Bicycle network design

The design of a bicycle network on TUD campus Zuid

CTB3000: Bachelor Thesis

Jonas Bottelier

TUDelft

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by

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'Cover: View of the Kluyverpark in autumn, by Karres Brands architects”

TU Delft

Preface

This bachelor thesis is written as the last task of completing the bachelor study Civil Engineering at the Delft University of Technology. The focus of this thesis is in the department of Transport and Planning. The assignment of this thesis is to design a bicycle network for the Kluyver area on the Campus of the Delft University of Technology. This area is expecting a large growth as the university has planned to build several buildings in this area. The assignment was formulated by the Campus Real Estate and facility management in order to get a better understanding of what a bicycle network could look like in the area, designed with traffic flow and bicycle standards in mind. I have chosen this assignment as it combines the subjects that have interested me the most during my bachelor's; urban planning and bicycle traffic. Designing a network for a soon-to-be-developed area gives the freedom and opportunity to really design the network to optimize traffic flow and serve the needs of cyclists. At the same time, the planned buildings and the physical elements of the area limit the possibilities of constructing the bicycle paths, which makes the assignment realistic.

If someone is interested in designing bicycle paths for the Kluyver area, chapter 2 contains the findings of the analyses on the area, and forms the basis for the paths. If someone would like to reevaluate the designed paths, chapter 3 consists of the designs of the paths. This report also includes the criteria used to evaluate the designs, a discussion and a conclusion.

I would like to thank my supervisors, Dr. Ir. A. Gavriilidou and Dr. Ir. Y. Yuan, for providing answers to my, sometimes vague, questions and giving feedback. I would also like to thank drs. ing. I.L. Oostlander-Çetin for taking the time to provide answers to all my questions regarding the development of the Kluyverarea, and clearly explaining the plans for the area. Lastly, I would like to thank my fellow students who weekly provided feedback; M. Claus, L. Dijkstra, S. de Haan, K. de Jong and S. Schaap.

Jonas Bottelier
Delft, October 2022

Summary

This thesis is about the design of a bicycle network for the Kluyver area, an area on the campus of the Delft University of Technology. Several new buildings are planned to be constructed in this area, which will result in a growth of almost 4000 study- and workplaces. As the current bicycle network is not designed for these intensities, a new network should be constructed.
The purpose of this thesis is to design a connection between the two main infrastructure axes in this area: the Rotterdamseweg and the Mekelweg. There are three potential areas for such a connection. During this thesis, several analyses are done. One to get an understanding of where exactly in the area the need for bicycle- paths and parking the most urgent is. Another is to analyse where the physical elements, such as green and blue structures, are in the area, and how they relate to each other. The last analysis is done to learn what the physical elements of bicycle infrastructure, such as width and distance to objects, are.
From these analyses can be concluded that the main growth in the Kluyver area is around the Kluyverpark, a park centrally located in the Kluyver area, making this the place where the need for bicycle parking and infrastructure is the most urgent. Other findings are that, especially on the western side, entries to the area are limited due to bushes and ditches, and that the park is designed for slow traffic. From these analyses, the bicycle paths in the three potential places are designed. The designs range from a cheap option with minimal safety and a big impact on the surroundings (bicycle path M), to an expensive option which is considered safer and less impactful on the surroundings (bicycle path S), and one in between (bicycle path N).
These bicycle paths, and combinations of bicycle paths, are compared to each other in a multicriteria analysis. The criteria on which the designs are judged are cohesion, comfort, cost, safety, and the impact on the surrounding area, of which the last three are considered as most important. The expensive, safe bicycle path scored the best on this MCA.
This thesis concludes that with these designs, criteria and weights, bicycle path S suits the future needs of the Kluyver area the best.

Contents

1
Introduction

In this chapter, an introduction to and motivation for this thesis is written. First, a short introduction to the subject will be given, after which the problem is described. Then, the research question and the sub-questions can be found, after which the approach of this thesis and the structure of the report will be explained.

1.1. Background information

The Technical University of Delft has one of the largest campus areas in the world [1]. There are more than 27,000 daily visitors and this is expected to grow to 40,000 students [2]. With this rising amount of students, some faculties are getting too big for their buildings. As the northern part of the campus has reached its capacity and renovating buildings is not enough to suit the demand, the TU has decided on expanding its campus to the south.
One area which will see a lot of development is the Kluyver area, an almost square plot of land south of the Kruithuisweg (N470), highlighted in figure 1.1. This area currently hosts the faculty of Aerospace Engineering, Faculty of Applied Sciences, study facility Fellowship, a logistics centre, and the Reactor Institute Delft. In the coming years, a new generic university building, a lecture building, the faculty of applied physics and several other buildings will be built. This redevelopment and intensification of the Kluyver area asks for a suitable and sufficient transport network, as the existing network will probably not meet the future demand.

Figure 1.1: Map of TU Delft campus

A growing campus asks for better connections with the surrounding neighbourhoods. Some new connections are already being designed. A new bridge south of the Abtswoudsebrug will be built, connecting the new neighbourhood Schieoevers Noord with the Campus. This new bridge is build to destress

the now most logical route between Delft South/West to the campus; Abtswoudseweg-Jaffalaan. Construction of the ”Gelatinebrug”, as it’s called, will start in 2023 [3] [4]. However, this new bridge will not be enough to suit the demand for 2040 [5]. Therefore, plans for a bridge south of the Kruithuisweg are proposed. The plans for this bridge, called ”Energiebrug” (Energybridge), are still vague, and are mentioned just a couple of times in reports of the municipality [5][6]. However, completion of it could have a massive impact in connecting the Kluyver area with the south of Delft, and the station Delft Campus.
Another major project that is relevant to the development of the Kluyver area, is the plan for a metropolitan bicycle route between Delft and Rotterdam Alexander. This route is part of a large project of the metropolitan area Rotterdam - The Hague, connecting different regions within the area with each other by building high quality bicycle paths [7]. These paths have a higher standard than normal a normal bicycle network and are built to give a viable alternative than taking the car. Plans for the path Delft - Rotterdam Alexander are not yet definitive, and where it will come has to be decided, but there is a good chance that it will run through the Kluyver area.

1.2. Problem description

As the campus needs to be accessible for students and employees, a sufficient infrastructure network is needed. With the campus being car-free; cars are redirected around the campus, and only a small percentage of parking places available per workplace/studentplace, public transport and bicycle transport are even more important. And, with the proposed tram line 19 not reaching the Kluyver area, the reliable bicycle network will be even more important [7]. Therefore, during this thesis, a design for a bicycle network that meets the future needs of the Kluyverarea is proposed.
To make a good design proposal, it is important to know what the future developments of the area and its surroundings are, be familiar with rules and standards of bicycle infrastructure, and know the topography of area. Once this information is gathered, proposals for bicycle paths will be designed which will be compared to each other using a multicriteria analysis. From the outcome of the multicriteria analysis, a conclusion can be made, and suggestions will be given.
The growth of the area focuses mainly around the Kluyverpark, as highlighted in figure 1.2 [8]. Most of the student- and workspace intense buildings will be built in these building blocks, resulting in the most need for a new bicycle network around these blocks. Therefore, the focus of this thesis is in designing bicycle paths in the focus area, connecting the Rotterdamseweg with the Mekelweg (figure A.2).
Quickly scanning the focus area and taking the limitations of these building blocks in mind, three axes come forward as possible bicycle paths (figure 1.3). All of these bicycle paths have their limitations. What these exactly are and how these paths could exactly be places, will be researched in this thesis. Which of the paths is most suitable, and if only one, or more paths are recommended, will be determined in this thesis.

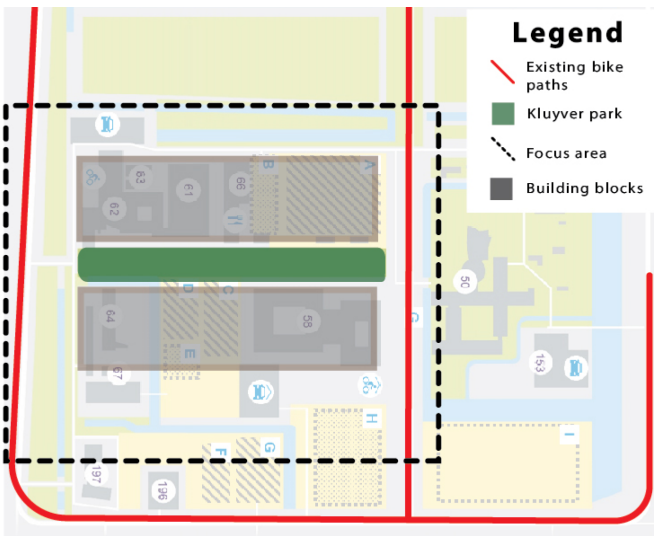

Figure 1.2: Planned building blocks in the Kluyver area, Kluyverpark highlighted

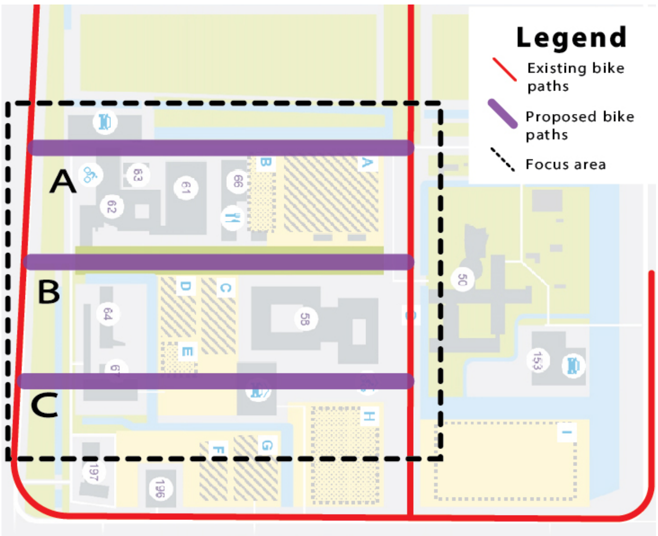

Figure 1.3: Proposed bicycle paths in the KLuyver area

1.3. Research question

The question that will be answered during this thesis is the following:

Which bicycle path, or combination of bicycle paths, is most suitable to satisfy future needs of the Kluyver area?

In order to answer this question, several sub-questions are formulated. Answering each of these sub-questions will is necessary to form an answer to the research question.

1. **Which parts of the area will see the highest intensities?**

   The answer of this sub-questions gives information on where the need for a bicycle network is most needed. It identifies which parts of the area should have prioritization in accessibility to the network, and shows where the need for new bicycle parking facilities is.

2. **What are the required dimensions for bicycle infrastructure?**

   Knowing the required dimensions of bicycle infrastructure is important to know how much space is needed. Minimum width, curvature radii and distance to other infrastructure falls under the required dimensions.

3. **What are the physical barriers of the Kluyver area that limit the construction of the bicycle paths?**

   In order to answer this subquestion, the physical elements of the kluyver area will be analysed, such as the buildings, blue and green structures and other infrastructure. Knowing where these are and how they are connected to each other is needed to understand where potentially the network can be built.

4. **What are the final designs of the bicycle paths?**

   This sub-questions covers the design part of the thesis. Designing the bicycle paths is done in a reproducbile way, based on the outcomes of the analyses.

5. **Which criteria and weights are used to form multicriteria analysis to compare the bicycle paths and combinations?**

   The multicriteria analysis is a way of making a considered comparison between designs. Formulating criteria and weights is done

1.4. Approach

The thesis is set up in a specific structure that starts with analysing the area. This is done in three analyses. The first is the usage analysis, during which is is analysed where exactly in the area the growth of study and work places is. This is needed to know where the need for bicycle infrastructure is the most, and with that where the need for bicycle parking is. During the second analysis, the basic measurements of bicycle infrastructure is analysed. This is needed to know how much space the network will need, and where it can be placed. The third analysis is done to learn what the area looks like; where exactly are the buildings and water structures etc.
Then, the designs for the three bicycle paths will be made. These designs will take the findings of the analyses in mind. When these are complete, the multicriteria analysis will be set up, and the bicycle paths, and combination of bicycle paths, will be reviewed and compared.

1.5. report structure

Chapter 2 contains the analyses. In this chapter, which analyses are performed, what is found during each analysis and a conclusion are written. The next chapter contains the designs. It starts with general interventions that each design has, and will then per bicycle path explain what is needed to construct that path. Lastly, it will contain the possible combinations. In chapter 4, the evaluation of the designs is explained. It starts with an explanation of the multicritria analysis. Then, per criteria, all of the designs are evaluated. Lastly it informs on the score of each design. Chapter 5 contains a discussion on the choices made in this thesis. It will discuss the alternatives and gives motivation for the assumptions. Chapter 6 contains a conclusion to the thesis - it will provide answers to the research question and the sub-questions, and discusses the possible future work. Lastly, chapter 6 is followed by the bibliography and the appendices.

2 Analyses

This chapter covers the analyses that are performed to get an understanding of the needs of the area, and the physical limitations of the area. First, a usage analysis is covered. This analysis shows where exactly the growth in the area is, and results in understanding where the need for parking is. The hierarchy analysis covers the standards for bicycle infrastructure; all the relevant measurements and minimal dimensions. Lastly, the site analysis researches the area; what the physical elements are and where how they connect.

2.1. Usage analysis

Before the network can be designed, it is important to understand how many people will use it and what their destination within the network is. The goal of this analysis is to produce an overview of the expected amount of users and to make a spatial map visualizing where the need for new parking is.
The users of a network can be categorized in three categories; those who arrive, those who leave and those who are only passing through. As the Kluyver area is for working and studying only, the first two categories can be seen as one. Students and workers arriving in the morning will leave in the afternoon or evening.
For the first two categories, the expected capacity of the area needs to be analysed. This is done by finding out how many study- and workplaces there currently are in the area, learning if these quantities are going to change and finding out how many study-, lecture- and workplaces will be added to the area with the completion of new buildings. These numbers will be found by contacting the existing buildings, searching on the website of the TU Delft and by contacting campus development team, as they know the dimensions and capacity of the future buildings. The change in student and employee places is roughly determined and rounded as it is not certain how many places there exactly will be. Then, these numbers are multiplied by the standards for bicycle parking on the campus.
The Kluyver area is split up in several plots that roughly follow the existing and planned faculties, as shown in figure 2.1. The plots that will change the most are plots **B** and **E**. These plots will see a changing need in parking facilities. In plot B, the existing fellowship with around 1030 study places will be moved to plot E, and the new physics building, with around 700 study places and 500 workplaces, and the cleanroomfacility with 80 workplaces, will be built here [9].
The need for parking facilities is determined on the basis of the amount of students and employees in a building, and are prescribed by the municipality of Delft. As the total campus of the Delft University of Technology is unique in its needs for bicycle parking, the municipality has a specific recommendation for this area. It recommends 0.6 bicycle parking places per student, and 0.5 per employee [10] [11]. The university itself extends this standard with 10%, to secure future needs.
Plot E sees a big increase in its bicycle parking need. Which is obvious as it changes from zero buildings to three. The increase in need for bicycle parking here is around 2070 parking spots for students, and 230 for employees. Table 2.1 shows for these plots an overview, as well as for plot A (faculty of Aerospace Engineering) and plot F (Applied Physics). An overview of all of the plots can be in appendix B; figure B.1.

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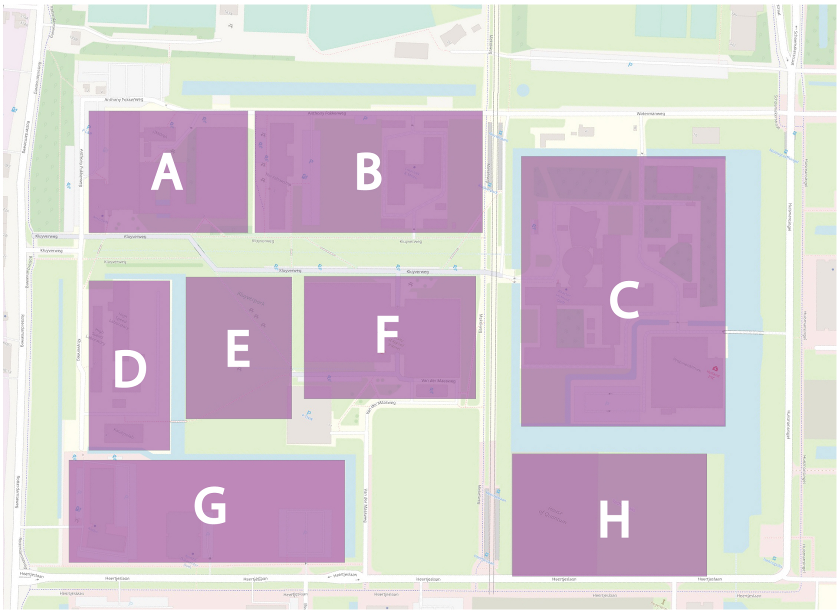

Figure 2.1: Plots in Kluyver area

Plot	Faculty	Students	Employees	#Spots students	#Spots employees
A	Aerospace	1190	662	786	364
B	Fellow	-1030	0	-680	0
	L&E	0	14	0	-8
	Physics	700	500	462	275
	Cleanroom	0	100	0	55
	Total			-218	322
E	GO	2000	20	1346	11
	QuTech	100	400	66	220
	Fellow	1030	0	680	0
	Total			2066	231
F	Applied Physics	531	?	351	?

Table 2.1: Change of study- and workplaces and parking spots

As the Kluyver area might become a part of the metropolitan bicycle network, the third category is something to take in account. However, those who are ”just passing through”, do not need the bicycle parking within the area, so their growth is only important for the minimum dimensions of the bicycle paths. The metropolitan area of The Hague and Rotterdam has labeled several spots in the metropolitan area as economic hubs. The TU Delft is one of them, and is labeled as one of the biggest, as it has the biggest reach of all of the spots - almost 1.2 million persons can reach the TU within 45 minutes of cycling, with an expected growth between 12 and 15 % in 2025 [12].
This does not say anything on how many people will use the possible metropolitan bicycle route through the KLuyver area. However, it does indicate that there are a lot of potential users of the route. And, also given that Delft lays between Rotterdam and The Hague, it is not crazy to think that this will be route with a high intensity.

2.2. Hierarchy analysis

In The Netherlands, building bicycle infrastructure is locally organized. Municipalities plan where to build bicycle paths, what dimensions they have and which places they connect. To ensure that infrastructure throughout The Netherlands is more or less the same, an institute advises the local government on how to build the infrastructure. This institute is called, in dutch, “*CROW: kennisinstituut voor infrastructuur, openbare ruimte, verkeer en vervoer, en werk en veiligheid”*, which is translated to English:

CROW: Knowledge institute for infrastructure, public space, traffic and transport, and work and safety. The CROW publishes an advice on how to plan public space and infrastructure. Municipalities are not obligated to follow this advice, but in most places, it is followed roughly.
Roughly once every ten years, the CROW publishes a book of guidelines for the implementation of bicycle infrastructure. The latest version, published in 2016, is reviewed for this thesis [13]. This guidebook is reviewed on suggestions for the minimum width of bicycle paths, distance to other infrastructure, curve radii and network standards such as the meshed network.
The specific elements that will be researched are:

- width with regards to intensities for bi-direction bicycle paths
- width with regards to intensities for uni-direction bicycle paths
- minimum distance to other infrastructure
- minimum distance to other elements (trees, buildings etc.)
- minimum curve radii
- other important elements that are found whilst reviewing the literature

Generally, a bicycle network has a hierarchical structure. It is divided in three components. The lowest rank is the basic structure. These are the access roads on neighbourhood scale, and all small roads that cyclists can use without regulations. The second rank is the main bicycle network, designed for higher intensities. Connections between districts fall under this category, as well as district access roads. The last category is the fast bicycle routes. These can be seen as bicycle highways [13].
The networks designed in this thesis fall mainly under the main bicycle network, as their main function is to connect parts of Delft with the Kluyver area. Smaller sections, such as a connection between a faculty and the network could be seen as a basic structure. However, the intensities of these sections will probably be too high to be classified as a basic structure. Therefore, primarily the main bicycle network and fast bicycle network dimensions will be analysed.

For different types of bicycle paths, the CROW suggests different minimum widths. It makes a distinction between solitary bicycle paths (ones that are not specifically adjacent to a street), fast bicycle paths (fall under the highest rank of the network hierarchy) and free bicycle paths, which are separated from roads with a minimum required distance [13].
Solitary bicycle paths require a minimum width of 4.5 meters. This is for intensities of 350 cyclists per hour, or more. Fast, bidirectional bicycle paths require a minimum of 4 meters, but if the intensity exceeds 3,000 cyclists per day, an extra 0.5 to 1 meter should be added. For a unidirectional fast bicycle path, the minimum width should be 3 meters, and a minimum central reservation of 0.5 meters should be placed. For normal unidirectional bicycle path, the minimum width should be 3,5, and for a bidirectional path, this should be 4,5 meters. A verge of at least 0.35 meters should separate these paths from the road. The metropolitan region Rotterdam - The Hague does also prescribe minimum dimensions for its metropolitan routes; a minimum of 4.5 meters should be pursued [7]. An overview of these minimum widths is shown in table 2.2. This table only shows the minimum widths in correspondence to the maximum intensities. A table for all intensities is added to appendix B; table B.3.

The CROW does also suggest dimensions for the infrastructure; the minimum distance to objects should be at least 0.25 m for objects with a height under 0.05 meter, and 1 meter distance for higher objects such as walls. Objects in the middle of bicycle paths, such as poles, should also have at least 1 meter of free space on either side of them, and preferably 1.5 m [13].
Main bicycle networks are normally designed for a speed of 30kph. This speed requires minimum curve radii of 20 meters for not having to slow down. Curves do also require an extra 0.5 meters of width to account for extra swinging. Lastly, the CROW does also recommend dimensions for networks. For main bicycle networks, the CROW recommends 300 to 500 meters between axes, in order to secure directness.

Type	Solitary	Normal paths	
		Uni	Bi
Max. intensity	350/hour	-	-
Min. width	4.5 m	3.5 m	4.5 m
Extra	-	min. 0.35 m distance from road	min. 0.35 m distance from road

Type	MRDH	Fast Paths	
	Max. intensity	Uni	Bi
Max. intensity	-	3000/day	3000/day
Min. width	4.5 m	3 m	4 + 0.5 m
Extra	-	min 0.5 m central axis between both	+ 0.5 m if I >3000

Table 2.2: Minimum widths of bicycle paths

2.3. Site analysis

The site analysis is an analysis of the physical elements of the Kluyver area, and an analysis of the bicycle network on the campus of the TU Delft. The analysis is done to get an understanding of the area; where are possible barriers of the network, how much space lays between the buildings and how are the green and blue structures connected. The analysis is done by tracing specific elements on tracing paper, based on a satellite image of the area. This is a useful technique to understand how the elements are structured and how they work together.

The specific elements that will be traced are the following:

- Green structures (grass, trees, etc)
- Water structures
- Existing infrastructure
- Existing buildings
- Planned buildings

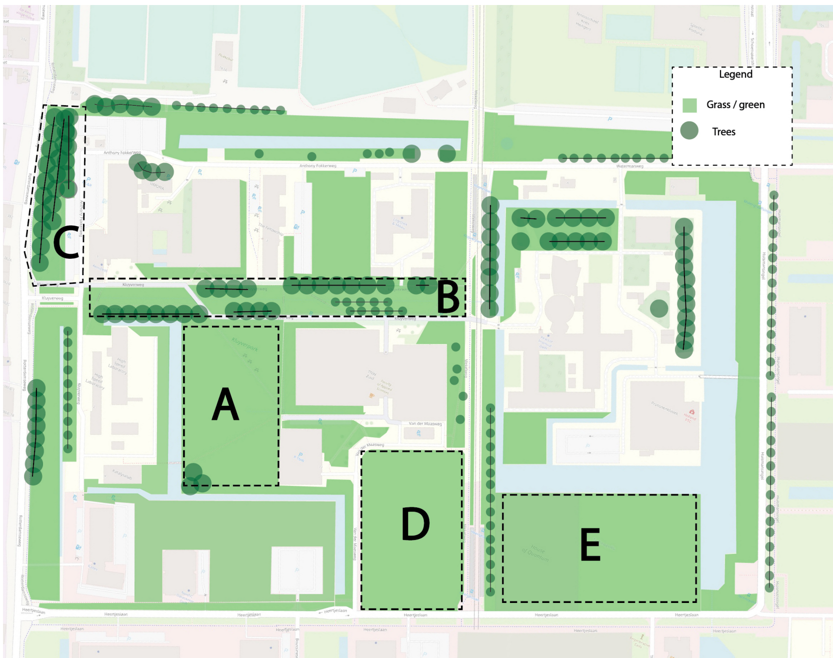

Figure 2.2: Green structures in Kluyver area

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2.3.1. Green structures

Anno 2022, the Kluyver area is quite a big open space. There's is a lot of green plots in the area, and quite some tree-lines. When the development has been completed, this will be changed. Area **A** in figure 2.2 is currently just a plot of grass of 150 by 90 metres and covers quite a large portion in the western part of the Kluyver area. Three buildings will be built here which will definitely make the area feel more compact.
The Kluyverpark, highlighted with **B** is the central axis of the western part. This park feels calm and is intended to reside. Several benches are placed making the area feel calm. It is comparable to the Mekelpark, but feels more secluded due to the fact that there are large trees present. Currently, there is a shared space along the park where cycling and walking is possible.
An interesting place is grove in the northwestern part of the Kluvyerarea (**C**). This is used as an unofficial entrance to the Kluyverarea. There are some walking paths in this grove, but these are also used by cyclists to go to the Anthony Fokkerweg (figure A.2) or bicycle parking adjacent to the faculty of Aerospace engineering. The trees are not far away from each other and are high and wide.
Lastly, there area two other areas of grass (**D** and **E**). These two will both see development. The house of Quantum will be built area E, but will probably not cover the entire area [14]. The dimensions of the building in area D are yet to be decided.

2.3.2. Water structures

Analysing the water structures learns that there are several permanent water structures within and surrounding the area, and some wadi's within the area. Water structure **A**, shown in figure 2.3, could form a limitation in how the adjacent road, the Anthony Fokkerweg, might grow. As it has a width of over 10 meters and quite some decay with respect to the road, this water structure forms a large barrier. Water structure **B** lies in the middle of the area. The presence of this water forms limitations to the dimensions of the future buildings on the neighbouring plot of grass. It has a bridge for pedestrians, shown in red. As of now, this bridge does not have the dimensions to be part of a bicycle network, but redeveloping this bridge might make this a possibility.

Lastly, Water structure **C** forms a barrier between the Kluyver area and the Rotterdamseweg. There are multiple entrances between these two, but not, for example, in line with the extension of the pedestrian bridge. However, this ditch is +/- 7 meters; not as wide as the others. It could therefore be a possibility to cross this ditch.
The wadi is not a permanent water structure, but is placed to store rainwater in events of excessive rainfall and can therefore not be overlooked. Multiple bridges cross the wadi to create a connection between the faculties [15].

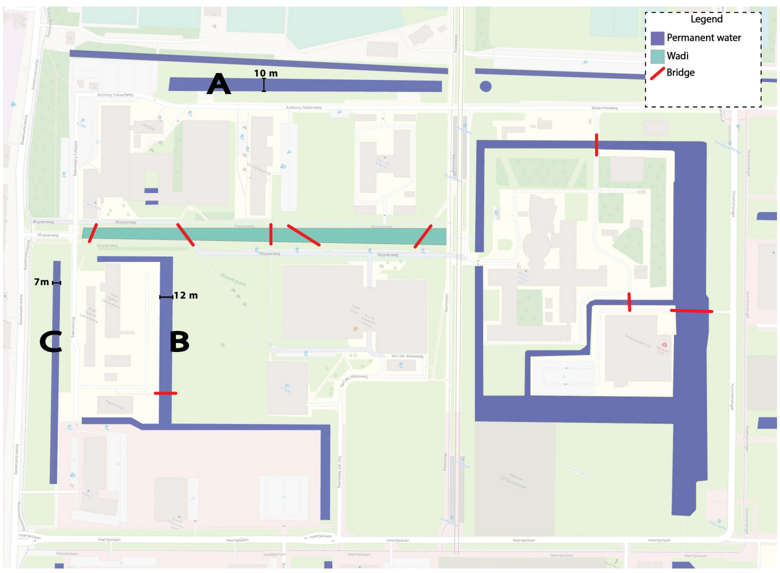

Figure 2.3: Water structures in Kluyver area

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2.3.3. Buildings

The analysis of the existing and planned buildings learns that the surface of the buildings will increase by a lot, resulting in a more ”compact” feeling of the area. The wide plot of land west of the faculty of applied physics will host three buildings; a general teaching facility (**A**), QuTech (**B**) and a study facility (**C**), the new fellowship, in figure 2.4. As definitive plans for these buildings do not exist yet, their exact dimensions and placement can only be estimated, based on the latest plans rough plans of the TU Delft campus 2.5. Based on the estimated locations of these buildings, what can be concluded is that there is a plot of land south of these buildings and a park between the northern and southern faculties where placement of bicycle infrastructure might be possible.

The faculties of Applied Sciences and Aerospace engineering are present in the area and are not planned to be demolished. The same goes for the nuclear reactor, the facilities on the southwestern side of the campus, and all the other existing buildings in Figure 2.4. The plans for the Physics building (**D**) are in a far stadium, and the dimensions of the building These buildings form barriers to the network and must be taken into account. The parking facility of Applied Physics (**E**) on the other hand does also have to be taken into account, but, if needed, could with small adjustments be renovated in a (partial) bicycle parking facility, or other infrastructure.

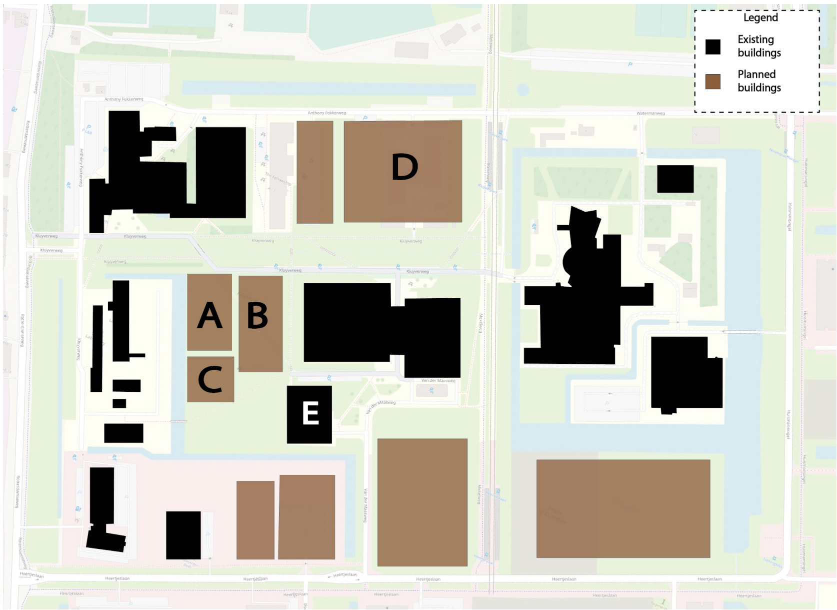

Figure 2.4: Buildings in Kluyver area

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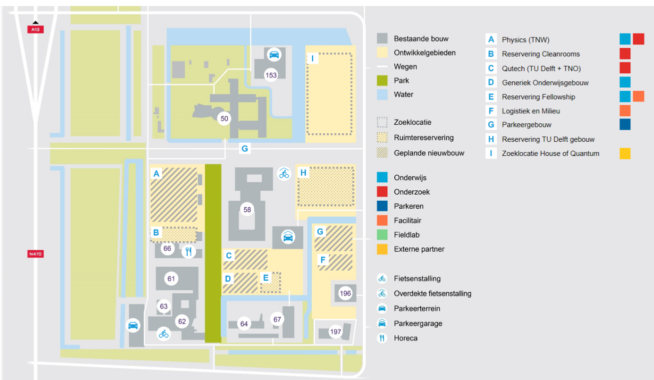

Figure 2.5: latest plans of the TU campus for the Kluyver development [8]

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2.3.4. Infrastructure

The Kluvyer is almost completely surrounded by a two-lane road, as shown in figure 2.6 in black. The campus can be entered with a car in multiple locations, mainly to access to parking facilities of the Faculties Applied Physics and Aerospace Engineering, but also to access some other buildings in the southeastern part of the area. The surrounding roads are dedicated to car traffic, whilst the roads inside the area share the space with other traffic users such as cyclists.
Cyclists can use the three dedicated north-south bicycle paths in the area, and the southern axis. The Mekelweg (**A**) is with 3,6 meters quite a wide bidirectional bicycle path but it is not wide enough according to the standards for the highest intensities, and not wide enough to suit a metropolitan bicycle route. The bicycle path adjacent to the Rotterdamseweg (**B**) is even narrower. Cyclists are in the area allowed on all the other infrastructure, such as the shared space in the middle of the area (**C**). If this space is seen as a main bicycle route, is is not advisable to be a shared space according to the CROW [16].
Parking, both for cars and bicycles, is currently located near the existing faculties of Aerospace Engineering and Applied Physics. Combined, there are currently around 2300 places to store bicycles. As the study facility Fellowship will be relocated, the bicycle parking facility (**D**) will likely be removed.
There are a lot of walkways throughout the area. it must be kept in mind that some will be removed when new buildings are developed.

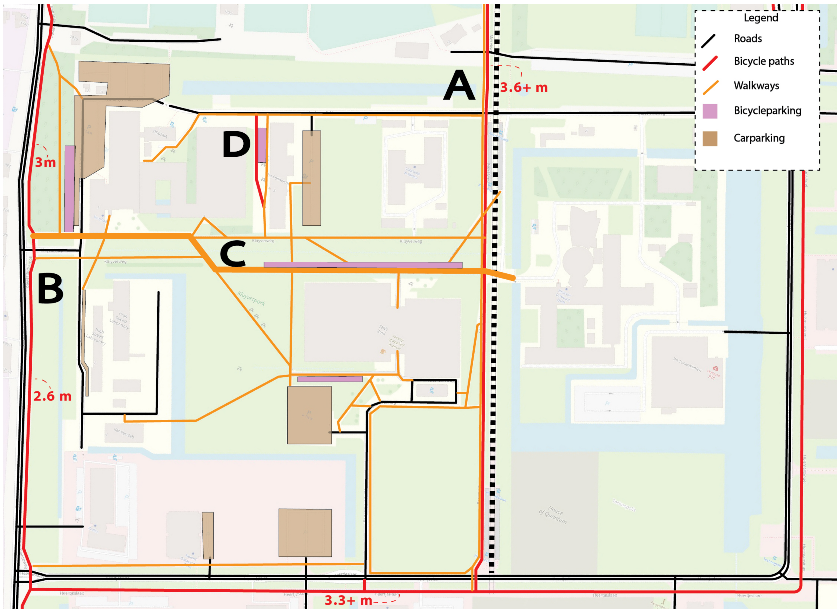

Figure 2.6: Infrastructure in Kluyver area

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2.3.5. Campus bicycle network

To ensure that there is cohesion in the infrastructure layout, it is important to analyse how the existing bicycle paths are placed throughout the campus. The campus has two (three if the schoenmakersstraat is counted in) main north-south axes; the Mekelweg and the Rotterdamseweg, which run almost over the entire campus. These axes are connected with east-west bicycle paths and together, they form a grid.
The grid-size of the campus is roughly between 300 and 350 meters, with an exception along the faculty of mechanical engineering, where due to limitations from the building a smaller grid-size is not possible. This is right at the lower spectrum of the suggested grid-size by the CROW [13] for a main bicycle network.
The bicycle infrastructure on the campus is mainly built up with bidirectional bicycle paths. Some can

be categorized as solitary whilst others are placed along a road. There are some bicycle roads where cars are allowed. The Leeghwaterstraat (**A** in figure 2.7) is a bicycle street; cars are welcome but are treated as a guest. Other roads where bicycles are allowed are highlighted in orange, are normal roads. The Mekelweg has across the campus roughly the same width of 3.6 meters. The bicycle path along the Rotterdamseweg varies quite a bit, with a narrow part of just 2.6 meters at **E**. East-west connections vary from 3.2 meters at **B**, where the width is limited due to an adjacent road and a trench, to 4.7 meters at **D** where there are no limitations. The bicycle path at the Drebbelweg (**C**) has a width of 3.6 meters.

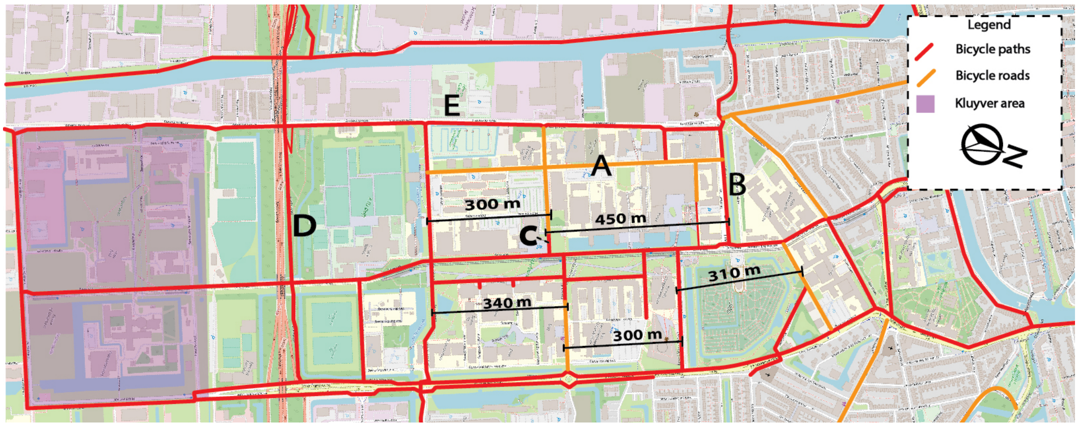

Figure 2.7: bicycle layout on the campus

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2.3.6. Urban plan

The Kluyver area is part of the region TU Delft campus Zuid. This region contains all the land that is part of the campus and south of the Kruithuisweg (figure A.2). There are plans to develop this area in a multifunctional area, where start-ups, high tech companies and the university come together. Developing the Kluyver area is part of the development of Campus Zuid.
Recently, in 2019, urbanism firm PosadMaxwan was assigned by the TU Delft to deliver an urban plan for the area [17]. This plan contains broad plans for architectural elements, public space, ecology, typology and but also mobility on Campus Zuid. The global goal is to develop Campus Zuid in a high quality area, with calm green and blue corridors through the building blocks and infrastructure redirected around the building blocks.
An interesting element of this plan is the Kluvyerpark. PosadMaxwan refers to this park, together with some other areas, as a special place, that functions has a centralizing function for the cluster. The facilities and faculties surrounding the Kluyverpark combined are the cluster.
Another element that is relevant to this thesis, is the proposed solution for bicycle parking. The urban plan proposes centralized parking in the Kluyver area. The parking spots should be placed to serve multiple buildings and be of high quality, offering more than just spots to park, such as cafes or a small supermarket.

2.4. Conclusion

A concluding map is shown in figure 2.8. It shows the boundaries between the area and the Rotterdamseweg (green structure C and water structures C and B). Also, the buildings surrounding the Kluyverpark as these need to be taken into account when designing the paths. The Kluyverpark itself is also highlighted as a special location within the area. Lastly, the existing bicycle paths and the bicycle parking are highlighted.

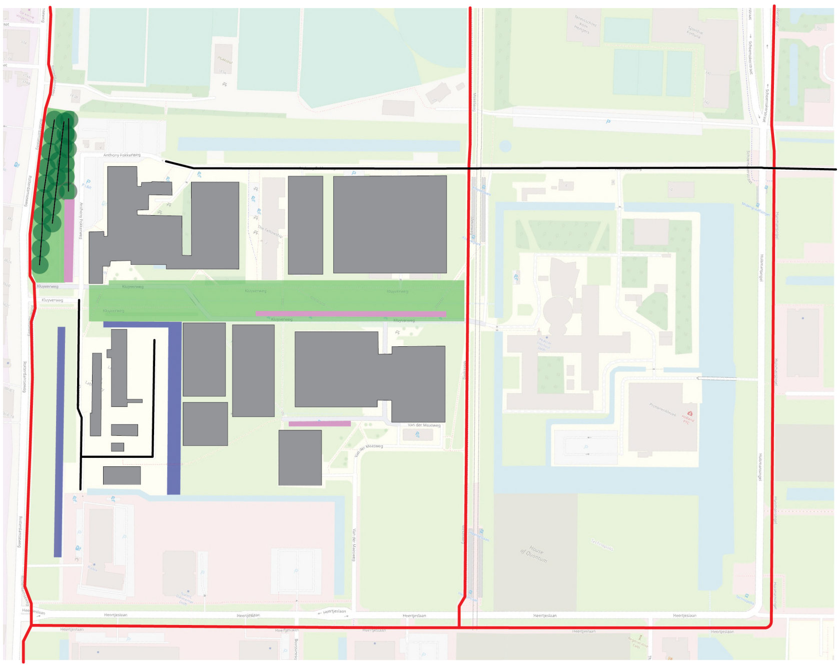

Figure 2.8: Concluding map

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3
Designs

This chapter contains the designs for the potential bicycle paths. As mentioned in the introduction, there are three possible zones to build a bicycle route, showed in figure 1.3. The analyses confirmed that these are indeed the most logical places to build bicycle paths, although some are more suitable than others. The bicycle paths are given a letter to distinguish them from each other. The northern path is given the letter **N**, the middle path **M** and the southern the letter **S**.
This chapter starts with the general elements of the network, which will be part of every design option. Then, the designs of the paths are explained. Lastly, combinations of the designs are explained.

3.1. General

The elements that are part of every design option are independent of the bicycle paths. They are built to suit the needs that came forth from the analyses, and the area shown in figure 3.1. These elements are: broadening of the Mekelweg and Rotterdamseweg bicycle paths and building parking facilities in plot E and B (see figure 2.1).
Whilst the bicycle path adjacent to the Mekelweg is, at 3.6 meters, already one of the widest in the area and the campus, it is needed to further widen it. This is because the Metropolitan area of Rotterdam and The Hague aims to have bicycle paths of at least 4.5 meters. The TU Campus is labelled as the most reachable economic spot and lies exactly between The Hague and Rotterdam, therefore it is expected that this route could see high intensities, and the aim of 4.5 meters should be reached
The same goes for the bicycle path adjacent to the Rotterdamseweg. This should at least be widened until the entrance of the Kluyverpark to 4.5 m, as this is the minimum width for the highest intensities. The bicycle paths are designed for the highest intensities as this can be expected; even with only a small portion of the possible 4000 students in the area arriving at the same time, these maximum intensities are met. If bicycle path S is built, the Rotterdamseweg should be widened until at least the entrance of this path. If this is not the case, it still needs widening to at least 3.5 m, as that is the minimum for an intensity level lower.
In two plots, new bicycle parking will be built. Plot B asks for new bicycle parking as, with the relocation of the Fellowship, the existing bicycle parking will be demolished. Parking for students could be built in the new Physics buildings, but could also be placed along the Anthony Fokkerweg. The placement and accessibility of this parking are not dependent on if path N is built. Employees parking is recommended to be placed inside the building. This can be combined with the adjacent Cleanrooms building.
The three expected buildings on plot E ask for a combined 2100 parking spots for students. A central parking facility will be built in the style of the Coffee&Bikes. This facility combines bicycle parking with a small-scale cafe to upgrade the facility, and also has 2100 bicycle places [18]. The facility on plot E will have similar dimensions and also a small cafe or supermarket. Employees should have a separate bicycle parking facility within the buildings, as recommended by the urban plan [17].

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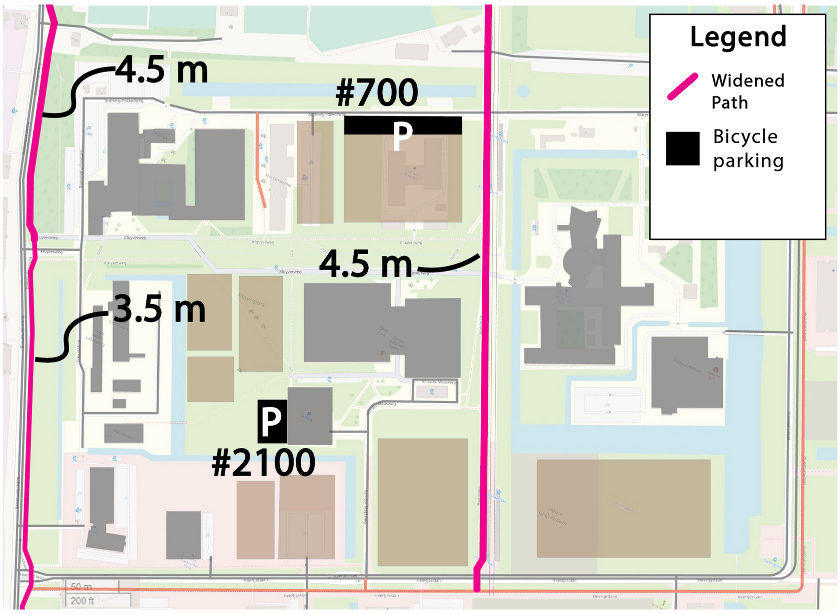

Figure 3.1: General elements of the proposed network

3.2. Path N

Path N is the northern path of the three. Building it requires redesigning the Anthony Fokkerweg in a bidirectional bicycle path of 4.5 meters wide, and extending it to connect with the Rotterdamseweg. This bicycle path will be accessible for motorized vehicles to ensure that the Cleanrooms and Physics will logistically be reachable. This destination traffic is of such a low intensity that a bicycle street is not required, and a bicycle path will suffice. Building solely this path would require building a link between the Mekelweg and the bicycle parking facility in Plot E (figure 2.1).

To make the connection with the Rotterdamseweg possible, some trees in the bush behind the faculty of Aerospace Engineering will need to be removed, to make room for the bicycle path and secure visibility. It is estimated that between 9 and 12 large trees will need to be removed, and some smaller ones. The small valley between the Rotterdamseweg and this bush will need to be (partly) filled to account for a "dip". The path swings around the parking area behind Aerospace Engineering. However, about 28 parking places will be removed.

In figure 3.2, a detail of this bicycle path is shown. The brown patch indicates where the trees should be removed. The curves have a radius of 20 m and the path is 4.5 m wide. An extra 1 meter on either side of the path is indicated with a black line. In this extra space, no are placed to fulfil the requirements of the CROW.

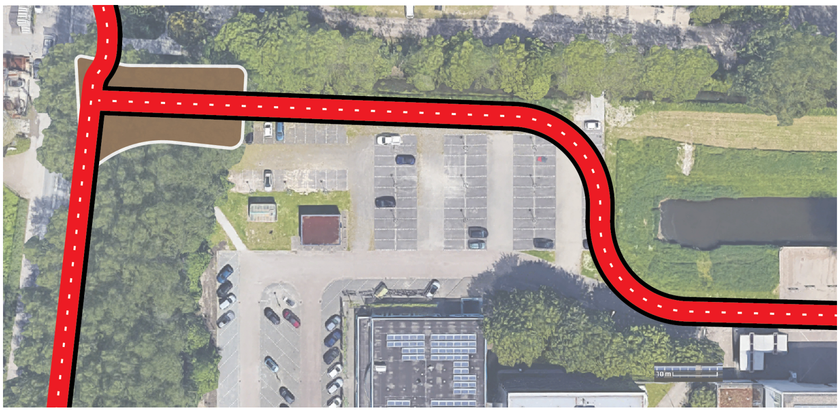

Figure 3.2: Detail of path N

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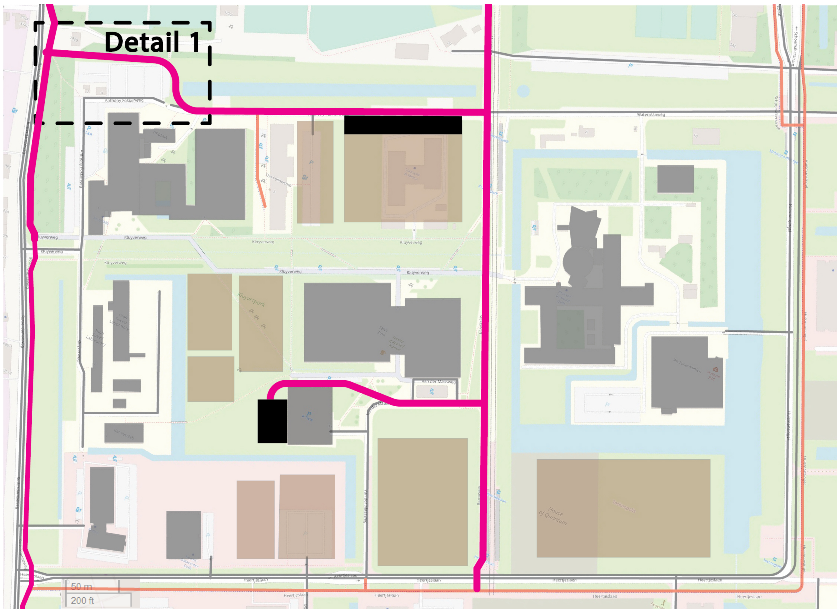

Figure 3.3: Path N

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3.3. Path M

Path M runs through the Kluyverpark. It replaces the existing walking path with a 4.5 m wide bicycle path. No large interventions or replacements will be needed to make this path, as the structure is already present. It will run on the northern side of the park and crosses the wadi on the existing bridge. This bridge is already 7.5m wide, so does not need to be widened. With this design, there is a lot of mixed traffic within the Kluyverpark. To regulate this, some pedestrian crossings will be built on the path, as shown in figure 3.5 Path M has one branch to connect with the bicycle parking facility.

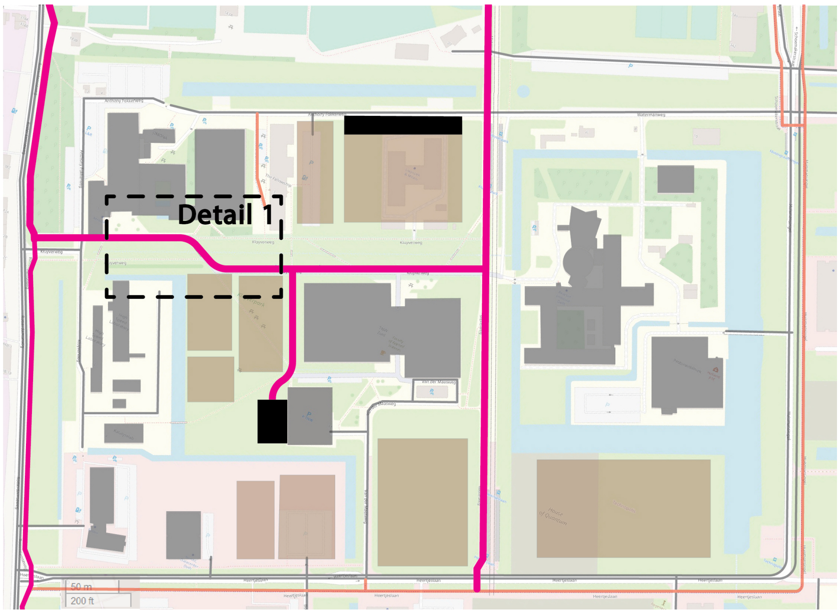

Figure 3.4: Path M

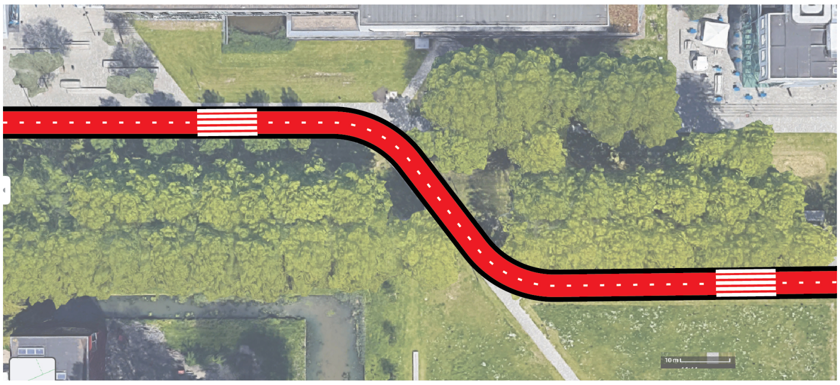

Figure 3.5: Detail of Path M

3.4. Path S

The construction of path S requires more work than the other paths. It runs in the southern part of the focus area where currently, for the most part, no other infrastructure or bicycle paths are. To build this path, two bridges and a pedestrian overpass need to be constructed. The left bridge on detail 3.7 is built to cross water structure C in figure 2.3. The right bridge will replace the pedestrian bridge crossing water structure B.
The path will run between the three buildings on plot E (figure 2.1) and the planned central bicycle parking facility. As the parking facility is built for these buildings, high intensities of pedestrian traffic is expected. To separate the bicycle traffic on this path and the pedestrians, an overpass is recommended. This overpass can be incorporated with the parking facility, as a multi-floor parking facility is presumable. This way, the required height is already achieved.
If only this path is built; the parking existing parking facility adjacent to the northern side of the faculty of Applied Sciences (see figure 2.6) is not accessible. It is therefore recommended to replace this parking facility to the lowest floor of the car-parking facility of the faculty of Applied Physics, as this place is very accessible with path S. Relocating these parking spots from the park to a place accessible with dedicated bicycle paths ensures that the pedestrian and bicycle traffic is separated.

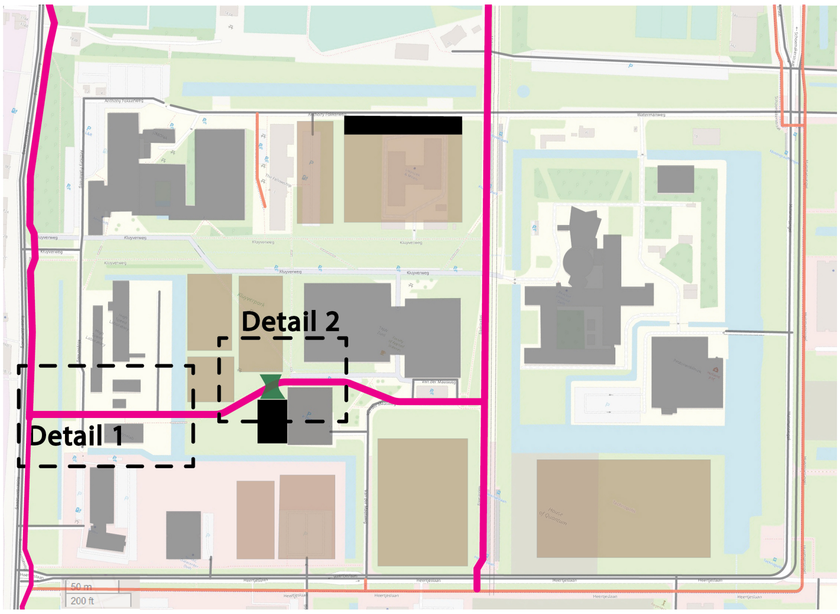

Figure 3.6: Path S

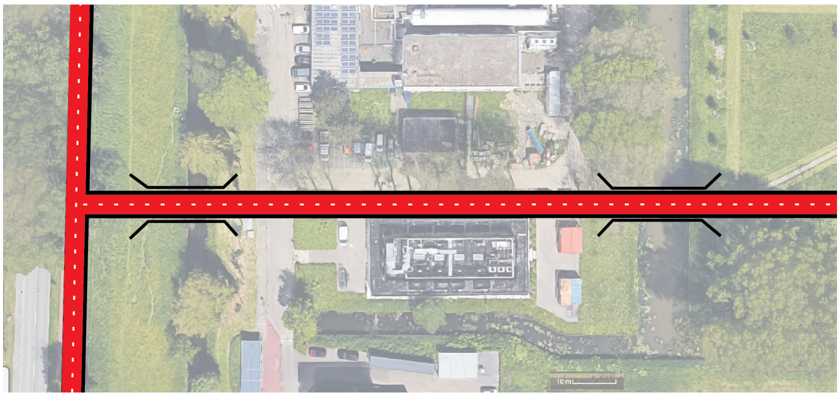

Figure 3.7: Detail 1 of Path S

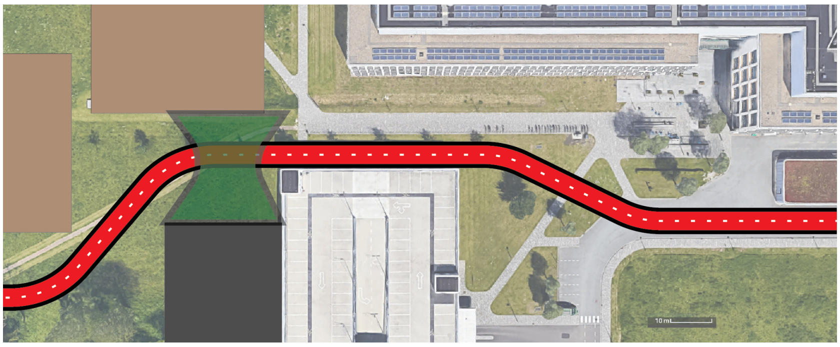

Figure 3.8: Detail 2 of Path S

3.5. Combinations

Combining the paths could lead to the following combinations: North-Middle (NM), North-South (NS), Middle-South (MS) and North-Middle-South NMS. These combinations follow the same requirements as building only one of the paths, but then added up. The only difference is, when path S is combined, the branches in figures 3.4 and 3.3 are not needed, as the parking facility will be accessible. Combination NM will build the branch in figure 3.4, as it requires less bicycle path to be built.

4 Evaluation of the designs

In this chapter, the evaluation of the designs is written. First, the criteria are explained and what weights they have. Than, the designs are each graded on the criteria and are given a score.

4.1. Criteria

The seven designs are compared to each other on five criteria; safety, cohesion, comfort, cost and surrounding. The first three are prescribed by the CROW. Cost is added as the feasibility of developing a network also depends on the cost. Criterion surroundings is added to analyse how the development of the network influences the rest of the area. The designs are graded on each criterion by getting a score between 1 and 5, with 1 the minimum and 5 the maximum. Five possible scores are chosen as it includes the possibility of scoring neutral (3), but still ensuring a difference between fulfilling the criterion (4) and standing out (5).
Safety is in many analyses the most important criterion. Safety is a large concept; a network can have a lot of aspects to ensure safety, such as separation from motorized traffic and minimizing the amount of crossings. All of the designs are separated from motorized traffic and have the amount of crossings minimized. The distinction between the networks in this criterion is therefore mainly in separation with other modes of traffic (pedestrians) and the amount of possible conflict points.
Cohesion is judged on how well the network suits the destinations of the area, as well as how good it fits in the surrounding networks. Cohesion should be ensured such that people can naturally understand the network, and that it doesn't feel that they have entered a different network. this criterion is judged on how well the paths suit the destinations, and how it contributes to the total network of the TU Delft
Comfort is judged on how comfortable the networks are; are there obstacles, how wide are the paths and are the curves large enough. How many times cyclists will have to slow down contributes to the score on this criterion.
Costs is hard to judge as it is hard to exactly know how much each design will cost. However, the costs can roughly be estimated and compared to each other with how many adjustments are needed, and how big these adjustments are.
Surroundings is added as the last criterion as the network will be part of an area where transport is not the sole intention. The area is namely also a place to reside, work and interact. How big the impact of the network is on the surroundings, is judged in this criterion.

The CROW does prescribe two other criteria which are not used in this multicriteria analysis; directness and attractiveness. Directness is not used as this network is on such a small level that the designs do not have a significant difference in directness. Attractiveness is judged on how aesthetically pleasing the path is, and how it fits in its surroundings. This criterion is very similar to "surroundings", and is therefore not chosen as a separate weight.

As the criteria are not equally important, they are given a weight to make a distinction. The weights are determined by evaluating each criterion to another, determining per criterion if it is more important than the other. If the criterion is more important, it gets graded with a 1. For example; safety is considered more important that cohesion. Therefore, it gets a 1 in the row:safety and column:cohesion (see

table **??**). These numbers are added up in the column score, and divided by the total amount (10) to determine the weight.
Safety is considered as the most criterion, it is more important than cohesion, comfort and surroundings as the main function of infrastructure is getting people from a to b safely. It is graded equally important as costs, as this is a limiting factor to the safety. One can aim for a unlimited safe network, however there is not always enough budget for that.
Cost is the second most important criterion. It highly determines how feasible a design is, as it is the main limiting factor. It is considered as equal important as safety, as it should not limit the network so much that it becomes unsafe. Surroundings is also considered as equal important. This is because the quality of the total developed area also depends on the quality of the bicycle network, and the budget for the total project exceeds the budget for the network. In other words; if there's too much being cut on the budget for the network that the network decreases the quality of the area, the cuttings might have such a large effect on the area that can not be compromised. Therefore, surroundings and costs are graded equal.
As said before, surroundings is one of the most important criteria. How well the network fits within the area is crucial for the total development. It is considered less important than safety as that is the main function of infrastructure, however it is considered more important than comfort and cohesion.
Comfort and cohesion area considered both as the least important criteria. These criteria area secondary to the rest as they are not essential for the network to function. As both criteria are complementary to the network, they are considered as eually important.

	Safety	Cohesion	Comfort	Cost	Surroundings	Score	Weight
Safety		1	1	0.5	1	3.5	0.35
Cohesion	0		0.5	0	0	0.5	0.05
Comfort	0	0.5		0	0	0.5	0.05
Cost	0.5	1	1		0.5	3	0.3
Surroundings	0	1	1	0.5		2.5	0.25

Table 4.1: weights of criteria

4.2. Score

The seven designs will be given a score per criteria. In each subsection, the grade per score design is discussed, and an overview is provided in a table. Each subsection starts with the discussion on the separate paths. Then, the combinations are discussed.

4.2.1. Safety

Path *N* is designed to separate cyclists from pedestrians, and minimizes the amount of crossings between the two modes of traffic. Path *N* does not get a 100% score on safety as visibility is still limited at the connection with the Rotterdamseweg, and there is a some mixed traffic on the path as destination traffic uses the path, all be it rarely. Therefore, the path gets a score of 4.
Path *M* is placed in the middle of the Kluyverpark. The park is designed as place to reside and to connect the adjacent faculties. It is expected that there will be a lot of pedestrians in the park. This criteria is mainly graded on separating the modes of traffic; and this path does separate these modes at all. It is therefore graded with a 1.
Path *S* is completely separated from other modes of traffic, as it does not see any motorized and pedestrian traffic. It is not limited in visibility and gets a the maximum grade of 5.

Extending the network with an extra (two) bicycle paths does increase the safety of path *M* a bit. While the amount of possible conflict points does not decrease, it could be argued that the intensities on this path are lower as cyclist have an second or third option to travel. Therefore, the combinations with *M* (*NM*, *MS*, *NMS*) are graded with a 2. Combination *NS* gets a maximum score for the same reason; adding an extra option means that the intensities on path *N* are lower and therefore the amount of possible conflicts with motorized traffic is decreased.

Safety: weight = 0.35							
Design	**N**	**M**	**S**	**NM**	**NS**	**MS**	**NMS**
Grade	4	1	5	2	2	5	2
Score	1.4	0.35	1.75	0.7	0.7	1.75	0.7

Table 4.2: Score on safety

4.2.2. Cohesion

Cohesion is graded on how well the paths serve the destinations, in this thesis the bicycle parking facilities, and how well it fits in the bigger network. The analysis on the bicycle network of the TU Delft showed that in general, the distance between axes around 300 meters is. A table with the distances to other axes for all the paths and combinations can be found in appendix B; table B.2.

With just path *N*, the biggest distance to another axis is 430 meters. This is bigger than the average of the TU Delft, but falls within size that the CROW prescribes. This bicycle path makes the parking behind Physics very accessible, but does a worse job for the parking north of Applied Physics. With this network, the large parking in plot E (figure 2.1) will be accessible, but cyclist entering the area from the Rotterdamseweg will have to make a detour. This makes that two of the three (Physics and Plot E) parking facilities are accessible by bicycle path, Therefore, the cohesion of building just this path is graded with a 3.

Path *M* is graded with a 3. The maximum distance to another axis remains roughly the same as path *N* (415 m) and also with two out of three, equal amount of parking facilities are accessible.

Path *S* is graded with a 2. This is because maximum distance to another axis is increased to 530 m. And, with just this path, only one out of the three bicycle parking facilities is accessible by bicycle path.

Building combinations makes the cohesion of the network increase. *NM* serves all of the parking facilities with and lowers the maximum distance to 280 m, and is graded with a 5. *NSM* gets the same grade, as it too serves all parking facilities and has similar distance to other axes. *MS* only serves two of the three parking facilities and does not decrease the maximum distance; it gets graded with a 3. Lastly, *NS* does serve only two of the three facilities, but lowers the maximum distance to 260 meters and therefore is graded with a 4.

Cohesion: weight = 0.05							
Design	**N**	**M**	**S**	**NM**	**NS**	**MS**	**NMS**
Grade	3	3	2	5	4	3	5
Score	0.15	0.15	0.1	0.2	0.2	0.15	0.25

Table 4.3: Score on cohesion

4.2.3. Comfort

Grading in this criterion is based on how likely it is that someone has to slow down whilst using the network. In all seven options, this is limited as the paths all fulfil the comfortable standards prescribed by the CROW (widths and curve radii). Therefore, how likely it is that someone has to slow down is based on intensity and the chance of encounters with others.

Paths *N* and *S* both are separated from the park and encounters with pedestrians are minimized. They are graded with a 4. Path *M* runs through the park. As there are more possible encounters with pedestrians, cyclists will lower their speed. Moreover, building solely path M requires building an off-path to the parking facility on plot E. This means an extra crossing where cyclists lower their speed. Path *M* is therefore graded with a 2. Expanding path *M* with path *N* does not change a dime on the comfort level of path *M*, therefore path *NM* is too graded with a 2. Adding path *S* to path *M* means that the off-path is not needed and thus, the extra crossing is removed. Combinations *MS* and *NMS* are therefore graded with a 3. Lastly, combination *NS* has all the benefits of *N* and *S* separately, but by combining the two, the intensities on each path will decrease, making the ride more comfortable. This combination is graded with a 5.

Comfort: weight = 0.05							
Design	**N**	**M**	**S**	**NM**	**NS**	**MS**	**NMS**
Grade	4	2	4	2	5	3	3
Score	0.2	0.1	0.2	0.1	0.25	0.15	0.15

Table 4.4: Score on comfort

4.2.4. Cost

Path *M* is the easiest and cheapest to build. It requires no extra infrastructure and no demolishment of things. There is already a wide enough walking path through the park, this just needs to be reconfigured into a bicycle path. Path *N* is the second cheapest, but needs some trees to be removed and a ditch to be (partly) filled. However, it is still a lot cheaper than path *S*, and gets graded with a 4. Of the three, path *S* is the most expensive. The completion of this path requires two bridges and a overpass. This path gets graded with a 4, because only combinations with this path are more expensive.

The cost of combinations are just the cost of the paths added up. Combining all three the paths is the most expensive, *NMS* is graded with 1. However, as *M* is considered the cheapest and its influence in the total costs is minimal, combinations with *M* will be graded as if *M* is not taken in calculation. That makes that *NS* is graded the same as *NMS*; 1. *NM* and *MS* are graded the same as *N* and S, and get respectively 4 and 2.

Cost: weight = 0.3							
Design	**N**	**M**	**S**	**NM**	**NS**	**MS**	**NMS**
Grade	4	5	2	4	1	2	1
Score	1.2	1.5	0.6	1.2	0.3	0.6	0.3

Table 4.5: Score on cost

4.2.5. surroundings

Path *N* gets a grade of 3 in this criteria, as it influences the area poorly by the removal of the old trees. Apart from that, it does not influence the quality of the area. Path *M* does influence the function of the park a lot, as building a bicycle path through the park decreases the connection between the faculties on both sides and decreases the quality of the park heavily. This path is graded with a 2. Path *S* does not have a bad impact on the area . It does not influence the function of the park and construction does not require demolishment of existing objects, apart from a small portion of a street. This path is graded with a 5.

Combining *N and* M is bad for the function of the area and requires demolishment of trees; *NMS* and *NM* are both worse than just *M*, and are graded with a 1. Like path *M* in criterion cost; path S does not influence the grade in its combinations, *MS* and *NS* are therefore the same as *M* and *N*, and respectively get a grade of 2 and 3.

Surroundings: weight = 0.25							
Design	**N**	**M**	**S**	**NM**	**NS**	**MS**	**NMS**
Grade	3	2	5	1	3	2	1
Score	0.75	0.5	1.25	0.25	0.75	0.5	0.25

Table 4.6: Score on Surroundings

4.3. Conclusion

Path S scores the highest score in this multicriteria analysis, with a score of 3.9 out of 5. Combining all bicycle paths leads to the lowest score; 1.65. The total multicriteria analysis can be found in appendix A; table B.1

Multicriteria analysis

Design	N	M	S	NM	NS	MS	NMS
Total Score	3.7	2.6	3.9	2.5	3.25	2.1	1.65

Table 4.7: total scores of the paths

5 Discussion

From all of the seven design proposals, bicycle path *S* received the highest score in the multicriteria analysis. This result is the outcome of the proposed designs, the chosen criteria and their weights, and the assessments of those designs. There are several assumptions and choices made throughout the thesis which can have influenced this outcome. The assumptions and choices were mainly made in the design process, composing the MCA and assessing the designs. In this chapter, these assumptions and choices are discussed. First, the choices in the design process will be discussed. Then, the MCA is evaluated and lastly, the assessment comes forward.

Designing consists of constantly making choices. Most would have led to the same result, however some would have changed the outcome. Designing path *S*, the choice was made to include two bridges over water structures C and B. An alternative was not to make a bridge over water structure C, but to connect the bicycle path via the Kluyverweg (figure A.2). This would have made bicycle path *S* cheaper. But, it would also make this path less comfortable due to the extra curves, less cohesive due to the bigger distance to the Heertjeslaan (figure A.2), and score poorer on surroundings or safety as it either would share the road with motorized traffic or require a complete redesign of the Kluyverweg. These are the reasons that this alternative was not chosen. If it was chosen, path *S* would still receive the highest score, but it would slightly drop to either 3.75 or 3.85.
Designing path *M*, the choice was made to include pedestrian crossings. An alternative was to replace these with shared spaces. This was not chosen as the CROW does not prescribe shared spaces for the intensities that are expected on these bicycle paths. However, this prescription could have been ignored - there are shared spaces with high intensities that seem to work, such as the shared space behind the Amsterdam central station. Nevertheless, the decision was made for pedestrian crossings as the safety of shared spaces is hard to measure.
Lastly, designing path *S*, a pedestrians overpass is included. This overpass is included as it completely separates pedestrian and bicycle traffic at a high-intensity place. This is a very costly piece of infrastructure, and it could be argued that it is too expensive. An alternative could be a pedestrian crossing at the place of the overpass. The choice for the overpass was partly made so that there is a clear distinction between all three options; a cheap, unsafe option (path *M*), an expensive, extra-safe option (path *S*) and one in between (path *N*). The other reason for choosing the overpass is that, if it weren't there, path S would have divided plot E (figure 2.1), more than paths *N* and *M* would have done. Nevertheless, choosing for a pedestrian crossing would have changed the outcomes; path *S* would have scored lower on safety and comfort (both probably -2 points), but higher on cost (+1). This would have resulted in a lower total score than path *N*

Setting up the multicriteria analysis has been with a level of subjectivity. Choosing not to take directness and attractiveness as separate criteria but evaluating these subjects in other criteria influences the outcome, as there are fewer criteria to score on. Determining the weights of the criteria is also with a lot of subjectivity. The explanation for determining the weights in this thesis is explained in chapter "Evaluation of the designs". It can not be stressed enough how much influence the weights have on the outcome. In this thesis, surroundings is considered quite an important criterion. However, this could be seen as subjective. Someone else could argue that it is on the same secondary level as comfort and cohesion, and that safety and costs are the only real important criteria. If e.g. surroundings was considered as less important and cost even more important, path *N* would probably score the highest score.

Composing the grades is prone to subjectivity. In this thesis, path *M* received low grades on comfort and safety, as this design has lots of possible encounters with pedestrians. One could argue that this low grading is overdone, as the TU Campus has more bicycle paths through a park, such as the Mekelpark, and that is therefore not representable to grade this low. There is a case in this argument, however, the Mekelpark is with 75 meters 50% wider than the Kluyverpark. The impact that constructing a bicycle path through the Kluyverpark brings is therefore bigger, and is graded worse in this thesis. Lastly, a five point-scale was chosen for grading the designs. It could be argued that a seven-point scale would provide a more comprehensive distinction between some designs Then, the extra cost that constructing path *M* brings to the combinations could have made a distinction between e.g. path *NMS* and *NS*. However, a seven point scale does not have give significant difference in mean and variation [19]. And, with a limited amount of knowledge, it is hard to further specify the grading. For example; with only estimations of cost, a global scale is more representable than a further specified scale. Therefore, a five point scale was used in this thesis.

6 Conclusion and Recommendation

This chapter consist of the conclusion of the thesis and the recommended future work.

6.1. Conclusion

This report results in a proposal for a bicycle network in the Kluyver area, which correlates to the answer to the research question: *"Which bicycle path, or combination of bicycle paths, is most suitable to satisfy future needs of the Kluyver area?"*. Formulating an answer to this question required composing five sub-questions, from which can be concluded that:

The plots surrounding the Kluyverpark see the highest intensities and have the most need for large scale bicycle parking. The faculties of Aerospace Engineering and Applied Sciences currently make up for the highest intensities. However, with the construction of three buildings on plot E (figure 2.1), the need for large bicycle parking will be the biggest in this part of the Kluyver area. Plot B (figure 2.1) does not see a large change in need for bicycle parking, it actually drop in total need. However, the current bicycle parking facility in this plot is removed, so creating new parking facilities is needed.

The CROW for multiple kinds of bicycle paths different minimum widths prescribes. They are, however, all around the 4.5 meters for maximum intensities. Other standard measurements are: curve radii of minimum 20 meters, a minimal distance of 1 meter to large objects and a recommended grid-size of 300 - 500 meters.

There are some elements surrounding the Kluyver area that complicate entries to the area, such as ditches and bushes. The park in the centre of the Kluyver area is designed to be place where people can reside, and while the current bicycle path in the middle of the Kluyver area is already quite wide (3.6 m), it is not wide enough to function as a metropolitan bicycle route.

The final three designs roughly follow the same space as the possible placements in the introduction, but have a clear distinction between them. They vary from a cheap and relative unsafe bicycle path to an expensive and very safe option.

The designs were graded on comfort, cohesion, safety, cost and how well it fits the surroundings. With the last three considered as most important and having the biggest weight.

These conclusions lead to an answer to the research question. From the seven possible designs, and the formulated multicriteria analysis, bicycle path *S* is considered as most suitable to satisfy the future needs of the Kluyver area.

6.2. Recommendation

This thesis concludes that bicycle path *S* is the best option for the a bicycle path in the Kluyver area. There are some tasks indicated that could be performed in the future, which could influence the outcome but will make for a more comprehensive decision.
It is recommended to perform more excessive analyses on safety and cost. If there is more objective data on these criteria, the grading could be done in a seven point scale instead of the five point scale used in this thesis. Using a seven point scale could result in better distinction between the designs.

Receiving objective data in these criteria can be done by e.g. doing a survey under students on how they perceive safety near bicycle paths / in shared spaces. A more extensive research on the costs of infrastructure gives better objective data in the criterion cost.
An analysis on the origin of visitors of the Kluyver area is also recommended. If there is data about where people come from, the construction of new entries to the area could be suggested. E.g., if there's data about how many cyclist have train station Delft Campus as origin and the Kluyver area as destination, there is reason to suggest the Energiebrug. How well the design proposals would work with these new entries could then be a criterion in the MCA.
It is also recommended to review the designs and analyses when the plans for the buildings are more concrete. Currently, the plans are still quite vague, especially for buildings planned on plot E (figure 2.1). Lastly, it is recommended to make the designs in a more advanced visualisation program, such as AutoCAD, especially when the desgins for the buildings are more detailed and if they are available in AutoCAD documents. While the measurements on the visualizations in this thesis are correct, more detailed maps could better explain the designs.

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Appendix A

This appendix contains maps used in the thesis.

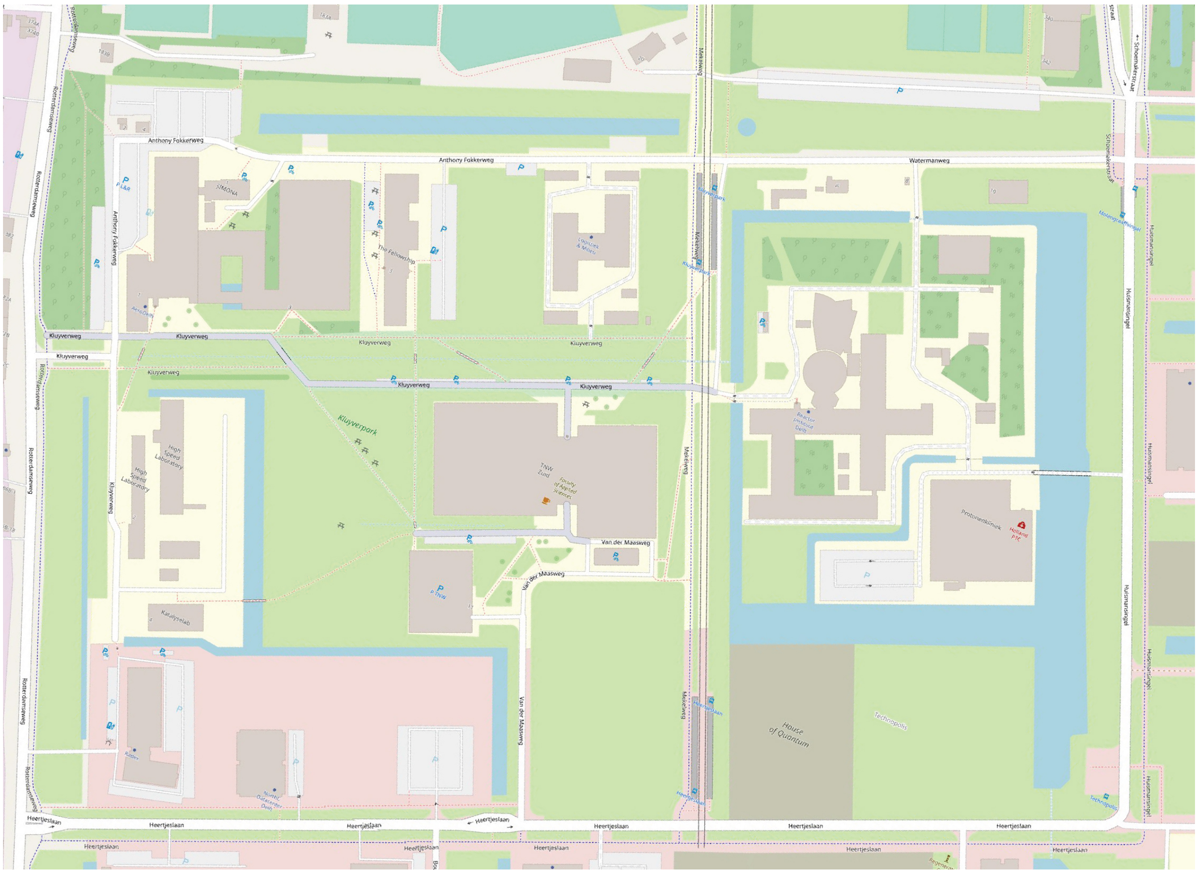

Figure A.1: Map used as base layer for all of the maps used.

Figure A.2: Names of streets in and surrounding the Kluyver area.

B

Appendix B

This appendix contains tables with data.

Multicriteria Analysis									
	Safety			Cohesion			Comfort		
	weight	grade	Score	weight	grade	Score	weight	grade	Score
N	0.35	4	1.4	0.05	3	0.15	0.05	4	0.2
M	0.35	1	0.35	0.05	3	0.15	0.05	2	0.1
S	0.35	5	1.75	0.05	2	0.1	0.05	4	0.2
NM	0.35	2	0.7	0.05	5	0.25	0.05	2	0.1
NS	0.35	5	1.75	0.05	4	0.2	0.05	5	0.25
MS	0.35	2	0.7	0.05	3	0.15	0.05	3	0.15
NSM	0.35	2	0.7	0.05	5	0.25	0.05	3	0.15
	Cost			Surroundings					
	weight	grade	Score	weight	grade	Score	Total		
N	0.3	4	1.2	0.25	3	0.75	3.7		
M	0.3	5	1.5	0.25	2	0.5	2.6		
S	0.3	2	0.6	0.25	5	1.25	3.9		
NM	0.3	4	1.2	0.25	1	0.25	2.5		
NS	0.3	1	0.3	0.25	3	0.75	3.25		
MS	0.3	2	0.6	0.25	2	0.5	2.1		
NSM	0.3	1	0.3	0.25	1	0.25	1.65		

Table B.1: Multicriteria analysis

Distance to other axes on Mekelweg			
	kruithuisweg (northern axis)	Heertjeslaan (southern axis)	Max distance
N	260	430	430
M	410	280	410
S	530	195	530
NM	260	280	280
NS	260	195	260
MS	410	195	410
NMS	260	195	260
Source: Google maps			

Table B.2: Disance from each path to other axes.

Plot	Faculty	Lecture	Study	Employee	#bike student	#bike employee	Existing parking students
A	Aerospace engineering	1071	119	662	785,4	364,1	981
					785,4	**364,1**	
B	Fellowship	-1030	0	0	-679,8	0	471
	Logistics&Environment	0	0	-14	0	-7,7	
	Physics	0	700	500	462	275	
	Cleanroom	0	0	80	0	44	
					-217,8	**311,3**	93,5
C	Nuclear powerplant	?	?	?			
D	Aerodynamics Laberatory	?	?	?			
E	GO	2040	0	20	1346,4	11	
	QuTech	0	60	400	39,6	220	
	Fellowship	1030	0	0	679,8	0	
					2065,8	**231**	
F	TNW Z	531	1	1	351,12	0,55	825
					351,12	**0,55**	
G	Logistics&Environment	0	0	14	0	7,7	
					0	7,7	
H	House of Quantum	?	?	?			

Figure B.1: Table of the total usage analysis

Bicycle path	Directional	Intensities		Min width [m]
Solitary	-	0-50	[fth/h]	1.5
		50-150	[fth/h]	2.5
		150-350	[fth/h]	3.5
		350	[fth/h]	4.5
Fast (CROW)	Uni	-	[fth/day]	3
	Bi	1000-3000	[fth/day]	4
		1000	[fth/day]	3 - 3.5
		3000	[fth/day]	4.5 - 5
Normal	Uni	0-150	[fth/h]	2
		150-750	[fth/h]	2.5 - 3
		750	[fth/h]	3.5 - 4
	Bi	0-50	[fth/h]	2.5
		50-150	[fth/h]	2.5 - 3
		150-350	[fth/h]	3.5 - 4
		350	[fth/h]	4.5
MRDH	Uni	-	-	3
	Bi	-	-	4.5

Table B.3: All minimum widths with regarding to the intensities