries for the station design. Considering the possibilities to expand the station, the zone where structural elements can be positioned are limited to the area that is indicated in figure 43. Two chargers have to be positioned in the same area. This is where the design of a new station starts.

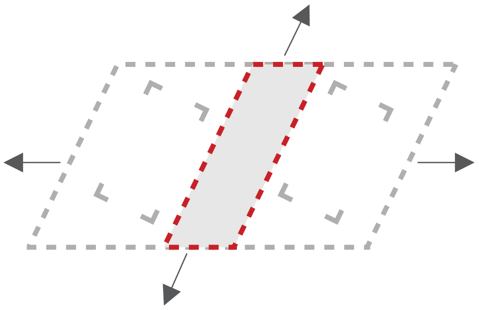
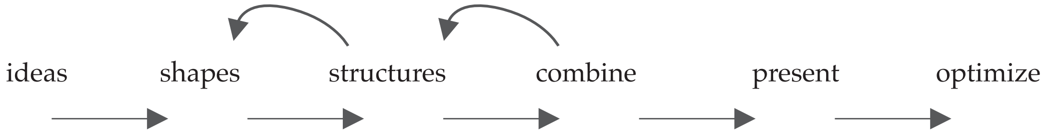


Figure 43 – The selected footprint where supports are allowed

The goal of this chapter is to find a solution for a modular station design, that uses standardized elements in a repetitive shape. This chapter follows the development of the design step by step. First, a number of inspiring ideas is presented, that helps to understand the considered options and to create an image. Thereafter is explained how shape and structure are created on the basis of these ideas. Finally, the design solution is presented and further optimized.



7.1 INSPIRATIONS FOR A NEW DESIGN

New ideas and solutions are generated by creating a collection of inspiring visualizations of other projects [architizer.com, archdaily.com]. These ideas are organized in five themes, and presented on the following pages including summarized notes.

First, it is important to recognize the aspects that create the appearance of a Fastned design. Ideas for timber structures and solar roofs are derived from this concept. Inspirations for canopy structures help to think in solutions for supporting the roof with limited column positions. Examples of architecture with repeating shapes show how a station can be expanded with use of similar or modular elements.

A Fastned design

- A timber structure: wood is a renewable material
- Solar panels: collect renewable energy from the sun
- Recognizable appearance by shape, material and color
- A design that represents a fast charging station

A timber structure

- Roof supporting timber structures
- Special shaped timber columns
- Structure is visible and important in appearance
- Shape of structure can be different from visual shape

A solar roof

- Lightweight solar roof panels
- Effect of sunlight through solar panels
- Solar panels are flat, or curved on canvas

Canopy structures

- Visual effect of cantilevers with slender structures
- The balance of a single column structure
- The effect of a long continuing cantilever span

Repeating shapes

- Effect of repeating shapes in one or two directions
- Asymmetrical shaped repetitions
- Extra dimension with a tunnel effect

7.2 FINDING THE ROOF SHAPE

The first step in working towards a design solution is to find a suitable and recognizable roof shape. Figure 44 illustrates a few of the examined shapes in top view. The most important aspect is that the roof shape can expand in multiple directions by adding more modules. These modules should be identical, because the repetitive use makes production and construction easier and cheaper. This advantage becomes in particular important when realizing a large number of stations.

The roof can have its own shape and does not have to be similar to the station footprint. Roof elements of different modules can be connected, or constructed as separate elements. However, in side perspective it is important that all modules together become one combined station.

The second step is to examine how these roof shapes can follow an expanding floor plan. The floor plan expands in 45 or 60 degrees, similar to the orientation of the car positions. Circles, triangles, pentagons and parallelograms are suitable shapes.

The third steps includes the roof shape in side view. Figure 45 presents three basic roof shapes, that can be created with flat or single curved solar panels. Shapes that allow the use of identical panels are cheaper, less complex, and fast to assemble. Roof shapes that require different double curved panels are therefore not taken into consideration.

The fourth step is experimenting with the repetition of shapes. A number of examples is presented in figure 46, including the possibilities to repeat the shape that Fastned applied for highway stations. A curved shape is preferred, because that is more associated with the distinctive Fastned shape, than a basic flat carport roof for parking.

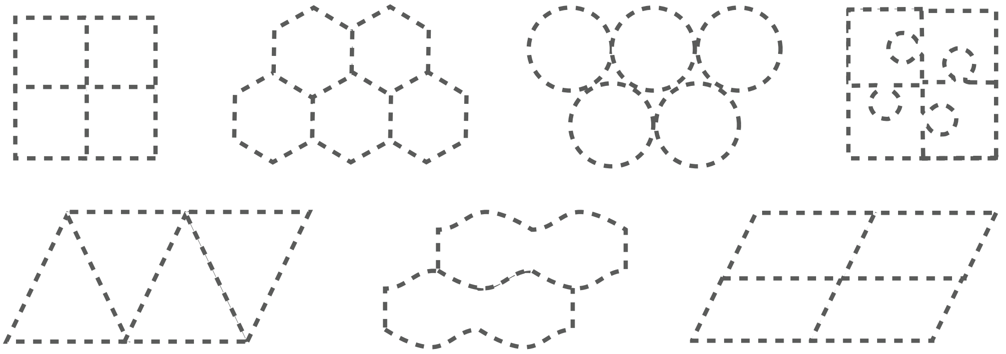


Figure 44 – Options to expand the shape of the roof in top view.

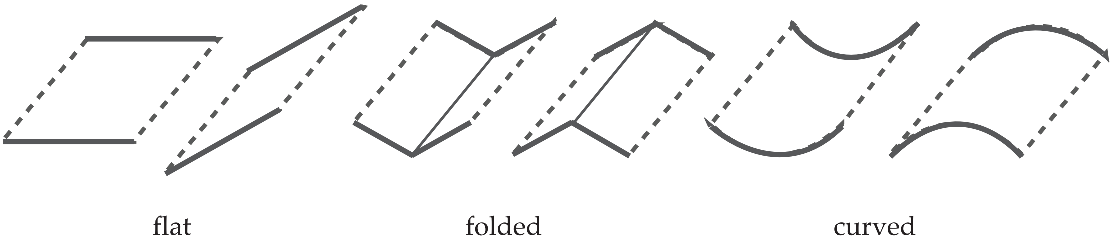


Figure 45 – Options to shape the roof from in front view

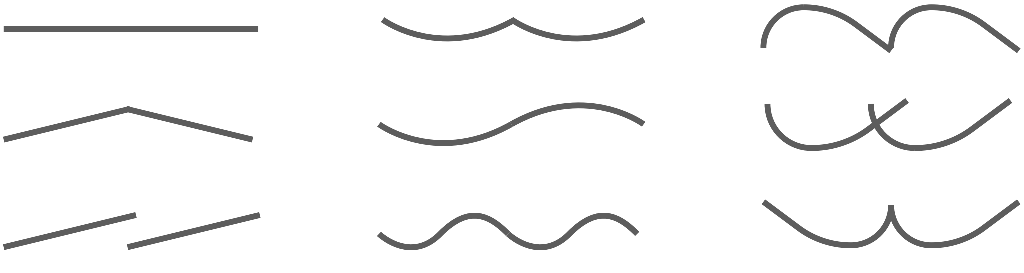


Figure 46 – Options to repeat the roof shape in front view

7.3 FINDING THE STRUCTURAL SHAPE

A number of different roof shapes now has been examined, and the next step is finding a solution for supporting this roof. A cantilever is the only solution for supporting the roof structure of one module, since columns can be positioned in the middle of the floor plan only. Figure 47 illustrates the advantage of connecting two modules. A single column requires a clamped connection at ground level. By adding more modules, an efficient three-hinged frame is created, and additional modules can be connected with the same principle.

This principle can be applied in two directions, to create a structural system that is stable. With this solution, there is no rotation in the foundation. That simplifies the connection with the column, optimizes the foundation, and might prevent the use of a piled foundation. These advantages comply with the principle of completely removing or replacing a station. The basis station will therefore exist of two modules, where one module has two columns and two chargers.

Figure 47 – Structural system to expand with more modules

A repeating curved shape is preferred for the side view of the roof. The structure can follow this curved shape, or act as a separate structural element that only supports the roof plane. Independent from the roof shape, figure 48 shows how the structural possibilities for supporting the roof plane: open, closed, or a combination.

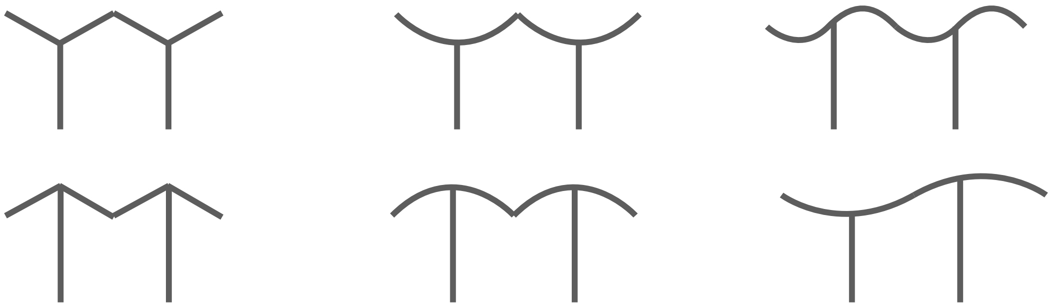


Figure 48 – Possibilities to orientate the roof plane

The choice for one of these options, is a consideration of the orientation of solar panels towards the sun, and the accumulation and disposal of rain and snow. Decisive aspects are that rain water should be disposed to the ground via the column in the middle, and that snow may not slide of the roof in the driveway.

7.4 THE COMBINATION OF SHAPE AND STRUCTURE

The ideas for a new design (section 7.1) showed a number of examples where the combination of shape and structure resulted in an inspiring total design. The aim of this section is to find a good combination of shape and structure, by experimenting with different combinations (figure 49).

Possibilities for using asymmetrical shapes, such as the yellow 'Fastned-curve', are examined. It is possible to include asymmetrical shapes like these in the repetitive form (49a-c). However, considering one module this shape does not represent the Fastned shape anymore. Breaking with the visual repeating effect is not a wanted effect. A symmetrical shape seems more suitable for repetitive shapes, and the structure has a more balanced shape when only one module is considered (49d-f).

The roof shape can be merged with the supporting structure (49a,b). The opposite effect can be created by making a floating roof shape, that has a different shape from the supporting structure (49c-f). Combinations (49 d-f) are suitable to dispose water, and prevent for snow sliding. The possible accumulation of rainwater and snow is the contrasting disadvantage.

There is no best solution that fits all considerations. However, the design solutions in figure 49d-f are representative for the ideas so far. The next step is to further optimize these shapes and to develop solutions for detailing.

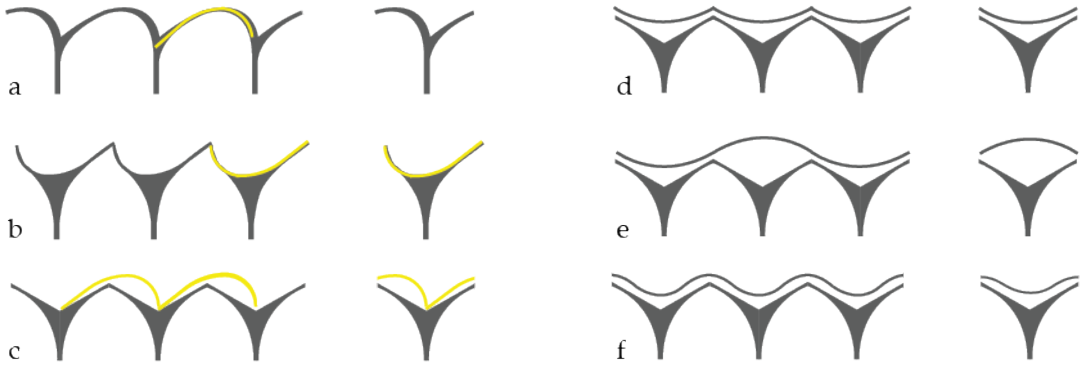


Figure 49 – Possibilities to repeat the roof shape in front view

7.5 THE EVOLUTION OF A NEW DESIGN

The evolution from shape to final design is illustrated in figure 50. First, the curved roof plane was positioned on top of the structure as a separated element. The dimensioning of the footprint and the limited height have a strong influence on the proportions between height and width. A stronger curved roof plane is coming close to following the shape of the timber frame. The visual effect of a floating roof is therefore almost lost, and twice the material is needed to support the same roof surface. For this reason, the column is now merged with the roof-supporting beam seamlessly.

The distinctive curved shape is applied in the longitudinal direction only. Figure 51 illustrates the combination of shape and structure in two directions. In the short direction, the columns are positioned closer to each other, and sufficient space should be reserved for the chargers. The three dimensional modeling learned that there is no structural or visual advantage of repeating the curved shape in the short direction. In this direction, a straight element supported with additional bracings, creates a stable frame between the two curved frames. This solution results in a minor visual repetition of the structure in the short direction, and avoids a more complex moment resisting connection at the top of the columns.

The visualization in figure 52 shows one station module. Straight purlins supported the roof surface, that can be created with straight or single curved glass planes. A cover around the roof plane protects the purlins from rain, and can emphasize the roof shape. Figure 53 and 54 visualize a station that is expanded with one extra module.

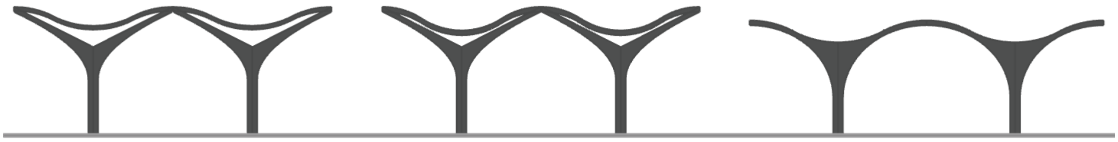


Figure 50 – The development of the shape in steps

Figure 51 – Two side views show the shape and the stability system in two directions

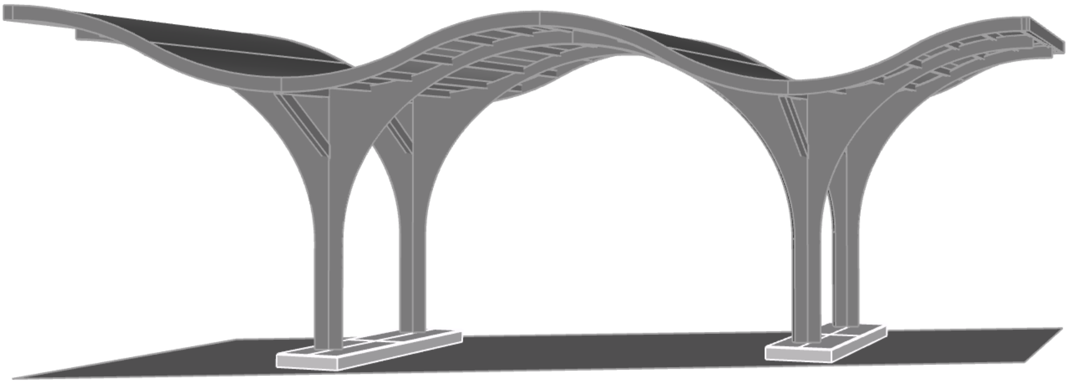


Figure 52 – A 3d-perspective in front view of the basis station

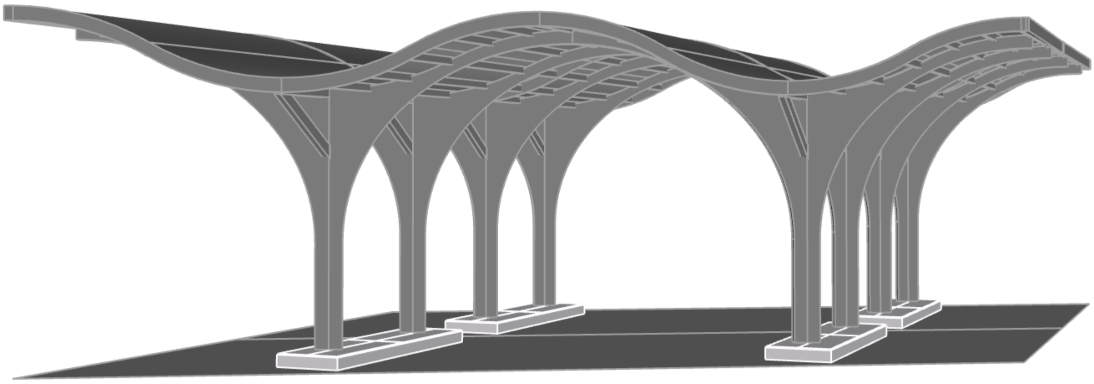


Figure 53 – A 3d-perspective in front view of two station modules

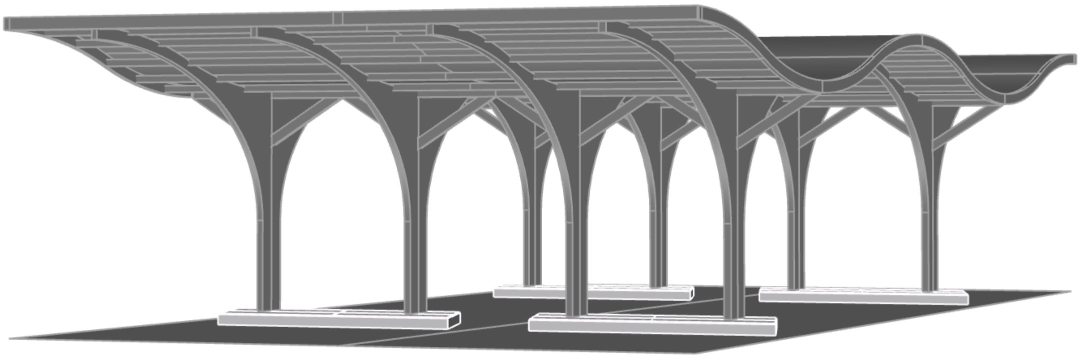


Figure 54 – A 3d-perspective in side view of two station modules

7.6 A MODULAR TIMBER STRUCTURE

The structure is optimized by applying the same elements where possible, and minimize the number of different elements. That makes large-scale production and construction easier, faster, and cheaper. A preliminary structural design is developed to show the principles for the load bearing structure, and to get an idea of dimensions of structural elements. Appendix **??** includes structural principles, load calculations, and preliminary checks for the estimated dimensions. Additional calculations should be performed to create a final structural design.

This section first summarizes starting principles and most important load combinations. Thereafter, the load bearing structure and the stability system are explained. The use of materials is summarized, and the production and shaping of the special shaped timber framed is elaborated in more detail. Finally, the preliminary dimensions are presented.

Load combinations

The load calculations are based on consequence class II, and a reference period of 15 year is applied. The most unfavorable load situations are considered, to apply the same load combinations for the calculating stations at different locations. In combination with the permanent loads, three variable loads are most important: snow accumulation (2,8 kN/m2), vertical wind suction (1,3 kN/m2 upwards), and horizontal wind pressure (1,2 kN/m2). Further specification of these load combinations is included in appendix **??**.

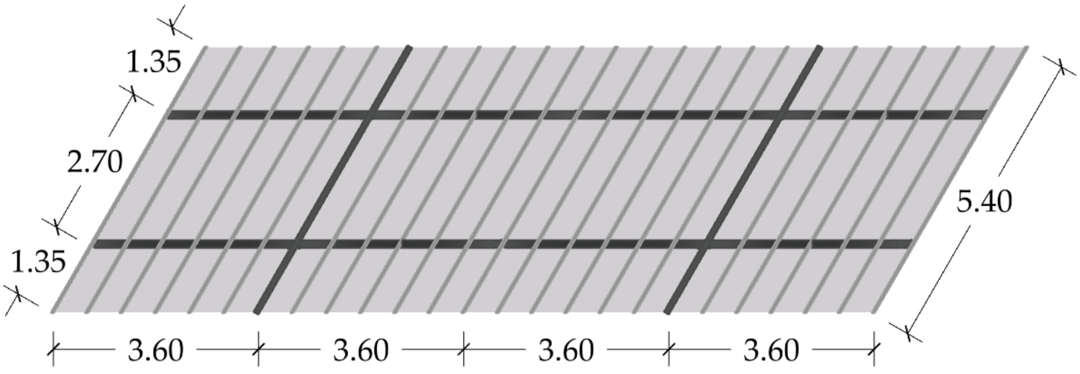


Figure 55 – Top view with dimensions of the timber frames

The structural system

The structural system consists of five different structural elements (figure 56: a concrete foundation block, a glued laminated timber frame, timber bracings, timber purlins, and glass roof panels.

Figure 55 shows the dimensions and the spans for the structure from top view. Glass roof panels span 0,65 meter, and are supported along two sides on the timber purlins. The purlins of 5.4 meter, transfer vertical loads to the frame. The outer ends of the frame have cantilevers that span 3.6 meter. Via the timber frames, vertical loads are finally distributed over four supports.

There are various possibilities to transfer the horizontal forces, caused by collisions or wind. Minor collisions by cars against the columns are prevented by the elevated concrete charger island. A free height of 3 meters is considered sufficient to prevent cars and minivans (including roof luggage) hitting the roof.

For transferring horizontal wind loads, a number of options are considered. Steel wind bracings between the timber frames are considered, but these cannot follow the shape of the roof. An alternative was applying wind bracings through the purlins, as applied in timber grid shells. Other considered solutions are clamping or bracing the timber frame in the horizontal plane. These options are elaborated in more detail in appendix **??**.

To limit the number of different elements in the structural system, the choice is made to use the glass panels for creating a stable roof plane. Both vertical and horizontal loads are following the load path as indicated in figure 56.

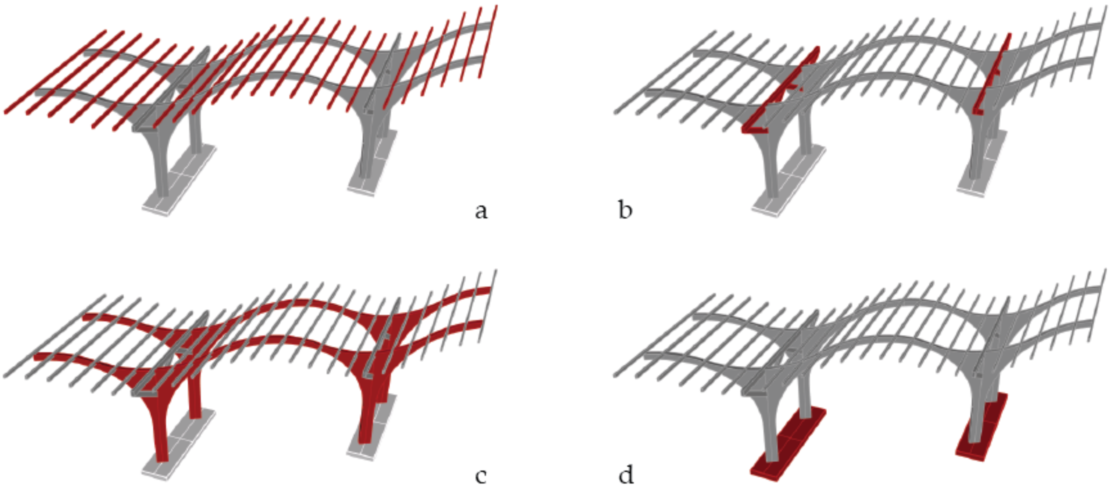


Figure 56 – Overview of structural elements

Horizontal forces caused by wind are limited, since the vertical roof surface is small. In longitudinal direction, the wind surface is limited to the structure only. Perpendicular to this side, the wind surface of the roof plane is only 1.5 meter in height.

The horizontal wind loads cause shear forces in the glass roof panels. Flat glass panels are preferred to transfer shear forces to the purlins, that distribute the loads on the timber frame (figure 56a). The structural connection between glass panels and purlins results in a stable roof surface. These connections are further elaborated in chapter 8, with drawings that illustrate the principles and preliminary dimensions.

The timber frame then provides the overall stability in two directions. In the direction with the smallest wind loads (56b) the braced frames transfer the horizontal back to the columns. In the opposite direction, with horizontal loads on 1.5 meter vertical roof surface (56c), the tree-hinged frame transfers normal forces and limited horizontal forces via a hinged connection to the concrete foundation block (56d). The concrete foundation is loaded with pressure, or tension in case of vertical wind suction.

Materials

For the timber frame and purlins, the tropical hardwood species iroko is selected. The durability of this material allows to use the structural elements for 25 years in outdoor conditions. This enables to use the timber structure even after the reference period of 15 years. The starting principles for the timber structure are summarized below:

- Glue laminated iroko
- Strength class D40
- Load duration: more than 10 years
- Climate class II, covered and open structures
- Durability class I, 25 years

The top and bottom plane of the roof panels are made of laminated heat strengthened glass, and the middle plane includes the photo voltaic absorbing layer. The higher strength of heat strengthened glass allows to reduce the thickness of the glass and self weight of the roof. The shattered glass pattern in case of breaking is favorable, since that will be less visible and does not eliminate sunlight on the solar cells. PVB layers keep the glass layers bonded in case of failure, which contributes to the safety of both users and maintenance staff.

Producing the glued laminated frames

Both sawed and glued laminated timber sections can be produced in the Netherlands. Since strength classes for glued laminated tropical hardwood species are not yet available, the calculations are based on the strength class for softwoods.

With use of glued laminated (glulam) timber, a column can be transitioned into a roof-supporting beam seamlessly. Examined is how to produce a timber element that can follow both the shape of the curved roof and the arc between two trusses. The production process of a curved glulam beam starts with the preparation of planks, which are joined lengthwise by means of finger joints. These continuous planks are then cut into laminations of the required length. Thereafter, the laminations are glued and pressed together in the desired shape. After the bending, both sides can be sawed to the desired shape independently. To reduce cutting losses, the frame could be constructed from two glulam elements, that are connected with a finger joint. An increase of the section is then required, since this joint will be located at the position with the largest bending moments (Heko Spanten & De Groot, 2014). One solid frame is preferred, without caps that influence the stresses in the frame and reduce its strength.

Shaping the timber frames

The exact shape that the frame is desired to follow, is determined with help of basic mathematics (inspired by Oosterhoff [2013] and Burford et al. [2009]). An arc with a radius of 3.5 meters determines the inner shape of the two modules. The center of this arc is positioned above ground level, to guarantee the free height of 3.0 meters for the cars. The repeating shape of the roof is based on a cosine function, which enables to define every point on the curve accurately. This simplifies the definition of the exact shape, and helps to determine the exact location of pre-drilled holes and slots for connections.

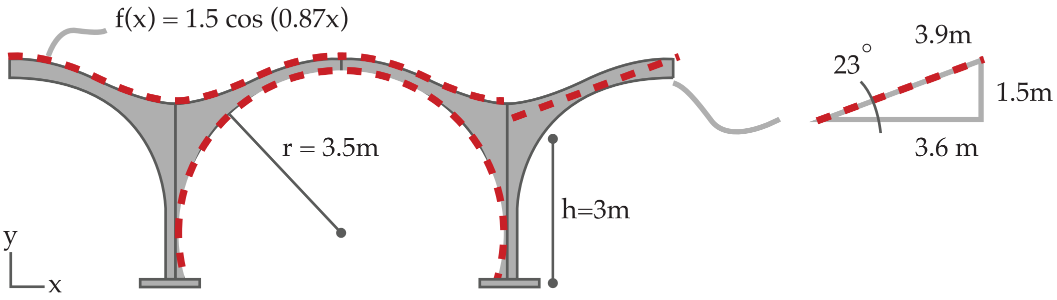


Figure 57 – Fine tuning and exactly defining the shape

The choice for a suitable main angle of the roof plane concerns three aspects. For a timber tree-hinged frame, a common angle is approximately 20 degrees. For optimal solar orientation, 30 degrees is preferred. Finally, the dimensions provide boundaries: three meters free height, and 5 meters maximum height requires less permits from municipalities. An angle of 23 degrees fits for all purposes.

Dimensioning of structural elements

The timber frame now has a shape that meets the design principles, but the dimensions finally depend on structural calculations. The dimensions are estimated, and basic stress checks are performed to check the dimensions with sufficient accuracy for the purpose of explaining details and connection in chapter 8. Additional structural calculations are necessary to determine final dimensions. This section summarizes the normative loads that act on the sections, and presents the preliminary dimensions in figure 58.

Cross-section A is loaded with normal forces parallel to the grain and laminates. Shear forces and bending moments are minimal, due to the hinged connection. The highest stresses occur in cross-section B. Shear forces, bending moments, and compression perpendicular to the grain are normative loads here, so this cross-section needs the the largest dimensions. Another critical point is between B and C, where the cross-section is smallest. For visual reasons, the dimension of cross-section C are similar to this critical point, although normal and shear forces are smaller here. For a load combination with snow, the maximum vertical occurring deflection of the cantilever is 12 mm. These deflections do not hinder the use of the station, thus no additional measurements are taken to reduce this deflection.

The purlins have a total length of 5.4 meter, and cantilever over 1.35 meter at both ends. The purlins are loaded with vertical loads from the roof, and have to transfer horizontal loads to the timber frame. The purlins and bracings that create a frame between the two columns, have similar dimensions.

The glass panels span over 0.65 meter and are supported along the two longest sides. The roof surface is shaped as a parallelogram, and the glass panels have that similar shape. All glass panels have the same dimensions, and three panels in a row will cover the complete surface between two purlins. The use of rectangular panels is not preferred, since this would require additional triangular shaped panels to cover the outer ends. An assumption is made for the thickness of the panels.

At ground level, the foundation slab is visible as an elevated concrete kerb, with a surface of 1 by 5 meters. The maximum pressure on this slab via two support is 2 x 55 kN downwards (pressure) and 2x 25 kN upwards (tension). There are no moments due to a hinged connection with the timber frame, and horizontal forces are limited.

The minimum weight of the foundation block should be 5000 kg. Including a safety margin of 20%, that results in a minimum dept of 6000 [kg] / (2400 [kg/m3] x 1 x 5 [m]) = 0,5 meter. Since a shallow foundation is applied, settlements may occur over time. Soil improvement is necessary to prevent initial settlements, and long term settlements can be corrected after some years during maintenance.

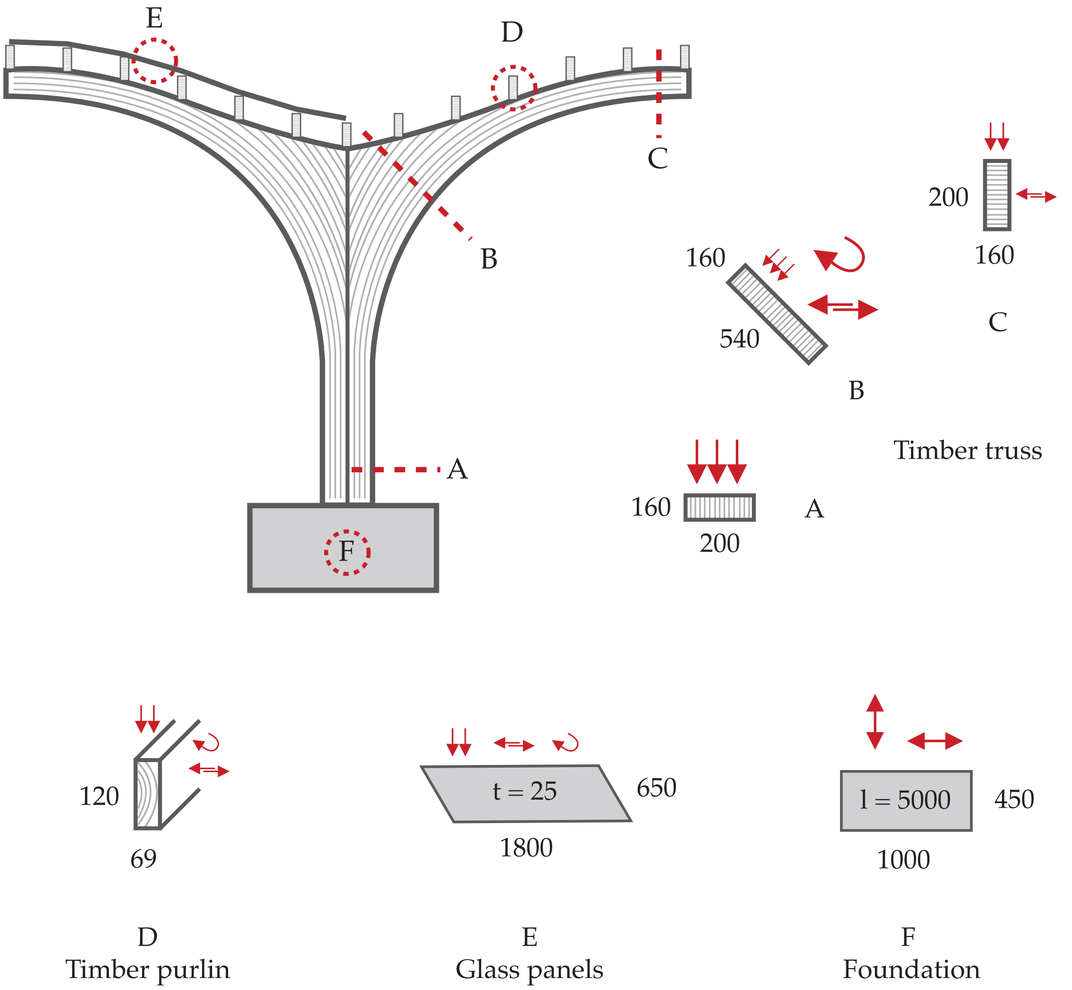


Figure 58 – Preliminary dimensions (in mm) and stress checks for structural elements

7.7 A SUMMARY OF DESIGN STEPS

The conclusion of this design chapter a summary of design steps that resulted in the final shape. This is visualized with the schematic overview that is presented in figure 59 below. Visualizations of the complete design are shown in the next section.

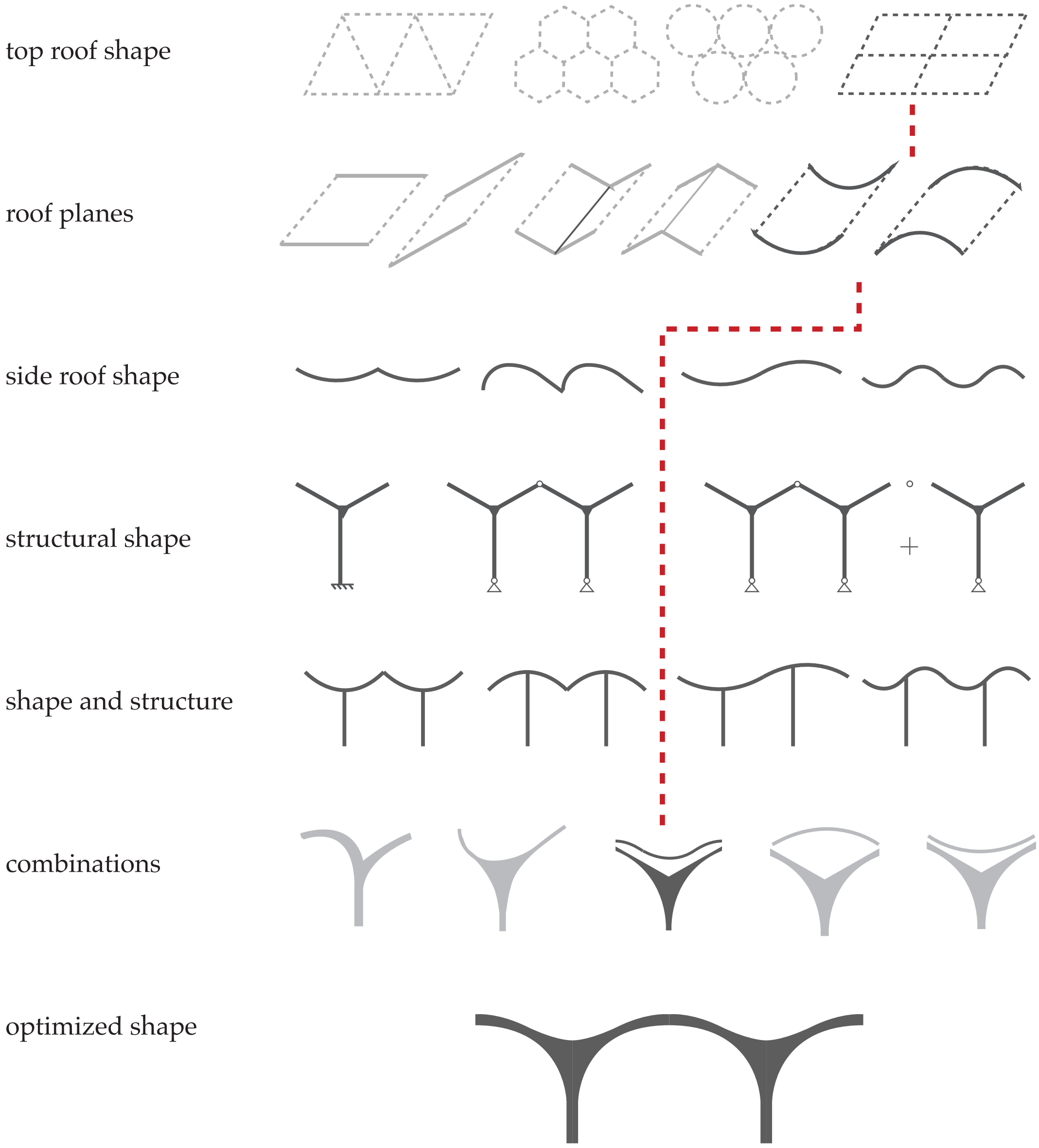


Figure 59 – A schematic overview of design steps

7.8 THE FINAL DESIGN SOLUTION

The following two pages show four figures that illustrate the final design solution. Figure 60 indicates one example location besides residential area in The Hague. The station is positioned between to main access roads. Figure 61 shows how two station modules can be integrated with the current infrastructure. Eight cars can charge at the same time, and cars can enter the station from both sides. There is sufficient space to create enter- or exit lanes. Considering the speed limit in this area, this additional infrastructure is optional.

The three pages that follow thereafter show the station design in the context of an urban environment. The first picture shows the basis station only. Thereafter, the visualization show how the station can be expanded in two different directions.

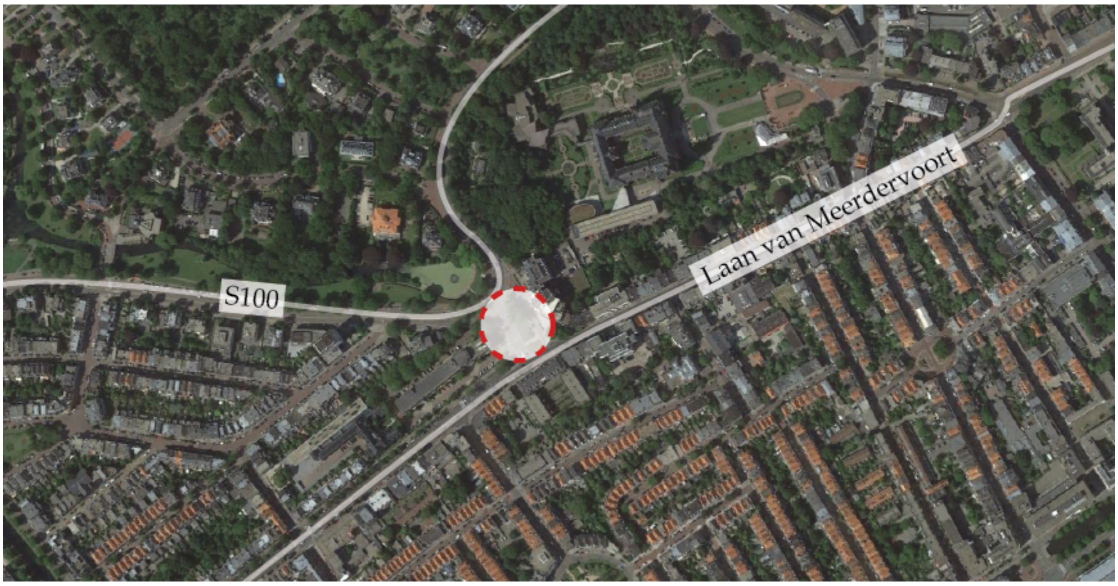


Figure 60 – Example location in The Hague [Google Earth, 2015]

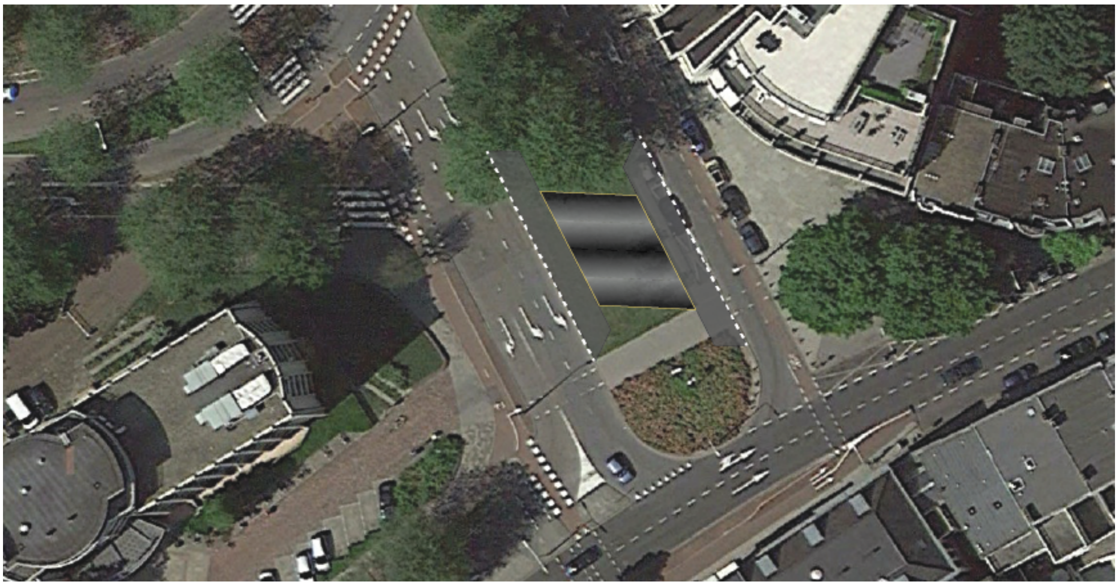


Figure 61 – Integration of two station modules with infrastructure [Google Earth, 2015]

8

DETAILING FOR DEMOUNTING

The concept of a flexible and modular station is presented in the previous chapter. The design is prepared for easy and fast constructing of identical modules. Expanding the basis station in additional modules provides flexibility. Repositioning or removing a station requires that all elements are prepared for disassembly. The detailing principles are important to make that possible.

The goal of this chapter is to explain how the detailing contributes to the modular, flexible, and demountable principles. A selected number of details is elaborated with help of illustrative drawings. The aim is to explain how different aspects (structure, water disposal, installations) are integrated, and to explain how connections are designed. A summary of other examined ideas and connections, can be found in appendix **??**. Figure 62 indicates which aspects are explained in this chapter:

1. A prefabricated charger island
2. The timber frame connections
3. Connections of the glass roof panels
4. Connection of two station modules

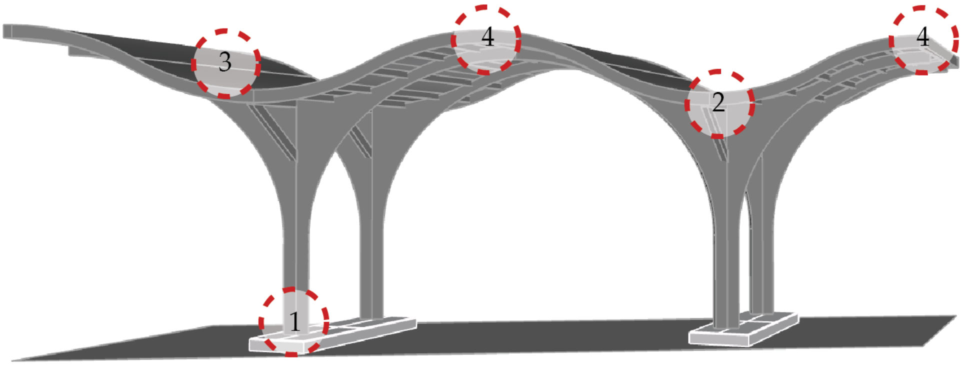


Figure 62 – Overview of the details that are explained

8.1 A PREFABRICATED CHARGER ISLAND

The charger island is a prefabricated foundation slab, where drains, cable pipes, steel footings, and charger connections are integrated. The slab is positioned above ground level, so that a concrete curb separates the driving lanes from chargers and columns.

Cables for solar and light installations are grouped at the column in a protective sink tube, which is similar to the drain. The drains and protective tubes are cast in concrete during prefabrication. After the island is positioned, the drains and cables can be connected easily.

The foundation slab has sufficient self weight to resist vertical wind suction on the roof surface. The strength of the soil layers determine the settlements, which will be different for every location. Soil improvement of the top layer is necessary to prevent unequal settlements between the charger islands and surrounding pavement. An additional gutter is positioned along the charger island, since long term settlements of the foundation are likely to occur.

The connection between foundation and timber frame allows for small deviations in height, which is necessary to compensate for settlements and deflections of the cantilevering frame in the long term. This allows to add a new station module to an existing module.

Further calculation should clarify if this shallow foundation slab is applicable for various locations. For bad soil conditions, where soil improvement is not sufficient, one universal piled foundations should be designed.

Explanation of figures 63 and 64:

1. Separated sink ducting for cables and water disposal. There is space between both ducts to connect the perpendicular bracings at roof level.
2. Two glued laminated timber truss sections.
3. Stainless steel bolts. A saving in the frame is made, so the drain and cables can go straight in the foundation block.
4. S235 steel plate with hinge pin, and slots for vertical adjustments in height.
5. Steel plate is fixed with anchors in the concrete slab. Slots for horizontally positioning.
6. Pavement, and an additional drain and gutter for water.
7. Concrete C45/55 foundation slab, including connection for hoisting the slab in and out.
8. A top sand layer, followed by soil improvement with a mixture of sand and gravel on top of the sub soil.

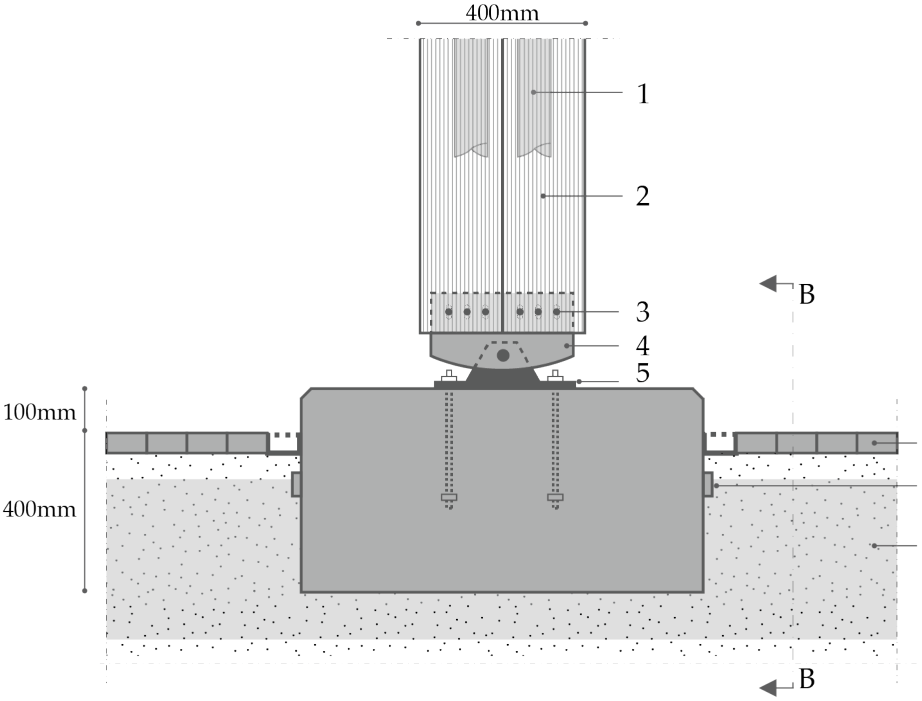


Figure 63 – Section A-A of the ground level connection [scale 1:20]

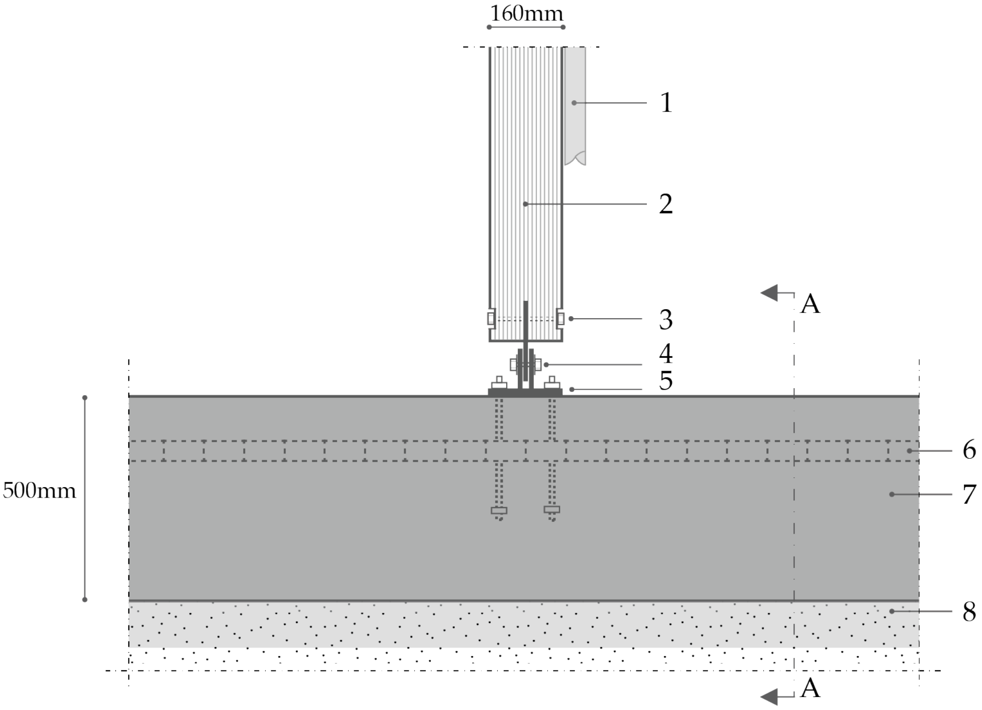


Figure 64 – Section B-B of the ground level connection [scale 1:20]

8.2 THE TIMBER FRAME CONNECTIONS

Two curved glued laminated timber frames are connected at the center with a steel plate (figure 65.1). This helps to create a more balanced load distribution and is applied to avoid a fixed connection at ground level. The plate is positioned in a sleeve in the middle of the sections, invisible from the outside. Timber dowels are preferred to connect both plates, and minimize the visual effect of this connection. Steel pins can be used when higher strength is required. Stainless steel is preferred for plates, pins, and bolts. This prevents gray or black discoloring of the iroko elements.

Two additional steel plates (figure 65.2) are welded to connect the timber bracings on both sides of the frame. Figure 66 shows this in more detail.

The purlins (figure 65.3) are positioned on top of the timber truss, and are fixed perpendicular to the angle of the curve. Sawed savings in the truss will interrupt the ongoing laminates, which reduces the strength. The moment of inertia of the purlins is not optimal with this orientation. However, it strongly simplifies the connections with the glass panels (next section).

Rainwater is collected in the gutter that is fixed on top of the middle purlin (figure 65.4). The gutter has a structural function as well, since it supports the middle glass planes with a structural silicon joint.

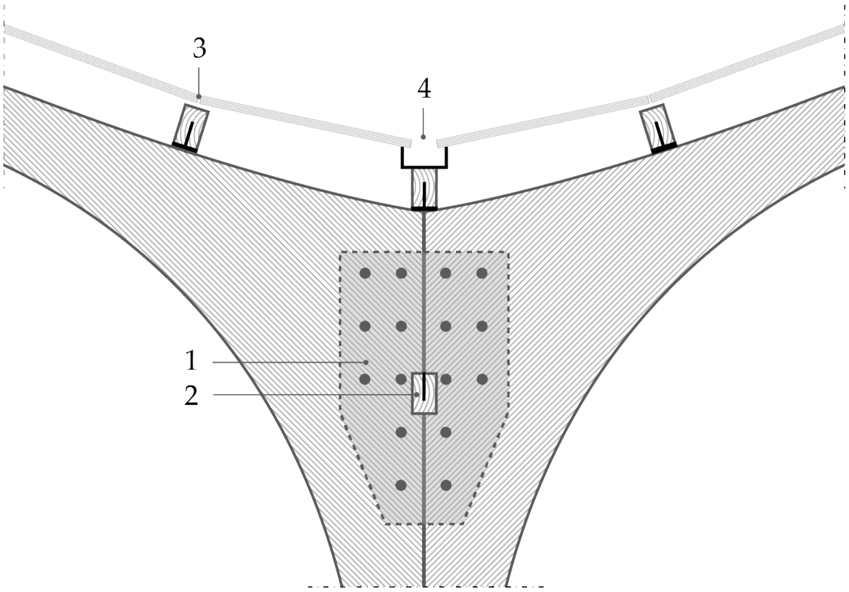


Figure 65 – Section of the frame in front view [scale 1:20]

Explanation of the connections of bracings (figure 66) and purlins (figure 67) the timber frame:

1. Timber purlin or bracing.
2. Stainless steel pins, which are visible from one side only.
3. Two S235 steel plates, welded in a T shape.
4. Fixing of the steel plate with screws
5. Curved timber truss

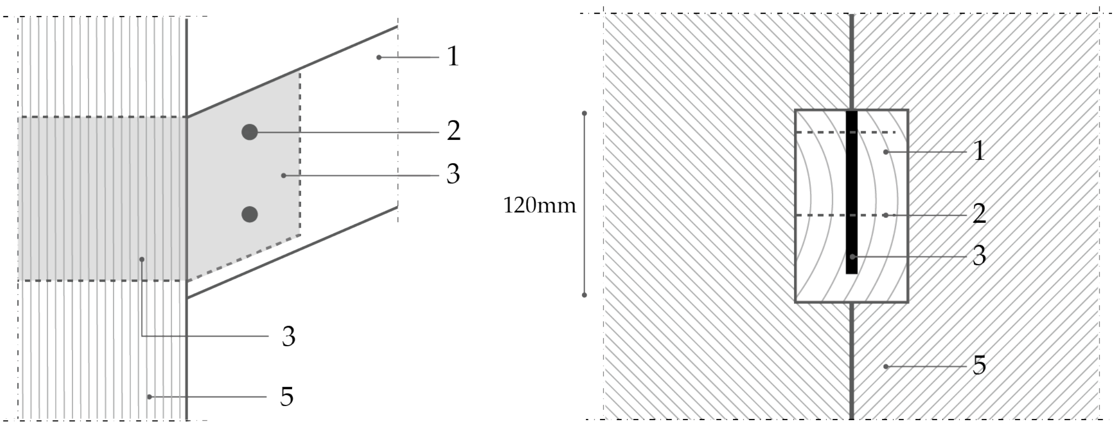


Figure 66 – Connection between frame and bracing [scale 1:5]

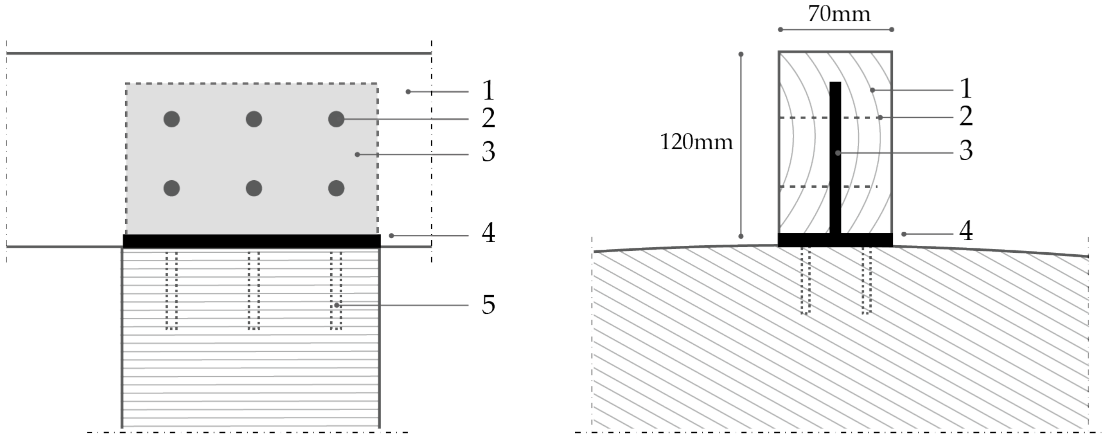


Figure 67 – Connection between frame and purlin [scale 1:5]

8.3 CONNECTION OF THE GLASS PANELS

A number of alternatives is developed for the connection detail of the glass panels. The aims was to find one universal solution for connecting all panels in the same way. However, every connection between two glass panels has a different angle, since the roof plane is curved. Furthermore, the roof plane should be water proof, and accumulating water near horizontal strips should be avoided.

Glass panels that are overlapping like traditional roof tiles are considered, but the solution for a structural connection between panels becomes complex. The use of cold formed curved glass panels, or connections that allow a flexible angle between two panels are examined as well (appendix **??**).

The solution is found in changing the orientation of the purlin, which makes the angles between glass panels and purlins almost the same for every connection. With the cosines function of the curve, every angle can be calculated and this results in a maximum angle of 10 degrees. The connection can be fixed upside down, to connect panels that have a similar, but mirrored angle. The connections of the glass panels with the timber frame is explained with help of figure 68:

1. Three parallelogram shaped glass panels cover the complete surface between two purlins. The glass panels are part of the stability system, and are loaded with shear forces and stresses in the plane. The position of the clamps on the purlin is identical for all purlins.
2. Friction grip connections are necessary to support the permanent loads and to transfer vertical loads and shear loads to the purlins. The clamps are positioned out of the corners to avoid major stress concentrations.
3. The structural silicone sealant along the edges helps to resists the shear stresses induced by the in plane force, and provides water tightness.

The principles for the local clamped connections are explained in more detail with help of figure 69.

1. Two layers of heat strengthened glass, a middle layer with solar cells, bonded with PVB layers.
2. Aluminium inter layers replace the PVB foils near the clamp, to prevent creep deformations that reduce the pressure of the clamp on the glass.
3. Neoprene setting blocks transfer the permanent loads.
4. The stainless steel top element has a protective cover, and is connected with bottom element by a (pretensioned) bolt.
5. The stainless steel bottom element can be fixed directly to the timber purlins in the factory.

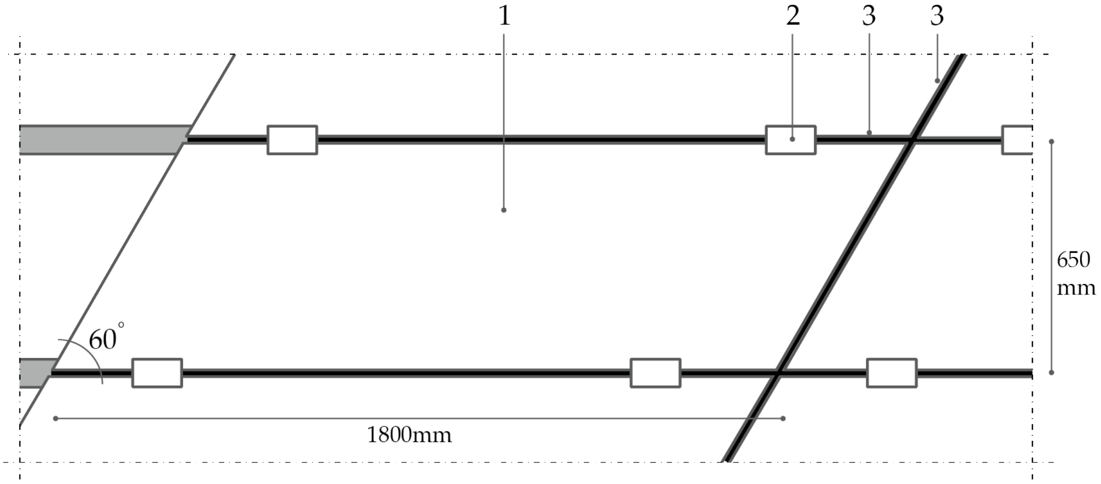


Figure 68 – Fixing of the glass panels in top view [scale 1:20]

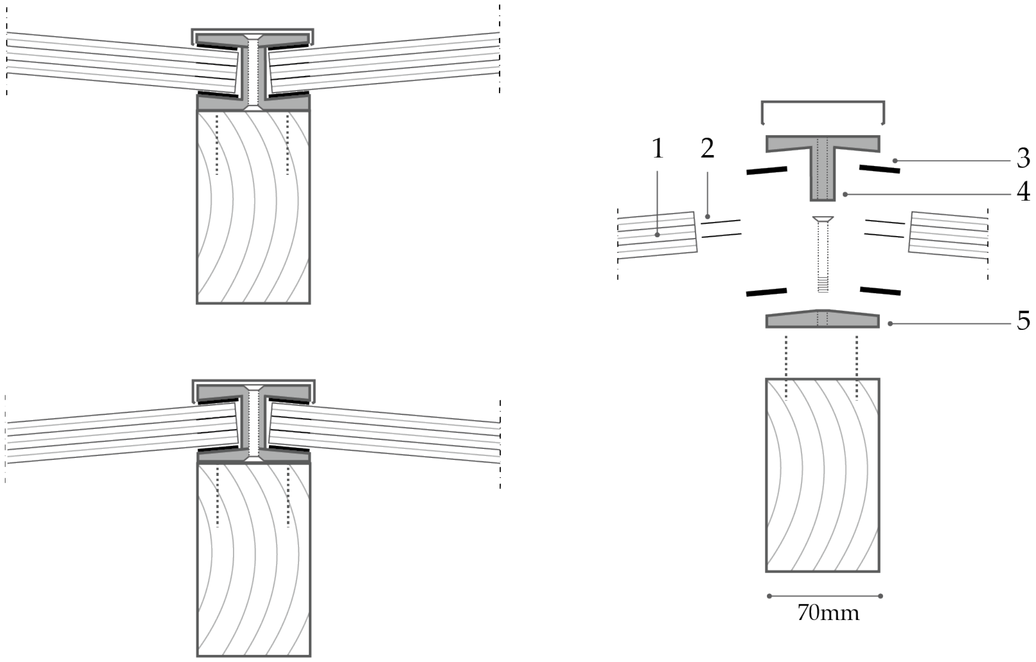


Figure 69 – Section of the glass clamps, and exploded view [scale 1:5]

8.4 CONNECTION OF TWO STATION MODULES

The basis station module can be expanded with additional modules. Figure 71 show the connection detail at the end of the cantilever frame. This connection can be transformed into the detail as presented in 71. Both connections are applied multiple times, at the outer ends of the trusses in the basis station.

1. The connection of the glass planes is similar to the connections at other purlins. A compression block is inserted at one side in the clamp, so that the glass panel can be clamped correctly.
2. A powder coated aluminium plate serves as finishing for the outer ends of the station. Additionally, a logo can be mounted on this side. Furthermore, it covers the timber purlins and two trusses from direct rainfall.
3. The vertical aluminium plate can be easily mounted and demounted with screws in the timber.
4. A horizontal aluminium cover can be fixed over the entire length, to close the gap between the outer glass panels.
5. Stainless steel pins, which are visible from one side only.
6. Cold formed S235 steel plate with hinge pin. An additional iroko element with a sleeve in the center can be slided over the connection to hide it.

8.5 A REVIEW ON THE DETAILS

The detailing and connection principles in this chapter explained how the charging station can be assembled and disassembled. A variety of aspects is taken into account, and the solutions presented in this chapter are neither the only solution or best solution. The preliminary design solutions need further development, but the key is that the principles show how a flexible, modular, demountable station can be constructed. These design principles are taken into account from the start, and finally that is an important condition for developing an integrated design that can be demounted after all.

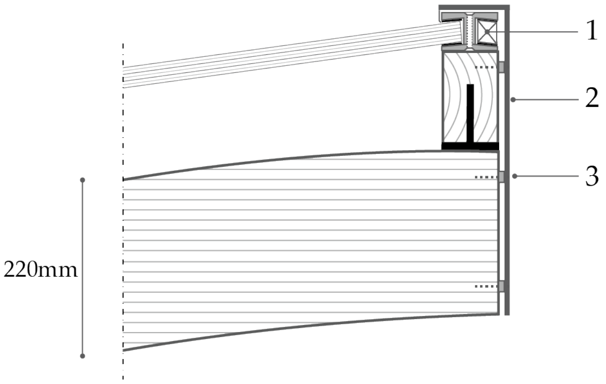


Figure 70 – Section front view, end of a module with cover plate [scale 1:10]

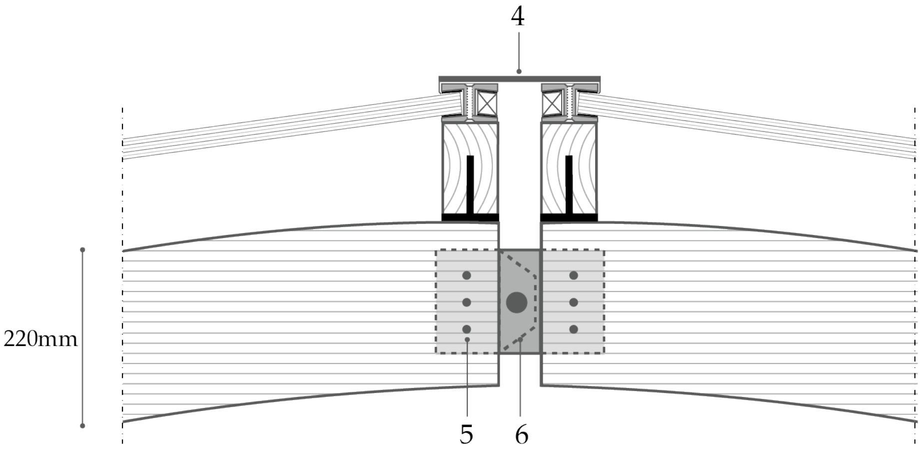


Figure 71 – Section front view, two modules connected [scale 1:10]

Part D

CONCLUSIONS AND RECOMMENDATIONS

9

CONCLUSIONS

In response to the emerging electric vehicle market, and the increasing shortage of public chargers in urban area, this research is concerned with the following research question:

How could urban areas provide public charging infrastructure for the rapidly increasing number of electric vehicles?

An efficient solution to prevent the expected shortage of public charging infrastructure in urban areas, is realizing modular and flexible charging stations with multiple fast chargers, at strategic locations along access roads.

9.1 THERE IS A SERIOUS CAPACITY GAP

This research resulted in the development of a tool that helps municipalities and market players to understand the need for public charging infrastructure in cities. This tool is based on a scenario model, that compares energy demand for electric vehicles with energy capacity of public chargers. Creating and comparing different scenarios with recent data of four Dutch cities, resulted in the following conclusions:

- There is a serious capacity gap: the current network of public slow chargers can provide significant more energy than is needed for charging all electric cars in these cities. The number of public chargers almost equals the number of electric vehicles, and users still experience a shortage of chargers.
- The current decentralized network, with public slow chargers located at hundreds of parking places, is underutilized and not cost efficient due to high exploitation costs. A more efficient solution is necessary for charging large numbers of electric vehicles in cities.
- The cost efficiency of charging infrastructure can be improved by creating a centralized network, with multiple fast chargers at a limited number of locations.

An increase of charging speed and capacity per charger will further decrease the costs per supplied kWh.

- A centralized network, with multiple fast chargers at a limited number of city locations, is an efficient solution for charging large numbers of electric vehicles, when high utilization rates are achieved. It is therefore important that drivers clear their position after charging, so other vehicles can start charging.
- A possible solution is a charging station, that EV drivers recognize as a location for fast charging. It should be a short stay location to stop, charge, and go.

9.2 A LARGE AND FLEXIBLE NETWORK IS NEEDED

The aim of this study was to design an efficient solution for charging a large, but uncertain number of electric cars in cities. The proposed solution is a preliminary design of a modular and flexible fast charging station, that can be assembled and disassembled at different city locations. Conclusions derived from the development of this station design are:

- The demand for charging strongly depends on the number of electric cars. A modular station that can be expanded, reduced, or replaced is flexible for changes in demand. Serial produced modules, with a minimized number of different elements, provide the opportunity for easy, fast, and cheap assembly of many stations.
- Strategic urban locations with available space are scarce. A station with a small and flexible footprint increases the possibilities for realizing stations at different locations, along access roads and other high traffic density roads in the city.
- The preliminary design of a prefabricated foundation, a modular and light weight timber structure, and the detailing of connections, show how station modules can be repositioned at other locations, or can be completely demounted for re-use.

10

RECOMMENDATIONS

Municipalities and private parties that are concerned with the development of charging infrastructure in cities, are recommended to realize a centralized network, with multiple fast chargers at a limited number of locations. This is the most cost efficient solution for charging large numbers of electric vehicles. For urban areas, a combination of local chargers and especially centralized fast charging stations is required. For rural area, the need for fast charging stations is less urgent.

Suggestions for further research and development of the scenario model are presented in the section below. Furthermore, recommendations are given for Fastned and other organizations that consider realizing charging stations in urban area.

10.1 IMPROVING AND EXPANDING THE SCENARIO MODEL

- This study focused on urban environment only. The model design and the calculation methods are universal, and with additional data for other cities or less urban area, similar model results can be extracted.

- The application of the tool can be enhanced by combining with other models. Combining with data- and optimization models for urban traffic, allows to make a quick, but accurate, estimate of the number, placing and sizing of charging stations [Sadeghi-Barzani et al., 2014].

- Optimization models for logistics (harbor terminal planning) or traffic routing (Wardrop equilibrium) are already available. The method and principles of these models can be applied for optimizing charger occupancy rates, or developing a collaborating network of chargers [De Dios Ortúzar and Willumsen, 2011]. With use of mobile applications or navigation systems, it is possible to involve electric vehicle drivers in this optimization process.

10.2 THE POTENTIAL OF THE PROPOSED DESIGN SOLUTION

- The preliminary design of the proposed charging station, offers a concept that can be used after further development. A complete structural analysis, and further elaboration of all details should be performed.
- With use of the modular elements of this station, an additional building can be constructed. With a lightweight facade and a prefabricated floor system, the modular structure be transformed in a matching shop or coffee place. A user survey among EV users can help to identify user wishes.
- Fastned is recommended to consider implementing this design for stations in urban area. Available space at strategic city locations is scarce, and the small and flexible footprint of this station increases the number potential locations.
- Fastned should also consider the proposed design for spacious locations where high demand is expected, because this modular station allows to be expanded with use of the same elements, with minimal adjustments, and without a making a new design. Furthermore, the distinctive curved shape remains intact when expanding the station.
- Alternatively, Fastned can continue constructing charging stations in two sizes (small and medium), and consider connection principles that are presented in this report to improve the detailing of the roof panels for their station design.

10.3 THINK ABOUT THE FUTURE PERSPECTIVE

The photograph on the right page is taken during my search for suitable station locations in urban areas. It shows a former petrol station along the Croeselaan in Utrecht. A location in residential area, along a road with high traffic density, close to central station and Jaarbeurs. This is considered as a good and strategic location.

Regardless the adaption of EV's and the further development of charging infrastructure, urban charging- or fuel stations should not become left-over space, with an unused graffiti painted building. Refueling and petrol stations might be disrupted by charging and charging stations. However, charging stations might be disrupted by other new technologies, such as wireless charging by induction, or solar powered cars. A flexible and demountable charging station is therefore a sustainable solution for the future.

Figure 72 – The *no-go* scenario

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INTERVIEWS AND DISCUSSIONS

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