MASTER

Development of a bikeability assessment tool for Dutch cities

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Summary

In the coming years, it is expected that the bicycle use in the Netherlands will only further increase due to ongoing urbanization (CROW-Fietsberaad, 2019). This expected trend goes hand in hand with the ambition of the Dutch government to increase the number of bicyclist (Ministerie van Algemene Zaken, 2020). However, the Dutch government has more bicycle related ambitions. Not only does the Dutch government want to increase the kilometres travelled by bicycle by 20% in the year 2027 (relative to 2017), they also want to make the Netherlands more bicycle friendly and decrease the number of people involved in bicycle accidents (Tour de Force, 2020).

An increase in bicycle use can lead to additional pressure on the bicycle infrastructure. Therefore, it is important to create enough space to facilitate these ongoing developments (Tour de Force, 2016). This would mean that it is necessary to develop new bicycle facilities and infrastructure as well as adjusting the existing infrastructure accordingly. To do so, Dutch municipalities are willing to invest in their bicycle network (Tour de Force, 2016). However, determining how and where to invest can be troublesome. Therefore, the task that lays ahead is to provide Dutch municipalities with a clear assessment tool which indicates the city's performance regarding the concept of bikeability, which can be used to provide useful insight for bicycle related investment decisions.

Bikeability is a relatively new concept that indicates the user friendliness of the bicycle network based on comfort, convenience, accessibility, safety and conduciveness. A tool that can be used to assess the bikeability level of an area can provide insight for potential improvements to increase bicycle use. However, the context in which the bikeability assessment tool is developed matters, as the included variables and measurements can be context specific. This study therefore focusses on the development of a bikeability assessment tool specifically for Dutch cities by researching the determinants of bicycle use and how these determinants can be translated into variables to assess the bikeability level.

A literature review regarding the determinants of bicycle use resulted in the identification of 41 different variables that influenced the bicycle use. These 41 variables can be divided into 5 determinant categories namely: Bicycle infrastructure, junction infrastructure, bicycle parking facilities, environment and accessibility. A second review was conducted, this time on the existing bikeability assessment tools to identify the variables and measurements currently used. A total of 18 bikeability assessment tools were reviewed. This second review led to the identification of 40 variables which were applicable for the Dutch context. When comparing the variables identified from the literature review with the variables currently used in bikeability assessment tools, it was found that 13 of the determinants were currently unaccounted for in the 18 reviewed bikeability tools. The comparison of the reviewed literature and existing tools led to a list of variables that should be included in a new bikeability assessment tool (figure S.1).

	Categories				
	Bicycle infrastructure	Junction infrastructure	Bicycle parking facilities	Environment	Accessibility
Variables	• Path type • Path width • Car intensity • Separation type • Roadside type • Speed limit • Centre line • Lighting • Obstacles • Pavement type • Pavement quality • Slopes • Land use • Speed limiting objects • One-way roads	• Junction type • Bicycle infrastructure at the junction • Speed limiting objects • Median island • Bicycle traffic lights • Bicycle box	• Bicycle parking facility type • Security measures • Parking costs • Visibility • Destinations within reachable distance • Distance to public transport stop • Capacity	• Bicycle path ratio • Bicycle infrastructure density • Intersection density • Bicycle parking density • Population density • Air quality • Green space • Land use mix • Road safety	• Distance to different type of destinations • Destination diversity • Destination density • Transit facility density

Figure S.1: List of variables for the new bikeability tool.

The list of variables was used to develop a new bikeability assessment tool focused on assessing the bikeability level of neighbourhoods in Dutch cities. The bikeability assessment tool consists out of five categories that each assess a different aspect of the neighbourhood: bicycle infrastructure, junction infrastructure, bicycle parking facilities, environment and accessibility. Each category has its own variables as seen in figure 1. The variables within each category are used to calculate a category score, representing the functioning of the category in a neighbourhood. These category scores are all on a scale from 0 to 10, thus making it possible to easily compare the categories with each other. This comparison can provide insight in which category could potentially cause a problem for the bikeability of the neighbourhood.

The category scores are then used to calculate the overall bikeability level of the neighbourhood. The importance of the categories determined how much each category was weighted for the calculation of the bikeability level. The category junction infrastructure had the highest weight (4), as junctions are the locations where bicyclists interact with motorized traffic, resulting in 54% of bicyclists' fatalities. The category bicycle infrastructure was assigned a weight of 3, the categories environment and accessibility as weight of 2 and bicycle parking facilities a weight of 1. With the established weights it is possible to calculate the bikeability level of a neighbourhood by calculating the average score across the five categories while taking into account their weights. The result of this calculation is the bikeability level of the assessed neighbourhood on a scale from 0 to 10, with 10 indicating that the bikeability level is as good as possible.

The functioning of the new bikeability assessment tool was illustrated with a case study, which assessed three fundamentally different neighbourhoods in the city of Eindhoven. The three neighbourhoods concerned a residential, a mixed-function and an industrial neighbourhood. These neighbourhoods were expected to have different bikeability levels, which the new bikeability assessment tool should illustrate. The case study showed that the categories 'bicycle infrastructure', 'junction infrastructure', 'environment' and 'accessibility' functioned as expected, however the category 'bicycle parking facilities' showed some problems. The reasons for these problems came from the lack of identified bicycle parking facilities within the case neighbourhoods and the large impact of the variable 'bicycle parking facility type' in comparison to the other variables within the category. Nevertheless, the overall functioning of the bikeability assessment tool provided the expected results and was thus able to correctly assess the bikeability level of each neighbourhood.

The newly developed bikeability assessment tool can be used by transportation planners to assess the bikeability levels of neighbourhoods, which can provide them with insight in which neighbourhoods can be troublesome for the bicycle use in the city. Furthermore, the category scores can be used to identify the specific aspect that causes a high or low bikeability level. This information can help municipalities with determining where to invest. Lastly, the bikeability assessment tool can be used to compare different scenarios of interventions and how these scenarios would affect the bikeability level of a neighbourhood.

Future research could focus on a better way to include the bicycle parking facility category to improve the functioning of the newly developed tool. Furthermore, future research could focus on creating different 'weight profiles' for the variables representing the preferences of specific groups of bicyclists. Nevertheless, the developed bikeability assessment tool can assess the bikeability levels of neighbourhoods which can be used to help with identifying problem areas for bicycle use and guide municipalities with their investment decisions.

1. Introduction

1.1 Context

A relatively new and emerging concept in the mobility and planning sectors regarding bicycles and bicycle infrastructure is 'bikeability'. This is a concept derived from the more popular and frequently used concept 'walkability', which is used to assess the pedestrian-friendliness of an area (Muhs & Clifton, 2015). Bikeability is a similar concept, it can be used to assess the bicycle-friendliness of an area. This assessment is based on numerous elements such as comfort, convenience, access to destinations and safety of the bicycle network (Kellstedt et al., 2020; Lowry et al., 2012). These elements can be translated into variables that measure the bikeability, which gives an indication of the conduciveness of the area for traveling by bicycle. However, there is not one single definition of the term bikeability (Kellstedt et al., 2020). Different definitions also lead to different interpretations on how to measure bikeability. Because of this there is also a disagreement about which assessment criteria should be included and how these criteria have to be included. As a result, numerous bikeability tools have been developed with different purposes in mind (Muhs & Clifton, 2015). For example, bikeability tools that measure the safety of the bicycle network (Klobucar & Fricker, 2007), assessing the conditions of the infrastructure (Nuñez et al., 2020) and measuring the overall cyclist friendliness (Krenn et al., 2015). All in all, the concept bikeability can be used to assess areas on specific bicycle related topics. These assessments can be used to evaluate existing bicycle facilities and identify problematic situation and suggest potential improvements.

The Dutch Knowledge Institute for Mobility Policy (KiM) expects that bicycle usage in the Netherlands will increase even further in the coming years due to the rising share of higher educated employees (who are expected to use the bicycle more often) and due to the ongoing urbanization (CROW Fietsberaad, 2019). Additionally, there is also an increase in different types of bicycles such as e-bikes and pedelecs (CROW Fietsberaad, 2021), enabling people to travel further distances by 'bicycle'. These developments concords with the ambitions of the Dutch government to make the Netherlands more bicycle friendly and increase the number of cyclists (Ministerie van Algemene Zaken, 2020). To strengthen this ambition, the 'Tour de force' program was established. This is a national collaboration between governments, market parties, civil society organizations and other institutions. The 'Nationale Fietsagenda' (National bicycle agenda) report indicates their goals for sustaining the growth of bicycle usage by prioritizing the bicycle policy, seizing opportunities and removing potential obstacles. Their main ambition is to increase the number of cycled kilometres by 20% in 2027 relative to 2017 (Tour de force, 2016) and to decrease the number of people involved in a bicycle accident (Tour de force, 2020). The 'Tour de force' parties want to achieve those ambitions by reaching numerous sub-goals including focus points such as stimulating more people to use the bicycle, creating a safer and more comfortable bicycle environment and improving the bicycle network connectivity (Tour de force, 2016).

However, these ambitions can also have a downside if they are managed poorly. The increase of bicycle use can lead to additional pressure on the bicycle infrastructure (CROW Fietsberaad, 2019). This additional pressure in combination with the high travel speed differences between the new and the traditional bicycles can cause safety risks and a decrease of comfort level for the cyclists (Li et al., 2012; Chen et al., 2018; Xu et al., 2016). Therefore, it is important to create enough space to facilitate these ongoing developments (Tour de force, 2016). This would mean that it is necessary to develop new bicycle facilities and infrastructure as well as adjusting the existing infrastructure accordingly. These actions are crucial for a good integration of these additional cyclists and relieving the pressure they cause on the bicycle network.

Depending on the overall quality of the bicycle network, ongoing developments can be either an improvement or a nuisance. Therefore, cities are willing to heavily invest in their bicycle infrastructure and facilities (Natera Orozco et al., 2020; Tour de Force, 2016). However, determining how and where to invest can be troublesome as the new focus on investing in the bicycle network rather than in the car infrastructure leads to a different mind-set with new priorities and infrastructure decisions (Tour de Force, n.d.). Bicycle network and bicycle usage data can potentially be used to help with the decisions making process on how and where to invest to improve the bicycle network (Natera Orozco et al., 2020). However, the relatively little bicycle data which is available is hardly used to facilitated bicyclists and determine the investment policy while such data could provide useful insight and a solid argument in favour of the investment decisions (Tour de Force, n.d.). Thus, a problem that cities are dealing with is that there is no clear indication to base the investment decisions on. Therefore, it would be useful to find a method to support decision making based on the available bicycle data which gives confidence in that the investments made in the bicycle network ensure that the network meets and continue to meet the necessary quality requirement.

1.2 Research motivation

As mentioned before, the Dutch government wants to make the Netherlands more bicycle friendly and safer while also increase the kilometres travelled by bicycle and increasing the number of cyclists (Ministerie van Algemen Zaken, 2020; Tour de Force, 2020). They want to achieve this by focussing on stimulating more people to cycle, create safer and more comfortable bicycle environment and improve the connectivity (Tour de Force, 2016). However, as they want to stimulate more people to cycle, it would also be important to understand what influence the bicycle use of different groups of cyclists. This is something that decision-makers should take into account. Nevertheless, it is already expected that the bicycle usage will increase in the coming years (CROW-Fietsberaad, 2019), which is good for achieving the national goals, but also means that the pressure on the bicycle network will increase. The decisions-makers must anticipate on this development and plan accordingly.

Trying to achieve the aim of the Dutch government to increase the travelled bicycle kilometres and increasing the number if cyclist while also making the bicycle network safer and more friendly, makes municipalities willing to invest in their bicycle network (Tour de force, 2016). However, determining how and where to invest can be troublesome. Therefore, the task that lays ahead is to provide Dutch municipalities with a clear assessment tool which indicates the city's performance regarding the concept of bikeability. An assessment tool that includes bicycle network data could be used to streamline the decision of where to intervene and how the invest to ensure that the network meets the current demands and improve the bikeability for future demand. A tool based on bicycle data can provide useful insight and a solid argument for determining the investment decisions.

To do so, it is necessary to understand which factors are of importance to increase the bikeability level of a city and how these factors can be measured. This is something that still needs to be clearly defined (Kellstedt et al., 2020). Furthermore, the context of bikeability assessment tool, as well as the type of bicyclists is of importance, as this can influence the included variables and measurements (Kellstedt et al., 2020; Arellana et al., 2020). Currently, no Dutch specific bikeability tool exists, meaning that there is no bikeability assessment method which can perform previously mentioned tasks for Dutch cities specifically.

1.3 Research question

The aim of this research is to develop an assessment tool to measure the bikeability level of a Dutch neighbourhood. Besides that, the goal is to test the bikeability assessment tool and thus look into the development of an assessment tool for which the data is available. To achieve the main aim, it is first necessary to understand how the bikeability level can be measured, and to then translate this understanding in an assessment method. Therefore, the main research question of this research is:

How can the bikeability level of a neighbourhood be measured and translated into an assessment method which provides an overall bikeability level and provide insight in potential improvement to increase the bikeability level of a neighbourhood?

To answer the main research question, multiple sub-questions need to be answered:

- *What is bikeability and what measures are available?*
- *Which variables can measure the bikeability level and how can these be quantified in terms of objective scores and importance?*
- *Which data is available and accessible for the calculation of the bikeability level?*

By answering these sub question, an assessment tool can be developed which would be able to provide the answer to the main research question.

1.4 Societal relevance

To summarize, the aim of the research is to develop a bikeability assessment tool. This tool should determine the bikeability level of a certain area and provide insight in how to improve the bicycle network to increase the bikeability level. Therefore, this research can help municipalities streamline their decision-making process of where to intervene and how to invest to ensure that the bicycle network not only meet current demand, but can also be improved for future challenges. This will not only be beneficial for the municipalities, but also for the residents living in these areas where the interventions take place as these will affect their living environment. For instances, improving the bicycle network will make it more attractive for residents to use the bicycle and to relinquish the car. This will result in less CO_2 emission and with that an improved air quality in their living environment (Johansson et al., 2017). Additionally, promoting active transportation can help with increasing the social capital in an area, which is positively related to physical and mental health as well as promoting healthy behaviours (Giles-Corti et al., 2010). Thus, it can be concluded that the research will be beneficial for society as a whole.

1.5 Scientific relevance

There is a lack of a document with clearly defined and testable variables to assess the bikeability level of an area. This results in the lack of a clear definition of the concept 'bikeability'. Therefore, this research will extensively research how to clearly define bikeability and how to assess the bikeability level of an area. By doing so, this research is expected to broaden the scientific knowledge regarding the concept and the assessment of bikeability. Providing the scientific community with a clearly defined list of variables which influence the bikeability of an area and a Dutch bikeability assessment tool to follow as example.

1.6 Reading guide

The report is structured as followed. Chapter 2 consist out of a literature review. This literature review first presents the findings regarding the determinants of bicycle use and explains the variables that can be deducted from these findings. Then, the literature review presents a review of existing bikeability assessment tools and their included variables and measurement methods. Lastly, the literature review compares the variables found in literature regarding the determinants of bicycle use and the variables found in existing bikeability tools to indicate the which determinants of bicycle use are currently not part of the bikeability assessment tools. In chapter 3, the variables found during the literature will be used in chapter 3 to develop a new bikeability assessment tool for Dutch cities. The specification for Dutch cities means that the variables and their measurements are designed to represent the Dutch bicycling context. Therefore, some identified variables will be excluded from the new tool as there are not applicable in the Dutch context. Then, in chapter 4 the working of the newly developed bikeability assessment tool will be illustrated by performing a case study using three Dutch neighbourhoods. Lastly, in chapter 5 the findings of the report are summarized and the practical implication of the developed bikeability assessment tool is discussed.

2. Literature review

In this chapter a literature review will be conducted to identify the different determinants of bicycle use. Furthermore, existing bikeability tools will be reviewed to obtain insight in the variables currently used to measure bikeability. In section 2.1 the determinants of bicycle use will be discussed. In section 2.2 the reviewed bikeability tools will be summarized. Lastly, in section 2.3 the determinants of bicycle use and the identified variables of existing bikeability tools will be compared.

2.1 Determinants of bicycle use

First and foremost, the term 'bicycle use' needs to be clarified as it can be a broad term. In this report the term 'bicycle use' is used to refer to the bicycle mode share, the volume of bicyclists, the cycling distance and the frequency travelled by bicycle.

During this literature review, determinants of bicycle use will be identified based on different type of research studies. One of the most important types of research study is 'route choice modelling'. It is a method to model the behaviour of travellers to identified preference in route characteristics based on set of variables connected to each route and the chosen route by the traveller. This information can then be used to explain the characteristics that influence the route choice of travellers and the degree of the influence (Prato, 2009). Route choice models thus leads to insight in the route preferences of bicyclists. It is assumed that if routes have those preferences, they promote bicycle use. Therefore, the result of route choice models can be used to determine which route aspects affect the bicycle use. Route choice modelling can be conducted by using stated preference based on hypothetical streets or using revealed preference often identified by using GPS trackers (Ton et al., 2017).

Another important type of research study is 'mode choice modelling'. This is a method to model the behaviour of travellers in regard to which mode they will choose for their trip and to predict the overall share of a certain transportation mode based on variables connected to the transportation mode (Koppelman & Bhat, 2006). This information can be used to explain which characteristics influence the mode choice of travellers. Mode choice modelling can provide insight in characteristics that can make individual switch from one transportation mode to cycling. Therefore, the insights of mode choice modelling are of importance for determining bicycle use in an area.

Besides, route choice models and mode choice models, other studies that identified determinants of bicycle use will also be reviewed. These studies included, to name a few, crash risk models, longitudinal analyses, and review studies. Some of the reviewed literature will provide insight in how certain characteristics can increase the safety, comfort or convenience for bicyclists rather than the bicycle use. However, this does not mean that this does not affect bicycle use. Research has shown that the factors safety, comfort and convenience are at the forefront of determining the bicycle use (Piatkowski & Marshall, 2015; Hull & O'Holleran, 2014; Heinen et al., 2010; DiGioia, 2017; Rietveld & Daniel, 2004; Handy et al., 2010). Thus, research indicate changes in safety, comfort and convenience of bicycle use are considered to affect the overall bicycle use and are therefore determinants of bicycle use.

The following subsections 2.1.1 to 2.1.6 will summarize the findings of the literature review regarding bicyclists' preferences and the determinants of bicycle use. Each subsection will discuss different categories of bicycle use determinants.

2.1.1 Socio-demographic determinants of cycling

Socio-demographic determinants include aspect regarding the individual that can influence their bicycle behaviour. The importance of the socio-demographic determinants is that is can potentially explain low levels of bicycle use based on individual characteristics. Existing research has identified multiple socio-demographics aspects that have a significant influence on the bicycle use. Research often identifies a significant relationship between gender and using the bicycle for transportation. Namely, that men cycle more often than women (Piatkowski & Marshall, 2015;). Ethnicity is also found to be related to the bicycle use, as non-white individuals showed lower levels of bicycle use than 'white' individuals (Chen et al., 2017; Piatkowski & Marshall, 2015; Steinbach et al., 2011). Furthermore, it is found that employment of the individual's matter. Individuals with a part-time job tend to uses their bicycle more often to get to work than individuals with a full-time job (Heinen et al., 2010; Boumans and Harms, 2004). Lastly, it is found that car ownership has a negative effect on cycling (Heinen et al., 2010; Piatkowski & Marshall, 2015).

The socio-demographics variables age, education level and income also have an influence on the bicycle use, however the findings are somewhat inconclusive. Heinen et al. (2010) mentions that multiple studies found a negative relation between age and bicycle use, meaning older individuals cycle less (Chen et al., 2017). However, there are also studies that did not find a significant relation between age and bicycle use (Heinen et al., 2010). For the education level results have shown both a positive and a negative relation between the level of education and bicycle use (Ton et al., 2019; Piatkowski & Marshall, 2015), making the expected result inconclusive. The same inconclusiveness is found for the income level, as research has shown a relation in both directions (Heinen et al., 2010).

The household composition also has somewhat of an unclear effect. Ryley (2006) concluded that households with children are less likely to use the bicycle for non-leisure trips. While Piatkowski & Marshall (2015) found that household size was positively related to bicycle use. However, they did indicate that roughly 70% of their respondents did not have children under the age of 16. This means that their result does not necessarily contradict that of Ryley (2006).

Numerous studies found a relation between multiple aspects of socio-demographics and bicycle use. However, Fishman (2016) mentions the Netherlands as an unmatched country in cycling population, in which a more diverse demographic group participates in cycling. According to the research of Fioreze & Lenderik (2020), 69% of the people in the Netherlands uses their bicycle on a weekly basis. In terms of bicycle ownership, the Netherlands is the number one in the world with a bicycle ownership of 1.3 bicycle per person (De Haas & Hamersma, 2020). Furthermore, 28% of all trips are conducted by bicycle, which is the highest percentage in the world, and the bicycle is the most important mode of transport for educational related trips and work trips shorter than 5 km (De Haas & Hamersma, 2020). Therefore, it can indeed be said that the Netherlands is an unmatched country in cycling population. Thus, it could be possible that the results regarding socio-demographics found in other countries may not hold true for the Netherlands.

Ton et al. (2019), conducted research on determinants of mode choice in the Netherlands and compared their result with the existing results regarding socio-demographic determinants worldwide. In contrary to previously found relationships between gender, age, ethnicity, employment and car ownership, no significant relationship was found between those variables and bicycle use in the Netherlands. Additionally, Ton et al. (2019) did not find a significant relationship between income and bicycle use, which in the existing literature resulted in mixed significant relations. They did, however, find a significant positive relation between education level and bicycle use. They explain this positive relation by assuming higher educated people are more aware of the health benefits of cycling and therefore cycle more frequently. Lastly, Ton et al. (2019) found a significant positive relation between household size and bicycle use. Meaning that an increase in the number of individuals living in a household increases the bicycle use. This can be explained by the fact that Dutch children cycle from an early age and that cycling is the most popular among children and adolescents in the Netherlands (Pucher and Buehler, 2008). Households with a higher number of individuals generally means that families occupy the dwelling, which also means the presence of children and adolescents.

The findings of the research of Ton et al. (2019) can be compared to the bicycle statics of the Netherlands. From the 69% of individuals that use their bicycle on a weekly basis, 48% is male and 52% is female (Fioreze & Lenderik, 2020). While women choose to travel by bicycle more often than men (29% and 27% respectively) (De Haas & Hamersma, 2020), men travel further distances than woman on a daily basis (3.27 and 2.75 km respectively) (CBS, 2020). Thus, the difference between the two genders is not that larger. Therefore, the results regarding gender of Ton et al. (2019) seem plausible.

Looking at the influence that age can have of bicycle use, CBS (2020) shows that the average distance travelled on a daily basis is roughly similar between age groups with two exceptions. First, for the age group of 12- to 18-years-olds, the distance travel on a daily basis is much higher than other age groups. This difference can be explained by the fact that for the age group 12- to 18-years-old the trips conducted by bicycle is the highest of all age groups, as well as the fact that the bicycle is the most important mode of transport for trips with educational purposes (De Haas & Hammersma, 2020) which is most relevant to this age group. Second, the average daily km of 65- to 75-year-olds is somewhat higher. A potential explanation is that these people use bicycles more for recreational purposes a not for work purposes as they do not need to work anymore. Based on this, the results of Ton et al. (2019) regarding age seem somewhat plausible.

For ethnicity it is found that native Dutch and people with western ethnicity use the bicycle more often than people with a non-western ethnicity, however the difference is small (De Haas & Hammersma, 2020). This small difference is in line with the results of Ton et al. (2019).

For the determinant household size, De Haas & Hammersma (2020) confirm that children participate more in cycling than adults. Which would indeed explain that households with more individuals (generally representing families), use the bicycle more often.

All in all, it can be concluded that socio-demographics of individuals in the Netherlands can have somewhat of an impact on the bicycle use, although the impact is quite small. Socio-demographic determinants therefore seem less relevant for determining the bicycle use in the Netherlands than for other countries. A reason for this can be the unique and diverse cycling population as well as the already high levels of cycling participation in the Netherlands. Based on the socio-demographic findings, it is decided to not use socio demographic determinants for explaining bicycle use in the Netherlands.

2.1.2 Bicycle infrastructure

The presence of dedicated bicycle infrastructure is often described as a key component for increasing bicycle use (Veilette et al., 2019; Piatkowski & Marshall, 2015). A previously conducted reveal-preference study has found that bicyclists have a higher preference for routes with dedicated bicycle infrastructure (Broach et al., 2012). This is in line with other research that found that dedicated infrastructure for active transport modes is needed to increase the use of those modes (Heinen et al., 2010; Handy et al., 2014; Fraser and Lock, 2010) and that areas with more dedicated infrastructure for bicycles have a higher bicycle mode share (Chen et al., 2017; Dill & Carr, 2003; Nelson & Allen, 1997; Parkin et al., 2007). For example, Handy et al. (2010) found that in the USA, dedicated bicycle infrastructure has a positive influence on bicycle use for transportation and that a network of separated bicycle paths would encourages individuals to use the bicycle for transportation. Rowangoud & Tayarani (2016) researched the effects of the removal of dedicated bicycle infrastructure and found that the removal of it would result in a decrease of bicyclists that currently cycle, but would stop cycling if the dedicated bicycle infrastructure would be removed.

Interestingly enough, research conducted by Ton et al. (2017) in Amsterdam, a city that is characterized by bicycling, did not find a significant relationship between bicycle infrastructure and the routes chosen by the bicyclists. Ton et al. (2017) do recognize that this result is in contrast with results of previously conducted studies, but explain these differences by the unique Dutch context and state that when bicycling is well established within an area (additional) bicycle infrastructure does not attract bicyclists and other aspects become more important for increasing bicycle use. This statement is strengthened by the findings of Rowangould & Tayarani (2016) who concluded that dedicated bicycle infrastructure is more important to the lesser experienced bicyclists and the presence of bicycle infrastructure play a major role in encouraging new individuals to bicycle. Caulflied et al. (2012) also found that more off road bicycle infrastructure would encourage people to begin to bicycle to their work.

Furthermore, the presence of dedicated bicycle infrastructure is not only important for increasing the bicycle use, but also for increasing the safety. Raihan et al. (2017) found that the presence of a bicycle lane opposed to a roadway without dedicated bicycle infrastructure, decreased the chance of bicyclists being involved in a crash. Risk modelling performed by Wall et al. (2016) also showed that painted bicycle lanes as well as protected bicycle paths decreases the number of bicycle injuries. It can be argued that the reason that the bicycle use increases after the implementation of dedicated bicycle infrastructure is because of the decreased crash risk. Current non-cycling individuals indicated that safety concerns are a reason for them to not to use the bicycle (Heinen et al., 2010). Thus, the presence of dedicated bicycle infrastructure could create a safe enough environment for these individuals to be willing to start with cycling.

Besides the presence of dedicated bicycle infrastructure, the continuity also plays an important role. Research has found that bicyclist prefer continuous bicycle infrastructure between their origin and destination (Saleans et al., 2003) and that sudden endings of the bicycle infrastructure are perceived negatively (Heinen et al., 2010). Furthermore, badly connected bicycle lanes can be a reason for people not to start bicycling (Caulflied et al., 2012). Thus, it can be concluded that it is not only important to have dedicated bicycle infrastructure present within an area, but it also important that the present bicycle infrastructure is serving complete routes.

2.1.2.1 Bicycle infrastructure typing

In the previous section, the importance of the presence of dedicated bicycle infrastructure has been established. In that section, scenarios when there is no dedicated bicycle infrastructure are compared to scenarios when there is dedicated bicycle infrastructure. However, different forms of dedicated bicycle infrastructure can potentially provide different levels of safety, convenience and encouragement of bicycling.

In the Netherlands, seven different types of dedicated bicycle infrastructure can be differentiated, which can be classified into three categories (SWOV, 2020a). There are three types of physically separated bicycle infrastructure types: bicycle path, moped & bicycle path, and optional bicycle path. The main difference between the 'moped & bicycle path' and the other two separated bicycle infrastructure types is that 'moped & bicycle path' also allows moped vehicles. This can cause overtaking disturbances for the cyclists due to the speed differences between the two modes, which reduces the cyclist's sense of safety (Chen et al., 2018).

There are two types of painted separated bicycle infrastructures: bicycle lane and bicycle suggestion lane. The difference between the two is that the type 'bicycle lane' is a dedicated space for only bicyclists, while the 'bicycle suggestion lane' is also used by motorized vehicles when they do not have enough space to pass another car coming from the opposite direction (Fietsberaad-CROW, 2015).

Meaning that bicyclists using a 'bicycle suggestion lane' are more exposed to motorized vehicles, which is not preferred by bicyclists (Broach et al., 2012) and can cause them more danger (Saelens et al., 2003)

There is one type of mixed bicycle infrastructure, the bicycle street. It is important to mention that mixed bicycle infrastructure in the Netherlands is not the same infrastructure as mentioned in most literature. In the Netherlands, this would indicate a 'bicycle street' which is a special kind of street designed for bicyclists that allows motorized vehicles as guests. Meaning, that the cyclists are the main users of the road and the motorized vehicles need to give them priority (Fietsberaad-CROW, 2015). While mixed bicycle infrastructure in research outside of the Netherlands mainly indicate lanes combining either bicycles and busses or bicycles and pedestrians. These types of bicycle infrastructures are not common practice in the Netherlands. Moreover, in the Netherlands it is forbidden to cycle on sidewalk or bus lane (ANWB, n.d.). Thus, findings regarding mixed bicycle infrastructure would be of lesser importance when focussing on cycling in the Netherlands as the findings are not relevant for the Dutch context.

Research on these three categories of bicycle infrastructure indicates that there is indeed a difference in impact of the type of bicycle infrastructure on the levels of safety, convenience and bicycle use. The findings regarding mixed bicycle infrastructure are that cycling in mixed traffic is perceived as less desirable than cycling in a space dedicated to bicyclists only (Hunt & Abraham, 2006). Research shows that individuals are less likely to cycle on combined bicycle and bus lanes (Caulfiled et al., 2012) and that the bicycle comfort increases when bicyclists have separated infrastructure from pedestrians (Li et al., 2012). Thus, it can be said that infrastructure solely dedicated to bicyclists is preferred over mixed bicycle infrastructure.

There are also differences found in dedicated bicycle infrastructure separated and unseparated from the roadway. The main conclusion is that separated infrastructure is preferred over unseparated infrastructure (Caulfield et al., 2012; Heinen et al., 2010; Veillette et al., 2019; Broach et al., 2012). The perception of comfort on unseparated bicycle infrastructure is found to be lower than on separated bicycle infrastructure (Li et al., 2012). Unseparated bicycle infrastructure still makes use of roads that combine traffic, thus still expose bicyclists to motorized vehicles and thus has a higher chance of accidents than separated bicycle infrastructure (Saelens et al., 2003). Research shows that bicyclists prefer routes that reduce their exposure to motorized vehicles (Saelens et al., 2003; Broach et al., 2012; Veillette et al., 2019). Increased concerns regarding the safety of the cyclists and involvement in accidents is found to lower the likelihood of bicycle use (Piatkowski & Marshall, 2015; Heinen et al., 2010). Conclusion, physically separated bicycle infrastructures are the most preferred bicycle infrastructure type, followed by bicycle infrastructure separated by paint and the least preferred bicycle infrastructure type is mixed traffic infrastructures.

2.1.2.2 Path width

The width of the bicycle infrastructure is another important determinant of bicycle use. The safety on the bicycle infrastructure is dependent on the number of passing events (Xu et al., 2016). A wider path can benefit bicyclists as it provides them with more space to avoid and overtake other users, decreasing the chance of an accident during such a passing event (Veroude & van Boggelen, 2021; Hull & O'Holleran, 2014). The number of passing events is dependent on the bicycle intensity on the path, as well as the allowance of moped vehicles. A higher bicycle intensity is negatively related to the comfort level of bicyclists (Li et al., 2012). Recommendation for bicycle path widths should take the bicycle intensity into account (Veroude & van Boggelen, 2021) and provided wide enough bicycle paths to ensure that the bicycle intensity does not negatively affect the bicyclist comfort. When moped vehicles are allowed on a bicycle path, it is expected that more overtakes take place, due to the large speed differences (Chen et al., 2018). The path width needs to be adjusted accordingly, to make the overtakes more convenient for both the bicyclists and moped vehicles.

Another benefit from a wider path is that bicyclists are less vulnerable to the doors of cars parked parallel to the bicycle infrastructure, as it provides them with more space to avoid opening car doors (Saelens et al., 2003; Hull & O'Holleran, 2014).

2.1.2.3 Speed difference and traffic volume

As established in section 2.1.2.1 bicyclists prefer bicycle infrastructure that is physically separated from motorized traffic. However, this is not always possible. When the bicycle infrastructure cannot be physically separated from the motorized traffic, bicyclists prefer a lower speed limit for the motorized vehicles with whom they share the road (Caulfield et al., 2012; Saelens et al., 2003). Research shows that road with lower speed limits have a positive effect on the bicycle mode share (Heinen et al., 2010). Furthermore, a higher speed limit can increase the stress level of the cyclists (Lowry et al., 2016; Gholamialam & Matisziw, 2019), thus reducing their convenience. In addition to applying a low maximum speed limit, it is also possible to enforce lower speeds by applying speed limiting objects such as speed bumps or speed limiting designs (SWOV, 2018).

Another preference for when bicyclists have to share the road with motorized vehicles is a lower level of traffic volume (Caulfield et al., 2012; Saelens et al., 2003; Broach et al., 2012; Parking et al., 2007). Research shows that higher levels of traffic volumes result in a decrease of comfort due to the increased risk of collisions (Li et al., 2012; Oh et al., 2008), while lower level of traffic volumes have a positive effect on bicycle use (Heinen et al., 2010). Making use of one-way streets can be a measure to lower the traffic volume (SWOV, 2018).

2.1.2.4 Separation types and roadside types

The type of the separation and roadside types are important determinants as they can affect the safety of the bicyclists. The separation type refers to a barrier between the bicycle path and roadway and the roadside type refers to what is present on opposite side of the bicycle infrastructure. The main concern regarding the safety comes from the separation and roadside types that have influence on the chance of a bicycle crash (Raihan & Alluri, 2017). The separation and roadside type can protect bicyclists from collisions with other vehicles, but can also increase the chance of a single-bicycle accident. A single-bicycle accident is an accident solely involving a bicyclist, mainly origin from falling over or hitting an obstacle (Schepers, 2009).

Different forms of separation and roadsides can provide different levels of safety for the cyclists (Schepers, 2009; Fietsberaad, 2011). Research conducted by Raihan & Alluri (2017) showed that physical objects and car parking results in the highest probability of a bicycle crash, followed by sidewalks. A positive finding from their research was that vegetation resulted in a lower crash probability. The problem with physical objects and parked cars is that they do not provide the bicyclists a chance to regain control or steering back on the bicycle path, whereas vegetation can give bicyclists a chance to prevent the accident (Raihan & Alluri, 2017). Furthermore, car parking spaces adjacent to the bicycle infrastructure also add the danger of cars crossing the bicycle infrastructure in order to park the car or when opening the car doors (Heinen et al., 2010; Saelens et al., 2003). The removal of parked cars adjacent to the bicycle network will reduce the bicycle crash probability (DiGioia et al., 2017).

2.1.2.5 Pavement

The pavement of the bicycle infrastructure also plays an important role for the bicycle comfort and convenience. The pavement type plays an important role in the perception of comfort (Hull & O'Halloran, 2014). So called closed pavement (asphalt and concrete) creates a flat surface which cause little to no vibrations while open pavement (pavement stone) can cause a lot of vibrations. These vibrations decrease the comfort of cyclists and therefore, bicyclists prefer to cycle on paths made of closed pavement (Fietsberaard, 2006).

The quality of the pavement is also of importance. A pavement with many cracks or holes decreases the bicycling comfort (Arellana et al., 2020) as it creates the possibility of the cyclists to get out of balance and fall over (SPV, 2020; SWOV, 2020a).

2.1.2.6 Lighting

Research has shown that darkness can negatively affect bicycle use (Heinen et al., 2010) and that it is importance to have lighting alongside bicycle infrastructures (Hull & O'Holleran, 2014). The presence of street lights provides cyclists with a safer bicycle environment during night time (Arellana et al., 2020) which makes individuals more likely to bicycle (Akar & Clifton, 2009). Therefore, it would be preferred to have lighting alongside all bicycle infrastructure.

2.1.2.7 Obstacles

Obstacles can make it less convenient to cycle, causing hindrances that slowdown the bicycle trip and increase the probability of single-person bicycle accidents which can have a negative influence on the bicycle use (CROW-Fietsberaad, 2014; Rietveld & Daniel, 2004). Therefore, bicycle infrastructure should avoid having obstacles on and around the path.

2.1.2.8 Slopes

A slope can influence the convenience of cycling as it requires additional effort to cycle uphill but it also requires additional effort in controlling the speed when going downhill. Control of the bicycle while going downhill is also important as going downhill increase the bicyclist's speed, which causes an increased chance in accidents and the severity of those accidents (Eriksson et al., 2019). Most research has indicated that slopes have a negative effect on bicycle use (Heinen et al., 2010; Rietveld & Daniel, 2004; Chen et al., 2017; Li et al., 2012; Nielsen et al., 2013). However, the research of Saelens et al. (2003) also indicates that bicyclists cycling for non-commuting purposes can prefer areas with hills. The assumption is that those individuals cycling for recreational or physical purposes which make them prefer graded terrain.

2.1.2.9 Land use

According to Hull & O'Holleran (2014) an attractive scenery such as green areas can encourage bicycling. Research conducted on the effect of land use has shown that this is indeed the case. But also show that more common land uses can have a positive influence on bicycle use. Research has shown that green and aquatic, retail, and residential areas all have a positive influence on the bicycle use (Zhao et al., 2020; Chen et al., 2017; Krenn et al., 2015; Saelens et al., 2003).

In contrary, it has been found that office land use causes a decrease in bicycle comfort (Xu et al., 2016) and industrial land use increases the risk of bicyclists being involved in an accident (Oh et al., 2008). Therefore, it is important to consider in which type of land use the bicycle infrastructure is situated.

Based on the literature a list with bicycle infrastructure determinants of bicycle use can be constructed. Table 2.1.1 shows the table with determinants of bicycle use found from bicycle infrastructure. In total, 14 determinants were identified that can be translate into 14 variables.

Table 2.1.1. Determinants of bicycle use from bicycle infrastructure.

Determinants of bicycle use	References
Presence	Veilette et al., 2019; Piatkowski & Marshall, 2015; Broach et al., 2012; Heinen et al., 2010; Handy et al., 2014; Lin & Wei, 2018; Chen et al., 2017; Handy et al., 2010; Rowangoud & Tayarani, 2016
Continuity	Saleans et al., 2003; Heinen et al., 2010; Cauflied et al., 2012;
Type	Raihan et al., 2017; Wall et al., 2016; SWOV, 2020a; Fietsberaad-CROW, 2015; Broach et al., 2012; Saelens et al., 2003); Hunt & Abraham, 2006; Li et al., 2012; Veillette et al., 2019
Path width	Veroude & van Boggelen, 2021; Hull & O'Holleran, 2014
Speed limit	Caulfield et al., 2012; Saelens et al., 2003; Heinen et al., 2010; Lowry et al., 2016; Gholamialam & Matisziw, 2019
Speed limiting objects	SWOV, 2018
Traffic volume	Caulfield et al., 2012; Saelens et al., 2003; Broach et al., 2012; Li et al., 2012; Oh et al., 2008; Heinen et al., 2010
One-way street	SWOV, 2018
Separation type	Raihan & Alluri, 2017; Schepers, 2009; Fietsberaad, 2011; DiGioia et al., 2017
Roadside type	Raihan & Alluri, 2017; Schepers, 2009; DiGioia et al., 2017
Pavement quality	SPV, 2020; SWOV, 2020a
Pavement type	Hull & O'Halloran, 2014; Fietsberaard, 2006
Lighting	Heinen et al., 2010; Hull & O'Holleran, 2014; Akar & Clifton, 2009
Obstacles	CROW-Fietsberaad, 2014; Rietveld & Daniel, 2004
Slopes	Eriksson et al., 2019; Heinen et al., 2010; Rietveld & Daniel, 2004; Chen et al., 2017; Li et al., 2012; Nielsen et al., 2013
Land use	Hull & O'Holleran, 2014; Zhao et al., 2020; Chen et al., 2017; Krenn et al., 2015; Saelens et al., 2003; Xu et al., 2016; Oh et al., 2008

2.1.3 Junction infrastructure

Junctions are an important infrastructure in regard to bicycle safety and the treatment of junctions is therefore of high importance (Schepers et al., 2017; SWOV, 2021). Bicycle crashes involving cars account for 60% of bicyclist's deaths and most of these crashes occur at intersections on distribution and arterial roads (Reurings et al., 2012). Thus, junctions are the most dangerous points for bicyclists and therefore a good junction design is of importance for the safety of the bicyclists (Weigand, 2008; Schepers et al., 2017). Based on this, it is expected that the junction infrastructure present in a neighbourhood will influence people's perception of safety and with that their bicycle use.

The existing literature reveals that the presence of junctions is not particularly liked by bicyclists. As route choice models showed that individuals prefer routes with fewer junctions and a higher number of junctions resulted in a smaller chance of that road being chosen (Caufield et al., 2012; Saelens et al., 2003; Ton et al., 2017). Additionally, a higher intersection density is often associated with lower levels of bicycle use (Piatkowskie & Marshall, 2015; Heinen et al., 2010). However, a study conducted in Denmark by Nielsen et al. (2013), found that network connectivity measured by the number of intersections had a positive effect on the likelihood of bicycle use. This result stresses the importance of junctions as they are needed for connectivity. So, although less junctions are preferred by bicyclists, they are needed for a good network connectivity. The presence of junctions is unavoidable and therefore it is importance to consider how to make junctions safer and more convenient for bicyclists.

Different types of junctions can provide different levels of safety. In the Netherlands five different types of junctions can be distinguished: Roundabout, priority square, intersection regulated with markings and signs, intersection regulated with traffic lights and intersections regulated with priority rules (SWOV, 2021). The roundabout is considered the safest type of junction due to their limited amount of conflict points, lower motorized vehicle speed and smaller impact angles when a crash does happen (SWOV, 2021). Intersections regulated with traffic lights and, to a lesser extent, with markings and signs have a negative effect on the travel convenience of the bicyclists due to the potential travel delay that they can cause (Broach et al., 2012). However, these negative effects on travel convenience are outweighed by the increased safety on intersection with a higher traffic volume (Broach et al., 2012).

Researches has compared intersections regulated with traffic lights and with markings and signs while controlling for the traffic flow intensity and found that intersections with traffic lights are less safe than those regulated with markings and signs (SWOV, 2021). When an intersection is regulated by traffic lights, they can be perceived as safer when they have dedicated traffic lights for bicyclists (Schepers et al., 2017; SWOV, 2021; Weigand, 2008). Furthermore, a traffic lights system that provides bicycle with priority (Hull & O'Holleran, 2014; Aker & Clifton, 2009), a pre-start (Schepers et al., 2017) or their own green phase (SWOV 2021; Weigand, 2008) provide even more safety for the bicyclists. When an intersection is not regulated by traffic lights, they should include speed limiting objects to reduce the speed of motorized traffic and increase their attention, which results in a lower likelihood of a crash with a bicycle (Heinen et al., 2010; Fietsberaad, 2011; Oh et al., 2008)

Intersections regulated with priority rules are not suitable for intersection on distribution or arterial roads and should only be applied on low-speed access roads (SWOV, 2021). Lastly, The priority square is relatively new. Therefore, there is little information about the benefits compared to the other junction types. Generally speaking, the priority square has more points of conflict than a roundabout, but these conflicts occur with a lower motorized vehicle speed than on other junction types (SWOV, 2021).

Another important junction aspect is the bicycle infrastructure at the junction. The safety that the bicycle infrastructure provides at a junction mainly depends on the distance between the bicycle infrastructure and the lane for motorized vehicles. Moving the bicycle infrastructure further away from the roadway increases the safety (Fietsberaad, 2011; Madsen & Lahrmann, 2017). This means that a separated bicycle path would provide the most safety for bicyclists at a junction. Research has shown that junctions with a bicycle path 2 to 5 meters away from the junctions lowers the number of crashes with 45%, mainly because it keeps bicyclists out of the blind spot of motor vehicles (Schepers et al., 2017). A bicycle lane present at a junction can also positively influence the bicyclist's safety of crossing the junction (Landis et al., 2003; Weigand, 2008). But as this is adjacent to the road, it is less effective than a bicycle path. Nevertheless, a bicycle lane is a safer infrastructure type than roads that have no dedicated or shared bicycle infrastructure (Madsen & Lahrmann, 2017).

Another form of bicycle infrastructure that can be used at the junction to prevent crashes is a bicycle box (Schepers et al., 2017; Weigand, 2008). This is an area where cyclists can line up in front of the motorized traffic when waiting to make a left turn on an intersection with traffic lights (SWOV, 2020b). This positioning can reduce the likelihood of an accident as bicyclists are better visible for the motorized traffic (Weigand, 2008).

A last piece of infrastructure that can make junction safer is a median island, which is a safe space to wait for bicyclists in between the two roadways (going into different directions) when crossing a street. The presence of a median island improves the safety, ease of travel and comfort for bicyclist on a junction (SWOV, 2021; Fietsberaad, 2011).

Based on the reviewed literature a list with junction infrastructure determinants of bicycle use can be constructed. Table 2.1.2 shows the seven identified determinants.

Table 2.1.2. Determinats of bicycle use from junction infrastructure.

Determinants of bicycle use	**References**
Design / typing / layout	Weigand, 2008; Schepers et al., 2017; Broach et al., 2012; SWOV, 2021
Junction density	Caufield et al., 2012; Saelens et al., 2003; Ton et al., 2017; Piatkowskie & Marshall, 2015; Heinen et al., 2010: Nielsen et al. 2013;
Bicycle specific traffic lights	Hull & O'Holleran, 2014; Aker & Clifton, 2009; Schepers et al., 2017; SWOV 2021; Weigand, 2008
Speed limiting objects	Heinen et al., 2010; Fietsberaad, 2011; Oh et al., 2008
Bicycle infrastructure at the junction	Fietsberaad, 2011; Madsen & Lahrmann, 2017; Schepers et al., 2017; Landis et al., 2003; Weigand, 2008
Bicycle box	Schepers et al., 2017; Weigand, 2008
Median island	SWOV, 2021; Fietsberaad, 2011

2.1.4 Bicycle parking facilities

An important, but often overlooked, aspect of bicycle travel are the bicycle parking facilities (BPFs) (Castañon & Ribeiro, 2021; Van der Spek & Scheltema, 2015; Heinen et al., 2010). Research suggests that the presence of BPFs positively influences the likelihood of cycling (Ton et al., 2019; Heinen & Buehler, 2019) BPFs nearby work locations and train stations can promote bicycle ridership (Jonkeren & Kager, 2021; Wardman et al., 2007; Noland & Kunreuther, 1995). On the other side, the lack of BPFs can be a barrier for people to start cycling (Heinen & Buehler, 2019). But not only the lack of BPFs can discourage cycling, overcrowded BPFs can also decrease the chance of new people to start cycling (Jonkeren & Kager, 2021). Furthermore, overcrowded BPFs can also result in people parking their bicycle elsewhere in the area which can result in inefficient use of space and nuisance for individuals using this space (Jonkeren & Kager, 2021). Thus, the presence of BPFs with sufficient capacity is an important determinant of cycling.

Not only is the presence of BPFs important for bicycle travel, the quality of the BPFs can further amplify the positive influence of bicycle use (Jonkeren & Kager, 2021; Heinen & Buehler, 2019). The quality of a BPF is determined by multiple characteristics. The typing of the BPF is one of these characteristics. Research conducted by Heinen & Buehler (2019) indicates that covered or inside BPFs instead of uncovered BPFs has a positively influence on the bicycle use.

The safety of the BPFs also has influence on the bicycle use. Unsecure BPFs with a risk of theft and or vandalism have a negative effect on bicycle use (Rietveld & Daniel, 2004). Therefore, BPFs with bicycle lockers, caged sheds and (video) surveillance are overall preferred by bicyclists and the presence of these forms of safety can increase bicycle ridership (Jonkeren & Kager, 2021; Heinen & Buehler, 2019). Additionally, bicyclists that have a more expensive bicycles value the security of the BPFs more than those with less expensive bicycles (Heinen et al., 2010).

Another characteristic is the parking cost of the BPF. Bicyclists highly appreciate free parking. In general, people are not willing to pay to park their bicycle and even think it should be free of cost (Van der Spek & Scheltema, 2015). When a BPF has an entry fee, the likelihood of cycling decreases while the likelihood increases when parking is free (Heinen & Buehler, 2019).

As mentioned before, overcrowding can have a negative effect on bicycle ridership, meaning that the capacity of a BPF is of importance to their quality. An increased number of parking spaces increases the bicyclist's satisfaction with the BPF (Jonkeren & Kager, 2021) and can increases the likelihood of bicycle use (Heinen & Buehler, 2019).

The distance between the BPF and the destination is another important characteristic. In general, bicyclist prefer to park their bicycle as close as possible to their destination (Van der Spek & Schelteman, 2015). Research regarding the relation between BPFs and train stations showed that BPFs located closer to the station entrance resulted in higher satisfaction levels (Jonkeren & Kager, 2021) and increase likelihood of individuals cycling to the station (Heinen & Buehler, 2019)

Lastly, the visibility of the BPFs is of importance for the use of it. BPFs need to be easily accessible and easy to find. Therefore, for the quality of the BPF, it is important that the entrance is located close and insight of the bicycle infrastructure (Van der Spek & Scheltma, 2015).

Based on the reviewed literature a list with BPFs determinants of bicycle use can be constructed. Table 2.1.3 shows these determinants. In total, 7 determinants of bicycle use were found in regards to bicycle parking facilities.

Table 2.1.3. Determinants of bicycle use from BPFs

Determinants of bicycle use	**References**
Presence	Ton et al., 2019; Heinen & Buehler, 2019
Distance to destinations	Jonkeren & Kager, 2021; Wardman et al., 2007; Noland & Kunreuther, 1995; Van der Spek & Schelteman, 2015
Typing	Heinen & Buehler, 2019
Safety	Rietveld & Daniel, 2004; Jonkeren & Kager, 2021; Heinen & Buehler, 2019; Heinen et al., 2010
Cost	Van der Spek & Scheltema, 2015; Heinen & Buehler, 2019
Capacity	Jonkeren & Kager, 2021; Heinen & Buehler, 2019
Visibility	Van der Spek & Scheltma, 2015

2.1.5 Environment

The environment can also include important determinants for bicycle use (Saelens et al., 2003; Zhao et al., 2013). In the previous section, the determinants were based on characteristics of the infrastructure. Environment refers to the determinants in an area segment that can influence the bicycle use. An often-associated environment determinant on bicycle use is population density. Research has found that population (or sometimes residential) density is positively related to bicycle use (Ton et al., 2019; Heinen et al., 2010; Nielsen et al., 2013; Cui et al., 2014; Saelens et al., 2003; Fraser & Lock, 2010; Parking et al., 2007). A potential reason for this is that a higher population density represents a denser urban area with shorter distances between destinations (Heinen et al., 2010). Another explanation is the so called 'safety-in-numbers' phenomenon, as research has shown that a higher volume of bicyclists reduces the likelihood of a bicycle-car accident when the number of cars is kept constant (Schepers et al., 2017). All in all, population density is found to be positive related to the bicycle use.

The land use mix is also considered to be an environment determinant that affects the bicycle use. As research found that higher level of mixed land use positively affected the bicycle use (Fraser & Lock, 2010; Chen et al., 2017; Zhao et al., 2020) and a less diverse mix of land uses had a negative effect on the bicycle use (Zhao, 2013). Saelens et al. (2003) found that especially when residential land use was mixed with retail, work related and other non-residential land uses, the bicycle use was higher and that individuals would bicycle to work more often.

The ratio of bicycle infrastructure and roadways is also an important factor in determining bicycle use. Akar & Clifton (2009) concluded that if people have to option to drive, they will be inclined to do so, but that the presences of more bicycle infrastructure can help with promoting bicycle use. Zhao (2013) also found that more main roads was related to less bicycling, while more exclusive bicycle infrastructure was related to an increase of bicycle use. Thus, stating the importance of a high ratio of bicycle infrastructure. Furthermore, the density of the bicycle infrastructure may also play an important role. Research has shown that a higher network density increases the likelihood of bicycle use (Piatkowski & Marshall, 2015; Hull & O'Holleran, 2014; Heinen et al., 2010). Areas with more bicycle infrastructure show higher rates of bicycle use (Dill & Carr, 2003; Handy & Xing, 2011). Gutiérrez et al. (2020) found that the willingness of individuals to bicycle depends on the total length of bicycle infrastructure at their origin location. Meaning that it is important that there is high amount of bicycle infrastructure nears one's dwelling.

The road safety in a neighbourhood can also influence bicycle use. Rietveld & Daniel (2004) found that the bicycle use increased when there were less victims of serious traffic accidents. Additionally, Zhao (2003) and (Handy & Xing, 2011) found that low levels of traffic safety can be one of the most important reasons for a reduction in bicycle use for commuting purposes. Fraser & Lock (2010), also found that perceived traffic danger is negatively related to the bicycle use of an area. Therefore, it is important that the roads in a neighbourhood are perceived as safe.

Another determinant of bicycling is the air quality of the area. A healthy air quality can be of importance to promote bicycle use and areas with hazardous levels of air pollution can discourage people from bicycling (Zahran et al., 2008). Zhao (2013) even found that that air pollution is one of two most important factors for a decline in bicycle use.

Lastly, Hull & O'Holleran (2014) stated the importance of an attractive scenery to encourage bicycle use. One of their examples for an attractive scenery is the incorporation of greenery when designing new bicycle infrastructure. The incorporation of greenery in the urban design is also something that Cole-Hunter et al. (2015) found to be the most stimulating environmental determinant for bicycle use. Zhao et al. (2020) and Fraser & Lock (2010) found that in general green space have a positive effect on the bicycle use. Therefore, it is important that an environment provides enough greenery to stimulate bicycle use.

Based on the reviewed literature a list with environment determinants of bicycle use can be constructed. Table 2.1.4 shows these determinants. In total, 6 determinants were identified.

Table 2.1.4. Determinants of bicycle use from the environment

Determinants of bicycle use	References
Population density	Ton et al., 2019; Heinen et al., 2010; Nielsen et al., 2013; Cui et al., 2014
Mixed land use	Heinen et al., 2010; Chen et al., 2017
Bicycle infrastructure ratio	Akar & Clifton 2009; Zhao, 2013
Bicycle infrastructure density	Piatkowski & Marshall, 2015; Hull & O'Holleran, 2014; Heinen et al., 2010
Road safety	Rietveld & Daniel, 2004; Handy & Xing, 2011
Air quality	Zahran et al., 2008; Zhao, 2013
Attractive scenery / greenery	Hull & O'Holleran 2014; Cole-Hunter, 2015; Zhao et al., 2020; Fraser & Lock, 2010

2.1.6 Accessibility

Accessibility can also be an important determinant for bicycle use, because if the bicycle infrastructure of a neighbourhood is highly suitable for bicycle travel, but if there are no destinations to travel to by bicycle, the infrastructure is not actually usable (Lowry et al., 2012). Research has shown that accessibility has been positively associated with bicycle use (Piatkowski & Marshall, 2015). For bicycle use, accessibility means that destinations are located within a by bicycle reachable distance of one's dwelling. According to McNeill (2011), this distance is roughly 5 km. Research has shown that the distance, but also travel time which is highly related to the distance, are one of the most important and most investigated variables for the likelihood of bicycling (Ton et al., 2019). Multiple studies found that bicyclists prefer shorter routes and lower travel times (Broach et al., 2012; Caulfield et al., 2012; Saelens, 2003). Furthermore, individuals that do not cycle often use long distances as an excuse not to use the bicycle for travelling (Heinen et al., 2010). More research has strengthened the negative association between distance and the likelihood of bicycle use. Longer distances result in a lower chance of people using the bicycle (Ton et al., 2019; Piatkowski & Marshall, 2015; Hunt & Abraham, 2006; Akar & Clifton, 2009). Therefore, it is important that destinations are located as close as possible to the dwellings of people.

This raises the question about which destinations need to be accessible by bicycle. Research conducted in the Netherlands by Ton et al. (2019) found that the bicycle is used for all kinds of trip purposes. Namely, trips with the purposes commute, education, leisure and shopping all were found to be positively associated with bicycling. Meaning that it would be important to have destinations for all these trip purposes in close proximity. Heinen et al. (2010) stated that the high bicycle use in small to medium sized Dutch cities, is most likely the result of the close proximity to all the amenities within such a city. Furthermore, Heinen et al. (2010) mention that the presence of convenience stores, offices, fast food restaurants and hospitals have a positive effect on cycling. In addition to this, Nielsen et al. (2013) found that a shorter distance towards retail locations increase the likelihood of bicycling. McNeil (2011) did research on the '20-min neighbourhood' in which a diverse number of destinations types were necessary within a reachable distance to make an area well accessible for bicycle travel. Research has shown that a diverse number of destinations types within an area are important for encouraging bicycle use (Saghapour et al., 2017; McNeil, 2011; Orga & Ndebele, 2014). Thus, it can be concluded that it is important that an area has a diverse amount of destination types.

Besides the diversity, the destination density also has an influence on bicycle use. Research has shown that a higher density of commercial and recreational facilities has a positive effect on the bicycle use (Chen et al., 2017; McNeill, 2011) and an increase of activity density results in more bicycle ridership (Cui et al., 2014).

Lastly, there is some special attention for the accessibility by bicycle to public transport stops, as the Dutch government sees this as an opportunity to promote the combination of bicycle and public transport (Jonkeren & Kager, 2021). Research has found that better accessibility to public transport stops by bicycle encourages individuals to travel by bicycle and then continue their journey by public transport (Cui et al., 2014; Heinen & Buehler, 2019). Meaning that a good accessibility to public transport stops can promote bicycle use for trips that are too far away for bicycling only.

Based on the literature a list with accessibility determinants of bicycle use can be constructed. Table 2.1.5 shows these determinants. In total, 4 determinants in regard to accessibility were found.

Table 2.1.5. Determinants of bicycle use from accesibility

Variable	**Reference**
Destinations within reachable distance	Broach et al., 2012; Caulfield et al., 2012; Saelens, 2003; Ton et al., 2019; Piatkowski & Marshall, 2015; Hunt & Abraham, 2006; Akar & Clifton, 2009; Nielsen et al., 2013;
Diversity of destinations	Ton et al. 2019; Heinen et al., 2010; Saghapour et al., 2017; McNeil, 2011; Orga & Ndebele, 2014
Destination density	Chen et al., 2017; McNeill, 2011; Cui et al., 2014
Access to public transport	Cui et al., 2014; Heinen & Buehler, 2019

2.2 Bikeability tool review

In this part of the literature review, existing bikeability tools will be reviewed to gain insight in the currently used variables to measure bikeability and potentially identify determinants that are not included in the existing bikeability tools. In section 2.2.1 the term bikeability will be explained. In section 2.2.2 existing bikeability reviews and their conclusions will be summarized. Then in section 2.2.3 to 2.2.9, a new bikeability tool review will be conducted and the identified variables will be discussed. Lastly, in section 2.2.10 a conclusion will be given about the identified variables.

2.2.1 Bikeability

Before reviewing existing bikeability assessment methods and uncovering variables that can measure the bikeability of an area, the term bikeability needs to be clarified. As mentioned in the introduction of this report, bikeability is a concept that can be used to assess the user friendliness of the bicycle network of an area. The assessment is often based on numerous elements that can be translate into variables. Frequently used elements in the assessment of the bikeability of an area are: comfort, convenience, access to destinations, safety, coherence and attractiveness of the bicycle network (Kellstedt et al., 2020; Lowry et al., 2012).

Although there is some consent on what bikeability means, there is not one single agreed upon definition of the term bikeability (Kellstedt et al., 2020). Lowry et al. (2012) describe bikeability as "*an assessment of an entire bikeway network for perceived comfort and convenience and access to important destination*" and specify that this is not the same as bicycle friendliness, which they explain as followed: "*an assessment of a community for various aspects of bicycle travel, including the bikeability, the laws and policies to promote safety, the education efforts to encourage bicycling, and the general acceptance of bicycling throughout the community*".

Meanwhile Nielsen & Skov-Petersen (2018) describe bikeability as "*the ability of a person to bike or the ability of the urban landscape to be biked*". Porter et al. (2019) says that "*bikeability is used to describe collective aspects of the environment that are conducive to bicycling*". The definitions given by Nielsen & Skov-Petersen (2018) and Porter et al. (2019) are less specific than the definition of Lowry et al. (2012), as they do not yet indicate which elements affect the ability to bicycle within an environment. This can, on the one side, make the definition of bikeability broader useable, but on the other side, make it not specific enough to be directly understood. This downside of a broader definition is quite important. Depending on the purpose of the bikeability research, the definition and interpretation of bikeability can differ. Different definitions of bikeability can also lead to different interpretations on how to measure bikeability (Castañon & Ribeiro, 2021). This can then also lead to a disagreement about which assessment criteria should be included and how these criteria have to be included. Therefore, it is important to define bikeability clearly enough so that it is understood which elements are to and are not to be included.

Multiple bikeability studies agree that the inclusion of 'accessibility to important locations' in the definition of bikeability is of importance (Saghapour et al., 2016; Lowry et al., 2012; McNeil, 2011). As it seems that accessibility is the key component that distinguishes bikeability from the concept 'bicycle level of service' (BLOS). BLOS is a framework that can be used to assess the bicycle suitability of a transportation network (Lowry et al., 2012; Pritchard et al., 2019). There are more methods to assess the bicycle suitability of a network, however BLOS is seen as the most well-developed method (Lowry et al., 2012). BLOS related assessments methods assess a bicycle network on numerous physical variables, for example, the width of the bicycle lanes, the type of infrastructure, number of intersections, etc. (Saghapour et al., 2016).

It is important to state that bicycle suitability is not the same as bikeability. A network can be suitable for bicycle travel, meaning there is a high perceived comfort and safety, but if there are no important destinations that can be accessed, it does not have a high bikeability level (Lowry et al., 2012). Thus, it seems that accessibility is a key component that makes the difference between bicycle suitability, measured with the BLOS, and bikeability. BLOS is a framework to assess the suitability of the transportation network to accommodate bicyclists, while bikeability is a term which indicates the user friendliness of the bicycle network based on comfort, safety, convenience, conduciveness and accessibility for bicyclists". This definition of bikeability is also the definition used in this report.

2.2.2 Existing bikeability reviews

Four studies have reviewed numerous research about assessment methods that try to measure bikeability and similar concepts. Moundon and Lee (2003) reviewed numerous environmental audit instrument that were used to capture the walkability and bikeability of environments. The purpose of their research was to review and evaluate the measurements used in these different instruments. This could then be used to showcase the current understanding of how the built environment is quantified. According to them, this could be used to develop a valid and efficient tool which helps with the creation of activity friendly environments. Moundon and Lee (2003) conclude that the reviewed instruments together have a wide range of variables to measure the physical environment, however there is not a single instrument that can cover this on their own. They advised for the inclusion of microscale elements and variability in the environmental factors. In their review, most of the instrument are based on the metropolitan area of the American west coast. This is an area which is developed for motorized vehicles and because of this considers a less diverse number of characteristics as they are not present in that area. Furthermore, most instrument only considers route factors, while it would also be important to include origin, destination and area characteristics. According to them, future instruments need to focus on the environment itself, the type of users and the different purpose of physical activity.

Kellstedt et al. (2020) also reviewed a number of different bikeability assessment methods. They were aware of the already conducted review of Moundon and Lee (2003) and therefore decided to focus on assessment methods which were developed after the review of Moundon and Lee (2003). Based on their review, Kellstedt et al. (2020) concluded that future research regarding bikeability should first focus on the question how to measure bikeability. This should lead to the development of a document with clearly defined and testable variables for a bikeability assessment method. Furthermore, Kellstedt et al. (2020) recommend, similar as Moundon & Lee (2003), that a new developed bikeability assessment tool should include the different types of bicycles and the different purposes one can have to use the bicycle.

Arellana et al. (2020) wrote a paper on the development of an urban bikeability index specifically for the global south. One conclusion they made in regard to their review is that bikeability measures are not universally applicable. They found factors which were considered in measurement methods, which were not applicable for cities in the Latin-American. Additionally, they found that measurement methods focusing on the global north often lacked factors that were relevant for the global south. Therefore, it is important to remember the context in which the bikeability assessment method is developed and for what type of locations it is used. Based on their review, Arellana et al. (2020) developed their own bikeability index which could calculate a different bikeability score for different type of cyclists with different trip purpose. However, they found that there was no significant difference between the two calculations. That there was no significant difference is interesting as Kellstedt et al. (2020) recommended that future bikeability assessment tool should focus on developing different calculations for different bicyclist and purpose.

The review conducted by Castañon & Ribeiro (2021) is the most recent study which reviewed bikeability assessment methods. The review found that most considered assessment elements for bikeability are cycle infrastructure, accessibility and safety. These three elements are always in some form associated with the assessment of bikeability. Furthermore, the review also provided insight in the missing elements of the latest developed bikeability assessment methods. Environmental issues, health issues, technological innovations and bicycle parking facilities were rarely included in the existing bikeability assessment methods. Most noteworthy is that the developments surrounding electric bicycles were not included in any of the reviewed studies. Bicycle-Shared-Services (BSS) were rarely included with only a few indicators and bicycle parking was only mentioned in one of the reviewed papers. That bicycle parking is an underused variable is also interesting, as it is not a newly emerging concept and also an important bicycling facility. Castañon & Ribeiro (2021) suggest that a new bikeability index should include bicycle parking and measure it with multiple variables such as: location, availability, quantity and parking features.

2.2.3 Review of existing bikeability tools

To obtain insight in variable and their measurements currently used in bikeability tools, a total of 18 bikeability tools were reviewed. Appendix **I** shows the complete list of the reviewed tools and the variables included. In section 2.2.4 to 2.2.9 the identified variables will be summarized. However, it must be noted that not all variable identified in the reviewed tools will be part of the summary. The reason for this is that some variables are not applicable for the Dutch context and are therefore left out. For example, Ito & Biljecki (2021) include the variable 'number of cul-de-sacs', which is not a common road design in the Netherlands. However, these variables can still be found in Appendix **I**.

Figure 2.2.1 gives an overview from the study locations of the reviewed bikeability tools. Figure 2.2.1 shows us that most included bikeability tools were developed based on the North American context, followed by Europa and then Asia. Only one bikeability tool was developed for Australia as well as one for South America. From the European bikeability tools, none was developed for the Dutch context specifically.

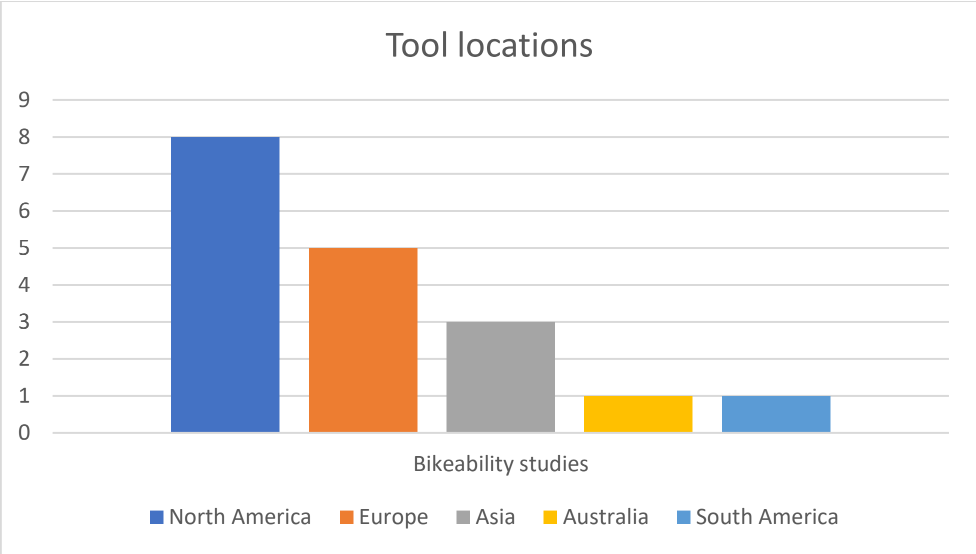


Figure 2.2.1 Location of the reviewed bikeability tools.

2.2.4 Bicycle infrastructure

The most common variable across all reviewed bikeability tools is a variable indicating presence of a certain type of bicycle infrastructure. Gholamialam & Matisziw (2019) use a scale ranging from rare to always to score the presence of a dedicated bicycle lane. Arellana et al. (2020) only includes it as a dummy variable, indicated that there is either bicycle infrastructure present or there is not. Gu et al. (2018) also use a dummy variable for the existence of bicycle infrastructure, but also use an additional variable to indicate the type which can increase the bicycle infrastructures score. Lowry et al. (2016), Schmid-Querg et al. (2021), Grigore et al. (2019) and Ito & Biljecki (2021) combine these two variables into one and assigns score based on the typing of the present bicycle infrastructure.

Some bikeability tools also measure the total meters present to determine a score for the bicycle infrastructure. Porter et al. (2019) measures the total meter of bicycle lanes within a buffer area. Ma & Dill (2016) also measure the meters of the bicycle infrastructure but do this separately for off-street paths, bicycle lanes and minor streets. Krenn et al. (2015) and Winter et al. (2013) measure the total length of all the bicycle infrastructure in an area and then add additional score if the paths are separated. Lin and Wei (2018), Winter et al., (2016) and McNeil (2011) also measure the total length of bicycle infrastructure but count separated bicycle paths more than bicycle lanes, and bicycle lanes more than shared infrastructure.

Although the most tools included the presence of the bicycle infrastructure only four studies included a variable for measuring the width. Lin and Wei (2018) and Lowry et al. (2012) measures the width in meters and Arellana et al. (2020) used a dummy variable that awarded score if the path was wider than 1.4 meters. Ito & Biljecki (2021) also included the width as a dummy variable, but in their tool it was about the total width of the road and not about the width of the bicycle infrastructure specifically.

The continuity and connectivity of the bicycle infrastructure is also something that is included in the reviewed bikeability tools. Lorwy et al. (2016) and Gholamialam & Matisziw (2019) measure this by the total path length. Lin and Wei (2018) measure it as the bikeway density and calculate the meters of bikeway per m^2 land area. Winter et al. (2013), Winter et al. (2016) and Ma & Dill (2016) measure the connectivity based on the intersection density.

The pavement quality was considered by four studies. Lowry et al. (2012), Eliou et al. (2009) and Arellana et al. (2020) all measure the quality in a scale with ranges from bad to good. Ito & Biljecki did not mention the pavement quality, but measured the presence of potholes with a dummy variable. Furthermore, Ito & Biljecki are the only tool that included the pavement type for which the score was based on category option where concrete was the highest scoring option.

Surprisingly, there were only two bikeability tool that included street lights Lin & Wei (2018) were the only bikeability tool to include the presence of street lighting alongside a road. Ito & Biljecki just looked at the presence of street lights and award the full score based on a dummy variable. They did not clearly indicate how many street lights needed to be present to obtain the score.

Three variables were found that in some form measured obstacles along the bicycle infrastructure. Arellana et al. (2020) determine the score of the obstacles on the amount of obstruction they cause measured with three categories (low – medium – high). Grigore et al. (2019) have the only tool that includes the presence of hazards. Different types of hazards have different negative effects on the score of the bicycle path. Gu et al. (2018) include a variable measuring the illegally parked cars on a bicycle lane. The ratio of bicycle lane covered with illegal parking is then deducted from the scoring.

Table 2.2.2 shows all the variables regarding bicycle infrastructure that were found in the reviewed bikeability tools with the used measurement methods. Altogether, 9 different bicycle infrastructure variables were identified. As can be seen in table 2.2.2, a variable representing the presence of different types of bicycle infrastructure was part of many bikeability assessment tools, while all other variables were only present in a maximum of four bikeability tools. Pavement type was even only included in one bikeability tool. Table 2.2.2 clearly shows that while there are many variables included across different bikeability tools, there is not one bikeability tools that includes all those variables.

Table 2.2.2 Bicycle infrastructure variables from existing bikeability tools.

Variables	Measurements	References
Presence of different types of bicycle infrastructure	1. Dummy variable 2. Scale from 1 to 5 3. Total meters 4. Total meters accounting for typing 5. Typing of the bicycle infrastructure	Arellana et al., 2020; Gholamialam & Matisziw, 2019; Porter et al., 2019; Gu et al., 2018; Grigore et al., 2019; Lowry et al., 2016; Schmid-Querg et al., 2021; Ito & Biljecki, 2021; Krenn et al., 2015; Winter et al., 2013; Lin & Wei 2018; Winter et al., 2016; McNeil. 2011;
Path width	1. Dummy variable 2. Total meters	Lin & Wei., 2018; Lowry et al., 2012; Arellana et al., 2020; Ito & Biljeck, 2021;
Continuity	1. Bicycle infrastructure length per m² land area 2. Bicycle infrastructure length	Lowry et al., 2016; Gholamialam & Matisziw, 2019;
Connectivity	1. Intersection density	Winter et al., 2013; Winter et al., 2016; Ma & Dill, 2016
Pavement condition	1. Scale 2. Dummy for potholes	Lowry et al., 2012; Eliou et al., 2009; Arellana et al., 2020; Ito & Biljecki, 2021
Pavement type	1. Category	Ito & Biljecki
Lighting	1. Number of street lights divided by the total road length 1 Dummy variable	Lin & Wei, 2018; Ito & Biljecki, 2021;
Obstacles	1. Decrease in score for each hazard 2. Categories	Grigore et al., 2019; Arellana et al., 2020
Illegal parking	1. Ratio of bicycle infrastructure coved with illegal parking.	Gu et al., 2018

2.2.5 Junction infrastructure

As the literature has shown that junctions are a dangerous point for bicyclists, it was expected that junction design would be an often-included variable. However, only four of the tools incorporated the design of the intersections. Grigore et al. (2019) adapted the score of the intersection based on the presence of bicycle specific traffic lights, a bicycle box and the number of car lanes. Gu et al. (2018) and Lowry et al. (2016) used a dummy variable, indicating if there was some form of crossing facility for the bicyclists present, but did not make a distinction between the types of crossing facilities. Schmid-Querg et al. (2021) did make a distinction in types of intersections: Intersections with regular traffic lights, intersection with traffic lights and markings, intersection with designated bicyclists traffic lights and intersections with designated traffic lights and a bicycle box. Lastly, Eilou et al. (2009) included the ease of use of an intersection with a scale from 1 to 6, but no specific elements were used to clarify the scoring.

The variable intersection density was identified two times. In contrary to the connectivity variable, mentioned in section 2.2.1, which is measured with intersection density, the variable intersection density negatively influenced the bikeability. A higher number of intersections on the road resulted in a lower scoring (Lin & Wei, 2018; Gholamialam & Matsziw, 2019).

Table 2.2.3 shows all the variable regarding the junction infrastructure that were found in the reviewed bikeability tools. Only a total of five variables are identified, which is on the lower side. Furthermore, the five identified variables are only included in a limited number of bikeability assessment tools. This means that current bikeability assessment tools do not focus enough on junction infrastructure.

Table 2.2.3 Junction infrastructure variables from existing bikeability tools.

Variables	**Measurements**	**References**
Intersection design	1. Utility based 2. Dummy variable 3. Categories	Grigore et al., 2019; Gu et al., 2018; Lowry et al., 2016; Schmid-Querg et al., 2021
Presence of bicycle traffic lights	1. Increase score when present	Grigore et al., 2019; Schmid-Querg et al., 2021
Presence of bicycle box	1. Increase score when present	Grigore et al., 2019; Schmid-Querg et al., 2021
Number of car lanes	1. Decrease score when higher	Grigore et al., 2019
Intersection density	1. Number of intersections on a road	Lin & Wei, 2018; Gholamialam & Matsziw, 2019

2.2.6 Bicycle parking facilities

Variables regarding bicycle parking were only mentioned in four of the reviewed bikeability tools. Ito & Biljecki (2021) did include the variable 'presence of bicycle parking' using a dummy variable. If a street did have bicycle parking, it would obtain the score. Schmid-Querg et al. (2021) went a step further and awarded scores based on the type of bicycle parking facilities present in the street. They included four categories: Bike lockers, roofed bike rack, regular bike rack and no bike rack. Lin & Wei (2018) looked at bicycle parking spaces across the whole area and calculated the density of the bicycle parking spaces. Lastly, Hamidi et al. (2019), looked at the available parking spots within a 250 meters range around public transportation hubs.

Interestingly enough, besides the type of the bicycle parking facilities, there were no variables accounting for bicycle parking facility attributes such as security measures, parking costs, parking capacity and the visibility. Which are determinants of bicycle use that were mentioned in the literature.

Table 2.2.4 shows all the variable found for bicycle parking facilities in the reviewed literature. Although, bicycle parking facilities were only mentioned four times, it did result in four different variables. However, the four different variables are identified across four different bikeability tools. Meaning that even the bikeability tools that do include bicycle parking do not include it in detail. Based on the bikeability tool review it can be concluded that variables concerning bicycle parking facilities are underrepresented in current tools.

Table 2.2.4 Bicycle parking facility variables from existing bikeability tools.

Variables	Measurements	References
Presence of bicycle parking	1. Dummy variable	Ito & Biljecki, 2021;
Typing of bicycle parking facilities	1. Categories based on typing	Schmid-Querg et al., 2021;
Bicycle parking density	1. Number of parking spaces divided by the area	Lin & Wei, 2018;
Parking spots around public transport	1. Categories based on spots	Hamidi et al., 2019;

2.2.7 Motorized traffic variables

The reviewed bikeability tools also included multiple variables regarding motorized traffic. Gholamialam & Matisziw (2019), Lowry et al. (2016), Arellana et al. (2020), Lowry et al. (2012) and Schmid-Querg et al. (2021) all included a variable regarding the speed limit for motorized vehicles on roads that are also used by bicyclists. A higher speed limit decreases the score of the road or path adjacent to the street.

The volume of motorized vehicles is also a variable included in existing bikeability tools. Lin and Wei (2018) measure the motorized traffic volume based on the highest traffic volume during peak hour among the intersection of an area, Arellana et al. (2020) measures the motorized vehicle volume per hour and scores it based on categories and Ito & Biljecki (2021) count the number of vehicles within an area. Another identified variable regarding the volume of traffic is the number of motorized vehicles lanes. Two bikeability tools (Gholamialam & Matisziw, 2019; Lowry et al., 2016) measure this variable with categories and streets with more lanes reduce the bikeability score.

There are also multiple variables that measure some form of road safety. Lin and Wei (2018) and Eliou et al. (2009) measure the bicyclist's perception of smooth traffic with a scale of 1 to 5. Eliou et al. (2009) also measure the attitude of car drivers against bicyclists with a scale from 1 to 5. Arellana et al. (2020) measure the actual criminality on the roads with a dummy variable. If there is an occurrence of crime, the score for the variable will be zero.

There were also three variables only found in one bikeability tool. Krenn et al. (2015) included the variable main roads for which they measured the total meters of main roads in the area. A higher amount of meter roads resulted in a worse score. Lin & Wei (2018) used a variable bus route ratio, which negatively affected the bikeability score. Furthermore, Lin & Wei (2018) included the variable parking space for motorized traffic. This variable measured the parking space density. A higher density resulted in a lower score.

Table 2.2.5 shows all the variable found for motorized traffic. A total of seven variables was found, from which 3 were only present in one bikeability tool. Table 2.2.5, clearly shows that speed limit for motorized traffic is a common occurrence in existing bikeability tools, while the other six variables are included less often. A total of seven variables is a decent amount, however there is not one bikeability tool that currently includes more than three of the seven variables in table 2.2.5.

Table 2.2.5 Motorized traffic variables from existing bikeability tools.

Variables	Measurements	References
Speed limit	1. Categories based on speed limit	Gholamialam & Matisziw, 2019; Lowry et al., 2016; Arellana et al., 2020; Lowry et al., 2012; Schmid-Querg et al., 2021
Motorized vehicle volume	1. Ratio of vehicles during peak hour per m² land area 2. Categories based on vehicle volume per hours 3. Number of vehicles	Lin & Wei (2018); Arellana et al. (2020); Ito & Biljecki, 2021;
Number of motorized vehicle lanes	1. Categories regarding number of lanes	Gholamialam & Matisziw, 2019; Lowry et al., 2016
Road safety	1. Scale 2. Dummy variable	Lin & Wei, 2018; Eliou et al., 2009; Arellana et al., 2020
Main roads	1. Meters	Krenn et al. 2015
Bus route ratio	1. Bus route length divided by total road length	Lin & Wei, 2018
Parking space density	1. Density	Lin & Wei, 2018

2.2.8 Environment

The reviewed bikeability tools also included numerous variables that can contributed to the atmosphere for bicycling in a neighbourhood. The most included environment variable is the slope variable. Three reviewed tools included a slope variable for the path, which decreased the paths score if the slope increased (Grigore et al., 2019; Lowry et al., 2016; Arellana et al., 2020). However, six tools used the variable slope, but looked at the whole area rather than the path. Lin & Wei (2018), Ma & Dill (2016), Krenn et al. (2015), Winter et al. (2013) and Ito & Biljecki (2021) all looked at the average slope in the area, which results in a score decrease the higher the average slope percentage is. Winter et al. (2016) also included the slope based on the area, but looked at the steepest point and use this to assign a scoring.

Variables about greenery were found to be present in two different forms. First, Lin & Wei (2018) included greenery as the green space density within the neighbourhood and Krenn et al. (2015) looked at the square meter of green spaces and aquatic areas and then provided a score based on categories. For both variables, an increase in green spaces is positively related to the bikeability score. The second, form of greenery are variables regarding tree coverage. In which streets covered by (more) trees gain a higher score. Porter et al. (2019) and Gu et al. (2018) both measured the percentage of street covered with trees, Lin and Wei (2018) looked at the number of trees ratio along the road and Arellana et al. (2020) uses a dummy variable indicating if trees are present alongside the road.

Variables regarding the air quality were mentioned by three bikeability tools. Porter et al. (2019) included the variable 'ozone level' which measures the average ozone level within the area. Lin & Wei (2018) and Ito & Biljecki (2021), included the air quality based on categories. For all three tools, worse air quality or ozone levels resulted in a worse bikeability scoring.

The mixed land-use variable was identified in five bikeability tools. Krenn et al. (2015) and Winters et al. (2013) both included the mixed land-use variable as a category variable. A higher number of different land uses results in a higher category score. Saghapour et al. (2017), Lin & Wei (2018) and Ito & Biljecki (2021) used a different method. Saghapour et al. (2017) calculated the mixed land-use variable based on the diversity and intensity of land uses using an area ratio for each land use category, while Lin & Wei (2018) calculated the mixed land-use score with the entropy index and Ito & Biljecki (2021) calculated the mixed land-use with the Shannon land use mix index.

There are also three identified variables, only present in one bikeability tool. The tool from Porter et al. (2019) is the only tool that included population density of the area. A higher population density results in a better score. Gu et al. (2018) included the variable street network density, which looked at the total street length present in the area. Although this variable measures the street network which is not exclusively for bicyclists, it is meant to positively affect the bikeability. The reason for this is potential that the study area mostly makes use of the street network for bicycling. Therefore, this variable could also be seen as bicycle network density. Lastly, Arellana et al. (2020) included the variable aesthetics of buildings, with which they measured if the condition alongside the bicycle infrastructure was of good quality. Resulting in a higher score when the quality was good.

Table 2.2.6 shows all the variable found regarding the environment. A total of eight variables were found. It can be seen that the variable slope is an often-included variable. Interestingly enough, the second most considered variable is tree coverages, which was not an identified determinant of bicycle use during the literature review. Eight total variable is a decent number of variables however, there is not one bikeability tool that currently includes all those eight variables.

Table 2.2.6 Environment variables from existing bikeability tools.

Variables	Measurements	References
Slope	1. Slope of the path 2. Average slope in the area 3. Steepest point	Grigore et al., 2019; Lowry et al., 2016; Arellana et al., 2020; Lin & Wei, 2018; Ma & Dill, 2016; Krenn et al., 2015; Winter et al., 2013; Ito & Biljecki, 2021
Green spaces	1. Green space density 2. Categories	Lin & Wei, 2018; Krenn et al., 2015
Tree coverages	1. Percentage of coverage 2. Number of trees 3. Presence	Porter et al., 2019; Gu et al., 2018; Lin & Wei 2018; Arellana et al., 2020
Air quality / ozon level	1. Categories 2. Average ozone level	Lin & Wei, 2018; Ito & Biljecki, 2021; Porter et al., 2019
Mixed land-use	1. Category 2. Area ratio 3. Entropy index 4. Shannon index	Saghapour et al., 2017; Lin & Wei, 2018; Ito & Biljecki, 2021
Population density	1. Density	Porter et al., 2019
Street network density (or bicycle network density)	1. Meters of streets in the area	Gu et al., 2018
Aesthetics of buildings	1. Category	Arellana et al. 2020

2.2.9 Accessibility

Lastly, multiple variables regarding accessibility were found in the bikeability assessment tools. While multiple tools included a variable regarding the number of destinations (Grigore et al., 2019; Ma & Dill, 2016; Winter et al., 2016; Ito & Biljecki, 2021), only one tool looked at access to a diversity of locations. McNeil (2011) awarded points for each different destination type present within a by bicycle reachable distance. Meaning that neighbourhoods with a high a number of one destination type scored worse than a neighbourhood with a few diverse numbers of locations.

Saghapour et al. (2017) included the variable travel impedance to indicate how accessible certain destinations are by bicycle. They measured this by comparing the average distance towards a location to the distance along bicycle paths. Lowry et al. (2016) also looked at the travel impedance to indicate the accessibility of locations. In their tool the travel impedance was calculated using the path costs (determined by effort) towards the destination compared to the actual distance. A higher travel impedance resulted in a lower score for both cases.

Multiple bikeability tools included variable regarding accessibility to public transportation locations. Porter et al. (2019) simply measured the distance to the nearest public transport station. Hamidi et al. (2019) did something similar. They looked at the number of public transport station at the intended destination and multiple this by the travel costs towards this location. For both variables, a shorter distance has a positive effect on the score. Ito & Biljecki (2021) looked at the number of transit facilities on the street. More transport facilities on the street resulted in a higher score. Lastly, Lin & Wei (2018) looked at the transit service area. The made buffers around public transport stops to calculate the service area and then dived this by the total land area.

Table 2.2.7 shows all the variable found regarding accessibility. A total of six variables were found to measure the accessibility. Four tools include a variable representing the number of destinations that are accessible by bicycle and one tool also looks at the diversity of those destinations. Although, six variables were identified, not one tool includes more than one of those variables in their assessment. Therefore, it can be concluded that the accessibility of destinations is underrepresented in current bikeability tools.

Table 2.2.7 Accessibility variables from existing bikeability tools.

Variables	Measurements	References
Number of destinations	1. Number	Grigore et al., 2019; Ma & Dill, 2016; Winter et al., 2016; Ito & Biljecki, 2021
Destination diversity	1. Points per different destination type	McNeil., 2011
Travel impedance	1. Average distance compared to distance by bicycle path 2. Distance using path costs compared to actual distance	Saghapour et al. 2017; Lowry et al. 2016
Distance to public transport	1. Meters 1. Distance and travel cost	Porter et al., 2019; Hamidi et al., 2019
Number of transit facilities	1. Density	Ito & Biljecki, 2020
Transit service area	1. Density	Lin & Wei, 2018

2.2.10 Conclusion

Concluding, during the review of 18 bikeability tools a total of 39 variables relevant for the Dutch context were identified across 6 categories. For both the categories 'bicycle infrastructure' and 'environment', the most variables were identified, namely 9 and 8 respectively. While the least variables were identified for the category 'bicycle parking facilities', namely 4. Furthermore, only four tools included a variable for bicycle parking. The lack of bicycle parking facility variables included in tools is also something that Castañon & Ribeiro (2021) identified. Thus, this is an element that is still largely missing in current tools. On the contrary, the advice for more environmental factors from Moundon & Lee (2003) seems to have been followed.

As it was concluded that accessibility is the key component that distinguishes bikeability from the BLOS, it is good to see that 6 different accessibility variables were identified across 10 different tools. However, most tool only had one variable present in their tool to account for the accessibility, which seems quite limited.

Lastly, it is surprising that there are only five variables for junction infrastructure as junctions were identified as most dangerous part of the bicycle infrastructure. Additionally, these five identified variables are only included in a limited number of bikeability assessment tools. The bikeability tool review showed that junction infrastructure is currently underrepresent in existing bikeability tools.

2.3 Comparison of determinants and bikeability tools

After completing both the literature review regarding the determinants of bicycle use and the review of the existing bikeability tools, it is possible to compare the findings. The comparison of the variables identified by literature review and tool review can provide insight in the variables that are currently not included in bikeability tools, but do influence the bicycle use.

The bikeability tool review led to the identification of 40 different variables across 6 categories. The literature review regarding bicycle use resulted in the identification of 41 different variable. Meaning that the bikeability tool included 1 less variable than the literature found to influence bicycle use. However, this does not mean that the bikeability tool included 40 of the variables identified in the literature review.

Regarding bicycle infrastructure, both the literature review and the bikeability tool review included variables regarding, presence of bicycle infrastructure, bicycle infrastructure type, continuity of the infrastructure, path width, pavement condition, pavement type, street lighting, slope and obstacles. Furthermore, the category motorized traffic variables of the bikeability tool included the variables speed limit and traffic volume which were identified as bicycle infrastructure determinants during the literature review. Meaning that the identified determinants of separation type, roadside type, speed limiting objects, one-way street and land use type were not found in any tool. However, Gu et al. (2018) did include the variable illegal parking, which measured the ratio of illegal parking on the roadside type. However, this variable does not fully measure what was identified in the literature as also other roadside types influence bicycle use. The variable connectivity of the bicycle infrastructure, identified during the bikeability tool review, was found in the literature but is regarded as a junction infrastructure variable.

The variables 'road safety' was identified as motorized traffic variable in the bikeability tool. In the literature review this variable can be found back in the environmental determinants, as the number of road crimes in the area. The variable main roads from the category motorized traffic variables from the bikeability tool is similar to the 'bicycle infrastructure ratio' found in the literature review. As both indicated that more meters of roadways result in a lower likelihood of bicycling. The only variable from motorized traffic variables that was not found in the literature was number of motorized vehicle lanes. This variable was only used by two bikeability tools. A potential reason that the motorized vehicle lanes were not identified during the literature review could be the lack of focus on bicycle travel across large roadways (more than 2 motor vehicle lanes) or because it is highly related to vehicle traffic volume.

The literature review and the bikeability tool review resulted in seven and five variables regarding the junction infrastructure, respectively. Both included the design, the presence of bicycle traffic lights, presence of a bicycle box and intersection density. Again, the bikeability tool review led to the identification of number of motorized vehicles lanes, which was not identified during the literature review. The literature review also identified the importance of speed limiting objects and a median island, which are currently not included in the existing bikeability tools.

For bicycle parking facilities the literature found seven variables, while there were only four variables identified in the bikeability tool review. Both reviews included the presence of bicycle parking facilities and the type of the facilities. The literature review identified variables such as distance to destinations, parking safety, cost of parking, capacity of the facility and the visibility to be important determinants of bicycle use. All these variables were not found in the bikeability tools. However, the tools did include a variable for the bicycle parking density and the number of bicycle parking spots near a public transport area.

Eight environment variables were identified in the bikeability tool review, while only seven were identified during the literature review. Both the reviews included population density, bicycle network density, air quality and mixed land use. The literature review also identified ‘attractive scenery’ as an important variable, this could relate to the identified variables ‘green spaces’ and ‘aesthetics of buildings’ in the bikeability tool review. The bikeability tool included the variable ‘tree coverages’, which was not identified during the literature review.

Lastly, the category accessibility from the bikeability tool review resulted in the identification of six variables and the literature review resulted in four. Both the reviews included the variables destination diversity, destination density and access to public transport. During the literature review it was found that for bicycle use it is important to have destinations within a reachable distance. This is something that was also found in the bikeability tool review, but was labeled travel impedance. Travel impedance indicated that if something was more difficult to reach by bicycle, the bikeability score decrease. Therefore, it is assumed that these two variables have the same application. The bikeability tool review also identified the variables number of transit facilities and transit service area, which were both not found in the literature review.

Based on the explanation given in this section and the conducted reviews, a list of variables that were only found in one of the two reviews can be constructed. Table 2.2.8 shows this list of variables. This information can be used to develop a new bikeability tool that includes previously excluded variables.

The variables that were not found in one of the reviewed bikeability tools, but were identified as determinants of bicycle use during the literature review should all be included in a newly developed bikeability tool. For the variables that were identified in the bikeability tools, but not found as determinants of bicycle in the literature, it should be considered if they should be included in a newly developed bikeability tool. Because it is unclear if they do or do not affect the bikeability level of an area. The variables ‘(car) parking space density’ and ‘bus route ratio’ were not found to determine bicycle use during the literature review and for that reason should be excluded from a new bikeability assessment tool.

Table 2.2.8 Variables not found in one of the reviews.

Variables not found in the literature review regarding determinants	**Variables not found in the bikeability tool review**
Motorized vehicle lanes	Separation type
Bicycle parking density	Roadside type
Bicycle parking density	Speed limiting objects on the street
Parking spots around public transport	One-way street
Tree coverage	Land use in which the bicycle path is located
Bus route ratio	Bicycle infrastructure at the junction
Parking space density	Median island
Number of transit facilities	Speed limiting objects at the junction
Serving area of public transport	Destinations in reach of BPFs
	BPFs security measures
	BPFs costs
	BPFs capacity
	BPFs visibility
	Destination density

The variables ‘motorized vehicle lanes’ and ‘tree coverage’ could potentially be excluded when developing a new bikeability tool for the Dutch context. In the Netherlands it is not common for bicyclist to share a road with motorized traffic that has more than two lanes, making the variable redundant. Furthermore, the variable ‘tree coverage’ is included to measure if streets have enough shade for bicyclists to bicycle comfortable. However, this may not be relevant in the Netherlands as it has a mild climate. The variable ‘bicycle parking density’ seems logical to include. As the literature indicated that the presence of a bicycle parking facilities at a destination would positively affect the bicycle use. Meaning that is seems reasonable to include the variable ‘bicycle parking density’. Lastly, the variables parking spots around public transport, number of transit facilities and serving area of public transport, could also be included in a new bikeability tool. As these three variables could somehow be included in the calculation of access to public transport, which was found to influence the bicycle use.

3. Development of the tool

In this chapter the method behind the development of the bikeability assessment tool will be explained. The literature study revealed the categories and variables that are relevant to determine the bikeability level of an area. Based on the findings from the literature reviews, a new bikeability assessment tool will be developed. First, in section 3.1 the main categories of the bikeability assessment tool will be discussed. Then, in section 3.2 to 3.11 the variables within these categories and how they are used to calculated the category scores will be discussed. In section 3.12 the necessary data for all the variables will be summarized and explained how to obtain the data. In section 3.13 the calculation method of the bikeability level based on the category scores will be explained. Lastly, in section 3.14 the relevance of the newly developed bikeability assessment tool will be discussed.

3.1 Categories of the tool

After conducting the literature review, a list of relevant variables to determine the bikeability level of an area is created. Many of those variables measure different aspects but try to communicate similar concepts. An example of this concerns the variables '*street lighting near the bicycle path*' and '*path width*'. Both variables measure different aspects, however they both try to communicate a certain part of the quality of the bicycle path infrastructure. Based on this argumentation, all the identified variables can be grouped into categories based on what the variables communicates regarding the bikeability level of an area.

For each category it will be possible to calculate an individual category score based on the variables included in the category. These category scores can then be combined to calculate the bikeability level of the neighbourhood. Furthermore, category scores can also provide more insight in how these categories are functioning within the neighbourhood compared to the other categories. This helps with understanding how the final bikeability score is constructed and on which category should be focused to improve the bikeability level of the neighbourhood.

Based on the literature review and the review of the existing bikeability assessment tools, five categories can be identified. These five categories are:

1. **Bicycle infrastructure**: This category represents the overall quality of the bicycle infrastructure of the neighbourhood. The bicycle infrastructure category first focusses on calculating a segment score for each individual segment of bicycle infrastructure in the neighbourhood and then combines these segment scores to calculate a 'bicycle infrastructure' category score. The segment scores are based on variables that measure aspects of the bicycle infrastructure itself and their direct environment. These variables are relevant to determine the overall quality of the bicycle infrastructure. Bicycle infrastructure is an important category as it assesses if the bicycle infrastructure present in the neighbourhood provides enough quality to safely and convenient travel through the neighbourhood by bicycle.
2. **Junction infrastructure**: This category represents the overall quality of the junction infrastructure in the neighbourhood, The junction infrastructure category first focusses on calculating individual scores for each junction which are then combined to calculate the 'junction infrastructure' category score. The individual junction scores are based on variables that measure safety and quality aspects of the junctions. Junction infrastructure is an important category as junction are the location were cyclists' cross path with both motorized and non-motorized vehicles. Most of the deadly cycle accidents are the consequence of a collision with motorized vehicles (SWOV, 2017a). Therefore, it is important to assess the safety and quality of the junctions present in a neighbourhood.

3. **Bicycle parking facility**: This category represents the presence and quality of the bicycle parking facilities within the neighbourhood. The bicycle parking facility category first focusses on calculating individual scores for each bicycle parking facility in the neighbourhood and then combines those scores to calculate the 'bicycle parking facility' category score. The individual bicycle parking facility scores are based on variables that measure aspects related to the quality of the facility. The category 'bicycle parking facility' is an important category as their presence and quality can influence the likelihood of cycling (Ton et al, 2019; Heinen & Buehler, 2019; Jonkeren & Kager, 2021). Therefore, it is important to include bicycle parking facilities in the assessment tool.
4. **Environmen**t: This category represents the atmosphere for bicycling in a neighbourhood. In contrary to the previous three categories, this category only focusses on area wide variables (such as population density or land use mix) that can affect the bicycle use. The 'environment' category score is directly calculated with the variables of the category. The 'environment' category is an important category as it assesses the atmosphere of the neighbourhood and if this atmosphere is promoting bicycle use.
5. **Accessibility**: This category represents how accessible different types of location are by bicycle for residents of a neighbourhood. The variables included in this category are various destinations to which an inhabitant can travel to by bicycle. The variables include common destinations such as a supermarket, but also more major attraction points such as a train station. The 'accessibility' category is important because even if an area has high quality bicycle infrastructure, if there is no destination within bicycle range the inhabitant of the neighbourhood will not consider to use the bicycle.

The variables included in each category will be discussed in more detail in the following sections. This includes the reasoning behind the inclusion, the assessment of the variable and how the variable contributes to the overall category score.

3.2 Bicycle infrastructure

The bicycle infrastructure can be seen as a key aspect of a bikeability, as it provides the infrastructure that enables inhabitants of a neighbourhood to cycle. It is a core aspect of bicycle travel and it is therefore always in some form included in bikeability assessment tools. Some tools include a variable to mention the existence of bicycle paths (Gholamialam & Matisziw, 2019; Gu et al., 2018), other tools go a bit further and also look at the different bicycle infrastructure types (Schmid-Querg et al., 2021), the total length of the bicycle paths (Porter et al., 2019; Ma & Dill, 2016) or both these aspect (Lin & Wei, 2018; Krenn et al., 2015). However, the bicycle infrastructure consists out of many more aspects and even though many bikeability evaluation tools include some of these aspects often they are still missing other important aspects that determine the quality of the bicycle infrastructure.

For the calculation of the bicycle infrastructure score, the bicycle infrastructure present within a neighbourhood will be assessed based on as many variables as possible. These variables are used to calculate a bicycle infrastructure score for each individual segment of the bicycle infrastructure in the area. These individual segment scores can in the end be combined into one overall score which represent the area's bicycle infrastructure score.

The variables as well as their measurement methods are based on the Dutch cycle environment, which can be vastly different from the focus areas of the studied existing international bikeability assessment tools. Therefore, sometimes different approaches are used. The category 'bicycle infrastructure' will consist out of the following 13 variables:

1. Path type
2. Path width
3. Car intensity
4. Separation type
5. Roadside type
6. Speed limit
7. Presence of a centre line
8. Presence of street light
9. Presence of obstacles
10. Pavement type
11. Pavement conditions
12. Presence of slopes
13. Land use type
14. One-way street
15. Speed limiting objects

These variables will now be discussed in further detail in the section 3.2.1 to 3.2.15.

3.2.1 Path type

The first variable of bicycle path infrastructure is the path type. The path type will be determined for each individual segment which allows bicyclists. This includes paths that are either specific 'bicycle paths' or roads that allow bicyclists and where dedicated bicycle infrastructure is expected. It is important to mention that in the Netherlands it is forbidden to cycle on sidewalk or bus lanes (AWNB, n.d.), which can be a common practice in other countries and was therefore commonly included in bikeability tools. Additionally, segments that are 'residence streets' and 'living streets' are excluded. Residence streets and living streets are mainly used for short final distances to reach houses and or stores. They are generally not meant to be used by through-traffic (traffic without origin or destination in that street) (SWOV, 2018). Cars that do travel through these streets are expected to adapt their driving to bicyclists and pedestrians that also use those streets (SWOV, 2017b). For residence- and living streets, it is not expected that they have dedicated bicycle infrastructure and are for that reason they are excluded from the calculation of the 'bicycle infrastructure' score.

'Path type' is an important variable as different path types can provide different levels of convenience and safety (Pucher & Buehler, 2016). In the Netherlands, it is possible to differentiate seven different path types where bicyclists are allowed to cycle. These path types are listed in table 3.2.1. (SWOV, 2020a). Furthermore, for the 'bicycle path', 'moped & bicycle path' and 'optional bicycle path', a difference can be made between one-way or two-ways paths. This does not influence the score, however it does influence the required width which will be discussed in section 3.2.2 as the path width is a variable of the bicycle infrastructure category.

Table 3.2.1. Path types in the Netherlands

Path types (SWOV, 2020a)	**Separations**	**Scores**
Bicycle path	Physical separation	10
Moped & bicycle path	Physical separation	9
Optional bicycle path	Physical separation	8
Bicycle street	Painted or no separation	7
Bicycle lane	Painted separation	5
Bicycle suggestion lane	Painted separation	4
Roadway	No separation	3

The score of each path type is based on the safety and convenience that each type provides for the cyclists. Path types that are separated from the motorized traffic roads are commonly perceived as safer and more convenient for cyclists and are therefore valued higher than path types that are only separated by markings or not separated at all (Schmidt-Querg et al., 2021; Gholamialam & Matisziw, 2019; Lin & Wei, 2018; Krenn et al., 2015; Lowry et al., 2016).

The bicycle path is scored the highest as it is a clear dedicated path for cyclist only, thus making it the safest and most convenient path type. The second highest scoring path is the ‘moped & bicycle path’ as it is highly similar to the bicycle path. The main difference is that it also allows moped vehicles. This can cause overtaking disturbances for the cyclists due to the speed differences between the two modes, which reduces the cyclist’s sense of safety (Chen et al., 2018). The lowest scoring path of the physically separated paths is the ‘optional bicycle path’, the reason for this is that these paths are often of lower overall quality than the ‘bicycle path’ and ‘moped and bicycle path’.

The bicycle street is a special kind of path type as there is often no separation between motorized traffic and the cyclists, but motorized vehicles are guests on these streets. This means that the cyclists are the main user of the road and the other users give them priority on the bicycle street (Fietsberaad-CROW, 2015). Therefore, it is expected that these streets are safer and more convenient than bicycle lanes, but still less preferred the fully separated path types.

For the paths separated by paint, the highest scoring is the ‘bicycle lane’ as this type of path has a dedicated area for cyclists where cars are not allowed. The ‘bicycle suggestion lane’ has a lower score as this path type requires cars to go on the bicycle lane when they are passing another car from the opposite direction (Fietsberaad-CROW, 2015).

The last path type is ‘roadway’, which does not have any dedicated space for cyclists. This is a road also used by motorized vehicles where cyclists are allowed to cycle, but without any dedicated infrastructure for them. This makes this path type the least safe and convenient for cyclists.

3.2.2 Path width

The second variable of the bicycle infrastructure is the path width. The width of the path is important as it provides cyclists with more space to avoid other users, decreasing the chance of an accident, and it also influences the satisfaction level of the cyclists (Veroude & van Boggelen, 2021; Li et al., 2012; Hull & O’Holleran, 2014). The recommended width of a path dependents on numerous aspects. As mentioned before, the path type as well is the number of directions of the path changes the recommended width. Additionally, for physically separated paths the bicycle intensity per hour and the route type is also of importance (Veroude & van Boggelen, 2021; Grigore et al., 2019; Li et al., 2012). Taking this into account, the recommended path width for physically separated paths can be found in figure 3.2.1.

Basic network and main routes							
Seperated One-way				Seperated Two-way			
Maximum bicycle intensity per hour	Path type			Maximum bicycle intensity per hour	Path type		
	Optional bicycle path	Bicycle path	Moped & bicycle path		Optional bicycle path	Bicycle path	Moped & bicycle path
50	220	220	220	50	220	260	270
100	220	220	250	100	270	270	360
300	220	260	330	300	270	360	360
400	220	270	360	400	350	360	440
600	260	330	360	600	350	440	500
1000	270	360	360	1000	380	520	600

Regional routes							
Seperated One-way				Seperated Two-way			
Maximum bicycle intensity per hour	Path type			Maximum bicycle intensity per hour	Path type		
	Optional bicycle path	Bicycle path	Moped & bicycle path		Optional bicycle path	Bicycle path	Moped & bicycle path
100	300	350	360	100	400	400	410
300	300	360	360	300	400	440	520
400	300	360	360	400	400	520	560
600	350	360	440	600	460	590	630
1000	350	360	440	1000	520	630	720

Figure 3.2.1 Recommended path width (Veroude & van Boggelen, 2021)

Looking at the tables, it can be seen that a higher intensity of bicycle per hours result in a higher recommended path width for all separated path types. Furthermore, paths of regional routes have a wider recommended path width than basic network and main route paths. When looking at the difference in recommendations between path types, it can be seen that 'moped & bicycle path' has the highest recommended width. The reason for this is that this path is also used by motorized vehicles and thus it is expected that more overtakes take place, resulting in the need for a wider path (Chen et al., 2018).

For paths separated by paint other widths are recommended. For the path type 'bicycle lane' the recommended width is always 225 cm and does not depend on any other aspect (Fietsberaad-CROW, 2015). The path type 'bicycle street has a standard recommendation of 580 cm and is measured as the full street width (Fietsberaad-CROW, 2015). The recommended path width for the path type 'bicycle suggestion lane' does depend on an additional aspect, namely the car lane width. This is the width of dedicated space for the car on the road. Figure 3.2.2 shows the recommended lane width for each car lane width.

Recommended bicycle suggestion lane width	
Car lane width	**Recommended lane width**
< 220	-
220-380	220
380-480	220
480-600	225
> 600	250

Figure 3.2.2: Recommended Lane width for bicycle suggestion lane (Fietsberaad-CROW, 2015)

As can be seen in figure 3.2.2., two rows are marked red. The reason for this is that these car lane widths are actually not recommended to be combined with a bicycle suggestion lane. The reason that a car lane width of smaller than 220 cm is not recommend is because it is too small and it is recommended to have the path type 'roadway' instead (Fietsberaad-CROW, 2015). The car lane width of 380 – 480 cm is not recommended as it give car drivers the least clarity of the expected driving behaviour. When dealing with such a car lane width it is recommended to decrease the car lane width to 380 and add the removed car lane width to the bicycle suggestion lane (Fietsberaad-CROW, 2015).

As these widths are not recommended, bicycle suggestions lanes that are part of a street with a car lane width of either smaller than 220 cm or between 380 and 480 cm are excluded from the score calculation. Instead, the variable will gain a score of -2. This score is given because the road design is not in line with the recommended design widths. Furthermore, a warning will be given within the tool indicating that the car lane width is troublesome and the road design should be changed.

After clarifying how the recommended path widths are determined, the calculation for the 'path width' score can be explained. The 'path width' score is calculated by dividing the actual path width by the recommended path width and subtracting this by 1. This leads to the following formula:

$$\text{Path width}_{\text{score}} = \frac{\text{Path width}}{\text{Recommended path width}} - 1$$

This formula rewards path with a larger width than the recommended width and punishes paths with a smaller width. Furthermore, when the path width is exactly the recommended width no additional score is obtained. This is reasonable, as it is expected that the paths follow the recommended widths. Lastly, the maximum score of the variable 'path width' is 1, indicating that the path width is twice the size of the recommended width. The paths with the type 'roadway' are excluded from this variable as they do not have a dedicated space for bicyclist. Therefore, they will always score zero points on this variable.

3.2.3 Car intensity

The third variable is the 'car intensity' which looks at the car traffic volume on the street and indicates if the traffic volume is in line with the acceptable traffic volume. Meaning, the number of cars using the street is below the maximum capacity of cars per day. The variable 'car intensity' is only applied to paths that have a path type which is physically unseparated from the street (table 3.2.1) as cyclist using these paths share the road with car drivers and cyclists using separated path do not. This variable is an important inclusion for the tool because a lower traffic flow creates a safer cyclist's environment (Ito & Biljecki, 2021; Li et al., 2012; Oh et al., 2008;) and increase bicycle use (Heinen et al., 2010), thus improving the bikeability. The calculation of the 'car intensity' is a combination of the approach of Ito & Bijecki (2021) who looked at the number of cars on the road and Arellena et al. (2020) who looked at the type of road. Thus, the car intensity score will be calculated based on the path type, as each path type has a different maximum traffic volume. In table 3.2.2 the maximum traffic flow of each path type is indicated. It can also be seen that a difference in car capacity can be made between bicycle suggestions lanes with a small and a large car lane.

Table 3.2.2 Maximum acceptable car capacity

Maximum car capacity	
Path type	Maximum cars capacity per 24 hours
Bicycle street	4.000
Roadway	6.000
Bicycle suggestion lane with a small car lane (220 – 380 cm)	6.000
Bicycle suggestion lane with a large car lane (> 480 cm)	10.000
Bicycle lane	20.000

(Fietsberaad-CROW, 2015)

Looking at table 3.2.2, it can be seen that bicycle suggestion lanes on street with a car lane width smaller than 220 cm or between 380 and 480 cm are not included in the maximum car capacity table. The reason for this, as mentioned before, is that those widths are not recommended. It is advised to change streets with a car lane width smaller than 220 cm to a roadway and with a car lane width between 380 and 480 cm to a width of 380 cm. Therefore, bicycle suggestion lanes with a car lane width of smaller than 220 will use the maximum cars capacity of roadway and bicycle suggestion lanes with a car lane width between 380 and 480 will use the maximum cars capacity of bicycle suggestion lane with a small car lane.

The car intensity score is calculated by dividing the actual car intensity by the maximum cars per day of the corresponding path type and subtracting this from 1. This results in the following formula:

$$\text{Car intensity}_{\text{score}} = 1 - \left(\frac{\text{car intensity per 24 hours}}{\text{Maximum car capacity per 24 hours}}\right)$$

This formula rewards bicycle paths with a lower car intensity than the maximum acceptable, punishes paths that exceed the maximum and rewards no score when the car intensity is equal to the maximum capacity. This corresponds to the safety of the cyclists, as a higher than acceptable number of cars would decrease the safety of the cyclists using that road (Li et al., 2012; Oh et al., 2008).

3.2.4 Separation type

The fourth variable is the 'separation type' and is only relevant for path types that are physically separated and thus non-separated paths are always scoring a 0 on this variable. The separation type refers to barrier between the bicycle path and roadway (figure 3.2.3). In case the bicycle path is completely isolated and thus not near a roadway, the lefthand side as seen from the bicyclist's perspective should be considered for a one-way path and either one of the sides should be used for a two-way path. The other side of the two-way path will then be used for the calculation of the variable '*roadside type*'.

Figure 3.2.3 Separation type example on the left side of the bicycle path (Cyclenation, 2014)

The type of the separation is important as it can affect the safety of the bicyclists. The main concern regarding the safety comes from separation types which increases the chances of a single-bicycle accident. Which is an accident solely involving a bicyclist, mainly origin from falling over or hitting an obstacle (Schepers, 2009). Different types of separation can create different dangerous situations when a bicyclist goes off road towards the separation barriers. Therefore, different forms of separation can provide different levels of safety for the cyclists (Schepers, 2009; Fietsberaad, 2011; Raihan & Alluri, 2017). Thus, it is important to include this variable in the calculation of the bikeability level. Table 3.2.3 shows the different type of separations and the scores assigned to them.

Table 3.2.3 Types of separation

Types of separation		**Scores**
Vegetation	Grass with levelled and a clean transition	0
	Grass without levelled and/or a clean transition	-0.5
	Hedges, plants, etc.	-0.5
Sidewalk	Levelled (or a few cm)	0
	Sloping curbs	-0.5
	High curbs	-1
Physical objects (poles, fences, etc.)		-1
Parking places		-1

As can be seen in the table, the variable 'separation type' can lower the bicycle infrastructure segment score. The variable punishes a path if the separation type can potentially cause an unsafe cycle environment.

'Grass with levelled and a clean transition' is seen as one of the two safest separation types. By 'a clean transition' is meant that there is no mud or unevenness in the grass. 'Grass with levelled and a clean transition' scores a 0 as it causes a relatively low chance of crashing (Raihan & Alluri, 2017) as there are no objects to hit or throw the cyclists off balance. Furthermore, when the bicyclist does fall, it provides a relatively soft landing and an empty space to fall on. 'Grass without levelled and/or a clean transition' scores a -0.5 as it can potentially create an unsafe situation for the bicyclist. When the separation is not levelled, bicyclist often fall over when they try to get back on the bicycle path and an unclean transition can cause a bicyclist to fall over when they go off the bicycle path and onto the separation barrier (Fietsberaad, 2011). However, when the bicyclist falls, they still fall relatively soft and onto an empty space. Therefore, 'grass without levelled and/or clean transition' only reduces the segment score with -0.5. 'Hedges, plants, etc.' also scores a -0.5. 'Hedges, plants, etc.' are objects that can be crashed into when going off road, which can cause an unsafe situation for the bicyclist. However, 'hedges, plants, etc.' are not solid objects and when a bicyclist crashes into them, they can catch them with their branches. This is not necessarily pleasant, but can potentially prevent more severe injuries.

As seen in table 3.2.3, there are three types of sidewalks which all differently affect the segment score. Sidewalks as separation type can cause dangerous situations as curbs with a large height difference alongside a bicycle path can cause a bicyclist to crash when they hit the curb with their wheel or pedal, which is a common occurrence in single-bicycle accidents (Schepers & Klein Wolt, 2012; Fietsberaad, 2011). Besides, increasing the chance of a crash, a high curb can also severely injure the bicyclist when they fall with their head on the curb (Fietsberaad, 2011). Therefore, it is recommended to keep the height difference to a minimum (Schepers, 2009). A 'levelled' sidewalk can prevent these situations to happen and therefore has a score of 0. 'Sloping curbs' can reduce the risks of a crash as bicyclist are less likely to lose their balance when hitting the curb and there is a smaller chance of hitting the curb with the pedals (Fietsberaad, 2011). However, there still is a risk for the bicyclist to fall and therefore a 'sloping curb' scores -0.5. As explained, 'high curbs' can create dangerous situations resulting in single-bicycle crashes and therefore scores a -1.

Separation with 'physical objects' can also create an unsafe bicycling environment and can cause single-bicycle accidents (Schoon & Blokpoel, 2000; Schepers & Klein Wolt, 2012; Raihan & Alluri, 2017). The danger lays in when a cyclist goes off the path and hits the physical object. This directly results in a crash without a chance of regaining control and steering the bicycle back on the bicycle path. Therefore, 'physical objects' scores a -1.

The last separation type is 'parking places' which can also create an unsafe bicycle environment, but can also cause nuisance. Roughly 7% of *'single-bicycle accidents'* are the result of hitting a parked car (Fietsberaad, 2011). This can be fault of the bicyclist themselves by going off road and crashing into the car, but it can also be the fault of a passenger of the car. A bicyclist who rides along a parked car can be hit or surprised with an opening car door, resulting in a crash with the car or falling over in an attempt to avoid the door (Jänsch et al., 2015; Fietsberaad-CROW, 2015). Furthermore, badly parked cars can take up space of the bicycle path which can cause nuisance (Fietsberaad-CROW, 2015; Fietsberaad-CROW, 2015). Therefore, it is not convenient to have parking spaces as separation type and thus it scores a -1.

The scoring of the variable 'separation type' can be determine based on the type and corresponding score as seen in table 3.2.3. However, it is possible that a bicycle path has alternating separation types along the entire path length. Therefore, the following formula will be used to calculated the score of 'separation type':

$$\text{Seperation type}_{\text{score}} = \text{X}_1 \cdot -0.5 + \text{X}_2 \cdot -1$$

Where X_1 is the percentage of the path length alongside separation types with a score of -0.5 ('grass without levelled and/or a clean transition', 'hedges, plants, etc.' and 'sloping curbs') and X_2 is the percentage of the path length alongside separation types with a score of -1 ('high curbs', 'physical objects' and 'parking places'). Thus, this formula decreases the segment score of bicycle paths alongside unsafe separation types.

3.2.5 Roadside type

The fifth variable is 'roadside type'. This variable is similar to the 'separation type' variable, however the 'roadside type' refers to what is present on the other side of the bicycle path. An example of this can be seen on the right side of the bicycle path in figure 3.2.4.

Figure 3.2.4 Bicycle path with a sloping curb as road side type (right of the bicycle path) (Cyclenation, 2014)

In case the bicycle path is completely isolated, the righthand side as seen from the bicyclist's perspective should be considered for a one-way path and the other side than the side chosen for 'separation type' should be used for a two-way path. The reasoning for the inclusion of this variable and the scoring of the variable (table 3.2.3) is the same as for 'separation type'. The following formula will be used for the calculation of the 'roadside type' score:

$$\text{Roadside type}_{\text{score}} = \text{X}_1 \cdot -0.5 + \text{X}_2 \cdot -1$$

Where X_1 is the percentage of the path length alongside roadside types with a score of -0.5 ('grass without levelled and/or a clean transition', 'hedges, plants, etc.' and 'sloping curbs') and X_2 is the percentage of the path length alongside roadside types with a score of -1 ('high curbs', 'physical objects' and 'parking places'). Thus, this formula decreases the segment score of bicycle paths alongside unsafe roadside types.

3.2.6 Speed limit

The sixth variable is the 'speed limit' representing the maximum speed of the road for motorized traffic. This variable is only relevant for path types where bicyclists share the road with cars. Research shows that road with lower speed limits have a positive effect on the bicycle mode share (Heinen et al., 2010). Furthermore, a higher speed limit can increase the stress level of the cyclists (Lowry et al., 2016; Gholamialam & Matisziw, 2019), thus reducing their convenience. Therefore, the speed limit is an important variable in determining the segment score. Existing bikeability tools determine the ‘speed limit’ score with categories of maximum speed and do not account for the different types of streets and the different speed limits that belong to them. However, this seems as an important distinction to make as different types of streets enable different types of speed limits. Table 3.2.4 shows the recommended speed limit for motorized traffic on each type of street with cyclists.

Table 3.2.4 Recommended speed limits for cars (Fietsberaad-CROW, 2015)

Path types	**Recommended speed limits for motorized traffic**
Bicycle lane	50
Bicycle suggestion lane with small car lane (< 480 cm)	30
Bicycle suggestion lane with large car lane (> 480 cm)	40
Bicycle street	30
Roadway	30

Furthermore, opposite to existing bikeability tools, the score of the variable will not be based on categories but calculated with a formula. Using a formula makes it possible to reward point if the actual speed limit is lower than the recommended speed limit and decrease points if the actual speed limit exceeds the recommendation. To do this, the following formula will be used:

$$\text{Speed limit}_{\text{score}} = 1 - \frac{\text{Actual speed limit for motorized traffic}}{\text{Recommended speed limit for motorized traffic}}$$

Where the recommended speed limit for motorized traffic is based on the bicycle path type as presented in table 3.2.4.

3.2.7 Presence of a centre line

The seventh variable is ‘presence of a centre line’ indicating if the bicycle path has a centre line dividing the path into a two-direction path. This variable is only relevant for path types that are two-way paths and bicycle streets. This is an important attribute as it divides the path in two clear strokes, one for each direction. The presence of a centreline makes the path layout clearer and can thus improve the convenience of the path (Pol & Linssen, 2019). However, it is expected that a two-way bicycle path has a centreline and therefore the score will not increase if the centreline is present. It will however be lowered if the centreline is not present. Table 3.2.5 shows the scoring of this variable.

Table 3.2.5 Presence of centreline

Presence of centreline	**Scores**
Yes	0
No	-1

3.2.8 Presence of street lights

The eight variable is the presence of street lights alongside the bicycle path. The presence of street lights provides cyclists with a safer bicycle environment during night time (Arellana et al., 2020) and positively influences the bikeability of an area (Lin & Wei, 2018; Akar & Clifton, 2009). Therefore, it can increase the chance of people using the bicycle in these areas. Thus, it is an important variable to include. Lin & Wei (2018) calculated the street light score by dividing the number of street lights by the length of the path. However, this does not seem as the best calculation method as one street light can cover multiple meters of path. For the calculation of the street lights score, based upon the lighting design guidance of Global Designing Cities Initiative (n.d.) the assumption is made that street lights should me placed every 15 meters to provide a well illuminated bicycle path. This leads to the following formula:

$$\text{Presence of street light}_{\text{score}} = \frac{\text{number of street lights}}{\text{path length}} \cdot 15$$

This formula gives out a higher score, the more street lights are present alongside a bicycle path. However, the maximum score of this variable is set as 1. The reason for this is that a score higher than 1 would indicate that there is more than one street light per 15 meters, which would not be necessary.

3.2.9 Presence of obstacles

The ninth variable is the 'presence of obstacles' (for example poles) on the bicycle path. Obstacles can make it less convenient to cycle, causing hindrances that slowdown the bicycle trip and increase the probability of single-person bicycle accidents which can have a negative influence on the bicycle use (CROW-Fietsberaad, 2014; Rietveld & Daniel, 2004). This includes obstacles on the path as well as obstacles located on the roadside (CROW-Fietsberaad, 2014). Therefore, the variable 'presence of obstacles' should be included as a variable. Arellana et al. (2020) included this variable with categories in their bikeability tool. Differentiating between low, medium and high overall obstruction on the bicycle path. However, they do not clearly define when an obstruction of the path is seen as high. For the calculation of the 'presence of obstacles' score, the example of Arellana et al. (2020), will be followed. Three categories will be distinguished and clearly defined. These categories can be found in table 3.2.6.

Table 3.2.6 Obstacle categories

Obstacle categories	Definitions	Scores
None	No obstacle on the path or roadside.	0
Limited	Obstacles at the start and /or end of the path used to keep cars from the bicycle path.	-0.5
High	Multiple obstacles on and /or near the path.	-1

Looking at table 3.2.6, it can be seen that when there are no obstacles, a score of 0 is assigned. The reason for this is that it is expected that there are no obstacles, thus nothing changes in the segment score. When there are limited number of obstacles, a score of -0.5 is assigned. This is because obstacles can be placed on the beginning and ending of a path to ensure cars will not drive across them. Thus, these obstacles have a function. However, such obstacles are placed too often without considering other potential solutions, while the placing of obstacles should be the last resort (CROW-Fietsberaad, 2014). Even though these obstacles block cars, they still create discomfort and potential single person bicycle accidents. Therefore, this results in a score of -0.5. The last category 'high' has a score of -1. This is because there are multiple obstacles on or near the path creating discomfort and potential accidents without the added benefit of keeping cars of the bicycle path.

3.2.10 Pavement type

The tenth variable is 'pavement type' which indicates how the bicycle path is paved. The type of pavement can influence the convenience of cycling. So called closed pavement (asphalt and concrete) creates a flat surface which cause little to no vibrations while open pavement (pavement stone) can cause a lot of vibrations. These vibrations decrease the comfort of cyclists and therefore, cyclists prefer to cycle on paths made of closed pavement (Fietsberaard, 2006). Ito & Biljecki (2021) included the pavement type in their bikeability tool with category-based scores. Close pavement types score a 1 and open pavement types score 0.5. Based on their scoring system, the scoring system as seen in table 3.2.7 will be used for the variable ‘pavement type’.

Table 3.2.7 Pavement types

Pavement types	Scores
Closed pavement (Asphalt, concrete)	1
Open pavement (Pavement stones)	0.5
Other (Sand, gravel, etc.)	0

3.2.11 Pavement conditions

The eleventh variable is ‘pavement conditions’ which indicates the quality of the paths surface. A pavement with many cracks or holes decreases the bicycling comfort (Arellana te al, 2020) as it creates the possibility of the cyclists to get out of balance and fall over (SPV, 2020; SWOV, 2020a). Thus, it is important that the pavement is flat and without cracks or holes. Previous bikeability tools (Ito & Biljecki, 2021; Arellana et al., 2020) included the pavement quality as a binary variable; 1 for a good quality and 0 for a bad quality pavement. The variable ‘pavement conditions’ will function similarly, however, an additional category is added. Table 3.2.8 shows all categories and their scores of the variable ‘pavement conditions’.

Table 3.2.8 Pavement conditions

Pavement conditions	Scores
Without any holes and/or cracks (good)	1
With a 1 or 2 holes and/or cracks (medium)	0.5
With more than 2 holes and/or cracks (bad)	0

As can be seen in the table, a path without any holes and/or cracks is seen as a good quality path and scores 1. A path with only 1 or 2 holes and/or cracks is seen as a medium quality path and therefore still score 0.5. The reason for this is that a path with 1 or 2 holes or cracks will most likely be convenient to cycle on, however the cyclists have to be extra aware at one or two points of the path. The last category is a bad pavement quality, which has more than 2 holes and/or cracks. When there are 2 or more holes or cracks in the pavement, it becomes inconvenient for the cyclist and they have to be extra aware when cycling on this path. Therefore, the score for a bad pavement quality is 0.

3.2.12 Presence of slopes

The twelfth variable is ‘slopes’ indicating if the path has a slope going upward or downward. A slope can influence the convenience of cycling as it requires additional effort to cycle uphill but it requires additional effort in controlling the speed when going downhill. Which is also important as going downhill increase the bicyclist’s speed, which causes an increased chance in accidents and the severity of those accidents (Eriksson et al., 2019). Therefore, ‘slopes’ is an important variable for determining the segment score. Existing bikeability tools often include the slope of either the area or the bicycle path (Ito & Biljecki, 2021; Arellana et al., 2020; Grigore et al., 2019). However, the Netherlands is for the largest parts a flat country. Slopes are therefore not a common aspect of the environment. Therefore, the variable ‘slope’ will be included in a different manner than the existing bikeability tools. The variable ‘slope’ will indicate the number of occurrences of an element that causes the cyclists to cycle uphill or downhill on the bicycle path. This can for example be caused by a bridge or a tunnel. Every occurrence is assumed to negatively impact the convenience. The following formula will be used:

$$\text{Slope}_{\text{score}} = \text{Number of elements} \cdot -0.5$$

The formula indicates that every element causing a slope decreases the segment score with -0.5. A maximum is set for two occurrences, which result in a score of -1. The reason for the scoring systems is that slopes are not a common occurrence in the Netherlands. Therefore, only one slope on a path already highly increases the effort of cycling the path. However, one slope can still be manageable, but two slope highly increase the effort in comparison to the normal flat Dutch environment.

3.2.13 Land use type

The thirteenth variable is 'land use type' representing in which land use type the bicycle infrastructure is located. This variable is important as different land use types can have different influences on the bicycle use. Therefore, it is important to consider in which type of land use the bicycle infrastructure is situated.

For the variable 'land use type' three categories will be distinguished, these categories are land use types that positively influence the segment score, land use types that negatively influence the segment score and those which do not influence the segment score. The category land use types that do not influence the segment score are the assumed standard for where bicycle infrastructure is present and therefore has no effect on the segment score. Even though research has found that residential areas have a positive influence on the segment score, it is assumed to be the most common land use type for bicycle infrastructure to be located in, and is thus seen as non-influential to the segment score. The category of land use types that positively influence the segment score consist out of green & aquatic and retail land use. The category of land use types that negatively influence the segment score consist out of office and industrial land use. Areas with other land use than the previously mentioned land uses are assumed to have no effect on the segment score and are for that reason excluded from the calculation. The following formula will be used to calculate the 'land use type' score:

$$\text{Land use type}_{\text{score}} = \frac{\mathrm{X}_1 - \mathrm{X}_2}{\text{Path length}}$$

Here X_1 is the meters of bicycle path located in a positive land use type and X_2 is the meters of bicycle path located in a negative land use type. If the complete path is located in a positive land use type, 'the land use type' score will be 1. If the complete path is located in a negative land use type, the score will be -1. If the complete path is located in residential land or other land uses, the score will be 0. Thus, the score will increase if the path is located more in positive land use and decreases when most of the path is located in negative land use.

3.2.14 One-way street

The fourteenth variable is 'one-way street' and indicates the number of directions in which motorized traffic can travel. This variable is only relevant for path types where bicyclists share the road with cars. This is an important variable as research has shown that higher traffic volumes result in lower comfort and increased risk of collision for bicyclists (Li et al., 2012; Oh et al., 2018). By implementing one-way streets, it is possible to lower the traffic volume (SWOV, 2018). Therefore, the segment score of segments where bicycle share the road with cars will increase if it is a one-way street. Table 3.2.9 shows the scoring of the variable.

Table 3.2.9 One-way street

One-way street	Scores
No	0
Yes	1

3.2.15 Speed limiting objects

The fifteen variable is 'speed limiting objects' which indicates if there are objects present on the segment that reduce the speed of the motorized traffic. This variable is only relevant for path types where bicyclists share the road with cars. This is an important variable because when bicyclists have to share the road with motorized traffic, they prefer that the motorized vehicles drive slower (Caulfield et al., 2012; Saelens et al., 2003). Speed limiting objects, besides speed limits, are a way to enforce slower motorized traffic speeds (SWOV, 2018). If a segment has speed limiting objects, the segment score will increase. Table 3.2.10 shows the scoring of the variable.

Table 3.2.10 Speed limiting objects

Speed limiting objects	Scores
No	0
Yes	1

3.3 Calculating the bicycle infrastructure category score

As mentioned in section 3.2, the bicycle infrastructure category score is calculated based on the segment scores of each individual segment of bicycle infrastructure present in the neighbourhood. The variables discussed in section 3.2 are used to calculated the segment score of each segment of bicycle infrastructure. Table 3.3.1 shows an overview of all these variables and their measurements.

As can be seen in table 3.3.1, all variables have an equal weight of 1, indicating that all variables are seen as of equal importance. However, looking at the scoring of the variables this is not completely true. The variable path type can award far out the most score, the reason for this is that the importance of the variable has been accounted for in the scoring of the variable. The weight of 1 are the recommended basis weight for the calculation of the segment score, make the segment score accurate for the largest group of bicyclists.

Looking at table 3.3.1, it seems that the maximum score a segment can have is 18, however this is not true. The maximum score a segment can have is 15, as not all variables are applicable to all bicycle infrastructure types. The maximum score of 15 comes from adding up all maximum scores applicable to the bicycle infrastructure type 'bicycle path', this excludes the variables 'car intensity', 'one-way street' and 'speed limiting objects'. Thus, each segment present in the neighbourhood can have a score ranging between 0 and 15. The segment score will be adjusted to be have a scale from 0 to 10 to make the segments scores easier to understand and the to-be-calculated 'bicycle infrastructure' score comparable to the other category scores. The following formula is used:

$$\text{Segment score}_{\text{adjusted}}(\text{j}) = \frac{\text{Segment score (j)}}{15} \cdot 10$$

In this formula 'j' represent the individual segment for which the calculation takes place. The contribution of each segment towards the bicycle infrastructure category score is based on the length of the segment. The longer the segment is, the heavier it counts towards the bicycle infrastructure category score of the neighbourhood. The length of the segment is taken it account because a high scoring segment of only 10 meters long will have less influence on the bikeability level of the neighbourhood than a low score segment of 1000 meters long. The contribution of a segment to the 'bicycle infrastructure' category score will be calculated as followed:

$$\text{Segment}_{\text{contribution}}(\text{j}) = \text{Segment score}_{\text{adjusted}}(\text{j}) \cdot \text{Path length (j) [m]}$$

Table 3.3.1 Variables and measurements to determine bicycle infrastructure segment scores

Variables	**Measurement type**	**Measurement**	**Scoring**	**Weight**
Path type	Category	[1] Roadway [2] Bicycle suggestion lane [3] Bicycle lane [4] Bicycle street [5] Optional bicycle path [6] Moped & Bicycle path [7] Bicycle path	[1] = 3 [2] = 4 [3] = 5 [4] = 7 [5] = 8 [6] = 9 [7] = 10	1
Path width	Calculation	$\frac{\text{Path width [cm]}}{\text{Recommended path width}} - 1$	Range = -1 to 1	1
Car intensity	Calculation	$1 - \frac{\text{car intensity per 24 hours}}{\text{Maximum car capacity per 24 hours}}$	Range = -1 to 1	1
Separation type	Calculation	$X_1 \cdot -0.5 + X_2 \cdot -1$ X_1= percentage of path adjacent to medium dangerous separation types X_2= percentage of path adjacent to highly dangerous separation types	Range = -1 to 0	1
Roadside type	Calculation	$X_1 \cdot -0.5 + X_2 \cdot -1$ X_1= percentage of path adjacent to medium dangerous roadside types X_2= percentage of path adjacent to highly dangerous roadside types	Range = -1 to 0	1
Speed limit	Calculation	$1 - \frac{\text{Speed limit}}{\text{Recommended speed limit}}$	Range = -1 to 0	1
Presence of a centre line	Category	[1] Yes [2] No [0] Not relevant	[1] = 0 [2] = -1 [3] = 0	1
Presence of street lights	Calculation	$\frac{\text{Number of street lights}}{\text{Path length [m]}} \cdot 15$	Range = 0 to 1	1
Presence of obstacles	Category	[1] None [2] Limited [3] High	[1] = 0 [2] = -0.5 [3] = -1	1
Pavement type	Category	[1] Closed pavement [2] Open pavement [3] Other	[1] = 1 [2] = 0.5 [3] =0	1
Pavement conditions	Category	[1] Good [2] Medium [3] Bad	[1] = 1 [2] = 0.5 [3] = 0	1
Presence of slopes	Calculation	$\text{Number of slope elements} \cdot -0.5$	Range = -1 to 0	1
Land use type	Calculation	$\frac{X_1 - X_2}{\text{Path length [m]}}$ X_1= Path [m] located in positively associated land uses X_2= Path [m] located in negatively associated land uses	Range = -1 to 1	1
One-way street	Category	[1] No [2] Yes	[1] = 0 [2] = 1	1
Speed limiting objects	Category	[1] No [2] Yes	[1] = 0 [2] = 1	1

The ‘bicycle infrastructure’ category score is then calculated by combining the segment contributions of all the segments and dividing this by the total path length of all segments:

$$\text{Bicycle infrastructure}_{\text{score}}(\text{i}) = \frac{\sum \text{Segment}_{\text{contribution}}(j)}{\sum \text{Path length (j) [m]}}$$

In this formula ‘i’ represent the neighbourhood for which the calculation takes place. Using this formula results in a ‘bicycle infrastructure’ score for neighbourhood (i) on a scale from 0 to 10, with 10 being the highest score and indicating that the bicycle infrastructure in the neighbourhood is excellent. The bicycle infrastructure score will be used to determine the overall bikeability score of the neighbourhood in section 3.13.

3.4 Junction infrastructure

Junctions can influence the safety and ease of travel of cyclists (SWOV, 2021; Schepers et al., 2017) and are therefore commonly included in bikeability assessment methods. However, the manner how junctions are included can differ. It is possible to only look at the presence of junctions on a bicycle route (Gholamialam & Matisziw, 2019; Ito & Biljecki, 2021) and writing this down as a hindrance for the ease of travel. But it is also possible to look at junctions on a more detailed level, not only considering the ease of travel but also the safety of the design. Distinguishes can be made based on how traffic is regulated at a junction (Schmid-Querg et al., 2021), the layout (Grigore et al., 2019) and the bicycle specific infrastructure that is present (Grigore et al., 2019). These differences can lead to different levels of safety and convenience (Schepers et al., 2017) and should therefore be considered when including junctions in the assessment tool.

The previously developed assessment tools only looked at some of the important aspects of junctions separately, but did not include all previous mentioned aspects together. For the calculation of the junction infrastructure score, the type of the junction, the present bicycle infrastructure and other design aspects will be included. Furthermore, the junction type roundabout will be included. This is a junction type which was not mentioned in previous assessment tools, but is a common junction type in the Netherlands. Lastly, the density of junctions in an area will be considered in the ‘environment’ category of the assessment in section 3.8.

A junction score will be calculated for each junction individually and later be combined into a ‘junction infrastructure’ category score for the whole area. The junctions that will be included in the calculations are junctions where at least one of the roads is a distribution road. These roads are characterized by higher speeds and traffic volumes and therefore created more danger for bicyclists (SWOV, 2017b; Reurings et al., 2012). Therefore, it is important to pay additional attention to infrastructure of these junctions. The junction scores will be calculated using the following 6 variables:

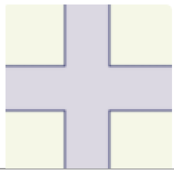
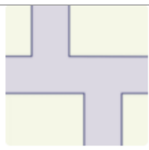
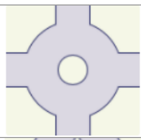
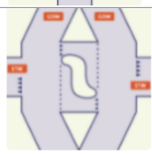
1. Junction type
2. Bicycle infrastructure at the junction
3. Presence of speed limiting objects
4. Presence of a median island
5. Presence of bicycle traffic lights
6. Presence of a bicycle box

The variables that determine the junction score in the bikeability assessment will now be discussed in more detail.

3.4.1 Junction types

The first variable of the junction score is the junction type which can influence both the safety and the ease of travel of the bicyclists. Different types of junctions provide different levels of safety and ease of travel (Weigand, 2008; Schepers et al., 2017) and therefore the type should be included in the calculation of the junction score. There are two steps in determining the type of the junction. The first step is to look at the layout. Based on the layout, 5 different types of junctions can be distinguished in the Netherlands (SWOV, 2021). Table 3.4.1 shows the different layouts.

Table 3.4.1 Junction layouts (SWOV, 2021)

Junctions	Junction layouts
Four-branch intersection	
Three-branch intersection	
Bayonet intersection	
Roundabout	
Priority square	

The four and three-branch intersection types, as well as the roundabout are well-known junction types. However, the priority square and bayonet intersection are less well-known. The priority square is a relatively new intersection type. This type of intersection is a combination of a roundabout and a four-branch intersection, where the main road is given priority over the secondary road. A priority square includes speed reducing elements as well as a median-island (SWOV, 2021). The Bayonet intersection is a variant on the four-branch intersection and consist out of two three-branch intersections relatively close to each other. The bayonet intersection, four-branch intersection and three-branch intersection will be grouped together as ‘intersection’, which can then be distinguished based on how the traffic is regulated. There are three ways to regulate traffic on an intersection. The first way is by priority ruling, meaning the driver gives priority to the drivers coming from his right side. The second way is by regulating traffic with markings and traffic signs and the last way is by the use of traffic lights. Making these distinctions leads to a list of 5 different junction types each providing a different level of safety and ease of travel. In table 3.4.2, all junction types and the scores belonging to those types are listed.

Table 3.4.2 Junction types

Junction types	Scores
Roundabout	9
Priority square	8
Intersection with markings and signs	7
Intersections with traffic lights	6
Intersections with priority rules	1

The scores for each type of junction are based on the safety and convenience that each junction provides for cyclists. The junction type roundabout has the highest score, as they are the safest type of junction due to their limited amount of conflict points, lower motorized vehicle speed and smaller impact angles when an accident does happen (SWOV, 2021). As can be seen in table 3.4.2, no distinction is made between roundabouts with and without priority for the cyclists. The reason for this is that both types of roundabouts benefit cyclists in a different way. Roundabouts without priority for cyclists are generally safer for cyclists, however roundabout with priority are more convenient for the travel flow (SWOV, 2021). Considering that both these benefits are of importance for the score of a junction, no distinction in terms of scoring is made between the two types of roundabouts.

The priority square is relatively new, therefore there is little information about the benefits compared to the other junction types. Generally speaking, the priority square has more points of conflict than a roundabout, but these conflicts occur with a lower motorized vehicle speed than on other junction types (SWOV, 2021). Based on this limited amount of information, the score assigned to the priority square is in-between that of a roundabout and an intersection with marking and signs. This is also, the final score of a junction of the type “the priority square”, as it is not clear how and if the other variables affect the safety and convenience of the junction. This means that no other variables will change the junction score of a junction with the typing ‘priority square’. However, when new studies find decisive results on the benefits and drawbacks of a priority square, the score can be adapted.

Lastly, there are three types of intersections distinguishable based on the manner of traffic control: ‘markings and signs’, ‘traffic lights’ and ‘priority ruling’. However, intersections regulated with priority ruling should not be applied on the junctions included in the ‘junction infrastructure’ score, as their field of application is mainly for residential areas (two intersecting access roads) (SWOV, 2021). Nevertheless, if a junction is regulated by ‘priority ruling’ a score of 1 will be assigned as it is not a desired junction type in combination with a distribution road.

When comparing ‘markings and signs’ and ‘traffic lights’, according to research, after controlling for intensity of the traffic flow, intersections regulated with traffic lights are the least safe type of intersection (SWOV, 2021). This differentiates from the assumption made in the bikeability tool of Schmid-Querg et al. (2021), who assumed that intersections with traffic lights would benefit the bikeability more than intersections without. However, Schmid-Querg et al. (2021) do not provide reasoning for the value distribution between different types of intersection. Therefore, following the research of the SWOV (2021), the type intersection with traffic lights is given a score of 6 and intersections with markings and signs is given a score of 7.

3.4.2 Bicycle infrastructure at the junction

The second variable of the junction score is the ‘bicycle infrastructure at the junction’. This refers to the path present for bicyclists at the junction. This is an important variable to include as different types of bicycle paths provide different levels of safety for the cyclists and should therefore be included in the tool. The level of safety mainly depends on the distance between the bicycle infrastructure and the lane for motorized vehicles, moving the bicycle infrastructure further away for the roadway increases the safety (Fietsberaad, 2011; Madsen & Lahrmann, 2017). In the Netherlands, 5 different bicycle infrastructures at the junction can be identified, each with a different distance between the bicyclists’ space and the space for motorized traffic (Fietsberaad, 2011). Table 3.4.3 shows the different types of bicycle infrastructure at junctions and their corresponding scoring.

Table 3.4.3 Bicycle infrastructure types at junctions

Bicycle infrastructure types	Scores
Shared lane	-1
Bicycle suggestion lane	0
Bicycle lane	0.5
Bicycle path within 2 meters of the roadway	0.75
Bicycle path between 2 and 5 meters of the roadway	1

Looking at table 3.4.3, it can be seen that 'shared lane' is the only type with a negative score. The reason for this is that a 'shared lane' has no dedicated space for bicyclist, meaning that there is no distance between the bicyclist and the motorized vehicles. The absence of a dedicated bicycle infrastructure space can potentially lead to drivers being less aware of the cyclists, decreasing the safety of cyclists (Madsen & Lahrmann, 2017). Furthermore, as the safety is dependent on the distance, it safe to assume not having any distance at all results in a negative score. Therefore, the scoring of 'shared lane' is -1.

The 'bicycle suggestion lane' has a score of 0. The reason for this is that it is assumed to be the bare minimum that can be present for bicyclists. The bicycle suggestion lane does provide a space for bicyclists, nevertheless it is hardly separated from the roadway. However, the presence of a bicycle suggestion lane can make drivers more aware of the presence of the bicyclists (Weigand, 2008).

The 'bicycle lane' is a safer bicycle infrastructure type than types where the road is shared with motorized vehicles (Madsen & Lahrmann, 2017). There is a dedicated bicycle infrastructure spaces which is separated from the roadway with painted lines. Thus, 'bicycle lane' provides some additional safety for the bicyclists and therefore scores a 0.5.

Lastly, the safest form of bicycle infrastructure at a junction is a 'bicycle path' (Madsen & Lahrmann, 2017). It is possible to distinguish two different types of bicycle paths that effect the safety at a junction differently. First, a 'bicycle path within 2 meters of the roadway' and secondly a bicycle path between 2 to 5 meters of the roadway' (Madsen & Lahrmann, 2017). As mentioned before, the levels of safety depend on the distance between the bicycle infrastructure and the roadway. Therefore, bicycle paths located between 2 to 5 meters of the roadway are the safest form of bicycle infrastructure at a junction and because of this score a 1. Bicycle paths within 2 meters of the roadway are second safest form. Those paths are still a dedicated space for bicyclist with a decent amount of distance between them and the roadway. Therefore, 'bicycle path within 2 meters of the roadway' scores 0.75.

3.4.3 Speed limiting objects

The third variable of the junction score is 'speed limiting objects'. Roundabouts are excluded from this variable as roundabouts themselves are speed limiting objects (SWOV, 2021). Speed limiting objects cause motorized traffic to reduce their speed and increase their attention level, resulting in less traffic accidents (Fietsberaad, 2011; Oh et al., 2008; Heinen et al., 2010). Additionally, even if a traffic accident occurs, it happens with a low speed. This makes the collision less severe and thus safer. This makes speed limiting objects and important variable to include in the calculation. Examples of speed limiting objects are traffic bumps and 'priority plateaus'. Table 3.4.4 shows the score distribution for the 'speed limiting objects' variable.

Table 3.4.4 Presence of speed limiting objects

Presence of speed limiting objects	**Scores**
None	0
Present	1

When there are speed limiting objects present, the safety of the junction increases. Therefore, the variable scores a 1 when there are speed limiting objects present near the junction and a 0 when there are none.

3.4.4 Presence of median islands

The fourth variable is 'presence of median islands', which is a safe space to wait in between the two roadways (going into different directions) when crossing a street. The presence of a median island is only relevant for two-way streets, with separated lanes for each direction. The presence of a median island improves the safety, ease of travel and comfort for bicyclist on a junction (SWOV, 2021; Fietsberaad, 2011). Median island enables bicyclists to cross a two-way street in stages. This does not only ensure that they only have to take into account motorized vehicles from one direction, but it can also reduce the waiting time at junction with a high traffic volume (Fietsberaad, 2011). Therefore, 'presence of median islands' should be included in the calculation of the junction score. Table 3.4.5 shows the scores belonging to the variable.

Table 3.4.5 Presence of median island

Roads at the junctions	**Presence of median islands**	**Scores**
Two-way street with separate lanes for both directions	Not present	0
	Present	0.5
Two-way street without separate lanes for both directions	Not relevant	0.5
One-way streets	Not relevant	0.5

As the variable is only relevant for junctions with two-way streets with separated lanes for both direction it is important to consider how it relates to other junctions that do not need a median island. The assumption is made that junctions other than two-way streets with separated lanes for both directions do not need a median island as the problems that the median island solves does not exist for these types of junctions. Therefore, it is decided to provide the same amount of scoring for junction without two-way street with separate lanes for both directions, as they provide the same amount of safety as two-way street with separate lanes for both directions and a median island.

When a median island is present at a two-way street with separate lanes for both directions, the safety as well as the convenience of the junction increases. Therefore, the variable scores a 0.5 when there is a median island present and a 0 when it is not.

3.4.5 Presence of bicycle traffic lights

The fifth variable is 'bicycle traffic lights' and is only relevant for intersections regulated with traffic lights. These intersections are safer and perceived as of higher quality when they have dedicated traffic lights for cyclists (Schepers et al., 2017). They are even safer and of higher quality when the cyclists have their own green phase (Schmid-querg et al., 2021; SWOV, 2021; Weigand, 2008). Therefore, intersection with bicycle specific traffic lights provide a higher score than those that do not have bicycle specific traffic lights. Table 3.6.6 shows the score distribution.

Table 3.4.6 Presence of bicycle traffic lights

Presence of bicycle traffic lights	Scores
No	0
Yes	0.5
Yes, and with own green phase	1

3.4.6 Presence of a biking box

The sixth variable 'biking box' is again only relevant for intersection with traffic lights. This is an area where cyclists can line up in front of the motorized traffic when waiting to make a left turn on an intersection with traffic lights (SWOV, 2020b) (figure 3.4.1). For cyclists, making a left turn on an intersection can be experienced as troublesome (Lowry et al., 2016). The presence of a biking box can make an intersection not only more convenient (Grigore et al., 2019; Schmid-Querg et al., 2021), but also safer (Schepers et al., 2017; Weigand, 2008; SWOV, 2021). Therefore, points are awarded if a biking box is present (table 3.4.7).

Figure 3.4.1: Example of a biking box (SWOV, 2020b)

Table 3.4.7 Presence of a biking box

Presence of a biking box	Scores
Not present	0
Present	0.5

3.5 Calculating the junction infrastructure category score

The 'junction infrastructure' category score is calculated based on the individual junction scores of all junctions present in the neighbourhood. The variables discussed in section 3.4 are used to calculated the individual junction scores. Table 3.5.1 shows an overview of all these variables and their measurements.

Table. 3.5.1 Variables and measurements to determine individual junction scores

Variables	Measurement type	Measurement	Scoring	Weight
Junction type	Category	[1] Intersection with priority rules [2] Intersection with traffic lights [3] Intersection with markings and signs [4] Priority square [5] Roundabout	[1] = 1 [2] = 6 [3] = 7 [4] = 8 [5] = 9	1
Bicycle infrastructure at the junction	Category	[1] Shared lane [2] Bicycle suggestion lane [3] Bicycle lane [4] Bicycle path within 2 meters [5] Bicycle path between 2 to 5 meters	[1] = -1 [2] = 0 [3] = 0.5 [4] = 0.75 [5] = 1	1
Presence of speed limiting objects	Category	[1] Not present [2] Present [0] Not relevant for the junction	[1] = 0 [2] = 1 [0] = 0	1
Presence of median island	Category	[1] Not present [2] Present [3] Not needed	[1] = 0 [2] = 0.5 [3] = 0.5	1
Presence of bicycle traffic lights	Category	[1] Not present [2] Present [3] Present and with own green phase [0] Not relevant for the junction	[1] = 0 [2] = 0.5 [3] = 1 [0] = 0	1
Presence of bicycle box	Category	[1] Not present [2] Present [0] Not relevant for the junction	1] = 0 [2] = 1 [0] = 0	1

As can be seen in table 3.5.1, all variables have an equal weight of 1, indicating that all variables are seen as of equal importance. However, just like the variable 'path type' of the category 'bicycle infrastructure', the variable 'junction type' award more score than the other variables. Once again, the importance of the variable has been accounted for in the scoring of the variable. The weight of 1 are the recommended basis weight for the calculation of the segment score, make the segment score accurate for the largest group of bicyclists.

Looking at table 3.5.1, it seems that the maximum score of a junction is 13.5, however the maximum score that a junction can actually have is 10.5 as not all variable are applicable for all the junction types. This means that each junction in the neighbourhood can have a score ranging between 0 and 10.5. Similar to the segment score of the category 'bicycle infrastructure', the junction scores will be adjusted to a scale from 0 to 10. This adjustment will make it possible to, once calculated, compare the 'junction infrastructure' category score with the other categories. The following formula is used for adjusting the junction scores:

$$\text{Junction score}_{\text{adjusted}}(\text{j}) = \frac{\text{Junction score (j)}}{10.5} \cdot 10$$

In this formula 'j' represent the individual junction for which the calculation takes place. The contribution of each junction towards the 'junction infrastructure' category score of the neighbourhood is equally large. The 'junction infrastructure' category score can be calculated by calculating the average adjusted junction score from all the junctions in the neighbourhood.

$$\text{Junction infrastructure}_{\text{score}}(\text{i}) = \frac{\sum \text{Junction score}_{\text{adjusted}}\,(j)}{\text{Number of junctions in the neighbourhood}}$$

In this formula 'i' represent the neighbourhood for which the calculation takes place. Using this formula results in a 'junction infrastructure' score for neighbourhood (i) on a scale from 0 to 10, with 10 being the highest score and indicating that all the junctions in the neighbourhood are as safe and convenient as possible for bicyclists. The junction infrastructure score will be used to determine the overall bikeability score of the neighbourhood in section 3.13.

3.6 Bicycle parking facility

Bicycle parking facilities (BPFs) are often not included in the assessment of the bikeability of an area (Castañon & Ribeiro, 2021) and when BPFs are included in the assessment of an area it is often in a restrictive form. Ito & Biljecki (2021) only included the presence of BPF, Schmid-Querg et al. (2021) also looked at the type of bicycle parking and Hamidi et al. (2019) looked at available parking spots near transit hubs, but disregarded the type of the facility. So even when BPFs are included, it is often seen as a small variable rather than a larger aspect. Therefore, BPFs is an undervalued category of bikeability, even though BPFs are a core aspect of bicycle travel and thus bikeability (Van der Spek & Scheltema, 2015; Heinen et al., 2010). BPFs that are connected to the bicycle network and nearby a multitude of destinations provide a space to store the bicycle, thus making these locations better reachable by bicycle. Previously conducted research shows that the presence of safe and high quality BPFs near one's work locations increase the chance that employee's cycle to work (Noland & Kunreuther, 1995; Wardman et al. 2007). Therefore, it can be said that BPFs can have a large influence on the bicycle behaviour of people.

However, determining the BPF score is a complicated process, the reason for this is that in general people prefer to park their bicycle as close as possible to their destination (Van der Spek et al., 2015). This means that it is very well possible that bicyclists choose to park their bicycle in a non-designated space in front of their destination rather than in a high-quality bicycle storage 500 meter further away. A potential reason for this can be the trip duration, the shorted the intended stay at one's destination, the less trouble one wants to go through for parking their bicycle (Van der Spek & Scheltema, 2015; Gemeente Utrecht, 2010). The bicycle parking of these types of short duration trips, focuses on one specific purpose will be classified as purpose parking and will be excluded from the assessment.

The 'bicycle parking facility' score will only focus on BPFs that are larger than 30 square meters. It is assumed that due to their size these BPFs serve a great purpose in the bikeability of a neighbourhood, as they serve a wider area and multiple target groups. There is one additional exclusion, which is BPFs for residents of dwellings. These are excluded from the calculation as these BPFs serve the origin rather than the destination. Additionally, in the municipality of Eindhoven (which is considered as the case study city in chapter 4) it is required that apartment buildings provided a BPF for their inhabitants (Gemeente Eindhoven, 2019). This means that in theory there should always be a place to park one's bicycle at the origin location.

A BPF score will be calculated for each BPF individually and later be combined into a 'bicycle parking facility' category score for the whole area. The BPF score will be calculated using the following seven variables:

1. Type of BPF
2. Security measures
3. Parking costs
4. Connection to the bicycle infrastructure
5. Destinations
6. Distance to transit
7. Parking spot ratio

The variables that determine the BPF score in the bikeability assessment will now be discussed in more detail.

3.6.1 Type of bicycle parking

The first variable of the BPF score is the 'type of the BPF'. In the study conducted by Van der Spek & Scheltema (2015), two different ways of distinguishing BPFs are discussed. In the first way the distinction can be made based on construction type. It can be either outdoor, meaning that the parking facilities is in open air, roofed or in a box, or it can be indoor, meaning inside a building. In the second way, the distinction is made based on technical aspects. Here, seven different ways of distinguishing Dutch BPFs can be made (Van der Spek & Scheltema, 2015):

1. Free space Stand (standard of the bicycle);
2. Pole, fence or railing in public spaces;
3. Basic bike rack (without security features);
4. Advanced bike rack (with security features);
5. Bike storage (supervised);
6. Bike storage (Guarded);
7. Bike service (VALET bike parking) or automated parking.

For the calculation of the BPF score, a combination of both ways of distinctions are used. To do so, the following changes will be made. First, type 1 and 2 of the Dutch bicycle parking facilities will be removed. Type 1 and 2 are not really considered as BPFs, but rather a chosen alternative by the bicyclist when there is no BPF close enough to their destination. This could potentially be anywhere in an area. Therefore, no score can be calculated for these types and are excluded from the calculation. Second, type 3 and type 4 are highly similar and will therefore be combined to the type 'bicycle rack'. However, a distinction will be made between bicycle racks that are roofed and those that are not. Thus, resulting in two different BPF types. Lastly, type 5, 6 and 7 will be combined into the type 'bicycle storage'. The difference between the types regarding supervised and guarded will be dealt with in another BPF variable. Table 3.6.1 shows the final three types of bicycle parking with the score.

The scores assigned to each type of BPF are based on the quality of the parking type measured by the ability to protect the bicycle from theft and heavy weather (Schmidt-Querg et al., 2021), as well as their influence on bicycle use. Bicycle storages and roofed bicycle racks are covered BPF types. Covered bicycle parking which has a positive influence on the bicycle use (Heinen & Buehler, 2019). Therefore, these two types of BPF score higher than the uncovered bicycle rack. Furthermore, the bicycle storage can protect bicycles from both theft and heavy weather and is therefore rewarded with the highest score. The roofed bicycle rack has the second highest score as it provides protect from heavy weather. Lastly, the bicycle rack does not provide any additional protection and thus has the lowest score.

Table 3.6.1 Bicycle parking facility types

Bicycle parking facility types	Examples	Scores
Bicycle storage (Inside)	 (Kraaijvanger, n.d.)	5
Roofed bicycle rack (outside)	 (Metec, n.d.)	3
Bicycle rack (outside)	 (Fietsersbond, 2015)	1

3.6.2 Security measures

The second variable of BPF concerns the additional security measures taken to protect the bicycles from theft. Besides the security obtained from the type of bicycle parking itself, security can also be obtained by implementing certain measurements. Therefore, the variable 'security measures' indicates how the bicycle parking place is secured. This is an important aspect as supervision reduces bicycle theft (Van der Spek & Scheltema, 2015) and BPFs with a higher risk of theft and or vandalism have a negative influence on bicycle use (Rietveld & Daniel, 2004). Table 3.6.2 shows the different types of security measures a BPF can have.

Table 3.6.2 Types of security measures for BPFs

Security measures	Scores
Bicycle lockers	2
Guarded	2
Surveillance	1
No security	0

The scores assigned to each type are based on the level of security measures and their influence on bicycle use. Overall, BPFs with a form of security measure are preferred over BPFs with no security measures and can increase bicycle use (Jonkeren & Kager, 2021; Heinen & Buelher, 2019). Therefore, the presence of a security measure is always rewarded with a positive score. The security measures 'guarded' and 'bicycle lockers' are seen as the highest form of security. Guarded BPFs have people actively watching the stored bicycles, reducing the chance of theft and vandalism (Van der Spek & Schelteman, 2015). Bicycle lockers do not have people actively watching the bicycles, but the bicycles are stored behind a lock. This also protects the bicycle from theft and is a widely appreciated bicycle security measure under bicyclists (Heinen et al., 2010). Because of this 'guarded' and 'bicycle lockers' are the highest scoring types.

Surveillance is the second most scoring type, which indicates that the BPF is monitored with cameras. Surveillance will provide a BPF with a basic level of security (Van der Spek & Scheltеman, 2015) and can effectively reduce bicycle theft (Chen et al., 2018). However, it is still possible for theft to happen. Surveillance cameras can go unnoticed by the bicycle thieves and surveillance can also have blind spots, thus still resulting in bicycle theft. Therefore, surveillance scores lower than guarded and bicycle lockers.

The last type is 'no security', which indicates that no additional security measures are taken. It is common for bicycle parking facilities to be unguarded, therefore if the parking facility has no form of security the score will not be lowered. Therefore, the no security type does not give any scoring.

3.6.3 Parking costs

The third variable is 'parking costs' indicating if one needs to pay for storing his or her bicycle at the BPF. The variable 'cost of parking' is an important variable to determine the score of a BPF. Bicyclists highly appreciate free parking. In general, people are not willing to pay to park their bicycle and even think it should be free, even when the facility is guarded (Van der Spek & Scheltema, 2015). Therefore, parking cost can relinquish the benefits obtained from surveillance or guarded facilities, especially considering that guarded parking services are more common to be paid facilities (Van der Spek & Scheltema, 2015). There are two types of paid parking. The first type is 'paid from the start', meaning that the cyclists need to pay once he or she starts using the bicycle parking facility. The second type is 'free for a day and paid for longer'. This means that the bicyclist can park his or her bicycle for free for 24 hours, but need to pay if the bicycle is parked in the facility for a longer period than that. This type of paid parking is still a good option for most bicyclists, as most people park their bicycle for less than 24 hours (Van de Spek & Scheltema, 2015). Table 3.6.3 shows the scores depending on the cost of parking.

Table 3.6.3 Cost of parking

Parking costs	Scores
Free	0
Free for a day, paid for longer	-0.5
Paid from the start	-3

As can be seen in table 3.6.3, free parking does not influence the BPF score. The reason for this is that it is most common for BPF to be free. Therefore, it is the standard for a BPF. The other two types of 'parking costs' decrease the BPF score. The reason for this is that most people are not willing to pay for storing their bicycle, which means that the BPF has a lower chance of being used when it is paid (Van der Spek & Scheltema, 2015) and de likelihood of people cycling also decreases (Heinen & Buehler, 2019).

As mentioned before, the type 'paid for longer' is still a good option for most bicyclists, as it for most bicyclists it is a free BPF. However, some users do need to pay and therefore, the score of 'paid for longer' lowers the BPF score a little bit.

'Paid from the start' decrease the BPF with a lot. The reason for this is that cyclists think that a BPF should be free even when it is guarded. The score of -3 for 'paid from the start' relinquishes the score obtained from the variable 'security measure' when it is guarded and shows that paying for storing the bicycle is something disliked even when that facility is guarded.

3.6.4 Connection to the bicycle infrastructure

The fourth variable is 'connection to the bicycle network' which looks at how close the BPF is located to the bicycle infrastructure. This connection is important because, for BPFs to be used they need to be easily accessible and easy to find (Van der Spek & Scheltma, 2015). The closer that the entrance of the BPF is to the bicycle network, the better. The score obtained from this variable is based on a formula, which makes the assumption that the maximum acceptable distance for the BPF to be connected to the bicycle network is 100 meters. This maximum is chosen, because after 100 meters it already becomes less accessible and more difficult to find from the bicycle network. If a BPF is located further away from the bicycle network than the maximum, it will decrease the score of the BPF and if it is closer the score will increase. The following calculation will be used to determine the score:

$$\text{Bicycle network connection}_{\text{score}} = 1 - \left(\frac{\text{Distance from the bicycle parking facility to the nearest bicycle infrastructure}}{100}\right)$$

Based on this calculation the maximum obtained positive score on this variable would be 1, which happens when the BPF is located directly next to the bicycle network. The calculation does not have a maximum negative score, but this will be set to -1. This is assumed to be the point at which the BPF has completed lost the connection to the bicycle network. A score of -1 indicates that the BPF is located 200 meters ore more away from the nearest bicycle infrastructure.

3.6.5 Destinations

The fifth variable is the 'number of destinations' within the range of the BPF. Destinations and the distance towards the destinations are of high importance for the functioning of a BPF. Having direct access to the destination is essential for the attractiveness of the BPF (Van der Spek & Scheltema, 2015). When a BPF has more destinations within a nearby distance, it can serve a wider range of bicyclists. More destinations in a close proximity means that it is used more and therefore adds more value for the neighbourhood and thus increase the score of the BPF. However, depending on the type of the BPF, different distances are acceptable as direct access (Gemeente Utrecht, 2010). In general, stand-alone bicycle racks are mostly used for destinations in close proximity, while guarded bicycle storages are also used for destinations located further away (Van der Spek & Scheltema, 2015). Therefore, when looking at the number of destinations within a close proximity, the acceptable range is based on the type of BPF. Table 3.6.4 shows the ranges of each type of BPF

Table 3.6.4 Range per bicycle parking facility type

Bicycle parking facility types	**Direct access ranges in meters**
Bicycle storage (Inside)	200
Roofed bicycle rack (outside)	100
Bicycle rack (outside)	50

These ranges can be used to calculated the score of the variable 'destinations' by counting all commercial, recreational, service, educational and retail destinations within the direct access range of the BPF. This is then divided by the direct access range and multiplied by 5 to indicate the number of destinations present per 5 meters of access range. These 5 meters are based on the assumption that a BPF with one destination per 5 meters can serve a sufficiently wide range of bicyclists. The formula that is used is as followed:

$$\text{Destinations score} = \frac{\text{Number of destinations in access range}}{\text{Access range [m]}} \cdot 5$$

This formula gives a higher score when there are more destinations present nearby the BPF. However, the maximum score of this variable is set as 1. The reason for this is that a score higher than 1 would indicate that there is more than one destination present per 5 meters, which deemed more than necessary based on the previously made assumption of 1 destination per 5 meters.

3.6.6 Distance to transit

The fifth variable is 'distance to transit' which looks at the distance between the BPF and the nearest public transit station. BPFs located nearby train stations or bus stations hubs make it easier to travel by public transport and therefore promote combining bicycle and public transport rather than using the car (Jonkeren & Kager, 2021), which improves the bikeability level of the area. However, a short distance between the BPF and the public transport platform is of high importance for the user satisfaction (Jonkeren & Kager, 2021) and increase the likelihood of individuals cycling to the station (Heinen & Buehler, 2019). Therefore, the closer the BPF is located to the transit hub, the higher the score.

As mentioned in subsection 3.6.5., depending on the BPF type, different distances can be considered as direct access. For the assessment of 'distance to transit' these differences will also be considered. The ranges of each BPF type mentioned in table 3.6.4 will also be used for the assessment of the variable 'distance to transit', which is calculated as followed:

$$\text{Distance to transit}_{\text{score}} = \frac{\text{Acceptable range}_{\text{n}}\ [\text{m}] - \text{distance to transit hub}[\text{m}]}{\text{Acceptable range}_{\text{n}}\ [\text{m}]}$$

Where n is the type of BPF and the acceptable range is the range corresponding to that type as shown in table 3.6.4. Using this formula, the 'distance to transit' score will increase when the BPF is closer to a transit station and decrease when it is further away. For this score it is important that the score does not punish BPFs located further away from a transit hub, as not all BPFs serve a transit hub. Therefore, the score of this calculation is only considered when it is larger than 0.

3.6.7 Parking spot ratio

The last variable is the 'parking spot ratio' which represent the efficiency of the BPF in providing parking spots. The number of actual bicycle parking spots can be lower for example due to poor design or higher due to vertical parking of bicycles. An efficient parking design is important as a higher capacity of parking spaces can increase bicyclist's satisfaction (Jonkeren & Kager, 2021) and can increase bicycle use (Heinen & Buehler, 2019). The parking ratio is calculated as followed:

$$\text{Parking ratio}_{\text{score}} = \frac{(\text{Parking spots } \cdot \text{average m}^2 \text{ per bicycle}) + (\frac{\text{Parking spots } \cdot \text{average m}^2 \text{ per bicycle}}{2})}{\text{BPF area}}$$

Here it is assumed that the average square meter which a parked bicycle occupies is 1.17 m² (Cambridge City Council, 2010). Furthermore, this formula assumes a standard layout where bicycles can be parked on each side of an aisle (figure 3.6.1). The formula takes into account that the space for aisles is necessary to park the bicycle and adds this to the total square meters used for bicycle parking. It is assumed that the aisle is as long as the length of one bicycle. A score of 1 or higher means that the area is used efficiently. A score lower than 1 means that the area could be used more efficiently. This means that the number of parking spaces can be increased, which would improve the user satisfaction with the parking facility. The maximum score for the parking ratio is set to be 2, as it is assumed that in that scenario the BPF design is most efficient and bicycles can be stored one layer above each other.

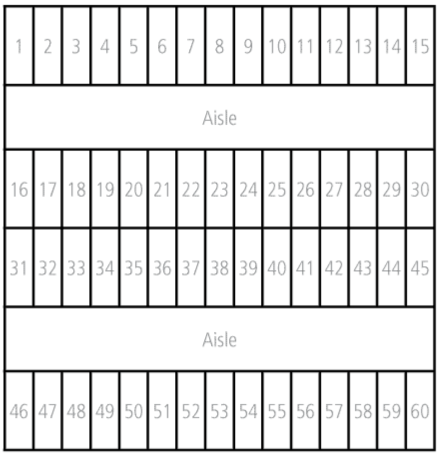


Figure 3.6.1 Standard BPF layout (Dero, n.d.)

A potential problem with this calculation is that it assumes that the design of all parking facilities is an aisle with on both sides straight parking and that the design uses the proposed dimensions. However, this in not necessarily true. A BPF can have a smaller aisle or a completely different layout. Meaning there could be more space used for bicycles in the actual situation than assumed and because of this the calculated score will be higher. However, it is difficult to account for all different layout types of BPF and therefore the most common layout is used for the calculation.

3.7 Calculating the bicycle parking facility category score

The 'bicycle infrastructure' category score is calculated based on the individual BPF scores of all BPFs present in the neighbourhood. The variables discussed in section 3.6 are used to calculated the individual scores of each BPF. Table 3.7.1 shows an overview of all the variables and their measurements.

Table 3.7.1 shows that all variables are weighted equally, indicating that all variables are seen as equally important for the determination of the BPF score. But just like the variables 'path type' and 'junction type', the variable 'BPF type' has the most impact on the total score of the BPFs. However, the impact of 'BPF type' on the BPF score is a bit smaller than the impact of 'path type' and 'junction type' on their corresponding scores, as the scoring ranges is only 1 to 5. Nevertheless, 'BFP type' will have the largest impact on the BPF score. The weight of 1 are the recommended basis weight for the calculation of the segment score, make the segment score accurate for the largest group of bicyclists.

Table. 3.7.1 Variables and measurements to determine individual bicycle parking facility scores

Variables	Measurement type	Measurement	Scoring	Weight
Bicycle parking facility type	Category	[1] Bicycle rack (outside) [2] Bicycle rack (covered) [3] Bicycle storage (inside)	[1] = 1 [2] = 3 [3] = 5	1
Security measures	Category	[1] No security [2] Surveillance [3] Guarded [4] Bicycle lockers	[1] = 0 [2] = 1 [3] = 2 [4] = 2	1
Parking costs	Category	[1] Free [2] Free for a day, paid for longer [3] Paid	[1] = 0 [2] = -0.5 [3] = -3	1
Connection to the bicycle infrastructure	Calculation	$1 - \frac{\text{Distance to bicycle infrastructure [m]}}{100}$	Range = -1 – 1	1
Destinations	Calculation	$\frac{\text{Destinations in access range [m]}}{100} \cdot 5$	Range = 0 - 1	1
Distance to transit	Calculation	$\frac{\text{Acces range [m]} - \text{distance to PT stop[m]}}{\text{Access range [m]}}$	Range = 0 -1	1
Parking spot ratio	Calculation	$\frac{(\text{Parking spots } \cdot \text{average m}^2 \text{ per bicycle}) \cdot 1.5}{\text{Area [m}^2\text{]}}$	Range = 0 - 2	1

The maximum score that a BPF can have is the combined highest score on each variable, which is 12. The score for the BPF will be adjusted to scale from 0 to 10 to make it possible to easily compare the category scores. The following formula is used for adjusting the BPF score:

$$\text{BPF score}_{\text{adjusted}}(\text{j}) = \frac{\text{BPF score (j)}}{12} \cdot 10$$

In this formula ‘j’ represent the individual BPF for which the calculation takes place. The contribution of each BPF towards the ‘bicycle parking facility’ category score of the neighbourhood is equally large. The ‘bicycle parking facility’ category score can be calculated by calculating the average adjusted BPF score from all the BPF scores in the neighbourhood.

$$\text{'Bicycle parking facilitiy' category}_{\text{score}}(\text{i}) = \frac{\sum \text{BPF score}_{\text{adjusted}}\,(j)}{\text{Number of BPFs in the neighbourhood}}$$

In this formula ‘i’ represent the neighbourhood for which the calculation takes place. Using this formula results in a ‘bicycle parking facility’ score for neighbourhood (i) on a scale from 0 to 10, with 10 being the highest score and indicating that all BPFs in the neighbourhood are of the highest quality. The ‘bicycle parking facility’ category score will be used to determine the overall bikeability score of the neighbourhood in section 3.13.

3.8 Environment

The environment of a neighbourhood can influence the safety and convenience of cycling. For example, a high density of green spaces can provide an attractive scenery and promote bicycle use (Hull & O'Holleran, 2014; Zhao et al. 2020; Fraser & Lock, 2010). But a neighbourhood with a high amount of traffic danger can decrease the feeling of safety and discourage individuals to bicycle (Zhao, 2003; Handy & Xing, 2011). Furthermore, a neighbourhood with a good cycling environment can promote bicycle use and discourage car use (Akar & Clifton, 2009). Because of influence of the environment, variables representing the environment in a neighbourhood are often included in bikeability evaluation tools.

In contrary to the previous categories, the environment category does not first calculate individual score for individual segments, but directly calculates the category. The variable in the 'environment' category are not focused on individual segments such as in the 'bicycle infrastructure' category, but focusses on area wide aspects such a density of infrastructure, amenities and population in the area. For the calculation of the 'environment' category score, variables that measure area wide aspects that influence the bicycle use are considered. The category 'environment' will consist out of the following variables:

1. Bicycle infrastructure ratio
2. Bicycle way density
3. Intersection density
4. BPF ratio
5. Population density
6. Air quality
7. Green spaces
8. Mixed land-use
9. Road safety

These variables will now be discussed in further detail.

3.8.1 Bicycle infrastructure ratio

The first variable of neighbourhood environment is 'bicycle infrastructure ratio' which represent how much meters of bicycle infrastructure is present for each meter of roadway. This is an important variable as it indicates if the neighbourhood is promoting bicycle use over motorized vehicle use. A neighbourhood with a higher amount of meter bicycle infrastructure encourages cycling (Akar & Clifton, 2009; Dill & Car, 2003; Lin & Wei, 2018). Therefore, a bicycle infrastructure ratio should be included in the calculation of the 'environment' category score. The variable 'bicycle infrastructure ratio' will be included similar to how Lin & Wei (2018) included it, by dividing the total bicycle infrastructure length of the area by the total length of road way.

$$\text{Bicycle infrastructure ratio}_{\text{score}} = \frac{\text{Total length of bicycle infrastructure [m]}}{\text{Total length of roadway [m]}}$$

Using this formula, the neighbourhood will have a higher score when the meters of bicycle infrastructure increase relatively to the meters of roadway. The formula does not necessarily have a maximum score, however a maximum score is set at 2. This would indicate that there is twice as much bicycle infrastructure as roadway, which is assumed to be a clear indication that the neighbourhood is promoting bicycle use.

3.8.2 Bicycle way density

The second variable is 'bicycle way density' which represent how much bicycle paths are present relative to the size of the neighbourhood. This is an important variable to considers as again, neighbourhoods with a higher amount of meters bicycle path encourage cycling more than neighbourhoods with a low amount (Handy & Xing, 2011; Gutiérrez et al., 2020). However, this variable also takes into account the size of the neighbourhood. Smaller neighbourhoods are expected to have less bicycle paths than large neighbourhood as there is less distance to cover. Therefore, it is important to take into account the size of the neighbourhood. Lin & Wei (2018) calculated the bicycle way density by dividing the total meters of bicycle path by the square meters area of the neighbourhood. Although this seems like a sufficient way to calculate the bicycle way density, it will often result in an extremely low score which can be problem as most variables in the tool focus on providing a score with a range of 0 to 1. This would mean that in the best-case scenario for each square meter of neighbourhood there should be 1 meter of bicycle path, which is not a reasonable assumption. Therefore, the bicycle way density will look at the meters of bicycle path per 100 m² of area, using the following formula:

$$\text{Bicycle way density}_{\text{score}} = \frac{\text{Total length of bicycle path [m]}}{\text{Area [m}^2\text{]}} \cdot 100$$

Using this formula, the score will increase if there is more bicycle path present in the neighbourhood. The maximum score for the variable is set to 1, indicating that there is 1 meter of bicycle path for every 100 m² of neighbourhood. It seems a reasonable assumption that 1 meter of bicycle path for every 100 m² of neighbourhood result in a high enough bicycle way density to positively influence the bicycle use.

3.8.3 Intersection density

The third variable is intersection density which represents the number of intersections within a neighbourhood. This is an important variable as the presence of intersections can have a significant influence of bicycle use. Ton et al. (2017) and Caulfield et al. (2012) indicated that cyclists prefer fewer intersection on their routes and Piatkowski & Marshall (2015) found that a higher intersection ratio (node to link) was negatively associated with bicycle use. The reason for this is that intersections often result in a delay due to red traffic lights or cause bicyclists to slow down to ensure safe crossing (Broach et al., 2012), which has a negative effect on bicycle use (Rietveld & Daniel, 2004). However, Broach et al. (2012) mention that traffic lights are sometimes a necessity for bicyclists to safely cross the road and thus traffic lights can also be an attractive feature. Additionally, it should not be forgotten that although a higher number of intersections is undesired by bicyclists, they are also necessary to get around the neighbourhood.

For the calculation of the intersection density, the included intersections will be the intersections where at least one of the roads is a distribution road. These roads are characterized by higher speeds and traffic volumes and therefore created more danger (SWOV, 2017b) and delays (Rietveld & Daniel, 2004) for bicyclists. Thus, these intersections will negatively influence the trips of bicyclists. In contrary to section 3.4, for the calculation of intersection density, all types of intersections are counted equally. Meaning, that the type of the intersection will not affect the intersection density score. However, it should be noted that the variable is 'intersection' density and not 'junction' density. This means that roundabouts and priority squares are not part of the score calculation of the variable 'intersection density'. The reason for this is that it is assumed that roundabouts and priority squares cause less delays and slowdowns for cyclists and because of that are not a hindrance for the ease of travel of cyclists. The intersection density score will be calculated as followed:

$$\text{Intersection density}_{\text{score}} = -\frac{\text{Number of intersections}}{\text{Area [ha]}}$$

This calculation only results in a negative scoring for the neighbourhood, the more intersection that are present, the lower the score. The maximum negative score for the variable intersection density is set to -1, indicating that for every hectare 1 intersection is present.

3.8.4 Bicycle parking facilities ratio

The fourth variable is 'bicycle parking facilities ratio' which indicates the areas served by BPFs. This is an important variable as the presence of BPFs is essential for bicycle use (Ton et al., 2019; Heinen & Buehler, 2019). Therefore, it is important that a high percentage of a neighbourhood is provided with access to BPF. Previously in section 3.6 'bicycle parking facilities', BPFs smaller than 30m² were excluded from the calculation as it is assumed they do not serve multiple target groups. However, BPFs smaller than 30m² do serve a purpose, even though it is only a small purpose. Thus, BPFs smaller than 30m² will be included for the calculation of the BPFs ratio variable. The BPFs ratio score will be calculated as followed:

$$\text{BPFs ratio}_{\text{score}} = \frac{\text{Areas served by BPFs [m}^2\text{]}}{\text{Area [m}^2\text{]}}$$

In this formula the served area of the BPFs is based on the access range of the BPFs type. These access ranges were previously established in section 3.6.5 and are 200 meters for a bicycle storage, 100 meters for a roofed bicycle rack and 50 meters for a bicycle rack. A buffer with as range the access range will be drawn around each BPFs and summed together to determine the area served by BPFs. The BPFs ratio score will be higher when more of the area is served by BPFs.

3.8.5 Population density

The fifth variable is the 'population density' of the neighbourhood. This variable indicates how many people are living within the neighbourhood. This is an important variable as research has found that the population density has a positive influence on the number of people that use cycling as a mode of transportation (Porter et al., 2019; Saelens et al., 2003). The influence of population density on the number of cyclists can be explained in two manners. First, according to Wang et al. (2019) population density affects the perceived level of safety, meaning a higher population density is related to higher sense of safety among residents. Which according to them is important as residents living in a neighbourhood that is perceived as safe are more likely to engage in physical outdoor activities such as cycling. Secondly, Nielsen & Skov-Petersen (2018) stated that a high population density generally also means a higher access to people, higher activity density and more traffic congestion. Which they say all effect the choice of cycling. Thus, population density is an important variable in determining the bikeability of a neighbourhood and therefore included. The variable will be including using the following formula:

$$\text{Population density}_{\text{score}} = \frac{\text{Population of the neighbourhood}}{\text{Area of the neighbourhood [m}^2\text{]}} \cdot 65$$

This formula calculates the number of people in a neighbourhood per 65 square meters of area. The reason for choosing 65 m² is that it is the average living space per person in the Netherlands (CBS, 2018). Choosing the average living square meters of the Netherlands does not only make sense because of the context of the research, but also internationally. Netherlands is the highest density country of the European union and of Europe when excluding the microstates (Monaco, Vatican City, Malta and San Marino) (WorldAtlas, n.d.). Thus, it can be assumed that the average living space per person of the Netherlands represents a high-density environment.

Using the 'population density' formula, neighbourhoods with a population density of 1 person per 65 m² will be rewarded with a score of 1. When the population density is less than 1 person per 65 m², the score will decrease. On the other hand, when the population density is more than 1 person per 65m², the population density score will increase. Theoretically this would mean that the population density score could increase indefinitely. Therefore, a limit is set at a score of 1, representing that there are living 1 person per 65 square meter in the neighbourhood. Which is the average living space per person in the Netherlands. It is assumed that an even higher population density would not further increase the benefits that population density has on the bikeability level.

3.8.6 Air quality

The sixth variable is the 'air quality' which indicates if the environment has clean air. This is an important variable as a bad air quality is not only bad for one's health, it can also influence people's willingness to cycle. Zhao et al. (2018) found that bad air quality can lead to a shift in transportation mode. When the air quality gets worse, the chance that people use the bicycle as transportation mode decreases. Therefore, it is an important variable for determining bikeability. Ito & Biljecki (2021) included the variable 'air quality' in their bikeability assessment tool and scored the variable based on how the air quality scored on the air quality index (AQI). The calculation of the variable 'air quality' score will follow their example. The AQI distinguishes six levels of air quality based on the $PM_{2.5}$ (World air quality project, n.d.). The six levels, their health implications and the scoring of each level can be found in table 3.8.1.

Table 3.8.1 Air quality index

AQI	Pollution levels	Health implications	Scores
0 - 50	Good	None.	2
51 - 100	Moderate	The air quality is acceptable, but people with unique sensitivity to air pollution should limit prolonged outdoor physical activity.	1
101 – 150	Unhealthy for sensitive groups	People part of sensitive groups (people with heart and lung diseases, elderly and children) should limit prolonged outdoor physical activity. However, the general public will not experience health implications.	0
151 – 200	Unhealthy	People part of sensitive groups should avoid prolonged outdoor activity. The general public should limit prolonged outdoor physical activity.	-1
201 – 300	Very unhealthy	People part of sensitive groups should all outdoor physical activity. The general public should limit outdoor physical activity.	-2
300 +	Hazardous	Everyone should avoid outdoor physical activity.	-2

(World air quality project, n.d.)

For the variable 'air quality', the AQI of the neighbourhood will be determined based on the measured yearly average AQI during either the morning or evening rush hours (7:00 till 9:00 or 16:00 till 18:00). Based on this measurement, the neighbourhood's pollution level can be classified and a score can be assigned. The scoring of the variable is based on the number of people that can safely cycle in a certain air quality. An AQI from 0-50 scores a 2, as everyone is able to safely cycle without health implications. An AQI from 51-100 scores a 1, as only a very unique group of people cannot cycle without health implications. An AQI from 101-150 scores a 0, as the general public is still able to cycle without health implication, however sensitive groups cannot. Meaning that the air quality is not good enough to provide the opportunity for additional groups, the sensitive groups, to participate in cycling. AQI scores higher than 151 have negative scores as they severely limit the groups of people that can cycling without health implications. An AQI from 151-200 has a score of -1, as sensitive groups should avoid cycling for long duration and the general public should limit it. An AQI from 201 and higher has a score of -2, as no one can cycle for a long period of time without having any health implications.

3.8.7 Green spaces

The seventh variable is 'green spaces' representing the urban greenery present within the neighbourhood. This is an important variable as research proves that the presence of urban greenery has a positive effect on people participating in active transportation and thus is important for bikeability (Wu et al., 2020; Fraser & Locker, 2010; Zhao et al. (2020); Krenn et al., 2015). Therefore, multiple existing bikeability evaluation tools include a variable representing some form of urban greenery. Porter et al. (2019), included a variable representing the number of parks within the area, as well as a variables representing tree coverages in the area. Lin & Wei (2018), as well as Krenn et al. (2015), included a variable representing the area of green space within a neighbourhood. The variable 'green space' will follow the example of Lin & Wei (2018) and Krenn et al. (2015), thus measuring the square meter of green space within the neighbourhood and scoring accordingly. The following formula will be used to determine the scoring of the variable:

$$\text{Green space}_{\text{score}} = \frac{\text{m}^2 \text{ of urban greenery}}{\text{number of dwelling in the neighbourhood } \cdot 40 \text{ m}^2}$$

The formula calculates if the present square meters of urban greenery in the neighbourhood is in line with the target square meters. First, it needs to be explained what is meant with urban greenery, as this term can be a bit unclear. Here, urban greenery is publicly accessible greenery which includes forest and parks but also smaller forms of greenery which does not serve a recreational purpose but enhances the visual experience of the neighbourhood. The total square meter of urban greenery is divided by the number of dwellings multiplied by 40 m^2. The 40 m^2 per dwelling is the target square meters of urban greenery and is based on a 'kengetal'. This 'kengetal' indicates that for Dutch cities 75m^2 of greenery per dwelling is expected (Bezemer & Visschedijk, 2003). However, this 75m^2 includes more types of greenery than the variable 'green spaces' intend to measure (graveyards, sport fields, agricultural fields, etc.). Therefore, this required 75m^2 can be lowered. Bezemer & Visschedijk (2003) present a diagram with the green type division of the 30 largest cities in the Netherlands. This diagram shows than 53% of the greenery matches with the measured greenery in the variable 'green spaces'. Thus, the 75m^2 is lowered with 47%, which is roughly 40m^2 per dwelling.

Using this formula, a 'green space' score can be calculated. The lowest possible score is 0, meaning that there is no urban greenery present. For the maximum score the limit is set to 1 and represent that the aim of 40m^2 of urban greenery per dwelling is achieved. As the aim is to have 40m^2 of urban greenery per dwelling, more square meters will not result in a higher score. Therefore, a maximum score of 1 is set.

3.8.8 Land-use mix

The eight variable is the 'land-use mix' which represent the diversity of land-use within the neighbourhood. This is an important variable as a diversity in land-use can lead to more people engaging in cycling (Saelens et al., 2003; Fraser et al., 2010; Zhao et al., 2020). The land use types, greenery, commercial and residential are found to have a positive impact on cycling frequency (Zhao et al., 2020; Saelens et al., 2003) and should therefore be included in the land-use diversity calculation.

Manaugh & Kreider (2013) argue that institutional, governmental and industrial land use should be combined with the commercial land use to represent a wider aspect of commercial and employment locations as these land use type all represent employment opportunities. Another of their reasons for combining these land-uses is that institutional, governmental and industrial land-use are highly specific categories and including them individually would most likely penalize most neighbourhoods as these land types are not commonly part of a neighbourhood. It seems reasonable to combine institutional, governmental and industrial land use with commercial land use, as they provide employment opportunities to which people can cycle. Based on their arguments it seems reasonable to included institutional, governmental, industrial and commercial land use in one category named commercial and employment.

The land-use mix score is calculated similarly to the land-use mix variable of Lin & Wei (2018), who use the entropy index. This index can be used to measure the diversity in land use within a neighbourhood using the following formula (Iceland, 2004):

$$\text{Land use mix}_{\text{score}} = \frac{-\sum_{\text{i}=1}^{\text{S}}(\text{D}_\text{i})\ln(\text{D}_\text{i})}{\ln(\text{s})}$$

Here 's' is the number of land use categories and D_i the area ratio of land use i. The formula calculates a score between 0 and 1, where 0 represent a lack of land use diversity and 1 represent a neighbourhood with a diverse land use. The land uses that will be included for the variable land use mix are: Residential, greenery, commercial and other. Here commercial represent institutional, governmental, retail and industrial land uses. The land use 'other' includes all other land uses. The reason for this is that it is assumed that the neighbourhood will mainly consist out of residential, greenery and commercial land uses. However, neighbourhood that have a good land use-mix will also have some other land uses, however this will not always be the same type of land use for each neighbourhood. Therefore, it is chosen to use the 'other' land use.

3.8.9 Road safety

The ninth variable is the 'road safety' which represent the number of traffic accidents occurring within the neighbourhood. This is an important variable as the perception of road safety can influence the bicycle use. Research has shown that concerns regarding the road safety and a heightened risk of being involved in an accident decreases the likelihood of cycling (Piatkowski & Marshall, 2015; Heinen et al., 2010). When less of bicyclists are involved in a serious traffic accident, the bicycle use increases (Rietveld & Daniel, 2004). Therefore, it is important to considered the number of traffic accidents occurring within a neighbourhood. For the calculation of the road safety score, the number of (reported) road accidents yearly within in a neighbourhood will be divided by the number of weeks in a year. The number of (reported) road accidents also included accidents that do not involve bicyclists. The reason for this is that these accidents can also contribute to a lowered perception of road safety and can potentially decrease the likelihood of cycling. The following formula will be used:

$$\text{Road safety}_{\text{score}} = -\frac{\text{Number of road accidents}}{52}$$

The decision to use weeks is made because if road accidents occur on a weekly basis there is a high chance of people witnessing or hearing about a road accident. This will most likely negatively influence their perception regarding the road safety and thus reduce the likelihood of cycling. When no accidents occur, the score will be 0 meaning that there are no road accidents that can contribute to a negative perception of road safety. When 52 road accidents occur, the score will be -1 meaning that there are road accidents on a weekly basis. The maximum score of the road safety calculation is -2, indicating that two road accidents happen on a weekly basis. It is assumed that in this case the number of road accidents is so high, that more accidents will not further decrease the perception of road safety.

3.9 Calculation of the environment category score

The 'environment' category score is calculated based on the variables discussed in section 3.8. Table 3.9.1 shows an overview of all the variables of the 'environment' category and their measurements.

Table. 3.9.1 Variables and measurements to determine the environment category score

Variables	**Measurement type**	**Measurement**	**Scoring**	**Weights**
Bicycle infrastructure ratio	Calculation	$\frac{\text{Total length of bicycle path}}{\text{Total length of roadway}}$	Range = 0 – 2	2
Bicycle way density	Calculation	$\frac{\text{Total length of bicycle path [m]}}{\text{Area [m}^2\text{]}} \cdot 100$	Range = 0 - 1	2
Intersection density	Calculation	$\frac{\text{Number of intersections}}{\text{Area [ha]}}$	Range = -1 – 0	1
Bicycle parking facility ratio	Calculation	$\frac{\text{Area served by BPFs [m}^2\text{]}}{\text{Area [m}^2\text{]}}$	Range = 0 - 1	1
Population density	Calculation	$\frac{\text{Population of the area}}{\text{Area [m}^2\text{]}} \cdot 65$	Range = 0 - 1	1
Air quality	Category	[1] = 0-50 [2] = 51 – 100 [3] = 101 – 150 [4] = 151 – 200 [5] = 201 +	[1] = 2 [2] = 1 [3] = 0 [4] = -1 [5] = -2	1
Green space	Calculation	$\frac{\text{m}^2\text{ of urban greenery}}{\text{Number of dwellings in the area} \cdot 40\text{ m}^2}$	Range = 0 -1	1
Land use mix	Calculation	$\frac{-\sum_{i=1}^{s}(D_i)\ln(D_i)}{\ln(s)}$ s = number of land use categories D_i = the area ratio of land use i	Range = 0 -1	1
Road safety	Calculation	$\frac{\text{Number of road accidents}}{52}$	Range = -2 - 0	1

As can be seen in table 3.8.1, the variable 'bicycle infrastructure ratio' and 'bicycle way density' have a weight of 2, indicating that they are more important for the environment score than the other variables. The reason for the weights of 'bicycle infrastructure ratio' and 'bicycle way density' is that these measure variables that are absolutely necessary for bicycling and are therefore deemed more important. The other variables are all weighted equally, meaning that those variables are equally important as one another.

The maximum score of the 'environment' category is 12. Similar to all other category scores the 'environment' category score will also be adjusted to be on a scale from 0 to 10. This adjustment will make it possible to compare the 'environment' category score with the other category scores. The following formula is used to determine the adjusted environment score:

$$\text{Environment score}_{\text{adjusted}}(\text{i}) = \frac{\text{Total score on the variables}}{12} \cdot 10$$

In this formula 'i' represent the neighbourhood for which the calculation takes place. Using this formula results in an environment score for neighbourhood (i) on a scale from 0 to 10, with 10 being the highest score and indicating that the environment of the neighbourhood provides a safe and convenient atmosphere for bicyclists. The environment score will be used to determine the overall bikeability score of the neighbourhood in section 3.13.

3.10 Accessibility

Accessibility is another key aspect of bicycle travel, as bicyclists prefer shorter routes and low travel times (Broach et al., 2012; Caulfield et al., 2012; Saelens, 2003). In this report, accessibility means that the residents of a neighbourhood have good access to numerous destinations when using the bicycle. This is an important aspect of bikeability in the case the infrastructure of a neighbourhood is highly suitable for bicycle travel, but if there are no destinations to travel to by bicycle, the infrastructure is not actually usable (Lowry et al., 2012). Even though it is such an important aspect of bikeability, it is a commonly overlooked or excluded aspect within existing bikeability assessment tools. A potential reason for this could be how some bikeability assessment tools define bikeability. For example, Nielsen & Skov-Petersen (2018) describe bikeability as "the ability of a person to bike or the ability of the urban landscape to be biked". Using this definition of bikeability, there is not direct indication that accessibility is a category that should be included in a bikeability assessment tool.

Grigore et al. (2019) included the number of destinations within the area in their bikeability assessment tool, but only used work places as destinations. McNeil (2011) has a more detailed approach towards destinations as his tool is mainly focused on by bicycle reachable destinations within the neighbourhood. His tool awards points for the presence of numerous different types of destinations. However, his tool lacks in including other categories of bikeability.

As existing bikeability assessment tools often overlook or exclusively focus on accessibility, a new developed tool should focus on including accessibility within the assessment of the bikeability level of an area. Therefore, an accessibility score for the neighbourhood will be calculated based on multiple variables. The category 'accessibility' will contain the following attributes:

1. Distance to day-care
2. Distance to elementary school
3. Distance to secondary education
4. Distance to supermarket
5. Distance to city centre
6. Distance to shopping centre
7. Distance to train station
8. Distance to greenery
9. Distance to hospital
10. Distance to general practice
11. Distance to pub
12. Distance to restaurant
13. Distance to library
14. Different destination types
15. Destination density
16. Transit facilities

The variables determining the accessibility score will now be discussed in further detail.

3.10.1 Distance towards destinations

Most of the variables of accessibility consists of the average distance towards destinations, as this implies the accessibility of these destinations. North-American focused bikeability tools often calculate the accessibility based on the distance between the residential and the commerce or working area. However, in the Dutch context, such destinations are much more scattered throughout the neighbourhood. Due to this there is no clear origin and destination point for common destinations. Therefore, the average distance to certain destination will be considered. McNeil (2011) considered a large range of different destination types that are important to be easily accessible. From his list the most important destinations and applicable destinations for the Dutch context were chosen to be used as variables for the calculation of the accessibility score. Furthermore, the destinations 'city centre', 'shopping centre', 'hospital' and 'general practice' were added as important location to be accessible by bicycle.

The scores of the all these individual 'distance to …' variables will be calculated in the same manner. The maximum by bicycle reachable distance is seen as roughly 5 kilometres (McNeil, 2011). Destinations with an average distance lower than 5 kilometres gain a positive score, while destinations located further away than 5 kilometres gain a negative score. The following formula will be used:

$$\text{Distance to location}_{\text{score}} = \frac{5 - \text{average distance towards location}_{\text{n}}}{5}$$

Where n is the destination type. This formula assigns a higher score when the destination has a lower average distance, with a maximum of 1. But it also gives out a more negative score when the average distance is higher than the maximum by bicycle reachable distance of 5 km.

3.10.2 Different destination types

The next variable of accessibility is the number of different destination types within the neighbourhood. This variable refers to the diversity of destination within a neighbourhood. This is an important inclusion as a diverse number of destinations makes a neighbourhood better travelable without a car (Saghapour et al., 2017; McNeil, 2011) and can therefore promote bicycle use. Based on McNeil's (2011) list of destination types 13 mayor destination categories are identified. Table 3.6.1 shows the destination categories and examples of destinations that fall within those categories.

Table 3.10.1 Destination categories

Destination categories	**Examples of destinations**
Transport	*Bus stop, train station, metro stop, etc.*
Education	*Day-care, elementary school, high school, university, etc.*
Grocery	*Supermarket, market, specialty store, etc.*
Catering services	*Pubs, restaurants, etc.*
Religious organizations	*Church, synagogue, mosque, etc.*
Sports	*Gym, sport club, sport fields, etc.*
Greenery	*Parks, ponds, etc.*
Services	*Beauty salon, barber, bank, mail service, etc.*
Library	*Public library*
Stores	*Other stores than grocery*
Entertainment	*(Movie) theatre, bowling alley, etc.*
Offices	*Office buildings*
Healthcare	*Hospital, general practice, dentist, etc.*

The calculation of the 'different destination types' score is based on the number of destination categories present within the neighbourhood. For these variables, it does not matter how many destinations of a category are present, it only matters that the category is present. The following formula will be used:

$$\text{Destination type}_{\text{score}} = \frac{\text{Number of destination categories present in the neighbourhood}}{13}$$

Using this formula, a maximum score of 1 will be assigned when all the destination categories are present and the score will decrease when a destination category is not present.

3.10.3 destination density

Another variable of accessibility is the 'destination density', which indicate if there is a higher number of destinations within a neighbourhood, disregarding the typing of the destinations. This is an important variable as research has shown that a high density of commercial facilities has a positive effect on bicycle use and the bikeability level of the neighbourhood (Chen et al., 2017; McNeill, 2011) and an increase of activity density results in more bicycle ridership (Cui et al., 2014). McNeill (2011), determined the destination density by calculating the number of destinations per square miles within a neighbourhood. This calculation method seems reasonable and will therefore also be used in the newly developed bikeability assessment tool. The destination density will be determined by counting all the destinations of each destination type mentioned in table 3.6.1, excluding the 'transport' category, within the neighbourhood. This number of destinations is then divided by the area of the neighbourhood in hectare. The following formula will be used to do so:

$$\text{Destination density}_{\text{score}} = \frac{\text{Number of destinations}}{\text{Area [ha]}}$$

This formula will assign a higher score to neighbourhoods when there are more destinations present. The maximum of the destination density score will be set to 1, which means that there is 1 destination per hectare. It is assumed that 1 destination per hectare would enough for a neighbourhood to be considered of high density. Especially considering that an average neighbourhood will mainly consist out of dwellings.

3.10.4 Transit facilities

The last variable of accessibility is the number of transit facilities, which indicate how many bus stops, metro stops, tram stops and train stations there are in a neighbourhood. These destination types gain additional focus as they enable inhabitants to combine bicycle travel with public transport to make longer distance trips (Jonkeren & Kager, 2021), which promotes bicycle use (Cui et al., 2014). More transit facilities in an area means that the residents have more opportunity to do so. Therefore, it is important to look at the presence of public transport stops in the neighbourhoods. Lin & Wei (2018) do this by looking at the area served by public transport stops and dived this by the total square meter of area. This method will also be used to calculated the 'transit facility' score. According to Tirachini (2014), a good spacing between bus stops is 600 meters in the suburbs and 400 meters in the central business district. Based on his findings, it is assumed that one public transport stop serves the area within a 250 meters ranges of the stop. To calculate the 'transit facility' score, the total area served by public transport stops is divided by the total area of the neighbourhood. This leads to the following formula.

$$\text{Transit facility}_{\text{score}} = \frac{\text{Area of the neighbourhood served by public transport [m}^2\text{]}}{\text{Area [m}^2\text{]}}$$

This formula rewards a higher score when a more area of the neighbourhood is served by public transport. When the ‘transit facility’ score is 0 it indicates that none of the neighbourhood is served by public transport and when the score is 1, all of the neighbourhood is served by public transport.

3.11 Calculation of the accessibility category score

The ‘accessibility’ category score is calculated based on the variables discussed in section 3.10. Table 3.11.1 shows an overview of all the variables of the ‘accessibility’ category and their measurements.

Table. 3.11.1 Variables and measurements to determine the accessibility category score

Variables	Measurement type	Measurement	Scoring	Weight
Distance to day-care	Calculation	$\frac{5 - \text{average distance to location [km]}}{5}$	Range = -1 to 1	1
Distance to elementary school	Calculation			1
Distance to secondary school	Calculation			1
Distance to supermarket	Calculation			1
Distance to city centre	Calculation			1
Distance to shopping centre	Calculation			1
Distance to train station	Calculation			1
Distance to greenery	Calculation			1
Distance to hospital	Calculation			1
Distance to general practice	Calculation			1
Distance to pub	Calculation			1
Distance to restaurant	Calculation			1
Distance to library	Calculation			1
Different destination types	Calculation	$\frac{\text{Number of destination categories}}{\text{Total number of destination categories}}$	Range = 0 - 1	1
Destination density	Calculation	$\frac{\text{Number of destinations}}{\text{Area [ha]}}$	Range = 0 -1	1
Transit facilities	Calculation	$\frac{\text{Area served by public transport [m}^2\text{]}}{\text{Area [m}^2\text{]}}$	Range = 0 -1	1

As can be seen in table 3.11.1, all variables are weighted equally, indicating that all variables are seen as equally important for the determination of the ‘accessibility’ category score. The maximum score of the ‘accessibility’ category is 16. Similar to all other category score the score will be adjusted to be on a scale of 0 to 10, as it will make it possible to compare the ‘accessibility’ category score with the other category scores. The following formula is used to determine the adjusted accessibility score:

$$\text{Accessibility score}_{\text{adjusted}}(\text{i}) = \frac{\text{Total score on the variables}}{16} \cdot 10$$

In this formula ‘i’ represent the neighbourhood for which the calculation takes place. Using this formula results in an accessibility score for neighbourhood (i) on a scale from 0 to 10, with 10 being the highest score and indicating that the accessibility of the neighbourhood towards a diverse number of destinations by bicycle is excellent. The accessibility score will be used to determine the overall bikeability score of the neighbourhood in section 3.1

3.12 List of required data

After discussing each category and the variables within those categories in detail, it is possible to create a list of data needed for the variable to be able to calculate each category score. These category scores need to be calculated in order to determine the bikeability level of a neighbourhood. Table 3.12.1 gives an overview of all the variables within each category and the necessary data for each variable.

The data listed in table 3.12.1 needs to be obtained from one or multiple data bases. The main data bases that will be used for obtaining this data will be OpenStreetMap, which is an open-source geographic database (OpenStreetMap, n.d.). This data base can be accessed in the QGIS software by using the QuickOSM plugin. The plugin enables the user to identified physical features by using tags that describe certain geographical data. A tag consists out of a 'key' and a 'value'. The key is often a broad aspect and the value a specification. An example of a tag is 'shop=bakery' in which shop is the key and bakery is the value. The tag 'shop=bakery' will identify all bakeries in the chosen area and the attribute data connected to those bakeries.

The OpenStreetMap data base is made by volunteers and can therefore sometimes be lacking data. The first step in obtaining the data in table 3.12.1 should be trying to obtain the data with OpenStreetMap. However, if the necessary data is missing in the OpenStreetMap data base, other data bases should be used to complete the data.

The next data bases to look for the necessary data would be CBS database, the open data base of the municipality of the neighbourhood or any publicly available data bases. These databases often provide a wide range of information that could complete the required data.

If the data is also missing in other publicly available data bases, it can be obtained through visual inspection (VI). VI is an inspection of the features made by looking at the features. The individual that performs the visual inspection must be have enough knowledge about to features to know what to look for and to correctly assess those features. A VI can be performed on location or by using Google maps. Visual inspection should only be used if there are no other options left to collect the necessary data. The reason for this is that visual inspection can be less accurate or biased as it is based on the observation of a single person. For example, if the VI is used to assess data measured as 'good' or 'bad', the results can be influenced by the subjectivity of the inspector and can therefore be biased. Furthermore, measurements made with google maps can be somewhat inaccurate and difficult to measure consistently. However, these inaccuracies can be small and VI does provides a method to measure what is intended. On the other side, there are also features that can be easily measured accurately with VI. For example, the type of a junction can be accurately measured with VI. Thus, as long as VI is used for features that can be measured accurately and as intended, the validity of the data acquired through VI can be seen as decent.

Table 3.12.1 Variables and necessary data for calculation of the category scores

Categories	Variables	Sections	Data
Bicycle path infrastructure	Path type	3.2.1	Path type of each path
	Path width	3.2.2	Network type of each path
			Car lane width of each unseparated path type [cm]
			Bicycle intensity of each separated bicycle path [bicyclists per hour]
			Car intensity of each unseparated path type [cars per 24 hours]
			Path width [cm]
	Car intensity	3.2.3	Car intensity of each unseparated path type [cars per 24 hours]
	Separation type	3.2.4	Separation types [m]
			Path length [m]
	Roadside type	3.2.5	Roadside types [m]
			Path length [m]
	Spee limit	3.2.6	Speed limit of the street [km/h]
	Presence of a centre line	3.2.7	Presence of a centre on two-way bicycle paths
	Presence of street lights	3.2.8	Street light locations
			Path length [m]
	Presence of obstacles	3.2.9	Bicycle obstacles
	Pavement type	3.2.10	Pavement type
	Pavement quality	3.2.11	Pavement conditions
	Slopes	3.2.12	Bridges
			Tunnels
	Land use	3.2.13	Green land uses
			Aquatic land uses
			Retail land use
			Office land use
			Industrial land uses
			Path length [m]
	One-way street	3.2.14	Number of motorized vehicle directions
	Speed limiting objects	3.2.15	Speed limiting objects
Junction infrastructure	Junction type	3.4.1	All junction and their type

	Bicycle infrastructure at the junction	3.4.2	Bicycle infrastructure near junctions
	Speed limiting objects	3.4.3	Speed limiting objects
	Presence of median island	3.4.4	Median islands
	Presence of bicycle traffic lights	3.4.5	Bicycle traffic lights
	Presence of biking box	3.4.6	Bicycle boxes
Bicycle parking facilities	Type of BPF	3.6.1	All bicycle parking facilities and their type
	Security measure	3.6.2	Security measures at the BPFs
	Parking costs	3.6.3	Cost of the BPFs
	Connection to the bicycle infrastructure	3.6.4	Bicycle infrastructure in the neighbourhood
			Distance from the entrance of the BPF to the bicycle infrastructure [m]
	Destinations	3.6.5	Retail destinations
			Commercial destinations
			Recreational destinations
			Service destinations
			Educational destinations
	Distance to transit	3.6.6	Transit destinations
	Parking ratio	3.6.7	Area of the BPF [m²]
			Number of bicycle parking spots of the BPF
Environment	Bicycle infrastructure ratio	3.8.1	Total amount of bicycle infrastructure [m]
			Total amount of roadways [m]
	Bicycle way density	3.8.2	Total amount of bicycle infrastructure
			Area of the neighbourhood [m²]
	Intersection density	3.8.3	Number of intersections
			Area of the neighbourhood [ha]
	BPF ratio	3.8.4	Area served by BPFs [m²]
			Area of the neighbourhood [m²]
	Population density	3.8.5	Population of the neighbourhood
			Area of the neighbourhood [m²]
	Air quality	3.8.6	Air quality [$PM_{2.5}$]
	Green space	3.8.7	Area of urban green [m²]
			Number of dwellings

	Land use mix	3.8.8	Land use map indicating the land use of the city
			Area per land use [m²]
	Road safety	3.8.9	Number of road accidents per year
Accessibility	Distance towards day-care	3.10.1	Average distance towards day-care [km]
	Distance towards elementary school	3.10.1	Average distance towards elementary school [km]
	Distance towards secondary education	3.10.1	Average distance towards secondary education [km]
	Distance towards supermarket	3.10.1	Average distance towards supermarket [km]
	Distance towards city centre	3.10.1	Average distance towards city centre [km]
	Distance towards shopping centre	3.10.1	Average distance towards shopping centre [km]
	Distance towards train station	3.10.1	Average distance towards train station [km]
	Distance towards greenery	3.10.1	Average distance towards greenery [km]
	Distance towards hospital	3.10.1	Average distance towards hospital [km]
	Distance towards general practice	3.10.1	Average distance towards general practice [km]
	Distance towards pub	3.10.1	Average distance towards pub [km]
	Distance towards restaurant	3.10.1	Average distance towards restaurant [km]
	Distance towards library	3.10.1	Average distance towards library [km]
	Different destination types	3.10.2	Transport destinations
			Educational destinations
			Grocery destinations
			Catering service destinations
			Religious destinations
			Sport destinations
			Greenery destinations
			Service destinations
			Library
			Stores
			Entertainment destinations
			Office destinations
			Healthcare destinations
	Destination density	3.10.3	Number of transport destinations
			Number of educational destinations
			Number of grocery destinations

			Number of catering service destinations
			Number of religious destinations
			Number of sport destinations
			Number of greenery destinations
			Number of service destinations
			Number of libraries
			Number of stores
			Number of entertainment destinations
			Number of office destinations
			Number of healthcare destinations
			Area [ha]
	Transit destinations	3.10.4	Area served by public transport [m²]
			Area [m²]

3.13 Bikeability level calculation

The final step of the tool consists of the calculation of the overall bikeability level of the neighbourhood based on the previous determined category scores. Each of the categories has a score ranging from 0 to 10, where 0 indicates that the category is performing as low as possible and a 10 as high as possible. A simple way to calculate the bikeability score would be to look at the average scores of the 5 categories and make this the overall bikeability score. However, this would mean that the importance of each individual category would be neglected. Therefore, each category has its own weight representing the importance of the category. A higher weight indicates that the category is seen as more importance. Table 3.13 shows all the categories that are used to calculate the bikeability level and their corresponding weights.

Table 3.13. Categories and their weights for determining the bikeability level

Categories	**Measurement**	**Scoring**	**Weights**
Bicycle infrastructure	*See table 3.3.1*	Range = 0 - 10	3
Junction infrastructure	*See table 3.5.1*	Range = 0 - 10	4
Bicycle parking facilities	*See table 3.7.1*	Range = 0 - 10	1
Environment	*See table 3.9.1*	Range = 0 - 10	2
Accessibility	*See table 3.11.1*	Range = 0 - 10	2

From the 5 categories of bikeability, BPFs will have the lowest weight, namely a weight of 1. The reason that the category BPFs has the lowest weight is that although it is important to bicycle use and thus the bikeability level, it is arguable the least important of the five categories. Even though BPFs provide a safe place to park one's bicycle, bicycles can in reality be parked almost everywhere. This is also something what many bicyclists do, as the often park their bicycle as closes as possible to their destination even if this means parking in a non-designated bicycle parking space. Therefore, BPFs have a weight of 1, which does not mean that BPFs are not important for bicycle use, but it is considered the least important of the 5 identified categories.

Junction and bicycle infrastructure will have the two highest weight of the five categories, namely a weight of 4 and 3, respectively. The reason that these two categories have the highest weights is that they both provide important infrastructure for cycling, the convenience of cycling and the safety of the cyclists. Cycling accidents can occur due to poor quality of the infrastructure, therefore these categories are of high importance. The difference in weight between the 'junction infrastructure' and 'bicycle infrastructure' is based on the fact that junctions are the points where bicyclists interact with motorized vehicles. With the large difference in speed and weight between cars and cyclists, a collision can be disastrous. Junctions are actual the most dangerous points for cyclists as 54% of cyclists traffic fatalities happen at a junction (SWOV, 2021). Therefore, the weight of the 'junction infrastructure' is set to be a bit higher than the weight of 'bicycle infrastructure'. Nevertheless, both infrastructure categories are of high importance and that is why they both have a high weight.

Lastly, the categories environment and accessibility will both have a weight of 2. For environment the reason for the weight is that it is important to provide an atmosphere which encourages cycling, however it is less important than creating a safe bicycling network. Therefore, it is weighted less than the bicycle path infrastructure and junction categories. For accessibility the reason for the weight is that although accessibility to locations is important, not all access location need to be present for within a neighbourhood. Furthermore, short distances towards location are important, but not more or equally important as getting there safely. Therefore, the weight of 2 is assigned to the category accessibility.

Now that the weights of each category are established, the final bikeability level can calculated. The final bikeability score is the average of the categories while taking into account their importance based on the weights. To calculate the bikeability level of a neighbourhood the following formula will be use:

$$\text{Bikeability level (i)} = \frac{\sum \text{Category}_\text{n} \cdot \text{Weight}_\text{n}}{\sum_\text{n} \text{Weight}}$$

In this formula 'i' represent the neighbourhood for which the calculation takes place and 'n' represent the different categories. Using this formula results in a bikeability level for neighbourhood (i) on a scale from 0 to 10, where 10 indicates that the neighbourhood has the highest possible bikeability level.

3.14 Relevance of the tool

It is important that the newly developed bikeability assessment tool provides new possibilities in terms of assessing the bikeability level of a neighbourhood and providing insight in how to improve the bikeability level. Looking at the newly developed tool, it can be concluded that the tool differentiate itself from existing tools and with those differentiations provides new possibilities of assessing the bikeability level and providing insight in how to improve the bikeability level. There are three main differentiations between the newly developed bikeability assessment tool and the existing tools.

The first differentiation is that the newly developed bikeability assessment tool is easily accessible. No extensive knowledge is needed about specific calculation and models. Most calculation used in the tool are easy to perform and include comprehensible elements. Furthermore, scores are often assigned based on categories, which is an easy-to-follow process. This makes the tool easily accessible and enables a wider group of organisations or individuals to make use of the tool.

The second differentiation is that the newly developed bikeability assessment tool is specifically focused on the Dutch context were most existing bikeability tools are either focused on North-America or general world-wide use. This differentiation is important, because the Dutch bicycle environment is vastly different than most other countries in the world. Due to this, different variables and considerations need to be included. An example of this is the inclusion of roundabouts, which was not mentioned once in the reviewed literature but is a common junction type in the Netherlands.

The third differentiation is the inclusion of multiple categories. Bicycle infrastructure is a commonly used category in route choice models and bikeability assessment tools, however junctions and bicycle parking facility are not so common. The newly developed bikeability assessment tool provides a detailed calculation for the score of both of these categories. Providing better insight in how to improve the bikeability of an area without only focusing on the bicycle infrastructure.

4. Case study Eindhoven

In this chapter a case study will be conducted to illustrated the functioning of the newly developed bikeability assessment tool. During this cases study it is possible that the developed bikeability assessment tool will be changed for practicality to illustrated the functioning. This happens when the necessary data for a variable is unobtainable. Missing data can result in either changes in the variable so that the variable can still be included or in worst case scenario, complete removal of the variable in the 'practical' tool used during the case study. However, the variables will only be adapted or removed for the practicality of illustrating the tool. Thus, the theoretical bikeability assessment tool is changed in a practical bikeability assessment tool. However, when the required data for these variables becomes available, it would be advised to once again include these variables. Meaning that the theoretical tool is preferred over the practical tool.

First, in section 4.1 the chosen neighbourhoods for this case study are explained and discussed. Next, in section 4.2 to 4.6 the functioning of the tool will be illustrated category by category. Then, in section 4.7 the overall bikeability level of the neighbourhoods will be discussed. Lastly, in section 4.8 the chapter ends with a conclusion regarding the overall functioning of the tool.

4.1 The neighbourhoods

To illustrated the functioning of the bikeability assessment tool, a case study will be performed. The city chosen for the case study is Eindhoven, which is the 5th largest city in the Netherlands (CBS, 2021). Three neighbourhoods located in the city of Eindhoven are chosen to illustrated the functioning of the tool. The characteristics of the neighbourhoods will be discussed in section 4.1.1, 4.1.2 and 4.1.3, to gain a good understanding of what kind of neighbourhoods they are. This is important because based on the characteristics of the neighbourhoods, an expectation regarding the bikeability level of the neighbourhood can be formed. It is also important that these three neighbourhoods are different in character to be able to expect different results from the assessment and properly evaluated if the functioning of the tool is correct.

The chosen neighbourhoods are Bergen, Blixembosch-Oost and Hurk. Figure 4.1.1 indicates the locations of the neighbourhoods within Eindhoven. Each neighbourhood will now be discussed in more detail. The information regarding each neighbourhood is obtained from the 'Eindhoven in Cijfers' data base, which is an open data base from the municipality of Eindhoven with statistics of each neighbourhood on numerous topics (Eindhoven in Cijfers, 2021).

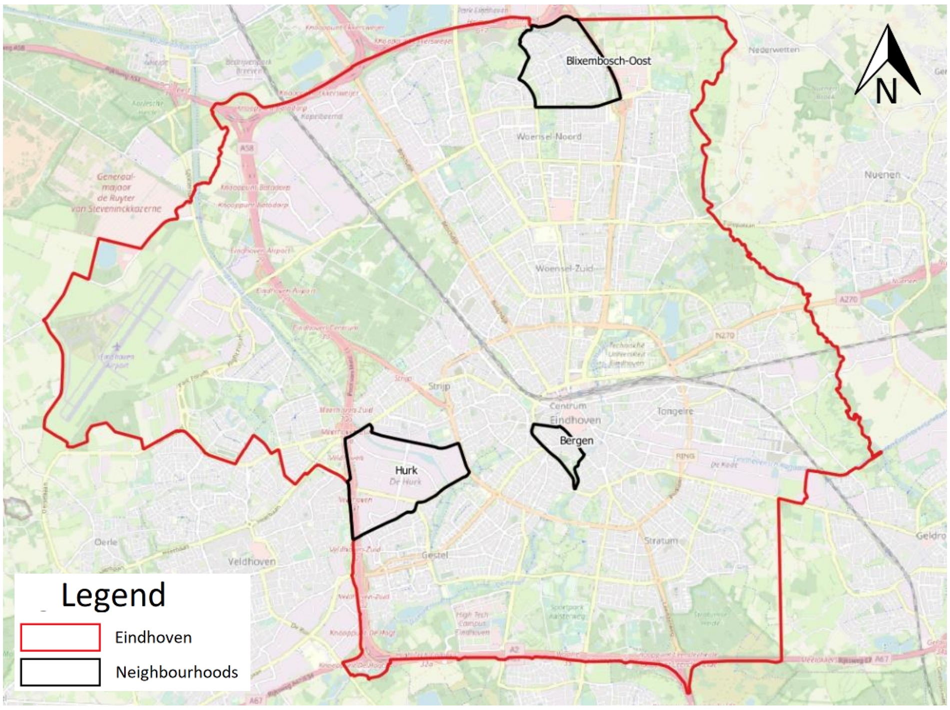


Figure 4.1.1 The case study neighbourhoods in Eindhoven

4.1.1 Bergen

The neighbourhood Bergen is a combination of a residential and commercial neighbourhood located near the city centre of Eindhoven. The neighbourhood is described as 'very strongly urban', indicating that there are more than 2,500 addresses per km². Furthermore, Bergen has a total of 2,775 inhabitants. Bergen has a total of 1,875 household of which 66% are one-person households. This is 18% higher than the percentage of one-person households in the total of Eindhoven. The percentage of households with children is 10% in Bergen and 26% in the total of Eindhoven. Furthermore, most dwellings in Bergen are rental dwellings (63%), which is a bit higher than in the total of Eindhoven (54%).

The neighbourhood has a total of 72 retail premises, making it the third highest neighbourhood in regards to retail premises. The only neighbourhoods with more retail premises are the city centre and the neighbourhood 'winkelcentrum' which mainly consists out of a mall (the translation of the word winkelcentrum).

Figure 4.1.2 shows the age of the residents in the neighbourhood. The table shows that most residents are young adults (20 – 39 years old) and there are not that many children (< 20 years old) living in the neighbourhood in comparison to other age groups.

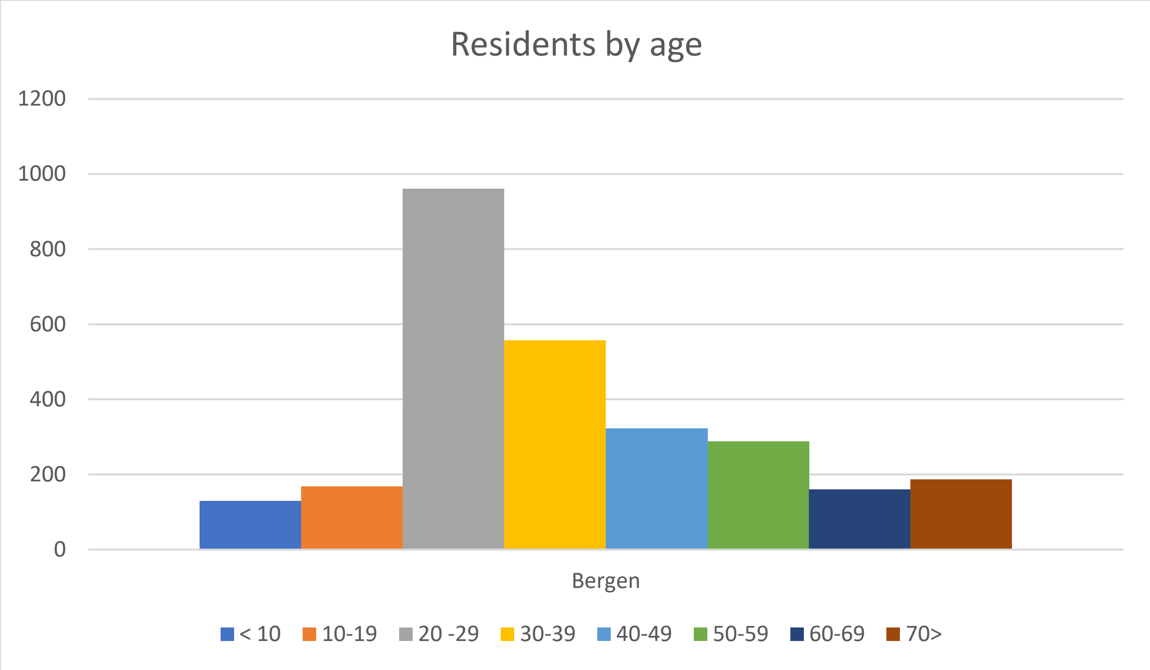


Figure 4.1.2 Residents in Bergen by age (Eindhoven in Cijfers, 2021).

Figure 4.1.3, 4.1.4 and 4.1.5 are street view imageries of the neighbourhood. These street view imageries are used to give an indication on how the streets in the neighbourhood look like. Figure 4.1.3 is an image of the street 'Kleine Berg', which is a street with many retail and catering buildings. Figure 4.1.4 shows the street 'Willemstraat', which is a large street on the periphery of the neighbourhood. Lastly, figure 4.1.5 shows the 'Sint Catharinastraat', which is gives an insight in the look of the average residential street of the neighbourhood.

Figure: 4.1.3 Kleine Berg (Google Maps, 2021)

Figure: 4.1.4 Willemstraat (Google Maps, 2021)


Figure: 4.1.5 Sint Catharinastraat (Google Maps, 2021)

4.1.2 Blixembosch-Oost

The neighbourhood Blixembosch-Oost is a residential neighbourhood located at the most northern point of Eindhoven. The neighbourhood is described as 'moderately urban', indicating that there are between 1,000 and 1,500 addresses per km². Blixembosch-Oost has a total of 7,222 inhabitants, which is the most inhabitants any neighbourhood has in Eindhoven.

Blixembosch-Oost has a total of 2,695 household, of which 53% are family households with children and 27% are family households without children. The number of family households with children is more than twice as high as the percentage of family households in Eindhoven. Meaning that Blixembosch-Oost can be described as a neighbourhood mainly focused on families with children. Most of the dwellings in Blixembosch-Oost are owner-occupied houses, namely 87%, and only 13% are rental dwellings. Also interesting is the construction year of the dwellings. 98% of the dwellings are built after

1970 and 23% of the dwellings are even built after 2000, making Blixembosch-Oost a relatively new neighbourhood.

Figure 4.1.6 shows the age of the residents in Blixembosch-Oost. Unsurprisingly, there are many children (age 0 to 19) and older adults (age 40-59). Which is in line with the high percentage of family household in the neighbourhood.

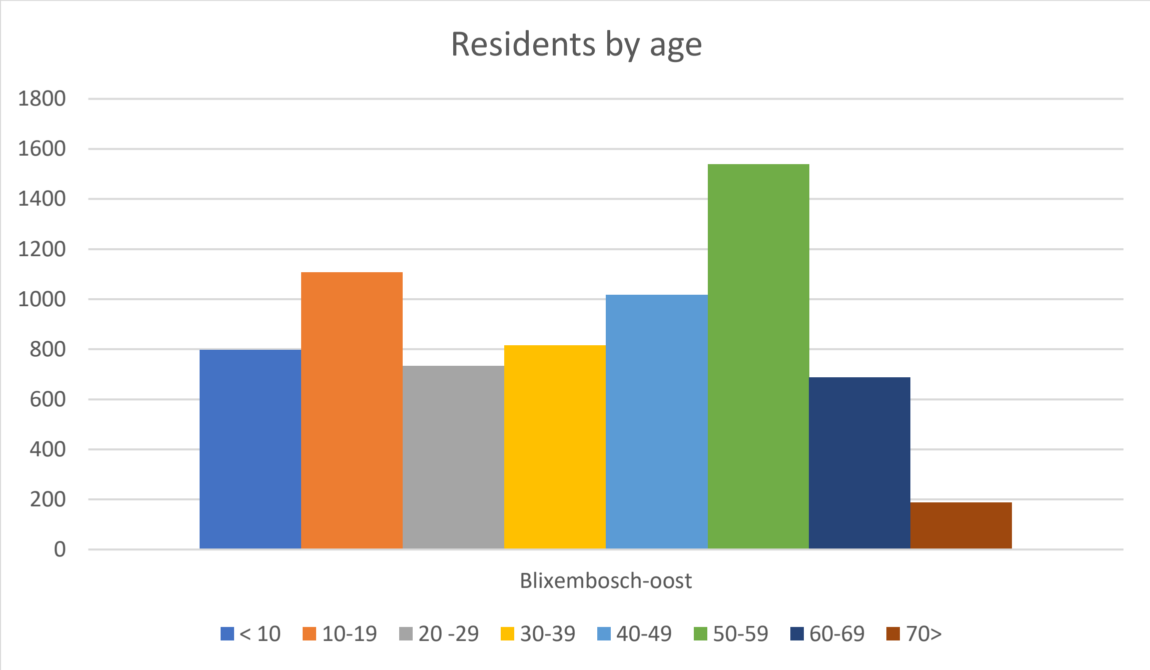


Figure 4.1.6 Residents in Blixembosch-Oost by age (Eindhoven in Cijfers, 2021).

Figure 4.1.7., 4.1.8 and 4.1.9 are street view imageries of the neighbourhood. These street view imageries are used to give an indication of the living environment in Blixembosch-Oost. Figure 4.1.7 is an image of the street 'Luisa Miller', which is part of a group of adjacent streets going across the neighbourhood. Figure 4.1.8 is an image of the street 'Buitendreef', which is a large street on the north-east periphery of the neighbourhood. Lastly, figure 4.1.9 shows the street 'Opera', which is one of the main distribution streets in the northern part of the neighbourhood.

Figure: 4.1.7 Luisa Miller (Google Maps, 2021)

Figure: 4.1.8 Buitendreef (Google Maps, 2021)

Figure: 4.1.9 Opera (Google Maps, 2021)

4.1.3 Hurk

The neighbourhood Hurk is an industrial neighbourhood located on the west side of Eindhoven and is connected to the ring-road of the city. This makes the neighbourhood well-accessible by car. Hurk is also described as a 'moderately urban' neighbourhood, however little of those addresses are from residents of the neighbourhood. Hurk only has a total of 65 inhabitants and a total of 40 households. However, the low number of inhabitants and households was to be expected from an industrial neighbourhood.

Hurk has a total of 648 company branches and 29 retail premisses. The retail premisses a total sales floor area of 32,711, making Hurk the 3th neighbourhood in sales floor area in Eindhoven. Furthermore, Hurk has a total of 13,155 people working in the neighbourhood. Which is the highest number of people working in a neighbourhood in Eindhoven.

Figure 4.1.10, 4.1.11 and 4.1.12 show street view imageries of the neighbourhood. Figure 4.1.10 shows the street 'Meerenakkerweg' which is one of the arterial roads in the neighbourhood. Figure 4.1.11 shows the street 'Hurkse straat' which is a street going through the office / industrial park of the neighbourhood. Lastly, figure 4.1.12 shows the street 'Beatrixkade' which is a road next to the canal in the neighbourhood.

Figure: 4.1.10 Meerenakkerweg (Google Maps, 2021)

Figure: 4.1.11 Hurksestraat (Google Maps, 2021)

Figure: 4.1.12 Beatrixkade (Google Maps, 2021)

4.1.4 Expectations from the neighbourhoods

Based on the statistics and the street view imageries, expectations can be made about the how each neighbourhood will score on the bikeability assessment tool. For Bergen, it is expected that due to the very strong urban layout and the high number of retail premisses, a lot of people will be present in the neighbourhood. For the people living inside the neighbourhood, it is expected that they would travel often by bicycle as there are a lot of amenities in short distance. Therefore, it is expected that there will be sufficient bicycle infrastructure present and that Bergen will have a good score on the 'accessibility' category. However, the very strong urban layout also creates some negative expectations. For one, due to the strong urban layout it may be possible that there is not enough space to provide separated bicycle paths. Furthermore, highly urban areas also attract a lot of people from outside the neighbourhood or even of outside the city. This would mean that people from far away drive to the neighbourhood, resulting in higher volumes of motorized traffic. Based on the percentage of single person households and the age distribution, it can be concluded that residential area of the neighbourhood is more focused on single young adults and not on family households. Therefore, it is expected that there is some demand for safe bicycle roads, but to a lesser extended than in a neighbourhood with many families with children.

Blixembosch-Oost is a relatively new neighbourhood, therefore it is expected that the bicycle infrastructure in the neighbourhood is also relatively new. Which leads to the expectation of high-quality bicycle infrastructure which is mostly in line with current design guidelines. Furthermore, from the street view imagery, it can be seen that numerous bicycle paths are separated from the roads, this increases the expectation that Blixembosch-Oost will have bicycle infrastructure with high segment scores. Additionally, Blixembosch-Oost has a high number of adolescents. The main transportation modes for this group of people are the bicycle. Therefore, it is expected that there will be a lot of bicycle infrastructure present, to make their trips more convenient. Blixembosch-Oost is a neighbourhood mainly consisting out of family households. It is expected that families with children have a high demand for a safe bicycle environment for their children, as children can be less aware of dangerous traffic situations. Since, Blixembosch-Oost has such a high number of family households with children, it is expected that the overall safety in the neighbourhood will be high, resulting in a high bikeability level.

Lastly, Hurk is an industrial neighbourhood which is not a typical place for people to cycle. Therefore, it is expected that Hurk will provide little accommodation for bicyclists and that only a limited amount of bicycle infrastructure is present in the neighbourhood. This is expected to negatively affect both the bicycle infrastructure score and the environment score of Hurk. Furthermore, the street view imagery shows that Hurk has a lot of parking space. Based on this, it is assumed that their mainly interested in attracting people by car. This in combination with the high number of people working in the neighbourhood, means that a high motorized traffic volume can be expected. A positive expectation for Hurk is that due to the high number of company branches and retail premisses, it is expected that Hurk will have a high destination density.

Concluding, based on the characteristics of all three neighbourhoods it is expected that Blixembosch-Oost will have the highest bikeability level, followed by Bergen and in last place Hurk. Additionally, the following category scores are expected for the neighbourhoods:

1. It is expected that Bergen will have a high accessibility category score
2. It is expected that Blixembosch-Oost will have a high bicycle infrastructure category score
3. It is expected that Hurk will have a low bicycle infrastructure and environment category score

4.2. Bicycle infrastructure

4.2.1 Data and variable preparation

For the calculation of the bicycle infrastructure score, information regarding the bicycle infrastructure needs to be obtained. To do so, the keys and values stated in table 4.2.1 will be used with QuickOSM in QGIS to identify all the bicycle infrastructure for the complete city of Eindhoven.

Table 4.2.1 Bicycle infrastructure identification.

Data	Keys	Values
Roads with bicycle infrastructure	Cycleway	Lane; shared_lane
	Cycleway:left	lane
	Cycleway:right	lane
	Cycleway:both	lane
	Bicycle	Designated
	Highway	Cycleway
Roads where bicycles are allowed but without special bicycle infrastructure	Highway	Tertiary; unclassified;

This results in a layer containing all the bicycle infrastructure in Eindhoven. Then the geoprocessing tool 'clip' is used to obtain three different layers, with in each the bicycle infrastructure of each specific neighbourhood. The bicycle infrastructure in this layer already has some attribute data, but not everything that is needed for the calculation of the bicycle infrastructure segment score is present. Table 4.2.2 shows the required data needed for the score calculation of all the bicycle infrastructure variables and if this data is already obtained from the OSM data base or that it needs to be obtained through other means. Furthermore, if the data is unobtainable, table 4.2.2 indicates how to change the variables or data needed so that it is possible to calculate the score of the variables.

Table 4.2.2 Bicycle infrastructure data obtained by the QuickOSM search

Variable	Required data	Data presence	Recommended changes in variable or data
Path type	Typing of the path	Present.	
Path width	Path width	Not present.	The bicycle intensity for each path will be set to the average bicycle intensity, which is 400 bicycles per hour. Path width, bicycle network infrastructure type and car lane width can all be obtained through visual inspection of the bicycle infrastructure.
	Bicycle network infrastructure type	Not present.	
	Bicycle intensity	Not present and is difficult to obtain.	
	Car lane width	Not present.	
Car intensity	Car intensity	Not present and is difficult to obtain.	As the data cannot be easily obtained, it is recommended to remove the variable from the case study's *'practical tool.'*
Separation type	Type of separation	Not present, but obtainable with VI.	Ideally the separation type would be calculation with a formula accounting for different separation types across one bicycle path. However, as this data is not already available and the separation type data will be obtained through VI, it will be too time consuming to measure all different separation types along one path for all paths in the three neighbourhoods. Therefore, the change is made to only use the most dominant separation type for the whole length of the path. When in doubt which separation type is the most dominant, the most negative scoring separation type needs to be chosen.
	Path length	Calculated using the field calculator	
Roadside type	Type of roadside	Not present, but obtainable with VI.	Ideally the roadside type would be calculation with a formula

	Path length	Calculated using the field calculator	accounting for different roadside types across one bicycle path. However, as this data is not already available and the roadside type data will be obtained through VI, it will be too time consuming to measure all different roadside types along one path for all paths in the three neighbourhoods. Therefore, the change is made to only use the most dominant roadside type for the whole length of the path. When in doubt which roadside type is the most dominant, the most negative scoring roadside type needs to be chosen.
Speed limit	Maximum speed	Present	
Presence of centre line	Centre line on the bicycle path	Not present.	Data regarding the presence of a centre can be obtained through visual inspection.
Presence of street light	Number of street lights	Not present.	There is data present indicating if the path is lit or not. Therefore, it is recommended to change the variable to a category variables with [1] 'no' and [2] 'yes' as answer. In this case, path length will not be necessary to calculate the variable score of 'presence of street light'
	Path length	Calculated using the field calculator	
Presence of obstacles	Obstacles on the bicycle path	Not present.	Obstacles can be found using the QuickOSM search term 'barrier=bollard'. This will provide a layer will all the bollards. These bollards represent the obstacles on and near the bicycle infrastructure. This layer can be used to determine if there are obstacles on the bicycle infrastructure.
Pavement type	Pavement type	Present	
Pavement quality	Pavement quality	Not present.	As the data cannot be easily obtained, it is recommended to remove the variable from the case study's *'practical tool.'*
Slopes	Number of slopes	Not present.	The number of slopes can be identified by using VI.
Land use type	Land use	Not present	

	Path length	Calculated using the field calculator	The land uses within the neighbourhood can be obtained from the CBS database regarding land uses (2015).
Speed limiting objects	Presence of speed limiting objects	Not present.	Speed limiting objects can be identified by using VI.
One-way street	One-way street	Present.	

Table 4.2.2 shows that after using QuickOSM, there is still a lot of missing data which is needed for the score calculation of the variables. However, most missing data can be obtained through visual inspection and be added to the data file. There are two variables, for which it is too difficult to obtain de necessary data: 'Car intensity' and 'Pavement quality'. As the necessary data cannot be obtained easily, it is decided to remove the variables from the tool to be able to still illustrate the functioning of the tool. The data regarding the bicycle intensity is also difficult to obtain. However, for this variable the assumption will be made that all bicycle infrastructures have the average bicycle intensity, which is 400 bicycle per hours. When the actual data regarding bicycle intensity is available, it would be advised to replace it with the made assumption to more accurately assess the path width variable.The variables 'separation type' and 'roadside type' are changed to make the missing data less time consumable to obtain with VI. Furthermore, the variable 'presence of street light' is also changed so that the already available data can be used for the calculation of the variable score.

As mentioned in table 4.2.2, the path length will be calculated using the field calculator with the expression '$length'. Obstacle data will be obtained by using QuickOSM and the search term 'barrier=bollard', this then generates a layer with bollards in Eindhoven. Then using the 'buffer' and 'count points in polygon' tool, data about obstacles nearby (closer than 1 meter) bicycle infrastructure can be obtained. The data needed for the 'land-use type' variable is obtained from the CBS data base 'Bestand bodemgebruik' (2015), which is the most recent available at the necessary level of detail. This data is added to the corresponding neighbourhoods in QGIS and then added to the bicycle infrastructure using the union geoprocessing tool.

4.2.2 Bicycle infrastructure category scores

After obtaining all the missing data and adjusting the problem variables, the bicycle infrastructure segment score can be calculated and with that also the bicycle infrastructure scores of each neighbourhood. Appendix II, shows all the data and corresponding scores. First some intermediate results will be discussed, followed by the bicycle infrastructure score of each neighbourhood.

Table 4.2.3 Bicycle infrastructure types in each neighbourhood as percentage of the total length

	Bicycle path	Moped & bicycle path	Optional bicycle path	Bicycle lane	Bicycle suggestion lane	Bicycle street	Roadway
Bergen	59%	0%	0%	10%	8%	0%	23%
Blixembosch-oost	85%	7%	1%	0%	7%	0%	0%
Hurk	25%	1%	0%	25%	0%	1%	48%

Table 4.2.3 shows the distribution of each bicycle infrastructure type for all the neighbourhoods. The percentage of the different types of bicycle infrastructure is important, as it is the variable that can provide the highest score (ranging from 3 to 10) and thus has a large impact on the neighbourhood's 'bicycle infrastructure' category score. This large influence is justified, as the bicycle infrastructure type forms the basis of the bicycle infrastructure. The other variables are used to adjust the typing score based on the additional aspects of the bicycle infrastructure. It is expected that larger differences in this variable between neighbourhoods would result in observable differences in the 'bicycle infrastructure' category score.

Table 4.2.3 shows that there are major differences in the distribution between the three neighbourhoods. In Blixembosch-Oost, bicycle path accounts for 85% of all the bicycle infrastructure. Furthermore, 93% of all bicycle infrastructure is separated. Almost all bicycle infrastructure in the neighbourhood consists out of separated bicycle infrastructure. This high percentage of separated bicycle infrastructure is expected to have a large positive influence on the 'bicycle infrastructure' score of Blixembosch-Oost, as these bicycle infrastructure types are the higher scoring ones.

Although bicycle path is also the most dominant bicycle infrastructure in Bergen, it only accounts for 59% of the bicycle infrastructure, followed by roadway with 23%, bicycle lane with 10% and bicycle suggestion lane with 8%. Looking at the neighbourhood it can be seen that the bicycle paths are all located around the boarders of the neighbourhood, while streets on the inside of the neighbourhood do not have any bicycle paths. Although the 59% percent of bicycle path is expected to have a large positive influence of the 'bicycle infrastructure' category score, it is also expected that the 23% of roadways will have a large negative impact, relinquishing part of the positive effect of the high percentage of bicycle paths.

In Hurk the most used bicycle infrastructure type is roadway (48%), followed by bicycle paths (25%) and bicycle lanes (25%). In Hurk, the bicycle paths are mainly located alongside two large roads, one going through and one on the edge of the neighbourhood. The bicycle infrastructure inside the neighbourhood mainly consists out of roadway, which provides no dedicated bicycle infrastructure. In Hurk, there is almost twice as many roadway as bicycle path. This is expected to have a large negative impact on the 'bicycle infrastructure' score of the neighbourhood, as roadway is the lowest scoring bicycle infrastructure type.

Table 4.2.4 Percentage of path widths in line with the recommendations

	Smaller than the recommended path width	**Recommended path width**	**Larger than the recommended path width**
Bergen	87%	0%	13%
Blixembosch-oost	74%	1%	25%
Hurk	82%	10%	8%

Table 4.2.4 shows the percentage of bicycle infrastructure path width in line with the recommended path widths, the percentage of bicycle infrastructure path width that is smaller than the recommended path width and the percentage of bicycle infrastructure path width that is larger than the recommended path width.

Interestingly enough, in each neighbourhood most bicycle infrastructure is smaller than the recommended path width. Blixembosch-Oost is the best neighbourhood in following the recommended path widths as 26% of the paths are the recommended path width or larger. Hurk is second best with 18% and Bergen performs the worst with 13%. However, bergen does have more bicycle infrastructure with larger than recommended path widths than Hurk. Based on the amount of bicycle infrastructure with a path width with a recommended path with or larger, it can be expected that Blixembosch-Oost will have bicycle infrastructure with higher segment scores than Bergen and Hurk. However, it should not be overlooked that all neighbourhood have a really larger amount of bicycle infrastructure that has a width smaller than the recommended one. Thus, this variable will mainly negatively impact all neighbourhoods.

An explanation for this high percentage of bicycle infrastructure that is not in line with the path width recommendations is that the recommended path width is based on the bicycle intensity. This data was unfortunately unobtainable. But, to still be able to include the path width variable in the practical tool, the average bicycle intensity was used for all bicycle infrastructure. However, this may not reflect the actual situation of the bicycle intensity on the bicycle infrastructure and may have resulted in recommending larger paths then necessary. Resulting in the higher percentage of bicycle infrastructure with a path width smaller than the recommendation.

Another interesting thing about the variable ‘path width’ is the actual impact that the variable has on the bicycle infrastructure segment score. As many bicycle infrastructures do not follow the recommended path width, it would be important to reflect this in the segment score. However, the variable actually does not have that large of an impact on the segment score. The calculation method used to determine the scoring may not be punishing enough on bicycle infrastructures that do not follow the width recommendations.

Looking at the other variables, which can be found in appendix II, the following results can be found. First, most bicycle infrastructure in each neighbourhood has the pavement type ‘closed pavement’, however Hurk also has a high percentage of bicycle infrastructure with the pavement type ‘open pavement’ which is less favourable for the bicycle infrastructure segment score. Secondly, in Bergen and Blixembosch-Oost, all bicycle infrastructure has street lights present, while some bicycle infrastructure in Hurk does not have street lights. Thirdly, the ‘land use’ variable is more favourable for Bergen and Blixembosch-Oost than for Hurk. The variable ‘land use’ assigns a score of -1 to bicycle infrastructure that is located in office or industrial land use, which is the main land use type of Hurk. Fourth, the separation and roadway types of Hurk and Bergen score worse than those in Blixembosch-Oost. Lastly, the other variables are roughly performing the same for all three neighbourhoods. Based on these variables it can be expected that Blixembosch-Oost will have a high ‘bicycle infrastructure’ score and the highest score compared to the other neighbourhoods. Followed by Bergen with still a decent score and in last place Hurk with a low score.

Table 4.2.5 shows the ‘bicycle infrastructure’ category score of each neighbourhood. Based on the previously stated expectations Blixembosch-Oost would have a high score, Bergen an average score and Hurk a bad score.

Table 4.2.5 Bicycle infrastructure category scores

Neighbourhoods	**Bicycle infrastructure scores**
Bergen	6.0
Blixembosch-Oost	7.9
Hurk	4.0

Looking at the scores in table 4.2.5, it can be seen that these expectations hold true. Blixembosch-Oost indeed has the highest score, which mainly can be explained by the high amount of separated bicycle infrastructure. The variable bicycle infrastructure type can provide the highest score an individual variable can give and the separated bicycle infrastructure types provide a high scores for the bicycle infrastructure. Additionally, the other variables are also mostly beneficial for Blixembosch-Oost. Although, a large part of the bicycle infrastructure has a width smaller than the recommended with, Blixembosch-Oost is still the best performing neighbourhood for this variable.

Bergen has the second highest score, which also was expected based on the amount of separated bicycle infrastructure. Bergen has a decent amount of bicycle paths, but also a decent amount of roadway. This withholds Bergen from obtaining a high score for the ‘bicycle infrastructure’ category. Furthermore, the other variables are also quite beneficial for Bergen, but not as much as for Blixembosch-Oost. Thus, as expected, Bergen scores an acceptable score which is lower than the score of Blixembosch-Oost.

Hurk's low scores originates from the bicycle infrastructure type. 48% of the bicycle infrastructure in Hurk is roadway, which is the worst scoring bicycle infrastructure. This was expected to have a large negative effect on the 'bicycle infrastructure' score of the neighbourhood. Furthermore, other variables were also not in favour of Hurk, as Bergen and Blixembosch-Oost out performed Hurk on almost every variable.

Based on the neighbourhood description in section 4.1, the 'bicycle infrastructure' score of the neighbourhood are also as expected. A residential neighbourhood such as Blixembosch-Oost is expected to have a higher-quality bicycle infrastructure to accommodate the many people, and potentially families, living there. While an industrial area such as Hurk is not a common place to bicycle, thus it is expected to be less accommodating for bicyclists.

Figure 4.2.1, 4.2.2 and 4.2.3 shows the distribution of the bicycle infrastructure in each neighbourhood. Something interesting that can be seen it the figures is that the neighbourhoods Hurk and Bergen both have good bicycle infrastructure at the periphery of the neighbourhood, while the bicycle infrastructure located inside the neighbourhood is most often bad. In contrary to Hurk and Bergen, Blixembosch-Oost does have good bicycle infrastructure inside the neighbourhood, which provides residents a safe and convenient way to travel through the neighbourhood.

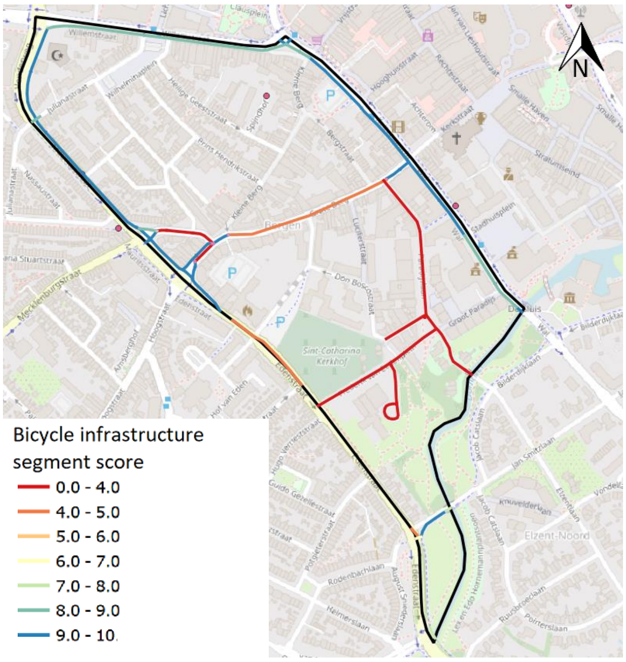


Figure 4.2.1 Bicycle infrastructure in Bergen

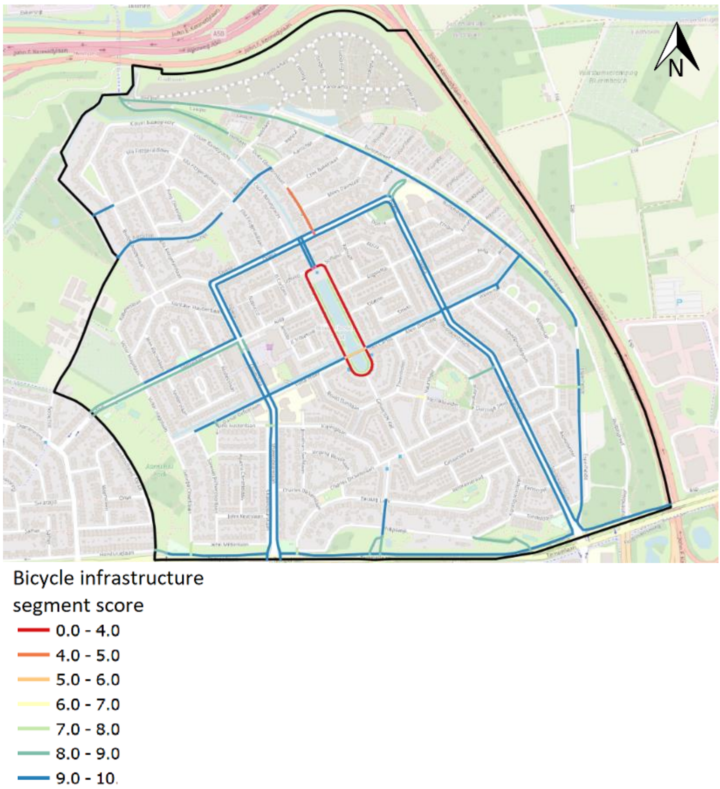


Figure 4.2.2 Bicycle infrastructure in Blixembosch-Oost

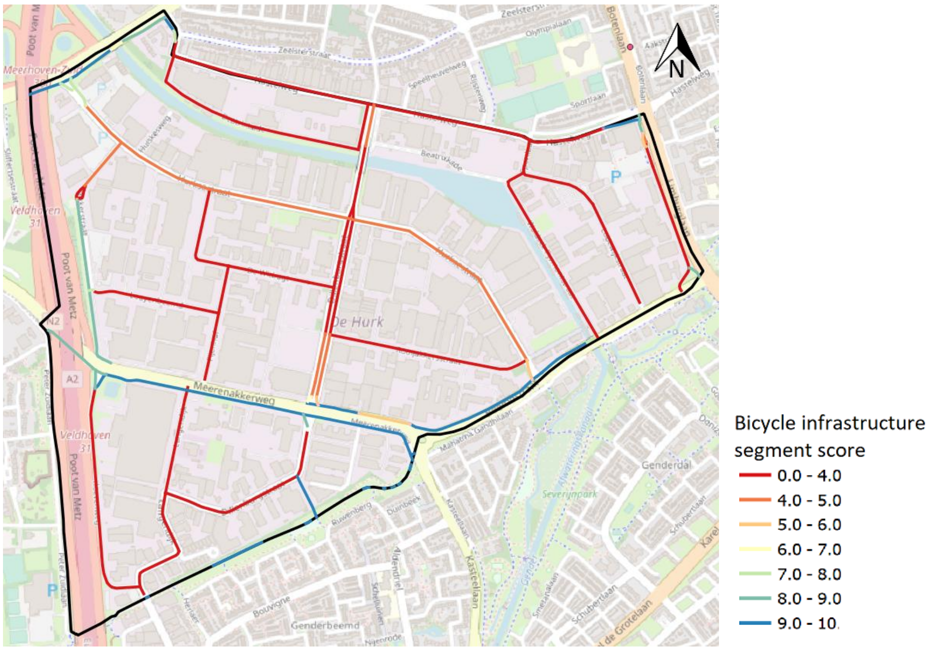


Figure 4.2.3 Bicycle infrastructure in Hurk

4.3 Junction infrastructure

4.3.1 Data and variable preparation

For the calculation of the junction infrastructure score, the junctions present within each neighbourhood need to be identified. As mentioned in section 3.3, the included junctions are junctions located on distribution roads. These roads are identified with QuickOSM and the following key and values:

- Highway=primary;
- Highway=secondary;
- Highway=tertiary.

This results in a layer containing all the distribution roads within the case study neighbourhoods. This layer is then used to identify the junctions by looking where these roads intersect with any other type of road. These locations will be noted in a new point layer, thus creating a layer with the junctions of the neighbourhood. These points representing the junctions need to have the following 7 attribute data fields that can hold whole numbers (integer):

1. Junction ID
2. Junction type
3. Bicycle infrastructure at the junction
4. Speed limiting objects
5. Median island
6. Bicycle traffic lights
7. Bicycle box

These data fields are used to store the junction data necessary to calculate the score of the junction infrastructure variables. The data about each junction will be obtained through visual inspection of the junctions. The identified information will be coded into a number which corresponds with one of the variable value options and is added to the corresponding attribute field of the junction. For example, through visual inspection it is found that junction 1 is an intersection with traffic lights. This is coded as ‘2’ for the variable junction type, so in the attribute field ‘junction type’ as 2 will be added. The full lists coded value options of each variable can be found in appendix III. Through visual inspection all the required data can be found with one exception. The only exception is the data regarding cyclists having their own green phases for the variable 'bicycle traffic lights', as this data cannot be obtained by using visual inspection. Which means that the variable 'bicycle traffic lights' is adapted to only have the answer 'no' and 'yes', scoring 0 and 0.5 respectively.

4.3.2 Junction infrastructure category scores

After obtaining the data regarding the junctions, the junction score of each individual junction can be calculated and with that also the junction infrastructure category scores of each neighbourhood. Appendix III, shows all the junction data and corresponding scores. First some intermediate results will be discussed, followed by the junction infrastructure scores of each neighbourhood.

Table 4.3.1 Junction types in each neighbourhood

	Number of junctions	Priority rules	Traffic lights	Markings & signs	Roundabout
Bergen	17	0%	41%	59%	0%
Blixembosch-oost	31	0%	16%	84%	0%
Hurk	23	13%	35%	48%	4%

Table 4.3.1 shows the total number of junctions in each neighbourhood and the distribution of junction types. This is an important variable to look at as it is the variable that can provide the highest score for a junction, ranging from 1 to 9. Meaning that it will have a large impact on the neighbourhood's 'junction infrastructure' category score.

In all three neighbourhoods most of the junctions are regulated by markings & signs, followed by traffic lights. However, in Blixembosch-Oost the actual percentage of junctions regulated by markings & signs is much higher than in Bergen and Hurk. The junction type regulated with markings & signs result in a higher score than junctions regulated with traffic lights. Thus, because of the high number of junctions regulated with marking & sings in Blixembosch-Oost, it is expected that Blixembosch-Oost will have a higher 'junction infrastructure' category score than Bergen and Hurk.

Some similarities can be seen when comparing the distribution of junction types in Bergen and Hurk. Both neighbourhoods have a decent percentage of junctions regulated by markings & signs and regulated by traffic lights. This could suggest that they would have similar scores for the 'junction infrastructure' category. However, junctions in Hurk are more diverse. Hurk is the only neighbourhood with a roundabout, which is located on the edge of the neighbourhood. However, Hurk is also the only neighbourhood with junctions regulated by priority rules only. Meaning that Hurk has both the worst and best scoring junction type present in the neighbourhood. Unfortunately, there are more junction regulated by priority rules than roundabouts in the neighbourhood. Therefore, it is expected that the overall 'junction infrastructure' category score will be lower than that of Bergen.

Table 4.3.2 Distribution of bicycle infrastructure at the junctions

	Number of junctions	Shared lane	Bicycle suggestion lane	Bicycle lane	Bicycle path < 2m	Bicycle path > 2m
Bergen	17	0%	0%	42%	29%	29%
Blixembosch-oost	31	0%	0%	10%	6%	84%
Hurk	23	17%	9%	35%	17%	22%

Table 4.3.2 shows the distribution of the bicycle infrastructure present at each junction. This is an important variable to look at as it can both provide positive and negative scorings based on the bicycle infrastructure type at the junction. Therefore, it can have a large impact on the junction score.

Bicycle paths (both '< 2 meters' and '> 2 meters' are the most common bicycle infrastructure at a junction in all the neighbourhoods. In Blixembosch-Oost 90% of the junctions has a bicycle path, which great for the safety of the junctions and with that the junction score. 10% of the junctions in

Blixembosch-Oost have bicycle lanes, which still provides a dedicated space for bicyclists and has a decent effect on the junction score. The high percentage of bicycle paths present at the junction is another reason why it is expected that Blixembosch-oost 'junction infrastructure' category score will be higher than the other two neighbourhoods.

In Bergen, 58% of the junctions have bicycle paths and 42% have bicycle lanes, which means that all junctions will have an increase in their score based on the bicycle infrastructure. However, due to the high percentage of bicycle lanes, this score increase will be lower than that of Blixembosch-Oost.

In Hurk only 39% of the junctions have bicycle paths and 35% have bicycle lanes. Which means that 74% of the junctions in Hurk have a dedicated space for bicyclists, however 26% does not. The junctions with bicycle suggestion lanes and shared lanes will be less safe and comfortable for the bicyclists and will therefore negatively impact the score of those junctions. This is another reason why it is expected that Hurk will have a lower 'junction infrastructure score'. Interestingly enough, Hurk is arguable the neighbourhood that has the highest demand for good bicycle infrastructure at the junctions, as it is expected that more trucks pass through this neighbourhood, which can cause more danger for bicyclists. However, it is the only neighbourhood where the bicycle infrastructure negatively effects some of the junction scores. A potential reason for this is that it is not expected that large volumes of bicyclists will travel through Hurk and therefore the necessary accommodations for bicyclists' safety are absent. This in contrary to Blixembosch-Oost where it is expected that large volumes of bicyclists will be present.

Table 4.3.3 shows the junction infrastructure scores of each neighbourhood. The scores have a range of 0 to 10, with 10 being the highest. Beforehand, it was expected that Blixembosch-Oost would have the highest junction infrastructure scores as it is a typical residential area which is expected to be accommodating for bicyclists at dangerous situations such as junctions. Furthermore, it was expected that Hurk would have the lowest score as industrial and business areas are generally less accommodating for bicyclists even though due to presence of trucks there would be the need for it.

Table 4.3.3 Junction infrastructure scores

Neighbourhoods	Junction infrastructure scores
Bergen	7.4
Blixembosch-Oost	8.1
Hurk	6.6

Looking at the scores in table 4.2.3, it can be seen that the expected ranking holds true. Blixembosch-Oost scores has the highest score, which can be explained by the high number of junctions regulated by markings & signs and the high number of junctions that have bicycle paths as their bicycle infrastructure. Overall, the neighbourhood has comfortable and safe junctions, which would promote bicycling.

Bergen has the second highest score. The score is somewhat lower than the score of Blixembosch-Oost, which was to be expected as Bergen has less junctions regulated with markings & signs and les junctions with a bicycle path as their bicycle infrastructure. Still, the neighbourhood has decently comfortable and safe junctions.

Hurk is the lowest scoring neighbourhood, but still has an acceptable score of 6.6. The difference in score between Hurk and the other neighbourhoods can be explained by the lack of dedicated bicycle infrastructure at some of its junctions and that some junctions are regulated by priority ruling. If these issues would to be resolved, Hurk's score would be more similar to that of Bergen. However, Hurk still has an acceptable score.

All in all, each neighbourhood has an acceptable junction infrastructure score. A potential reason for this can be that the municipality of Eindhoven has a good grip on the designing and construction of safe and convenient junction. Implementing a safe and convenient junction in every neighbourhood of Eindhoven, even in an industrial neighbourhood like Hurk.

4.4 Bicycle parking facilities

4.4.1 Data and variable preparation

For the calculation of the bicycle parking facilities (BPFs) score, all the BPFs with an area of 30m² or more in each neighbourhood need to be identified. These BPFs are identified using QuickOSM and the search term 'amenity=bicycle_parking'. This will result in a layer with all the BPFs. In theory, this layer should include information regarding the BPFs type, area, security, fee and the capacity. However, the information is not always complete. In this case, the missing information can be completed by visual inspection. With this information it is possible to calculate the scores of the variables 'type of BPF', 'security measures', 'parking costs' and 'parking spot ratio'.

For the calculation of 'connection to the bicycle infrastructure', the previously obtained layer of bicycle infrastructure in section 4.2.1 is used. The data necessary for the variables 'distance to transit' and 'destinations' is also obtained with the use of QuickOSM. By using QuickOSM, the different destination types and public transport stops present in each neighbourhood can be identified. There are 13 destination categories for which all destinations need to be identified:

1. Transport
2. Education
3. Grocery
4. Catering services
5. Religious organizations
6. Sports
7. Greenery
8. Services
9. Library
10. Stores
11. Entertainment
12. Healthcare
13. Offices

Appendix IV shows the search terms used to obtain all the different types of destinations from each category.

After obtaining all these destinations a buffer needs to be made around the BPF representing the direct access range of the BPF. This is done by using the geoprocessing tool buffer. After that the analysis tool 'count points in polygon' can be used to determine the number of destinations within the range of the BPF.

The network analysis tool 'distance to nearest hub' can be used to calculated the distance between the BPF and the bicycle infrastructure as well as the distance to the nearest public transport stop. This data is then used for the calculation of the variables 'connection to the bicycle network' and 'distance to transit'.

4.4.2 Bicycle parking facilities category score

After obtaining all the necessary data the BPFs category scores can be calculated. Appendix V shows all the data and score calculation of the variables. First, the intermediate results will be discussed, followed by the overall 'bicycle parking facility' category score.

Table 4.4.1 Variable scores of the category bicycle parking facilities

	Type	Security	Costs	Connection to the bicycle infrastructure	Distance to public transportation	Destinations within reachable distance	Parking ratio
Bergen	1	0	0	0.91	0.07	0.5	0.58
Blixembosch-oost (Average)	1.5	0	0	0.99	0	0.36	0.95
Hurk	3	0	0	0.7	0	0.05	0.88

First, it needs to be mentioned that there were not many BPFs identified in the three case study neighbourhoods. For Bergen and Hurk only one BPF was identified and for Blixembosch-Oost four. Table 4.3.1 shows the scores of the BPF. For Blixembosch-Oost this is the average score across the four identified BPFs is shown, while for Bergen and Hurk these are the score for the only identified BPF.

The type variable has a scoring range from 1 to 5. Looking at the table, it can be seen that both Bergen and Blixembosch-Oost score badly on this variable, while Hurk has a decent score. This is quite the important variable as this is the variable that can assigned the most score. Meaning, since Bergen and Blixembosch-Oost both scores really low on this variable, it is already highly unlikely that they will be able to gain a decent 'bicycle parking facilities' category score. Thus, if a neighbourhood only has bicycle racks and no other type of bicycle parking, it will already score badly on the category 'bicycle parking facilities'.

Security measures are not found at any of the BPF, which increase the expectation that the neighbourhoods will have low 'bicycle parking facilities' scores. However, the lack of security measures is not unexpected, as most of the BPFs are bicycle racks which generally do not have any security. Security measures are something which is more common at large scale BPF near large locations (train station, city centre, etc.). Therefore, the tool may be to rewarding to the BPF type 'bicycle storage' which already has a score of 5 on typing and will more often be rewarded additional score on the variable 'security measures'.

The variable costs also result in a score of 0 for all the three neighbourhoods, however this is something positive. The variable 'costs' assigns a negative score if bicyclists need to pay for the use of the BPF. Because of this, even though all three neighbourhoods have the best possible score for this variable, it will not increase their 'bicycle parking facility score'. Thus, not changing the expectation of a low category score.

The variable 'distance to public transport' also provides almost no score for all the three neighbourhoods, although it was expected during the tool development that not every BPF would serve public transport stops. However, the scores on the variable 'destinations within reachable distance' is also quite low for Blixembosch-Oost and Hurk. The score for Bergen seems decent, but considering that Bergen is a mixed function neighbourhood and the BPF is located between the city centre and a street with many restaurants and shops, the score seems a bit low.

The variables 'connection to the bicycle infrastructure' and 'parking ratio' do provide higher scores for all the three neighbourhoods. All BPFs seem to be good connected to the bicycle infrastructure, resulting in high scores for all three neighbourhoods. The parking ratio scores of Blixembosch-Oost and Hurk are also high. The parking ratio score of the BPF in Bergen is a bit lower. After looking at the BPF it can be concluded that this is mainly due to the very wide path going through the parking area. This path is much wider than the assumed path width in the calculation and therefore causes a lower score. Although 'connection to the bicycle infrastructure' and 'parking ratio' provide the neighbourhoods with some positive scores, it will not outweigh the loss of points on the variables 'type' and 'security' and therefore it is still expected that all three neighbourhoods will have a low 'bicycle parking facilities' category score.

Table 4.4.2 gives an overview of the 'bicycle parking facility' category score of each neighbourhood. The scores are low which was expected based on the previously discussed variable scores.

Table 4.4.2 Bicycle parking facilities scores

Neighbourhoods	Bicycle parking facilities scores
Bergen	2.5
Blixembosch-Oost	3.1
Hurk	3.8

Looking at table 4.4.2 it can be seen that Hurk has the highest bicycle parking facilities score. This can be explained by the fact that the only considered BPF in Hurk was a covered bicycle rack, while those in Bergen and Blixembosch-Oost were almost all uncovered bicycle racks. The score difference between Bergen and Blixembosch-Oost can be explained by the better parking ratio that the BPFs in Blixembosch-Oost have and that Blixembosch-Oost has three uncovered bicycle racks, but also a covered one.

All in all, the score of each of the three neighbourhood is quite low. Which would indicate that all neighbourhoods have a problem in the area of bicycle parking facilities. The low scores mainly come from the lack of bicycle storages facilities and the lack of security measures which could large increase the score of the BPFs. However, these two aspects may have too much impact on the overall score, as without it is impossible to have a high bicycle parking infrastructure score. Indicating that without these aspects a neighbourhood would have a BPF problem, which is not necessarily the case. Meaning that the scoring of 'bicycle parking facilities' may not reflect the actual situation in the neighbourhood.

4.5. Environment

4.5.1 Data and variable preparation

The data for the calculation of the neighbourhood category is obtained from multiple sources. For the variables 'bicycle way ratio' and 'bicycle way density' the previously established layer in section 4.2.1, with all bicycle infrastructure in Eindhoven is needed once again. However, the roads where bicycles are allowed but without dedicated bicycle infrastructure should be removed for the calculation of these variables. Furthermore, for the variable 'bicycle way ratio' data needs to be obtained about all the roads in the neighbourhood. This can be obtained through QuickOSM using the following keys and values:

- Highway=living_street
- Highway=unclassified
- Highway=trunk
- Highway=residential
- Highway=tertiary
- Highway=secondary
- Highway=primary

This results in a layer containing all the roads in within the case study neighbourhoods. For the variables ‘bicycle way ratio’ and ‘bicycle way density’, the total length of all bicycle infrastructure and roads within each neighbourhood needs to be calculated. This can be done using the analysis tool ‘sum line lengths’.

The data necessary for the variables ‘Intersection density’ and ‘Bicycle parking facilities ratio’ can obtained by using the previously established layers of junction and BPFs in section 4.3.1 and 4.4.1, respectively. For the variable ‘intersection density’ the roundabouts and priority squares need to be removed from the data file and then the number of junctions for each neighbourhood can be identified using the count points in polygon tool. For the variable ‘BPFs ratio’ a buffer needs to be drawn around the BPFs in each neighbourhood. The size of the buffer depends on the direct access range of the BPF type. These buffers in each neighbourhood need to be merged within one another to prevent from overlapping buffers to count double. Then the BPFs served area can be calculated for this file using the field calculator and the expression ‘$area’.

Data regarding the number of dwellings, population and number of road accidents, which are needed for the variables ‘green space’, ‘population density’ and ‘road safety’, can all be acquired from the ‘Eindhoven in Cijfers’ data base. The data required for the variable ‘air quality’ is obtained from the open data source of the municipality of Eindhoven (data.eindhoven.nl). Information obtained from these two data bases is imported to QGIS and assigned to the corresponding neighbourhood.

The previously obtained data about land use from the CBS data base ‘Bestand bodemgruik’ (2015) in section 4.2.1 will also be used for the calculation of the variable ‘mixed-land use’. The land uses in each neighbourhood are first measure using the field calculator and the expression $area and then assigned to their corresponding land use categories established in the tool development phase. The data about the land use ‘greenery’ will also be used for the calculation of the variable ‘green spaces’

4.5.2 Environment category scores

After obtaining all the data the ‘environment’ category scores can be calculated. Appendix VI, shows all the environment data and corresponding scores. First, the intermediate results will be discussed, followed by the overall ‘environment’ category score.

Table 4.5.1 Environment variable scores part 1

	Bicycle way ratio	Bicycle way density	Intersection density	BPFs ratio	Population density
Bergen	0.50	0.79	-0.49	0.06	0.52
Blixembosch-oost	1.35	0.75	-0.18	0.02	0.28
Hurk	0.39	0.38	-0.11	0.01	0.00

Table 4.5.1 shows the scores of the neighbourhoods on five of the environment category variables. It is important to mention that the variables ‘bicycle way ratio’ and ‘bicycle way density’ both have a weight of 2, while all other variables have weight of 1. Since Blixembosch-Oost score well on both these variables, it is expected that it will have a large positive influence on the ‘environment’ category score of Blixembosch-Oost.

On the contrary, Hurk has a bad score for both ‘bicycle way ratio’ and ‘bicycle way density’. Furthermore, Hurk has a population density score of 0, which was expected based on the low number of inhabitants. These three variables will most likely heavily affect the overall ‘environment’ category score of Hurk in a negative manner.

Bergen has an acceptable score for ‘bicycle way ratio’ and a positive score ‘bicycle way density. Furthermore, Bergen has the worst score for intersection density, but has the highest score for population density. Based on these four variables, it is expected that bergen will have an average overall category score.

Table 4.5.1 also shows that the BPFs ratio is low for all three neighbourhoods. The reason for this is the low number of identified BPFs, which was previously discussed in section 4.4.2. These low scores will make it more difficult for all three the neighbourhoods to reach a high 'environment' score. Furthermore, as the actual number of BPFs may be higher than the identified BPFs, the environment score of all three neighbourhoods will be lower than the actual situation and not completely accurate represent the actual situation in the neighbourhoods.

Table 4.5.2 Environment variable scores part 2

	Air quality	Green space	Mixed land use	Road safety
Bergen	2	0.49	0.92	-0.31
Blixembosch-oost	2	1	0.69	-0.40
Hurk	2	1	0.33	-1.03

Table 4.5.2 shows the other variables of the 'environment' category. All three neighbourhoods score the full score on the variable air quality. Meaning, that this variable will not create any underlying difference, but will increase all their 'environment category scores'.

The green space score in Bergen is surprisingly low, as Bergen does have a park present in the neighbourhood. While the green space score for Hurk is incredibly high, even though the neighbourhood has no park. The reason for these scores is due to the inhabitant count of both neighbourhoods, as the determined necessary green space for a good score is based on the number of inhabitants. The neighbourhood Hurk has an extremely low number of inhabitants and therefore needs only a low amount greenery to gain a high score. While the very dense neighbourhood Bergen with a high number of inhabitants need a high amount of greenery. Because of this the green space score of Bergen is on the lower side, even though there is a lot of greenery present in the neighbourhood.

Looking at all the variable form table 4.5.1 and 4.5.2, it can be expected that Hurk will score badly on the 'environment' category as it scores bad on five of the seven variables. Bergen has some alternating scores, resulting in the expectation of an average score for the 'environment' category. And, Blixembosch-Oost scores good on numerous variables, but even more important on the variables that have double the weight. However, Blixembosch-Oost also scores badly on the variables 'population density' and 'road safety'. Therefore, it is expected that Blixembosch-Oost will have a good to average 'environment' category score. Table 4.5.3 gives an overview of the environment category scores of each neighbourhood.

Table 4.5.3 Environment scores

Neighbourhoods	Environment scores
Bergen	4.8
Blixembosch-Oost	6.3
Hurk	3.1

Looking at the scores in table 4.5.3, it can be seen that the expected score somewhat holds true. Hurk indeed has a bad score for the 'environment' category. However, the scores of bergen and Blixembosch-Oost are somewhat lower than expected. One of the reasons for this would be the 'BPF ratio' variable on which all the neighbourhood scored extremely low. This resulted in lower overall scores for all three the neighbourhoods.

However, looking at the ranking of the environment scores, the results seem reasonable. Blixembosch-Oost has the highest environment score which can be explained by the presence of a high amount of bicycle infrastructure, a high amount of green space and a decent amount of mixed land use. Bergen has the second highest score. The difference between Bergen and Blixembosch-Oost can be explained by the lack of bicycle infrastructure and green space in bergen. However, part of these shortcomings, Bergen makes up for in land use mix and population density. Hurk has the lowest score of all the three neighbourhoods. This was to be expected as Hurk only scores good on the variables 'air quality' and 'green spaces'. Which is actually an unexpected result for an industrial neighbourhood.

4.6 Accessibility

4.6.1 Data and variable preparation

The data needed for the calculation of the accessibility category comes from two sources. The data for the 'distance to …' variables are obtained from the CBS data (2019) base regarding proximity to amenities. The data found in the CBS data base is shown in appendix VII together with all other data necessary for the accessibility score calculation. From the CBS data base, information can be obtained regarding the proximity to a multitude of amenities. This proximity is calculated by measuring the distance between every dwelling in the neighbourhood and the closest specified amenity using car infrastructure. Then the average of all these distances is used to express the proximity of the specified amenity.

The only two 'distance to …' variables that could not be found in the data base are 'average distance to city centre' and 'average distance to public green'. The average distances for these variables are calculated within QGIS using the 'distance to nearest hub' tool, where the input point is the centre of the neighbourhood and the target hub is the centre of the public green and city centre (obtained using the 'centroid' tool).

The necessary data for the variables 'destination types', 'transit facility density' and 'destination density' is the same data collected for the variables 'distance to transit' and 'destinations' in section 4.3.1. Once again, the 13 destination categories are:

1. Transport
2. Education
3. Grocery
4. Catering services
5. Religious organizations
6. Sports
7. Greenery
8. Services
9. Library
10. Stores
11. Entertainment
12. Healthcare
13. Offices

Appendix IV shows the search terms used to obtain all the different type of destinations of each category.

4.6.2 Accessibility category scores

After obtaining all the necessary data, the 'accessibility' category score can be calculated for each of the neighbourhoods. First, the intermediate results will be disucced, followed by the overall 'accessibility' category score.

Table 4.6.1 'Distance to …' variable scores for each neighbourhood.

	Supermarket	Day-care	Elementary school	Secondary education	Train station	Centre	Shopping centre
Bergen	0.88	0.92	0.92	0.78	0.66	0.91	0.70
Blixembosch-oost	0.88	0.92	0.90	0.78	-0.10	-0.12	0.38
Hurk	0.84	0.84	0.84	0.70	0.38	0.41	0.62

Table 4.6.2 'Distance to …' variable scores for each neighbourhood, continued.

	Greenery	Pub	Restaurant	Library	Hospital	General practice
Bergen	0.92	0.96	0.98	0.88	0.44	0.92
Blixembosch-oost	0.87	0.66	0.88	0.10	0.28	0.87
Hurk	0.86	0.82	0.86	0.36	0.16	0.80

Table 4.6.1 and 4.6.2 show the score for each 'average distance to …' variable for each neighbourhood. The scores of the variables have a maximum score of 1. Looking at tables, it can be seen that all three neighbourhoods have small average distance to a supermarket, day-care, elementary school, restaurant, greenery and general practice. And also, a decent average distance towards secondary education and pub. Meaning that all those destinations are easily accessible by bicycle for every neighbourhood. There are some small differences in the variable scores between the three neighbourhoods, all in favour of Bergen. Therefore, it is expected that based on these variables Bergen will slightly outperform both Blixembosch-Oost and Hurk in their score for the 'accessibility' category.

Train station, city centre, shopping centre, library and hospital are less common destinations compared to the other destinations. Meaning that there a fewer of those destinations with a city, meaning that the average distance towards these destinations has a larger chance to be further away. Resulting in lower scores for these variables. Looking at the variable 'average distance to train station' it can be seen that Blixembosch-Oost has bad access to a train station. It even has a negative score, which means that the nearest train station is out of bicycle range. For Bergen and Hurk, the nearest train station is within bicycle distance, but the scores are a bit worse than for the more common destinations. The main reason for this is that Eindhoven only has two train stations that are both located near the centre of Eindhoven. Therefore, it is logical that Blixembosch-Oost, which is located all the way in the north of Eindhoven, scores badly on this variable. The same reasoning applies to the variables 'average distance to city centre' and 'average distance to library'. Eindhoven only has one library which is located adject to the city centre and the city centre is located in the middle of Eindhoven. Thus, Blixembosch-Oost also score badly on those two variables.

For both 'average distance to library' and 'average distance to train station' this can be changed by developing new locations with these functions closer to Blixembosch-Oost. Although, building a new train station requires much more effort than a new library. However, the distance from Blixembosch-Oost towards the city centre cannot be changed. Again, Bergen scores the best on these 'average distance to …' variables. However, this time the difference between Bergen and the other neighbourhoods is much larger. Therefore, it is expected that based on these variables, Bergen will gain a much higher 'accessibility' than Hurk and Blixembosch-Oost.

Table 4.6.3 ‘Destination types’, ‘destination density’ and ‘transport facility’ variable scoring

	Destination types	Destination density	Transport facility density
Bergen	0.92	1.00	0.74
Blixembosch-oost	0.69	0.16	0.29
Hurk	0.54	0.24	0.45

Table 4.6.3 shows the scores for the variables ‘destination types’, ‘destination density’ and ‘transport facility density’ with a scoring range from 0 to 1. It can be seen that Bergen scores well all three variables, indicating that the neighbourhood does not only have a diverse number of different destination types, but also a higher number of destinations and public transport stops. This is to be expected from a neighbourhood that has a mixed-function purpose. Bergen has multiple streets where multiple different types of destinations are present.

Blixembosch-Oost has a decent score on ‘destination types’, meaning that most types of destinations are present within the neighbourhood. However, it has a low ‘destination density’ and ‘transport facility’ score, meaning that of those destination types that are present, there are few. The scores are as expected from a residential neighbourhood. In Blixembosch-Oost most buildings have a residential purpose, however the limited number of buildings that are not provide a diverse number of destinations types. Providing, the neighbourhood with many amenities, but with little options.

Hurk has more than half of the destination types present in the neighbourhood and even has a slightly higher destination density than Blixembosch-Oost. The lack in destination diversity was to be expected from an industrial area, however it was expected that the destination density score would be higher. It was expected that the destinations in Hurk would fall into one of the 13 destination categories described before. But it could be that they are not part of one of those categories. Another explanation is that the buildings in Hurk have a larger footprint, meaning that the neighbourhood potentially has a lot spaces dedicated to the destinations, but there are less destinations per m². Resulting in a low destination density.

Based on the variable scores on ‘destination types’, destination density’ and ‘transport facility density’, Bergen once again out performs Hurk and Blixembosch-Oost. Therefore, it is expected that the overall ‘accessibility’ score of Bergen is much higher than that of Hurk and Blixembosch-Oost. Table 4.6.4 shows the ‘accessibility’ category scores of each neighbourhood. The scores have a range from 0 to 10. Beforehand, it was expected that Bergen would have the highest ‘accessibility’ score as it is a centrally located neighbourhood with a mixed-function purpose. Meaning that the residents of the neighbourhood are near many and a diverse number of destinations. Furthermore, it was expected that Blixembosch-Oost would have a low ‘accessibility’ score, as it is located far away from the centre of Eindhoven and most buildings in the neighbourhood have a residential function.

Table 4.6.4 Accessibility scores

Neighbourhoods	Accessibility scores
Bergen	8.5
Blixembosch-Oost	5.3
Hurk	6.1

Looking at the scores in table 4.6.4, it can be seen that the expectation holds true. Bergen indeed has a high accessibility score and Blixembosch-Oost has a low score. Bergen has the highest score which come from their short average distances to almost every destination, the presence of many destination types and a high destination density. This means that the residents in this neighbourhood have a good accessibility by bicycle towards many destinations.

Blixembosch-Oost has the lowest score of all three neighbourhoods. One of the reasons for this is that it is located in the north of Eindhoven, while some destination (train station, city centre, library) are only located in the centre of the city. Destination that are not within bicycle reach do not only not positively affect the score, but even affect the score negatively. Therefore, Blixembosch-Oost losses a lot of scoring on being too far away from certain destinations.

Hurk's score is a bit better than that of Blixembosch-Oost and even not so bad for an industrial neighbourhood, which does not necessarily need to be well connected to many destination types. A potential explanation for this is that Hurk is located next to residential neighbourhoods and thus also has a decent access to destinations types that are more common in such types of neighbourhoods. Additionally, Hurk, in contrary to Blixembosch-Oost, is located relatively close to the centre. Meaning it also has decent access to the destinations only present in the centre. This could explain the scoring difference between Blixembosch-Oost and Hurk.

4.7 Bikeability level

After calculating all the category scores, it is possible to calculated the bikeability level of the three neighbourhoods. Table 4.7.1 shows the calculation of the bikeability level of each neighbourhood. Each category is scored on a scale from 0 to 10, with 10 being the highest. The bikeability level of the neighbourhood also uses a scale from 0 to 10.

Table 4.7.1 Bikeability level calculation

Categories	**Weight**	**Neighbourhoods**		
		Bergen	Blixembosch-Oost	Hurk
Bicycle infrastructure	*3*	6.0	7.9	4.0
Junction infrastructure	*4*	7.4	8.1	6.6
Bicycle parking facilities	*1*	2.5	3.1	3.9
Environment	*2*	4.8	6.3	3.1
Accessibility	*2*	8.5	5.3	6.1
Bikeability level		6.4	6.9	5.0

Table 4.7.1 shows that Blixembosch-Oost has the highest bikeability level, followed by Bergen and in last place Hurk. Blixembosch-Oost has the best score on three of the five categories, including the two variables with the highest weights. It is therefore logical that Blixembosch-Oost has the highest bikeability level. However, the bikeability level of Blixembosch-Oost is not that higher. Blixembosch-Oost has a bikeability level of 6.9, which seems a bit low when looking at their 'bicycle infrastructure' and 'junction infrastructure' category score. One of the reasons is the extremely low score on the category 'bicycle parking facilities. Although the 'bicycle parking facilities' category has only a weight of 1, the extremely low score can have a large impact on the bikeability level. This is something that is not only true for Blixembosch-Oost, but also for Bergen and Hurk. Furthermore, Blixembosch-Oost 'accessibility' is the lowest score of all three neighbourhood. All in all, this leads to an overall score of 6.9 for Blixembosch-Oost

Bergen has a bikeability level of 6.4, which seems acceptable for the neighbourhood based on the category scores. Bergen has the second highest score on three of the five categories and has the highest score on the category 'accessibility'. Furthermore, Bergen also has a decent score on the 'junction infrastructure' category which is the highest weighted category. However, Bergen also has the lowest score on the 'bicycle parking facility' category and does not score particularly well on the 'environment' category. All in all, a bikeability level of 6.4 seems reasonable score for Bergen

Lastly, Hurk has a bikeability level of 5.0. Hurk scores badly on three of the 5 categories. However, Hurk does have a decent score on 'junction infrastructure', namely a 6.6. 'Junction infrastructure' is the highest weighted category, thus it is good for the bikeability level of Hurk that it has a decent score for the junction infrastructure. All in all, a bikeability level of 5.0 seems reasonable for the industrial neighbourhood Hurk.

4.8 Conclusion & discussion

In this chapter a case study was conducted for the neighbourhoods Bergen, Blixembosch-Oost and Hurk in Eindhoven to illustrated the functioning of the tool. During the case study the tool was adjusted to a practical tool due to the inability to collect data for all the variables. No data was obtained for the variables 'car intensity' and 'pavement quality'. This meant that the practical tool made use of 50 variables instead of the recommended 52. Nevertheless, the tool was still functionable without these two variables.

In general, most of the necessary data for the variables was easy obtainable by using QuickOSM and the OpenStreetMap data base. Data that was missing in this data base was information about the bicycle infrastructure width, the separation type and the roadside type. This information was also difficult to obtain through other sources and thus it was chosen to use VI for data gathering. However, this would be too time intensive for separation type and roadside type and thus these variables score calculation was changed. Data regarding junctions was also missing in the OpenStreetMap data base, but this data was easy to obtained using VI. The average distance to destinations was something that was not found in the OpenStreetMap data base, but it could potentially be calculated with the data present in their data base. However, CBS data base already contained this information. Thus, this data was obtained from the CBS data base.

During the case study some problems occurred with the 'bicycle parking facility' category, which resulted in lower category scores for all three the neighbourhoods. The problems on the 'bicycle parking facility' category has two reasons. First, there were only a total of six BPF facilities identified across all three the neighbourhoods. Secondly, the scores of the variable 'BPF type' may have to large of an impact on the overall score of a BPF.

4.8.1 Potential improvements BPFs

The first proposed improvement for the category 'bicycle parking facilities' is to reconsider the scoring of the variables included. It should be investigated if the scores of the variables are in proportion of one another. Currently, it seems like the variables 'type' and 'security measurements' have too much of an impact on the overall BPF score. BPFs that are not of the type 'bicycle storage' or 'bicycle locker' on the variable 'type' will not be able to gain high BPF scores even when the BPF scores perfectly on the other variables. Furthermore, bicycle storages are the type of BPFs that is most often combined with security measures, meaning that these two variables may be rewarding a BPF that is a bicycle storage twice. Therefore, scorings of the variables 'type' and 'security measures' need to be reconsidered. A potential chance that could be made is to is to not only rethink the scorings, but also redefine the BPFs types. New types could potentially already account for the variable 'security measures'.

Another important improvement is to focus on the purpose of the BPFs. As the current scoring systems is highly in favour of bicycle storages, it needs to be questioned if this is always the most necessary BPF type. It is questionable if some neighbourhoods actually need bicycle storages. It can very well be that the bicycle racks may be a suitable option for the intended purpose of the BPF. Therefore, it would be recommended to research the effect of different intended purposed on the required aspects of a BPF. Thereby, it would also be recommended to not look at the destination in reach of the bicycle parking facility, but to look if destination that can attract bicyclist have the proper BPF.

As the number of identified BPFs was extremely low, it would be recommended to include smaller scaled BPFs in the tool. Currently, only BPFs of 30m² and larger are included in the research. However, useful BPFs can be smaller than that. Especially when the sever less destinations. Future research should investigate the benefits of smaller bicycle parking facilities and how these can be compared to larger scaled ones.

Lastly, the variable 'parking ratio' currently assumes a basic layout of an aisle with parking on both sides. However, it is very well possible that a BPF has a different design. Future research could look at improved ways of measuring the parking ratio while accounting for different BPF layouts.

4.8.2 Potential improvement junction infrastructure

The junction score calculation would benefit from the inclusion of a variable that compared if the chosen junction type fits with the expected traffic volume at the junction. The junctions regulated by traffic lights in Bergen and Blixembosch-oost are all located on the edge of the neighbourhood, a reason for this could be that these roads are not only used for traffic towards the neighbourhood but also by traffic passing by while traveling to other neighbourhoods. It can be expected that for that reason the traffic volume is higher and traffic lights are necessary to make the junction better manageable. This is something that is currently not considered in the calculation of the junction score. This is however, something applied in the calculation of the score of a bicycle infrastructure segment. Namely the variable 'car intensity'. As similar variable could be added to the 'junction infrastructure' category.

Furthermore, the inclusion of the maximum speed for motorized traffic would also be a good variable to add to the junction infrastructure category. Junction with a high maximum speed limit can cause more safety concerns for bicyclists than junction with a low maximum speed limit.

4.8.3 Potential improvements accessibility calculation

As mentioned in 4.6.2 'data and variable preparation', the data obtained from the CBS data base which was used for the calculation of the 'average distance to …' variables, is based on the distance travelled across car infrastructure. The aim of this category is to assess accessibility towards destination by bicycle. Therefore, it would be better if data regarding the average distance to these destinations travelled across bicycle infrastructure was used. However, this data is currently not available or does not exist. When the data is available, it would be recommended to use it instead of the currently used data from the CBS data base.

All in all, it was possible to calculate the category scores for each neighbourhood. These calculations worked as intended and led to the expected results for both the category scores and for the overall bikeability level of the neighbourhood. Therefore, it can be concluded that the assessment tool is working as intended.

5. Conclusion

The aim of this study was to broaden the understanding of 1) the concept of bikeability; 2) how the bikeability level of a Dutch neighbourhood could be assessed and; 3) how such an assessment could provide planners with insights on how to improve the bikeability level within neighbourhoods. This was accomplished by conducting a literature review on determinants of bicycle use, bicyclists' preferences and existing bikeability assessment tools. This resulted into the identification of a set of variables that could be used to measure the bikeability level of a neighbourhood. These variables were used to develop a new bikeability tool to assess the bikeability level of Dutch neighbourhoods.

Section 5.1 will summarize the findings regarding the concept of bikeability and the variables identified during the literature review. Section 5.2 will explain the developed assessment tool. Section 5.3 will present the results from a case study, which illustrates the working of the developed bikeability tool. Section 5.4 will discuss the implications for policy and practice. Finally, section 5.5 will discuss the limitations of the tool and the recommendations for future research.

5.1 Bikeability and the identified variables

A bikeability assessment tool is a method for measuring or monitoring the quality of the bicycle network in a specific area such as a neighbourhood or a municipality. In the literature multiple different descriptions of the term bikeability were found. Although different definitions of the term bikeability were used, the term bikeability was always used to assess (the level or quality of) the bicycle network in an area. Based on the reviewed literature regarding bikeability, the following description of bikeability was established: "Bikeability is a term which indicates the user friendliness of the bicycle network based on concepts such as comfort, convenience, accessibility, safety and conduciveness". These concepts can be translated into variables to measure and assess the bikeability level of an area.

Variables that were used to measure the five concepts mentioned before were identified during a literature review on the determinants of bicycle use (which includes bicycle ridership, frequency and cycling distance) and bicyclists' preferences. Socio-demographic determinants were investigated but considered as less relevant for explaining bicycle use in the Netherlands than in other countries due to the unique and diverse cycling population as well as the already high levels of cycling participation in the Netherlands.

The literature review resulted in numerous physical determinants and preferences that can influence bicycle use. These determinants and preferences were translated into variables that could be used for the development of a bikeability assessment tool. The variables are categorized into five groups of variables: bicycle infrastructure, junction infrastructure, bicycle parking facilities, environment, and accessibility. Table 5.1.1 show all the variables of each category.

Table 5.1.1 Identified variables per category

	Categories				
	Bicycle infrastructure	Junction infrastructure	Bicycle parking facilities	Environment	Accessibility
Variables	• Path type • Path width • Car intensity • Separation type • Roadside type • Speed limit • Centre line • Lighting • Obstacles • Pavement type • Pavement quality • Slopes • Land use • Speed limiting objects • One-way roads	• Junction type • Bicycle infrastructure at the junction • Speed limiting objects • Median island • Bicycle traffic lights • Bicycle box	• Bicycle parking facility type • Security measures • Parking costs • Visibility • Destinations within reachable distance • Distance to public transport stop • Capacity	• Bicycle path ratio • Bicycle infrastructure density • Intersection density • Bicycle parking density • Population density • Air quality • Green space • Land use mix • Road safety	• Distance to different type of destinations • Destination diversity • Destination density • Transit facility density

The identified variables were compared with the variables included in existing bikeability assessment tools. This led to the conclusion that ‘bicycle parking facilities’ as well as ‘accessibility’ are often overlooked categories in existing bikeability assessment tools. Additionally, it was found that junctions are often included, however design specific variables of junctions are often left out.

Due to the specific circumstances in the Netherlands, existing bikeability assessment tools may not be applicable to the Dutch context. Bikeability assessment tools often include country specific variables, which are not applicable for the Netherlands. For example, bikeability tools focused on North-America often include the presence of bus lanes, as these can be used for cycling. This is however, not allowed in the Netherlands. On the contrary, Dutch specific design elements which are not applicable for other countries are neither present. For example, the bicycle suggestion lane is something common in the Netherlands, but was not found in existing bikeability tools. Additionally, the Netherlands already has a high bicycle mode share and well-developed bicycle network, in contrast to many study locations where the existing bikeability assessment tools are applied on. This is an important difference, as those tools often lack more details regarding the bicycle infrastructure qualities and often purely focus on the presence of the bicycle infrastructure.

5.2 Bikeability assessment tool

The identified categories and variables were used to develop a new bikeability assessment tool, oriented to the Dutch context. Figure 5.1.1 illustrates the global design of the bike ability assessment tool.The tool has a total of five categories which each assess a specific part of the bikeability level of the neighbourhood. Each category will calculate a category score based on the variables mentioned in table 5.1.1. This category score represents how well the neighbourhood scores on that specific category, enabling the user of the tool to have better insight into which category causes problems, resulting in a lower bikeability level for the neighbourhood.

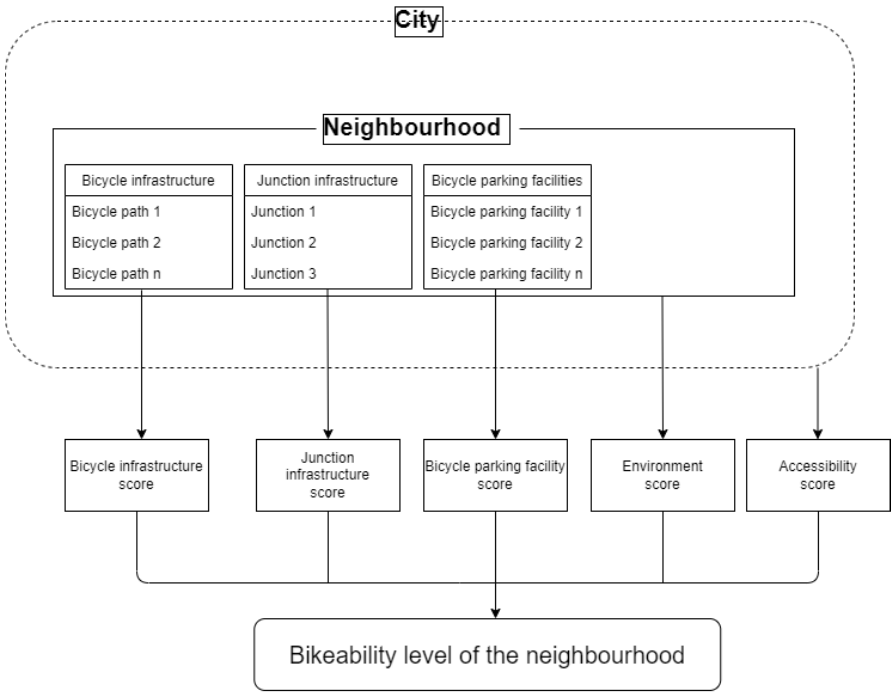


Figure 5.1.1 Global design of the bikeability assessment tool.

Figure 5.1.1 shows that the bicycle infrastructure that is assessed is part of the neighbourhood. For the category 'bicycle infrastructure' an individual score is calculated for each bicycle infrastructure segment present in the neighbourhood. The average of all the individual bicycle infrastructure segments scores is used as the 'bicycle infrastructure' category score, representing the quality of the bicycle infrastructure in the neighbourhood. The same method is used for the calculation of the 'junction infrastructure' category score and the 'bicycle parking facility' category score. First an individual score for all the junctions and bicycle parking facilities is calculated and then the average of the individual junction scores and bicycle parking facility scores is used to calculated the junction infrastructure category score and the bicycle parking facility category score. Figure 5.1.1 also shows that the environment category score is based on the environment inside the neighbourhood. The features of the neighbourhood are used to calculate the scores of the environment variables, which can then be used to determine the overall environment category score. Lastly, figure 5.1.1 shows that the neighbourhood that is assessed is part of a city. The city that the neighbourhood is part of is important for the calculation of the 'accessibility' category scores. The reason for this is that the city has amenities. These amenities form destination for residents of the neighbourhood to cycle towards. Some amenities are not present in the neighbourhood itself, but are present in the city. Resident of the neighbourhood still have access to these amenities even though they are not present in their own neighbourhood. Therefore, both the neighbourhood and the city in which the neighbourhood is located are used for the calculation of the 'accessibility' category score.

Finally, all category scores are used to determine the overall score for the bikeability level of the neighbourhood. Not every category is weighted equally in this final calculation. 'Junction infrastructure' has a weight of 4, 'bicycle infrastructure has a weight of 3, 'environment' and 'accessibility' have a weight of 2, and 'bicycle parking facility' has a weight of 1. The reason for 'junction infrastructure' and 'bicycle infrastructure' having the two highest weights is that they both provide important infrastructures for cycling, the convenience of cycling and the safety of the cyclists. Cycling accidents can occur due to poor quality of the infrastructure, therefore these categories are of high importance. Furthermore, most bicyclists' fatalities happen at junctions (SWOV, 2021), therefore junctions have a higher weight than ‘bicycle infrastructure’. The categories ‘environment’ and ‘accessibility’ both have a weight of 2. The reason for the weight is that it is important to provide an environment which encourages cycling. However, it is more important to create a safe cycling network. Lastly, the category ‘bicycle parking facilities (BPFs)’ has the lowest weight. The reason that the category ‘bicycle parking facilities’ has the lowest weight is that it is not an absolute necessity for enabling individuals to cycle in a neighbourhood. Although BPFs offer a safe place to park one’s bicycle at his/her destination, bicycles can in reality be parked almost everywhere and many cyclists choose to park their bicycle at non-designated spaces.

5.3 Case study

The working of the newly developed bikeability assessment tool was illustrated by assessing the bikeability level of three different neighbourhoods in the city of Eindhoven. The three chosen neighbourhoods are: Blixembosch-Oost, a residential neighbourhood in the north of the city; de Bergen, a mixed function neighbourhood centrally located in the city; and de Hurk, an industrial neighbourhood in the west side of the city. These neighbourhoods differ in their main purpose and location, meaning that it is expected that the results obtained from the bikeability assessment tool will be different from each neighbourhood and provide a good illustration of the tools validity. It is expected that Blixembosch-Oost will have the highest bikeability level and that de Hurk will have the lowest bikeability level.

The OpenStreetMap data base was used as the primary data source and accessed with the QuickOSM plugin in the QGIS software. Unfortunately, OpenStreetMap was missing some necessary data for the assessment. The CBS data base, Eindhoven Open Data base and the ‘Eindhoven In Cijfers’ data base, were used to obtain the data missing in the OpenStreetMap data base. However, these data bases also did not have all the necessary data. This last missing data was obtained through visual inspection which means that the features were observed to obtain the necessary data. For example, the bicycle infrastructure present at a junction was obtained by inspecting the junction using Google Maps and then writing down what type of bicycle infrastructure is present at the junction. Nevertheless, some necessary data was unobtainable through visual inspection or too time intensive to collect. For example, it was not possible to obtain the data regarding car intensity with visual inspection and it was to time intensive to measure all the different part of roadside type adjacent to the bicycle infrastructure. Because of this some variables could not be included or needed to be adjusted to be included during the illustration of the tool. The variables ‘car intensity’ and ‘pavement quality’ were removed and the variables ‘presence of streetlights’, ‘roadside type’ and ‘separation type’ were adjusted. Due to these changes, the theoretical tool was changed in a practical tool to illustrate the working of the new bikeability assessment tool. All the data necessary for the variables were imported and handled into QGIS, after which it was extracted to perform the variable score calculation in excel.

Table 5.2.1 shows the results from the case study. Based on the results from the case study, it can be concluded that the newly developed bikeability assessment tool performs as expected with one exception. The categories ‘bicycle infrastructure’, ‘junction infrastructure’, ‘environment’ and ‘accessibility’ perform as expected. These categories have higher scores for the neighbourhood where higher scores were expected. Thus, these categories of the tool seem to work properly.

Table 5.2.1 Results from the case study

Categories	Weight	Neighbourhoods		
		Bergen	Blixembosch-Oost	Hurk
Bicycle infrastructure	*3*	6.0	7.9	4.0
Junction infrastructure	*4*	7.4	8.1	6.6
Bicycle parking facilities	*1*	2.5	3.1	3.9
Environment	*2*	4.8	6.3	3.1
Accessibility	*2*	8.5	5.3	6.1
Bikeability level		6.4	6.9	5.0

The category 'bicycle parking facilities' however, results in very low scores for all of the neighbourhoods. The low 'bicycle parking facilities' category scores were expected after not identifying a bicycle parking facility with the type 'bicycle storage' or 'bicycle locker' in any of the neighbourhoods. The lack of these bicycle parking facility types results in low bicycle parking facility category scores for all the neighbourhood. It can be argued that the bicycle parking facility type variable has too big of an impact on the overall category score. Due to this, neighbourhoods without bicycle storages and lockers will be unable to obtain a decent 'bicycle parking facilities' category score. Thus, it is currently unclear if the low scores on bicycle parking facilities actually reflects an existing problem regarding bicycle parking facilities within the neighbourhoods. However, as this is a first attempt of including the bicycle parking facilities consisting out of multiple variables in a bikeability assessment tool, it is expected that it will not function perfectly. Therefore, it would be recommended that future research would further investigate the inclusion of this category.

Concluding, the tool performs mostly as expected and is considered to be able to reasonably assess the bikeability level of Dutch neighbourhoods. However, the bikeability assessment tool is not completely without flaws and can still be further improved. Nevertheless, the bikeability assessment tool can be used as a starting point for future research in developing a bikeability assessment tool for Dutch neighbourhoods.

5.4 Implications for policy and practice

The bikeability assessment tool developed in this study can be used by transportation planners to assess the bikeability levels of neighbourhoods. This can show the municipality which neighbourhoods can be troublesome for the bicycle use in the city. A low bikeability level of a neighbourhood is not only a problem for the neighbourhood itself, but can also form an obstacle for adjacent neighbourhoods. Individuals living in a neighbourhood with a high bikeability level surrounded by only low bikeability level neighbourhoods can potentially discourage these individuals to bicycle to locations outside of their neighbourhood. Because for those trips they have to bicycle through low bikeability level neighbourhoods, which may be unappealing. Therefore, it is important for the municipality to be able to assess the bikeability level of each neighbourhood in their city.

Furthermore, due to the category scores, the bikeability assessment tool can help with identifying the specific aspect that causes a high or low bikeability level of neighbourhoods. The category scores provide insight in how the overall bikeability score is constructed. This can help the municipality with determining where and in which to invest. For example, the category scores can show that the bicycle infrastructure in a neighbourhood is extremely good and that investing in even better bicycle infrastructure would be ineffective. In addition, the category scores show that the accessibility score of the neighbourhood is very low, indicating that there are no destinations to cycle to. Therefore, investing in accessibility of destinations would be an effective way to increase the bikeability level. Thus, the municipality should focus on developing destinations in and around this neighbourhood to increase the bikeability level rather than investing in the bicycle infrastructure.

The bikeability assessment tool can also provide insight in potential infrastructure or environment changes and what the impact of these changes will be on the bikeability level of the neighbourhood. An example of this is that the municipality can change all bicycle suggestion lanes into bicycle paths in the bikeability assessment tool and observe what this does to the bikeability level of the neighbourhood. They can then also decide to chance all bicycle suggestion lanes into bicycle lanes and see how this would differ from the bicycle path scenario. Another example, they could remove a green space and replace with dwellings and see if this would be harmful for the bikeability level of the neighbourhood. Thus, municipality can use the bikeability assessment tool to investigate and compare different scenarios and see the different impacts of each scenario. This information can be used to decide the most satisfying scenario or even if they have to design new scenarios with an even higher impact.

5.5 Limitations & future research

One of the draw backs of this study is the missing of data necessary to perform the assessment. The lack of data results in the need to adjust the theoretically developed bikeability assessment tool into a practical tool which excludes the variables which data are missing. This means that the developed theoretical model is adapted to work with existing data, which brings it further away from the actual situation. Thus, this adjustment of the tool is not desired. Luckily, most missing data could be obtained through visual inspection. However, visual inspection is not a 100% accurate form of data requirement and takes a lot of time/effort. Therefore, the results of the adapted tool itself are more prone to inaccuracies and due to this less reliable.

It would be recommended for municipalities to better record data about the bicycle network. Data about pavement quality, path width, bicycle intensity, separation type, roadside type and the presence of centre lines should be gathered for all bicycle paths within the city. Data regarding car intensity was also missing. It would be recommended that municipalities would also gather data regarding car intensity for all roadways in the city. However, gathering all this data can also be a difficult and time intensive task for the municipality. Therefore, for future research, it would be recommended to investigate the use of a combination of satellite photos and computer vision to obtain this data for all the bicycle infrastructure in a city. Computer vision could eliminate the inaccuracies of visual inspection and ensure that each path is measured exactly in the same manner. Thus, the use of computer vision could remove the potential human error in the data gathering. Furthermore, computer vision could collect data much quicker than an individual would and update the data more frequently. Ito & Biljecki (2021) already investigate some aspect of the appliance of computer vision to measure bicycle infrastructure. However, more research can still be conducted on how to apply computer vision for gathering data about the bicycle infrastructure and all of its aspects, as well as on how to make a system that regularly updates the bicycle infrastructure data.

Another drawback comes from the problems regarding the ‘bicycle parking facilities’ category. As mentioned before, the ‘bicycle parking facilities’ scores of all the neighbourhoods are on the lower side. The main problem comes from the scores assigned to the variable ‘bicycle parking facility type’, which may be too punishing on the bicycle parking facilities that are not acknowledged as storages or lockers. Furthermore, the variable ‘security measures’ also has a large impact on the scoring and is somewhat intertwined with the bicycle storage type, as bicycle storage are the type of bicycle parking facilities that is most often combined with security measurements. Meaning that these two variables may be rewarding a bicycle parking facility that is a bicycle storage twice. These two variables combined create a large difference between bicycle parking facilities that are bicycle storages and those that are not. Because of this, neighbourhoods without bicycle storages struggle to obtain a higher score on the 'bicycle parking facility' category. Therefore, the scoring of the variables 'bicycle parking facility type' and 'security measures' needs to be reconsidered. A potential chance that could be made is to not only rethink the scorings, but also redefine the bicycle parking facility types. New types could potentially already account for the variable security measures. It is also not clear if the low scores on 'bicycle parking facilities' actually reflect an existing problem within the neighbourhood. The reason for this is that it is questionable if all neighbourhoods would actually need a bicycle storage or lockers. It could very well be that the existing bicycle parking facilities are suitable for their intended purposes.

While this study presented a first attempt of including bicycle parking facilities consisting out of multiple variables in a bikeability assessment tool, and identifies important variables, there is still room for improvement. Future research could further investigate the inclusion of this category and build upon the steps made in the development of this tool. Future research could specifically focus on the assessment of bicycle parking facilities, to gain a better understanding of the assessment of different types of bicycle parking facilities. It is recommended to research the different intended purposes of bicycle parking facilities and how these can influence the preferences of cyclists/residents. It would also be recommended to not look at the destinations in reach of the bicycle parking facility, but to look if destinations that can attract bicyclist have proper bicycle parking facilities. Another suggestion for future research would be to focus on the benefits of the smaller bicycle parking facilities, as those were excluded from the tool.

Another aspect that is recommended to look further into is the chosen weights for the categories and variables. The chosen weights that were used for the bikeability assessment tool, are based on what the general public find most important. This makes the category scores and the bikeability level represent the largest group of individuals. However, research has shown that different groups of people can see different variables as most important. For example, elderly put additional importance on surface quality of the bicycle path, because surfaces with poorer quality require them to focus more on the bicycle path. This results in less attention for dangerous traffic situations and less opportunities to enjoy the surroundings (Van Cauwenberg et al, 2019). Another example of this, for e-bike riders, distance is less important as they can more easily travel further distances. However, as their bicycles are more expensive, they can have a higher preference for better security at bicycle parking.Thus, for different groups of bicyclists, different variables are important. Therefore, 'weight profiles' can be developed for different groups, indicating what they think is most important and assessing the bikeability level of the neighbourhood from their perspective. This is something that was not yet investigated in this study. However, future research could investigate different 'weight profiles' for the bikeability tool developed in this study or could use the variables included in this tool as a basis for their research. Stated or revealed preference surveys could be used to identify weight profiles for different groups of individuals. This would make it possible to assess the bikeability of a neighbourhood for different groups of people (elderly, e-bikers, recreational cyclists, etc.) and ensure a high neighbourhood bikeability level for all.

Having said all of that, the newly developed bikeability assessment tool can score five categories related to bicycle use and assess the overall bikeability level of a neighbourhood. The assessment can provide insight specific problem of a neighbourhood and insight for the investment decisions of municipalities. This enables municipalities to create and maintain neighbourhoods of high bikeability levels that support and promote bicycle use.

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Appendix I

Appendix I includes a list of all the reviewed bikeability assessment tools during the tool review with information about the tool's development year, development context, method and the included variables.

Study	Year	Location	Method	Variables
Assessing bikeability with street view imagery and computer vision – Ito & Biljecki	2021	Singapore & Japan	Street view imagery and computer vision are used to assess the bikeability in the form of a multicriteria assessment in which all variables are weighted equally and scaled between 0 and 1.	Number of intersections with lights
				Number of intersections without lights
				Number of cul-de-sacs
				Slope
				Number of POIs
				Shannon land use mix index
				Air quality index
				Scenery: greenery
				Scenery: Buildings
				Scenery: water
				Type of road
				Presence of potholes
				Presence of street light
				Presence of bike lanes
				Number of transit facilities
				Type of pavement
				Presence of street amenities
				Presence of utility pole
				Presence of bike parking
				Road width
				Presence of sidewalk
				Presence of crosswalk
				Presence of curb cuts
				Attractiveness for cycling
				Spaciousness
				Cleanliness
				Building design attractiveness
				Safety as a cyclist

				Beauty
				Attractiveness for living
				Number of vehicles
				Presence of on-street parking
				Presence of traffic lights / stop signs
				Number of speed control devices
The Munich bikeability index: A practical approach for measuring urban bikeability – Schmid-Querg et al.	2021	Germany	The authors used GIS-software to obtain data which they used in a multi-criteria assessment to determine the bikeability of Munich. The score of the variables is determined by categories.	Existence and type of bike path
				Speed limit
				Parking facilities for bicycles
				Quality of intersection infrastructure for bicycle
Developing an urban bikeability index for different types of cyclists as a tool to prioritise bicycle infrastructure investments – Arellana et al.	2020	Global South	The authors use a multinomial logit model to weight identified variables which determine the bikeability of road segments for differ types of cyclists. The variables are then normalized ranging between 0 and 1.	Presence of bicycle infrastructure (regarding presence of bicycle infrastructure)
				Presence of bicycle infrastructure (regarding comfort & attractiveness)
				Quality of bike path pavement
				Obstacles on bike paths
				Slope of bike paths
				Width of bike paths
				Presence of trees
				Aesthetics of buildings
				Presence of bicycle infrastructure (regarding traffic safety)
				Presence of traffic control devices
				Bus traffic flow
				Vehicle traffic flow
				Motorcycle traffic flow
				Pedestrian traffic flow
				Motorised transport speed
				Presence of police officers
				Presence of security cameras
				Bike traffic flow
				Lightning
				Criminality on roads

Modeling bikeability of urban systems – Gholamialam and Matisziw	2019	USA	The authors develop a multi-criterion shortest path framework which evaluates multiple paths between origin and destination based on different characteristics of bikeability to determine the ‘shortest path’ based on path costs. The result is a set of Pareto-optimal paths for four different scenarios. These paths represent the bikeability of the urban area.	Path length Speed limit Number of lanes Presence of dedicated bike lane Number of intersections
Bikeability in Basel – Grigore et al.	2019	Switzerland	They used existing route choice studies to identify attributes which can represent cycling qualities that influence route choice behaviour. They used cost components to calculate path cost which they called perceived distance. The bikeability is then calculated as the average of the perceived distances along the shortest paths that are connected to all destinations of interests, divided by the intensity of the activity at the destinations.	Bicycle specific traffic light Slope of the road Type & dimensions of the cycling infrastructure Presence of hazards Aesthetics and comfort of the environment Signals at intersections Intersection layout Destinations Activity intensity
Inequalities in access to bike-and-ride opportunities: Findings for the city of Malmö – Hamidi et al.	2019	Sweden	The authors propose a regression equation for calculating bikeability based on multiple criteria with each their own weight. The values of the criteria have been normalized.	Accessibility Available bike parking spots Public bike share stations
Bikeability: assessing the objectively measured environment in relation to recreation and transportation bicycling – Porter et al.	2019	USA	The authors identified potential objective environmental factors that influence bikeability. They combined these findings with an online questionnaire regarding the bicycle use of individuals living in the study area. Then they used a spearman correlation to determine the effect of the environmental factors on the bicycle frequency, resulting in a multiple regression equation to calculate bikeability.	Bike lanes Residential density Population density Ozone level Distance to transit Parks Tree canopy coverage
Using open-source data to measure street walkability and bikeability in China - Gu et al.	2018	China	They used high-resolution street view imagery, point of interest data and building footprint raster data which they linked to the street segments to obtain spatial information of each street segment. With this, they identifying 12 indicators for calculating a walkability & bikeability score, which they calculated with a multiple regression equation.	Bike lane existence Crossing facility existence Bike lane with illegal parking Streets with tree shades Bike lane isolation Street network density Crossing facility density

				Facility accessibility
Assessing area-wide bikeability: A grey analytic network process -Lin and Wei	2018	Taiwan	The authors developed a method that uses an analytic network process (ANP) containing multiple criteria to calculate the bikeability of urban areas.	Bikeway density
				Bikeway width
				Bikeway exclusiveness
				Bike parking space density
				Parking space for motorized traffic
				Traffic volume
				Bus route
				Law enforcement
				Transit service
				Public bike service (BSS)
				Public bike unavailability (BSS)
				Tree shade
				Green space
				Air quality
				Slope
				Smooth traffic
				Conflictless traffic
				Night lighting
				Intersection density
				Bikeway ratio
				Mixed land use
Measuring cycling accessibility in metropolitan areas – Saghapour et al.	2017	Australia	GIS software was used to perform an origin-destination cost matrix analysis and a service area analysis. This calculated the cycling catchments of the destinations as well as the distance (or travel time) between the origins and destinations. These results are then used to calculated the area ratio and the travel impedance, which can be combined to calculate the CAI.	Area ratio (measuring diversity and intensity of the land uses)
				Travel impedance
Do people's perception of neighbourhood bikeability match reality? – Ma and Dill	2016	USA	The authors analysed a potential mismatch between the objective and perceived bicycling environment using a combination of factor and cluster analyses.	Off-street bike paths
				Bike lanes
				Minor streets
				Destinations
				Street connectivity
				Hilliness

Prioritising new bicycle facilities to improve low-stress network connectivity - Lowry et al.	2016	USA	The authors calculate the stress levels that bicyclists experience during their journey with the uses of two marginal rate of substitutions values (stress increasing and stress decreasing factors). This is then used in combination with the distance and the slope to calculate the path costs. The route choice is then based on that the bicyclist will minimize the path cost to choose the shortest path.	Roadway stress factor (based on number of lanes and speed limit) Bicycle accommodation stress reduction factors (bike lanes types) Cross-street stress factor (based on number of lanes and speed limit) Crossing stress reduction (bicycle accommodation during crossings) Path length Slope of the path Intersection turn factor
Bike Score: associations between urban bikeability and cycling behaviour in 24 cities - Winters et al.	2016	USA & Canada	Bike score is a simple multi criteria assessment to assign a bikeability score to cities based on three environmental variables.	Bike lane score Hill score Destination and connectivity score
Development of a bikeability index to assess the bicycle friendliness of urban environments – Krenn et al.	2015	Austria	The authors developed a multi criteria bikeability index consisting of 6 variables that could each score up to 10 points. These points were assigned based on the measured results in a GIS software.	Cycling infrastructure Bicycle pathways Main roads Green and aquatic areas Topography (slope) Land use mix
Mapping bikeability: A spatial tool to support sustainable travel - Winters et al.	2013	Canada	Results of an opinion survey, travel behaviour studies, and focus groups led to the identification of components and their weights that can be used to calculate bikeability of urban areas. GIS data was obtained for these components, which enabled them to calculate and map the bikeability of Vancouver.	Bicycle route density Bicycle route separation Street connectivity Topography Land-use
Assessment of communitywide bikeability with bicycle level of service -Lowry et al.	2012	USA	The proposed bikeability assessment is a combination of calculating the bicycle suitability based on the highway capacity manual and the access to important destinations. The calculation determines the bikeability by identifying the shortest route between zones by minimizing link suitability multiplied by link distance.	Width of outside lane Width of bike lane Width of shoulder Proportion of occupied on-street parking Vehicle traffic volume Vehicle speeds Percentage of heavy vehicles Pavement conditions Presence of curb

				Number of through lanes
				Width (off-street shared-used pathways)
				Presence of painted centreline (off-street shared-used pathways)
				Hourly volumes of pedestrian, bicyclist and roller skaters (off-street shared-used pathways)
				Accessibility
				Importance of destination
				Distance decay (depends on impedes)
Bikeability and the 20-min neighbourhood: How infrastructure and destination influence bicycle accessibility - McNeil	2011	USA	The bikeability is determined by a scoring system which provide score for different types of destinations within the distance threshold from the origin point, where locations scored lower points if they were located in a larger radius distance.	Destinations
				Effective length of road segment (based on road infrastructure)
Evaluation of the bikeability of a Greek city; Case study 'City of Volos' - Eliou et al.	2009	Greece	The authors developed a questionnaire to evaluated the bikeability based on multiple criteria. In the questionnaire ratings needed to be assigned to certain bikeability elements and the average of these ratings resulted in the bikeability score.	Bicycle safety on and off road
				Infrastructure surface quality
				Intersection ease of use
				Car drivers' behaviour towards cyclists
				General ease of use bicycle

Appendix II

Appendix II includes the acquired data necessary for the variable score calculations of the category bicycle infrastructure and the calculated scores with these data for each neighbourhood. Furthermore, table A.II explains the coded answers used in the excel file for certain variables.

Table A.II Coded answers bicycle infrastructure

Variables	Coded Category	Category
Path type	1	Bicycle path
	2	Moped & bicycle path
	3	Bicycle suggestion lane
	4	Two-way bicycle path
	5	Two-way moped & bicycle path
	6	Two-way bicycle suggestions lane
	7	Bicycle lane
	8	Bicycle suggestion lane
	9	Bicycle street
	10	Roadway
Network type	1	Basic network and main routes
	2	Regional routes
Center line	1	Present
	2	Not present
Separation type	0	Not dominant separation type
	1	Dominant separation type
Roadway type	0	Not dominant roadway type
	1	Dominant roadway type
Street lights	1	Not present
	2	Present
Obstacles	1	None
	2	Limited
	3	High
Pavement type	1	Closed pavement
	2	Open pavement
	3	Other
Land use type	1	Neutral land use type
	2	Positive land use type
	3	Negative land use type
Speed limiting objects	1	Present
	2	Not Present
One-way	1	Present
	2	Not present

Acquired data for the bicycle infrastructure score calculation of Bergen:

ID	Path t	Network t	Car lane wi	Bicycle inte	Car inten	Path wid	Speed limit	Center li	Path len	ST Vege	ST Vegetati	ST Vegetat	ST Curb L	ST Curb sl	ST Curb I	ST Phy	ST Parking	RT Vege	RT Veg	RT Vege	RT Curb Le	RT Curb slopin	RT Cu	RT Ph	RT Pa	Streetl	Obstac	Pavement t	Pavement cond	Slope	Land #	Land u	Land u	sp_lim	one-wa
#	Cat.	Cat.	cm	Bicycle per hou	Cars per da	cm	km/h	Cat.	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	#	Cat.	Cat.	Cat.	#	m	m	m	cat.	cat.
w7165757	7	1		400		160	50		40	1															1	2	1	1		0	2				
w7165759	7	1		400		160	50		17																1	2		1		0	2				
w7165761	1	1		400		240			17						1							1				2	1	1		0	2				
w7165761	1	1		400		240			11						1							1				2	1	1		0	1				
w540500263	7	1		400		160	50		44																1	2	1	1		0	2				
w540501755	7	1		400		160	50		9																1	2	1	1		0	2				
w540501755	7	1		400		160	50		34																1	2	1	1		0	1				
w7157784	4	1		400		420		1	56			1									1					2	1	1		0	2				
w7166020	4	1		400		340		2	8		1										1					2	2	2		0	1				
w80628759	7	1		400		350		1	5						1							1				2	1	1		0	2				
w80628761	7	1		400		160	50		4													1				2	1	1		0	2				
w80628762	7	1		400		360			5			1								1						2	1	1		0	2				
w80628762	7	1		400		360			3			1								1						2	1	1		0	2				
w80628763	7	1		400		400		1	12						1							1				2	1	1		0	2				
w80628763	7	1		400		400		1	7						1							1				2	1	1		0	2				
w115753262	1	1		400		220			46				1								1					2	1	1		0	2				
w129470412	1	1		400		220			6				1									1				2	1	1		0	2				
w129470413	1	1		400		280			5			1										1				2	1	1		0	2				
w135177418	1	1	0	400	0	250	0	0	118	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	1				
w135177421	1	1	0	400		200	0	0	24	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	1				
w135177421	1	1	0	400		200	0	0	39	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	2				
w138669725	1	1	0	400	0	200	0	0	202	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	2				
w142916268	1	1		400		200			4				1									1				2	1	1		0	2				
w181557554	1	1		400		300			22						1								1			2	1	1		0	2				
w181557557	1	1		400		210			29						1					1						2	1	1		0	2				
w181557558	1	1	0	400	0	200	0	0	12	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2	1	1		0	1				
w181557558	1	1	0	400	0	200	0	0	109	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2	1	1		0	2				
w181557558	1	1	0	400	0	200	0	0	20	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	2	1	1		0	1				
w182788370	1	1		400		250			42						1							1				2	1	1		0	1				
w182788388	1	1		400		240			28					1						1						2	1	1		0	1				
w210073161	1	1		400		200			44			1										1				2	1	1		0	2				
w210073184	1	1		400		500			5						1							1				2	1	1		0	1				
w503231109	4	1		400		400		1	63			1											1			2	1	1		0	2				
w540501758	1	1		400		210			70					1								1				2	1	1		0	2				
w626310729	1	1		400		200			5				1								1					2	1	1		0	2				
w626310730	1	1	0	400		200			116				1									1				2	1	1		0	2				
w686145496	4	1	0	400	0	400		1	153	1	0	0	0	0	0	0					1					2	1	1		0	2				
w745723100	1	1		400		300			3						1							1				2	1	1		0	1				
w12345667	8	1	380	400		200	50		202				1										1			2	1	1		0	2				
w12345667	8	1	380	400		200	50		80				1										1			2	1	1		0	1				
w540502467	7	1		400		160	50		45				1								1					2	1	1		0	1				
w7166109	7	1		400		160	50		61				1									1				2	1	1		0	1				
w540502466	7	1		400		160	50		52				1									1				2	1	1		0	1				
w7157784	4	1		400		420		1	7			1									1					2	1	1		0	1				
w7166020	4	1		400		340		2	7		1										1					2	2	2		0	1				
w80628759	7	1		400		350		1	4						1							1				2	1	1		0	2				
w80628761	7	1		400		160	50		14				1									1				2	1	1		0	2				
w129470412	1	1		400		220			6				1									1				2	1	1		0	1				
w129470413	1	1		400		280			5			1										1				2	1	1		0	1				
w135177418	1	1	0	400	0	250	0	0	39	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	1				
w135177421	1	1	0	400		200	0	0	337	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	2	1	1		0	1				
w138669721	1	1		400		200			148			1										1				2	1	1		0	1				
w138669725	1	1	0	400	0	200	0	0	35	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	2	1	1		0	2				
w142916268	1	1		400		200			5				1									1				2	1	1		0	2				

w181557554	1	1		400		300			4						1									1			2	1	1		0	1					
w181557558	1	1	0	400	0	200	0	0	108	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2	1	1		0	1					
w182788370	1	1		400		250			27						1								1				2	1	1		0	1					
w626310730	1	1	0	400		200			39				1										1				2	1	1		0	1					
w745723104	1	1		400		200			126				1									1					2	1	1		0	1					
w7157808	10		670	400			50		2						1									1			2	1	1		0	2			2	2	
w7165767	10		710	400			50		155						1									1			2	1	2		0	3			1	2	
w7165805	10		670	400			50		16									1								1	2	1	2		0	2			1	2	
w7165996	10		500	400			50		151						1											1	2	1	2		0	3			2	2	
w7157808	10		670	400			50		9						1									1			2	1	1		0	2			2	2	
w7157822	10		670	400			50		2						1									1			2	1	1		0	2			2	2	
w7165767	10		710	400			50		80						1									1			2	1	2		0	1			1	2	
w7165805	10		670	400			50		345									1								1	2	1	2		0	1			1	2	
w12345678	10		400	400			30		79									1								1	2	1	2		0	1			2	2	

Score calculation of the bicycle infrastructure variables for Bergen

ID	Path type	Car intensity	Path width	Separation type	Speed limit	Center line	Roadside type	Streetlight	Obstacles	Pavement type	Pavement conditions	Slope	Land use type	Sp_lim_ob	one-way		Score	Path lenght	
#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
w716575	5	1	-0,36	0	0	0	-1	1	0	1	0	0	1	0	0		4,7428571	40	189,714
w716575	5	1	-0,36	0	0	0	-1	1	0	1	0	0	1	0	0		4,7428571	17	80,6286
w716576	10	0	-0,111111111	-1	0	0	-0,5	1	0	1	0	0	1	0	0		8,1349206	17	138,294
w716576	10	0	-0,111111111	-1	0	0	-0,5	1	0	1	0	0	0	0	0		7,4206349	11	81,627
w540500	5	#DIV/0!	-0,36	0	0	0	-1	1	0	1	0	0	1	0	0		4,7428571	44	208,686
w540501	5	#DIV/0!	-0,36	0	0	0	-1	1	0	1	0	0	1	0	0		4,7428571	9	42,6857
w540501	5	#DIV/0!	-0,36	0	0	0	-1	1	0	1	0	0	0	0	0		4,0285714	34	136,971
w715778	10	0	0,166666667	-0,5	0	0	0	1	0	1	0	0	1	0	0		9,047619	56	506,667
w716602	10	0	-0,055555556	-0,5	0	-1	0	1	-0,5	0,5	0	0	0	0	0		6,7460317	8	53,9683
w806287	5	#DIV/0!	0,4	-1	1	0	-0,5	1	0	1	0	0	1	0	0		5,6428571	5	28,2143
w806287	5	#DIV/0!	-0,36	0	0	0	-0,5	1	0	1	0	0	1	0	0		5,1	4	20,4
w806287	5	#DIV/0!	0,44	-0,5	1	0	-0,5	1	0	1	0	0	1	0	0		6,0285714	5	30,1429
w806287	5	#DIV/0!	0,44	-0,5	1	0	-0,5	1	0	1	0	0	1	0	0		6,0285714	3	18,0857
w806287	5	#DIV/0!	0,6	-1	1	0	-0,5	1	0	1	0	0	1	0	0		5,7857143	12	69,4286
w806287	5	#DIV/0!	0,6	-1	1	0	-0,5	1	0	1	0	0	1	0	0		5,7857143	7	40,5
w115753	10	0	-0,185185185	0	0	0	0	1	0	1	0	0	1	0	0		9,1534392	46	421,058
w129470	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	1	0	0		8,7962963	6	52,7778
w129470	10	0	0,037037037	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0		8,5978836	5	42,9894
w135177	10	0	-0,074074074	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1613757	118	963,042
w135177	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0		7,6719577	24	184,127
w135177	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0		8,3862434	39	327,063
w138669	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	1	0	0		8,7433862	202	1766,16
w142916	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	1	0	0		8,7433862	4	34,9735
w181557	10	0	0,111111111	-1	0	0	-1	1	0	1	0	0	1	0	0		7,9365079	22	174,603
w181557	10	0	-0,222222222	-1	0	0	-0,5	1	0	1	0	0	1	0	0		8,0555556	29	233,611
w181557	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	0	0	0		8,3862434	12	100,635
w181557	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	1	0	0		9,1005291	109	991,958
w181557	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	0	0	0		8,3862434	20	167,725
w182788	10	0	-0,074074074	-1	0	0	-0,5	1	0	1	0	0	0	0	0		7,4470899	42	312,778
w182788	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0		7,7777778	28	217,778
w210073	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0		8,3862434	44	368,995
w210073	10	0	0,851851852	-1	0	0	-0,5	1	0	1	0	0	0	0	0		8,1084656	5	40,5423
w503231	10	0	0,111111111	-0,5	0	0	-1	1	0	1	0	0	1	0	0		8,2936508	63	522,5
w540501	10	0	-0,222222222	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0		8,4126984	70	588,889
w626310	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	1	0	0		9,1005291	5	45,5026

w6263107	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7433862	116	1014,23
w6861454	10	0	0,111111111	0	0	0	0	1	0	1	0	0	1	0	0	9,3650794	153	1432,86
w7457231	10	0	0,111111111	-1	0	0	-0,5	1	0	1	0	0	0	0	0	7,5793651	3	22,7381
w1234566	4	#DIV/0!	-0,090909091	0	-0,666667	0	-1	1	0	1	0	0	1	0	0	3,7445887	202	756,407
w1234566	4	#DIV/0!	-0,090909091	0	-0,666667	0	-1	1	0	1	0	0	0	0	0	3,030303	80	242,424
w5405024	5	#DIV/0!	-0,36	0	0	0	0	1	0	1	0	0	0	0	0	4,7428571	45	213,429
w7166109	5	#DIV/0!	-0,36	0	0	0	-0,5	1	0	1	0	0	0	0	0	4,3857143	61	267,529
w5405024	5	#DIV/0!	-0,36	0	0	0	-0,5	1	0	1	0	0	0	0	0	4,3857143	52	228,057
w7157784	10	0	0,166666667	-0,5	0	0	0	1	0	1	0	0	0	0	0	8,3333333	7	58,3333
w7166020	10	0	-0,055555556	-0,5	0	-1	0	1	-0,5	0,5	0	0	0	0	0	6,7460317	7	47,2222
w8062875	5	#DIV/0!	0,4	-1	1	0	-0,5	1	0	1	0	0	1	0	0	5,6428571	4	22,5714
w8062876	5	#DIV/0!	-0,36	0	0	0	-0,5	1	0	1	0	0	1	0	0	5,1	14	71,4
w1294704	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,0820106	6	48,4921
w1294704	10	0	0,037037037	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,8835979	5	39,418
w1351774	10	0	-0,074074074	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1613757	39	318,294
w1351774	10	0	-0,259259259	-1	0	0	-0,5	1	0	1	0	0	0	0	0	7,3148148	337	2465,09
w1386697	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,6719577	148	1135,45
w1386697	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7433862	35	306,019
w1429162	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7433862	5	43,7169
w1815575	10	0	0,111111111	-1	0	0	-1	1	0	1	0	0	0	0	0	7,2222222	4	28,8889
w1815575	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	0	0	0	8,3862434	108	905,714
w1827883	10	0	-0,074074074	-1	0	0	-0,5	1	0	1	0	0	0	0	0	7,4470899	27	201,071
w6263107	10	0	-0,259259259	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,0291005	39	313,135
w7457231	10	0	-0,259259259	0	0	0	0	1	0	1	0	0	0	0	0	8,3862434	126	1056,67
w7157808	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	1	0	0	2,3809524	2	4,7619
w7165767	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	1	0	1,3095238	155	202,976
w7165805	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	1	1	0	2,7380952	16	43,8095
w7165996	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	151	89,881
w7157808	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	1	0	0	2,3809524	9	21,4286
w7157822	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	1	0	0	2,3809524	2	4,7619
w7165767	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	0	1	0	2,0238095	80	161,905
w7165805	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	0	1	0	2,0238095	345	698,214
w1234567	3	#DIV/0!	0	-1	0	0	-1	1	0	0,5	0	0	0	0	0	1,7857143	79	141,071

Acquired data for the bicycle infrastructure score calculation of Blixembosch-Oost:

ID	Path t	Network t	Car lane wi	Bicycle inte	Car inten	Path wid	Speed limit	Center li	Path len	ST Vege	ST Vegetati	ST Vegetat	ST Curb L	ST Curb sl	ST Curb l	ST Phy	ST Parking	RT Vege	RT Veg	RT Vege	RT Curb Le	RT Curb slopin	RT Cu	RT Ph	RT Pa	Street	Obstac	Pavement t	Pavement cond	Slope	Land #	Land u	Land u	sp_lim	one-wa
#	Cat.	Cat.	cm	Bicycle per hou	Cars per da	cm	km/h	Cat.	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	#	Cat.	Cat.	Cat.	#	m	m	m	cat.	cat.
w7163265	8	1		400		200	30		133									1								2	1	1		0	1				
w4991155	4	1		400		360		1	63				1								1					2	2	2		0	1				
w7159843	4	1		400		240		2	18			1										1				2	2	2		0	1				
w7159844	1	1		400		240		2	28				1											1		2	2	2		0	1				
w7163065	4	1		400		400			205				1							1						2	1	1		0	1				
w7163066	4	1		400		400		1	11					1								1				2	2	2		0	1				
w7163253	1	1		400		230			77					1				1								2	1	1		0	1				
w7163253	1	1		400		230			3					1				1								2	1	1		0	1				
w7163257	1	1		400		230			77	1												1				2	1	1		0	1				
w7163257	1	1		400		230			3	1												1				2	1	1		0	1				
w7163309	4	1		400		350		2	184	1								1								2	1	1		0	1				
w7823149	4	1		400		350		2	130	1								1								2	1	1		0	1				
w24665283	4	1		400		400		1	228					1				1								2	2	1		0	1				
w24665283	4	1		400		400		1	49					1				1								2	2	1		0	2				
w25183877	4	1		400		400			227				1							1						2	1	1		0	1				
w25185723	6	1		400		380		2	57							1								1		1	1	1		0	1				
w25185727	4	1		400		400			145			1								1						2	1	1		0	1				
w25185730	4	1		400		400			239			1								1						2	1	1		0	1				
w25185730	4	1		400		400			11			1								1						2	1	1		0	4				
w25316441	1	1		400		240			616				1									1				2	1	1		0	1				
w25316441	1	1		400		240			70				1									1				2	1	1		0	2				
w25316448	1	1		400		240			981				1									1				2	1	1		0	1				
w25316450	1	1		400		240			16				1									1				2	1	1		0	1				
w25316450	1	1		400		240			115				1									1				2	1	1		0	2				
w25316477	1	1		400		240			383	1								1								2	1	1		0	1				
w25316477	1	1		400		240			37	1								1								2	1	1		0	2				
w25316485	1	1		400		240			131				1									1				2	1	1		0	1				
w25316510	1	1		400		240			278				1									1				2	1	1		0	1				
w25316510	1	1		400		240			686				1									1				2	1	1		0	1				
w25316510	1	1		400		240			66				1									1				2	1	1		0	4				
w25316557	4	1		400		400		1	120			1									1					2	1	1		0	1				
w25316557	4	1		400		400		1	144			1									1					2	1	1		0	2				
w25316561	4	1		400		320		2	3	1								1								2	1	1		0	1				
w25316561	4	1		400		320		2	159	1								1								2	1	1		0	2				
w26777698	4	1		400		420		1	19				1								1					2	1	1		0	2				
w26777699	4	1		400		400		1	8	1								1								2	1	1		0	2				
w26777701	4	1		400		320		1	55			1											1			2	2	1		0	1				
w28336653	1	1		400		240			270				1									1				2	1	1		0	1				
w28336653	1	1		400		240			1				1									1				2	1	1		0	2				
w28940593	4	1		400		400		1	137	1												1				2	1	1		0	2				
w28940594	4	1		400		380		2	32	1													1			2	2	2		0	2				
w28940598	4	1		400		410		2	37	1								1								2	1	1		0	1				
w31177134	1	1		400		240			426				1									1				2	1	1		0	1				
w36857582	4	1		400		400		2	11	1								1								2	1	2		0	1				
w36857590	4	1		400		400		1	14						1								1			2	2	2		0	1				
w36857596	1	1		400		220			46	1												1				2	1	1		0	2				
w36857597	1	1		400		220			61		1							1								2	1	1		0	2				
w36857598	1	1		400		380		1	76					1								1				2	1	1		0	1				
w36857598	1	1		400		380		1	20					1								1				2	1	1		0	2				
w118046505	4	1		400		360		1	13						1								1			2	2	2		0	1				
w121272043	1	1		400		240			614				1									1				2	1	1		0	1				
w121272043	1	1		400		240			38				1									1				2	1	1		0	2				
w206567415	5	1		400		410		1	150	1								1								2	1	1		0	4				
w235509588	5	1		400		410		1	139	1								1								2	1	1		0	4				

w235546321	1	1		400	220			5		1								1			2	1	1	0	1
w235546321	1	1		400	220			60		1								1			2	1	1	0	4
w255069553	4	1		400	400		1	825	1						1						2	1	1	0	4
w258344063	1	1		400	220			59		1								1			2	1	1	0	4
w269867148	1	1		400	240			271		1								1			2	1	1	0	1
w338310121	4	1		400	400		1	516		1									1		2	1	1	0	2
w620568019	1	1		400	330		2	71						1					1		2	1	2	0	1
w626003727	5	1		400	410		1	148	1						1						2	1	1	0	4
w693158744	4	1		400	360		1	27				1						1			2	1	1	0	2
w807585943	5	1		400	410		1	162	1						1						2	1	1	0	4
w810607063	4	1		400	360		1	29					1					1			2	1	2	0	2
w815466665	4	1		400	410		2	14	1						1						2	1	1	0	1
w815466666	4	1		400	410		2	81	1						1						2	1	1	0	1
w933043889	4	1		400	400		1	82			1					1					2	1	1	0	1
w933043898	1	1		400	220			0	1	0								1			2	1	1	0	1
w933043898	1	1		400	220			73	1	0								1			2	1	1	0	2
w933043898	1	1		400	220			84	1	0								1			2	1	1	0	2
w933043899	1	1		400	220			1	1									1			2	1	1	0	1
w933043899	1	1		400	220			0	1									1			2	1	1	0	1
w933043899	1	1		400	220			152	1									1			2	1	1	0	2
w955065768	1	1		400	240			14				1						1			2	1	1	0	2
w955065769	1	1		400	240			15				1						1			2	1	1	0	2
w955065772	1	1		400	240			15				1						1			2	1	1	0	1
w955065773	1	1		400	240			14				1						1			2	1	1	0	1
w966512321	5	1		400	410		1	154	1						1						2	1	1	0	4
w981241191	5	1		400	410		1	112	1						1						2	1	1	0	4
Fp-1-bbo	8	1	500	400	200	30		704				1								1	2	1	1	0	1
w7163265	8	1		400	200	30		5							1						2	1	1	0	1
w7163065	4	1		400	400			5			1					1					2	1	1	0	1
w7163253	1	1		400	230			8				1			1						2	1	1	0	1
w7163257	1	1		400	230			8	1									1			2	1	1	0	1
w24665283	4	1		400	400		1	16				1			1						2	2	1	0	2
w25183877	4	1		400	400			4			1					1					2	1	1	0	1
w25185727	4	1		400	400			5		1						1					2	1	1	0	1
w25185730	4	1		400	400			2		1						1					2	1	1	0	1
w25316477	1	1		400	240			13	1						1						2	1	1	0	2
w26777698	4	1		400	420		1	9			1						1				2	1	1	0	2
w26777699	4	1		400	400		1	122	1						1						2	1	1	0	2
w26777701	4	1		400	320		1	6		1									1		2	2	1	0	2
w26777710	4	1		400	400		1	160	1						1						2	1	1	0	2
w28940593	4	1		400	400		1	129	1									1			2	1	1	0	2
w31177134	1	1		400	240			13			1							1			2	1	1	0	2
w36857590	4	1		400	400		1	5					1						1		2	2	2	0	1
w121272043	1	1		400	240			10			1							1			2	1	1	0	1
w255069553	4	1		400	400		1	24	1						1						2	1	1	0	1
w693106734	1	1		400	380		1	77	1									1			2	1	1	0	2
w693158744	4	1		400	360		1	0				1						1			2	1	1	0	2

Score calculation of the bicycle infrastructure variables for Blixembosch-Oost:

ID	Path type	Car intensity	Path width	Separation type	Speed limit	Center line	Roadside type	Streetlight	Obstacles	Pavement type	Pavement conditions	Slope	Land use type	Sp_lim_ob	one-way		Score	Path lenght	
#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
w716326	4	1	-2	0	-1	0	0	1	0	1	0	0	0	0	0		2,1428571	133	285
w499115	10	0	0	0	0	0	0	1	-0,5	0,5	0	0	0	0	0		7,8571429	63	495
w715984	10	0	-0,333333333	-0,5	0	-1	-0,5	1	-0,5	0,5	0	0	0	0	0		6,1904762	18	111,429
w715984	10	0	-0,111111111	0	0	0	-1	1	-0,5	0,5	0	0	0	0	0		7,0634921	28	197,778
w716306	10	0	0,111111111	0	0	FALSE	-0,5	1	0	1	0	0	0	0	0		8,2936508	205	1700,2
w716306	10	0	0,111111111	-0,5	0	0	-0,5	1	-0,5	0,5	0	0	0	0	0		7,2222222	11	79,4444
w716325	10	0	-0,148148148	-0,5	0	0	0	1	0	1	0	0	0	0	0		8,1084656	77	624,352
w716325	10	0	-0,148148148	-0,5	0	0	0	1	0	1	0	0	0	0	0		8,1084656	3	24,3254
w716325	10	0	-0,148148148	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1084656	77	624,352
w716325	10	0	-0,148148148	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1084656	3	24,3254
w716330	10	0	-0,027777778	0	0	-1	0	1	0	1	0	0	0	0	0		7,8373016	184	1442,06
w782314	10	0	-0,027777778	0	0	-1	0	1	0	1	0	0	0	0	0		7,8373016	130	1018,85
w246652	10	0	0,111111111	-0,5	0	0	0	1	-0,5	1	0	0	0	0	0		7,9365079	228	1809,52
w246652	10	0	0,111111111	-0,5	0	0	0	1	-0,5	1	0	0	1	0	0		8,6507937	49	423,889
w251838	10	0	0,111111111	0	0	FALSE	-0,5	1	0	1	0	0	0	0	0		8,2936508	227	1882,66
w251857	8	0	0,085714286	-1	0	-1	-1	0	0	1	0	0	0	0	0		4,3469388	57	247,776
w251857	10	0	0,111111111	-0,5	0	FALSE	-0,5	1	0	1	0	0	0	0	0		7,9365079	145	1150,79
w251857	10	0	0,111111111	-0,5	0	FALSE	-0,5	1	0	1	0	0	0	0	0		7,9365079	239	1896,83
w251857	10	0	0,111111111	-0,5	0	FALSE	-0,5	1	0	1	0	0	0	0	0		7,9365079	11	87,3016
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	616	5011,11
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0		8,8492063	70	619,444
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	981	7980,36
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	16	130,159
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0		8,8492063	115	1017,66
w253164	10	0	-0,111111111	0	0	0	0	1	0	1	0	0	0	0	0		8,4920635	383	3252,46
w253164	10	0	-0,111111111	0	0	0	0	1	0	1	0	0	1	0	0		9,2063492	37	340,635
w253164	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	131	1065,67
w253165	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	278	2261,51
w253165	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	686	5580,56
w253165	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0		8,1349206	66	536,905
w253165	10	0	0,111111111	-0,5	0	0	0	1	0	1	0	0	0	0	0		8,2936508	120	995,238
w253165	10	0	0,111111111	-0,5	0	0	0	1	0	1	0	0	1	0	0		9,0079365	144	1297,14
w253165	10	0	-0,111111111	0	0	-1	0	1	0	1	0	0	0	0	0		7,7777778	3	23,3333
w253165	10	0	-0,111111111	0	0	-1	0	1	0	1	0	0	1	0	0		8,4920635	159	1350,24
w267776	10	0	0,166666667	0	0	0	0	1	0	1	0	0	1	0	0		9,4047619	19	178,69

w2677769	10	0	0,111111111	0	0	0	0	1	0	1	0	0	1	0	0	9,3650794	8	74,9206
w2677770	10	0	-0,111111111	-0,5	0	0	-1	1	-0,5	1	0	0	0	0	0	7,0634921	55	388,492
w2833665	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1349206	270	2196,43
w2833665	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,8492063	1	8,84921
w2894059	10	0	0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0	9,0079365	137	1234,09
w2894059	10	0	0,055555556	0	0	-1	-1	1	-0,5	0,5	0	0	1	0	0	7,1825397	32	229,841
w2894059	10	0	0,138888889	0	0	-1	0	1	0	1	0	0	0	0	0	7,9563492	37	294,385
w3117713	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1349206	426	3465,48
w3685758	10	0	0,111111111	0	0	-1	0	1	0	0,5	0	0	0	0	0	7,5793651	11	83,373
w3685759	10	0	0,111111111	-1	0	0	-1	1	-0,5	0,5	0	0	0	0	0	6,5079365	14	91,1111
w3685759	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7962963	46	404,63
w3685759	10	0	-0,185185185	-0,5	0	0	0	1	0	1	0	0	1	0	0	8,7962963	61	536,574
w3685759	10	0	0,407407407	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	8,1481481	76	619,259
w3685759	10	0	0,407407407	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,8624339	20	177,249
w1180465	10	0	0	-1	0	0	-1	1	-0,5	0,5	0	0	0	0	0	6,4285714	13	83,5714
w1212720	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1349206	614	4994,84
w1212720	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,8492063	38	336,27
w2065674	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	150	1171,27
w2355095	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	139	1085,37
w2355463	10	0	-0,185185185	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7248677	5	38,6243
w2355463	10	0	-0,185185185	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7248677	60	463,492
w2550695	10	0	0,111111111	0	0	0	0	1	0	1	0	0	0	0	0	8,6507937	825	7136,9
w2583440	10	0	-0,185185185	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7248677	59	455,767
w2698671	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7777778	271	2107,78
w3383101	10	0	0,111111111	-0,5	0	0	-1	1	0	1	0	0	1	0	0	8,2936508	516	4279,52
w6205680	10	0	0,222222222	-1	0	0	-1	1	0	0,5	0	0	0	0	0	6,9444444	71	493,056
w6260037	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	148	1155,65
w6931587	10	0	0	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,5714286	27	231,429
w8075859	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	162	1264,97
w8106070	10	0	0	-1	0	0	-0,5	1	0	0,5	0	0	1	0	0	7,8571429	29	227,857
w8154666	10	0	0,138888889	0	0	-1	0	1	0	1	0	0	0	0	0	7,9563492	14	111,389
w8154666	10	0	0,138888889	0	0	-1	0	1	0	1	0	0	0	0	0	7,9563492	81	644,464
w9330438	10	0	0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,2936508	82	680,079
w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,0820106	0	0
w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7962963	73	642,13

Acquired data for the bicycle infrastructure score calculation of Hurk:

ID	Path ty	Network ty	Car lane wi	Bicycle intensit	Car intensit	Path wid	Speed limit	Center li	Path len	ST Vege	ST Vegetati	ST Vegetat	ST Curb L	ST Curb sl	ST Curb I	ST Phy	ST Parking	RT Vege	RT Veg	RT Vege	RT Curb Le	RT Curb slopin	RT Cu	RT Phy	RT Par	Streetl	Obstac	Pavement t	Pavement cond	Slope	Land #	Land u	Land u	sp_lim	one-wa
#	Cat.	Cat.	cm	Bicycle per hou	Cars per da	cm	km/h	Cat.	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	#	Cat.	Cat.	Cat.	#	m	m	m	cat.	cat.
w111560333	7	1		400		220	50		145														1			2	1	2		0	3				
w54067786	7	1		400		220	50		45														1			2	1	1		0	3				
w54067786	7	1	610	400		220	50		188														1			2	1	1		0	3				
w4715670	1	1		400		400		2	110		1								1							2	2	1		0	3				
w4715670	1	1		400		400		2	23		1								1							2	2	1		0	2				
w30951238	4	1		400		320		1	156	1											1					2	1	2		0	3				
w30980931	4	1		400		320		1	148	1												1				2	1	2		0	1				
w30981004	5	1		400		310		1	8						1							1				2	1	1		0	1				
w30981004	5	1		400		310		1	5						1							1				2	1	1		0	3				
w30981004	5	1		400		310		1	23						1							1				2	1	1		0	2				
w34694116	4	1		400		380		2	15	1												1				2	1	2		0	3				
w79504155	1	1		400		170			92				1									1				2	1	2		0	3				
w111560314	4	1		400		355		1	13	1												1				2	1	1		0	3				
w111560314	4	1		400		355		1	3	1												1				2	1	1		0	2				
w112794030	7	1		400		170			26														1			1	1	1		0	2				
w112794030	7	1		400		170			24														1			1	1	1		0	3				
w112794031	7	1		400		170	50		2														1			2	1	1		0	2				
w112794031	7	1		400		170	50		53														1			2	1	1		0	3				
w115118081	1	1		400		350		1	0	1											1					1	1	1		0	3				
w115118081	1	1		400		350		1	11	1											1					1	1	1		0	2				
w115118096	4	1		400		380		2	26	1												1				2	1	2		0	3				
w115127506	1	1		400		150			19						1								1			2	1	1		0	3				
w121622512	4	1		400		350		1	403			1										1				2	1	1		0	3				
w12247863	2	1		400		180			41						1								1			2	1	1		0	3				
w12247864	2	1		400		210			27						1								1			1	1	2		0	3				
w14575555	4	1		400		390		1	8							1					1					1	1	1		0	3				
w14598023	4	1		400		350		1	53	1												1				2	1	1		0	3				
w14609795	4	1		400		360		1	468		1											1				2	1	2		0	3				
w14609796	4	1		400		350		1	2		1											1				2	1	1		0	3				
w14609796	4	1		400		350		1	67		1											1				2	1	1		0	2				
w17098727	5	1		400		385		1	22	1												1				2	1	1		0	3				
w22490261	4	1		400		350		1	3							1						1				1	1	1		0	3				
w22490261	4	1		400		350		1	6							1						1				1	1	1		0	3				
w22490261	4	1		400		350		1	15							1						1				1	1	1		0	2				
w22490261	4	1		400		360		1	162			1										1				2	1	1		0	3				
w22490261	1	1		400		325		1	9				1								1					2	1	1		0	3				
w24098902	4	1		400		330		2	32						1							1				2	1	1		0	1				
w241166867	1	1		400		260			111				1									1				2	1	1		0	3				
w291311349	4	1		400		310		1	176	1								1								2	2	1		0	3				
w291311349	4	1		400		310		1	50	1								1								2	2	1		0	2				
w29837074	1	1		400		350		1	51							1						1				2	1	2		0	2				
w29884570	4	1		400		350		1	77			1										1				2	1	1		0	3				
w431631695	1	1		400		200			31			1										1				2	1	1		0	3				
w56030561	4	1		400		470		1	47		1															1	1	1		0	1				
w56036463	5	1		400		360		1	56	1								1								2	1	1		0	3				
w56594309	1	1		400		170			22						1								1			2	1	1		0	2				
w60578480	1	1		400		200			12					1								1				2	1	2		0	3				
w611808030	7	1		400		220			25														1			2	1	1		0	3				
w68495104	1	1		400		325		1	9				1								1					2	1	1		0	3				
w68495104	7	1		400		200			43														1			2	1	1		0	3				
w73022105	1	1		400		230		0	49	1								1								1	1	1		0	3				
w86632092	4	1		400		440		2	6	1										1						2	2	1		0	3				
w958881108	9	1		400		350	30	2	86				1								1					2	1	1		0	3				
w958881109	9	1		400		350	30	2	68				1								1					2	1	1		0	3				

w958881111	4	1		400		360		1	155			1								1						2	1	1		0	3						
Rf1	7	1		400		140			37								1								1	2	1	1		0	1						
Rf1	7	1		400		140			712								1								1	2	1	1		0	3						
rf2	7	1		400		140			122					1								1				2	1	1		0	3						
rf3-h	7	1		400		155			63					1								1				2	1	1		0	2						
rf3-h	7	1		400		155			96					1								1				2	1	1		0	3						
w4715670	1	1		400		400		2	0		1								1							2	2	1		0	2						
w30951238	4	1		400		320		1	5	1											1					2	1	2		0	3						
w79504155	1	1		400		170			3				1									1				2	1	2		0	3						
w145755557	4	1		400		390		1	208							1					1					1	1	1		0	3						
w146097967	4	1		400		350		1	292		1											1				2	1	1		0	3						
w170987274	5	1		400		385		1	19	1												1				2	1	1		0	3						
w224902619	1	1		400		325		1	7				1								1					2	1	1		0	3						
w291311349	4	1		400		310		1	0	1								1								2	2	1		0	2						
w29837074	1	1		400		350		1	62							1						1				2	1	2		0	3						
w29884570	4	1		400		350		1	517			1										1				2	1	1		0	3						
w431631695	1	1		400		200			5			1										1				2	1	1		0	3						
w56036463	5	1		400		360		1	0	1								1								2	1	1		0	1						
w56594309	1	1		400		170			17						1								1			2	1	1		0	3						
w684951045	1	1		400		325		1	9				1								1					2	1	1		0	3						
w684951046	7	1		400		200			18														1			2	1	1		0	3						
w730221054	1	1		400		230		0	4	1								1								1	1	1		0	3						
w86632092	4	1		400		440		2	0	1										1						2	2	1		0	2						
Rf1	7	1		400		140			593								1								1	2	1	1		0	1						
rf3-h	7	1		400		155			2					1								1				2	1	1		0	3						
rf4-h	7	1		400		150			1574					1											1	2	1	1		0	3						
w7167470	10		740	400			50		97						1								1			2		2		0	3			2	2		
w7167478	10		710	400			50		22						1								1			2		1		0	3			2	2		
w7167478	10		710	400			50		34						1								1			2		1		0	3			2	2		
w7167478	10		710	400			50		26						1								1			2		1		0	2			2	2		
w7167540	10		440	400			50		330						1										1	2		2		0	3			2	1		
w7168714	10		880	400			50		197						1								1			2		1		0	3			2	2		
w7168723	10		880	400			50		555								1								1	2		1		0	3			2	2		
w7168777	10		880	400			50		183						1								1			2		1		0	3			2	2		
w40109584	10		440	400			50		332						1										1	2		2			3			2	1		
w40109584	10		440	400			50		32						1										1	2		2			3			2	1		
w29884692	10		590	400			50		32						1								1			2		2			3			2	1		
w7167489	10		760	400			50		39	1														1		1		2			1			2	2		
w7167489	10		760	400			50		649	1														1		1		2			3			2	2		
w7167518	10		800	400			50		142					1								1				2		1			3			2	2		
w7167524	10		800	400			50		371					1											1	2		1			3			2	2		
w7167527	10		500	400			30		76								1								1	2		2			3			2	2		
w7167555	10		900	400			50		152					1											1	2		1			3			2	2		
w7167598	10		620	400			50		76					1											1	2		1			3			2	2		
w7167600	10		500	400			50		139						1								1			2		2			3			2	2		
w7168380	10		910	400			50		589						1										1	2		2			3			2	2		
w7168798	10		900	400			50		304						1										1	2		2			3			2	2		
w7168819	10		680	400			50		679						1								1			2		1			3			2	2		
w89597726	10		620	400			50		300					1											1	2		1			3			2	2		
w91979592	10		620	400			50		241					1											2	2		1			3			2	2		
w227673114	10		580	400			50		486							1									1	2		2			3			2	2		
w227673114	10		580	400			50		41							1									1	2		2			4			2	2		
w55579699	10		500	400			30		393								1						1			2		2			3			2	2		
w95888564	10		670	400			50		232								1						1			2		1			3			2	2		
w961122301	10		670	400			50		292								1						1			2		1			3			2	2		

w54067787	10		770	400			50		199					1								1				2		1		0	3			2	2		
w7167540	10		440	400			50		18						1										1	2		2		0	3			2	1		
w40109584	10		440	400			50		23						1										1	2		2			3			2	1		
w29884692	10		590	400			50		7						1								1			2		2			3			2	1		
w7167489	10		760	400			50		0	1														1		1		2			1			2	2		
w7168380	10		910	400			50		7						1										1	2		2			3			2	2		
w7168798	10		900	400			50		13						1										1	2		2			3			2	2		
w89597726	10		620	400			50		8					1											1	2		1			3			2	2		

w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7962963	84	738,889
w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,0820106	1	8,08201
w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,0820106	0	0
w9330438	10	0	-0,185185185	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,7962963	152	1337,04
w9550657	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,4920635	14	118,889
w9550657	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,4920635	15	127,381
w9550657	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7777778	15	116,667
w9550657	10	0	-0,111111111	-0,5	0	0	-0,5	1	0	1	0	0	0	0	0	7,7777778	14	108,889
w9665123	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	154	1202,5
w9812411	9	0	-0,068181818	0	0	0	0	1	0	1	0	0	0	0	0	7,8084416	112	874,545
Fp-1-bbo	4	#DIV/0!	-0,111111111	-0,5	0,25	0	-1	1	0	1	0	0	0	0	0	3,3134921	704	2332,7
w7163265	4	#DIV/0!	-2	0	-1	0	0	1	0	1	0	0	0	0	0	2,1428571	5	10,7143
w7163065	10	0	0,111111111	0	0	FALSE	-0,5	1	0	1	0	0	0	0	0	8,2936508	5	41,4683
w7163253	10	0	-0,148148148	-0,5	0	0	0	1	0	1	0	0	0	0	0	8,1084656	8	64,8677
w7163257	10	0	-0,148148148	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1084656	8	64,8677
w2466528	10	0	0,111111111	-0,5	0	0	0	1	-0,5	1	0	0	1	0	0	8,6507937	16	138,413
w2518387	10	0	0,111111111	0	0	FALSE	-0,5	1	0	1	0	0	0	0	0	8,2936508	4	33,1746
w2518572	10	0	0,111111111	-0,5	0	FALSE	-0,5	1	0	1	0	0	0	0	0	7,9365079	5	39,6825
w2518573	10	0	0,111111111	-0,5	0	FALSE	-0,5	1	0	1	0	0	0	0	0	7,9365079	2	15,873
w2531647	10	0	-0,111111111	0	0	0	0	1	0	1	0	0	1	0	0	9,2063492	13	119,683
w2677769	10	0	0,166666667	0	0	0	0	1	0	1	0	0	1	0	0	9,4047619	9	84,6429
w2677769	10	0	0,111111111	0	0	0	0	1	0	1	0	0	1	0	0	9,3650794	122	1142,54
w2677770	10	0	-0,111111111	-0,5	0	0	-1	1	-0,5	1	0	0	1	0	0	7,7777778	6	46,6667
w2677771	10	0	0,111111111	0	0	0	0	1	0	1	0	0	1	0	0	9,3650794	160	1498,41
w2894059	10	0	0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0	9,0079365	129	1162,02
w3117713	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	1	0	0	8,8492063	13	115,04
w3685759	10	0	0,111111111	-1	0	0	-1	1	-0,5	0,5	0	0	0	0	0	6,5079365	5	32,5397
w1212720	10	0	-0,111111111	0	0	0	-0,5	1	0	1	0	0	0	0	0	8,1349206	10	81,3492
w2550695	10	0	0,111111111	0	0	0	0	1	0	1	0	0	0	0	0	8,6507937	24	207,619
w6931067	10	0	0,407407407	0	0	0	-0,5	1	0	1	0	0	1	0	0	9,2195767	77	709,907
w6931587	10	0	0	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,5714286	0	0

Score calculation of the bicycle infrastructure variables for Hurk:

ID	Path type	Car intensity	Path width	Separation type	Speed limit	Center line	Roadside type	Streetlight	Obstacles	Pavement type	Pavement conditions	Slope	Land use type	Sp_lim_ob	one-way	Score	Path lenght	
#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
w1115603	5	1	-0,12	0	0	0	-1	1	0	0,5	0	0	-1	0	0	3,1285714	145	453,643
w5406778	5	1	-0,12	0	0	0	-1	1	0	1	0	0	-1	0	0	3,4857143	45	156,857
w5406778	5	#DIV/0!	-0,12	0	0	0	-1	1	0	1	0	0	-1	0	0	3,4857143	188	655,314
w4715670	10	0	0,481481481	-0,5	0	0	-0,5	1	-0,5	1	0	0	-1	0	0	7,1296296	110	784,259
w4715670	10	0	0,481481481	-0,5	0	0	-0,5	1	-0,5	1	0	0	1	0	0	8,5582011	23	196,839
w3095123	10	0	-0,111111111	0	0	0	0	1	0	0,5	0	0	-1	0	0	7,4206349	156	1157,62
w3098093	10	0	-0,111111111	0	0	0	-0,5	1	0	0,5	0	0	0	0	0	7,7777778	148	1151,11
w3098100	9	0	-0,295454545	-1	0	0	-0,5	1	0	1	0	0	0	0	0	6,5746753	8	52,5974
w3098100	9	0	-0,295454545	-1	0	0	-0,5	1	0	1	0	0	-1	0	0	5,8603896	5	29,3019
w3098100	9	0	-0,295454545	-1	0	0	-0,5	1	0	1	0	0	1	0	0	7,288961	23	167,646
w3469411	10	0	0,055555556	0	0	-1	-0,5	1	0	0,5	0	0	-1	0	0	6,468254	15	97,0238
w7950415	10	0	-0,37037037	0	0	0	-0,5	1	0	0,5	0	0	-1	0	0	6,8783069	92	632,804
w1115603	10	0	-0,013888889	0	0	0	-0,5	1	0	1	0	0	-1	0	0	7,4900794	13	97,371
w1115603	10	0	-0,013888889	0	1	0	-0,5	1	0	1	0	0	1	0	0	9,6329365	3	28,8988
w1127940	5	#DIV/0!	-0,32	0	1	0	-1	0	0	1	0	0	1	0	0	4,7714286	26	124,057
w1127940	5	#DIV/0!	-0,32	0	0	0	-1	0	0	1	0	0	-1	0	0	2,6285714	24	63,0857
w1127940	5	#DIV/0!	-0,32	0	0	0	-1	1	0	1	0	0	1	0	0	4,7714286	2	9,54286
w1127940	5	#REF!	-0,32	0	0	0	-1	1	0	1	0	0	-1	0	0	3,3428571	53	177,171
w1151180	10	0	0,296296296	0	0	0	0	0	0	1	0	0	-1	0	0	7,3544974	0	0
w1151180	10	0	0,296296296	0	0	0	0	0	0	1	0	0	1	0	0	8,7830688	11	96,6138
w1151180	10	0	0,055555556	0	0	-1	-0,5	1	0	0,5	0	0	-1	0	0	6,468254	26	168,175
w1151275	10	0	-0,444444444	-1	0	0	-1	1	0	1	0	0	-1	0	0	6,1111111	19	116,111
w1216225	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1230159	403	2870,58
w1224786	9	0	-0,5	-1	0	0	-1	1	0	1	0	0	-1	0	0	5,3571429	41	219,643
w1224786	9	0	-0,416666667	-1	0	0	-1	0	0	0,5	0	0	-1	0	0	4,3452381	27	117,321
w1457555	10	0	0,083333333	-1	0	0	0	0	0	1	0	0	-1	0	0	6,4880952	8	51,9048
w1459802	10	0	-0,027777778	0	0	0	-0,5	1	0	1	0	0	-1	0	0	7,4801587	53	396,448
w1460979	10	0	0	-0,5	0	0	-0,5	1	0	0,5	0	0	-1	0	0	6,7857143	468	3175,71
w1460979	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1230159	2	14,246
w1460979	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	1	0	0	8,5515873	67	572,956
w1709872	9	0	-0,125	0	0	0	-0,5	1	0	1	0	0	-1	0	0	6,6964286	22	147,321
w2249026	10	0	-0,027777778	-1	0	0	-0,5	0	0	1	0	0	-1	0	0	6,0515873	3	18,1548
w2249026	10	0	-0,027777778	-1	0	0	-0,5	0	0	1	0	0	-1	0	0	6,0515873	6	36,3095
w2249026	10	0	-0,027777778	-1	0	0	-0,5	0	0	1	0	0	1	0	0	7,4801587	15	112,202
w2249026	10	0	0	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1428571	162	1157,14

w2249026	10	0	0,203703704	0	0	0	0	1	0	1	0	0	-1	0	0	8,0026455	9	72,0238
w2409890	10	0	-0,083333333	-1	0	-1	-0,5	1	0	1	0	0	0	0	0	6,7261905	32	215,238
w2411668	10	0	-0,037037037	0	0	0	-0,5	1	0	1	0	0	-1	0	0	7,473545	111	829,563
w2913113	10	0	-0,138888889	0	0	0	0	1	-0,5	1	0	0	-1	0	0	7,4007937	176	1302,54
w2913113	10	0	-0,138888889	0	0	0	0	1	-0,5	1	0	0	1	0	0	8,8293651	50	441,468
w2983707	10	0	0,296296296	-1	0	0	-0,5	1	0	0,5	0	0	1	0	0	8,0687831	51	411,508
w2988457	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1230159	77	548,472
w4316316	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	6,957672	31	215,688
w5603056	10	0	0,305555556	-0,5	0	0	0	0	0	1	0	0	0	0	0	7,718254	47	362,758
w5603646	9	0	-0,181818182	0	0	0	0	1	0	1	0	0	-1	0	0	7,012987	56	392,727
w5659430	10	0	-0,37037037	-1	0	0	-1	1	0	1	0	0	1	0	0	7,5925926	22	167,037
w6057848	10	0	-0,259259259	-0,5	1	0	-0,5	1	0	0,5	0	0	-1	0	0	7,3148148	12	87,7778
w6118080	5	#DIV/0!	-0,12	0	0	0	-1	1	0	1	0	0	-1	0	0	3,4857143	25	87,1429
w6849510	10	0	0,203703704	0	1	0	0	1	0	1	0	0	-1	0	0	8,7169312	9	78,4524
w6849510	5	#DIV/0!	-0,2	0	0	0	-1	1	0	1	0	0	-1	0	0	3,4285714	43	147,429
w7302210	10	0	-0,148148148	0	0	0	0	0	0	1	0	0	-1	0	0	7,037037	49	344,815
w8663209	10	0	0,222222222	0	0	-1	-0,5	1	-0,5	1	0	0	-1	0	0	6,5873016	6	39,5238
w9588811	7	#DIV/0!	-0,396551724	0	0	-1	0	1	0	1	0	0	-1	0	0	4,7167488	86	405,64
w9588811	7	#DIV/0!	-0,396551724	0	0	-1	0	1	0	1	0	0	-1	0	0	4,7167488	68	320,739
w9588811	10	0	0	-0,5	1	0	-0,5	1	0	1	0	0	-1	0	0	7,8571429	155	1217,86
Rf1	5	#DIV/0!	-0,44	-1	1	0	-1	1	0	1	0	0	0	0	0	3,9714286	37	146,943
Rf1	5	#DIV/0!	-0,44	-1	1	0	-1	1	0	1	0	0	-1	0	0	3,2571429	712	2319,09
rf2	5	#DIV/0!	-0,44	-0,5	1	0	-0,5	1	0	1	0	0	-1	0	0	3,9714286	122	484,514
rf3-h	5	#DIV/0!	-0,38	-0,5	1	0	-0,5	1	0	1	0	0	1	0	0	5,4428571	63	342,9
rf3-h	5	#DIV/0!	-0,38	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	3,3	96	316,8
w4715670	10	0	0,481481481	-0,5	0	0	-0,5	1	-0,5	1	0	0	1	0	0	8,5582011	0	0
w3095123	10	0	-0,111111111	0	0	0	0	1	0	0,5	0	0	-1	0	0	7,4206349	5	37,1032
w7950415	10	0	-0,37037037	0	0	0	-0,5	1	0	0,5	0	0	-1	0	0	6,8783069	3	20,6349
w1457555	10	0	0,083333333	-1	0	0	0	0	0	1	0	0	-1	0	0	6,4880952	208	1349,52
w1460979	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1230159	292	2079,92
w1709872	9	0	-0,125	0	0	0	-0,5	1	0	1	0	0	-1	0	0	6,6964286	19	127,232
w2249026	10	0	0,203703704	0	0	0	0	1	0	1	0	0	-1	0	0	8,0026455	7	56,0185
w2913113	10	0	-0,138888889	0	0	0	0	1	-0,5	1	0	0	1	0	0	8,8293651	0	0
w2983707	10	0	0,296296296	-1	0	0	-0,5	1	0	0,5	0	0	-1	0	0	6,6402116	62	411,693
w2988457	10	0	-0,027777778	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	7,1230159	517	3682,6

w4316316	10	0	-0,259259259	-0,5	0	0	-0,5	1	0	1	0	0	-1	0	0	6,957672	5	34,7884
w5603646	9	0	-0,181818182	0	0	0	0	1	0	1	0	0	0	0	0	7,7272727	0	0
w5659430	10	0	-0,37037037	-1	0	0	-1	1	0	1	0	0	-1	0	0	6,1640212	17	104,788
w6849510	10	0	0,203703704	0	1	0	0	1	0	1	0	0	-1	0	0	8,7169312	9	78,4524
w6849510	5	#DIV/0!	-0,2	0	0	0	-1	1	0	1	0	0	-1	0	0	3,4285714	18	61,7143
w7302210	10	0	-0,148148148	0	0	0	0	0	0	1	0	0	-1	0	0	7,037037	4	28,1481
w8663209	10	0	0,222222222	0	1	-1	-0,5	1	-0,5	1	0	0	1	0	0	8,7301587	0	0
Rf1	5	#DIV/0!	-0,44	-1	1	0	-1	1	0	1	0	0	0	0	0	3,9714286	593	2355,06
rf3-h	5	#DIV/0!	-0,38	-0,5	1	0	-0,5	1	0	1	0	0	-1	0	0	4,0142857	2	8,02857
rf4-h	5	#DIV/0!	-0,4	-0,5	-0,666667	0	-1	1	0	1	0	0	-1	0	0	2,452381	1574	3860,05
w7167470	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	97	57,7381
w7167478	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	22	20,9524
w7167478	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	34	32,381
w7167478	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	1	0	0	2,3809524	26	61,9048
w7167540	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	330	432,143
w7168714	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	197	187,619
w7168723	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	555	528,571
w7168777	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	183	174,286
w4010958	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	332	434,762
w4010958	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	32	41,9048
w2988469	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	32	41,9048
w7167489	3	#DIV/0!	0	0	-0,666667	0	-1	0	0	0,5	0	0	0	0	0	1,3095238	39	51,0714
w7167489	3	#DIV/0!	0	0	-0,666667	0	-1	0	0	0,5	0	0	-1	0	0	0,5952381	649	386,31
w7167518	3	#DIV/0!	0	-0,5	-0,666667	0	-0,5	1	0	1	0	0	-1	0	0	1,6666667	142	236,667
w7167524	3	#DIV/0!	0	-0,5	0	0	-1	1	0	1	0	0	-1	0	0	1,7857143	371	662,5
w7167527	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	76	45,2381
w7167555	3	#DIV/0!	0	-0,5	-0,666667	0	-1	1	0	1	0	0	-1	0	0	1,3095238	152	199,048
w7167598	3	#DIV/0!	0	-0,5	-0,666667	0	-1	1	0	1	0	0	-1	0	0	1,3095238	76	99,5238
w7167600	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	139	82,7381
w7168380	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	589	350,595
w7168798	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	304	180,952
w7168819	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	679	646,667
w8959772	3	#DIV/0!	0	-0,5	-0,666667	0	-1	1	0	1	0	0	-1	0	0	1,3095238	300	392,857
w9197959	3	#DIV/0!	0	-0,5	-0,666667	0	-2	1	0	1	0	0	-1	0	0	0,5952381	241	143,452
w2276731	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	486	289,286
w2276731	3	#DIV/0!	0	-1	0	0	-1	1	0	0,5	0	0	0	0	0	1,7857143	41	73,2143
w5557969	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	393	233,929
w9588856	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	232	220,952
w9611223	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	-1	0	0	0,952381	292	278,095
w9611223	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	1	0	0	0	0	0	1,6666667	29	48,3333
w5406778	3	#DIV/0!	0	-0,5	-0,666667	0	-0,5	1	0	1	0	0	-1	0	0	1,6666667	199	331,667
w7167540	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	18	23,5714
w4010958	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	23	30,119
w2988469	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	1	1,3095238	7	9,16667
w7167489	3	#DIV/0!	0	0	-0,666667	0	-1	0	0	0,5	0	0	0	0	0	1,3095238	0	0
w7168380	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	7	4,16667
w7168798	3	#DIV/0!	0	-1	-0,666667	0	-1	1	0	0,5	0	0	-1	0	0	0,5952381	13	7,7381
w8959772	3	#DIV/0!	0	-0,5	0	0	-1	1	0	1	0	0	-1	0	0	1,7857143	8	14,2857

Appendix III

Appendix III includes the acquired data necessary for the variable score calculations of the category junction infrastructure and the calculated scores with these data for each neighbourhood. Furthermore, table A.III explains the coded answers used in the excel file for certain variables.

Table A.III Coded answers junction infrastructure

Variables	Coded Category	Category
Junction type	1	Intersection with priority rules
	2	Intersection with traffic lights
	3	Intersection with markings and signs
	4	Roundabout
	5	Priority square
Bicycle infrastructure	1	Shared lane
	2	Bicycle suggestion lane
	3	Bicycle lane
	4	Bicycle path within 2 meters of the roadway
	5	Bicycle path between 2 and 5 meters of the roadway
Speed limiting objects	1	Not present
	2	Present
Median island	1	Not present
	2	Present
	3	Not necessary
Bicycle traffic lights	1	Not present
	2	Present
	3	Present and with own green phase
Bicycle box	1	Present
	2	Not present

Acquired data for the junction variable score calculation of Bergen

ID	Junction type	Bicycle path type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box
#	Cat.	Cat.	Cat.	Cat.	Cat.	Cat.
1	2	5	1	2	2	1
2	3	5	1	1		
3	3	5	1	1		
4	2	5	1	2	2	1
5	2	4	1	1	2	1
6	3	3	1	3		
7	3	3	1	3		
8	3	3	1	3		
9	3	3	1	3		
10	2	4	1	1	2	1
11	3	3	1	1		
12	2	4	1	2	2	1
13	3	4	1	1		
14	2	4	1	2		
15	2	3	1	1	1	1
16	3	3	1	1		
17	3	5	1	2		

Score calculation of the junction variables of Bergen

ID	Junction type	Bicycle infra type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box		Score	count
Weight -->	1	1	1	1	1	1			
1	6	1	0	0,5	0,5	0		8	1
2	7	1	0	0	0	0		8	1
3	7	1	0	0	0	0		8	1
4	6	1	0	0,5	0,5	0		8	1
5	6	0,75	0	0	0,5	0		7,25	1
6	7	0,5	0	0,5	0	0		8	1
7	7	0,5	0	0,5	0	0		8	1
8	7	0,5	0	0,5	0	0		8	1
9	7	0,5	0	0,5	0	0		8	1
10	6	0,75	0	0	0,5	0		7,25	1
11	7	0,5	0	0	0	0		7,5	1
12	6	0,75	0	0,5	0,5	0		7,75	1
13	7	0,75	0	0	0	0		7,75	1
14	6	0,75	0	0,5	0	0		7,25	1
15	6	0,5	0	0	0	0		6,5	1
16	7	0,5	0	0	0	0		7,5	1
17	7	1	0	0,5	0	0		8,5	1

Acquired data for the junction variable score calculation of Blixembosch-Oost

ID	Junction type	Bicycle path type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box
#	Cat.	Cat.	Cat.	Cat.	Cat.	Cat.
1	1	5	2	3		
2	1	5	1	3		
3	1	5	1	3		
4	1	5	1	3		
5	3	3	2	3		
6	3	5	1	1		
7	3	5	1	3		
8	3	5	1	3		
10	1	5	1	3		
11	3	5	2	3		
12	2	4	1	2	2	1
13	2	4	1	2	2	1
14	2	4	1	2	2	1
15	2	5	1	2	2	1
16	3	5	2	3		
17	1	5	1	3		
18	1	5	1	3		
19	3	5	1	3		
20	2	5	1	3	2	1
21	1	5	1	3		
22	1	5	1	3		
24	1	5	1	3		
26	1	5	1	3		
27	1	5	1	3		
27	1	5	1	3		
29	1	5	1	3		
30	1	5	1	3		
31	1	5	1	3		
32	1	5	1	3		
34	1	5	2	3		
35	1	3	1	2		

Score calculation of the junction variables of Blixembosch-Oost

ID	Junction type	Bicycle infra type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box		Score	count
Weight -->	1	1	1	1	1	1			
1	7	1	1	0,5	0	0		9,5	1
2	7	1	0	0,5	0	0		8,5	1
3	7	1	0	0,5	0	0		8,5	1
4	7	1	0	0,5	0	0		8,5	1
5	7	0,5	1	0,5	0	0		9	1
6	7	1	0	0	0	0		8	1
7	7	1	0	0,5	0	0		8,5	1
8	7	1	0	0,5	0	0		8,5	1
10	7	1	0	0,5	0	0		8,5	1
11	7	1	1	0,5	0	0		9,5	1
12	6	0,75	0	0,5	0,5	0		7,75	1
13	6	0,75	0	0,5	0,5	0		7,75	1
14	6	0,75	0	0,5	0,5	0		7,75	1
15	6	1	0	0,5	0,5	0		8	1
16	7	1	1	0,5	0	0		9,5	1
17	7	1	0	0,5	0	0		8,5	1
18	7	1	0	0,5	0	0		8,5	1
19	7	1	0	0,5	0	0		8,5	1
20	6	1	0	0,5	0,5	0		8	1
21	7	1	0	0,5	0	0		8,5	1
22	7	1	0	0,5	0	0		8,5	1
24	7	1	0	0,5	0	0		8,5	1
26	7	1	0	0,5	0	0		8,5	1
27	7	1	0	0,5	0	0		8,5	1
27	7	1	0	0,5	0	0		8,5	1
29	7	1	0	0,5	0	0		8,5	1
30	7	1	0	0,5	0	0		8,5	1
31	7	1	0	0,5	0	0		8,5	1
32	7	1	0	0,5	0	0		8,5	1
34	7	1	1	0,5	0	0		9,5	1
35	7	0,5	0	0,5	0	0		8	1

Acquired data for the junction variable score calculation of Hurk

ID	Junction type	Bicycle path type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box
#	Cat.	Cat.	Cat.	Cat.	Cat.	Cat.
1	2	5	1	2	2	1
3	3	3	2	3		
4	3	3	1	3		
5	3	3	1	3		
7	3	4	1	2		
8	2	4	1	2	2	1
9	2	4	1	2	2	1
10	3	2	1	3		
13	3	3	1	1		
14	2	5	1	2	2	1
15	3	2	1	1		
16	4	5				
17	2	5	1	2	2	1
18	1	1	1	3		
19	3	1	1	3		
20	2	3	1	2		
21	3	4	1	3		
22	2	3	1	1		
25	2	5	1	2	2	1
27	1	1	1	3		
29	1	1	1	3		
30	3	3	2	2		
31	3	3	1	3		

Score calculation of the junction variables of Hurk

ID	Junction type	Bicycle infra type	Speed limiting objects	Median island	Bicycle traffic lights	Bicycle box		Score	count
Weight -->	1	1	1	1	1	1			
1	6	1	0	0,5	0,5	0		8	1
3	7	0,5	1	0,5	0	0		9	1
4	7	0,5	0	0,5	0	0		8	1
5	7	0,5	0	0,5	0	0		8	1
7	7	0,75	0	0,5	0	0		8,25	1
8	6	0,75	0	0,5	0,5	0		7,75	1
9	6	0,75	0	0,5	0,5	0		7,75	1
10	7	0	0	0,5	0	0		7,5	1
13	7	0,5	0	0	0	0		7,5	1
14	6	1	0	0,5	0,5	0		8	1
15	7	0	0	0	0	0		7	1
16	9	1	0	0	0	0		10	1
17	6	1	0	0,5	0,5	0		8	1
18	1	-1	0	0,5	0	0		0,5	1
19	7	-1	0	0,5	0	0		6,5	1
20	6	0,5	0	0,5	0	0		7	1
21	7	0,75	0	0,5	0	0		8,25	1
22	6	0,5	0	0	0	0		6,5	1
25	6	1	0	0,5	0,5	0		8	1
27	1	-1	0	0,5	0	0		0,5	1
29	1	-1	0	0,5	0	0		0,5	1
30	7	0,5	1	0,5	0	0		9	1
31	7	0,5	0	0,5	0	0		8	1

Appendix IV

In table A.IV the search terms used to identify destinations in QGIS by using QuickOSM are described. Search terms contain to terms: a key and a value. Combing these will result in the identification of the requested destinations.

Table A.IV search terms to identify destinations

Destination categories	**Destinations**	**Key**	**Value**
Transportation	*Bus stop, train stop, etc*	*Public_transport*	*platform*
Education	*Day-care, elementary school, high school, university, etc.*	*Amenity*	*School; kindergarten; driving_school; college*
Grocery	*Supermarket, market, specialty store, etc.*	*Amenity*	*Marketplace*
		Shop	*Alcohol; bakery; beverages; butcher; cheese; convenience; deli; dairy; frozen_food; greengrocer; seafood; supermarket;*
Catering service	*Pubs, restaurants, etc.*	*Amenity*	*Restaurant; pub; ice_cream; food_court; fast_food; café; biergarten; bar*
Religious organizations	*Church, synagogue, mosque, etc.*	*Amenity*	*Place_of_worship*
Sports	*Gym, sport club, sport fields, etc.*	*Leisure;*	*Swimming_pool; sport_centre; pitch; miniature_golf; ice_rink; golf_course; fitness_station; fitness_centre; dance;*
Greenery	*Parks, ponds, etc.*	*Leisure*	*Garden; park*
Services	*Beauty salon, barber, bank, mail service, etc.*	*Amenity*	*Veterinary; townhall; post_office; police; fire_station; community_centre; clinic; bicycle_repari_station; bicycle_rental; bank*
Library	*Public library*	*Amenity*	*Library*
Stores	*Other stores than grocery*	*Shop*	*All shop values expect those included in the destination category grocery*
Entertainment	*(Movie) theatre, bowling alley, etc.*	*Amenity*	*Theatre; nightcub; event_venue; confrenence_centre; cinema; casino; arts_centre;*
		Leisure	*Stadium; sauna; playground; marina; escape_game; bowling_alleymosk; adult_gaming_centre*
		Tourism	*Zoo; museum; attracion*
Healthcare		*Amenity*	*Doctors; dentist; pharmacy; healthcare; hospital*
Office		*Office*	*(no value used)*

Appendix V

Appendix V includes the acquired data necessary for the variable score calculations of the category bicycle parking facilities and the calculated scores with these data for each neighbourhood. Furthermore, table A.V explains the coded answers used in the excel file for certain variables.

Table A.V Coded answers bicycle parking facilities

Variables	Coded Category	Category
BPF type	1	Bicycle rack (no cover)
	2	Bicycle rack (cover)
	3	Bicycle storage
Security measures	1	No security
	2	Surveillance
	3	Guarded
	4	Bicycle locker
Cost	1	Free
	2	Paid after 24h
	3	Paid from the start

Acquired data for the bicycle parking facility variable score calculation of Bergen

ID	Type of BPF	Security	Fee	Area	Distance to bicycle network	Distance to transit	Destinations	Parking spots
#	Cat.	Cat.	Cat.	m²	Meters	Meters	#	#
w9143228	1	1	1	128	9,11170724	46,50537622	5	42

Score calculation of the bicycle parking facility variables of Bergen

ID	Type score	Security score	Cost score	Connection to bicycle network score	Distance to transit score	Destination score	Parking ratio score		Score	count
Weight -->	1	1	1	1	1	1	1			
w91432283ẞ	1	0	0	0,908882928	0,069892476	0,5	0,575859375		3,054635	1

Acquired data for the bicycle parking facility variable score calculation of Blixembosch-Oost

ID	Type of BPF	Security	Fee	Area	Distance to bicycle network	Distance to transit	Destinations	Parking spots
#	Cat.	Cat.	Cat.	m²	Meters	Meters	#	#
n9317680791	1	1	1	40	1	236	2	22
n9317680788	1	1	1	40	1	278	4	22
n9317680787	2	1	1	40	1	230	11	20
n9317680789	1	1	1	40	1	224	3	22

Score calculation of the bicycle parking facility variables of Blixembosch-Oost

ID	Type score	Security score	Cost score	Connection to bicycle network score	Distance to transit score	Destination score	Parking ratio score		Score	count
Weight -->	1	1	1	1	1	1	1			
n931768079	1	0	0	0,99	0	0,2	0,96525		3,15525	1
n931768078	1	0	0	0,99	0	0,4	0,96525		3,35525	1
n931768078	3	0	0	0,99	0	0,55	0,8775		5,4175	1
n931768078	1	0	0	0,99	0	0,3	0,96525		3,25525	1

Acquired data for the bicycle parking facility variable score calculation of Hurk

ID	Type of BPF	Security	Fee	Area	Distance to bicycle network	Distance to transit	Destinations	Parking spots
#	Cat.	Cat.	Cat.	m²	Meters	Meters	#	#
w832277996	2	1	1	144	30	490	1	72

Score calculation of the bicycle parking facility variables of Hurk

ID	Type score	Security score	Cost score	Connection to bicycle network score	Distance to transit score	Destination score	Parking ratio score		Score	count
Weight -->	1	1	1	1	1	1	1			
w83227799(	3	0	0	0,7	0	0,05	0,8775		4,6275	1

Appendix VI

Appendix VI includes the acquired data necessary for the variable score calculations of the category environment and the calculated scores with these data for each neighbourhood.

Acquired data for the environment variable score calculation of all neighbourhoods:

ID	Bicycle way	Road way	Area	Intersections	BPFs area	dwellings	Population	Air quality	LU: Green s	LU: residential	LU: Commercial	LU: Other	Road accidents
#	Meters	Meters	m^2	#	m^2	#	#	AQI	m^2	m^2	m^2	m^2	#
Bergen	2747	5536	346080	17	21953	1622	2775	14	31901	75194	116979	122006	16
BBO	12464	9240	1658092	31	36630	2653	7222	12	193017	1035779	28761	400535	21
Hurk	7892	20110	2077168	22	35497	16	65	23	71379	62	1802030	203697	54

Score calculation of the environment variables of all neighbourhoods:

ID	Bicycle way ratio	Bicycle way density	Intersection density	parking space density	Population density	Air quality	Green spac	Mixed land us	Road safety
Weight -->	2	2	1	1	1	1	1	1	1
Bergen	0,992413295	1,587494221	-0,491215904	0,06343331	0,521194521	2	0,4916924	0,927379605	-0,307692308
BBO	2,697835498	1,503414768	-0,186961881	0,022091657	0,283114568	2	1	0,690885802	-0,403846154
Hurk	0,784883143	0,759880761	-0,105913436	0,017089133	0,002034019	2	1	0,336962885	-1,038461538

Appendix VII

Appendix VII includes the acquired data necessary for the variables score calculation of the category accessibility and the calculated scores with these data for each neighbourhood.

Acquired data for the accessibility variable score calculation:

ID	Dis. Supermarket	Dis. Day-care	Dis. Elementary	Dis. Secondary educ	Dis. Train station	Dis. Centre	Dis. Shopping centre	Dis. Hospital	Dis. Greenery	Dis. General practice	Dis. Pub	Dis.Restaurant	Dis. Library	Destination types	Destinations	Transit facilities	Area
#	km	km	km	km	km	km	km	km	km	km	km	km	km	#	#	#	m^2
Blixembosch-Oost	0,6	0,4	0,5	1,1	5,5	5,6155603	3,1	3,6	0,633559411	0,4	1,7	0,6	4,5	9	26	5	1658484
Bergen	0,6	0,4	0,4	1,1	1,7	0,4655784	1,5	2,8	0,390632966	0,4	0,2	0,1	0,6	12	155	4	346245,6
Hurk	0,8	0,8	0,8	1,5	3,1	2,93152766	1,9	4,2	0,682868968	1	0,9	0,7	3,2	7	48	8	2078163

Score calculation of the accessibility variables:

ID	Dis. Supermarket	Dis. Day-care	Dis. Elementary	Dis. Secondary educ	Dis. Train station	Dis. Centre	Dis. Shopping centre	Dis. Hospital	Dis. Greenery	Dis. General practice	Dis. Pub	Dis.Restaurant	Dis. Library	Destination types	Destinations	Transit facilities
Weight -->	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Blixembosch-Oost	0,88	0,92	0,9	0,78	-0,1	-0,12311206	0,38	0,28	0,873288118	0,92	0,66	0,88	0,1	0,692307692	0,15676966	0,292000379
Bergen	0,88	0,92	0,92	0,78	0,66	0,906884319	0,7	0,44	0,921873407	0,92	0,96	0,98	0,88	0,923076923	1	0,740416591
Hurk	0,84	0,84	0,84	0,7	0,38	0,413694468	0,62	0,16	0,863426206	0,8	0,82	0,86	0,36	0,538461538	0,23097327	0,453078131