Wireless Charging of E-Bikes in Two-Tier Bicycle Rack

The design of the TILER® UP-Charge

Graduation Thesis

MSc Integrated Product Design

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Preface

This thesis graduation report marks the culmination of my journey in the Master of Integrated Product Design at TU Delft and my wonderful time as a student. Since 2018, when I started my bachelor's at the very same faculty, I've had the chance to develop myself and explore my interest in the field of Industrial Design. From the unique approach to problem-solving to designing products that real people will actually use, I must say that this has been a much appreciated and enjoyed daily occupation. Among many other things I discovered an interest in great user interaction, especially the ones that are so well designed that one would think twice about it.

After being introduced to the company of TILER roughly one year ago, I have also grown more and more interest in the world of future, sustainable mobility. Having had the opportunity to combine those interests in the design of a wireless charging solution for E-bikes in a two-tier bicycle rack for this graduation thesis, along with a shared goal with TILER of making sustainable solutions as effortless as possible, it truly feels like a full circle moment. Therefore, I would like to thank the many people who have contributed, directly or indirectly, to making this graduation thesis a reality.

To my supervisor, Daan van Eijk, and mentor, Jelle Zijlstra, I sincerely want to thank you for the guidance in this project, the thoughtfulness and flexibility, the critical view, and, of course, the support and trust when needed. The shared enthusiasm for this project really contributed to the enjoyment and final result of this graduation project.

To Joris Koudijs, my company mentor from TILER, who helped me understand the world of TILER, start-ups, and LEV's. Over the previous winter we already got to know each other as colleagues, but during this graduation project you have been not only greatly appreciated for your expertise but also as a great companion. Your passion for TILER and the improvement of their unique wireless charging solution motivated me to create a final product that might one day actually be seen at bicycle parking facilities all around. Additionally, your perspective as a mechanical engineer really helped me through some of the more technical intricacies of this graduation project.

To Olivier Coops, CEO of TILER, who introduced me to the company and has given me the opportunity to do my graduation project at TILER. Thanks for trusting me to tempoariliy become a part of the fantastic team at TILER.

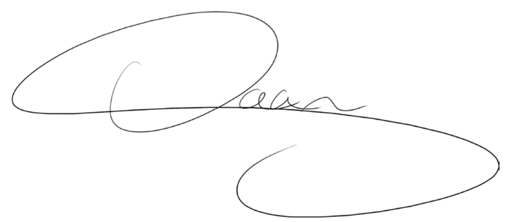
And to that fantastic team of other colleages at TILER, I want to thank you all for being great company during time at TILER.

A special thanks to Feiko Withagen from VelopA for being open to this graduation project and sharing the perspective from the bike parking infrastructure industry. Thank you for providing me with my very own bicycle rack to use for the design, prototyping, and testing of this graduation project.

Finally, thank you to my family, friends and roommates for your unconditional support during this period. Your love and attention has been essential for the completion of this project.

And to you, as a reader of this graduation thesis report, I hope you will enjoy your time and hopefully get inspired to make the future of sustainable transport a reality.

Thanks, and enjoy!



Abstract

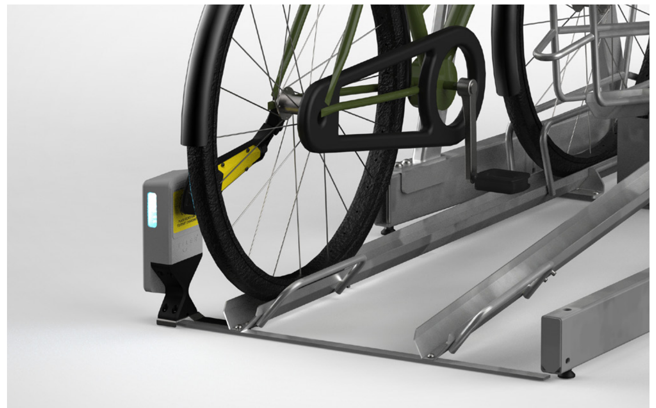
This graduation project aimed to design a wireless charging solution for charging E-bikes in two-tier bicycle racks. The starting point of this project was the 'Charging Kickstand' from the Delft-based start-up 'TILER'. This Charging Kickstand, when mounted and connected to any E-bike, is typically placed on top of a TILER 'Charging Tile' when the E-bike is parked. Within the context of this graduation project, two-tier bicycle racks, as commonly found at public locations such as train stations, forcing users to put their kickstands down to the ground to charge their E-bikes in addition to already placing their bikes within these racks is cumbersome and not a viable solution. Therefore, the main aim of this project was to develop a solution that utilized the same Charging Kickstand for wireless charging, without requiring users to perform any additional steps compared to regularly parking their bikes in two-tier bicycle racks.

The biggest challenge within this project was to design a charging solution that would not obstruct the bike when entering the bicycle rack. The Charging Kickstand is mounted in the exact location that any other kickstand would be on an E-bike: at the center between the pedals or at the rear of the bike on the chainstay. For a wireless charger to end up next to the kickstand when the bike is placed in the bicycle rack, it was determined that it would always cross paths with the pedals and cranks of the bike, possibly causing a collision or preventing a bike from entering the bicycle rack, which would result in the bicycle rack failing at its primary goal of storing bikes.
Through an exploratory initial prototyping and ideation process, two methods for preventing pedal collision were identified and tested:

1. Ensuring a pedal position upon entering the bicycle rack so that the pedals would move over the charger.
2. Having the charger 'rest' in such a position that it would not collide with the pedals and then automatically moving the charger itself towards the Charging Kickstand when the bike is placed all the way in the bicycle rack.

Both approaches proved to be unsuitable due to tight spatial margins within two-tier bicycle racks. It was then concluded that this project would result in a charging solution in which pedal collision is inevitable.

The resulting final design is a charger that can be pushed all the way flat to the ground by the pedals upon collision, allowing the pedals to pass over it. After being passed by the pedals, the flexible hinging mechanism on which this charger is placed causes the charger to spring back up to its upright charging position, giving this design the fitting name 'TILER UP-Charge'.



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1. Introduction

This chapter introduces the graduation project with its initial design brief. It also provides a brief overview of the project's context, as well as some concepts and abbreviations to help the reader better understand the rest of the report and design project.

1.1 Project Design Brief

TILER, a startup based in Delft, has developed a wireless charging solution for Light Electric Vehicles (LEVs). This technology, created in collaboration with Delft University of Technology in 2019, consists of a 'Charging Kickstand' on the E-bike and a 'Charging Tile' in the ground, which inductively transfers power to the battery when in close proximity. This project aims to extend TILER's existing wireless charging technology to a new context: charging E-bikes in two-tier bicycle racks commonly found in large bicycle parking facilities.

As a result project operates at the intersection of shared, semi-public bicycle racks and individually owned electric bicycles. This will introduce many variables in the design process as everyone has different needs and prioroties.

Key stakeholders might include:
- **TILER:** Looking to create a marketable product.
- **Bicycle Rack Companies (e.g., VelopA):** Seeking compatibility with their racks.
- **E-bike Owners:** Needing a reliable and convenient charging experience.
- **Bike Parking Facilities:** Prioritizing reliability, durability, and safety.

Opportunities in this project arise from the extensive use of bicycle parking facilities, potentially expanding TILER's market reach. The goal for TILER and this graduation project is to create an ecosystem where any E-bike can charge seamlessly.
However, the diversity of bikes and the shared nature of racks present challenges, necessitating universal compatibility and an instruction-free user experience. Additionally, the shared environment poses risks of potential misuse, highlighting the need for robust electronic components.

Figure 1.1: Two tier bicycle racks at Amsterdam Central train station SOURCE: het Parool

1.1.1 Problem Description

The problem to be solved in this graduation project is the inability to use the TILER system when an E-bike is stored in a bicycle rack, rather than on the TILER Charging Tile. Two-tier bicycle racks offer necessary efficient storage for large numbers of bicycles therefore finding a solution to charge bikes within them is essential for the future of E-bikes.

The designed charging solution in this project will be based on an interaction, read wireless power transfer, with the TILER Charging Kickstand. Thereby expanding TILERs wireless charging product range compatable with their Charging Kickstand and thus moving further towards their goal of creating an universal wireless charging solution for E-bikes. With the Charging Kickstand as the designated wireless charging interface for this project, a solution must be found to accommodate different mounting points of kickstands on E-bikes. Given that the necessary charging technology already exists, the focus of this project will be on the interaction between the E-bike user and the racks. This interaction should require minimal additional manual actions compared to storing a regular bike in these racks. Furthermore, the project aims to demonstrate, through prototype testing, that the E-bike can be charged using the in two-tier bicycle racks through the TILER Charging Kickstand.

Significant value can be achieved in the interaction with the to be designed solution: to achieve wide adoption, this addition to current bike racks should not add any hassle to using the rack and charging the bike. This is crucial for TILER, to market a desirable product, and for E-bike owners, who will experience this interaction daily.

1.1.2 Project Goal

For this graduation design project the project goal was stated as such:

Create a design and prototype that allows for the wireless charging of E-bikes parked in two-tier bicycle racks using the TILER Charging Kickstand.

1.2 Context introduction

In the Netherlands, bicycles play a significant role in daily life, evidenced by the fact that there are approximately 23 million bicycles, surpassing the population count. In recent years, E-bikes have increasingly contributed to this number. Research shows that over 50% of the population now uses E-bikes (RAI Vereniging, n.d.). This project addresses the parking and charging needs of this growing number of E-bikes, particularly in densely populated urban areas. While high-density bicycle parking solutions like two-tier racks, as seen in figure 1.2 are common for regular bikes, E-bikes pose an additional challenge: charging.

Charging E-bikes in two-tier bicycle racks presents several challenges compared to the more common practice of home charging.

First, consider the locations where these bicycle racks are typically found: (semi-) publicly accessible bicycle parking facilities near train stations, universities, city centers, and mobility hubs. These facilities, whether outdoors or indoors, generally lack public access to power outlets, never mind having them available for each parking spot.

Even if power outlets were available, using them would be impractical. Riders would need to carry heavy and bulky charging cables with them. Additionally, plugging in chargers would be cumbersome and could obstruct other users of the parking facility. People could also trip over the cables, potentially causing injury or damage. Maneuvering between bikes to plug in within the limited space of the bike racks themselves would also be very difficult.

Finally, the user behavior in this context should be considered. People using these bike racks are typically in a hurry and/or unwilling to spend much time and effort parking and charging their bikes. For example, people using E-bikes for their daily commute to work, especially longer commutes: Even though most E-bikes nowadays have sufficient battery capacity to make a roundtrip from home to work and back, it would give peace of mind knowing that their E-bike is fully charged when they go home at the end of the day, even when they decide to have a detour. Usually, they would have to haul a bulky charger with them every day and still spend time and mainly a lot of effort each morning to plug their charger in, wherever in the bike parking that may be, but often not that easily accessible. This would result in a lot of daily hassle and make them lose valuable time. No less cumbersome would it be to hire someone to manage and charge all employees' E-bikes. E-bike users should be rewarded for their more sustainable choice, not deterred by any additional hassle. Therefore, any charging solution for two-tier bicycle rack parking must require minimal time and effort from the user.

Figure 1.2: Fully packed high density bicycle parking facility equiped with two tier bicycle racks. SOURCE: Vies Mobiles

1.3 Important terms and abbreviations

Several technical terms/concepts and specific abbreviations are used in this graduation project and the report itself to make the reading easier and less repetitive. This chapter compiles and briefly explains the most important concepts and abbreviations to facilitate the reading of the rest of this report.

Charging Tile: The current, as of summer 2024, charging tile developed by TILER as part of their Wireless E-bike Charging solution. Meant to be placed horizontally in/on ground. An E-bike needs to be parked on top of this tile with the Charging Kickstand in order to wirelessly charge the battery.

Charging Kickstand: The current, as of summer 2024, special kickstand developed by TILER as the accompanying part to the Charging Tile for their wireless E-bike Charging solution. It replaces the normal kickstand on an E-bike and is equipped with charging technology that allows it to wirelessly charge when placed on top of the Charging Tile.

PTC (Power Transferring Coil): This is the coil that is directly connected to the power grid. This coil turns electrical power into an electromagnetic field and thereby wirelessly 'sends' power to the Kickstand on the E-bike. It contains not only the coil windings but also the ferrite block around which the copper wire is wound for TILER's wireless charging solution.

PTU (Power Transferring Unit): Refers to the system responsible for 'sending' the power to the E-bike. It includes the PTC, it's encasing, and whatever else is needed strictly for getting the electromagnetic field to the Kickstand and, thus, the E-bike. Excludes additional modules not directly responsible for creating this electromagnetic field, such as a cloud module, additional circuitry or power converters.

PRC (Power Receiving Coil): The coil that, when placed within the electromagnetic field created by the PTU, converts it to electrical power again. It refers to the combination of copper windings and the ferrite block.

PRU (Power Receiving Unit): The whole system included in the Charging Kickstand that is responsible for converting the received electromagnetic field to proper electrical power that can be used to charge an E-bike's battery.

LEV (Light Electric Vehicle): Any small personal transportation vehicle powered or aided by an electrical motor and a rechargable battery meant for traveling short distances. Exact vehicle type definitions differ between countries, but for this report it refers to any LEV within the (future) scope of TILER: E-bikes, Speed-Pedelecs/Speedbikes, E-Cargobikes, E-mopeds, and E-scooters.

2. Analysis

In this chapter an in depth analysis of the complete context of this graduation project is conducted. The technology of wireless charging, intricacies of two-tier bicycle racks and E-bikes will be discovered, resulting in comprehensive list of initial design requirement for this graduation project.

2.1 Tiler

TILER, the company behind this graduation project, is a startup based in Delft that aims to make wireless charging for Light Electric Vehicles (LEVs) effortless. Founded in 2019 after collaborating with Delft University of Technology to develop its technology, TILER seeks to simplify the charging process to encourage the use of LEVs over traditional fossil fuel-powered vehicles, making the world more sustainable.
TILER achieves this by combining charging with the unavoidable act of parking. The Charging Kickstand replaces the normal kickstand on an E-bike and connects wirelessly to the Charging Tile placed on the ground. Integrating charging into the natural act of parking makes the process user-friendly and minimizes hassle compared to using charging cables or swapping batteries. As of now, TILER has successfully implemented this wireless power transfer technology for E-bikes through induction.

2.1.1 TILERs Wireless charging technology

Wireless charging involves transferring power from one point to another without any physical connection. This is achieved through electromagnetic induction, where an alternating current (AC) in a transmitting coil generates an oscillating magnetic field as shown in figure 2.1. When a receiving coil is placed within this field, it induces an AC current in the receiving coil. This is the basic principle behind the wireless charging between TILER's Charging Tile (transmitting coil) and the Charging Kickstand (receiving coil).

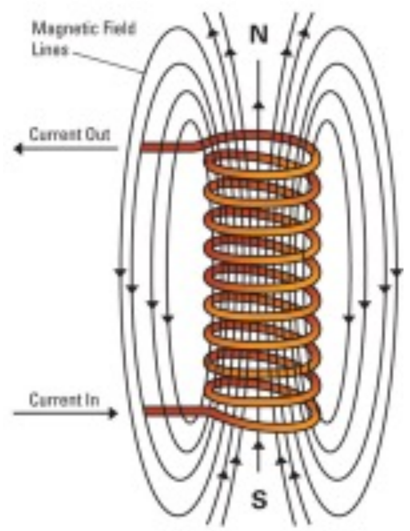

Figure 2.1: Magnetic field around a coil. SOURCE: lanl.gov

Resonant Inductive Coupling
To enhance the efficiency of wireless power transfer, TILER uses resonant inductive coupling, a method used in almost all wireless charging systems. By tuning both the transmitting and receiving coils to resonate at the same frequency, the system achieves higher efficiency, allowing for a greater distance between the coils without significant power loss.

TILERs coil design
While TILER did not invent wireless charging, their design features make their system particularly suitable for charging E-bikes. Both the transmitting and receiving coils are wrapped around U-shaped ferrite blocks of which an example of the transmitting coil can be seen in figure 2.2. Ferrite is highly conductive for magnetic fields but not for electrical currents, guiding the magnetic field lines efficiently. This design increases the power transfer efficiency from the Charging Tile to the Kickstand by ensuring less magnetic field lines 'branch off' out of reach of the coils, but rather are guided towards them, with only a small air gap left in between.
Additionally, the shape of the ferrite blocks allows for some freedom of movement between the coils. The wide slabs of ferrite in the U-shaped blocks ensure that as long as the receiving coil's ferrite plates are positioned above the transmitting coil's plates, the system will function correctly. Since the plates on the transmitting coil are quite big, the receiving coil, this design makes it easier for the Charging Kickstand to align with the Charging Tile, ensuring effective wireless charging even with slight misalignment.

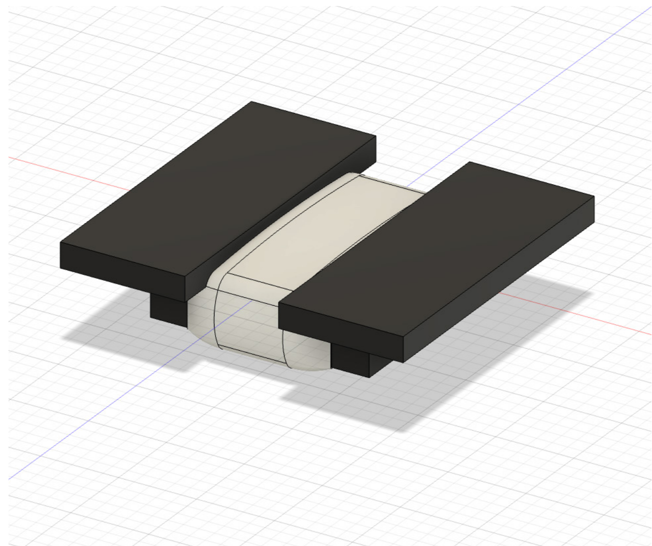

Figure 2.2: Transmitting coil from TILER Charging Tile

2.1.2 TILER Charging Tile and Kickstand

TILER's wireless charging technology is currently being used to wirelessly charge E-bikes through their Charging Tile and Charging Kickstand. This chapter will explain the components that make up this wireless charging system and their workings, from the power cable to the E-bike's battery.

Components breakdown
The basis of TILER's wireless E-bike charging system lies within its transmitting and receiving coils. However, many more components are needed to make it work.

TILER Charging Kickstand
The Charging Kickstand is a specially designed kickstand that can be mounted on E-bikes instead of a regular kickstand that can placed on top the Charging Tile to transfer the power from the Tile through the Kickstand to the battery of the E-bike. The internal components of the Charging Kickstand can be seen in figure 2.3.

- **Power Receiving Coil:** Consists of a coil wrapped around a much smaller ferrite block compared to the coil in the Tile.
- **Circuit board**: controls and contains all processes in the Kickstand to transfer the current generated in the coil to the battery of the E-bike correctly. One of the most important parts is the transformer that bring the voltage of the system to a number on which the E-bike battery can be charged.
- **Power cable:** connects the kickstand to the battery of the E-bike in order for it to be charged.

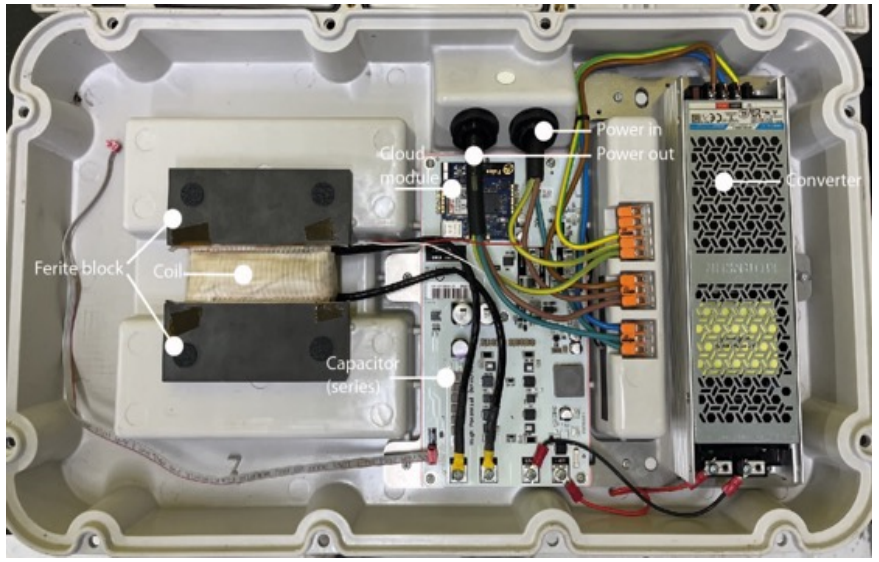

Figure 2.3: Inside of the TILER Charging Tile

TILER Charging Tile
The TILER Charging Tile is responsible for transmitting power to the Charging Kickstand. The components of the Charging Tile, as seen in figure 2.3, can be broken down to a couple of important main parts:

- **Power cable:** connect the Tile to the power grid
  - **Converter:** Converts the AC coming into the Tile straight from the power cable to a direct current and voltage on which the circuit board can run.
  - **Circuit board:** controls all processes happening within the Tile to make it work. It contains several notable parts:
- **Capacitor:** Changes the DC current to AC again and brings the coil in resonance.
- **Cloud module:** Allows the data from the Tile to be collected remotely
- **Power Transfering Coil:** Creates the magnetic field needed for inductive power transfer. It consists of the ferrite block with the coil being tighly wrapped around it.
- **LED module:** used to indicate the charging status of the E-bike when parked on the Tile
- **Housing:** To house and protect all the internal components of the Charging Tile from damage and the environment a strong, plastic housing is used. Rubber seals are used to make the whole watertight when the lid is screwed on.

Figure 2.4: Inside of the TILER Charging Kickstand

Wireless charging process
The wireless charging system has to go through several steps in order to deliver power from the powergrid into the battery of the E-bike. This is a simplified overview of all of these steps. These are the same steps that wireless charging solution for two-tier bicycle racks need to go through in order to work with the current TILER charging technology.

From power source to battery
When charging an E-bike's battery, power is transfered in the following steps:

1. Regular household power (AC - 220V) is delivered to the Tile through a power cable with a connector
   a. Another power cable going directly back out of the Tile allows for daisy chaining of multiple Tiles together.
2. The electricity passes through a converter. Bringing the voltage down from 220V to 48V and changing it to DC. This is necessary to ensure the voltage doesn't get to high after going through the later capacitors in order to bring the coil in resonance.
3. Power goes to the circuitboard.
   a. A part is used to power the cloud module
   b. Some is used to turn on the LED indicator on the top of the Tile
4. By passing through a series of capacitors the coil is brought in resonance with high frequency AC current
5. An electromagnetical field is generated and guided through the ferrite block
6. The ferrite block in the kickstand guides the electromagnetic field through the receiving coil
7. AC is generated in the receiving coil and converted to DC again before going through the PCB of the Kickstand
8. Before going to the battery to charge it a Buck/Boost converter is used to make sure it is the right voltage for the specifications of the battery
9. The battery is being charged

2.1.3 Future technological developments

Since TILER is still a startup, their products and technology are constantly under development. With regard to the Charging Tile and Kickstand there are several envisioned changes in the design for the future including: A new design for the PTC and PRC (coils used in the Tile and Kickstand), removal of several parts in the Tile and Kickstand to be replaced with software features, and some material changes to the kickstand. These changes are described in further detail in Appendix A.

For this graduation project it was decided to discard these technological developments and base the designed charging solution on the current state of TILER charging technology. Two changes, however, have assumed for this graduation project as they are fundamentally enabling the Charging Kickstand to be used in the context of a two-tier bicycle rack:

- New design of the Power Receiving Coil (PRC)
- Material changes of Kickstand housing

These changes and its implications are described in the next part of this chapter.

New Power Receiving Coil (PRC) design
The current design of the Charging Kickstand uses the PRC, shown in Figure 2.4. The black portion represents the ferrite block, while the grey/white part is the coil wrapped around it.
This design is specifically optimised to receive magnetic fields from the bottom. For this project, a newly designed coil will be used in the Charging Kickstand. The updated design (undisclosed) also allows the coil to receive a magnetic field from the side. As a result, contact with the PRC in the Charging Kickstand can still be established when the Kickstand is flipped up in a two-tier bicycle rack by placing the PTC to the side of the Kickstand

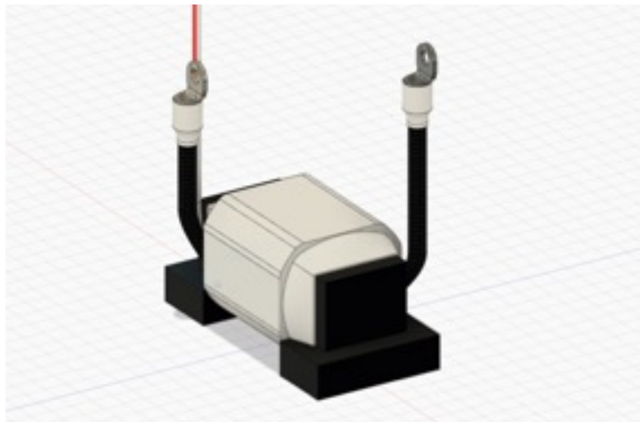

Figure 2.4: Current design of the PTC

Changes to Kickstand housing
To accommodate the new PRC design, modifications are needed for the Charging Kickstand. The current design features a durable plastic bottom (or foot) and an aluminum housing on the outside of the kickstand. However, the new PRC design requires a change because inductive charging cannot pass through aluminum. Despite this, aluminum provides beneficial cooling properties to the kickstand.

To incorporate the new PRC design while retaining cooling properties, the materials of the kickstand's housing will be switched. In the new design, the outside (facing away from the bike) will be made of plastic, and the inside housing (facing towards the bike) will be made of aluminum. This change necessitates TILER to develop and purchase new molds for manufacturing. However, they are willing to make this adjustment to enable charging the kickstand from the side.

2.2. Two-tier bicycle racks

The Netherlands is one of the most bike-oriented countries in the world. This is represented by the high number of bicycles per capita and the sheer amount of bicycle infrastructure present in the streetscape (Goozee, n.d.).

As the Netherlands is densely populated and built up, there is often limited space available for storing all these bicycles, especially in urban areas or at bicycle hotspots such as train stations or educational facilities. As a result, two-tier bicycle racks have become essential in Dutch bicycle infrastructure.

2.2.1 High-density bike parking

Two-tier bicycle racks are designed to efficiently utilize all available space in bike parking facilities. Compared to traditional bicycle parking solutions, two-tier racks occupy more total volume but allow for a higher density of bicycle parking spots within the same floor area due to their unique design features.

The most notable feature is the two-tiered design, which allows bikes to be parked one above the other, effectively doubling the number of parking spaces. Additionally, bicycles are parked in an alternating low-high fashion on both the bottom and top layers of the racks. This arrangement allows handlebars, often the widest part of bicycles, to overlap, reducing the gaps between bikes.

While the alternating low-high design is common in many modern bike parking solutions, two-tier racks have a unique feature: they support and stabilize the bikes at the front wheel and guide them with a 'gutter' in which both wheels are placed. This is essential for lifting bikes to the second level but also ensures that all bikes are perfectly parallel to each other. This precise alignment prevents bikes from being misaligned with their back wheels, which could take up additional space needed for other bikes.

This precise placement allows two-tier bicycle racks to be designed with tight spatial margins, optimizing their use of available space even further. As a result, these racks provide a highly efficient solution for high-density bike parking.

2.2.2 Parking in two-tier bicycle racks

While there are several different brands and designs of two-tier bicycle racks, the process of using these racks is generally the same. In figure 2.6 a step of the process for putting the bike on the top level can be seen. The whole process for both levels can be broken down in the following steps:

Parking on the Bottom Level:
1. Approach the Bicycle Rack:
   - Line up the front wheel with the beginning of the gutter.
2. Align the Bike:
   - Either align the whole bike to be parallel to the gutter beforehand or push the bike in and line up the rest along the way while the front wheel is guided by the gutter.
3. Guidance by the Gutter:
   - The gutter ensures the front of the bike correctly reaches the bracket at the end, which grips either the front tire or fork, keeping the bike upright and stable without the need for a kickstand.

Parking on the Top Layer:
1. Prepare the Sled:
   - Pull out the sled and push it down towards the ground.
2. Lift the Front Wheel:
   - Lift the front wheel of the bike to place it in the bottom of the gutter. Most racks have features to prevent the front wheel from rolling back out.
3. Lift and Push:
   - Simultaneously lift the rest of the bike and push it upwards along the gutter until the back wheel is in the correct position to prevent the bike from rolling back down.
4. Return the Sled:
   - Push the sled up until it is fully horizontal, often assisted by a gas spring.
   - Push the sled all the way back into the bicycle rack.

Both processes seem to be very straightforward and simple. Several things, however, are important to note:
It can be quite difficult for an user to place the front wheel correctly on the sled for the top layer, since they need to simultaneously lift it up high and aim for it to land in the gutter.

Because of this they could bump or land their wheel in the side of the sled. The same can happen in the bottom layer if users try to lift their front wheel into the gutter instead of aligning it from the back. This leads to the following requirement:

R23: The design must withstand an unintentional hit from the side with the front wheel of a bicycle.

When using two-tier bicycle racks, users should push their bicycles in from the back of the bike because the other parked bikes, the rack itself, or its height prevent them from standing anywhere else. As a result, users can never be directly on the side of their bike or reach any part except from the back. This leads to two other design requirements:

R14.4: The design must allow the user to keep standing behind their bike when parking it in the two-tier bicycle rack

R14.3: The design should not require the user to interact with any part of the bike after being placed inside of the rack, except from the back.

Figure 2.6: Lifting up a bike in the top level of a two-tier bicycle rack. SOURCE: Velopa

2.2.3 Variation in two-tier bicycle racks

There are many different brands and models of two-tier bicycle rack. While the space-saving principles are shared among all of them, the execution and design of the racks do differ. This chapter will compare those racks and highlight is most important differences. For this exploration, bike rack models from the following 4 biggest two-tier bicycle rack brands/producers have been considered:

- VelopA
- Vconsyst
- Klaver
- Falco

Some of the considered models will be shown to highlight the main differences. A complete overview of all models can be found in Appendix B.

Let's start with the bottom layer of two-bicycle racks. On all models, the gutter of the 'low' parking spot is straight and flat on the ground. The difference is in the 'high' parking spot at the bottom level: some racks feature a straight gutter mounted diagonally, as shown in Figure 2.7. The other option is a gutter that starts out flat on the ground but has a bend that moves up further along the gutter, as shown in Figure 2.8.

The next differences can be found on the top level of the racks. Starting off with the sliding consoles themselves. The design of these is a result of the chosen material used in the consoles and its manufacturing capabilities. Some (cheaper or more traditional) models use a galvanized steel console in which a gutter or guiding rails, with a similar function, are welded on. An example can be seen in Figure 2.8. The other option is aluminum consoles. In these designs, as seen in Figure 2.7, the gutter is integrated into the bend of the aluminum console itself. While the aluminum option is lighter and more premium, the steel option results in a slimmer profile and is generally cheaper.

Figure 2.7: Optima Ventura bicycle rack. SOURCE: VConsyst

The last important difference is in the way bikes are prevented from rolling back off the sliding consoles. Most designs do this with a bracket at the back, holding the back wheel in place, like in Figure 2.7. Another option is to have a clamp at the front where the fork of the bike needs to be maneuvered in, like in the close-up in Figure 2.9. This allows the bike to be rolled on straight from the back, eliminating the need to lift the front wheel up high. However, it requires extra effort to correctly place the fork in the clamp.

There are also slight differences in handle design and the exact dimensions of the racks themselves but these have little influence on the usage and design of the rest of the rack, so can be neglected.

Figure 2.8: Velopa Capacity bicycle rack SOURCE: Velopa

Figure 2.9: Front fork clamp. SOURCE: KlaverCycloParking

2.2.4 Legislation of bike parking (FietsparKEUR)

The world of bicycle parking solutions, including two-tier bicycle racks, is very broad, diverse, and continuously subject to change. The same can be said about bicycles themselves. To create a certain level of compatibility, safety, and usability within bicycle parking, an independent organization called 'FietsparKEUR' was brought to life in 1998. They are the leading organization in the Netherlands for the certification of bicycle parking solutions. Their requirements for what can be considered a safe, comfortable, secure, and properly usable bicycle parking solution can be found in their normative document. Because of their widely adopted and respected certification, two-tier bicycle racks, despite their seemingly many possible variations, all fall within a certain level of commonality. This allows this graduation project to be more applicable to a wider range of two-tier bicycle racks rather than just one specific model.

It is important to note that these norms are meant to apply to the two-tier bike racks themselves. However, the addition of the proposed wireless charging solution as a result of this graduation project must not result in the bicycle rack as a whole conflicting with any of the earlier stated norms.

2.2.5 Guiding bike rack: Velopa-Up

For this design project and the development of a wireless charging solution for E-bikes in two-tier bicycle racks, the VelopA-Up two-tier bicycle rack, shown in Figure 2.10, was selected as the primary model to base any further designs on. This bike rack was selected through several considerations:

Market Leadership:
Velopa is a market leader in the Benelux region for bicycle parking solutions. Their designs and brand name are well-known within the market where TILER operates, making their products a familiar choice for potential customers.

Recent and Relevant Design:
The VelopA-Up is the newest addition to Velopa's lineup, incorporating the latest design insights. It is expected to be used in many future projects and remain relevant for several years, ensuring that the developed wireless charging solution stays up-to-date.

Premium Compatibility:
The VelopA-Up features an aluminum sliding console, positioning it as a premium product. This aligns with TILER's market for premium bike accessories. Customers willing to invest in high-quality E-bike infrastructure, such as TILER's Charging Kickstand, are likely to prefer a premium bike rack like the VelopA-Up.

Collaborative Relationship:
TILER and Velopa have a history of collaboration and plan to potentially continue this partnership with this design project. While the ultimate goal is to ensure compatibility with various brands and models of two-tier bicycle racks, starting with the VelopA-Up provides a solid foundation for this collaboration.

Design features that are important to note and could set the VelopA-Up apart from other two-tier bicycle racks are:

- **Straight Diagonal Gutter:** Used for the 'high' parking spaces on the bottom level.
- **Horizontal Distance:** The distance between the centers of the gutters is 39 cm.
- **Security Bracket:** Located on the right side at the beginning of the gutter for locking the bike.
- **Aluminum Sliding Console:** Features an integrated gutter on the top level.
- **Roll-Off Prevention Bracket:** Located on the sliding console to prevent the bike from rolling off. The front wheel must be lifted past this bracket when placing the bike in the top level.

Figure 2.10: Velopa UP two tier bicycle rack SOURCE: Velopa

2.3 E-bikes

As the world is currently moving toward more sustainable transport solutions due to the quest to make our presence as a humans on this earth less harmful to the planet and the ever-changing landscape of cities and urban areas has led to a trend of micro mobility, the presence of E-bikes has been increasing significantly in the streetscape. It are these E-bikes that this design project aims to conveniently charge in two-tier bicycle racks. While this project will mainly focus on the connection between (in the form of some intermediator of electrical power) the bike racks and the E-bikes, it is very important to understand those E-bikes as well. This chapter will explore E-bikes, their relevant mutual differences and their influence on this design project.

2.3.1 Types of E-bikes

E-bikes come in various different types, and as they rise in popularity, more categories are introduced. Several main categories can be distinguished (ANWB, n.d.):

- **Electric 'family' bike:** A sturdy bike often with child seats mounted on them to transport young children
- **Electric 'transport' bike:** An extra robust frame that is meant to carry heavier loads. Most of the time, it is fitted with either an additional rack or crate on the front.
- **Electric mountainbike/ E-MTB:** A bike suitable for riding offroad trails. Tires are generally a lot wider than 'regular' bikes. A more athletic frame and, therefore, a less upright seating position. Comes with a suspension fork in the front and sometimes even backwheel suspension.
- **Electric Cargobike:** A long bike with a big cargo compartment mounted in the front between the rider and the front wheel. It is much wider and heavier than a normal bike and, therefore nowadays, often assisted by an electric motor.
- **Electric 'city' bike:** A more simplified but still robust bike model with a very upright seating position. Often with less comfort or performance features like an intricate gearing system compared to bikes meant for longer distances due to a chance of breaking or being stolen. Nowadays, it is seen with more integrated and modern frames to allude to the 'urban/city' demographic.t
- **Fatbike:** A category of bikes currently rising in popularity rapidly. Bikes with significantly wider tires and smaller wheel diameters. Accompanied by a smaller frame, therefore the rider sits much closer to the ground and feels more stable.
- **Speed pedelec/ Speedbike:** A much faster version of E-bikes, not limited to 25 km/h, that can reach speeds of 40-45 km/h. A helmet, licence plate and a special licence are mandatory. Due to high speeds fitted with slightly wider tires and sometimes a suspension fork. Much heavier than a normal E-bike due to the big and heavier battery.
- **Electric men's/woman's bike or 'classic' E-bike:** The quintessential and very common E-bike based on traditional male or female-specific frame models. Body position is slightly more forward than a 'city' bike but more upright than a sports bike. Largely present under the elderly generation as these were one of the first widely available models geared towards increasing the mobility of the elderly.

Within this project's several categories are considered out of scope. Cargobikes and fatbikes will not be included in this project since they are not parked in two-tier bicycle racks. E-MTBs are excluded because they commonly do not have kickstands mounted on them and therefore won't be fitted with the TILER Charging Kickstand. Electric transport bikes fall into a gray area since they are often not allowed to park in two-tier bicycle racks due to their crate or rack being too wide. However, they are sometimes assigned to park in so-called 'BMF' or 'Buiten-Model Fietsen' (translating to Out-of-Model Bikes) two-tier bicycle racks designed with additional space between the bikes. Transport bikes won't be actively excluded from this project, but neither actively included.

2.3.2 Differences in E-bike design

Among the e-bikes included in this project, there are several additional distinctions to be made regarding their functioning and design. The remaining part of this chapter will provide a brief overview of the most notable differences. A comprehensive description of what these differences might mean for the bike itself can be found in Appendix C.

The location of the electrical motor is the first main difference between E-bikes. They can be mounted either in the front wheel axle, in the middle of the bike as part of the bottom bracket, or in the rear wheel axle. Each has its own driving characteristics, but the middle-mounted motor is currently most common (Fietsersbond, n.d.-c).

The battery on E-bikes can also be mounted in different locations on the bike. The traditional location is beneath the luggare rack on the back, which makes them easily accessible. They, however, can now also be integrated into the frame of the bike itself, lowering the center of gravity (Fietsersbond, n.d.-a). Within E-bike batteries there is also the distinction whether they are 'swappable' and can be taken out of the bike to charge or are permanently fixed to the bike. (Fietsersbond, n.d.-b)

The last difference between E-bikes might seem insignificant, but is actually the most influential on this design project: the location of the kickstand. Normal bikes used to almost always have kickstands mounted in the center of the bike, just behind the crankset. Within E-bikes another mounting location is common as well: on the back of the bike (chainstay) near the rear wheel. This is done since E-bikes can have a lot more of their weigt towards the back, that needs to be properly supported by a kickstand.

Both center mounted and rear mounted kickstands can be found on E-bikes. From TILERs own database it is apparent that there is no clear bigger group among E-bikes
For this design project this implies that the coil for charging (PRC) can be in two different locations relative to the bike. This leads to the following design requirement:

R3.1: The design must be able to charge E-bikes with center mounted and rear mounted Charging Kickstands.

2.4 Competitive products/ solutions

As E-bikes rise in popularity, so will the need for E-bike (charging) facilities. While TILER might have been the first on the market with a fully flat Charging Tile in the past, several other products and solutions have come to market over the years. This chapter gives a comprehensive overview of current possibly competitive products or alternative solutions to combining the parking and charging of E-bikes.

The several identified possibly compettitve product to this graduation project have been devided in different categories. Detailed descriptions and all images of the individual products can be found in Appendix D.

Fully Integrated parking and automatic charging
This category contains solutions that provide both the parking (and/or locking) and charging of E-bikes in the same system, without the user being required to go through additional steps to achieve either one of these. This category is most similar to TILER's charging solution as they all add a charging point to the bike that comes in contact with the charger when you park it. Firgue 2.11 shows an example from this category.

Figure 2.11: Swiftmile bicycle dock charging SOURCE: Swiftmile

Integrated bike locking and cable charging
This category consists of products that require the user to park the bike in a certain location but perform additional steps to lock and/or charge be bike. While chargers have to be manually connected to the bike, they are provided as an integrated part of the system. An example can be seen in figure 2.12

Integraded parking & locking – 'BYOC' (Bring Your Own Charger)
The products in this category integrate the process of locking E-bikes within the parking itself but do require the user to bring their own charger. While steps are saved by automatically locking the bike, additional steps are required by plugging in their own charger into the provided power socket and the E-bike. An example can be seen in figure 2.13

Traditional bike rack with additional power outlets
For this category, the products don't integrate any charging, locking or parking features but offer the possibility of doing them all manually. This ultimately results in traditional one or two-tier bicycle racks with the added benefit of being offered a power outlet in a somewhat accessible location. An example can be seen in figure 2.14

Conclusion
By analyzing a variety of competitive products and grouping them based on their similarities, it is evident that there are currently no user-friendly solutions for charging E-bikes in two-tier bicycle racks. All existing solutions that require minimal extra effort from users, apart from parking the bike in a specific position, are only suitable for ground-level bicycle parking. These solutions are too bulky and require too much space to be used in high-density bicycle parking areas like two-tier bicycle racks. All charging solutions for higher density bicycle parking situations appear to be designed as an afterthought and require users to bring their own E-bike charger along. This presents a great opportunity for this graduation project to create a user-friendly, integrated wireless charging solution for two-tier bicycle racks using TILER's Charging Kickstand, thus eliminating the need to bring along and use annoying and clumsy charging cables.

Figure 2.12: Q-Rack E-Bike charging station SOURCE: AttiaDesign

Figure 2.13: Bikeep bike locking station with integrated power outlet SOURCE: Bikeep

Figure 2.14: VelopA-UP bicycle rack with additional power outlets SOURCE: Velopa

2.5 Pedal collision zone

In this design project, the Charging Kickstand will be used to charge E-bikes when they are parked in two-tier bicycle racks. TILER's main goal is to make it user-friendly and to require as little extra effort from the user as possible in order for them to charge their E-bikes. Therefore the Charging Kickstand should be designed to remain flipped up when charging in two-tier bicycle racks. This means the PTC needs to be positioned higher up, reaching the PRC in the Kickstand when flipped up.

However, a potential problem arises when rolling a bike forward through the gutter of the two-tier bicycle rack, as there is a risk of hitting any additional part of the bike rack resulting from the final designed solution. Pedals could be in any orientation when placing the bike into a bicycle rack, creating a "pedal collision zone" where any fixed part resulting from the final design could collide with the left-side pedal. This collision would prevent the bike from being parked in the bicycle rack, so avoiding such collisions is essential to ensure the proper functioning of the two-tier bicycle rack.

The dimensions of the pedal collision zone depend on the height of the bottom bracket (axis of crankset) and the length of the cranks themselves. Figure 2.15 and 2.16 shows this 'Pedal Collision Zone'.

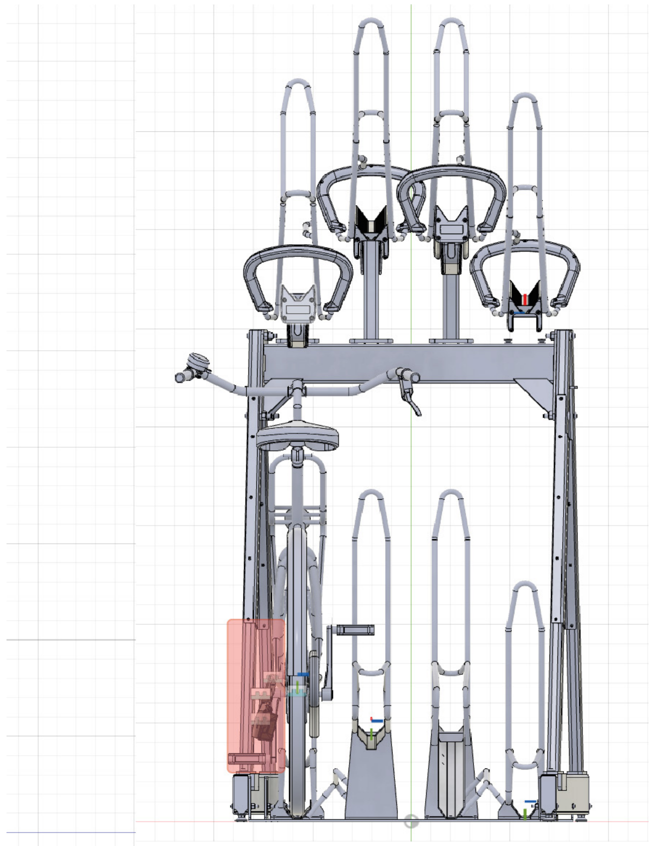

Figure 2.15: Pedal collision zone rear view

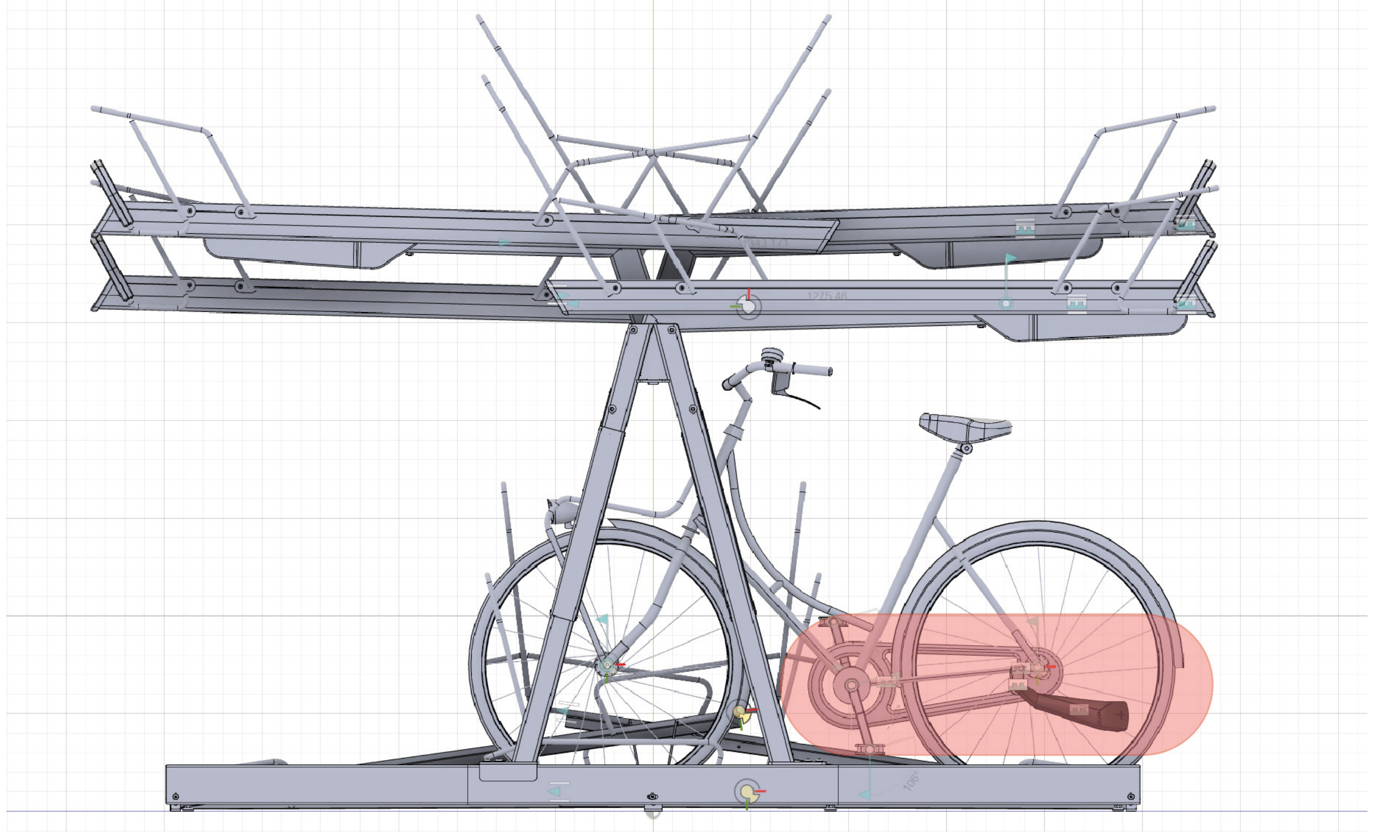

Figure 2.16: Pedal collision zone sideview

2.6 PRC height requirements

As previously established, the Charging Kickstand will remain flipped up when E-bikes are charging in two-tier bicycle racks. Therefore the PTC will need to be at a similar height as the PRC in its flipped-up position in order for it to charge. Not all E-bikes are the same; the height-to-ground of kickstand mounting points can vary between models. This chapter will determine the required PTC height and evaluate if the current placement margins can accommodate the variation in E-bike dimensions.

The design of the Charging Kickstand is inherently beneficial for accommodating varying kickstand mounting point heights among different E-bikes. Unlike regular bicycle kickstands, the length of the TILER Charging Kickstand cannot be adjusted because it consists of a single fixed housing piece from the swivel point downwards. Regular kickstands have adjustable lengths to suit a bike's specific kickstand mounting point height compared to the ground, ensuring the bike stands in a stable and secure position. This adjustment is not possible with the TILER Charging Kickstand. To address this, TILER has developed a solution to ensure a stable parking experience when using their Charging Kickstand. Instead of changing the dimension of the kickstand itself, they use adaptor brackets. This way, they ensure that their kickstands are always mounted at the ideal height, even when the original mounting point would result in an unstable parking experience.
These adapter brackets have the result that the charging kickstand's swivel point is always at a certain height from the ground. Therefore, they coincidentally minimize the kickstands and the PRC's resulting height variation even when the kickstand is flipped up.

This means that the PTC can be mounted at a fixed height compared to the ground for either the center or rear-mounted kickstand E-bike models. For the center-mounted variation, the middle of the PTC would need to be fixed at 160.5 mm from the ground level, while for the rear-mounted E-bike charger, this would be at a height of 195.5 mm. Appendix E elaborates on how these heights have been determined. These dimensions and movement ranges can be viewed in a simplified diagram in Figure 2.17.

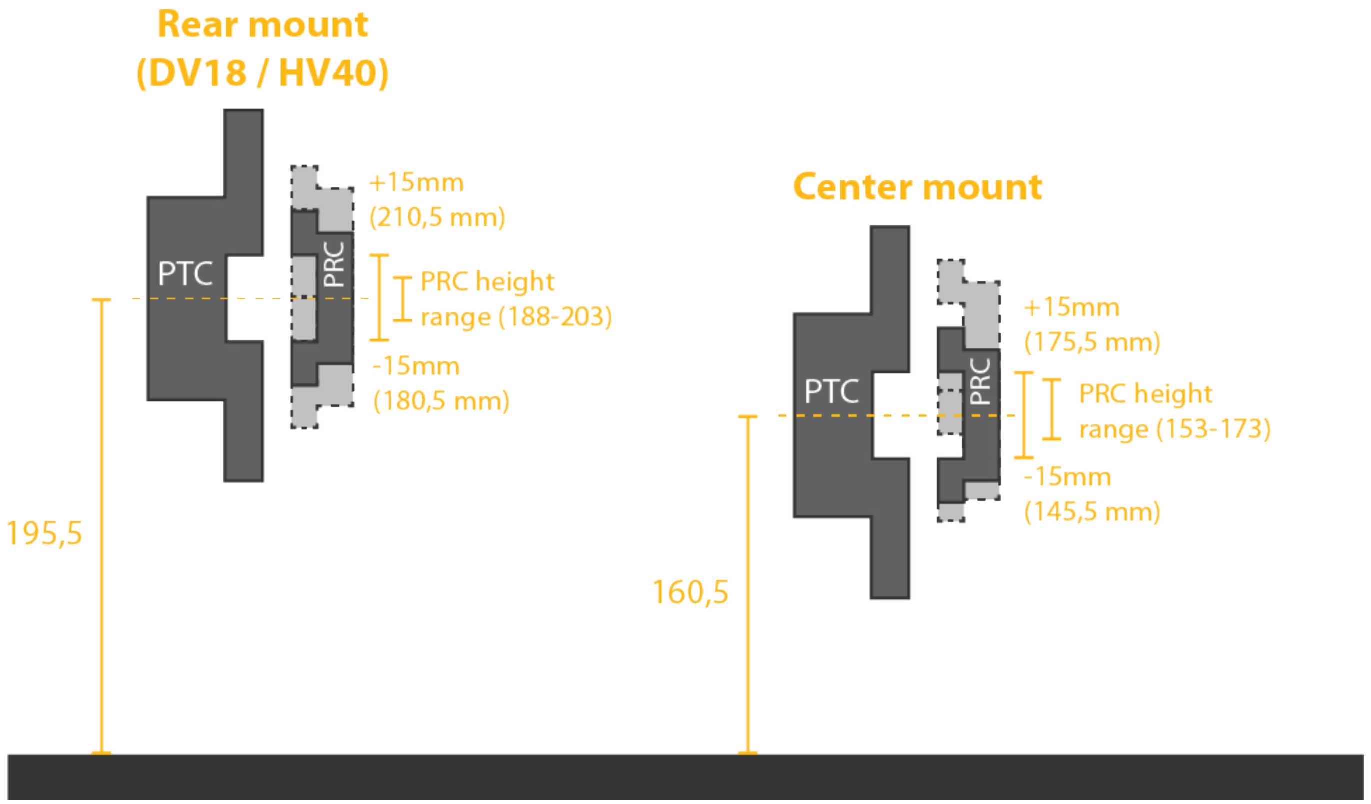

Figure 2.17: Required PRC height for E-bikes with center and rear mounted kickstands

2.7 PTC horizontal coverage

Due to differences in frame geometry, E-bikes vary not only in the height of their kickstand mounts but also in their horizontal positioning relative to the front wheel. This chapter evaluates the horizontal variation the PTC can accommodate.

The PTC's ferrite plates are significantly larger than those of the PRC, allowing for considerable play as long as the plates remain parallel. When the Charging Kickstand is flipped up, the PRC's ferrite plates are horizontally aligned, enabling the PTC to maximize horizontal coverage. As shown in Figure 2.18, the PTC can accommodate a horizontal variation of ±100 mm.

Horizontal E-bike kickstand variation
To determine whether 100 mm of coverage is enough to accommodate all E-bikes within one single PTC, the most important measurement is the horizontal distance between the frontmost point of the front wheel and the PRC in the flipped-up kickstand itself. This dimension will determine the horizontal placement of the PRC in relation to the whole bicycle racks.

Conclusion
Even though the horizontal variation of the PRC might or might not be sufficiently covered by the PTC, it is apparent that the PTC will in no circumstance be able to accommodate both E-bikes with a centre and rear-mounted kickstand at the same time. Therefore it is important to note that 2 separate PTCs will be required to charge all E-bikes in the same bike rack: one towards the middle of the bike rack for center-mounted kickstands and one towards the back for rear-mounted kickstands.

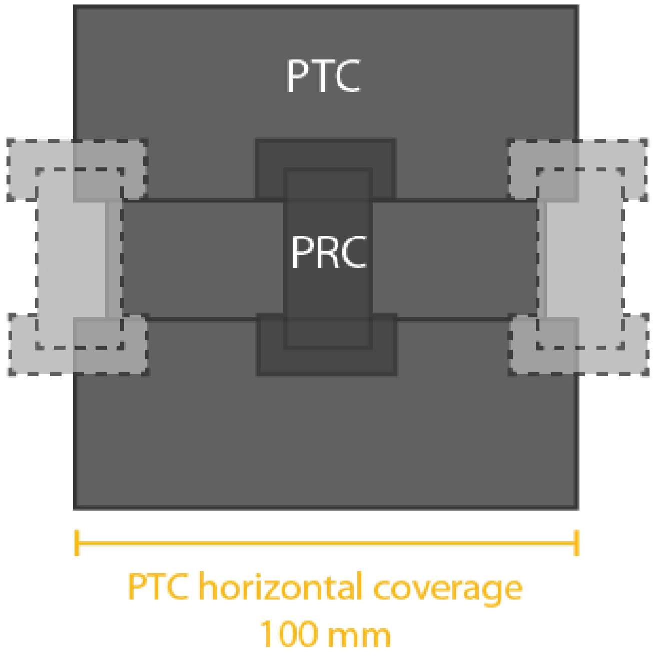

Figure 2.18: Horiontal coverate of the PTC

2.8 Adjustment of project scope

Through this analysis, several factors have led to an adjustment of the project's scope. Initially, the goal was to create a solution for wirelessly charging E-bikes on any parking space of the two-tier bicycle racks. However, the focus has now shifted to enabling wireless charging only on the ground level. The considerations that led to this adjustment are as follows:

- **Variation in Pedal Collision Zone:** Each of the four possible types of parking spots on the Velopa-Up two-tier bicycle rack (bottom level high or low and top level high or low) involves a different trajectory for the bike and pedals. This could necessitate four different designs to avoid pedal collisions.
- **Need for Accommodating Center and Rear-Mounted Kickstands:** Since the PRC of rear and center-mounted Charging Kickstands cannot be accommodated by a single PTC, the project would require two different designs to charge all E-bikes. Each location has specific challenges that cannot be addressed with a single design.
- **Unlikelihood of E-bikes Being Parked on the Top Level:** Due to the weight of E-bikes, it is challenging to place them on the top level of two-tier bicycle racks. E-bike users are more likely to prefer parking their bikes on the bottom level.

These considerations would result in potentially needing to design eight different variations of the proposed wireless charging solution. This is beyond the feasible scope for the project's timeframe and could lead to incomplete designs. Therefore, the project will focus solely on charging E-bikes on the bottom level of two-tier bicycle racks. This includes both low and high spots on the bottom level and both center and rear-mounted kickstand E-bike models, leading to four potential design variations.

2.9 List of requirements and wishes

As a result of the analysis phase a list of requirements was created, which can be found in Appendix F. The Product Life Cycle method from the Delft Design Guide (Van Boeijen et al., 2020) was used to identify and organize these requirements and wishes initially. Throughout this graduation project, requirements have been adjusted and added. This chapter highlights and explains the most influential requirements and wishes.

R1.1 The design must not prevent regular access for the bike into the bicycle rack
As identified in the analysis phase, there is a pedal collision zone that could obstruct bikes from entering the bicycle rack if the charging solution is located within that zone. It is important that the addition of the charging solution does not alter or prevent the original purpose of the two-tier bicycle rack: storing bikes.

R3.1 The design must charge E-bikes fitted with both rear- and center-mounted TILER Charging Kickstands
The TILER charging ecosystem aims to create a universal charging solution through the TILER Charging Kickstand. To be truly universal, the charging solution designed for two-tier bicycle racks must be compatible with all E-bikes, whether they have a rear—or center-mounted Charging Kickstand.

R4.1 The design must use the PTC design for the TILER Charging Tile in the PTU
The power transferring coil, as currently used in the Charging Tile, is custom designed for TILER. Development and production of a new PTC specifically for this charging solution will be very expensive. Therefore, it was decided that this charging solution must reuse the previously developed PTC found in the Charging Tile.

R4.2 The design must bring the PTC within effective range of the PRC
For the charging solution to work in two-tier bicycle racks, one of the design's main requirements to allow wireless charging for the e-bike is to position the PTC in relation to the PRC so that wireless power transfer can take place.

W2 The design should minimise the amount of custom parts/components &
W3 The design should reuse components from TILERs current product line-up where possible
TILER is a start-up, so its resources are limited. If the design requires developing and producing many custom parts, this might lead to very high R&D costs. Additionally, significant initial investments are often required for custom production, which TILER has already done for the Kickstand and Tile. Therefore, it would be preferred to minimize the need for new custom parts by reusing components from other products.

R14.2 The design must not require additional steps from the user other than placing their E-bike in the bicycle rack to start charging
The main benefit of wirelessly charging E-bikes in bicycle racks for the user would be that similar to only having to park their bike regularly with a kickstand to use the Charging Tile, they can simply park their bike in a bicycle rack as they would do regularly and their bike would automatically get charged. This interaction, with a lack of additional required steps, is essential for improving the otherwise cumbersome current methods for charging an E-bike parked in a bicycle rack.

3. Ideation

This chapter will describe, show and highlight important steps, conclusions and designs throughout the ideation phase this project. The goal of this ideation fase was to come up with an idea, later to be fully conceptualized, that allowed E-bikes to wirelessly charge through the TILER Charging Kickstand when parked on the bottom level of two-tier bicycle racks, specifically the VelopaUP two-tier bicycle rack.

3.1 Problem breakdown

To find possible solutions to this design project's complex challenge, it was important to first break it down into several smaller challenges that needed to be explored and solved individually. Several of these challenges became apparent right from the start of this ideation phase in the analysis phase.

3.1.1 Charging component separation

The current TILER Charging Tile contains all the components to make wireless charging work with the TILER Charging Kickstand, all contained within a durable and weatherproof housing. This whole can be considered the Power Transfer Unit (PTU) of the current TILER wireless charging system. These current components result in a quite voluminous package with most space taken up by several big components:

- Power supply
- Circuit board/PCB
- Coil/ PTC

Individual small cables or the LED module were neglected for now due to their small volume.
An overview of the main parts required to let the PTU function can be seen in figure 3.1 to 3.3.

The space available for designing a charging solution in a two-tier bicycle rack with a parked bike is very limited, as evidenced by the identified pedal collision zone. It would be challenging to fit all components of a newly designed charging solution within a single volume, similar to the current TILER Charging Tile. Trying to fit such a volume alongside the bike while connecting the PTC and PRC without ending up in the pedal collision zone is not feasible.

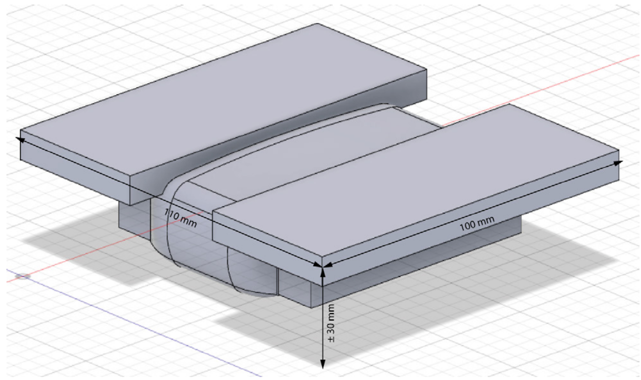

Figure 3.1: Model of the PTC

As a result, these components have been divided and will be treated as separate 'modules' or units for the rest of the project. The resulting modules are:

- **Power Transferring Unit (PTU):** containing the PTC and a to-be-designed way of bringing the PTC up to the location of the PRC in relation to the bicycle rack.
- **Technological Unit (TU):** consisting of the power inlet, converter and circuit board, all previously developed by TILER.

The separation of these components into modules allow for them to be spread out over the space on two-tier bicycle rack, which creates more opportunity for exploration in this ideation phase without disastrously keeping ending up within the pedal collision zone rendering the bike rack itself unusable.

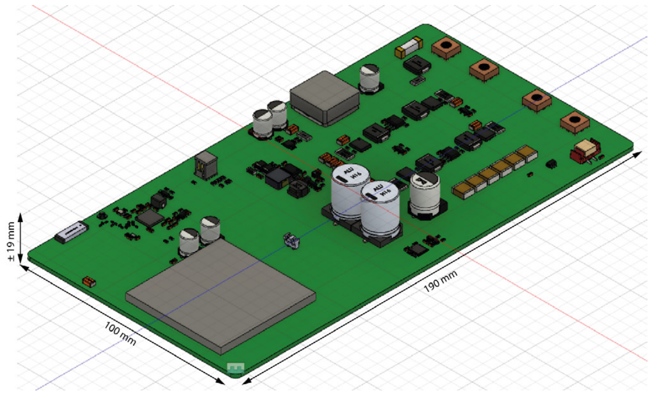

Figure 3.2: Model of the PCB

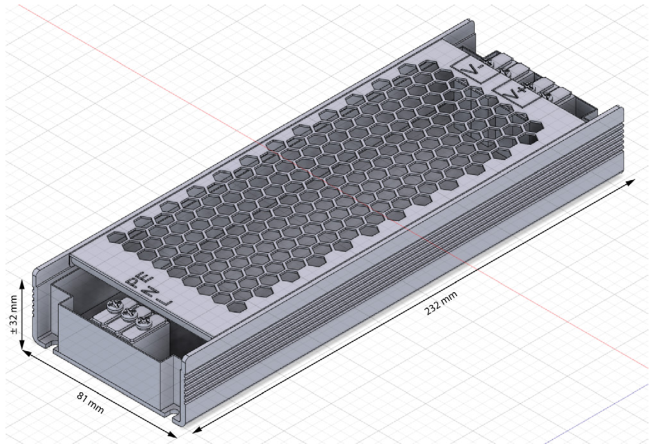

Figure 3.3: Model of the power supply

3.1.2 Avoiding pedal collision

In order to start the ideation phase and come up with design ideas to charge e-bike batteries through inductive power transfer between the PTC and PRC the previously identified 'pedal collision zone' was reevaluated.

Effective pedal collision zone
Since the height of both the pedal PTC and PRC are known it the boundaries of the pedal collision zone have become clear. The maximum height of the PTC will be the height of PRC in relation to the ground. As can be seen in Figure 3.4, there are certain pedal positions for the left side pedal to be placed above the PRC and thus have the possibility of moving over a potential PTU instead of colliding into it. This means that whenever the left pedal of an E-bikes stays within the 'safe zone' indicated in green in figure 3.4, a pedal collision with the PTU can be avoided.

Right pedal safe zone
The identified 'safe zone' for the left-side pedal of an E-bike also has implications for the right-side pedal because both pedal positions are dependent on each other; as the left pedal moves up, the right pedal will move down and vice versa. This means that the 'safe zone' can also be achieved by having the right-side pedal in a certain position as is illustrated in figure 3.5.

Center mounted Kickstand safe zone
The safe zone for E-bikes with center mounted kickstands is very similar to that of rear mounted kickstands as can be seen in figure 3.6. This is because there is only a slight difference in height between the two types of kickstands when flipped up.

One additional thing to note from figure XXX and the center-mounted kickstand safe zone is that the PRC in the Kickstand is located outside of the perimeter of the collision/safe zone. This means that if the bike has gotten in a proper parking position in the bicycle rack, without the pedals colliding with the PTU prior, the PRC of center mounted kickstand can be reached no matter the pedal position.

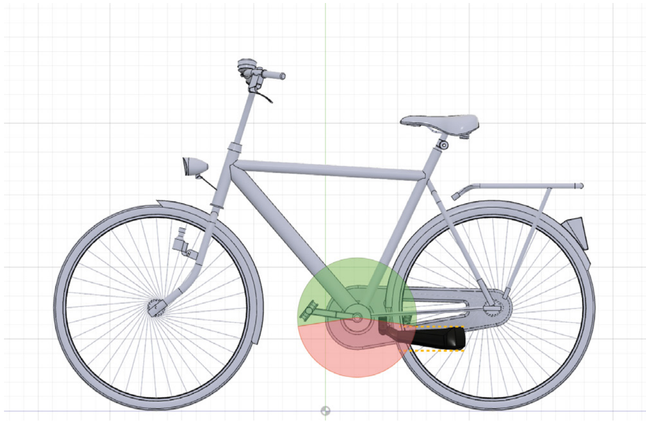

Figure 3.6: Center kickstand pedal 'save zone'

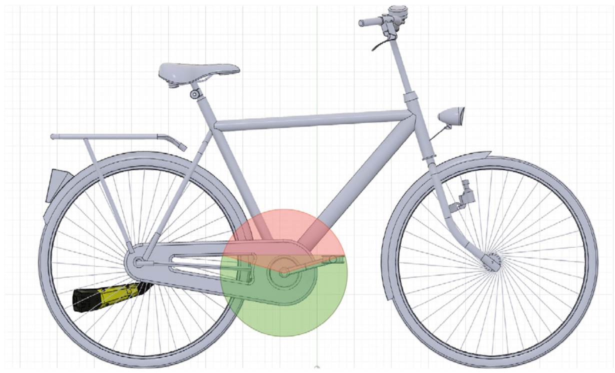

Figure 3.5: Right pedal 'save zone'

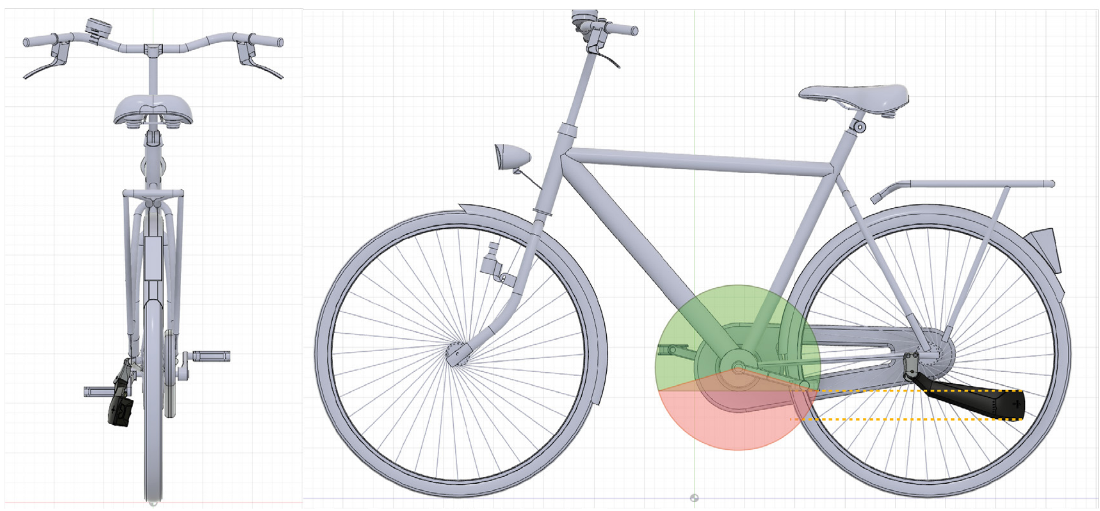

Figure 3.4: Pedal collision safe zone

Backpedal collision trajectory
Up to this point, the pedal collision zone and the identified 'safe zone' have only considered a bike moving forward into a two-tier bicycle rack. However, an unavoidable part of parking bicycles in bike racks is also taking them out backwards.

When a bicycle with a freehub is moving forward or stationary, the pedals can stay still or move freely backwards. When the bicycle moves backwards, the cranks and pedals move backwards due to the freehub engagement. It's important to consider backpedaling for the project to avoid pedal collision with the bike rack or its additions. To ensure this, pedals should stay within the 'safe zone' during the whole backwards translation of the bike.

The pedals turn backwards based on the wheel size, wheel rotation, and gear ratio.
To account for as many bikes as possible, popular E-bike models in the Netherlands were considered, all with 28-inch wheels. These models typically use either the Shimano Nexus 8-speed or 7-speed internal gear hubs (Fietsersbond, n.d.-d). The minimal crank movement (highest gear), maximum crank movement (lowest gear), and the commonly used gear in city environments (4th gear for Nexus 8-speed and 3rd gear for 7-speed) were calculated. The degrees of backpedal rotation for these gears are visualized in Figure 3.7, overlaid on the previously identified 'safe zone'. The starting point for the pedals is ideally chosen to maximize rotation within the safe zone. The backpedal movement is the angle between the black dashed lines, connected by the yellow arrow.

Even though there is plenty of room when the bike is in the higher gears to stay within the 'save zone', it can clearly be seen that no matter the starting position of the cranks in the lowest gears, the cranks and pedals will end up in the 'collision zone' when the bike is taken out of the bike rack.

Therefore it can not be assumed that pedals will always freely pass back out of the bike rack the same way they would have done as they were put into the rack earlier.

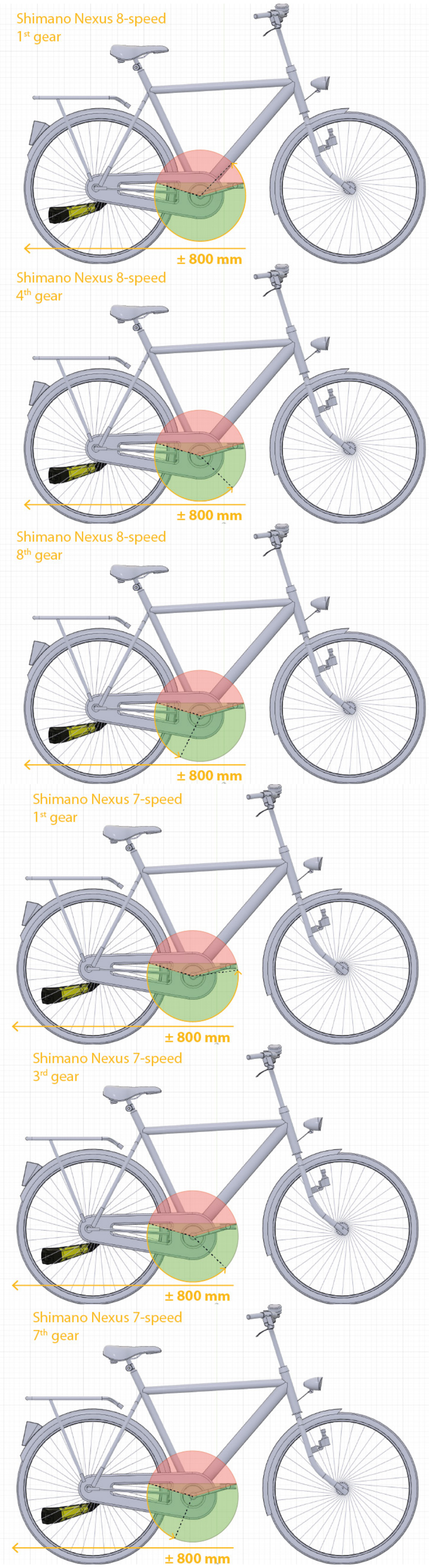

Figure 3.7: Backpedal save zone analysis

3.2 Initial design directions: Anti-pedal collision

Starting the ideation phase the main obstacle to overcome seemed to be finding a way to avoid the pedals from colliding with the PTU in the Pedal Collision Zone. The additional task of designing the PTU itself was determined a challenge to be tackled later on in the process since it was expected to not be particularly difficult: the coil is already designed by TILER and ultimately needs to reach a certain height in order to connect with the PRC of the Kickstand.
So all initial ideation explored ways to avoid pedals from hitting the to be designed PTU. The rest of this chapter will explain the four initially found design directions.

No intervention, only the PTU
The first design direction was the simplest one that relies on no active design intervention at all, but rather on user behaviour to prevent pedal collision. As can be seen in a simplified sketch in figure 3.8, the PTU will be mounted alongside the gutter to line up with the PRC. Users would have to manually put their own pedals in a save position to not hit the PTU. This design would rely on user not wanting to damage their expensive E-bike or the bicycle rack when placing it inside the rack to charge.

Forcing 'safe zone' pedal positiont
The second design direction is an addition to the first one. It does not rely on people actively not wanting to hit the PTU with their pedals but rather prevents anyone from putting their E-bike into the rack as a whole when the pedals are in a Pedal Collision Zone position. Only if users actively put their pedals in the correct position would they be able to push their E-bike into the rack. It could be compared to trying to fit a piece in a jigsaw puzzle: you can only do it if the shape matches up.

This could be executed in two different variations:
- Forcing left pedal position
- Forcing right pedal position

Simplified sketches of what this could look like can be seen in figure 3.9 and 3.10.

An argument for putting the 'jigsaw piece' on the left is that most people step of their bike on the left side. This means that they would be able to see the slot in the jigsaw piece more easily when trying to line up their pedal correctly. However, as the PTU is located quite far back on the bicycle rack this might cause their required positions to overlap.

The right side, however, seems to have more space for a jigsaw piece. But it would be more challenging for people to position their pedal correctly because they wouldn't be able to see the exact slot very well. If they stepped off on the left side of their bike, they would also have to line up the right pedal by moving it with the left pedal, which might feel counterintuitive.

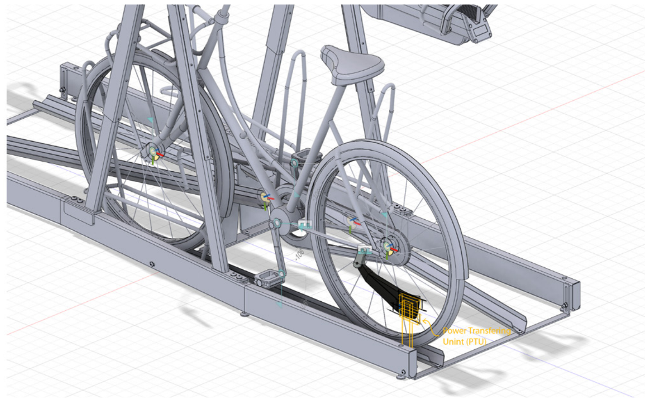

Figure 3.8: PTU location on bicycle rack

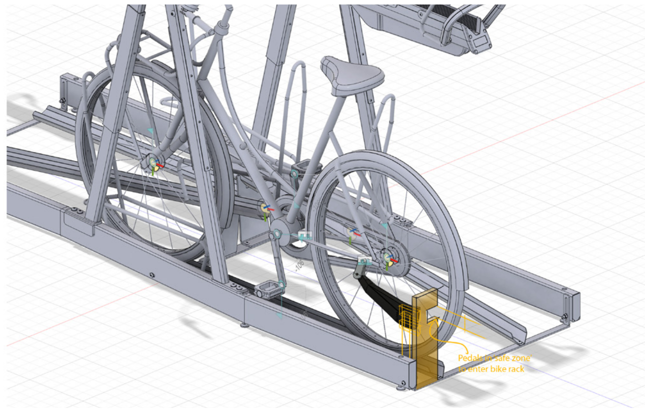

Figure 3.9: Forcing left pedal position sketch

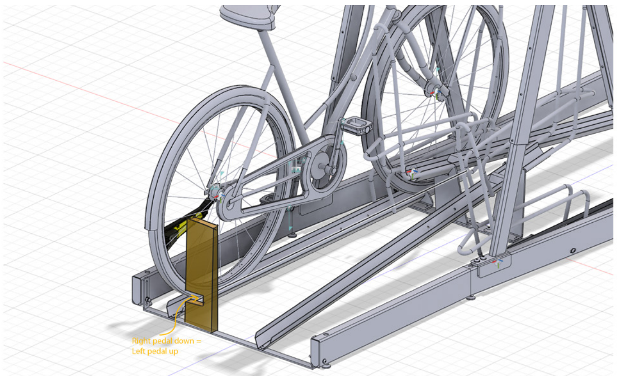

Figure 3.10: Forcing right pedal postion sketch

Guiding safe pedal position
Rather than forcing users to put their pedals in a certain position, this design direction guides the pedals into a safe position as the bike moves into the rack. This would make use of the freehub body of the E-bikes to move the pedals backwards until they have reached a desired position. By doing this in on the right side of the bike, it allows for the right pedal to move backwards and down, thereby moving the left pedal up, over the PTU. This is illustrated in figure 3.11.

In this design, the pedals are intended to run against the guiding railing next to the gutter. Instead of coming to a halt upon contact, the pedal should smoothly glide along the railing. It's crucial to consider the angle of the guiding rail in relation to the crank, as an incorrect angle could result in the bike getting stuck. As illustrated in figure 3.12 if the crank is perfectly perpendicular to the angle of the railing, there is no resulting force that could cause it to slide. If the angle is more than 90 degrees, the pedal will try to slide, however, in the wrong direction as this would engage the freehub in the rear axle.
In conclusion the angle of the guiding rail must be such that, while the rightside pedal is not yet in the safe zone, the collision angle is always less than 90 degrees.

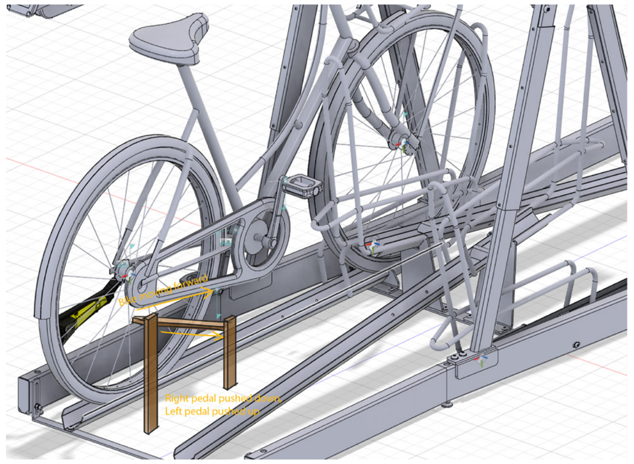

Figure 3.11: Guiding pedal position sketch

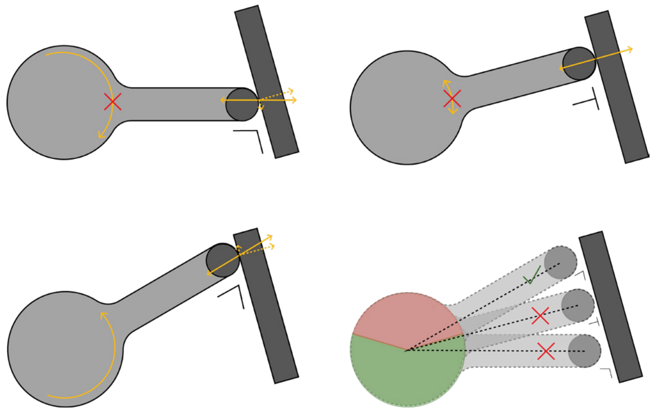

Figure 3.12: Pedal sliding impact angle

Preventive moving the PTU
This design direction takes a very different approach to avoid the pedal collision zone: instead of moving the pedal into a certain position to not hit the PTU, the PTU itself will be moved out of the way of the pedals. This would allow users to put their E-bike into the bike rack without any additional steps.

For this, the PTU as a whole would swivel to the side. Only when a bike is placed into the rack, would the PTU move toward the PRC in the Kickstand when the back wheel is in place, and the pedals have passed by.
This movement would be engaged by placing the back wheel of the E-bike on a pressure plate and, through a lever, swiveling the PTU. This principle can be seen through a prototype in figure 3.13.

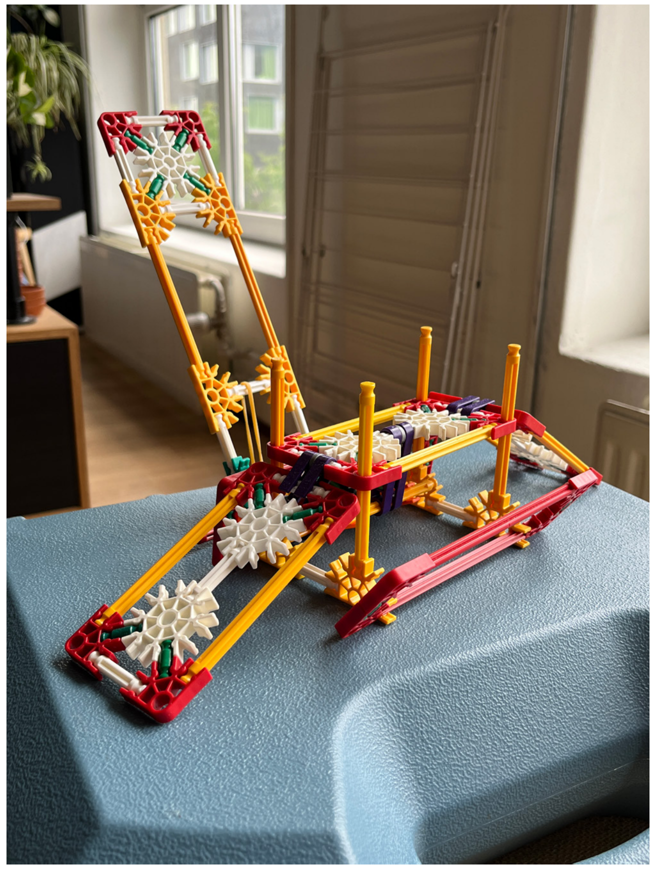

Figure 3.13: K'nexx prototype model of PTU moving mechanism

3.2.1 Prototype exploration

After the initial design directions were theoretically explored and sketches were made the underlying principles for avoiding pedal collision were evaluated through prototyping. In this prototyping the focus was mainly on the prevention of pedal collision and not yet on the actual PTU itself. This chapter will showcase the prototypes that were made and highlight the most important conclusions from those prototypes. These prototypes had two main objectives to fullfill in order to prove potentially successful for the project:

- Prevent a collision between the pedals and the PTU/ prevent the bike from getting stuck when putting it in the bicycle rack
- Allow for the bike to move backward out of the bicycle rack despite the backpedaling effect of the pedals.

Forcing pedal position prototype
This prototype explored the principle of forcing a certain pedal position (within the safe zone) when entering the bicycle rack to avoid hitting the pedals against the PTU. This relied on only allowing bikes to enter the rack if the pedal position was correct. Otherwise, the user would have first to change their pedal position. The principle is similar to a shape sorter puzzle for children.

The wooden prototypes for this can be seen in figures 3.14 and 3.15, as both a version for the left and right side pedal was created.

Guiding pedal position prototype
This prototype was created to test the principle of automatically guiding the pedals in a safe position when the bike is placed in a bicycle rack. This prototype should work without requiring any user intervention when parking the bike, unlike systems that force the user to put pedals into a safe position themselves. The wooden prototype can be seen in figure 3.16. However, despite initial expectations and sketches, the prototype resulted in a small and steeply angled surface for guiding the pedals. This occurred because the safe zone for the right pedal is relatively large, so it only needed to be moved out of a small range of unsafe positions at the top of its rotation. The steep angle was determined by the theory of pedal collision angles explained in chapter 3.2.

Figure 3.14: 'jigsway' design direction prototype on bicycle rack

Figure 3.15: Right side jigsaw prototype testing

Figure 3.16: Pedal guiding prototype set-up

Figure 3.17: Pedal being guided into the 'save zone'

Prototype conclusions:
By testing the prototype for forcing the pedal position, it was discovered that placing the pedals in the right position was very difficult since it was only possible to check whether one had done it correctly when the pedals were right up to the board. However, if the pedals were not in the correct position at that point, the board itself made it impossible to adjust the pedals to another position. Additionally, this adjustment would need to be done by feet, and the bike would need to move backwards out of the bike rack, making the whole process extremely cumbersome.

The prototype for guiding the pedals into a save position seemed to work most of the time. However, it would sometimes get stuck due to the earlier explained collision angle between the cranks and the guiding surface. A better angle of the guiding surface could fix this.

Another more substantial problem became apparent when a placeholder model for the PTU was added: since the prototype would cause the pedals to spin only as the bicycle was moving forward into the rack, that rotation would cause a collision with the PTU as can be seen in figure XXX. This was already the case for a PTU in the center-mounted kickstand position. For a PTU further back the bicycle rack, this effect would only be more present.

The solution would be to allow the pedal to rotate earlier in the process of pushing the bike into the rack. However, that would require the pedal guiding mechanism to be placed so far back that it would not be within the boundaries of the bicycle rack itself.

So in conclusion both concepts for avoiding pedal-PTU collision by moving the pedals were deemed impossible by the results of prototype testing.

Figure 3.18: PTU prototype getting struck by pedal during testing

Preventive moving PTU prototype
In order for the bicycle to trigger a system that would move the whole PTU out of the way of the pedals a more complex mechanical prototype would be needed. Because of the inability to achieve this out of a rough wooden prototype a more suitable medium was used: K'nex. With the K'nex system a prototype was made to prove the following mechanical principle: A pressure plate that moved up and down horizonally, that, when pressed down, i.e. by the weight of the backwheel of an E-bike, would move the PTU towards the Charging Kickstand. A prototype can be seen in figure 3.19.

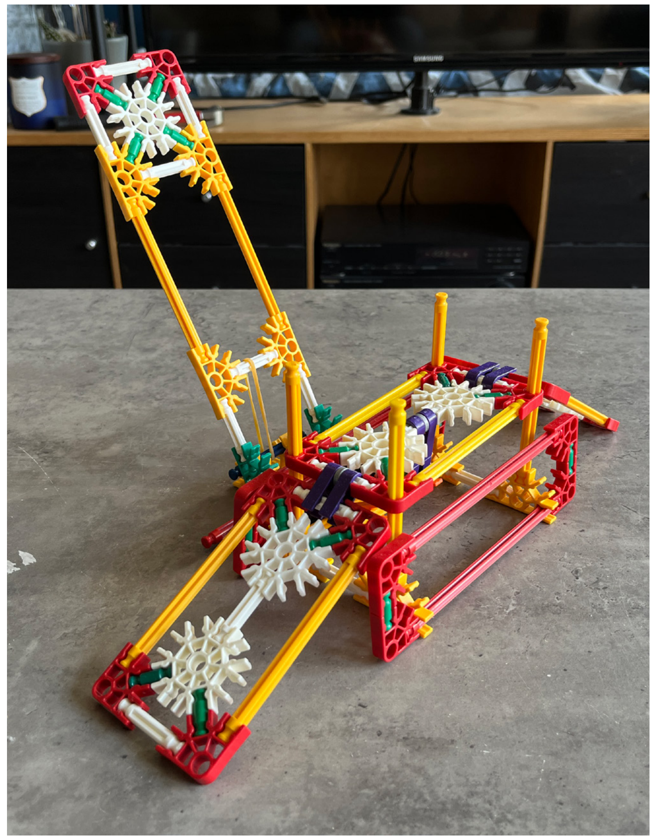

Figure 3.19: K'nexx prototype for pressure plate mechanism

In addition to testing the mechanical principle of this idea direction, the physical space required for this principle to work was also prototyped—but not physically, but rather through a visual scale prototype. This was done because of the limited design space in two-tier bicycle racks and the expected complications with a design requiring sideways movement in relation to the bicycle and the gutter.

Figure 3.20 shows a visual simplification of the possible movement paths for the PTC and the arm on which it would be moved.
A few things are important to note to understand this visual:

- The bicycle rack is shown from behind and consists of alternating high- and low-parking space gutters, meaning they are either flat to the ground or diagonal (high)
- All pedals of potential bikes are shown in their lowest possible position
- For the rear-mount kickstands, all gutters are on the ground since all gutters reach the ground at the backmost part of the bicycle rack. The pedals, however, are further into the rack and are, therefore, further from the ground when they are on the diagonal (high) gutters.
- Bike locking rings are only shown for rear mounted kickstands, as only those PTU's could possibly collide with them.
- The PTU must not collide with the potential location of neighbouring bikes since it would prevent those bikes from being moved in and out of the rack in case the PTU to the right in its downward/resting position.

This visual prototype explored where the PTC could move so that it would not collide with the pedals of bikes or the bicycle rack itself. Since the PTU always needs to end up in a specific spot next to the PRC in the kickstand, and the arm needs to rotate around a mechanism in the bottom left of each gutter, a curve along which the top of the PTC would move could be drawn (yellow curved path). Between the point of rotation and the PTC, the shape of the arm itself could be changed to move the PTC to a collision-free space. By varying the geometry of this arm, it could prevent collisions between the PTU and bike pedals or the bicycle rack, except for the PTU for rear-mounted kickstands of a diagonal (high) gutter with a low gutter to the left. This is shown in the top right corner of Figure XXX.

From this, the following can be concluded: even in the most simplified and stripped-down version of a sideways-moving PTU, it is not possible to prevent collisions between the PTU and other bicycles. This means that it would either prevent bikes from moving in and out of the rack for half of the parking spots (if fitted with a rear kickstand charging system) or only allow half of the parking spots to be equipped with a rear kickstand charging system. Both would defeat the purpose of creating a universal charging solution for high-density parking setups (two-tier bicycle racks). Therefore, actively moving the PTU to the side to prevent collisions with bikes is not a suitable solution either.

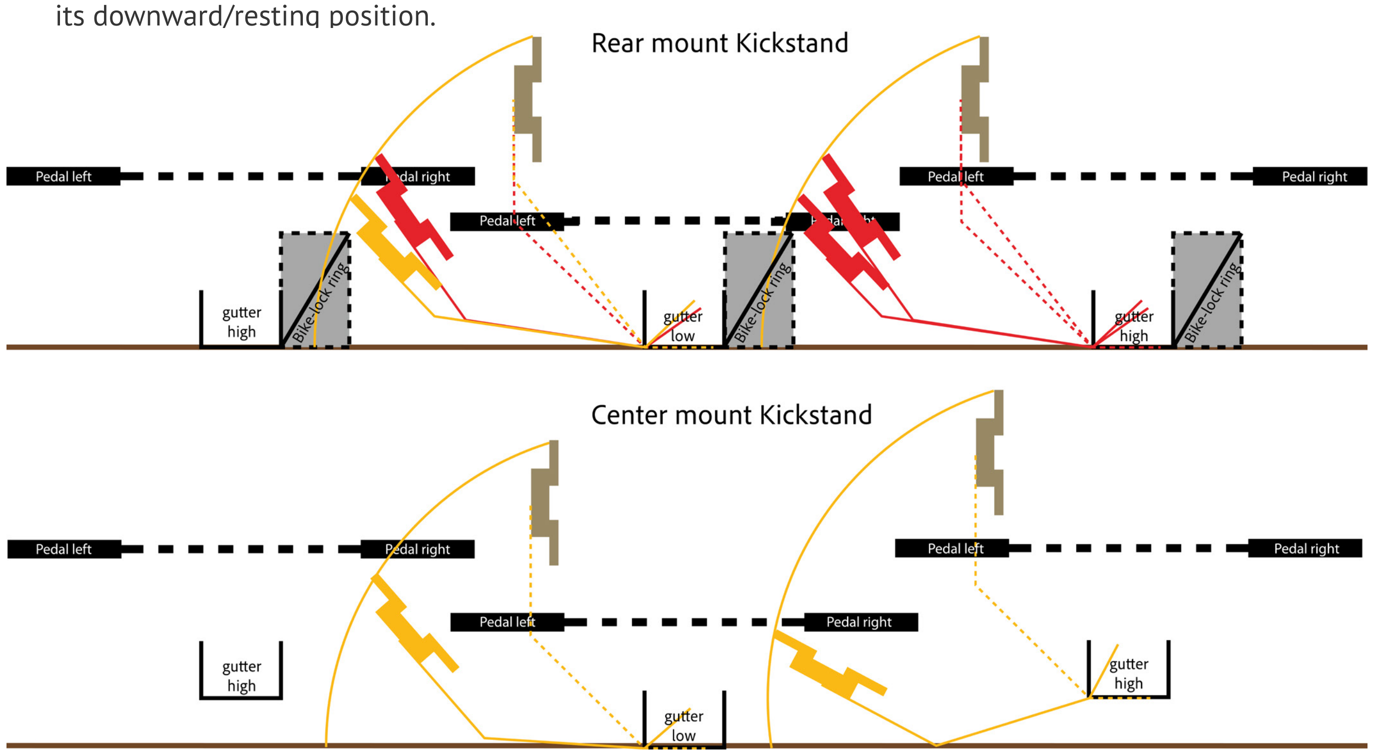

Figure 3.20: Visual prototype for sideways movement and collsion of the PTU with neighbouring bikes

3.3 New design direction: embracing pedal collision

As all the original ideas of avoiding pedal collision at all costs to allow bicycles to enter the bicycle rack without them getting stuck on their way in/out proved to be either impractical or impossible, a new approach was needed; the following question was explored:
What if we used the pedal collision? What if the pedal collision would cause the PTU to move out of the way instead of the other way around?

This meant that the PTU would need to do the following:

1. Collide with the pedals
2. Be moved/pushed out of the way such that the pedals (and bike) can continue their trajectory.
3. Allow the pedal to fully move past the PTU
4. Move back to the correct position for charging (bringing the PTC in contact with the PRC)

Additionally it had to be determined where/ in what direction the pedal collision would move the PTU. Previously, it had become obvious that sideways movement, relative to the bike and gutter, was very difficult because of the limited amount of space. Therefore the most likely option was to move it out of the way alongside the gutter. Since this is already the direction of travel of the bike and the pedals, this movement would be mechanically very simple: pedals could rotate the PTU around an axis, pushing it down towards the ground and allowing them to pass over the PTU. A mechanism then would have to cause the PTU to rotate back up.

3.3.1 Pedal collision prototype

To test the fundamental principles of this new design direction, several prototypes have been created. The initial prototype, depicted in Figure 3.21, was constructed using K'nex to investigate the mechanics of rotating an arm from an upright position to a completely horizontal position and back again.

Although this prototype was quite simple, it demonstrated the importance of considering the point of rotation: for the arm to lie flat and have the lowest overall profile for pedals to pass over, the point of rotation must be at a height equal to half the width of the arm. As illustrated in figure 3.22 having the point of rotation either lower or higher, will result in the PTU sticking up higher when pushed down.

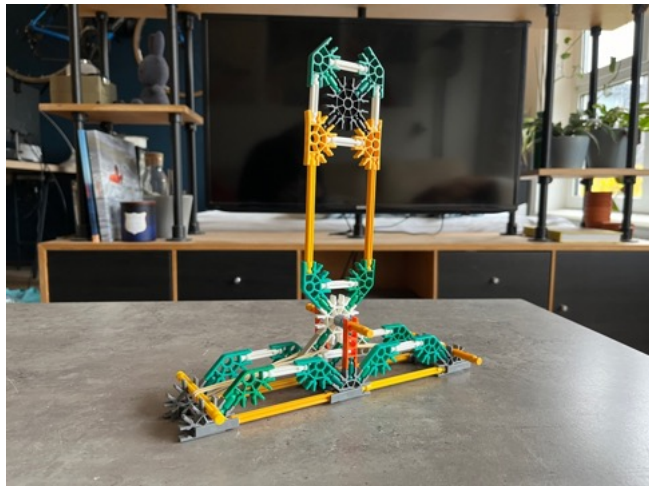

Figure 3.21: K'nexx model of pedal collision prototype

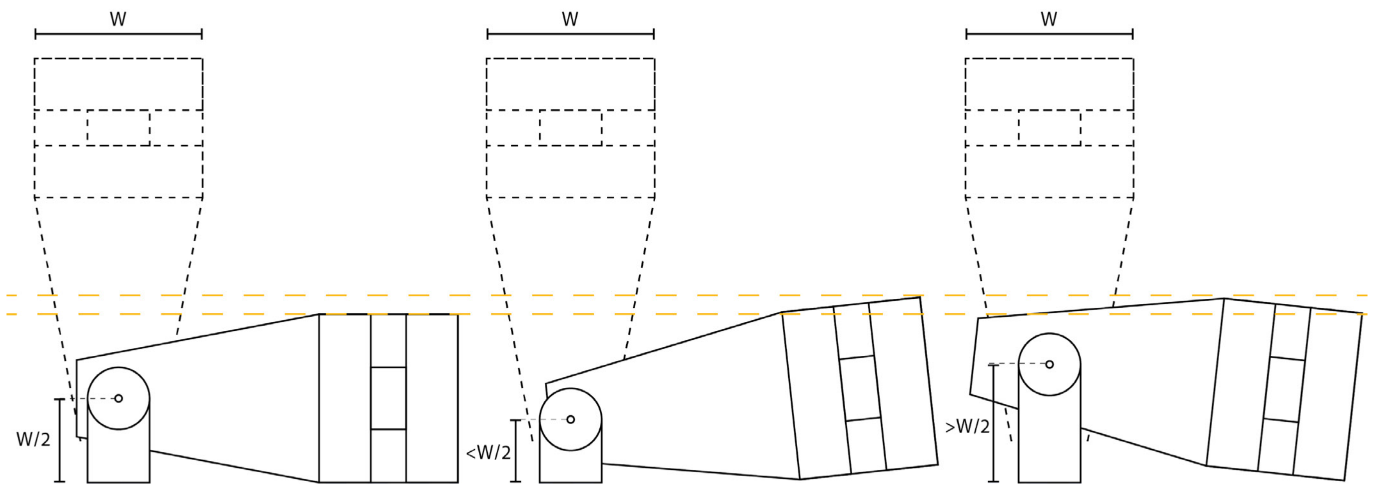

Figure 3.22: Effects of different heights for the PTU rotation point

A full-scale prototype was created to further test this new idea. The prototype can be seen in figure 3.23 and 3.24. It was important for this prototype to have the actual dimensions of the PTC, as the PTC always needed to end up at a certain height and fit within the arm of the PTU. A wooden model of the PTC was included in the prototype to ensure this. Rubber bands were used in the wooden prototype to bring the PTU back up to a vertical position, but this was not representative of any real mechanism. The mechanism for bringing the PTU back to vertical position was something to be explored later.

Prototyping results
The prototype was tested with various E-bikes on the VelopaUP bicycle rack. During testing, different pedal positions were used while pushing the bike into the bicycle rack. Some pedal positions went right over the PTU, causing no problems, while others collided with the PTU, pushing it down as intended. An example of this is shown in figure 3.26.
The bikes also easily moved backwards out of the bicycle rack without any issues, as demonstrated in figure 3.25. Despite the bikes backpedaling, there were no instances where the pedals got stuck on the PTU. Even when the bike pedals were deliberately moved to their lowest possible position and the PTU needed to be pushed all the way down, the pedals were still able to move over the PTU (figure 3.26).

Initially, there were doubts about whether the pedals would completely move past and clear the PTU if the prototype was aligned with a center-mounted kickstand. However, testing showed that there was sufficient distance between the pedals, regardless of their position, and the PTU for it to move back up to its vertical position.

Based on prototyping and testing, it can be concluded that this design direction is a feasible option for a PTU design that positions the PTC correctly while allowing all E-bikes to enter the bicycle rack without requiring additional user steps.

It's important to note that this principle can only work if the PTU arm is not too wide for pedals to pass over it when fully pushed down.
From testing bikes, it was found that the lowest possible pedal position is only 120 mm from the ground.

The width of the PTC is 100 mm, leaving only 20 mm of space for any additional design features around the sides of the PTC. If this space is exceeded, it cannot be guaranteed that bikes can pass over the PTU when the pedals are in their lowest position.

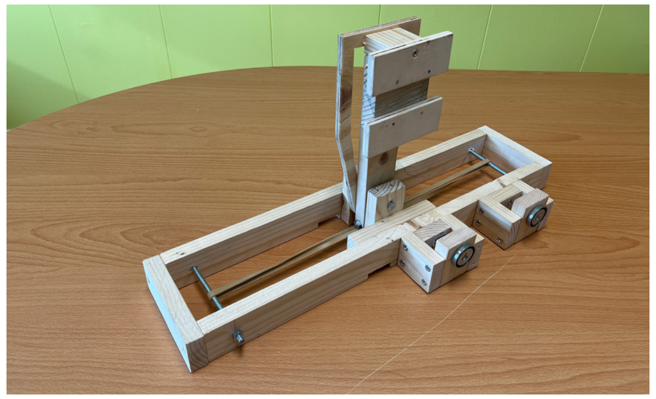

Figure 3.23: Pedal collision PTU wooden prototype

Figure 3.24: Pedal collision prototype on bike rack

Figure 3.25: Prototype pushed backwards

Figure 3.26: Prototype pushed flat to the ground

3.4 Exploring PTU Mechanisms

All previous ideation and exploration had now led to a single idea direction that had potential to work for a final design. This allowed the design space to be opened again and diverge in order to find a way to make this idea direction into real concepts. Except from several requirements and the principle of allowing the PTU to be moved by the pedal and moving it back up, not a lot was defined on how to make this into a concept. It had to be figured out how to make the PTU do that movement in not just a wooden prototype, but a real potential product.

3.4.1 How to... move the PTU?

To explore mechanisms for moving the PTU down and back up, I used the "How to's?" method. This approach is ideal for generating a wide range of potential solutions to a specific design question. Instead of fixating on the first solution that comes to mind, this method encourages considering all possible answers. The question I addressed for this phase was: "How can we move the PTU down and back up?" The outcome of this method is depicted in figure 3.27.

Two main groups can be identified (apart from some on the left that don't fit into a bigger group):
- Designs using springs
- Designs using the elastic properties of materials

An overview of several designs to help you understand the different mechanisms is provided. However, for a more detailed description, please refer to Appendix G.

In the spring group, there is a variant similar to the mechanism in the earlier wooden prototype, but it uses springs instead of rubber bands. Another design worth highlighting is the torsion spring, which uses a spring loaded by rotation instead of regular springs loaded by linear deformation.

In the "material properties" group, all designs utilize the same principle of bending the arm made out of a flexible material and allowing it to flex back to its original position. The differences lie in the specific part that is made out of the flexible material, causing them to bend in different ways.

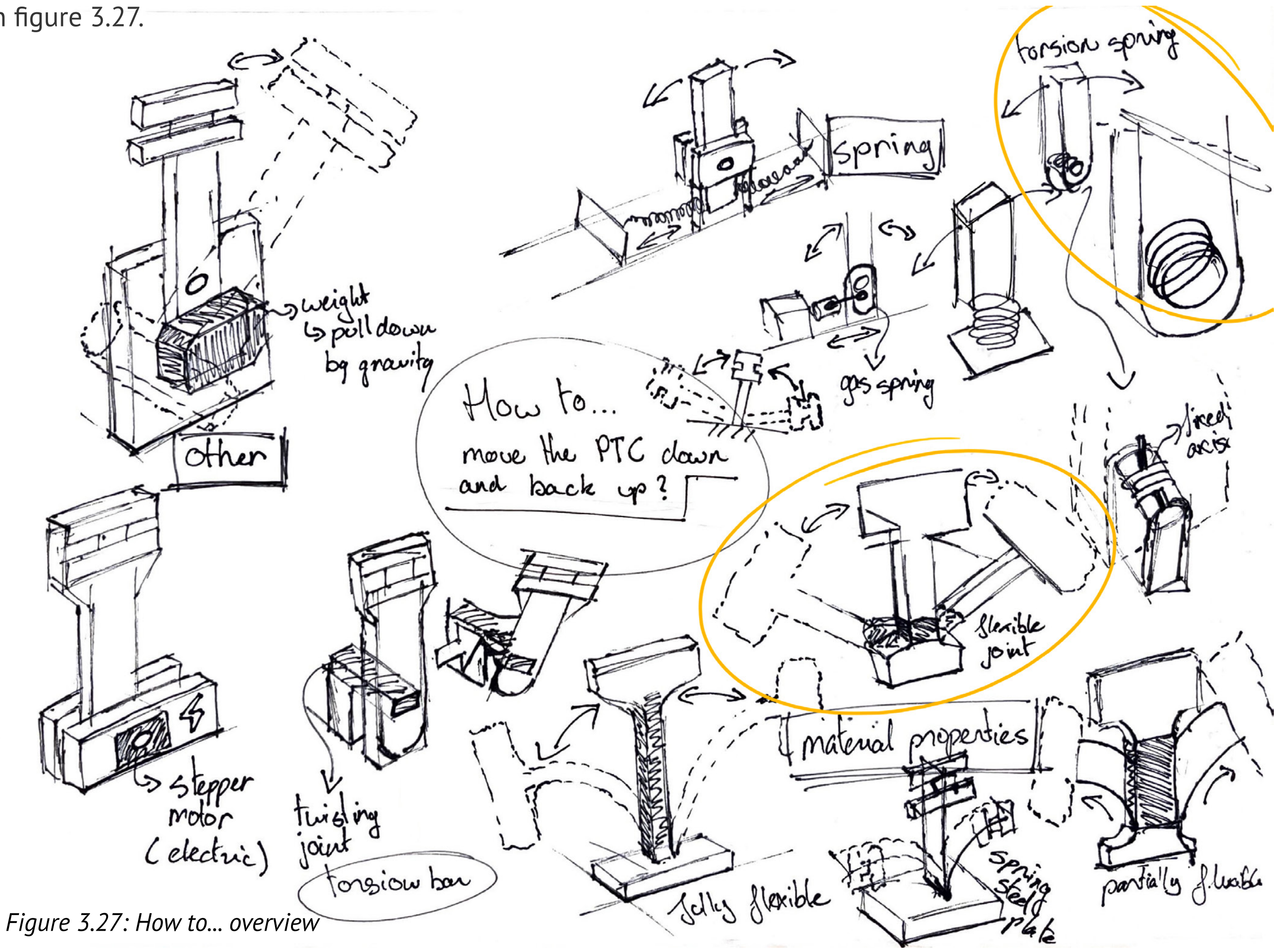

Figure 3.27: How to... overview

3.4.2 Selected PTU mechanisms

From all different possible solutions to make the PTU move down and back up, two were selected as best suited for this design project. They are circled in yellow in figure XXX. The two 'mechanisms' in question are:

- Torsion spring mechanism
- Flexible joint

These mechanisms have been selected based on the following criteria:

- Not taking up too much space/ causing the final design to be unnecessarily big since space in the bicycle rack is minimal.
- Affordability, since the whole system should not be as expensive as it is supposed to be implemented in large quantities in bicycle parking facilities. Requiring many or big custom parts could cause mechanisms to get expensive quickly.
- Creating a controlled movement and rotation of the PTU. As established earlier, the exact point of rotation is very important for allowing the pedals to pass over the PTU. Therefore, the mechanism should allow for that movement to be very controlled.

A more comprehensive explanation of these mechanisms and their selection criteria can be found in Appendix G.

4. Conceptualisation

This chapter will show to process of, and the developments needed for transforming the idea of a wireless E-bike charger in two-tier bicycle racks into real, feasible concepts by combining it with the torsion spring and flexible hinge mechanism to make the PTU move down out of the way of any pedal and moving it back up to reach the Charging Kickstand and start charging. Real electrical components will be compared and added to the design, shaping the concepts along the way. Ultimately, this will lead to one final concept for this graduation project: the 'Flexjoint'.

4.1 Concept building blocks

To turn the ideas from the ideation phase into concepts, many components/building blocks had to come together in a specific way. Electronical parts needed to be combined with mechanical principles for moving the PTU. All had to be arranged such that they work together and simultaneously fit within the space of a two-tier bicycle rack, all contained within a housing to give it structure and protect it from the outside elements. Figure 4.1 shows how these different parts could results in different concepts.

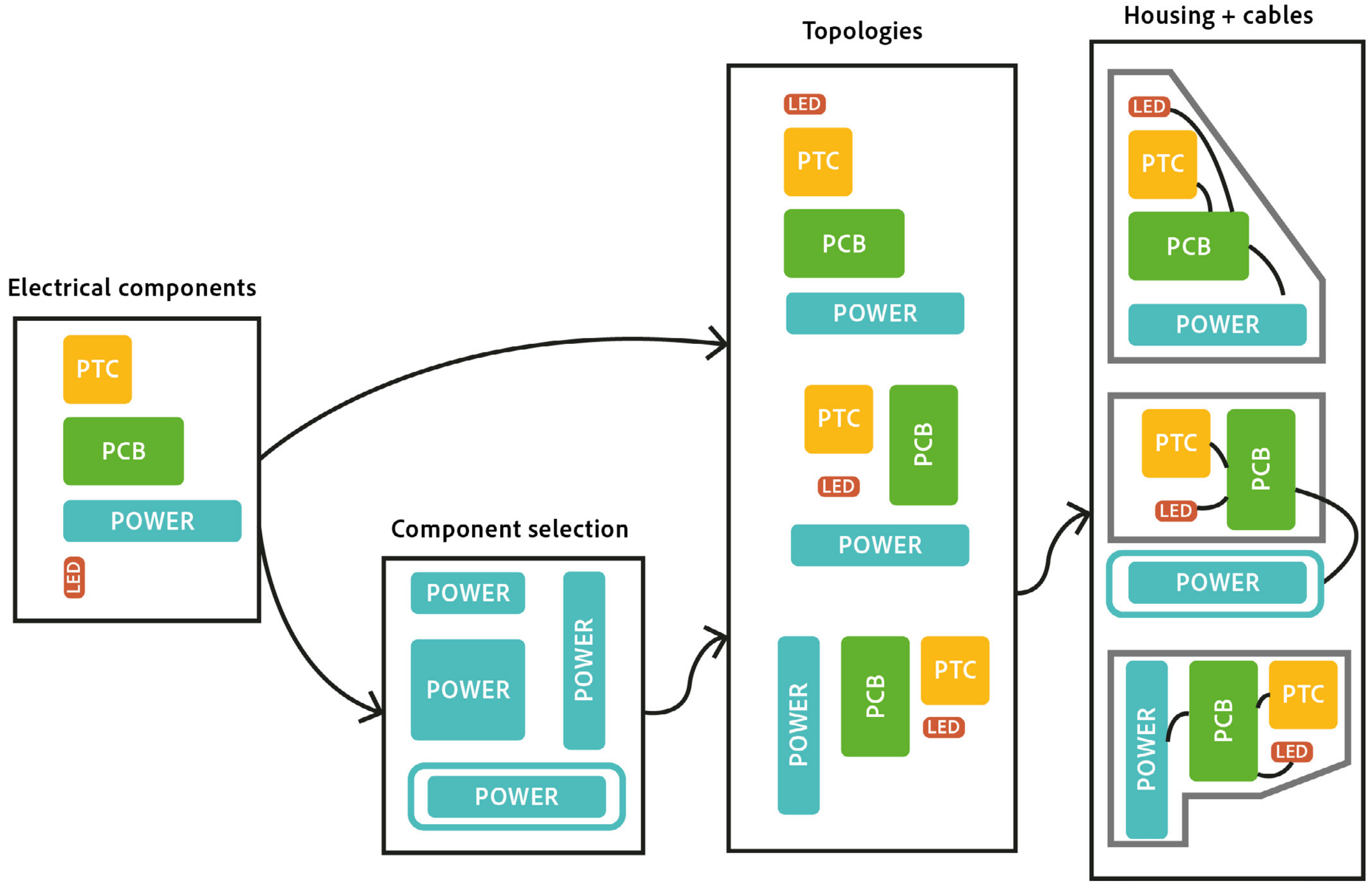

Figure 4.1: Schematic overview of concept building blocks

4.1.1 General Component Overview

Any concept for charging E-bikes with a moving PTU arm must consist of several main components that ultimately transfer power wirelessly from the PTU to the PRC in the Kickstand. This part will give an overview of those components, some of which have special requirements or are predetermined by the TILER charging technology. Their influence on building a final concept will also be highlighted.

Power Transmitting Coil (PTC)
The PTC generates the electromagnetic field for wireless charging, which is to be received by the Power Receiving Coil in the Charging Kickstand. The custom-designed coil consists of coated copper windings around a U-shaped ferrite block. Due to high development costs, the same PTC used for the Charging Tile must be used in this design. In the final design, the top of the PTC must be positioned at a height of 250 mm to reach the PRC, which determines its location within the PTU arm.

PCB
The PCB controls all specific functions required for TILER's wireless charging technology. This part is custom designed for the TILER Charing Tile and, because of the abundance of space in the tile, is quite big. Because R&D costs for developing a new custom PCB are high, the same PCB as is in the tile will be used in this design.

Power supply
The TILER Charging system can be plugged into any household electrical power. However, a power supply is needed to turn 220V AC power into 48V DC to drive the PCB. This part has specific requirements but isn't custom for TILER. Therefore, it is open to different variants with different benefits, like smaller sizes or self-contained waterproof housings. This will be further explored in the next part.

LED
The LED is added to the system to indicate the user's charging status. This doesn't bring many additional requirements as it is a COTS (Commercial Of The Shelf) product, except for it needing to connect to the PCB and be visible to the user.

Housing
All components must be enclosed in a housing to protect them from external elements and impacts, as well as to position them correctly. Although some components may be standard, their unique configuration in the design requires a custom-designed housing. Each part of the custom housing requires a new mold, making it quite expensive. Therefore, the number of housing parts should be minimized.

(High-voltage) cables
All components need to be connected by electrical wires. The power supply on one side must connect to a power outlet and to the PCB on the other. From the PCB, a cable must run to the LED and the PTC. The latter has special requirements; in order to generate the electromagnetic field, the PCB transfers the 48V DC to high voltage AC. These are connected through a special high voltage cable, which is rather fragile and needs to be well hidden from users due to safety precautions. This specific cable can't be exposed in any way.

4.1.2 Power Supply Exploration

Since the power supply is a generic component used in many electronic applications, numerous highly specialised companies manufacture various variants, each with different specifications and features. Unlike other components, it didn't have to be reused from the TILER Charging Tile design and was open to component selection. It only had some specific requirements:
Transform AC to DC electrical power
Deliver a 48V output
Power output of at least 200W at operating temperature

The final requirement is closely linked to power supply ratings and their associated cooling capabilities. This is because most power supplies deliver lower wattage when operating temperatures increase. For a more detailed explanation and comparison, please refer to Appendix H.

Several power supplies have been compared based on, among other things, size, temperature performance, and implications on component topologies and housing.
Two different power supplies were selected, each with different benefits and features. Both will be highlighted below:

Open-frame power supply
The first option for a power supply is the EPP-500-48 from MeanWell (figure 4.2). This open-frame power supply is relatively small compared to other power supplies with their own enclosure. This allows it to be positioned in more different locations or the total housing to be smaller. Due to its compact size, it has no cooling features and relies on cooling to ambient air (within the housing). As it was rated for optimally ventilated situations, due to expected temperature-induced power loss, a much higher-rated version (500W) was selected.

External power supply
The HLG-240H-48 power supply from MeanWell (shown in figure 4.3) comes with its own waterproof enclosure, unlike the open frame. This makes it larger but can be placed outside any housing designed for the other components. Since it doesn't need to be inside a housing, it can be cooled by the outside air. It can also be placed anywhere on the bicycle rack, where the risk of pedal collision would not be a concern.

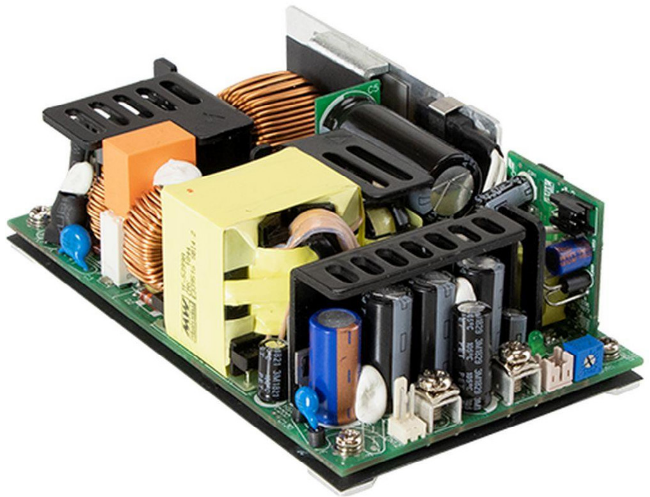

Figure 4.2: Meanwell EPP-500-48 open frame power supply. SOURCE: MeanWell

Figure 4.3: Meanwell HLG-240H-48 external waterproof power supply. SOURCE: MeanWell

4.1.3 Topology Exploration

Now that all components are known, their dimensions are also given. All of these components will need to fit in the system, not only in relation to each other but also with regard to the available space within bicycle racks. This can be done in many different ways, each with its own possibilities and benefits. This 'set-up' or arrangement of components within the system can be considered its topology.
Several possible topologies have been explored by rearranging these components in the form of digital models in Fusion 360 in different ways.
All topologies had to follow some 'ground rules':

- The PTC is always in the same location
    - The vertical ferrite block face is 125mm left of the center of the gutter
    - The coil center is 60 mm in front of the end of the gutter
    - The coil top is 250 mm from the ground
- The system must fit within a maximum of 2 housing sections: PTU arm and PTU base.
- No part, except for anything in the moving PTU arm, can exceed a height of 100 mm (to prevent pedal collision)

This exploration has resulted in 3 different possible topologies for the final design. An extensive description of these topologies and the exploration process can be found in Appendix I.

Topology 1: PCB and power supply in PTU base
This topology places the power supply on top of the PCB, effectively utilizing the space beneath the slanted edges of the Velopa-UP gutter by positioning a section of the PCB inside it. The primary advantage of this setup is that it keeps the PTU arm lightweight and provides more flexibility in designing the housing for the PTU arm. However, it also means that the delicate high voltage wires connecting the PTC to the PCB would need to run through the rotation mechanism and thus move with each rotation of the PTU arm, potentially causing damage over time. This topology can be seen in figure 4.4.

Topology 2: PCB in PTU arm
For this topology the PCB was moved to be incorporated into the PTU arm. This results in the PTU base to be smaller, since it must only include the power supply and a rotation mechanism, but causes the PTU arm to be a lot move voluminous. A main benefit of this topology is that it allow the cables between the PCB and the PTC to remain stationary. This topology is shown in figure 4.5

Topology 3: External power supply
In contrast to the other topologies this topology utilized the external power supply. The best way to capitalize on this change was to place the PCB in the PTU arm again, as this topology would then only require a waterproof housing to be made for the PTU arm itself. The rotation mechanism could be placed externally, resulting in the topology shown in figure 4.6.

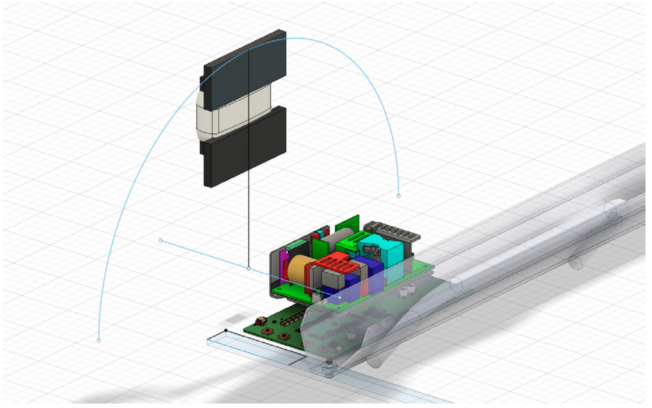

Figure 4.4: Topology 1 'PCB and power supply in base'

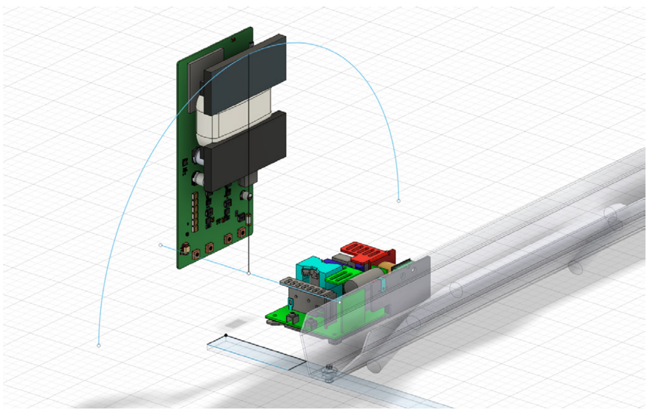

Figure 4.5: Topology 2 'PCB in PTU arm'

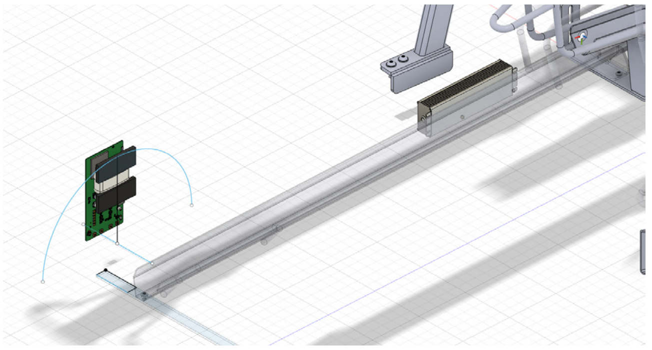

Figure 4.6: Topology 3 'External power supply'

4.2 Concept creation

An idea turns into a concept when more details are being added, all contributing to it feasibility. For this project many different aspects creating a concept had been explored: a way of preventing pedal collision, mechanisms to always bring the PTU to its intended postion, components selection and different effective ways to arrange those components. The combination of these building blocks has shaped the ideas into concepts. This section will show how the resulting concepts and how those concepts came together.

4.2.1 Idea combination

To turn the principle of the moving PTU arm into concepts, a simplified morphological chart was used. On one axis, the different hinging mechanisms—the torsion spring and the flexible hinge—were placed. On the other axis, the three topologies for the main components were placed. The goal was to end up with two possible concepts.

The first concept quickly became clear as the variations - the "flexible hinge" and the "external power supply" - complement each other very well. Using the external power supply topology would require only one housing for the PCB and PTC in total. Since a flexible hinge doesn't use any mechanical part that would benefit from being inside a protective housing, unlike the torsion spring, the PTU arm in this topology could be placed on top of a flexible hinge. The result is a very minimal concept consisting of a protective housing with the PTC and PCB inside, on top of a flexible hinge that is connected to the bicycle rack only through a bracket. One single cable could run from the power supply through the flexible hinge, into the PTU. This concept was called the "Flexjoint concept" and is further described in the next section.

For the torsion spring concept one of the remaining two was used to create variety in the concepts. When comparing topology 1 and 2, the topology with the PCB placed in the PTU arm together with the PTC was preffered (topology 2). This is because toplogy 1, even though making efficient use of the space available, would only work with the specific design of the VelopA-UP bicycle rack. While requirement 10 states that the design must work with the VelopA-UP bicycle rack, wish 6 adds that it would preferably also work with other two-tier bicycle racks. That last wish simply can't be guaranteed by topology 1. Combining topology 2 with the torsion spring mechanism led to the 'Torsion spring concept', which is further explained in 4.2.3.

4.2.2 Flexjoint Concept

The first concept is the Flexjoint concept. A concept drawing can be seen in figure XXX. It consists of 3 main parts:

1. **Main PTU arm:** A protective housing containing the PCB and the PTC.
2. **Flexjoint:** the flexible hinge is made out of an elastomer/rubber material and is designed such that it bends in a specific location. If bent, the elastic deformation of the material will cause the PTU arm to rotate back up to its vertical position
3. **External powers supply (not shown in drawing):** In the bicycle rack near the front wheel the Meanwell HLG-240H-48 will be placed, with a cable running along the gutter, passing through the flexjoint into the PTU main body.

Flexjoint design
The specific design of the flexjoint is crucial for its proper functioning. The PTU arm needs to rotate around an axis 50 mm from the ground in order to lay completely flat on the ground and allow pedals to pass over it. Therefore, a part of the flexjoint must be heavily tapered to concentrate all bending in that specific spot.

In addition, the flexjoint must allow a power cable to pass through. For this, two options were designed: a hollow variant where the flexjoint only consists of an outer wall made out of flexible material, and a solid variant with a channel running through which a cable can be passed. The more effective variant will be determined later in the project.

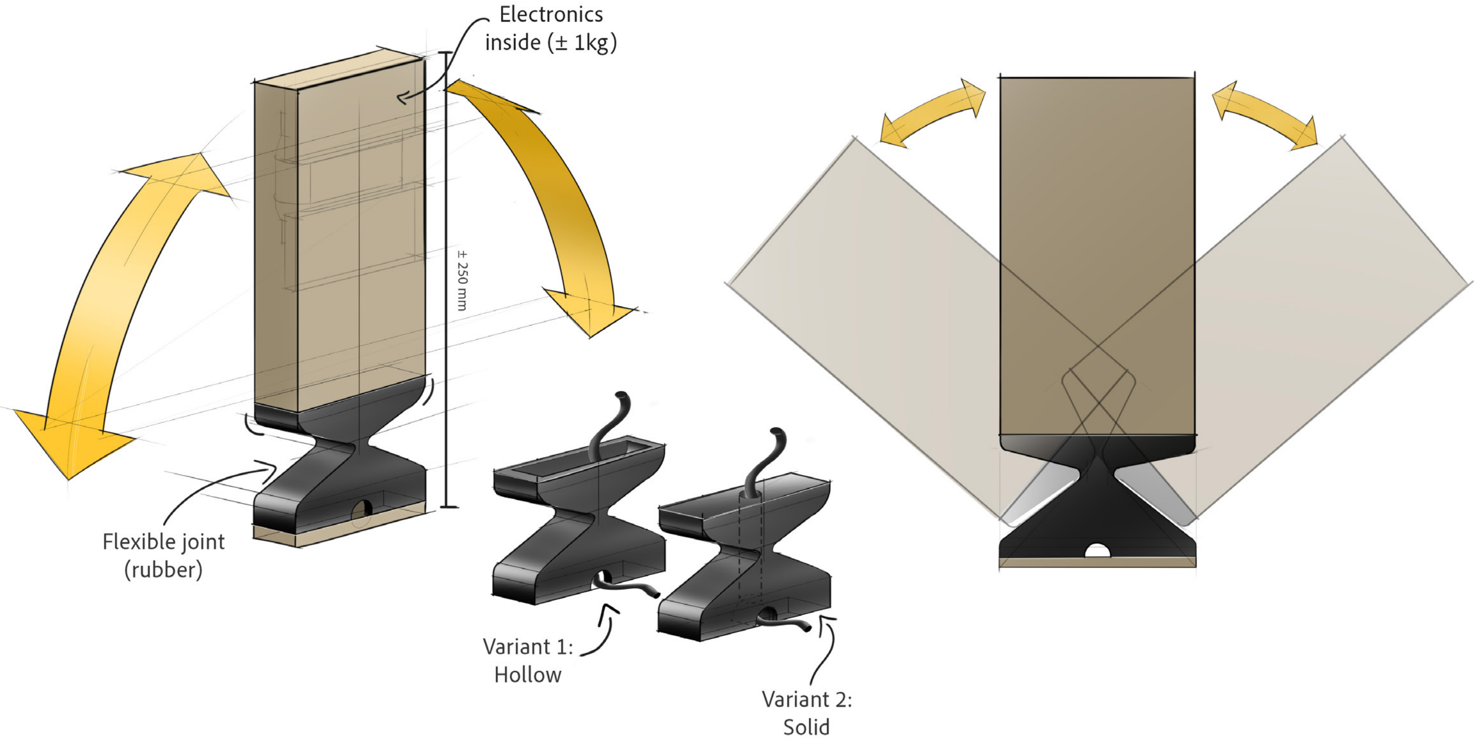

Figure 4.7: Flexjoint concept drawing

4.2.3 Torsion Spring Concept

The second concept combines a torsion spring mechanism with topology 2, and is called the 'Torsion Spring Concept'. Figure XXX shows a concept drawing for this design. The concept can be split up in 3 main parts:

1. **PTU arm:** similar to the 'Flexjoint' concept, this protective housing contains the PCB and PTC
2. **PTU base:** The base of the whole system, which is meant to be mounted to the bike rack itself. It contains the power supply, protecting it from outside elements. Additionally, it houses most of the torsion spring mechanism.
3. **Torsion spring mechanism:** The mechanism responsible for allowing the PTU arm to swivel back and forth. If the PTU arm rotates one of two torsion springs gets tensioned in the opposite direction causing the arm to move back when released. This mechanism is also the bridge between the PTU body and arm, allowing cables to pass through from the power supply to the PCB.

Torsion spring mechanism
The torsion spring mechanism consists of a central hollow axis with two opposite torsion springs around it. This axis is fixed within the PTU arm and therefore rotates with it. This allows the cable exit, as shown in figure XXX, to always remain the same position relative to the PTU arm. On the other end the cable entrance is the open end of the hollow axis. The combination of these allows for minimal cable movement/bending when rotating the PTU arm.

To ensure that the torsion springs function properly, they need to be connected to both the rotating mechanism axis and the stationary PTU base. One end of the torsion springs is clamped onto the axis, while the other end has a flange that rests on a part of the PTU base housing. When the axis, and therefore the torsion spring, is rotated against its resting surface, the spring becomes tensioned and generates a force that causes the axis and PTU arm to rotate back.

It's important to note that torsion springs are designed to be tensioned in only one direction of rotation. Rotating them too far in the other direction could cause them to fail. To address this, two torsion springs are used, each serving as the mirrored counterpart of the other. As the torsion springs rotate with the axis, if the axis is rotated in the "wrong" direction for a given spring, the flange simply lifts up from the resting surface, allowing that spring to freely rotate with the axis. This design enables the axis to rotate in both directions and spring back to its neutral position without causing damage to the torsion springs.

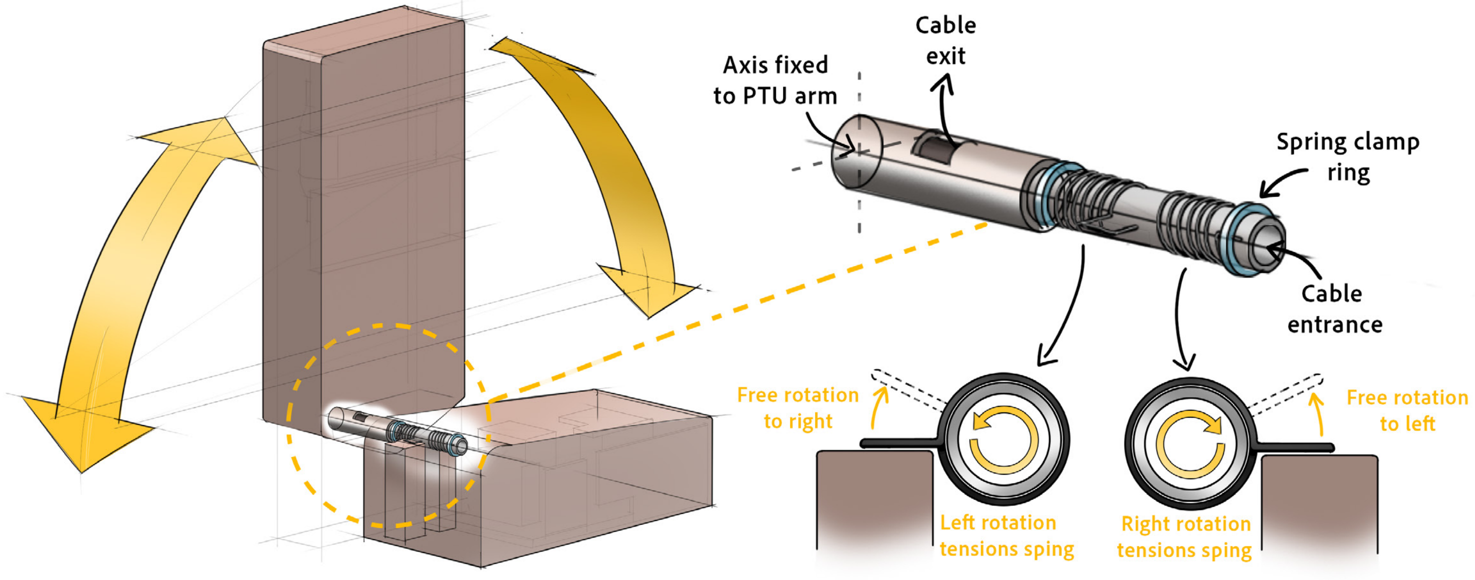

Figure 4.8: Torsion Spring concept drawing

4.3 Concept comparison

To pick a concept for the final design of this project, the Flexjoint and Torsion Spring concepts were compared. Since these concepts are not fully embodied designs it is hard to quantify some of their attributes. There the ‘Datum Method’ (Delft Design Guide) was used. This method compares concepts on different criteria that were selected as important in this phase (or the future) of development. It is done by selecting one concept at the ‘datum’. This is the neutral value to which the rest is to be compared. In this project, the Flexjoint was used as the datum concept. Each criterion for the other concepts is then compared to this datum and scored with either a ‘+’, ‘-’ or ‘S’, corresponding to it being better, worse or the same, respectively, to the datum.

The criteria used for this datum method are:

- Amount of custom parts required (less is better)
- Durability
- Ability to accommodate a wide variety of E-bikes
- Controlled movement of the PTU arm
- Size (smaller is better)
- Simplicity

Appendix J further explains the relevance of these criteria.

	Flexjoint concept	Torsion Spring concept
Nr. custom parts	▪	-
Durability	▪	+
E-bike variety	▪	-
Controlled movement	▪	+
Size	▪	-
Simplicity	▪	-
Σ+	▪	2
Σ-	▪	4
Σtotal	▪	-2

Table 1: Resulting scores from ‘Datum Method’

4.3.1 Final concept choice: Flexjoint Concept

Table 1 shows the results of the datum method. It can be seen that the Torsion Spring concept scores lower on these selected criteria than the Flexjoint concept. Therefore the Flexjoint concept was chosen as a basis for the final design.
Some of the main advantages of the Flexjoint concept over the Torsion spring will be highlighted below. For a full explaination on the resoning behind the scores of the datum method, please refer to Appendix J.

Flexjoint advantages

- The Flexjoint concept requires fewer custom parts compared to the Torsion Spring concept due to its simpler design and construction. This results in cost savings for R&D and manufacturing, which is crucial for a startup like TILER.
- For this wireless E-bike charging system to be truly universal, the PTU system must be compatible with as many different E-bikes as possible. The PTC and Tiler adapter brackets for kickstands help bring the PTC and PRC within reach of each other. The flexible nature of the Flexjoint also allows the PTU to move slightly sideways in relation to the bike. Therefore, it can work for E-bikes with kickstands sticking further out to the side and bikes possibly leaning more to the side, rather than standing perfectly straight. The Torsion Spring concept only allows the PTU to rotate in one specific plane.

5. Finalisation

This chapter presents the final design for the graduation project: the TILER UP-Charge. It highlights the different custom components and their design features. Additionally, it discusses the process of turning the Flexjoint concept into the final design by adding details such as aesthetics and manufacturing. The chapter also shows how this design has been validated (and reiterated) through prototype and user testing.

TILER UP-Charge

Push it down to charge it up

5.1 Presenting: TILER UP-Charge

The final design for this graduation project is the 'TILER UP-Charge'. This wireless charging system allows for E-bikes to be charged on the ground level of a two-tier bicycle rack without any additional steps from the user other than simply placing their E-bike in the VelopA-UP Bicycle rack. All they would need to do is to have the TILER Charging Kickstand installed on their E-bike. The UP-Charge is shown in figure XXX and XXX.

The UP-Charge aligns the PTC to the side of the TILER Charging Kickstand and automatically starts charging. If the pedals of the E-bike happen to be in such a position that they hit the UP-Charge, the whole system hinges on top of the 'flexjoint' and can be pushed all the way down to the ground to allow the pedals to move over it. After the pedal has passed, the UP-Charge will automatically move back up to its vertical position, aligning with the PRC in either a center or rear-mounted Charging Kickstand.

Figure 5.1: Render of the TILER UP-Charge

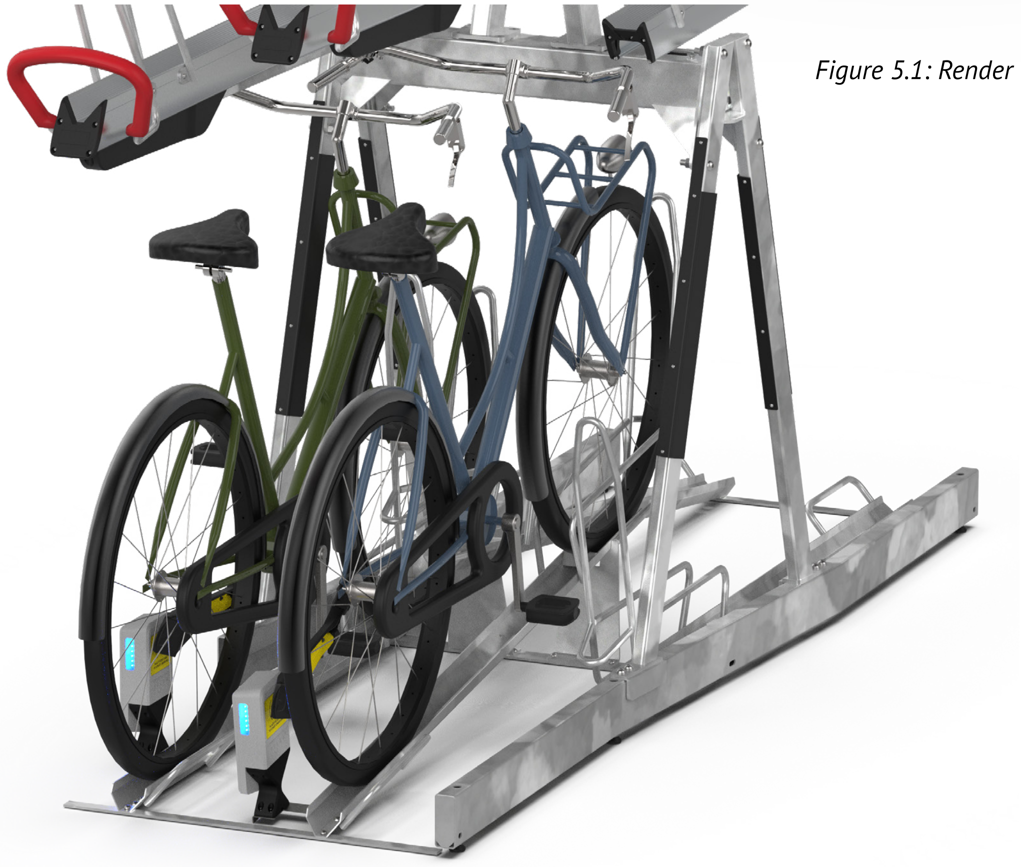

Figure 5.2: Render of the TILER UP-Charge mounted to the VelopA-UP bicycle rack

UP-Charge Components

The main part of the UP-Charge design consists of the flexjoint and the PTU on top of it, which fulfill the most important functions of the UP-Charge system: allowing it to move back and forth and transferring the power from the UP-Charge to the E-bike, respectively. The individual components in this section of the design can be seen in the exploded view in figure 5.3. In figure 5.4, the inside of the PTU case can be seen, showing how all components are mounted within the PTU case itself.

Figure 5.3: Exploded view front side

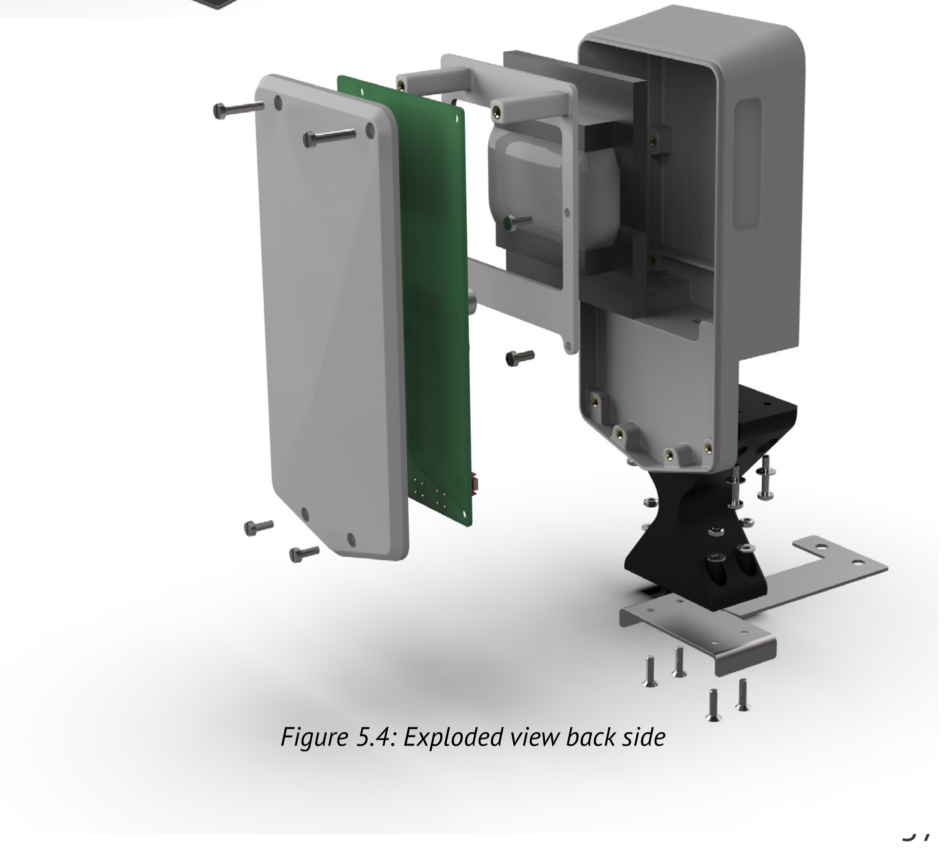

Figure 5.4: Exploded view back side

5.1.1 Flexjoint design

The flexjoint is the flexible hinge made out of polyurethane that allows the UP-Charge to move back and forth so pedals can move over it. A closer look into is design can be seen in figure 5.5.

The flexjoint has an hourglass shape, with a wide base and top. This design ensures that there is enough surface area for the flexjoint to securely mount to the mounting bracket on the bottom and avoid being torn off when pedals collide with the UP-Charge.

Mounting holes are added to bolt the flexjoint onto the PTU case and mounting bracket. This method of mounting the UP-Charge has been chosen with prototyping capabilities in mind. In a final production version of the UP-Charge, this mounting method for the flexjoint is likely to change, as will be further explained in Chapter 5.3 'Manufacturing'.

The top of the flexjoint is equally as wide as the PTU case, whose width is determined by the size of the PCB and PTC. This creates a smooth transition between these parts and thereby allows pedals to glide along the full side of the UP-Charge without getting stuck on any protruding parts.

Perhaps, even more importantly, the wide top and base, combined with the tapered section right in the middle, which gives it its recognisable hourglass shape, concentrate all the bending in the middle, allowing it to bend at the required height of 50 mm. This tapered section has the smallest area moment of inertia, providing that section with the least resistance to bending of the whole flexjoint. Bending at this specific section allows the PTU to move from its vertical position fully to a horizontal position, lying flat on the ground.

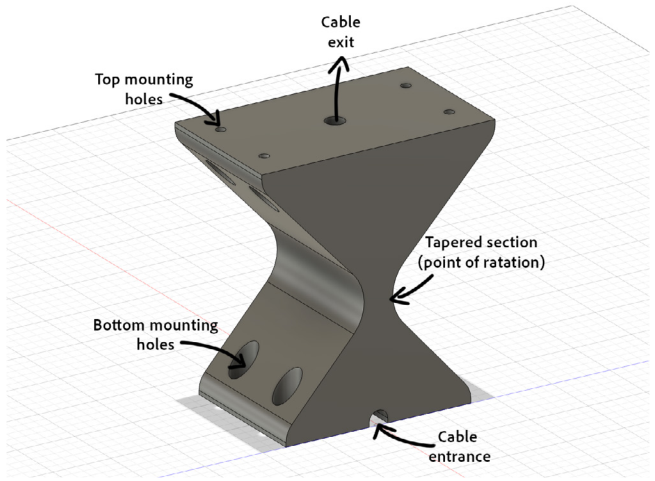

Figure 5.5: Annotated design of the flexjoint

The exact profile of the hourglass shape is important to consider. When the flexjoint bends, the top section rotates 90 degrees in either direction, causing it to fill the cavity between it and the base. To allow for a full 90 degrees of rotation, the angle between the slanted sides of the hourglass profile must be greater than 90 degrees, as shown in figure 5.6. If the angle were smaller, the top would collide with the bottom before a full 90-degree rotation is completed. This would then prevent the PTU from being fully horizontal, possibly causing the pedals to become stuck in it when moving into the bicycle rack.

Flexjoint properties: design, dimensions and material

The flexjoint is designed not only to rotate the PTU down to a horizontal position but also to spring the PTU back up to a fully vertical position. To investigate the feasibility of the flexjoint being able to do that, and to generate sufficient restorative power without breaking or tearing in the process, extensive calculations on the physics of the flexjoint were performed. This calculation is shown and explained in Appendix K.

As a result of this calculation, the following design choices were made:

- The flexjoint needs to be a solid shade with only a vertical cylindrical hole for the cable to pass through. This is in comparison to an earlier possible variant in which the flexjoint could be designed to be hollow, as shown in its original concept drawing.
- The tapered middle of the flexjoint is 15 mm wide
- The flexjoint needs to be made of Polyurethane with a Young's Modulus of 5 MPa.

These design choices proved essential to finding the right balance between the flex joint generating enough rightening moment to move the PTU back up and being flexible enough that it would fail under the stresses experienced when bent to its maximum angle of 90 degrees.

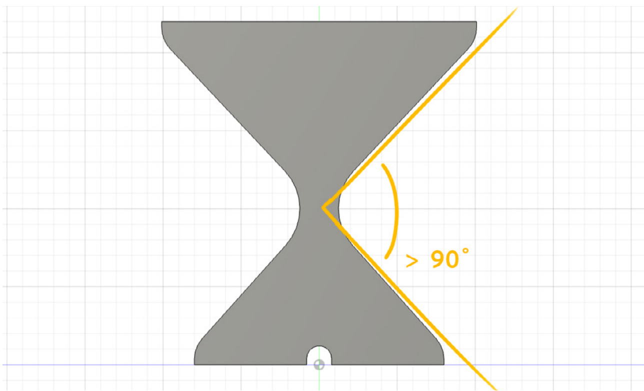

Figure 5.6: Flexjoint angle

5.1.2 PTU Case design

The Power Transfer Unit consists of everything above the flexjoint and wirelessly transfers electrical power from the UP-Charge to the Charging Kickstand. The main electrical components in this are the PCB and the PTC. These components and all wires need to be kept in the right place and protected from outside elements. The PTU case fulfills that purpose in the design of the UP-Charge.

The design of the PTU case (with the backcover removed) can be seen in figure 5.7. It consists of 3 parts:

1. Main housing body: all other parts and components are placed inside of here and screwed into place.
2. PTC cover bracket: keeps the PTC in place as the PTC itself can not be attached with screws on its own.
3. PTU back-cover: Closes off the main housing body to keep all the internals protected from outside elements.

Component mounting

All components are securely mounted inside the PTU case. They need to be placed inside in a specific order to reach all required screw holes. Figure 5.8 shows all components being added one by one. The used screw holes for each step are circled in yellow. The current design of the PCB requires some of its mounting holes to also be used for the bolts of the backplate. It should be noted that the limited space left by the PCB also requires 'mounting pillars' for the PCB to be placed on top of the PTC cover bracket, making that part arguably unnecessarily harder to manufacture since it can no longer simply be a flat cutout. A future redesign of the PCB could solve this.

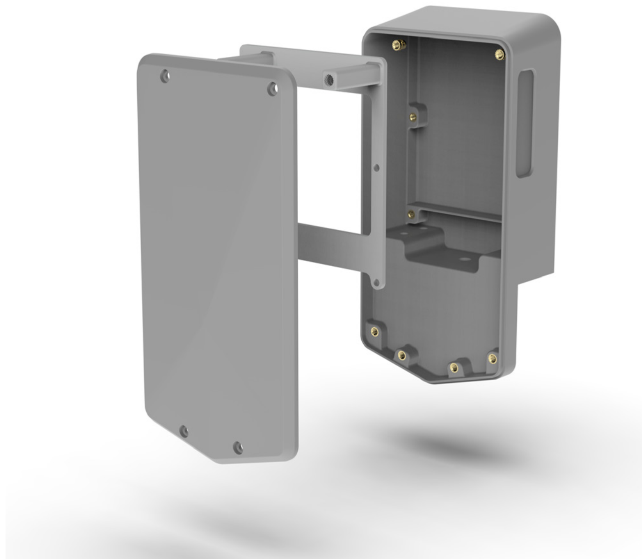

Figure 5.7: Inside of PTU case

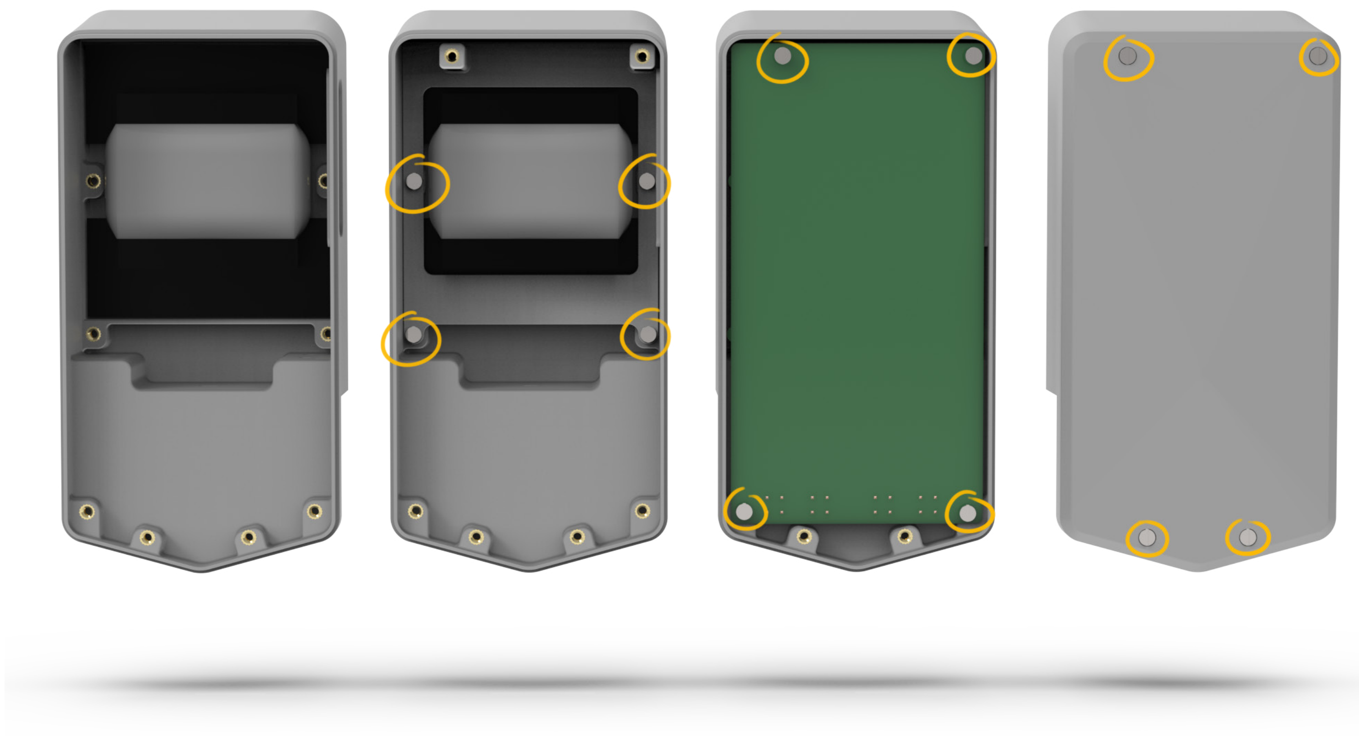

Figure 5.8: PTU case component mounting steps

PTU case design features:
Apart from the general purpose of the PTU case to contain and protect the electrical components required for charging, there are some additional design features worth highlighting:

- **PTC box:** The ferrite block itself for the PTC can not be drilled into directly, therefore the PTC couldn't be screwed into place by itself. As permanently glueing the PTC in place would make replacement or repairs very difficult, a special PTC box was designed. The PTC securely fits in a special cutout in the main housing body and is kept in place by the PTC cover bracket.
- **'L-shaped' case:** The overall shape of the PTU case resembles that of an upside-down 'L'. This results from the PCB needing to be fully contained by the PTU case while simultaneously keeping the design of the UP-Charge beneath its maximum height. This reasoning will be further explained in Chapter XXX 'Prototyping'.
- **LED status indicator:** The side of the PTU case has a 'window' for the LED status indicator. These LED's are used to communicate with the user about the charging state of the UP-Charge and their E-bike. Figure XXX show the different charging states.

*Figure 5.9: Different LED status indicators.
Blue = Charging, Green = Fully charged, Red = Error*

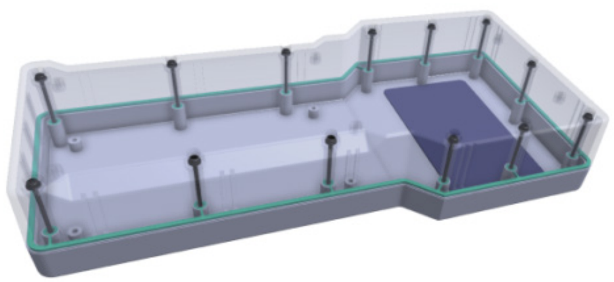

Figure 5.10: Example of a waterproof enclosure with a rubber gasket seal SOURCE: Jiga

Case waterproofing
One requirement for the UP-Charge is that it be waterproof, with an IP66 rating. Unlike the charging tile, the UP-Charge will not need to withstand total submersion. However, it would need to endure high-pressure water, as bicycle parking facilities are not unlikely to be cleaned with a pressure washer.

To make the case more waterproof a 'ridge' was added to the seam between the main housing and the backplate. On this ridge a rubber bead must be laid, incorporating any fasteners that protrude to the outside of the case, as seen in the example in figure 5.10.
Additionally a cable gland similar to figure 5.11 will make sure that the entrance point of the power cable into the case is sealed.

The case waterproofing rating is something that must be tested with a final production version of the UP-Charge. However, there are certain limitations of the current design of the UP-Charge that are expected to hinder the waterproofing of the case. For a waterproof enclosure, it is advised to have fasteners closing the case all around the edges, with a distance of no further apart than 35 mm (Jiga, n.d.). While this might be too much for the required waterproofing of the UP-Charge, the current design, with a total of only four fasteners along the case, is expected to be insufficient. The addition of fasteners is, however, impossible with the current design of the PCB as it takes up nearly all available space in the housing, and increasing the width of the housing itself is impossible due to the maximum width of the PTU case to still allow pedals in their most downward position to pass over it.
Unless proven otherwise, a redesign of the PCB will be needed to achieve the required IP66 rating for the UP-Charge.

*Figure 5.11: Example of a cable gland
SOURCE: RSOnline*

5.1.3 Mounting brackets

The UP-Charge is mounted onto two-tier bicycle racks by mounting brackets. Mounting it directly into the ground would prevent it from being used in the 'diagonal' bicycle gutter on the rack and would also require the unwanted permanent alteration of the ground of bicycle parking facilities.

These mounting brackets differ for each possible mounting location for the UP-Charge, resulting in the four brackets shown in figures 5.12 - 5.15. These brackets also ensure the correct positioning of the UP-Charge in relation to the bicycle rack and the E-bikes, ensuring proper alignment between the PTC in the UP-Charge and the PRC in the Charging Kickstand.

The brackets are made of 3 mm-thick steel sheet metal. Because the brackets for the diagonal gutter cannot rest on the ground, bent flanges have been added to increase their resistance to bending, resulting in stronger brackets.

Bicycle rack compatibility
Each bracket is different for each different mounting location on the bicycle rack. This allows the same flexjoint and PTU case to be reused in different setups. It is considerably cheaper to have differently designed brackets than to require a different design for the whole UP-Charge. These brackets have been designed specifically to work with the VelopaUP two-tier bicycle rack. However, due to the simple nature of this mounting solution, brackets could easily be designed for different additional two-tier bicycle racks, increasing compatibility and therefore reach and potential

Figure 5.12: UP-Charge in center kickstand location on diagonal bike gutter

Figure 5.13: UP-Charge in rear kickstand location on diagonal bike gutter

Figure 5.14: UP-Charge in center kickstand location on flat bike gutter

Figure 5.15: UP-Charge in rear kickstand location on flat bike gutter

5.2 Design aesthetics

The design of the UP-Charge did not only have to meet functional requirements, it was also important for the design to be aesthetically pleasing and apropriate for the context to result in a desirable product. This was mainly captured in the following requirements/ wishes:

W9: The design should convey the intentionality of being hit by the bike/ pedals
W5: The design should fit the context of (semi-) public infrastructure/ bicycle racks
W4: The design should fit the aesthetic of the TILER product ecosystem.
R9: The design must contain TILER branding

An extensive explaination on the process of aesthetic exploration is provided in Appendix L.

5.2.1 Design inspiration

The aesthetic design of the UP-Charge was inspired on several existing product designs shown in figure 5.16. These product were selected for their combination of looking rugged, yet modern.

After analysis of these designs, which is further explained in Appendix L, several key insight for achieving this particular aesthetic were identified:

- The combination of rounded corners and chamfered edges give the products a smooth yet serious appearance.
- Chamfers and fillets gradually changing in size look more dynamic
- Raised pannels create a feeling of inentionallity of that section, drawing the attention

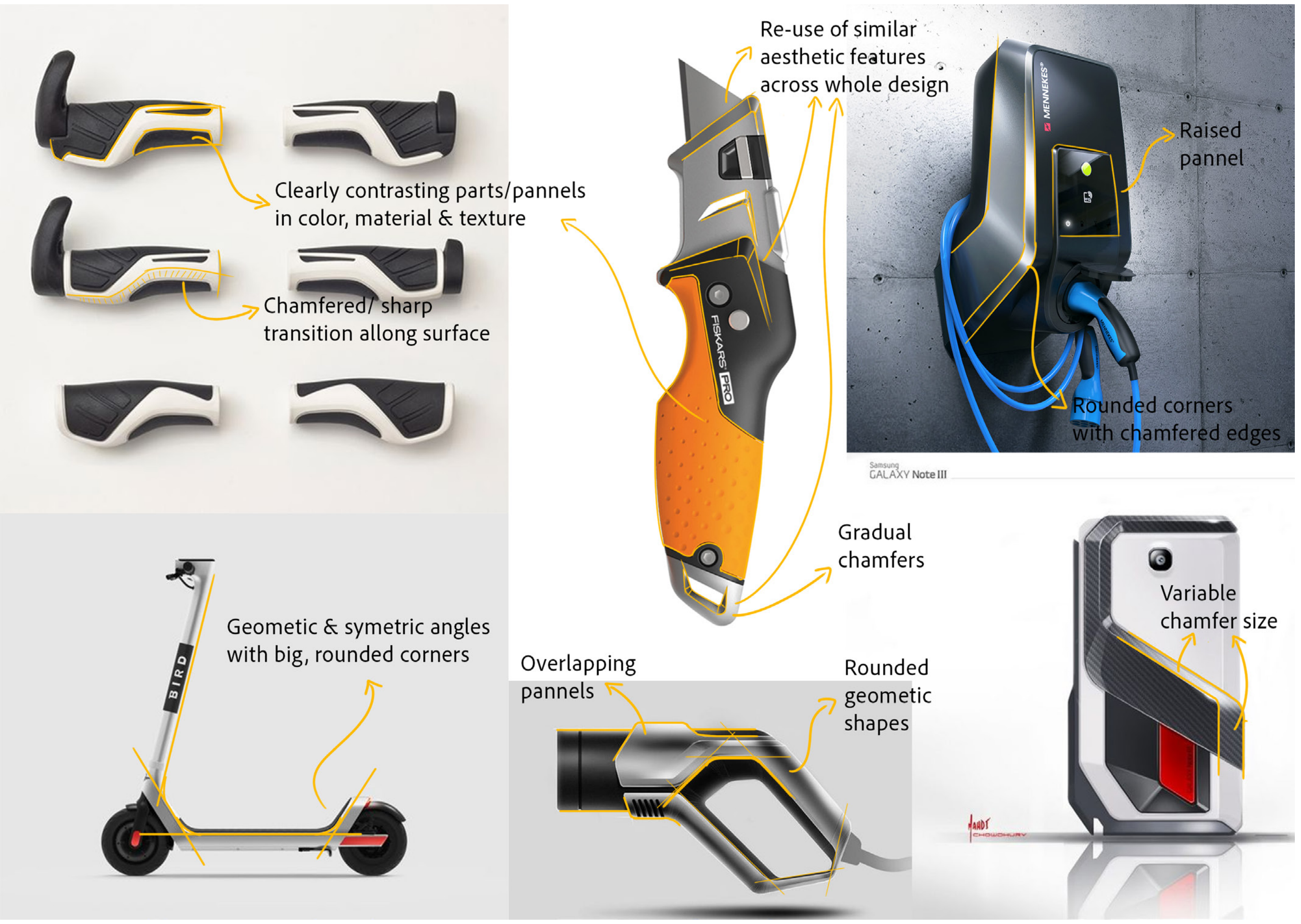

Figure 5.16: Aesthetic analysis of inspiration designs

Additionally design inspiration was taken from the design of the TILER Charging Tile to make the UP-Charge blend in with the TILER ecosystem. Figure 5.17 shows an analysis of its design aesthetic.

5.2.2. UP-Charge Aesthetics

Figure 5.18 highlights the aesthetic design features of the UP-Charge. It can be noted that expecially the usage of chamfers and rounded corners were used to achieve a design that looks rugged and modern. Hints to the Charging Tile are found in the color of the UP-Charge and implementation of TILER branding. Additionally the raised charge zone indicator is reminiscent of the top of the Charging Tile.

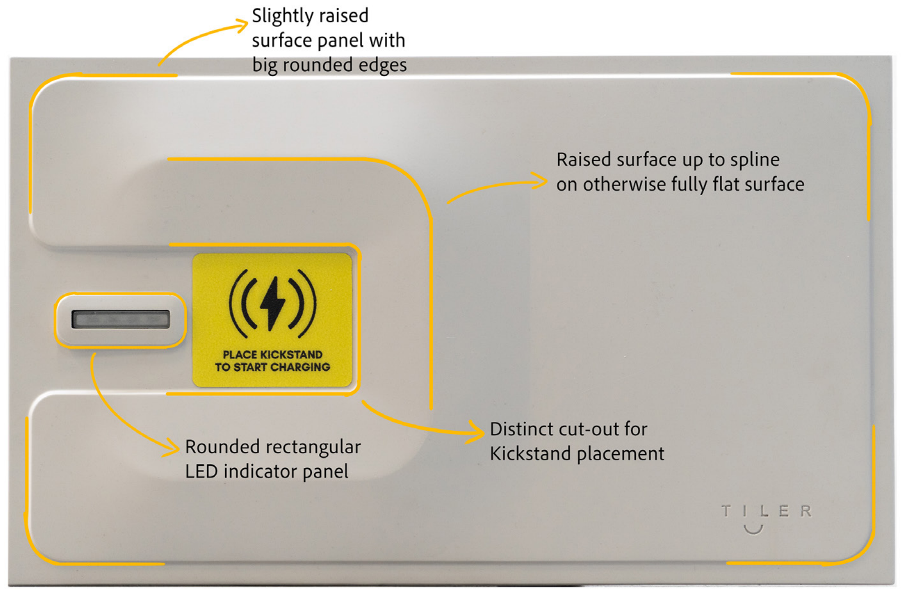

Figure 5.17: TILER Charging Tile aesthetic charasteristics

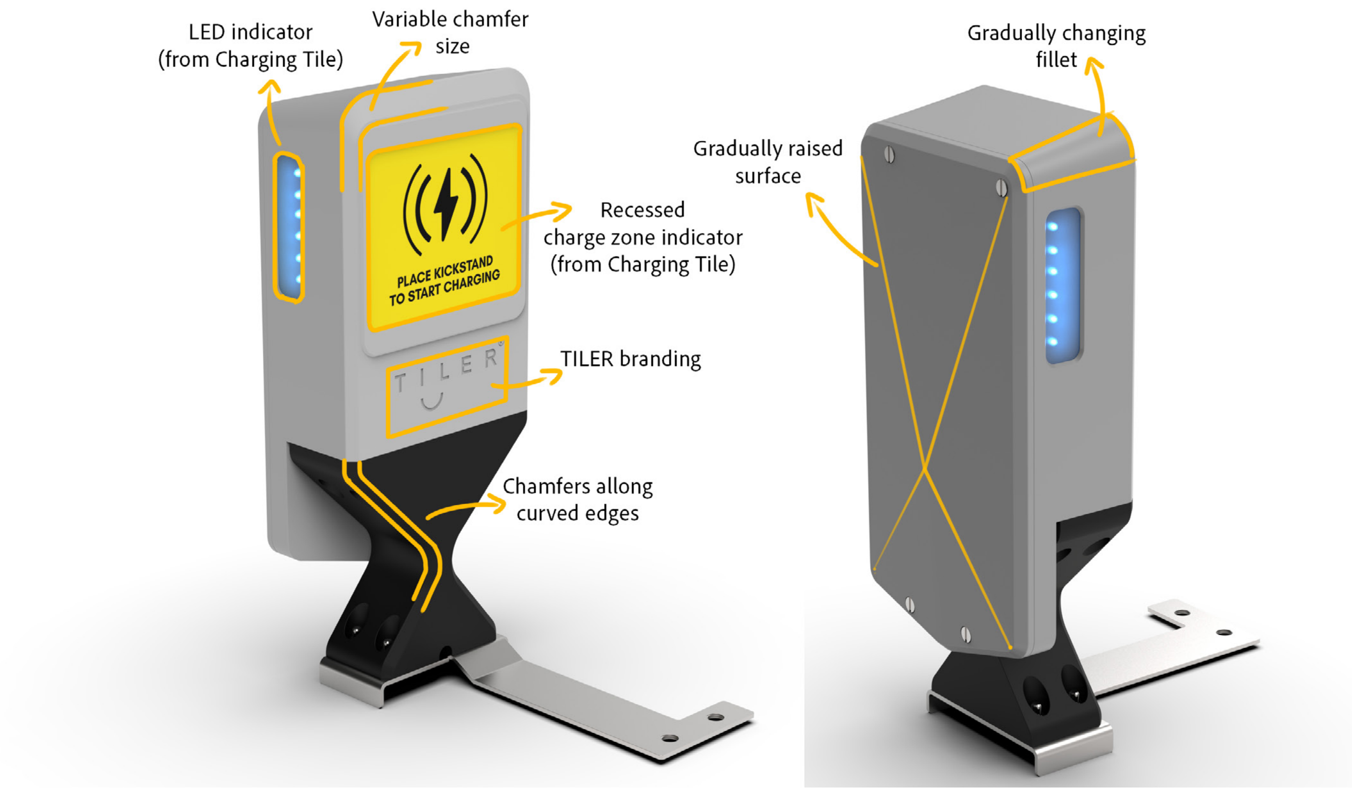

Figure 5.18: UP-Charge Aesthetic design features

5.3 Manufacturing

The current design of the UP-Charge as presented previously in this chapter, was created with the goal of creating a technically feasible product closely related to a potential final production version. This design originated from the possibilities of real large scale manufactureing techniques, as it was required to design for a serial production of ± 1000 units. However, in the current design the possibilities of prototyping were also kept in mind, resulting in some design choices specific to the prototyping process. This chapter will explain the intended manufacturing techniqies and its associated adjustments from the current design for the main components of the UP-Charge: the flexjoint and the PTU case.

5.3.1 PU (polyurethane) molding

The flexjoint is made from polyurethane (PU). PU is a rubber-like material available in either the form of a thermoset or thermoplastic. This material was mainly selected because of its associated Young's modulus and yield strength, allowing the flexjoint to generate a sufficient spring force to move the UP-Charge back up and simultaneously withstand deformation without permanent damage. Polyurethane, however, also has exceptional abrasion and fatigue resistance, preventing the flexjoint from sustaining permanent damage due to repeated impacts from bike pedals in the context of frequently used two-tier bicycle racks (Industrial Quick Search [IQS], n.d.).

Polyurethane parts, with a higher hardness, can be machined from larger blocks; however, for the production of the flexjoint molding, it is much more suitable to achieve the desired shape of the flexjoint in combination with it utilizing a more flexible variant of PU.

Figure 5.19: Example of PU directly cast on metal wheels

PU casting vs. injection molding
Common methods for producing flexible PU parts are PU casting and injection moulding. In PU casting, a PU resin is cast into a flexible mould and then cured. This flexible mould can easily be peeled off to remove the part. (Industrial Quick Search [IQS], n.d.). This method is well suited for prototyping and low to mid-volume productions ranging between 30 and 50 parts per mould (Polyurethane Casting Advantages, and Disadvantages, Design Tips, and Uses, n.d.). This is because the flexible mould becomes damaged from repeated use, and the process of removal is very labour intensive. The initial moulds for this process, however, are quite affordable, making this technique suitable for a first test run of the UP-Charge.

For the higher production volume of 1000 units as set by the requirement for this design, injection moulding PU is more suitable. This method injects a liquid form of PU under high pressure into a metal mould. This method allows for a high-quality finished product. These metal mold can be used repeatitly for high production volumes, however the initial cost of the mold are higher and add up very quickly as the mold gets more complex.

Flexjoint design adjustments
The hourglass shape of the flexjoint forces any injection molding mold to be split along the hourglass shape of the flexjoint, as another division between molding sides would make the removal process impossible. The current design of the flexjoint contains several cavities running through the entire design in a different direction to the mold removal. This would require additional slides to be added to a mold used in injection moulding; however, this makes the mold much more complex and very expensive (How to Estimate Injection Molding Cost?, n.d.).

To reduce the costs of injection molding, instead of running fasteners all the way through the flexjoint, fasteners should be directly included during the molding process. This is possible due to the excellent bonding properties of PU. This technique is similar to the production of PU wheels in which the PU is directly cast to a metal core, as seen in figure XXX. The only slide required in the mold would be for the cable pass-through. In total, this adjustment would reduce the required amount of sliders from 9 to 1.

5.3.2 Compression molding

Unlike the 3D printed final prototype for the UP-Charge, a production version will have a case made out of Sheet Molding Compound (SMC). Product made out of SMC are produced with compression molding. In this production process a sheet of SMC is placed between 2 halves of a mold, wich are then compressed together. Afther the SMC is cured the product can be removed from the mold and will have taken on its shape (HAMC, 2024).

Case design implications
Compression moulding of SMC allows for much more complex geometries to be included in the design of the intended final product due to the fibres are 'loose' in SMC compared to other fibre-reinforced materials, in which they are woven together. This allows the addition of reinforcing ribs and internal embossing for fastener inserts without those being molded in the outside of the part (HAMC, 2024).

However, general compression molding design rules still apply, such as the draft angle for removal from the mold. Due to the nature of compression molding, a part with a negative draft angle would require the addition of slides for removing the part from the mold. This, again, would make the mold very complex and expensive. In the current design, the main body of the PTU case is angled down toward the back of the UP-Charge, as seen in the cross-section in figure 5.20. This feature was included for aesthetic reasons but would make mold removal impossible. For final production, this part of the PTU case should be reconsidered to be angled as illustrated in yellow in figure 5.21.

Figure 5.20: Negative draft angle in current UP-Charge design

Figure 5.21: Draft angle redesign for compression molding

5.4 Prototyping

To test whether the design of the UP-Charge would work as intended, several full-scale prototypes were created. These prototypes were used to test the mechanical principles of the UP-Charge, explore its movement in physical space with a real bicycle, and ultimately create a physical representation of what the final produced UP-Charge could look like in real life. An extensive description of the prototyping process can be found in Appendix M. It must be noted that the design of the UP-Charge has been changed during and as a result of this prototyping process.

5.4.1 Flexjoint prototyping

After the theoretical proof that the flexjoint would work, according to the calculations in Appendix K, this needed to be tested in real life. An accurate prototype of the flexjoint was therefore created, as can be seen in figure 5.22

Prototype process
The prototype for the flex joint, as seen in Figure 5.23, was made by 3d printing a break-away single-use mold. This mold was then filled with a specifically selected two-component Polyurethane called PT-Flex 70. All considerations regarding this prototyping process can be found in Appendix L. After the PU was cured, the mold was broken away and removed, revealing the flex joint prototype in Figure 5.22.

Prototype adjustment
The initial prototype for the flexjoint turned out to be a lot stiffer than expected based on the calculations. As a result, it was almost impossible to bend this version of the flexjoint prototype. However, through empirical testing, a better design for the flexjoint was found. For this prototype, the tapered part of the flexjoint was reduced in width. This new version worked much better as it was possible to bend, but it still showed substantial force for springing back into its original position. The old and new prototypes can be seen relative to each other in figure 5.24, where the reduced width of the flexjoint is clearly visible.

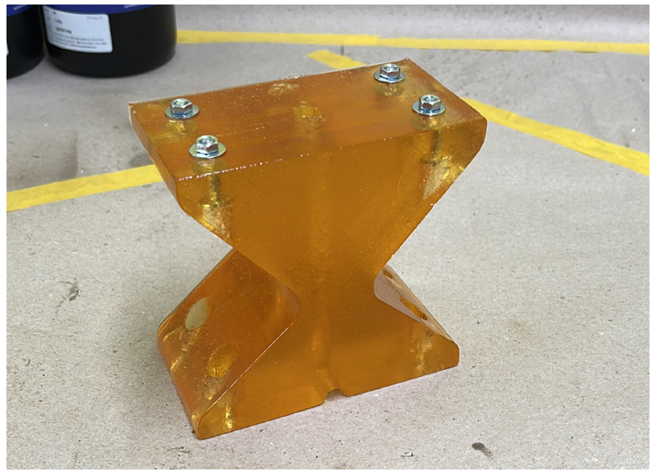

Figure 5.22: PU flexjoint prototype after mold removal

Figure 5.23: Process of casting PU flexjoint

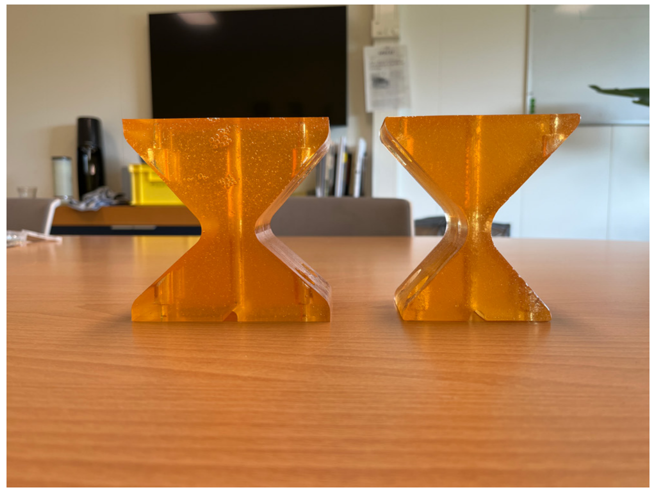

Figure 5.24: Comparision between initial and adjusted flexjoint prototype

5.4.2 Case prototyping

To prototype the PTU case its design was optimized for 3d printing and printed in separate parts. The printed parts, together with the electrical components of the PTU are shown in figure 5.25. Heated treaded insterts were placed in the screw holes of the main housing body. The PTU case was then assembled as shown in figure 5.26, resulting in the PTU case prototype in figure 5.27

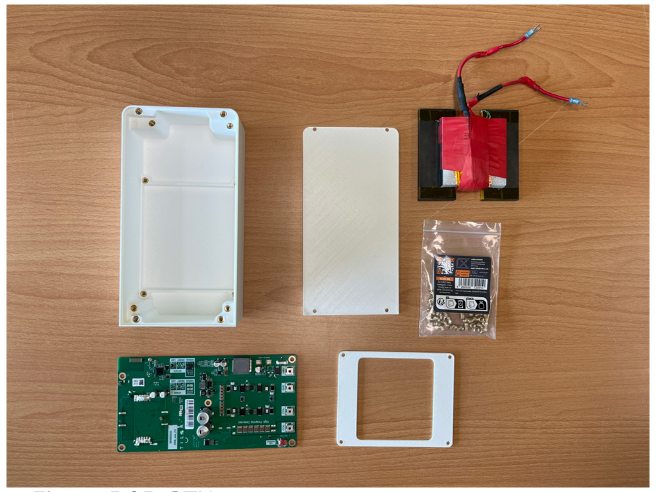

Figure 5.25: PTU prototype components

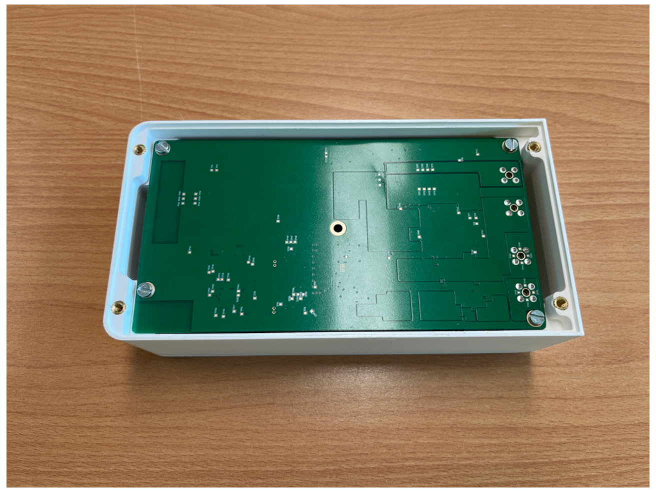

Figure 5.26: PCB mounted in PTU case prototype

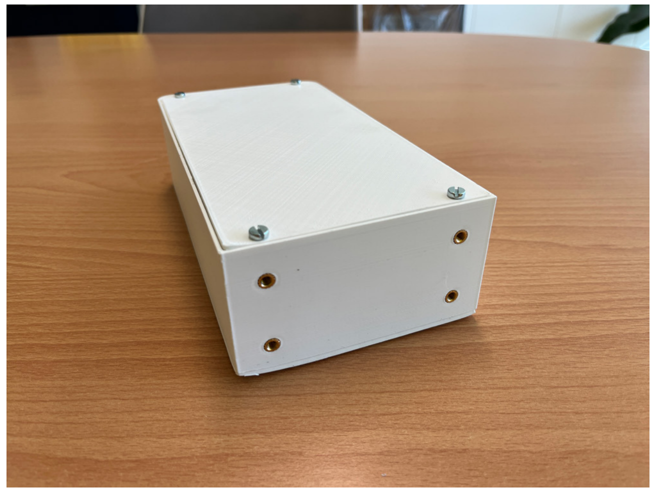

Figure 5.27: Fully assembled PTU prototype

5.4.3 Prototype assembly

The prototyped flexjoint and PTU case were assembled together to form the prototype shown in figure 5.28. M4 bolts and washers were used to connect the two prototypes together, as can be seen in Figure 5.29. To make it more stable, since a proper mounting bracket was yet to be designed, it was bolted on top of an aluminum sheet of metal (figure 5.30).

Figure 5.28: Initial UP-Charge prototype

Figure 5.29: Close-up of flexjoint mounted to PTU

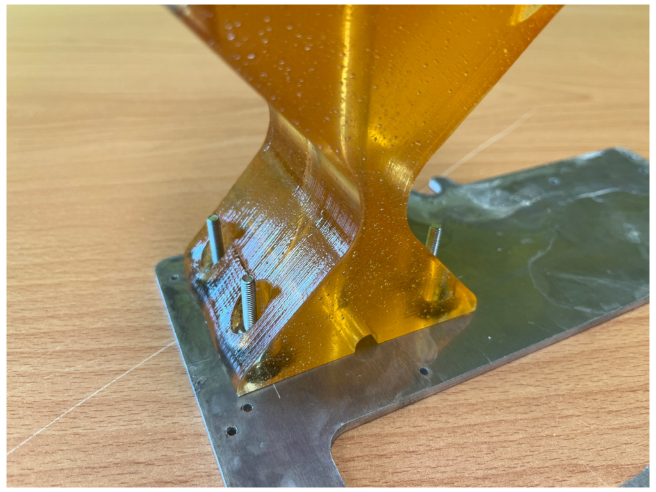

Figure 5.30: Close-up of flexjoint mounted to baseplate

5.4.4 Prototype testing

The initial prototype of the UP-Charge was fully assembled and could be used for testing. The initial impressions were very positive as the whole assembly could stand upright by itself. This meant that the flexjoint was able to support the weight of the PTU on top of it, without it sagging to either side.

When the PTU was pushed all the way into its horizonally flat position, as shown in figure 5.32, the flexjoint did not break or tear, neither were any permanent deformations or damages visible. When it was release, the PTU bounced right back up to its vertical position. This was promising and therefore the prototype was placed onto the Velopa-UP bicycyle rack in the set-up as shown in figure 5.31.

5.4.5 Testing results

Testing the prototype with real E-bikes moving in and out of the bicycle rack proved to be mostly successful. When the UP-Charge was placed in the position for E-bikes with rear-mounted Charging Kickstand, the PTU was pushed out of the way of any pedals and moved right back up to the kickstand. Figure 5.33 shows this alignment between the UP-Charge and the Charging Kickstand. In this figure it can also be seen that the flexjoint allows for some required sideways flexing as the bike leans more to the left.

In contrast to the successful tests with the UP-Charge in the rear kickstand position, problems occurred when it was moved to align with center-mounted kickstands. As the bike was placed into the bicycle rack, in certain pedal position they would not fully pass by the prototype, preventing it from moving back to is original position. Figure 5.34 shows an example of this happening. This would mean that this design of the UP-Charge would not work effectively for E-bikes with center-mounted kickstands.

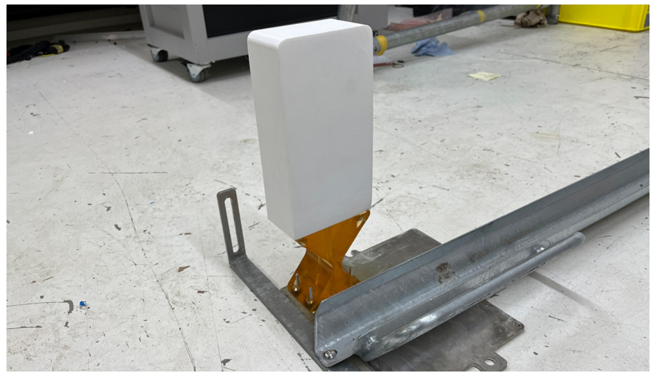

Figure 5.31: Prototype on bicycle rack for testing

Changed topology

It was discovered that this unexpected result of the PTU getting stuck underneath the pedals was a result of a change that was made to the topology of the UP-Charge compared to the original topology of the flexjoint concept:
Because actual dimensions were added to the flexjoint, this resulted in the whole flexjoint being much taller than just slightly above the the point of rotation (as originally intended). As the flexjoint ended up being taller, the PCB was moved upwards in the topology. Therefore, the PTU case is also now much taller than the top of the PTC. This height increase proved to be too much to function as intended for center-mounted kickstands.

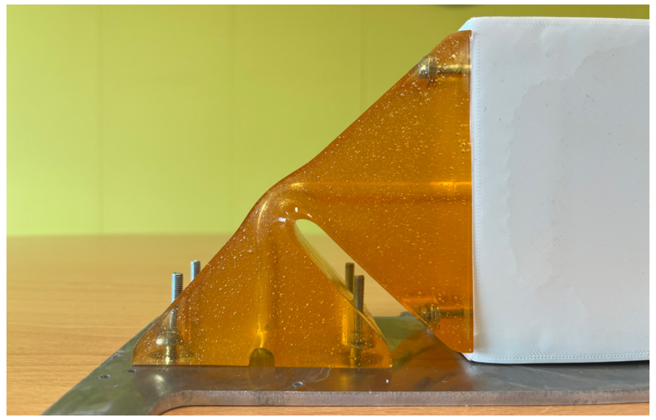

Figure 5.32: Bending test of prototype

Figure 5.33: Prototype kickstand allingment & sideways flexing

Figure 5.34: Failed initial prototype testing for center kickstand position

5.4.6 Design adjustments

Since this design of the UP-Charge could not properly be used for E-bikes with a center-mounted kickstand and one of the main requirements was to design a solution that would charge all E-bikes, including those with center-mounted kickstands, an adjustment of the design was required.

Two different approaches were taken to decrease the height of the design:

1. A lower flexjoint design, with a narrower base, allows the top section to flare out faster, decreasing the overall height.
2. A topology in which the PCB was lowered such that its bottom would end up next to the flexjoint instead of starting above it. This required a redesign of the PTU case to an upside-down L-shape.

As the first option would require only a redesign of the flexjoint, this was initially preferred. The resulting prototype can be seen in figure 5.35. However, despite this approach lowering the design by a total of 32 mm, prototype testing found that this design still did not provide enough clearance between the UP-Charge and the pedals for its center kickstand position. This is demonstrated in figure 5.36.

Lowering the PCB decreased the design's total height by 60 mm which is shown in comparison to the original topology in figure 5.37. This proved to be enough to create sufficient clearance between the UP-Charge and the pedals regardless of any pedal position. This changed topology led to the upside down L shape found in the final design of the UP-Charge.

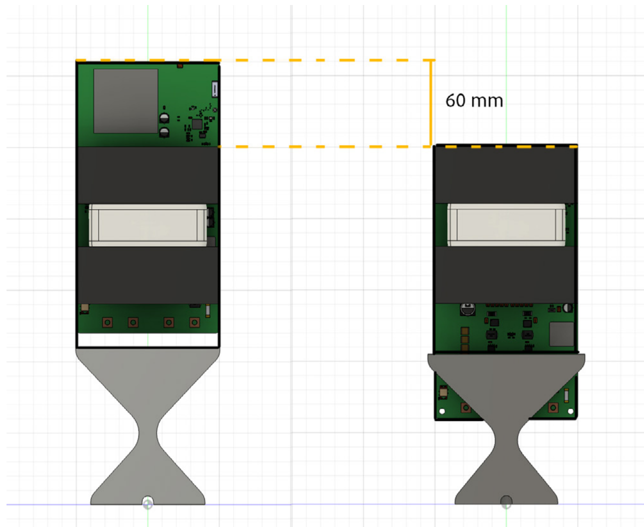

Figure 5.37: Adjusted topology comparisson

Figure 5.35: Initial PTU prototype with lowered flexjoint

Figure 5.36: Lowered flexjoint prototype stuck under pedal during testing

5.4.7 Final showcase prototype

After the redesign of the UP-Charge a final showcase prototype was produced to closely resemble the intended final design of the UP-Charge. This prototype can be seen in figures 5.38 and 5.39. Similar to previous testing prototypes, the PTU case was 3D printed. However, this prototype was extensively sanded and painted to resemble the look of a compression molded part made out of SMC. A demonstration of this final prototype can be seen in the showcase video accompanying this graduation report.

Figure 5.38: Frontside of final showcase prototype


Figure 5.39: Backside of final showcase prototype

5.5. User testing

The final design of the UP-Charge was proven to be functionally successful through prototype testing. This meant that the UP-Charge allows users to place E-bikes in a bicycle rack and align them with the kickstand without any additional steps compared to placing a bike in a regular two-tier bicycle rack, regardless of the pedal position. However, additional user testing was conducted to determine whether users, especially first-time users, would understand how to use the UP-Charge correctly.

For user testing, participants were asked to perform the following tasks: cycle towards a bicycle rack fitted with a prototype of the UP-Charge, place the E-bike in the bicycle rack, walk around the bike, and take it out. Prior to the user test, participants were introduced to the wireless charging capabilities of the TILER Charging Kickstand in combination with the UP-Charge prototype. However, they were specifically not informed about the functionality of the flexjoint to simulate a first-time user experience. Afterward interviews were conducted to gain insight in the user experience and understanding of the UP-Charge. A detailed explanation of the user testing process and setup is provided in Appendix N.

5.5.1User testing results

A total of 5 participants were involved in user testing. This group of participants, consisting solely of males aged between 20 and 24 years, is not very representative of the full expected intended user base of the UP-Charge. However, they provided valuable insights into their interaction with the prototype and subsequently participated in interviews regarding their user experience and general opinions on the design of the prototype itself. Full transcriptions of these interviews are provided in Appendix O.


Figure 5.40: Bike being lifted over the UP-Charge in user testing

As a result of the interviews, it became apparent that first-time users of the UP-Charge do not intuitively understand its intention to be pushed out of the way by the pedals of a bike. All participants indicated that before interacting with the prototype, they did not think that the prototype would move the way it did. Four out of five participants initially still doubted the intention for the prototype's movement even after user testing, as they were afraid that their bike simply would get stuck or that they would damage the prototype. This was confirmed by the observation of the behaviour of participants during user testing, as shown in screenshots from video recordings of the tests in Figures 5.40 and 5.41. In these tests, the participants actively sought ways to prevent the pedals from hitting the prototype, for example, by rotating the pedal or lifting the bike up over the prototype. A more detailed explanation of these interactions can be found in Appendix N.

Conclusion
If the UP-Charge is to be used in a completely public and unsupervised setting, it should not be expected that first-time users will use it correctly as intended. They would ultimately still be able to charge through this design, as it starts charging automatically when aligned with the Charging Kickstand, even if the user takes additional, unnecessary steps to place the bike in the correct position. However, these users would not experience the intended benefits of the UP-Charge of it requiring no additional steps from normally parking their E-bike in a two-tier bicycle rack.

To achieve the full intended benefits of the UP-Charge design explanation in the form of personal instructions when purchasing a Charging Kickstand or as an addition to a bicycle rack, a supplementary explanatory sign or sticker should be added. Another option would be to conduct further research into effective use cues for the UP-Charge and implement those into the design


Figure 5.41: Pedals moved by foot in user testing

6. Recommendations & final conclusion

To conclude this graduation project and thesis, this chapter examines the final design and the design process itself. It explains how the UP-Charge can be improved in further development and evaluates my experience working on this project.

6.1 Recommendations

After completing this graduation project, the final result is the design of the UP-Charge, which could be used to wirelessly charge E-bikes in two-tier bicycle racks. However, certain aspects of the design require further attention and research before the UP-Charge can be considered a production-ready design ready to be sold to bicycle parking facilities. This chapter will review the most important recommendations for the future development of the UP-Charge.

To start off, a redesign of the PCB is highly recommended and could even be considered inevitable for making the UP-Charge design a reality. As the PCB in this project was initially designed for the spacious enclosure of the TILER Charging Tile, it is very large. The size of the PCB in the current design leaves no space for the fasteners required to create a waterproof enclosure. Additionally, the size of the PCB greatly dictates the design of the UP-Charge PTU case. In the current design, many additional features added to the enclosure would either conflict with the PCB or cause the UP-Charge design to exceed the maximum size required for pedal clearance. It is, therefore, desirable for the PCB to be redesigned into a more efficient layout of components to reduce its overall size and to include cutouts that would allow for more fastener locations to be molded into the enclosure to achieve the required waterproofing.

Additionally, after the redesign of the PCB, the design of the PTU case should be reconsidered to further optimize it for compression molding of SMC. The current design of the PTU case has certain features that directly result from the limitations imposed by the current PCB. Some of these features make the existing design unsuitable for compression molding.

Before the UP-Charge enters production, it is crucial to assess the durability of its design with the intended materials. This assessment includes conducting repeated stress tests on the flexjoint. While polyurethane (PU) is known for its durability and resistance to repeated stress and abrasion, the flexjoint must be evaluated for the effects of frequent bending. Given that the UP-Charge is designed for a lifespan of at least five years of daily use, this results in at least roughly 10000 bending cycles (assuming multiple bikes daily impact the UP-Charge's body). Over time, the PU material may degrade, sustain damage, or experience fatigue. Additionally, the durability of the SMC case needs to be examined. Although this material being exceptionally well suited to impacts, facing 10000 strikes could significantly damage the UP-Charge visually. Testing for these effects is essential, and if needed, impact protection or bumpers may need to be incorporated into the design.

Despite the UP-Charge's current design functionally performing as intended, users indicated that they struggled to determine its intended usage during user testing. A more in-depth user experience study could be conducted to identify and add certain use cues to the design that more clearly communicate the design's intentionality of being struck by pedals and ability to move out of the way.

Lastly, the current Charging Kickstand is required. The current design of the Kickstand does not yet include a coil that can be charged from the side. For wireless power transfer to work, the kickstand's housing material must also be changed from aluminium to plastic to allow the electromagnetic field to pass through to the coil. If the kickstand is to be redesigned, it is also desired to design both the UP-Charge and the Charging Kickstand for better connection and coil alignment.

To conclude, the current design of the UP-Charge is a great starting point for expanding TILER's wireless LEV charging ecosystem to include two-tier bicycle racks. However, further development is required to fulfill the UP-Charge's promises of being a totally hassle-free charging solution for E-bikes in two-tier bicycle racks.

6.2 Final conclusion

Now that this graduation project has come to an end after a period of 6 months, the final result is the design of the TILER UP-Charge: a wireless charging solution that allows E-bikes to be automatically charged when they are parked in two-tier bicycle racks.

I can proudly say that I have succeeded in translating the effortlessness of the TILER Charging Kickstand and Tile system into the context of crammed two-tier bicycle racks. Where one could previously simply park their E-bike on top of the Charging Tile, lock their bike, and walk away while their E-bike gets automatically wirelessly charged, they would now be able to take that same E-bike again, drive to work or a train station, and park their bike in one of the many available bicycle racks, along with hundreds of other bikes all neatly organized, only to come back later to a fully charged E-bike ready to take them wherever they need.

The process of this graduation project, leading up to the final design, has involved many challenges. Designing anything in the context of two-tier bicycle racks proved to be very difficult as there is only so little space available within these high-density bicycle parking solution. The process often was more a process of elimination and trying a new approach rather than a constant improvement of a single concept. I think it is very interesting to see how a seemingly simple objective of getting two charging coils to align eventually leads to a whole graduation project based on not getting a bike stuck in a bicycle rack. New perspectives on this problem were acquired, as the initial approach was to totally prevent a collision between the pedals and the charger, but eventually was changed into the inevitability of this collision and fully embracing that interaction as a way to move the UP-Charge out of the way.

In this process, it became very clear how vital prototyping and testing is in developing such a product. Many pivotal moments in this graduation project resulted from interacting with prototypes instead of theoretically coming up with a solution.

However, user testing at the end of the project also indicated the importance of an outside perspective, as it was concluded that users might not understand the capabilities of a design if they do not know the intention behind it. A good product can only be successful if people understand how to use it.

In the end I am very happy with the result of this graduation project, the design and the final prototype of the TILER UP-Charge. And I am very much looking forward to how this might one day make the use of E-bikes just as effortless as any other of the 23,5 million bikes in the Netherlands.

There is no more hassle with hauling cables, crawling and maneuvering inside bike racks to plug in, or even carrying a heavy battery. Just park the bike. That's it. I truly think this design contributes to the 'set it and forget it' ideology of the TILER charging ecosystem. I hope this will result in the wide adoption of high-density bicycle charging facilities as we move toward more sustainable modes of transport.

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Appendices

Initial Graduation Project Brief

A. TILER future technological developments
B. Two-tier bicycle rack models
C. Differences between E-bikes
D. Competitive E-bike charging solutions
E. PRC height calculation
F. List of Requirements and Wishes
G. Rotation Mechanism Exploration
H. Power supply selection
I. Component topology exploration
J. Datum method concept comparison
K. Flexjoint calculations
L. Aesthetic Exploration
M. Final prototyping process
N. User testing
O. User testing interview transcriptions

Personal Project Brief – IDE Master Graduation Project

Name student Daan Vooijs **Student number** 4,840,992

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Implementation of inductive charging for E-bikes in 2-leveled bycicle storage racks

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

TILER, the startup based in Delft, has pioneered a wireless charging solution for Light Electric Vehicles (LEVs). Developed in collaboration with Delft University of Technology in 2019, this patented technology has led to a product in the market—consisting of a 'Charging Kickstand' on the E-bikee and a 'Charging Tile' in the ground, inductively transfering power to the battery when in close proximity. This project extends the existing wireless charging technology from TILER into a new context: charging E-bikes in two-tier bicycle racks commonly found in large bicycle parking facilities.

The project operates at the intersection of two domains: the shared, semi-public space of bicycle racks and the private realm of individually owned electric bicycles. Stakeholders include TILER, aiming to create a marketable and profitable product; bicycle rack companies (e.g., VelopA), seeking compatibility with their racks without compromising original functionality; E-bike owners, desiring a reliable and convenient charging experience; and bike parking facilities, prioritizing reliability, durability, and safety.

Opportunities in this domain arise from the scale of bicycle parking facilities, potentially expanding TILER's reach. The goal is to create an ecosystem where any E-bike can charge seamlessly, aligning with TILER's vision. However, the diversity of bikes and the shared nature of the racks introduce challenges, necessitating universal compatibility and an instruction-free user experience. Additionally, the shared environment poses the challenges of potential misuse, emphasizing the need for robust and foolproof electronic components.

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image / figure 1 The TILER Charging Kickstand mounted on an E-bike, placed on the Charging Tile

image / figure 2 Example of two tier bicycle racks

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The problem I want to solve in this graduation project is the current inability to utilize the TILER system when it is not parked on the TILER Charging Tile but instead stored in a bicycle rack. I see a need for such a solution since bicycle racks allow for very efficient storing of bicycles at large scale in an organized manner.

While I mainly want to focus on bicycle rack part of this design, I will also explore whether is it preferable to reuse the current TILER Kickstand or whether another connection point on the E-bike is required. When reusing the Kickstand I want to find a solution to the different mounting points of kickstands on E-bikes. Since the required charging technology already exists, I mainly want to focus on the interaction the E-bike user has with their bike and the racks. I want that interaction to require minimal additional manual actions from the user, compared to storing a regular bike in these racks. Alongside I want to prove that the E-bike can in fact be charged with the Kickstand, or any other design resulting from this graduation project, through prototype testing.

I think that great additional value is to be gained from the actual interaction: To be widely adopted, this addition to the current bike racks should not add additional hassle to using the rack and charging the bike. This is important to TILER, to sell a desirable product, and for the E-bike owner since they will experience it on a daily basis.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Create a design and prototype that allows for the wireless charging of E-bikes parked in two-tier bicycle racks through the means of the TILER Charging Kickstand.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

For this project I will (in broad lines) have to go throuh at least the following steps:
- Understand the charging technology and it's required components
- Understand the functioning and design of two tier bicycle racks
- Identify differences, and commonalities, between E-bikes
- Explore possible ways of transfering power to the E-bike --> whether to use the Kickstand or another solution
- Find desired charging interactions
- Create prototypes
- Test prototypes
- Adjust the design based on tests
- Finalize the design
- Create a final prototype

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	23 apr 2024
Mid-term evaluation	21 juni 2024
Green light meeting	23 aug 2024
Graduation ceremony	20 sept 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

This graduation project really sparks my interest and enthousiasm because I think the development of sustainable 'micromobility' with LEV will be very present in the future. With this project I can contribute to that mobility transition. The fact that TILER is a startup allows me to have quite short connections within their company and really make an impact.

This project combines the more technical side and detailed side of my IPD master and my additional interest in user-product interactions and the resulting user experience. I have a natural prefferefence and tendency to a hollistic design approach, wanting to think about the 'bigger picture' of a design project. I feel like this project is really suitable for and might benefit from such a approach.

With regards to my personal learning ambitions, in addition to getting a better understanding of world of LEVs, I want to way I execute design projects:
- Long term project planning: Project planning has always been a challenge for me, mainly in indicating the time certain processes might take. In this graduation project I want to really get better at planning ahead and sticking (of adjusting when necesarry) the planning.
- I have a big interest in the development of AI and its influence on the design process and productivity. For this graduation project I want to experiment with implementing AI in my design process to enhance or optimise the process itself.

Appendix B: Two-tier bicycle rack models

This appendix is a collection of different two-tier bicycle rack designs used to explore the differences between bicycle parking solutions.

https://vconsyst.com/nl-NL/dubbellaags-fietsparkeersysteem/optima-v10

https://vconsyst.com/nl-NL/dubbellaags-fietsparkeersysteem/optima-ventura

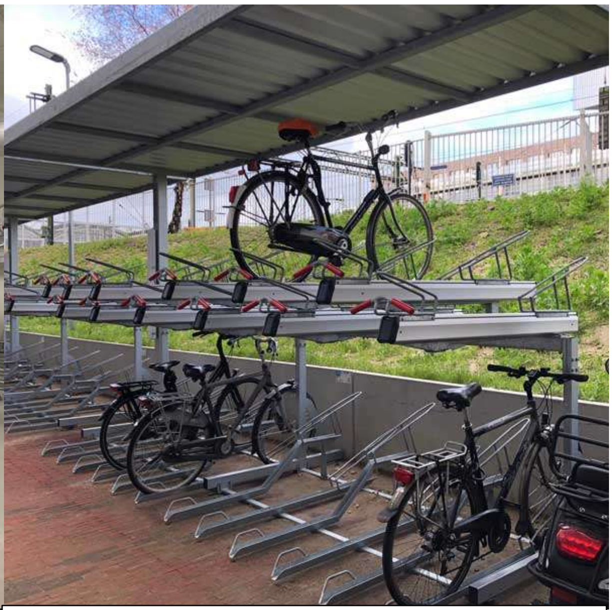
https://www.velopa.nl/assortiment/fietsparkeren/dubbellaags-fietsparkeren-etagerekken/velopa-up-etagerek/

https://www.velopa.nl/assortiment/fietsparkeren/dubbellaags-fietsparkeren-etagerekken/capacity-etagerek/

https://www.klaverfietsparkeren.nl/producten/dubbellaags-fietsenrekken/2parkup-etagesysteem-

https://www.klaverfietsparkeren.nl/producten/dubbellaags-fietsenrekken/2parkup-met-

https://www.falco.nl/producten/fietsparkeren/compact-fietsparkeren/etage-fietsenrek-falcolevel-eco.html



https://www.falco.nl/producten/fietsparkeren/compact-fietsparkeren/etage-fietsenrek-falcolevel-premium.html

Appendix C: Differences between E-bikes

There are many differences in the actual design of E-bikes. This appendix compiles the most important and common differences. It also elaborates on what effects these differences have on the E-bike itself.

- **Motor location:** The electrically powered drive system in an E-bike can be either of 3 different types: front, middle or rear mounted. With front-mounted motors, the motor is integrated into the hub of the front wheel of the bike. This is the cheapest option. However, it adds extra weight to the front fork of the bike, requiring more force to steer the bike. In rear motor E-bikes, the motor is integrated into the hub of the back wheel and, therefore, directly driving the same wheel that would be powered by the pedalling of a human. These are becoming less common because they quickly overheat when putting out a lot of power. However, it is still present in Speedbikes or modern-looking integrated city bikes because it allows for a more sleek and minimalistic design of the frame itself. The third option is the middle motor, which adds extra power to the front chainring and therefore makes the rider's own pedalstroke 'more powerful'. This is currently the most common system in new E-bikes since it feels the most natural when pedalling and doesn't have the overheating issues of a back-mounted motor. (https://www.fietsersbond.nl/de-fiets/fietssoorten/elektrische-fietsen/wat-voor-motor-moet-ik-hebben/)
- **Battery location:** E-bikes inherrenly add some extra required component compared to a normal non-electric bike. An obvious one is the battery, since it often quite big and heavy. This battery needs to be mounted somewhere on the bicycle. One option is for the battery to be placed underneath the luggage carrier on the back of the bicycle. This means it is easily accessible when taking it out of the bike to charge it separately. As a result of this there is more weight on the back of the bike, making it harder to lift up the back wheel. The other option is to have it be inside or as a part of the frame. These are either placed in the (diagonal) downtube or the seattube of the bike. Both result in the weight being more distributed over the middle of the bike. (https://www.fietsersbond.nl/de-fiets/fietssoorten/elektrische-fietsen/de-plek-van-de-accu-maakt-het-wat-uit/?psafe_param=1&gclid=CjwKCAjw4f6zBhBVEiwATEHFVo28Xp4AB0f1jdbacuiymeCgW5QksR-Ycq8a6KvzkuR-ZNrpqY6iyBoCwCIQAvD_BwE)
- **Swapabillity of the battery:** Apart from the location of the battery on the bike, the batteries themselves can be either 'swappable', meaning that they are not permanently fixed on the bike and can be taken out to for example charge them inside or any location independent of where the bike parked, or they can be permanently fixed (and often integrated with) the bike frame. The latter results in a lighter battery that is better protected from the elements or being bumped and hit. This however required the battery to be charged in the same place the bike is parked. (https://www.fietsersbond.nl/de-fiets/fietssoorten/elektrische-fietsen/de-plek-van-de-accu-maakt-het-wat-uit/?psafe_param=1&gclid=CjwKCAjw4f6zBhBVEiwATEHFVo28Xp4AB0f1jdbacuiymeCgW5QksR-Ycq8a6KvzkuR-ZNrpqY6iyBoCwCIQAvD_BwE)

- **Location of the kickstand:** Probably the most relevant variation between different E-bikes for this project is the location of the kickstand as it determines where in relation to the bike and the bicycle rack the charging point of the TILER Charging Kickstand will end up. Kickstands on E-bikes can be mounted in the center of the bike or on back of the bike frame, close to the hub of the backwheel (commonly on the left side of the bike). Center mounted kickstands generally are more stable as they are in the middle of the weight distribution of the bike, but as E-bikes can also have a lot more weight toward the rear of the bike, rear mounted kickstands could also be preferred. So in conclusion both option are prevalent among many different models of E-bikes.

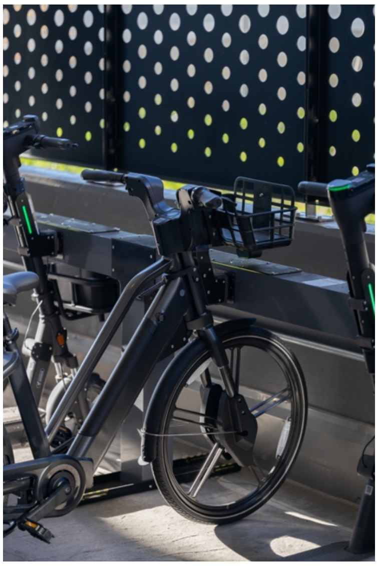
Appendix D: Competitive E-bike charging solutions

This appendix gives an overview of several potentially competitive charging solutions to TILERs charging solution and this graduation project. They are put together in several categories with overlapping charasteristics and detailed descriptions for all individual products.

Fully Integrated parking and automatic charging
Within this category, products are placed that provide both the parking (and/or locking) and charging of E-bikes in the same system, without the user required to go through additional steps to achieve either one of these. By parking the bike, you automatically charge the E-bike. Product that fall into this category are:

- Pedal.Clip Wireless charging by Bike.Box (figure XXX). This system parks any bike by clamping one of the pedal to keep it upright. Wireless charging is provided by lining up a wirless charger mounted on the rack with the side of the E-bike where their own wireless receiver is mounted. https://www.bike-box.nl/products/pedal-clip-wireless-charging-system

- Kuhmute (figure XXX). An universal park and charge solution that works by driving the front on a LEV against a rack/bar. Their special adapter simoultainiously locks and charges the LEV when it makes contact with a docking point and clicks into place. It works with several types of LEVs, including E-bikes, however is limited to specific models. https://www.kuhmute.com/



- Port E-hub (figure XXX and XXX). These parking and charging stations lock and charge LEVs through a special adapter mounted on bottom of the front fork. These docking stations currently work with their own selection of LEVs including E-bikes. https://port.app/

- Swiftmile micromobility charging station (figure XXX). E-bikes fitted with a special adapter mounted on the front of the bike lock and charge when plugged into an empty slot on the charging station. Compatable with any E-bike, however must all share the same mounting heigt for the adapter. https://swiftmile.com/

Integrated bike locking and cable charging
This category consists of products that require the user to park the bike in a certain location but perform additional steps to lock and/or charge be bike. While chargers have to manually be connected to the bike, they are provided as an integrated part of the system. This category includes:

- ChargeLock™ by Metromobility (figure XXX). E-bike charging hubs that lock and charge the bikes through the same cable. The bikes still need to be parked on their own kickstand. Only compatible with special ChargeLock™ editions of specific E-bike models. https://www.metromobility.io/stations

- Q-Rack E-bike Charging Station (figure XXX). A 'lean-on' bike stand that comes with integrated charging cables with several different adaptors to fit common E-bike battery charging ports. https://attiadesign.com/produkt/qrack-en/

Integraded parking & locking – 'BYOC' (Bring Your Own Charger)
The competitive products in this category integrate the process of locking E-bikes within the parking itself, but do require user to bring their own charger. While steps are saved by automatically locking the bike, additional steps are required by plugging in their own charger into the provided powersocket and the E-bike. The following product fall into this category:

- Basecamp bike capsule by Alpen Storage (figure XXX and XXX). A fully sealed off bike storage locker that has internal power outlets for users to plug in their own E-bike charging cable. Charging cable is locked inside the capsule with the E-bike. https://alpen-storage.myshopify.com/products/basecamp-bike-capsule

- Bikeep Parking and Charging Station (figure XXX and XXX). Public bike locking system that can lock the frame of any personal E-bike. A power outlet is available in a separate compartment that also locks in the personal charger when the bike itself is locked. https://bikeep.com/smart-bike-parking-station/

- Parkent Secure Charging Station (figure XXX). Public bicycle locking system for personal E-bikes that framelocks any closed frame bike when driven inside its arms. Power outlets are available in the center console, however, chargers can only stowed, not locked, away in a separate compartment. https://www.parkentcycles.com/

Traditional bike rack with additional power outlets
For this catorogy the products are don't integrate any of the charging, locking or parking features but do offer the possibility of doing them all manually. This ultimately results in traditional one or two-tier bicycle racks with the added benefit of being offered an power outlet in a somewhat accessible location. The following product are examples of this category:

- Velopa-UP two-tier bicycle rack with charging points (figure XXX). A two-tier bicycle rack with the addition of power outlets on long arms to make them more easily accessible. Only available on the bottom level of the rack with no integrated way to lock the chargers. https://www.velopa.nl/assortiment/fietsparkeren/oplaadpunten-en-parkeervoorzieningen/velopa-up-etagerek-met-oplaadpunten/

- Velopa Variant 3 with charging points (figure XXX). A high/low model one tier bicycle rack with the addition of a bicycle billard that integrates power outlets to be used with personal E-bike chargers. Can easily lock bicycle, but not the chargers themselves.
  https://www.velopa.nl/assortiment/fietsparkeren/oplaadpunten-en-parkeervoorzieningen/variant-3-fietsenrek-met-oplaadpunten/
-

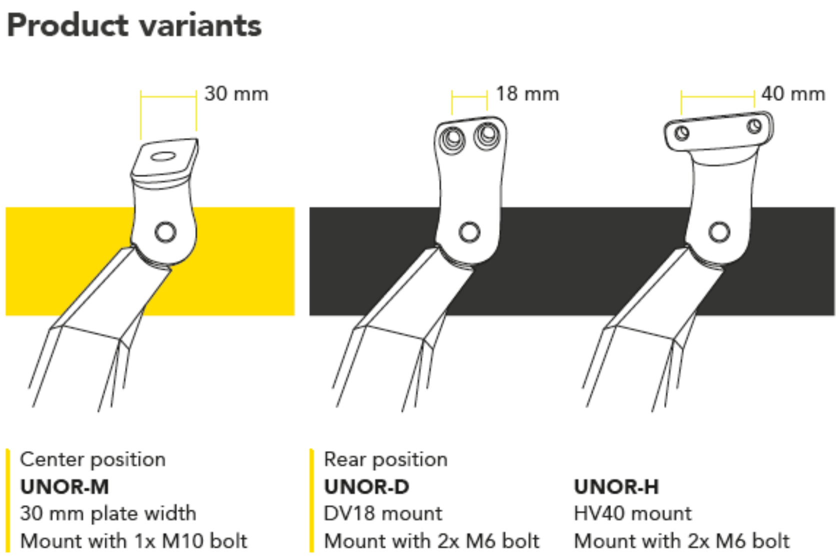
- Velopa Fourchet+ with lockable charging points (figure XXX). High/low model bicycle rack with added charging points in the form of power outlets and a compartment for the charger that can be locked with a bike's own cable lock.

https://www.velopa.com/products/bicycle-parking/bicycle-racks-and-stands/fourchetplus-bicycle-rack-with-charging-points/

Appendix E: PRC height calculation

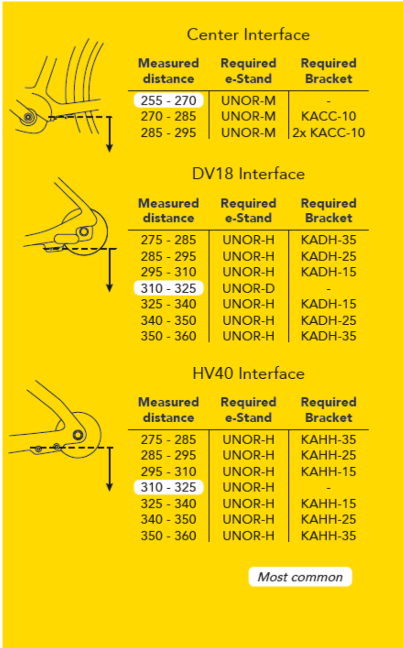
This appendix explains the theoretical analysis of the height of the PRC in the TILER Charging Kickstand when they are mounted on different E-bikes. This height was essential to know, since it would give insight in the location of the PTC.

Kickstand adapter brackets
Within the variation of E-bike models there is not only a variation in mounting location, center- or rear-mounted, but also variation in mount type itself. In figure XXX and overview can be seen of the different mount types TILER offers for their kickstands.



TILER Charging Kickstands, unlike normal kickstands have a fixed length. Therefore TILER uses adaptor brackets for different types of E-bikes to ensure a similar distance to the ground.
For proper kickstand mounting height, TILER provides brackets for each mounting type and location that cover a specific range of original kickstand mounting points on E-bikes. Their brackets allow for a 10 or 20 mm lowering of the mounting point for center-mounted kickstands and a 15, 25, or 35 mm decrease in height, or an increase when the bracket is flipped upside down, for rear-mounted kickstands. Figure XXX provides an overview of the recommended bracket for each original kickstand mounting height. The most common occurring mounting heights for E-bikes are highlighted in white.

A comprehensive list of all possible PRC heights has been compiled based on the heights of the mounting points and their respective bracket dimensions. This information can be found in tables 1 and 2, which display the minimum and maximum PRC-to-ground height ranges for various bracket options.



For the central interface, the distance between the final mounting point and the center of the PRC in its flipped up position is 102 mm. In the case of rear-mounted interfaces (DV 18 or HV 40), this distance is 122 mm due to slight angle differences in the kickstand between the central and rear-mounted variants. PRC heights commonly found on E-bikes, according to TILER, are highlighted in yellow.

Center Interface					
Mount height		Adjusted mount height		PRC center height	
Min	Max	Min	Max	Min	Max
255	**270**	**255**	**270**	**153**	**168**
270	285	260	275	158	173
285	295	265	275	163	173

DV 18/ HV 40 interface					
Mount height		adjusted mount heigth		PRC center height	
min	max	min	max	min	max
275	285	310	320	188	198
285	295	310	320	188	198
295	310	310	325	188	203
310	**325**	**310**	**325**	**188**	**203**
325	340	310	325	188	203
340	350	315	325	193	203
350	360	315	325	193	203

Conclusion

If the average resulting PRC center height for the most common mounting heights is chosen as the height to align the center of the PTC with, the current design of the PTC and PRC allows for all possible kickstand mounting heights to be within the coverage range of the PTC. This is possible because the largest potential vertical variation of the PRC for center-mounted kickstands is 20 mm, and for rear-mounted kickstands, it's 15 mm. The PTC and PRC allow for a variation of 30 mm (15 mm up and 15 mm down from the midpoint).

Appendix F: List of Requirements and Wishes

This appendix lists all requirements and wished identified during the design process of the UP-Charge for this graduation project. The Product Life Cycle method has been utilized to organize and group all requirement.

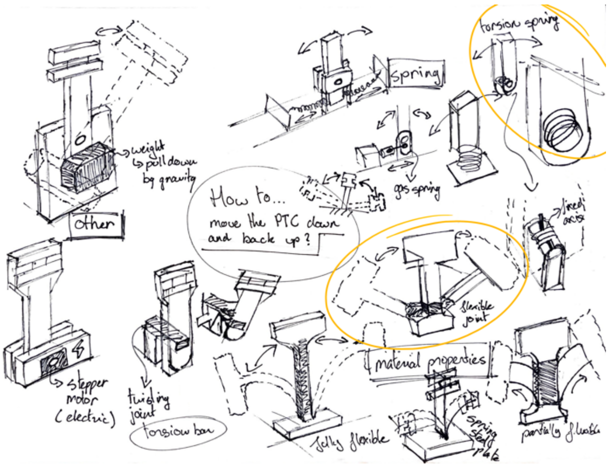
Nr.		Description	Life cycle
R	1.1	The design must not prevent normal access for the bike into the bicycle rack	Originate
R	1.2	The design must not hinder normal operation of a two-tier bicycle rack	Originate
R	2.1	The design must comply to all relevant FietsparKEUR norms	Originate
R	2.2	The design must not cause the two-tier bicycle rack to conflict with any of the relevant FietsparKEUR norms	Originate
R	3.1	The design must charge E-bikes* fitted with both rear- and center mounted TILER Charging Kickstands	Originate
R	3.2	The design must be compatable with the current design of the TILER Charging Kickstand	Originate
R	3.3	The design must only charge E-bikes with TILER Charging Kickstands or TILER licenced products	Originate
R	4.1	The design must use the PTC design for the TILER Charging Tile in the PTU	Originate
R	4.2	The design must bring the PTC within effective range of the PRC	Originate
R	4.3	The design must position the ferrite plates in the PTC parallel to the ferrite plates of the PRC	Originate
R	5.1	The design must be weatherproof	Originate
R	5.2	The design must withstand outside temperatures between -20˚C and 40˚C	Originate
R	5.3	The design must have and IP66 rating	Originate
R	6.1	The design must not generate such heat that it permanently damages parts/components	Originate
R	6.2	The design must stop charging in case of overheating	Originate
R	7.1	The design must be feasable for a series of 1000 units	Originate
R	7.2	The design must be produced with production methods suitable for a series of 1000 units	Originate
W	1	The design should charge all E-bikes* fitted with both rear- and center mounted TILER Charging Kickstands	Originate
W	2	The design should minimise the amount of custom parts/components	Originate
W	3	The design should reuse components from TILERs current product line-up where possible	Originate
R	8	The design must have a total costprice less than €450 for a series of 1000 units	Distribute
R	9	The design must contain TILER branding	Distribute

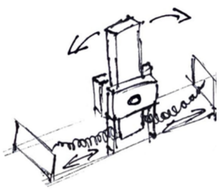
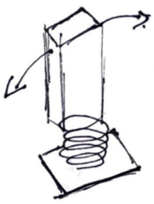
W	4	The design should fit the TILER product ecosystem aesthetic	Distribute
W	5	The design should fit the context of (semi-) public infrastructure/ bicycle racks	Distribute
R	10	The design must fit on the VelopaUP Two-Tier Bicycle Rack	Installation
R	11	The design must allow installation on existing and assebled two-tier bicycle racks	Installation
R	12	The design must be able to install without disassebly of the product	Installation
R	13.1	The design must prevent disassebly with standard tools after being installed	Installation
R	13.2	The design must prevent direct unwanted access to any high-voltage part/component	Installation
R	13.3	The design must be able to be disconnected from its powersource	Installation
W	6	The design should fit multiple two-tier bicycle racks	Installation
R	14.1	The design must not require the user to interact with any part of the bike other than when being parked in a regular two-tier bicycle rack	Use
R	14.2	The design must not require additional steps from the user other than placing their E-bike in the bicycle rack to start charging	Use
R	14.3	The design must allow the user to keep standing behind their bike when parking it in the two-tier bicycle rack	Use
R	15.1	The design must allow the E-bike to continue its trajectory in case of a collision with the bike's pedals	Use
R	15.2	The design must allow any bicycle to be parked in the bicycle rack regardless of its pedal position	Use
R	15.3	The design must allow any bicycle to be taken out of the bicycle rack regardless of its pedal position	Use
R	16.1	The design must move the PTU out of the way in case of a collision with the pedals	Use
R	16.2	The design must automatically move the PTU into a charging position after being moved	Use
R	17.1	The design must not interact with any neighbouring bikes parked in the two-tier bicycle rack	Use
R	17.2	The design must fully be located within the footprint of the two-tier bicycle rack in its resting position	Use
R	18	The design must protect the internal electronics from a pedal collsion	Use
R	19	The design must allow the pedals to slide over the outside of the product when moving allongside it	Use
R	20.1	The design must allow the user to normally lock their bike to the bicycle rack	Use
R	20.2	The design must allow neighborings bike to be normally locked to the bicycle rack	Use

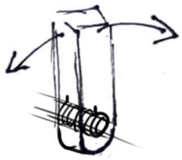
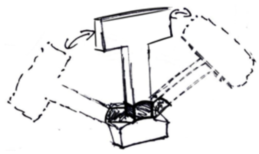
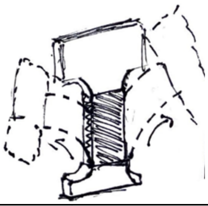
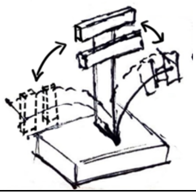
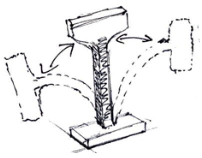
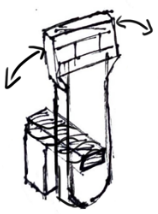
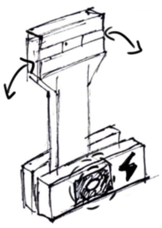
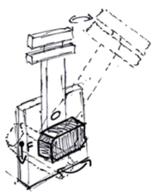
R	21	The design must automatically start charging the E-bike after being correctly parked in the bicycle rack	Use
R	22.1	Intended usage of the design must not cause permanent damage to any E-bike	Use
R	22.2	Intended usage of the design must not cause permanent damage to any part of the design	Use
R	22.3	Intended usage of the design must not cause permanent damage to any part of the bike rack	Use
R	23	The design must withstand an unintentional hit with the front wheel of a bicycle	Use
R	24	The design must allow software to be updated	Use
R	25.1	The design must allow for it to be dissasebled without permanent damage to any of its parts	Use
R	25.2	The design must allow all electronic parts to be replaced	Use
W	7	The design should automatically stop charging the E-bike when it's battery if fully charged	Use
W	8	The design should allow software to be updated without disassebly of the product	Use
W	9	The design should convey the intentionality of being hit by the bike/ pedals	Use

Appendix G: Rotation Mechanism Exploration

This appendix elaborates on the How To… method used to explore different possible mechanisms that would allow the PTU to move down so that pedals could pass over it and back up automatically after the pedals have cleared. It first describes the different ‘solutions’ that came from the How To… method and then elaborates on the choice for the torsion spring and flexible hinge solutions. The overview of the How To method result can be seen in figure XXX.



Sketch	Description	Small	Affordable	Controlled movement/ rotation
	Horizontal spring balance. Two springs are put under tension on the bottom of a swinging arm, keeping it upright. If rotated, the opposite spring will pull it back up.	-	+	+
	Horizontal gas spring. Mounted to the bottom of a swinging arm, gas inside a cylinder either compresses or expands if the arm is rotated. By going back to its original state the arm is pulled back up	-	-	+
	Rocking spring similar to playground equipment. A strong spring keeps up the arm and bounces back when moved.	+	+	-

	Torsion spring. The arm rotates around a fixed axis with a torsion spring around it. When rotated the spring is tensioned and will move the arm back to its neutral position	+	+	+
	Flexible hinge. A small connection part between a base and the arm is flexible and will move back elastically after being bent	+	+	+
	Partially flexible arm. A substantial part of the arm is made out of a flexible material allowing it to bend to the side and move back.	+	-	-
	Springsteel arm. The arm itself is made out of thin spring steel that would want to move back to its normal position after being bend.	+	+	-
	Fully flexible arm. The whole arm is made out a flexible material allowing it to bend along the full length of the arm.	-	-	-
	Torsion bar. Fuctions similar to a torsion spring but relies on a solid rod of flexible material being twisted to generate the rotating force to move the arm back up	+	+	-
	Electric motor. A motor attached to the arm would detect the arm moving down after pedal collision and start turning it back up	-	-	+
	Gravity swing. A heavy counterweigh attached to the bottom of a swinging arm will be pulled toward the ground by gravity, simultaneously rotating the swinging arm back.	-	+	-

How to… selection criteria

In order to select which solutions that came from the How To method would be suitable for working out into different concepts, all solutions were compared on a number of different criteria. The results from that can be seen in Table XXX, and the criteria itself will be further explained below.

1. **Size**
   Based on previous analysis, ideation, and prototype testing, it became apparent that there is very limited space in the two-tier bicycle racks. Therefore, it was crucial for me to ensure that the mechanism responsible for allowing the PTU arm to move down and back up did not take up too much space. It should not require the arm itself or the rest of the system to take up valuable space. The components needed for wirelessly charging the E-bikes (power supply, PCB, and PTC) already occupy a significant volume. Because they need to be enclosed in housing, this mechanism should occupy the least amount of space possible.

2. **Costs**
   The current Tiler charging system is quite expensive. This design will be different from the current TILER Charging Tile. It will use a lot of the same components: Power supply, PCB, PTC, LED indicator and housing. While the housing itself might be smaller, this system would need an additional mechanism in comparison to the Tile. Because the costs for this new system should not exceed that of the Tile, the costs of the rotating mechanism should be minimized. Expensive components or a lot of custom-designed parts will drive up the costs very quickly. Therefore, it is important for me to pick a mechanism that is simple and cost-effective and preferably uses standard or affordable custom parts.

3. **Predictable rotation and controlled movement**
   During prototype testing, we found that the height at which the PTU arm rotates is crucial. There is very little space between the pedals and the PTU in its fully pushed down position. If the point of rotation is not at the right height or cannot be controlled, it may cause the pedals to get stuck on the PTU arm. Therefore, the mechanism should allow for the point of rotation to be located at an exact spot. Rotation axes work well for this, but flexible parts bend over a larger distance unless a specific part of the arm is designed to be flexible.

   Additionally, the movement of the PTU arm should feel controlled to create a user experience that evokes trust. If the PTU arm keeps swinging back and forth or bounces all over the place after being hit by the pedals, it might not feel like intentional movement. For the user, it should feel okay to hit the PTU with their pedals. A nice and controlled path of movement might feel much more intentionally designed and is therefore an important factor for selecting a mechanism.

Selected solutions

In table XXX the selection criteria are evaluated for each sketch resulting from the How To method. They are all graded with either + or – as an indication of whether they suit that selection criteria or not. Two solutions ended up with 3 +'s and were therefore selected as most suitable for this design: Torsion spring mechanism and a flexible hinge. These are also highlighted in yellow in table XXX.
I will now elaborate on why these two mechanism were selected below:

Torsion spring

A torsion spring is a quite simple mechanism to counteract a rotation. These springs are placed around the rotation axis itself. One side of the spring is fixated on a stationary part of the mechanism, while the other is connected to the part meant to rotate. As the arm rotates, this spring will be put under tension and generate a spring force in the opposite direction of the rotation. If the arm is released, this spring force will cause the arm to rotate back to its original position.

Size
Torsion springs are quite small as they are meant to be incorporated around a rotation axis. Therefore, they would not take up too much space in a housing and PTU arm, which would need to be produced anyway to enclose all the required electronics.

Price
Additionally, it is a very common and mass-produced part. Therefore, it can be found in many different configurations to fit the needs of this design. Even if a custom torsion spring would be required, it can also easily be made to order as it is produced by a spring wire bending machine programmed to the spring's requirements rather than requiring a fully custom mould.

Predicatble and controlled movement
Lastly, this mechanism operates with a fixed rotation axis, meaning that the point of rotation is always in the same spot. With the addition of a bearing and possibly a rotation damper to smooth out the PTU arm moving back up, the whole movement can be very smooth and controlled.

Flexible hinge

The flexible hinge may not be considered a traditional "mechanism" for rotation, but it serves the same purpose. By using a flexible material to replace a small part (the hinge) of the otherwise rigid PTU arm, it allows for the PTU to move.

Predicatble rotation
This design is more suitable for the design because having only a small part that can bend focuses the bending and rotation to a specific location, as opposed to the entire PTU arm being flexible. It also is a quite 'simple' system compared to a mechanism exitsting out of many moving parts.

Size
When considering replacing a larger or smaller part of the PTU arm with a flexible component, it may seem that this wouldn't change the overall size of the system. However, it can be argued that using small flexible parts would result in a smaller design compared to making a larger part flexible. Many of the electronics are rigid and cannot be mounted inside a flexible component. Therefore, they would need to be located elsewhere. By using a flexible hinge instead of a flexible arm, more space becomes available inside the arm itself for positioning electronics, thus preventing the need to place them elsewhere and avoiding an increase in the overall size of the system.

Costs
A flexible hinge would need to be custom-made. However, due to its smaller size compared to making the entire PTU flexible, it would require a smaller mold and less material. This would contribute to a more affordable end product.

Appendix H: Power supply selection

This Appendix elaborates on the thought process behind and implications of the power-supply selection. Unlike other components reused from the TILER Charging Tile, the power supply was open for exploration. I will explain the selection criteria for power supplies and their comparison, which has led to the selection of two potential power supplies, each with its own implications for the project.

1. MeanWell HLG-240H-48
2. MeanWell EPP-500-48

Power supply functions

The power supply for this design had to fullfill the same requirements/specifications as it does in the TILER Charging Tile:

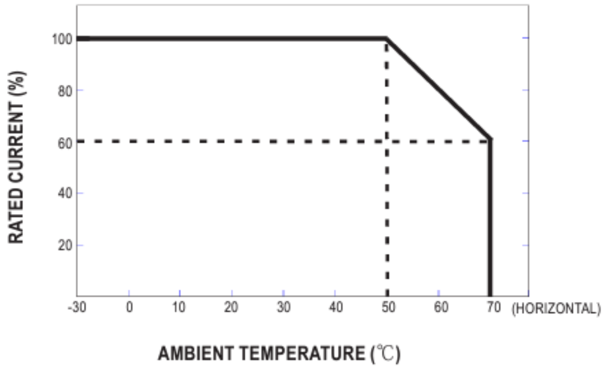
- Transform AC to DC electrical power
- Deliver a 48V output
- Power output of at least 200W at operating temperature

Regarding the last requirement space openen up to explore a new power supply compared to the TILER Charging Tile. The original Charging Tile was designed to be used as a tile and placed in the ground. Therefore, it was crucial for it to be fully waterproof, as there might be puddles forming on top and around it, partially submerging the tile. This means the tile had to be completely watertight and sealed off all around. As a result, it not only kept water out but also trapped air inside. Since power supplies generate some heat and are only rated to perform well up to a specific temperature, they need some cooling. The trapped air in the tile prevents it from cooling by convection, so a power supply was chosen that can be cooled by being placed on top of an aluminum plate to function as a sort of heatsink. The specific power supply chosen was the MeanWell UHP-350-48, which can be found in table XXX.

For this project, the final charging solution is to be fully placed above ground and, therefore, won't be submerged. It still needs to be weatherproof, but it could incorporate some ventilation or at least cool better to the outside air as it is not dug into the ground but rather surrounded by free-moving (and therefore cooling) air. Additionally a power supply could even be placed externally of any housing used for other component to potentially safe some space within a custom housing.

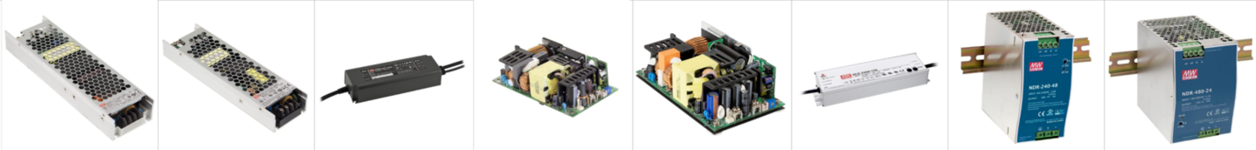
Power supply cooling

As the main function of the power supply is to deliver the right, but also enough electrical power to the charging system, the performance of the power supply is very important. Each power supply is rated for certain specifcatoin, but the actual performance is highly dependant on the ambient temperature around the power supply. This can seen in the graph in figure XXX, which is the percentage of it's rated current that the MeanWell UHP-350-48 can output at different increasing temperatures. As the temperature rises, it will decrease and eventually stop working.



To properly charge E-bikes the system must have at least 200W of power going from the power supply to the PCB. This was highly influential in the selection process of a new power supply. All power supplies have different rated power outputs, different cooling capabilities and therefore deliver different power at different temperatures. This can be seen in table XXX in the row 'Power Performance'.

It's crucial to consider the location of these power supplies, as they are rated for their ambient temperature. There's a significant difference between ambient temperature as the outside air (if a power supply can be placed externally) and it being trapped air inside a protective housing when it is internally mounted. This can also be seen in table XXX and was taken into account for finding suitable power supplies.



Name	MEANWELL UHP-350-48	MEANWELL UHP-200-48	MEANWELL PWM-200-48KN	MEANWELL EPP-400-48	MEANWELL EPP-500-48	MEANWELL HLG-240H-48	MEANWELL HLG-240H-48	MEANWELL HLG-480H-48
Power performance	350 W at ambient temperature up to 50˚C 210 W when ambient temperature is at 70˚C	200 W at ambient temperature up to 50˚C	200 W at ambient temperature up to 45˚C	250 W at ambient temperature up to 45˚C (without fan) 190 W when ambient temperature is at 60˚C	320 W at ambient temperature up to 45˚C (without fan) 300 W when ambient temperature is at 50˚C 240 W when ambient temperature is at 60˚C	240 W at ambient temperature up to 60˚C	240 W at ambient temperature up to 50˚C	480 W at ambient temperature up to 50˚C
Mounting	Internal	Internal	External	Internal	Internal	External	External	External
Effective opperating temperatre	Temperature inside housing	Temperature inside housing	Outside temperature	Temperature inside housing	Temperature inside housing	Outside temperature	Temperature in general 'power box'	Temperature in general 'power box'
Cooling features	Cooling with aluminum plate	Cooling with aluminum plate	Cooling to outside air	x	x	Cooling to outside air	Cooling through vented enclosure box	Cooling through vented enclosure box
Dimensions	210 x 62 x 31	194 x 55 x 26	195 x 68 x 39,5	127 x 76,2 x 35	127 x 76,2 x 41	220 x 68 x 38,8	x	x
Suitable?	✓	✗	✗	✓	✓	✓	✓	✓
Design implications	PTU body housing doesn't need to be vented. --> cooling through aluminium plate. Housing will be bigger than open frame	x	x	PTU body housing needs to be vented	PTU body housing might not need vents. Smaller housing compared to enclosed power supply	PTU body only needs joint and cable pass-through. Find suitable mounting location allong bike rack	Find space for additional power box. 1 power supply per charger. Run cables along rack	Find space for additional power box. 2 power supplies per charger. Run cables along rack

Power supply comparison

Several power supplies from MeanWell, the current power supply supplier for TILER, have been compared for this project. They can be categorised into different types/series:

- Enclosed power supplies with aluminium plate cooling
  - UHP-350-48
  - UHP-200-48

- Open-frame power supplies
    - EPP-400-48
    - EPP-500-48
- External ‘block’ type power supplies
    - PWM-200-48KN
    - HLG-240H-48
- External DIN-rail power supplies
    - NDR-240H-48
    - NDR-480H-48

Two initially considered power supplies were deemed **not suitable**:

- UHP-200-48: only rated for the required 200W up to 50˚C, which would be for the temperature inside of another housing. So it could not guarantee suffiecient power in all expected circumstances.
- PWM-200-48KN: Even though it is an external power supply and would deliver sufficient power up to expected outside temperatures (bike parking facilites are not expected to exceed the rated 45˚C), it was deemed not suitable as it did not have any waterproof rating at all. This is not suitable for bike parking as that may be located outside, exposed to rain, or be cleaned with water/pressure washers.

Ultimately two supplies have been selected: One to be used internally inside a housing along with other components of the system and one that could be placed externally.

Internal power supply: EPP-500-48 (open frame)
This open-frame power supply was selected because it is much smaller than its enclosed counterparts from the UHP series. The ‘500’ was also selected over the ‘400’ because it wouldn’t require the housing design to have ventilation holes that could compromise the weatherproofing or make the production process more complex/expensive.

External power supply: HLG-240H-KN
The HLG series was chosen as the external power supply. Its relatively larger size won't be an issue as it can be placed anywhere on the bicycle rack and doesn't need to be inside the housing with other components. It is fully waterproof on its own, which is why it was chosen over the NDR series, as the NDR series would need to be placed in a special enclosure with a DIN rail system inside. This enclosure could hold multiple power supplies, but it is still a big object to add within the limited space of a bicycle rack. The HLG offers much more flexibility regarding placement.

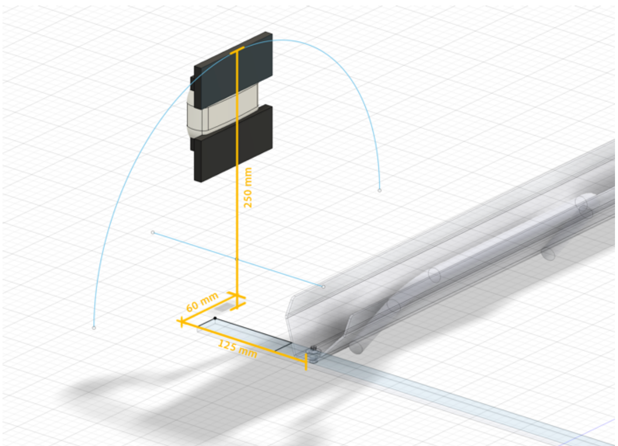
Appendix I: Component topology exploration

This appendix will show the process of the topology exploration that was done to find suitable arrangements of all main electrical components: PTC, PCB and the power supply. It will not only display the different considered topologies itself, but also explain the reasoning behind it and whether they were deemed suitable for the creating a final concept.

Topology requirements

Many different arrangements of all components are possible. However, to give some guidance to the process and end up with usable topologies some groundrules were set:

- Each topology must include the Power supply (either internal or external), the PCB and the PTC.
- The PTC is always in the same spot (figure XXX):
    - The vertical ferrite block face is 125mm left of the center of the gutter
    - The coil center is 60 mm in front of the end of the gutter
    - The coil top is 250 mm from the ground
- The system must fit within a maximum of 2 housing sections: PTU arm and PTU base.
- No part, except for anything in the moving PTU arm, can exceed a height of 100 mm (to prevent pedal collision)

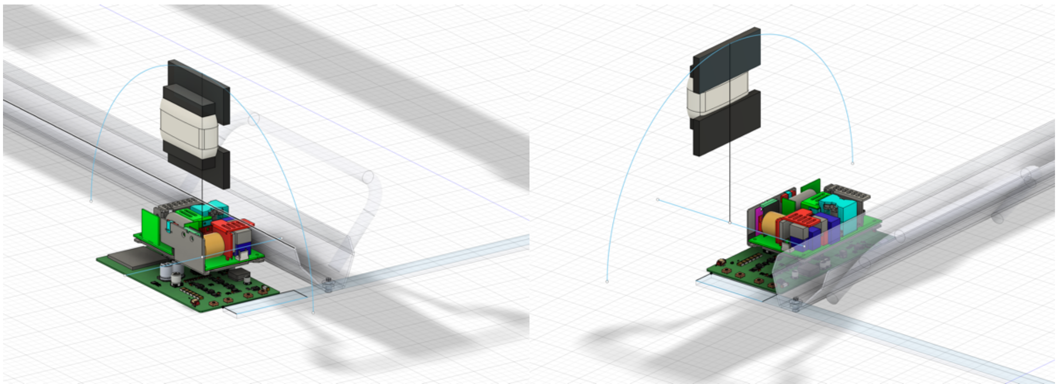


Tested topologies

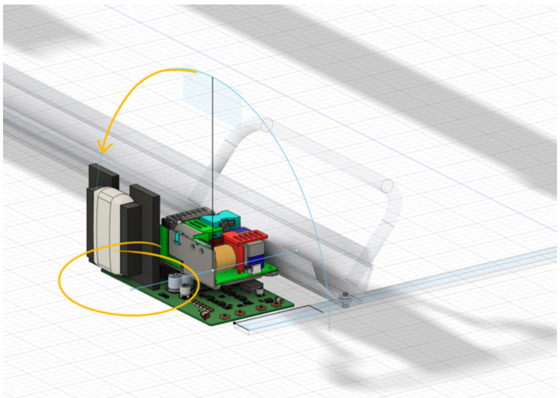
As many different topologies were tried, I will only highlight the most usable, or important (for example to find what definatley would not work) topologies. The different topologies can be caterogized in several types:

Topology type 1: PCB + Power base

This topology places the PCB and the power supply together in the base of design. Therefore, regardless of the rotating mechanism (torsion spring or flexible hinge), the only component in the swing arm is the PTC. Benefits of this would be that it keeps move design freedom for the PTU, allowing for a smaller and more sleek design. Additionally the weight of the PTU arm would be minimal, requiring the mechanism responsible for bringing the PTU arm back up to counteract a smaller force.
This topology can be seen in figure XXX and XXX.

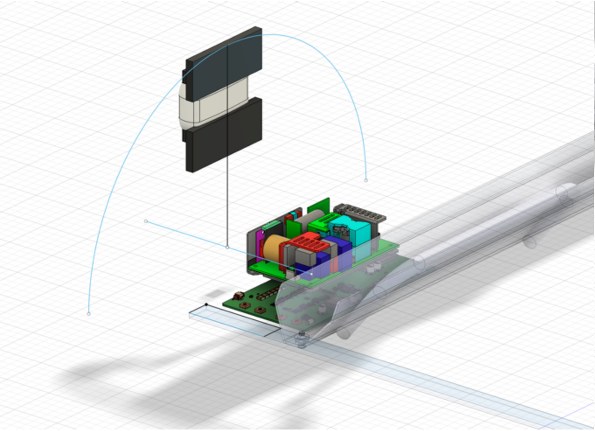
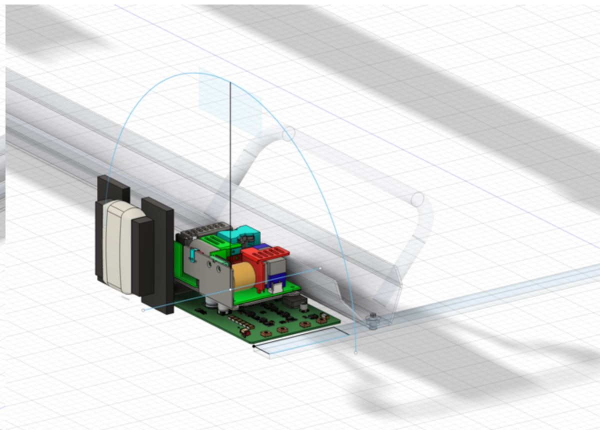


Within this specific topology a problem arises as the PTU arm and thus the PTC would rotate down 90˚. As circled in yellow in Figure XXX, the PTC would hit the PCB when coming down, especially since it is to be expected that there would be housing around the PCB.

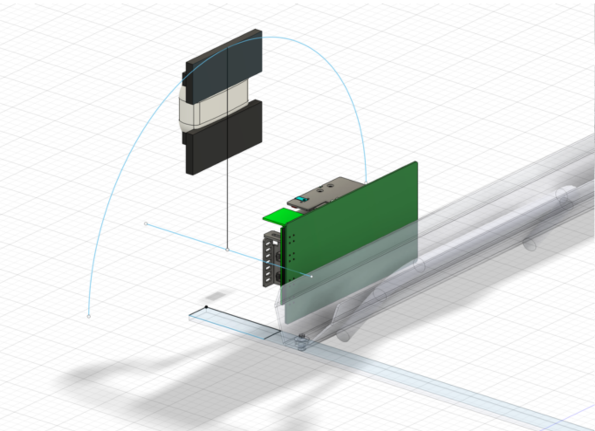
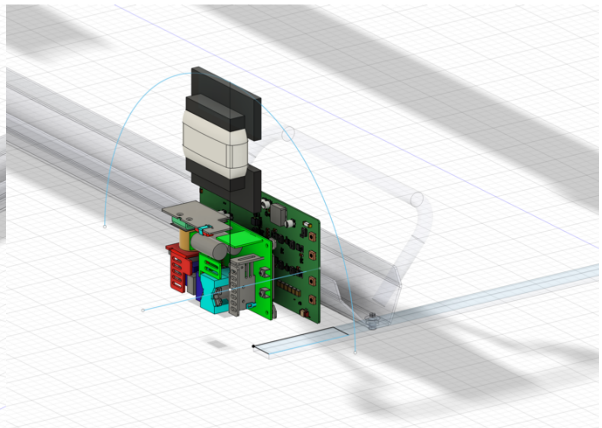


To solve this, the PCB would need to be moved. Luckilly there is is some space available to the right of the PCB because of the geometry of the gutter of the Velopa-UP bicycle rack. This can be seen in figure XXX. Figure XXX shows how the PCB would be moved sideways, which results in enough clearance between the PTC coming down and PCB.

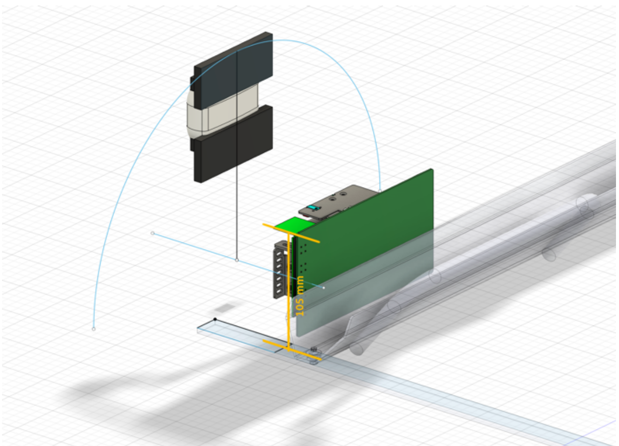
The full adjusted topology can be seen in figure XXX and XXX. It is to be noted that this toplogy is only possible due to the specific profile of the Velopa-UP gutter, which is the leading bicycle rack in this design project. However, if a bicycle rack is to be used with a more square profile, this placement of the PCB is not possible and therefore this geometry wouldn't be feasible.

This previous topology occupies much of the sideways available space. Even though it all seems to fit, another topology in which the PCB and power supply are placed together was explored, the only difference being that it would be rotated on its side. This topology can be seen in figure XXX and XXX. In this topology there is much more space

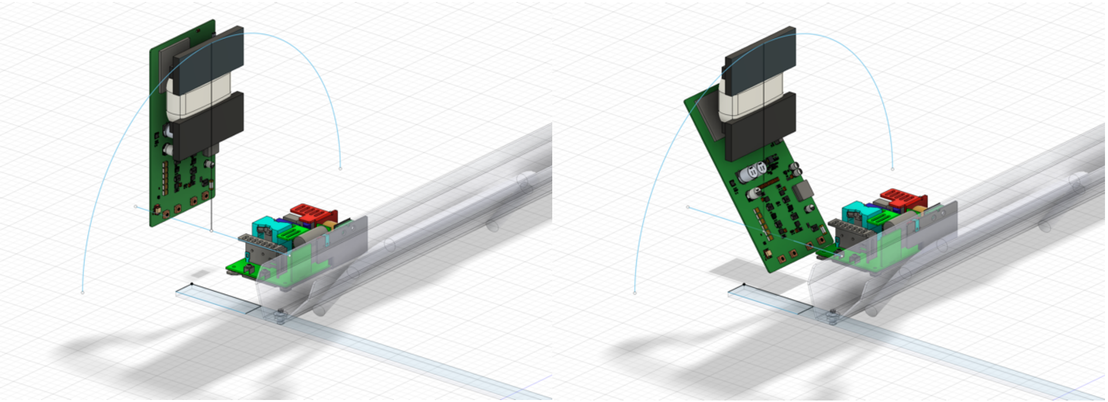
between what would be the PTU base and arm. However, as seen in figure XXX, this topology would break one of the ground rules for suitable topologies: the PCB, on its side, ends up being higher than the maximum of 100 mm. Therefore there is a chance of pedals hitting the non-movable PTU base, especially when a to be designed housing for



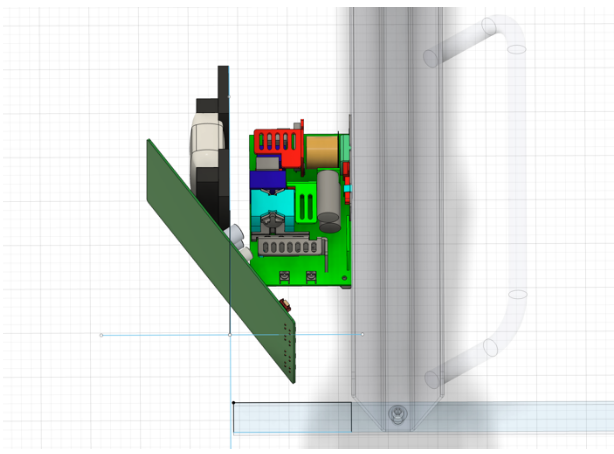
the base would add extra milimeters to the total height. Therefore this topology was not considered for further development.

Topology type 2: PCB in PTU arm

A different topology places the PCB in the PTU arm with the PTC. This causes the PCB and PTC to move together, allowing the high-voltage wires between them not to have to bend or rotate back and forth. A potential downside is that the PTU arm needs to accommodate the big size of the PCB, resulting in a much ‘chunkier’ design of the arm. Two variants of this topology can be seen in figure XXX and XXX.

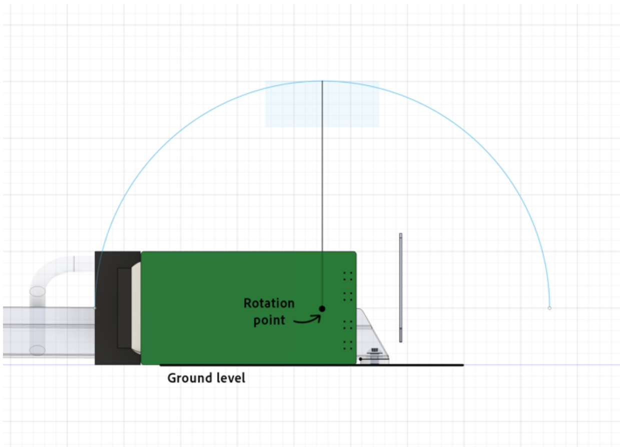


Both topologies were designed with a similar rough placement of components, but there are some key differences to highlight. The diagonal topology in figure XXX was created to make the eventual design slightly more dynamic by allowing for a diagonal connection between the PTU base and the PTC. However, this diagonal placement of the PCB requires the power supply to be moved further away from the PTU arm to enable it to rotate all the way down without intersecting the power supply. This can be seen in figure XXX. The location of the PTC, and inherently the point of rotation, cannot be changed. This causes a potential issue with the PTU base housing, which would need to be bigger if it is to include the power supply and the rotation mechanism, compared to the vertical PCB topology. It could be argued that the implied higher costs of a bigger base housing aren’t justified simply to create a more ‘dynamic’ looking design.

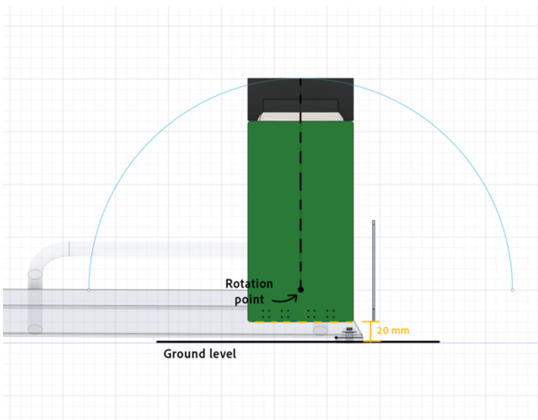


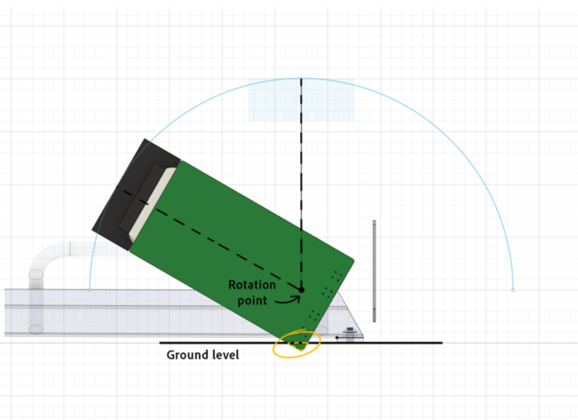
PCB height

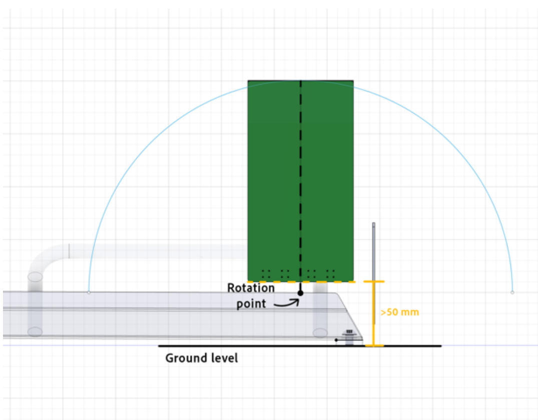
The width of the PCB is, coincidentally, the same as the PTC. Therefore the PTU arm can still rotate fully down to a horizontal position using the original rotation point, even when the PTC is added, as is shown in figure XXX.

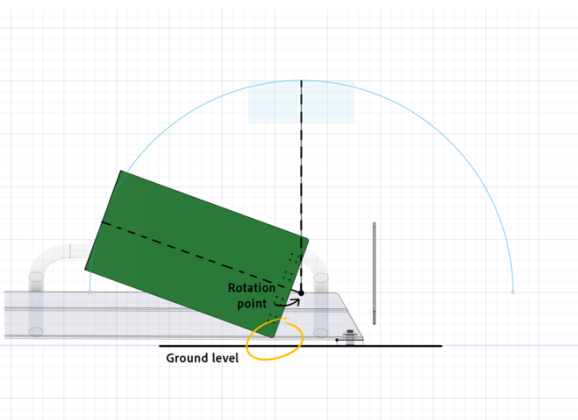


However, the rectangular shape of the PCB causes it to theoretically move through the ground if the bottom is lower than the point of rotation. An example can be seen in figure XXX. Figure XXX shows the downward left end of the PCB going through the ground. In contrast, figure XXX and XXX show that the PCB stays clear from the ground if the bottom is placed at least 50 mm above the ground. It is important to keep this in mind for both variants of this topology type.



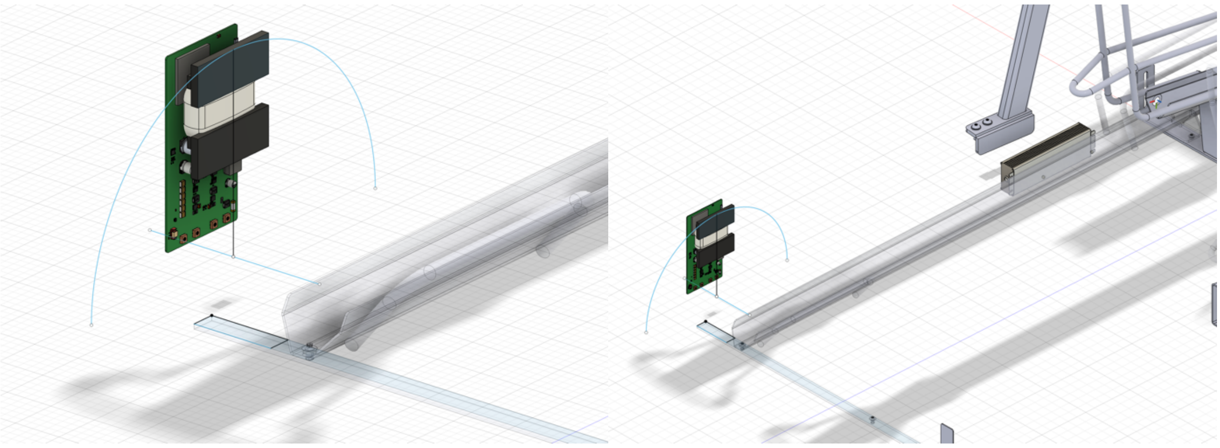






Topology type 3: external power supply

In the third topology, an external power supply is used instead of the previous internal power supply. By moving the power supply away from the rest of the PTU, only the PTC and the PCB remain. Of these two components, only the PCB can be moved. Placing the PCB inside a PTU base would require a large housing to be designed, along with a housing for the PTU arm. Therefore, it was decided that the topology with an external power supply would place the PCB together with the PTC in the PTU arm, similar to the vertical variant of topology type 2. This creates a topology that keeps the final design relatively simple, as its main housing is only the PTU arm. A rotation mechanism would need to be added between the PTU arm and the bicycle rack. This topology can be seen in figure XXX. Figure XXX shows the external power supply located elsewhere in the bicycle rack, where it would not be subjected to pedal collisions.



Topology conclusion

Each topology type has resulted in a feasible arrangement of the main components. Type 1 allows for a smaller and lighter PTU arm, while type 2 allows the base to be smaller. Type 3 has the benefit of potentially only requiring a waterproof housing to be made for the PTU arm, since the rotation mechanism itself would contain exposed electronics that need weatherproofing.

Appendix J: Datum method concept comparison

This appendix elaborates on the Datum method used to make the final concept choice between the Flexjoint and Torsion Spring concepts. It will firstly explain the method, then highlight the used criteria and finally give the reasoning behind the scoring of the concepts for each criteria.

The Datum Method

The Datum Method is a structured approach used to evaluate and compare multiple design concepts against a selected reference design, known as the "datum." Each concept is assessed based on specific criteria, scoring them as either "not as good," "same," or "better" than the datum, indicated by a '-', 'S', or '+' respectively.

To use the method, relevant criteria are selected, and concepts are arranged in a matrix alongside these criteria. A datum is chosen for comparison, and each concept is evaluated against this reference. This process helps in finding the most suitable design for further development. (Van Boeijen et al., 2020)

Design criteria

Each of the design criteria on which the Flexjoint and Torsion Spring concepts were compared are described below:

- Amount of custom parts required (less is better)
    - Each concept consists of a combination of COTS parts and custom components. For all custom components, R&D and initial manufacturing costs are required. Having a lot of custom components, especially in lower quantities such as the estimated 1000 pcs. for this design project. Since TILER is a start-up company, the number of (expensive) custom parts should be limited to make this design viable for them.
- Durability
    - Every time an E-bike is placed into the bicycle rack, it can be expected that the PTU arm is moved after being hit by the pedals. With a life expectancy of 5 years, the rack being used by two bikes a day for that whole period, and each bike going in and out of the bicycle rack, this results in 5 x 365 x 2 x 2 = 7300 potential pedal strikes and PTU arm rotations. The rotation mechanisms will need to withstand repeated stresses as well as possible.
- Ability to accommodate a wide variety of E-bikes
    - The goal of this project is to result in a universal wireless charging solution for E-bikes with the TILER Charging Kickstand installed. E-bikes vary greatly in size and kickstand location, so the final design must work with as many E-bikes as possible.

- Controlled movement of the PTU arm
    - For the user experience, it is beneficial to have the movement of the PTU arm evoke a level of confidence in the user that it is meant to move that particular way. If the movement is more controlled, it will seem more purposefully designed to behave that way for the final user. It will also indicate a high-quality and well-designed product.
- Size (smaller is better)
    - As space in bicycle racks is limited, the less space occupied by the addition of a wireless charging system, the better. Within the size category, both the design's size and the amount of ‘useful’ space occupied must be considered.
- Simplicity
    - A simpler design contains fewer parts that could potentially fail. It is also easier to manufacture/assemble and replace. If adjustments to the design are needed in further developments, this is also easier accomplished with a simpler design compared to a more complex and intricate product.

Results

The results from comparing the Flexjoint and Torsion Spring concepts can be seen in figure XXX. It can be seen that the Flexjoint concept scores better compared to the Torsion Spring concept on these design criteria. The reasoning behind the scoring of the Torsion Spring concept compared to the ‘datum’, flexjoint, concept is explained below:

	Flexjoint concept	Torsion Spring concept
Nr. custom parts	▪	-
Durability	▪	+
E-bike variety	▪	-
Controlled movement	▪	+
Size	▪	-
Simplicity	▪	-
Σ+	▪	2
Σ-	▪	4
Σtotal	▪	-2

Nr. Custom parts

The Torsion Spring concept requires more custom parts than the Flexjoint concept. The Torsion Spring concept requires custom parts for the torsion spring mechanism, including the custom axle, torsion springs and clamp rings. Additionally, every protective housing consists of at least two parts to enable components to be placed inside and then closed off. The Torsion Spring concept has a separate housing for the PTU arm and the PTU base, adding to the total of custom components. The Flexjoint concept, in comparison, only requires the PTU arm housing and Flexjoint itself as custom parts.

Durability
The Torsion Spring mechanism uses a metal axis, likely placed in bearings, to rotate the PTU arm. Torsion springs are designed to withstand repeated tensioning and unloading, assuming they are used in their intended load direction. This makes the torsion spring mechanism well-suited for repeated rotation of the PTU arm.

On the other hand, the Flexjoint relies on the elastic deformation of an elastomer material to generate a restorative force. As the flexjoint is bent, stresses and compression occur within the material. Repeated usage or damages/cuts in the flexjoint could create stress concentrations that over time surpass the material's limit and tear/rip the flexjoint.

The PTU arm is identical for both concepts, so pedal strikes to the protective housing can be neglected for this comparison. In conclusion, the Torsion Spring concept is expected to be more durable in terms of repeated rotation of the PTU arm.

E-bike variety
The Flexjoint's flexible nature allows the PTU arm to rotate along the direction of the bicycle rack and also has some slight sideways movement. TILER adapter brackets compensate for any height variation in the kickstand location, and the longer ferrite plates in the PTC allow for horizontal variation lengthwise of the E-bikes. However, E-bikes can also vary in the amount by which their kickstand sticks out to the side or does not fully stand straight in the bicycle racks. The Flexjoint could deliver the extra flexibility needed to align the PTC and PRC correctly.

The Torsion Spring concept can only rotate the PTU in a straight plane and, therefore, cannot compensate for any sideways variation.

Controlled movement
The Flexjoint concept attempts to concentrate the point of rotation for the PTU arm by incorporating a heavily tapered section in the middle of the flexjoint. However, this will never be as precise as rotating around a dedicated rotation axis, as in the Torsion Spring concept.

Furthermore, the flexjoint could cause the PTU arm to bounce back and forth for a while after it is released from the pedals. In the torsion spring, the same thing could happen; however, a rotation damper might be added to the rotation axle to slow down the PTU as it moves back up, bringing it to a gradual halt at its vertical position.

Size
The PTU arm for both the Flexjoint and the Torsion Spring concepts is almost the same in terms of size. However, the Flexjoint concept saves space because it uses an external

power supply located deeper into the bicycle rack. Therefore, it doesn't need a dedicated PTU base, but rather only the flex joint placed on top of a sheet metal bracket.

Simplicity

The Flexjoint is a single object made of elastomer material, while the Torsion Spring Mechanism is more complex with many small parts that need to work together. The Flexjoint concept has only a few main parts, making it simpler and easier to service or repair compared to the Torsion Spring concept.

Since the design is likely to undergo further changes before potential production, having fewer parts that need to work together makes implementing changes to the Flexjoint concept easier.

Appendix K: Flexjoint calculations

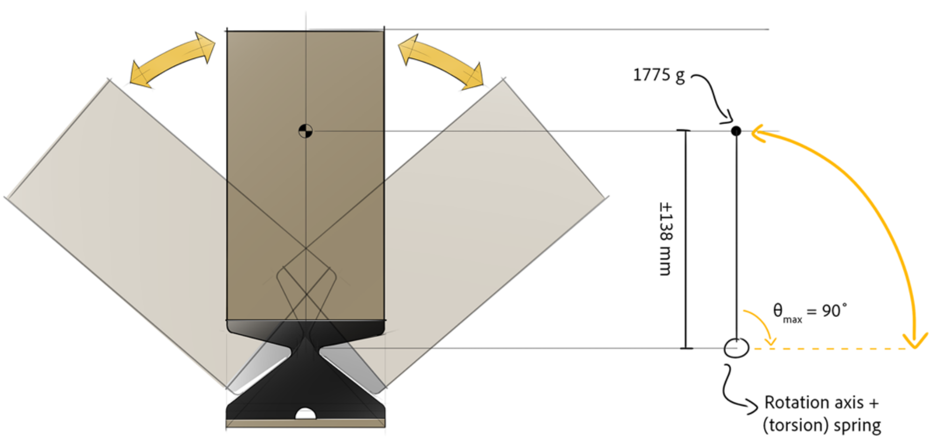
This appendix outlines a theoretical approach and analysis for the flexjoint concept of my gradutation project. This hinge must support the motion of an arm that rotates from a vertical to a horizontal position, and return the arm to vertical through the hinge's restoring force. The goal was to design a hinge that provides flexibility for moving the PTU out of the way in case of collision while generating sufficient force to restore the arm to its upright position. Meanwhile, the hinge must withstand the stresses generated during operation, without deforming or failing.

This appendix follows the step-by-step progression of this exploration, showing how each calculation and analysis led to the final conclusion on the feasibility of the flexjoint concept . It includes material evaluations, comparisons of hinge cross-sectional geometries, and the detailed calculation of forces and stresses. Each section discusses the reasoning behind the chosen approaches, providing numerical values and results throughout the process.

Simplified (spring) system

Whether we are considering the spring-hinge or the flexjoint concept, their basic functioning is the same: Allow the PTU arm to rotate (hinge) around a set point so that pedals could move over it. Then after being pushed out of the way the build up tension should move it right back up to the vertical position. Despite its components and different designs I have simplified the whole system as a starting point for this analysis:

A weightless arm with a certain length (up to the center of mass of the PTU above the hinge) with a point mass (total mass of the PTU above the hinge) at the end of that arm, that rotates around a single point (the hinge/rotation axis) that generates a spring force when moved from it's neutral (vertical) position. In this rough simplification, only the PRC and the PCB have been considered, as their location is roughly predetermined This is illustrated in figure XXX.



System description

The system consists of a vertical arm with a length of 138 mm and a point mass of 1.775 kg at the top (representing the product's mass and center of gravity). This setup generates a gravitational torque around the base, which the hinge needs to counteract. To begin with, I simplified the problem by modeling the system as a spring-loaded vertical arm.

Objective: Calculate the spring force (and corresponding spring constant) required to restore the arm from a horizontal to a vertical position.

Spring Force Calculation

The force required to return the arm to its vertical position can be estimated by calculating the torque generated by the gravitational force of the mass at the top of the arm, and the restoring torque produced by the spring.

1. Gravitational Torque:

$$\tau_{\text{gravity}} = m \cdot g \cdot L$$

Where:

- *m = 1,775 kg* is the mass at the top of the arm
- *g = 9,81 m/s*^{2} is the gravitational acceleration
- *L = 0,138 m* is the length of the arm.

Substituting the values:

$$\tau_{\text{gravity}} = 1.775 \times 9.81 \times 0.138 = 2.4\text{Nm}$$

The gravitational torque acting to pull the arm down is **2,4 Nm**.

2. Restoring Torque from the Spring:

The spring generates a restoring torque proportional to the angle of deflection (θ)

$$\tau_{\text{spring}} = k \cdot \theta$$

Where:

- *k* is the spring constant (Nm/rad),
- θ is the angle of deflection (radians)

At the full deflection ($\theta = 90° = 1.57\text{rad}$), the spring's torque must at least equal the gravitational torque to restore the arm to the vertical position:

$$k \times 1.57 = 2.4\text{Nm} \Rightarrow k = \frac{2.4}{1.57} = 1.53\text{Nm/rad}$$

Conclusion: The spring constant must be at least 1.53 Nm/rad to return the arm to the vertical position from the horizontal. This converts to 0,0267 Nm/deg or 26,70 N·mm/deg.

Investigating an Equilibrium Point

After determining the spring constant, I wanted to know if the system had a potential equilibrium point between the vertical and horizontal positions. This was important to ensure that the arm would not stop at an angle or ‘sag’ to one side before returning fully vertical.

Energy of the simplified spring system

The approach for finding this potential extra balance point in the PTU’s movement was to consider the total energy of the system as a whole. On one side, there is the potential energy from the centre of mass of the PTU being positioned above the ground, and on the other side, energy in the form of elastic energy is stored in the spring as the PTU is rotated from its neutral (vertical) position.

1. Gravitational Potential Energy:

Gravity acts on the point mass at the top of the arm. The gravitational potential energy of the point mass at a given height is:

$$U_g(\theta) = m \cdot g \cdot h(\theta)$$

Where:

- m is the mass of 1.775 kg,
- g is the gravitational acceleration of 9.81 m/s^2,
- $h(\theta)$ is the height of the mass as a function of the angle θ.

The height $h(\theta)$ changes depending on the angle θ that the arm makes with the vertical position and can be expressed as:

$$h(\theta) = L \cdot (1 - \cos(\theta))$$

Thus, the gravitational potential energy becomes:

$$U_g(\theta) = m \cdot g \cdot L \cdot (1 - \cos(\theta))$$

2. Elastic Energy in the Spring:

The energy stored in a rotational (torsion) spring is given by:

$$U_s(\theta) = \frac{1}{2} \cdot k \cdot \theta^2$$

Where *k* is the spring constant we calculated earlier (11.09 Nm/rad), and θ is the angle in radians.

3. Total Energy:

The total energy of the system is the sum of the gravitational potential energy and the elastic energy stored in the spring:

$$U_{\text{tot}}(\theta) = U_g(\theta) + U_s(\theta)$$

This can be written as:

$$U_{\text{tot}}(\theta) = m \cdot g \cdot L \cdot (1 - \cos(\theta)) + \frac{1}{2} \cdot k \cdot \theta^2$$

We can now compute the total energy as a function of the angle θ and look for a minimum. A minimum in this energy represents a stable equilibrium state for the system.

Finding an equilibrium

To find the equilibrium points, we need to take the derivative of $U_{\text{tot}}(\theta)$ with respect to θ and set it equal to zero.

$$\frac{dU_{\text{tot}}}{d\theta} = \frac{d}{d\theta}(m \cdot g \cdot L \cdot (1 - \cos(\theta))) + \frac{d}{d\theta}(\frac{1}{2} \cdot k \cdot \theta^2)$$

Taking the derivatives:

1. Gravitational potential energy derivative:

$$\frac{d}{d\theta}(m \cdot g \cdot L \cdot (1 - \cos(\theta))) = m \cdot g \cdot L \cdot \sin(\theta)$$

2. Elastic energy derivative:

$$\frac{d}{d\theta}(\frac{1}{2} \cdot k \cdot \theta^2) = k \cdot \theta$$

Thus, the derivative of the total energy is:

$$\frac{dU_{\text{tot}}}{d\theta} = m \cdot g \cdot L \cdot \sin(\theta) + k \cdot \theta$$

Finding the Equilibrium Point

To find the equilibrium points, we set the derivative equal to zero:

$$m \cdot g \cdot L \cdot \sin(\theta) + k \cdot \theta = 0$$

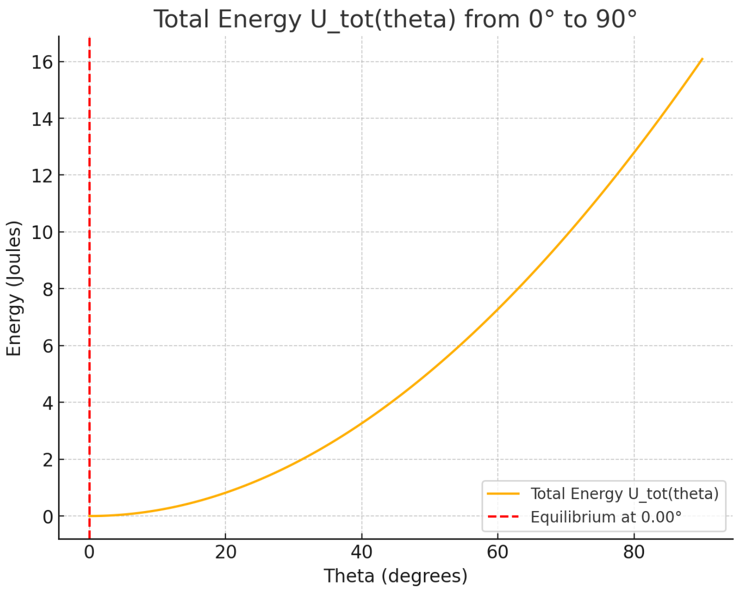
Substituting the known values for m , g , L , and k :

$$1.775 \cdot 9.81 \cdot 0.138 \cdot \sin(\theta) + 11.09 \cdot \theta = 0$$

This simplifies to:

$$2.4 \cdot \sin(\theta) + 11.09 \cdot \theta = 0$$

Solving this equation gives a value for θ of 0, meaning that there is only a minimum in the energy balance when the angle θ is 0. Therefore it can be concluded that for this simplified scenario is angle at which the system is at equilibrium except for when it is in its vertical position. This can also be shown from the graph of the energy balance equation in figure XXX.



Conclusion: Between fully vertical (θ = 0˚) and fully horizontal (θ = 90˚) there is no intermediate equilibrium point, and the arm will always fully return to vertical once released from any angle.

The Flexjoint (rubber) hinge

The findings from the previous simplified scenario are built upon to theoretically analyse the feasibility of the Flexjoint concept since we now know that the flexible hinge should generate a spring force of at least 1,53 Nm/rad and that it will not 'sag' to the side. For the flexjoint hinge, several other factors must be taken into account:
Since it relies on the bending of an elastomer, a balance must be found between the stiffness of the material, thus its resistance to bending, which in turn generates the

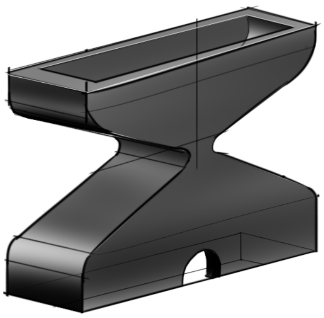
spring force required to rotate the PTU back into the vertical position, and its flexibility or resistance to stress/tearing so that it doesn't rip or break when fully pushed into the horizontal position.

Initial Assumptions:
- Material: initially assumed the rubber would have properties similar to NBR (an elastomer) with an elastic modulus of 2 MPa.
- Cross-sectional dimensions: The hinge was assumed to be 10 mm thick and 40 mm wide, with a length of 30 mm (representing the region where most of the bending would occur).

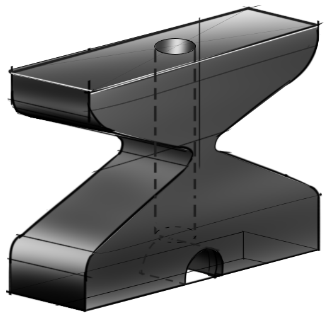
These assumptions were used to theoretically test the principle of the hinge's behavior before refining the design further.

Variant A vs. variant B

In the next part, I explored two design variants for the rubber hinge, each with a different cross-sectional geometry. Both variants include considerations for routing a cable through the hinge, but in different ways. They can be seen in figure XXX.



Variant A:
Hollow



Variant B:
Solid + hole

Variant A: Hollow Rectangular Cross-Section

- Design: A hollow rectangular cross-section with an outer width of 40 mm, an outer thickness of 10 mm, and an inner hollow section.
- Purpose of hollow section: The hollow section was designed to reduce material usage and allow space for the cable.
- Assumption: The hollow section was initially assumed to have 2 mm thick walls.

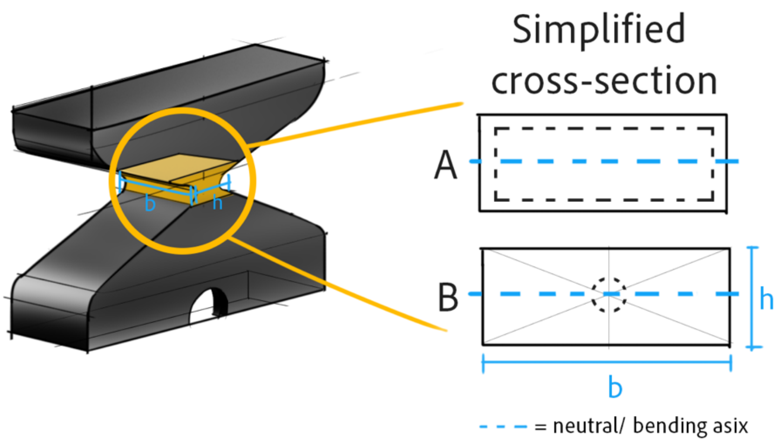
The moment of inertia for this hollow section is:

$$I_A = \frac{b \cdot h^3}{12} - \frac{(b_{\text{inner}} \cdot h_{\text{inner}}^3)}{12}$$

Where:

- b is the width of the cross section (0,04 m)
- h is height of the cross section (0,01 m)
- b_{inner} is the width of the hollow rectange within the cross section
- h_{inner} is the height of the hollow rectangle within the cross

Figure XXX shows the dimensions of the simplified cross section.



Variant B: Solid Cross-Section with a Cylindrical Hole

- Design: A solid rectangular cross-section with an outer width of 40 mm, an outer thickness of 10 mm, and a cylindrical hole of 8 mm diameter running through the middle.
- Purpose of cylindrical hole: The hole allows the cable to pass through while maintaining a more solid structure.
- Advantage: Greater bending stiffness than the hollow variant.

The moment of inertia for this design is:

$$I_B = \frac{b \cdot h^3}{12} - \frac{\pi \cdot r_{\text{hole}}^4}{4}$$

Where:

- Outside dimensions of the cross section are the same as in variant A
- $r_{\text{hole}} = 4\text{mm}$ is the radius of the cylindrical hole.

Bending stiffness

With the different moments of inertia (I) for both variants A and B, the accompanying bending stiffness can be calculated through the following formula.

$$D = \frac{E \cdot I}{L}$$

Where:

- E is the elastic/Young's modulus for the elastomer/rubber
- L is the assumed length over which the bending happens (0.1 m).

Bending moment

From the bending stiffness (D), the bending moment (M) can be calculated for an angular displacement of 90° ($\theta = 1.57$rad) via:

$$M = D \cdot \theta$$

Variant A: Comparison of wall-thickness and material

Several wall thicknesses and elastomeric materials have been compared as part of this exploration to estimate their respective influence on the bending moment of variant A for the Flexjoint. The wall thicknesses taken into account were 2, 3, and 4 mm. The elastomers/rubbers are EPDM, Silicone, and NBR, initially chosen for their weather resistance, flexibility, and higher stiffness, respectively. The resulting bending moment can be seen in Table XXX.

Wall thickness (mm)	Bending moment EPDM (Nm)	Bending moment Silicone (Nm)	Bending moment NBR (Nm)
2	0,1405	0,0843	0,2811
3	0,1650	0,0990	0,3299
4	0,1733	0,1040	0,3467

In comparison to the required **2,4 Nm** to overcome the torque resulting from the gravity pulling down on the arm in the horizontal position, these bending moments for all situations in Variant A are very small.

Conclusion: Variant A of the Flexjoint is not feasible to bring the PTU back into an upright position. Even choosing thicker walls or stiffer materials are not likely to be sufficient, since the resulting bending moment needs to be almost 10 times higher.

Variant B

As for variant B, the only initial exploration was done with regard to the materials, since that would most clearly show the effect of the mostly solid geometry of variant B compared to the mostly hollow one from variant A. The same materials were considered as in variant A: EPDM, Silicone, and NBR. This delivered the following results:

- EPDM: 0,164 Nm
- Silicone: 0,0983 Nm
- NBR: 0,328

Comparison
Initially, variant B seems less effective than variant A with a 4 mm wall thickness. However, it is important to note that a 4 mm wall thickness in variant A would only leave a gap of 2 mm in the middle of the flexjoint for a cable to pass through.

Both variants of the flexjoint up to this point can be considered insufficient in their ability to bring the PTU up to its vertical position. Both would require changes to their geometry and/or material. Therefore, other factors must be taken into account in order to determine between these variants.

Variant B was determined to be the most promising because of the following reasons:

- It is a more robust design as it is mainly solid throughout and, therefore, better prevents the flex joint from creasing, buckling, and sinching the cable. The bending would be a more controlled and predictable movement.
- A less complex moulding process. Casting/machining a solid rubber part rather than hollow would require a much less complex mould, reducing initial costs.
- Better expected durability. As variant B is less likely to crease/buckle, less repeated stress concentration would occur, limiting the chance for premature failure.
- Better cable pass-through. The required wall thickness in variant A would make cable passthrough impossible in the current geometry, as 4 mm still didn't result in sufficient bending moment. Trying to make variant A work for both the cable pass through and have the right mount of bending moment would be illogical given the other identified disadvantages compared to variant B.

Conclusion: Variant B has been selected for further development and analysis in the flexjoint concept. Changes will be implemented in the geometry and material of variant B in the following sections to achieve a feasible flexjoint with the correct bending moment.

Material Comparison: Balancing elasticity and strength

To increase the bending moment of the flexjoint, I looked for other elastomers with a higher Young's modulus compared to NBR. The most promising was Polyurethane (PU), with a Young's modulus of 5 MPa.

PU is especially suitable in the application of the flexjoint as it is very resistant to wear (abression) and tear (high tensile strength).

Calculating bending moment PU flexjoint (variant B)
To see the influence of using PU instead of NBR in the flexjoint, the bending moment was recalculated with a Youngs modulus of 5 MPa. Using the same geometry as before this increase in stiffness by using PU lead to a resulting bending moment of **0,820 Nm**.
This is considerablu higher than the earlier calculated 0,328 Nm for NBR in variant B, but still not enough to overcome the 2,4 Nm required to rotate the PTU back upright.

Geometry changes: increasing cross section

As the use of PU still didn't result in enough bending moment, it was now clear that changes had to be made to the flexjoint's geometry as well. The moment of inertia has a great influence on the final bending moment. Within the moment of inertia, the 'height' of the cross-section of the flexjoint is a main contributor as it is to the power of 3, as can be seen in the formula below:

$$I_B = \frac{b \cdot h^3}{12} - \frac{\pi \cdot r_{\text{hole}}^4}{4}$$

The hole in the centre also significantly influences the decrease of the moment of inertia, but it can't be removed as the cable must pass through it. Therefore to increase the moment of inertia, the height of the cross section was increased.
To explore its influence on the bending moment, a height increase to both 12 mm and 15mm was considered.

Calculating bending moment for increased height
By substituting the original height of 10 mm for 12 and 15 mm in the calculation for the moment of inertia, and meanwhile keeping NBR as the material to keep the comparison equal, the moment of inertia and thus the bending moment was effectively increased. This gave the following results:

- 12 mm: 0,582 Nm
- 15 mm: 1,156 Nm

A larger increase in height wasn't explored because it was expected to cause problems later on due to the maximum stress in the material. A greater distance from the centerline of a bending object significantly increases the stress that a material experiences.

Conclusion: increasing the height of the cross-section of the flex joint isn't sufficient to generate a big enough bending moment to over the required 2,4 Nm.

Combining material and geometry changes

As previously explored, changes to PU as a material for the flexjoint and a bigger cross-section both proved to increase the bending moment of the flexjoint but were individually insufficient at increasing it enough, so it was decided to combine both approaches.

Combined bending moment

By using PU (Young's modulus of 5 MPa) and increasing the height of the cross-section of the flexjoint to 15 mm the bending moment was recalculated to be 2,89 Nm, which is indeed enough to overcome the required 2,4 Nm to bring the PTU back to the vertical position from a fully horizontal position.

Stress Analysis for Flexjoint

Up to this point is has been established that the flexjoint will not sag to the side and always retug to the ubright position if it is made out of PU and the design tapers down to a width of 15 mm.

The next step in validating the feasibility of the flexjoint concept is to determine whether the flexjoint can withstand the required amount of bending/deformation when pushed down horizontally all the way to the ground, allowing the pedal of an E-bike to move over it. This can be done by calculating the maximum stress the material experiences at its maximum deformation. This involves analyzing the outermost fiber in the bending part of the flexjoint when the deformation is at its maximum (θ = 90˚).

Stress Calculation

A stress analysis was performed to ensure that the stresses generated withing the flexjoint would not exceed the maximum allowable stress for PU.

The maximum stress at the outermost fibres of the hinge, during full deflection (θ = 90˚), is given by:

$$\sigma_{\text{max}} = \frac{M \cdot y}{I_B}$$

Where:

- M = 2,94 Nm (bending moment)
- $y = \frac{h}{2} = 0.015/2 = 0.0075\text{m}$
- $I_B = 1.125 \times 10^{-8}\text{m}^4$

Substituting these values:

$$\sigma_{\text{max}} = \frac{2.94 \times 0.0075}{1.125 \times 10^{-8}} = 1.96 \times 10^6\text{Pa} = 1.96\text{MPa}$$

Comparison with Allowable Stress

Polyurethane (PU) has a maximum allowable stress between 40-51 MPa. The calculated stress of 1.96 MPa is well below this limit, confirming that the hinge will not experience permanent deformation or failure during operation.

Conclusion

Summary of Findings

- Spring Constant and Restoring Force: Initially modeled as a spring system, the required spring constant to restore the PTU arm to a vertical position was calculated to be 1.53 Nm/rad. Translating to a maximum torque of 2,4 Nm at maxium rotation (90˚)
- The final rubber hinge (flexjoint) generated sufficient restoring force to exceed this requirement, with a bending moment of 2,94 Nm.
- Equilibrium Point Analysis: Energy balance calculations showed that the arm will always fully return to vertical, with no intermediate equilibrium points.
- Design Comparison: Two hinge variants (A and B) were compared, with Variant B (solid with a cylindrical hole) selected due to its greater bending stiffness and ability to route a cable through the hinge.
- Material Selection: Polyurethane (PU) was selected for its high elastic modulus (5 MPa) and maximum allowable stress (40-51 MPa).
- Geometry Adjustment: Increasing the hinge thickness to 15 mm provided the necessary bending moment to restore the arm and maintain the integrity of the material.
- Stress Analysis: The maximum stress in the hinge was 1,96 MPa, well within the safe limits of the material.

The final design, consisting of a 15 mm thick Polyurethane hinge with a solid cross-section (Variant B), meets all functional and structural requirements. It generates sufficient restoring force to return the arm to vertical, with stresses well below the allowable limits for Polyurethane. The hinge is durable, capable of withstanding repeated flexing.

Appendix L: Aesthetic Exploration

This appendix elaborates on the aesthetic design decisions leading up to the final design for the 'UP-Charge'. The design must not only be functional (feasibility) and wirelessly charge E-bikes, but it must also have an appearance that conveys certain qualities to look appropriate for its context and usage to increase its 'desirability'. This appendix will explain the aesthetic design requirements, explore and identify design features from different products that fit the desired aesthetic and finally, show their implementation in the final design.

Aesthetic requirements & wishes

The UP-Charge's design aesthetic results from several requirements related to its intended usage, context, product category, and ecosystem, combined with functional requirements like its topology and movement mechanism.
The most influential requirements were:

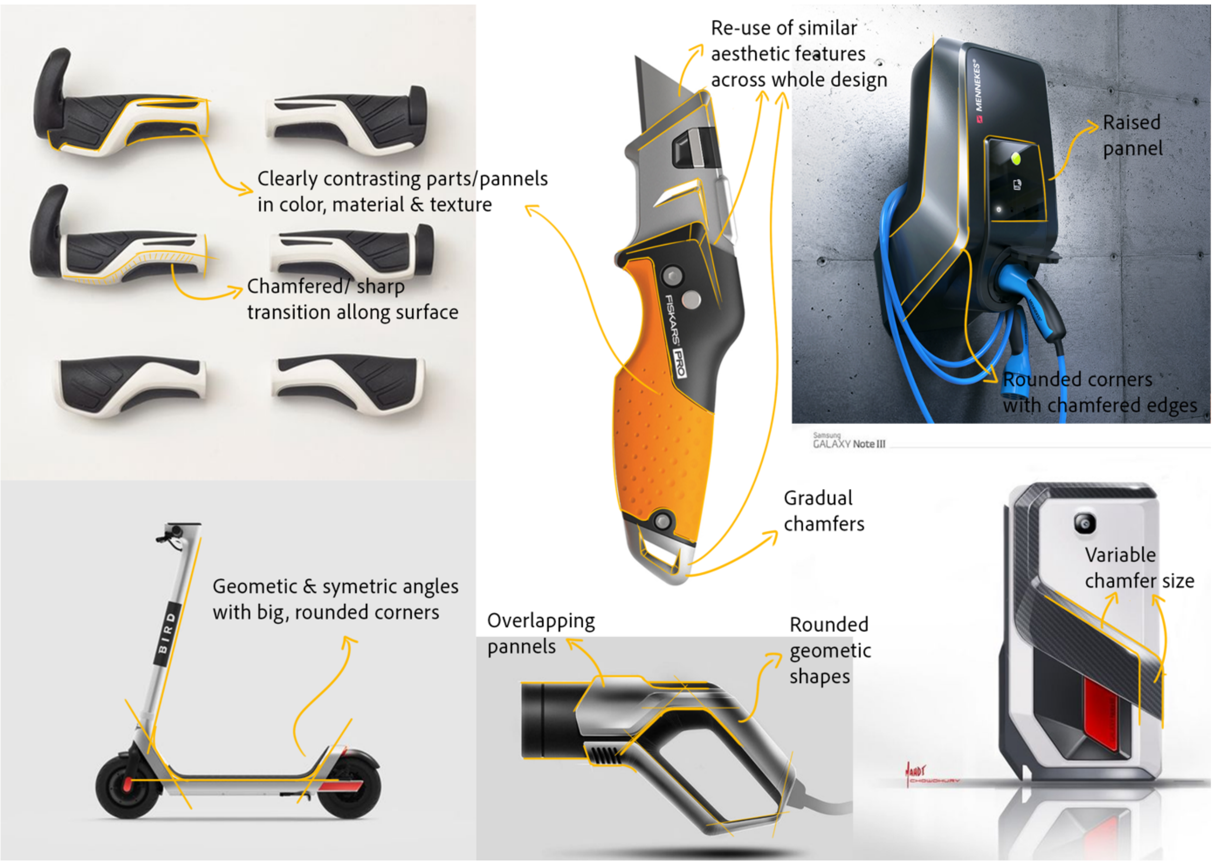
W9: The design should convey the intentionality of being hit by the bike/ pedals
Collisions between the UP-Charge and bike pedals are unavoidable. The flexjoint mechanism ensures that any contact with the pedals is not a problem, yet users may still find it unpleasant to let their bike pedals strike the UP-Charge. Thus, the design of the UP-Charge must clearly communicate that it is designed to endure such impacts and convey its resilience against pedal collisions. *The UP-Charge needs to look 'rugged'.*

W5: The design should fit the context of (semi-) public infrastructure/ bicycle racks.
The two-tier bicycle racks for the UP-Charge are part of the semi-public bike parking infrastructure. These products must endure various weather conditions and frequent use, blending seamlessly into the streetscape. As a result, they often appear simple or minimalistic and lack distinct features. Consequently, for the UP-Charge to fit that aesthetic, its *design should be more subdued rather than flashy*, especially when compared to consumer electronics or products that can be very expressive.

W4: The design should fit the aesthetic of the TILER product ecosystem.
R9: The design must contain TILER branding.
The UP-Charge is intended to be part of a broader TILER ecosystem created around its 'universal' charging solution, the Charging Kickstand. Therefore, it is important that it *incorporates the design aesthetic and features of both the Kickstand and Tile*. Additionally, as TILER naturally benefits from increased brand awareness to grow as a startup, there should be *clear TILER branding*.

Form language analysis

An analysis of various products has been conducted to identify a design language that aligns with the aesthetic vision of the UP-Charge. This selection includes consumer products associated with micro/electric mobility, bicycles, and other influences that shaped the UP-Charge's final design. A shared characteristic among these products is their ability to appear simultaneously rugged and modern, while avoiding an excessively futuristic look. An annotated overview of these products can be seen in figure XXX.

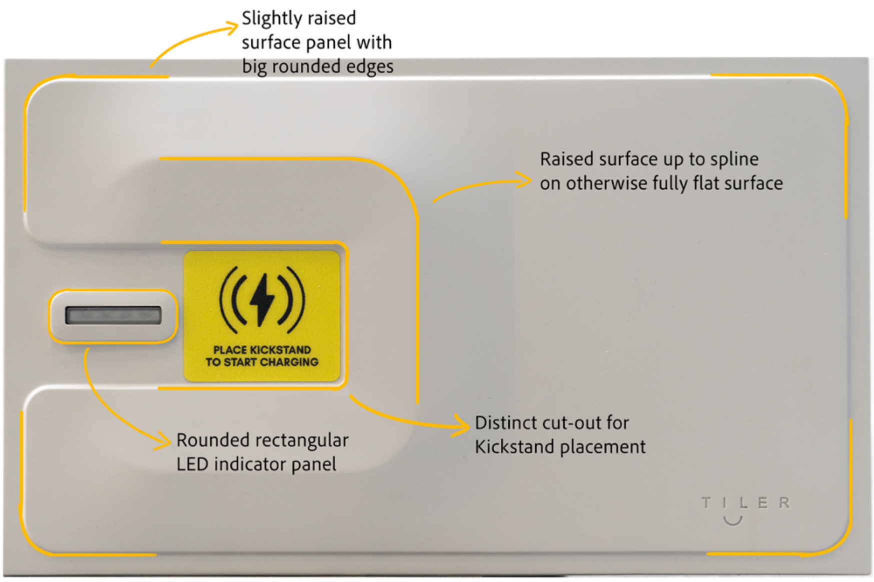


There are several main take-aways that were carried across to the design of the UP-Charge:

- **Rounded profile with chamfered edges.** The outside profile of these designs generally has many rounded shapes/corners that are contrasted by more angular chamfered edges as a transition between surfaces. This combination of rounded corners with chamfered edges gives these products a more rugged (compared to rounded edges) while not becoming too aggressive.
- **Chamfers with varying sizes.** The size of chamfered edges changes as they go around a corner to give it a more dynamic look.
- **Pronounced surface/pannel transitions.** The transition between different parts or panels of the products is extra pronounced by contrasting them in colour or exaggerating their size instead of seamlessly overlapping.
- **Lack of flat/ simple surfaces.** Generally, no surface is simply a flat plane. Rather they are broken up by either a chamfer or a sudden transition in the surface face.
- **Consistency in design features.** Even with many contrasting features, the design often borrows geometry from elsewhere to keep it cohesive. Angles, fillets, and chamfers (even though they are variable within a design feature) are mostly kept the same throughout the design.

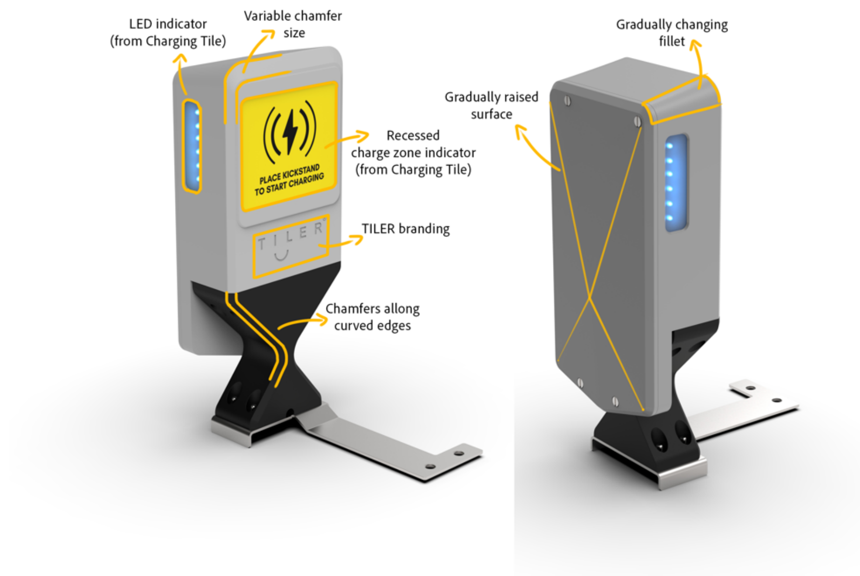
Charging Tile (ecosystem) design aesthetic

To fit in with the current TILER Charing ecosystem several aesthetic design features from the TILER Charging Tile were identified and used as reference for the design of the UP-Charge. These features are highlighted in figure XXX.



Implementation in UP-Charge design

Figure XXX shows how the design features from both the reference products and the Charging Tile have been implemented in the design of the UP-Charge.
The main aesthetic design features are the frequent combination of rounded corners and chamfered edges. Additionally, hints to the design of the Charging Tile have been implemented in the form of a raised and then recessed charging zone indicator, referencing the raised surface of the top of the Charging Tile. Additionally, the shape of the LED indicator was reused for a bigger LED window. The TILER logo has been embossed in the front of the UP-Charge.



Appendix M: Final prototyping process

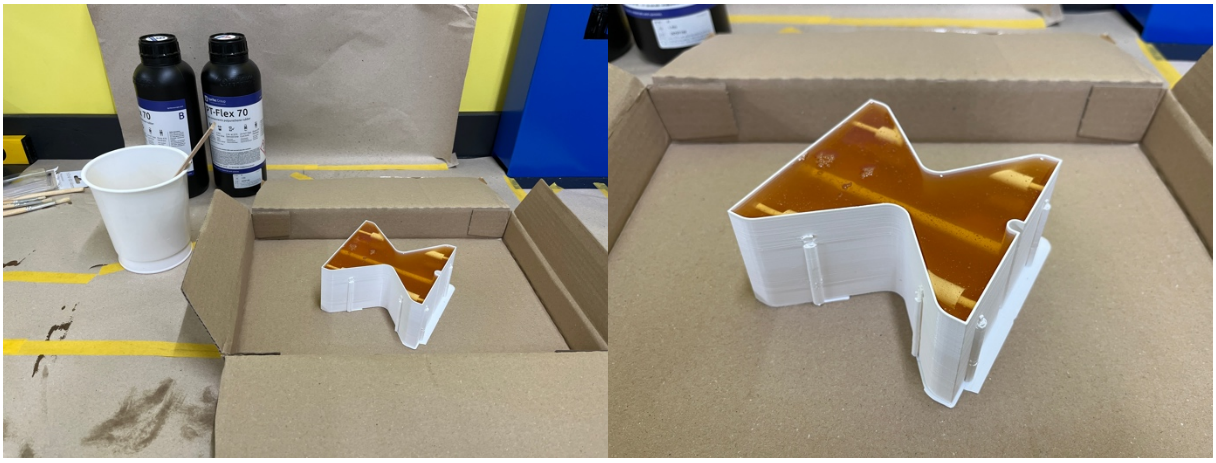
This appendix describes the prototyping process in the final stage of this graduation project. Prototyping was used in this stage to validate the theoretical performance of the UP-Charge design. The described process will include the making of a prototype for the initial design of the UP-Charge and its choices made to translate that design into a physical object, the functional testing of that prototype and its findings, and finally the reasoning behind and the prototyping of the final design for the TILER UP-Charge.

Initial (functional) prototype

The goal of this prototype, which can be seen in figure XXX, was to conduct simplified functional testing when mounted onto a bicycle rack and interacting with an E-bike fitted with the TILER Charging Kickstand. This prototype is a simplification of what a production version of the design would be, but it still needed to be dimensionally accurate, contain the main electronic components (to simulate its actual weight), and use a close representation of the polyurethane flexjoint.

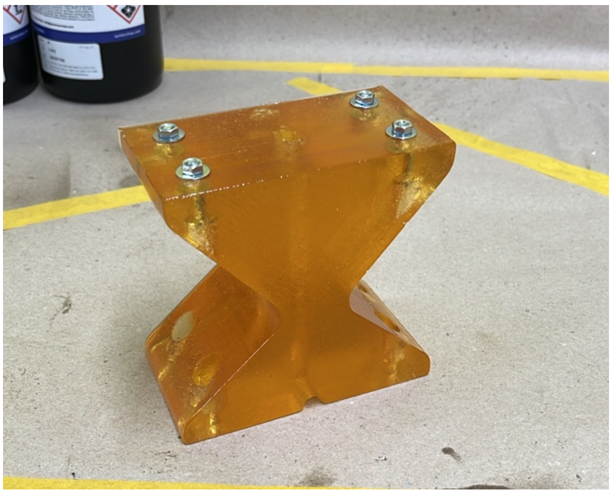
Flexjoint casting

To produce the polyurethane flexjoint, a two-part polyurethane rubber was poured into an open-face 3D printed mold, as shown in figure XXX. The type of polyurethane used was ‘PT flex 70’, where ‘70’ indicates the Shore A hardness of the material. This particular polyurethane was chosen for its quick curing and demolding capabilities, and its elastic modulus closely aligns with the theoretically required specifications for the flexjoint.



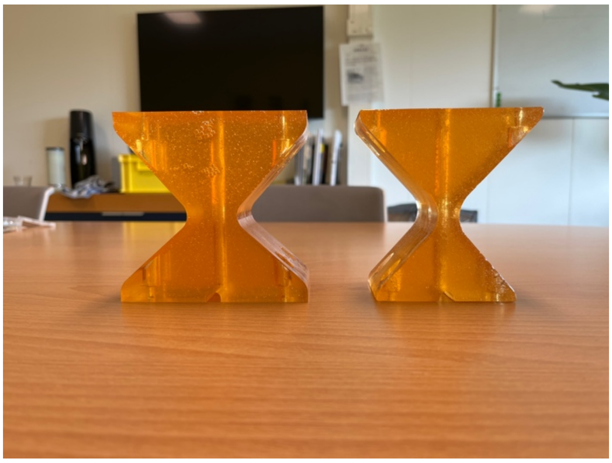
Single-use breakaway mould

The design integrated several holes throughout the model to attach the flexjoint prototype to the PTU prototype case and a mounting bracket. Figure XXX illustrates fasteners being inserted through these holes. During the moulding process, the mould included several cylinders inside the mould, so that they would ultimately leave cavities in the flexjoint upon removal. However, this approach required complete destruction of the mould to extract the cast flexjoint, making it impractical for actual production due to the labor-intensive removal and the requirement for a new mould for every UP-Charge. Nevertheless, this method proved effective for prototyping. In final production, fasteners could be cast into the polyurethane, allowing for a simpler and reusable mould.



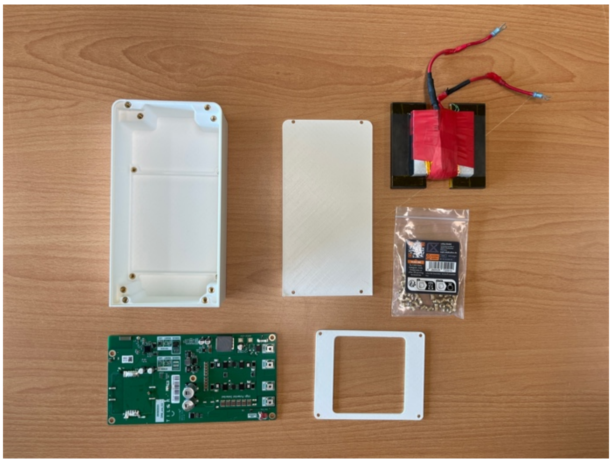
Flexjoint design adjustment

The flex joint was initially designed according to the specifications of the PT Flex 70 polyurethane rubber. Even though its Young's modulus was the closest to the theoretically determined required number, it was still lower than required. Therefore, the width of the tapered section in the flexjoint was increased to increase its stiffness. However, upon removal from the mould, this variant of the flexjoint proved nearly impossible to bend and would, therefore, be too stiff for use in the prototype.
A new version of the flexjoint was designed and cast, which had a new, smaller tapered section with a width of ± 12 mm. This new flexjoint can be seen in comparison to the original prototype in figure XXX.



Prototype assembly

The case of the initial UP-Charge prototype was 3D printed to accurately represent the dimensions of the design, despite not truly representing the intended material for the UP-Charge. All components shown in figure XXX were mounted inside of this case at their appropriate location to simulate the weight distribution. To mount these components, heated threaded inserts were placed in the 3D printed case, so that bolt could be screwed into it.



Prototype simplifaction

It must be noted that this prototype contains a simplification of the components required to have a functional final product. For this prototype, only the main electronic components have been included: the PTC and the PCB. The PTC, located at the proper height, was included as it is a significant part of the total weight in the PTU case. The PCB, while being relatively lightweight in comparison, was added as it is the main reason for the case being this size and shape.

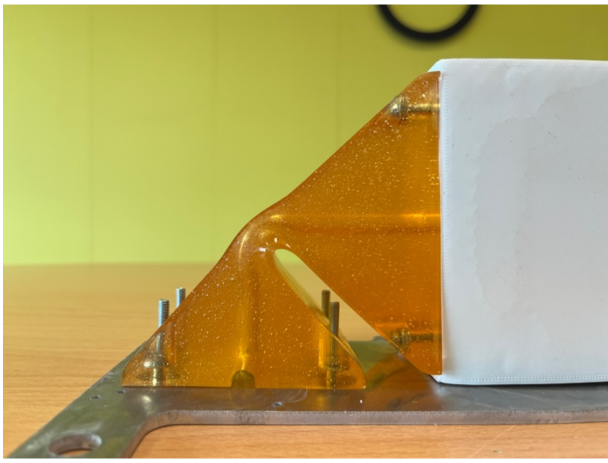
Functional prototype testing

This prototype version of the UP-Charge was used to answer the following questions:

- Does the flexjoint behave as expected and predicted?
    - Does the flexjoint bend 90˚ in both directions, without breaking/ permanent deformation?
    - Does the flexjoint bend only in the tapered section?
    - Does the flexjoint return back to the vertical/ neutral position after being released with the PTU case on top?
    - Does the flexjoint allow for added sideways flexibility?
- Does the prototype interact with an E-bike as intended when mounted to a bicycle rack?
    - Can pedals effectively push the prototype out of the way and fully return to the charging kickstand position?
    - Can the prototype be pushed all the way down to a horizontal position?

Flexjoint behaviour

During the prototype testing, the flexjoint's behaviour functioned as expected. Figure XXX shows a close-up of the flexjoint bending at a 90˚ angle, clearly indicating that bending occurs solely in the tapered section. The added sideways flexibility was also demonstrated, as seen in figure XXX. This feature ensures effective contact between the Charge-UP and the Charging Kickstand, even when the bike leans slightly to the side.

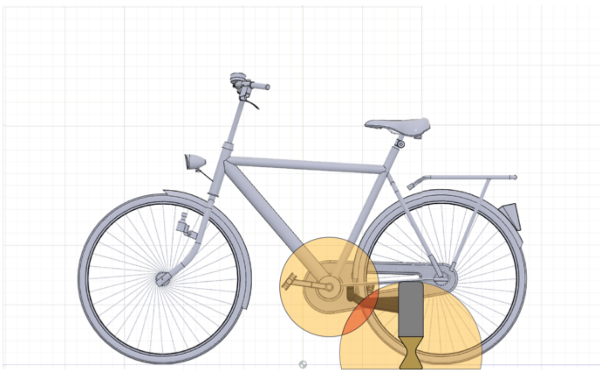


Pedal passage test

This prototype was tested on the 'flat' bicycle rack gutter in both the rear- and center kickstand positions, with corresponding E-bike models and pedals in several different positions. For the rear kickstand set-up, as shown in figure XXX, all pedal positions proved to successfully pass over the prototype, even when the pedals were in their most downward position. This can be seen in figure XXX where the E-bike is moved back out of the bicycle rack.

During testing of the prototype in the center kickstand position, most pedal positions caused no problem with regard to pedal passage. However, when the bicycle was pushed fully into the rack with the pedals in the position shown in figure XXX, they failed to clear the prototype completely. This resulted in the prototype getting caught under the pedals, preventing it from returning to the necessary vertical position for charging.

This problem of getting stuck under the pedals is caused by its total height. Because the PCB is included within the PTU case placed on top of the flex joint, this design is much taller than just the required height of the PTC. As a result, in this center kickstand position, the pedal collision zone overlaps with the prototype's movement as illustrated in figure XXX.



The initial design of the UP-Charge needed to be reduced in height so that it would work for all E-bikes and kickstand positions.

Final prototype iteration

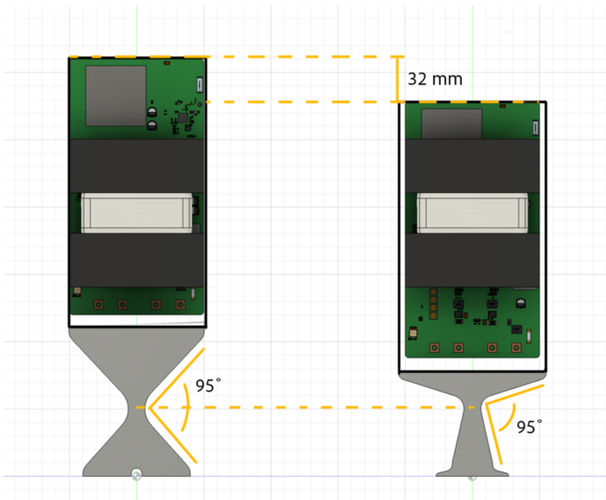
After the discovery of the design flaw with the previous prototype, a new version of the UP-Charge design was explored, prototyped and tested. In this iteration the total height of the design had to be reduced. There seemed to be 2 main approaches to this:

1. Keep all TILER custom electrical components, specifically the big PCB, the same and...
    a. Reduce the height of the flexjoint
    b. Find a new topology in which the PCB is placed lower
2. Advice TILER to develop a new custom, smaller PCB

The first option was explored, as developing a new custom PCB was not preferred due to the implied high R&D costs.

Flexjoint height reduction

The simplest method, requiring minimal alterations to the original design, was to maintain the case while reducing the height of the flexjoint. This approach allowed the case to be positioned lower, effectively decreasing the overall height of the design as illustrated in figure XXX.



This revised flexjoint design features a narrowed base. Since the angle between the sections above and below the flexjoint's tapered part must be at least 90˚, adjusting the flexjoint to be less symmetrical and creating a steeper bottom angle causes the section above the taper to flare out more rapidly, thereby achieving the necessary case width at a significantly lower height. As seen in figure XXX this reduces the height by 32 mm. In this redesign, the narrowest part of the flexjoint is still at the same height as the original to concentrate most of the bending in that location. The flange at the bottom was only added to mount the new flexjoint.

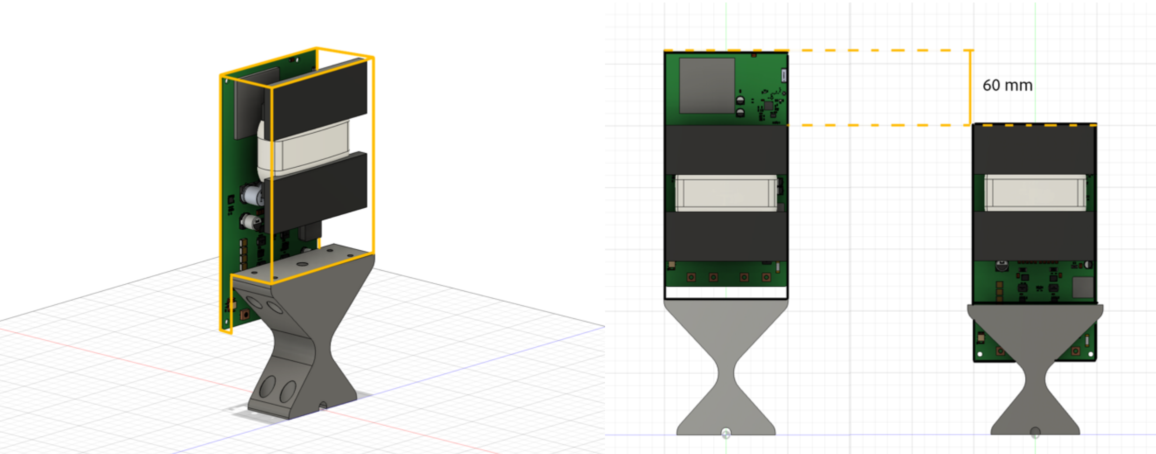
Lowered flexjoint testing

Testing the new flexjoint design was crucial. With the base now significantly smaller, the difference between the most tapered section and the base became less apparent. This might lead to the flexjoint bending differently, preventing the PTU case from lying completely horizontal on the ground. Additionally, tests were conducted to determine if the height reduction provided sufficient clearance between the prototype positioned on a center kickstand and the pedals.

This newly designed flexjoint was cast from polyurethane in a similar fashion to that of the earlier prototype. Figure XXX shows the lowered flexjoint fitted onto the previously used PTU case. This configuration was then placed on the bicycle rack for testing. Unfortunately, during testing, a specific pedal position still caused the prototype to get stuck under the pedals, as shown in figure XXX.

Lowering PCB (new topology)

As the lowered flexjoint version didn’t decrease the design height enough, a different strategy was tried. This involved completely altering the PCB's topology in relation to the flexjoint, requiring a full redesign of the PTU case. In this new approach, the PCB was lowered and positioned ‘behind’ the flexjoint. Figure XXX shows this updated topology, with the general shape of the PTU case indicated in yellow. For this design to be effective, the flexjoint's thickness was decreased from 60 mm to 40 mm. This modification led to a height reduction of 60 mm, as depicted in Figure XXX, which was assessed to be sufficient for clearing the pedals in the central kickstand position.



Appendix N: User testing

This appendix explains and analyses the user testing conducted with the final prototype of the UP-Charge. It will go over the process of user testing and give further details on the extracted information from testing.

Testing set-up

The user testing consisted of 3 main parts:

1. Short questionaire to gather basic participant information, such as age, gender and familiarity with E-bikes and two-tier bicycle racks.
2. User test task in which participants were asked to place an E-bike in the bicycle rack with the prototype wireless charger mounted to it.
3. Post-test interview with the participants about their experience and thoughts on the product.

The following text describes the exact questions asked and instructions given to the participants:

General questions (questionaire)

1. What is your age?
2. What is your gender?
3. Have you ever used an E-bike?
   a. No → Proceed to question 5, skip questions 6 and 8.
4. Do you own an E-bike?
5. Have you ever placed a bike in a double-layer bike rack, such as those found at train stations?
   a. No → No further questions.
6. Have you ever specifically placed an E-bike in a double-layer bike rack?
   a. No → Skip question 8.
7. Would you describe placing a bike in a double-layer bike rack as something you do daily, weekly, monthly, or less frequently?
8. And for an E-bike? Daily, weekly, monthly, or less frequently?

Instruction:

This is an E-bike with a special charging kickstand. Normally, it charges the E-bike when you park it on a special charging tile. This stand has been adapted so that it can also be wirelessly charged from the side.
A wireless charger is mounted to the bike rack, which automatically charges the E-bike through the kickstand.
I would like to ask you to ride the bike to the rack and then park it on the left side of the rack, as you think it is the correct way.
After that, you may lock the bike, walk around the rack, and then remove the bike from the rack.

That will be the end of the user test. Afterwards, I would like to ask you some feedback questions.

Interview questions:

1. What were your thoughts or experiences when placing the bike in the rack and using it?
2. Are there any modifications or additions that would make using this charger better or easier?
3. Do you have any other feedback regarding the usage or design of the charger?

Test participants

Five users were tested. All participants were male and between 20 and 24 years old. Participants were questioned about their familiarity with E-bikes and bicycle racks, as their past experiences moving bikes—and particularly heavier E-bikes—into racks was anticipated to affect their performance in the user test.
Four out of five participants had used E-bikes before. However, despite all participants indicating that parking bicycles in two-tier bicycle racks was something they regularly did on a weekly or daily basis, no one had parked an E-bike in a two-tier bicycle rack before.

User test highlights

All user tests were video recorded in order to analyse the behaviour of the participants during testing. From these videos, the most insightful moments are highlighted and explained below. All associated interview transcriptions can be found in Appendix XXX.

Participant 1
During the user test of participant 1, the pedals were in such a position that they skimmed right over the top of the prototype, resulting in the prototype moving slightly back and forth. This moment can be seen in figure XXX. However, in a subsequent interview, the participant indicated that they were unaware of the movement of the prototype, nor its intended flexibility.

Participant 2

Participant 2 was observed to be moving the bicycle in the rack by completely lifting the pedals over the prototype, as shown in figure XXX. Upon removal of the bike, it did not hit or move the prototype at all. This lifting behaviour was later indicated to be normal bike parking behaviour for this participant. Despite this, the participant also seemed to be totally unaware of the prototype's ability to move.

Participant 3

The third participant showed a different interaction with the prototype. When placing the bike in the bicycle rack, he stopped right before the prototype and manually rotated the pedals into such a position, as shown in figure XXX, that they would not hit the prototype. When removing the bike from the rack, he lifted up the back of the bike to move it over the prototype, which can be seen in figure XXX..

Participant 4

In user testing with participant 4, it was not until the bike was removed from the bicycle rack that the pedals hit the prototype, causing it to move out of the way. This moment was captured in figure XXX. The interview afterwards indicated that, even though the participant was previously unaware of the prototype's ability to move, this ‘incident’ eventually demonstrated its intended behaviour. However, the participant still indicated that they were unsure whether this movement was harmful to the prototype.

Participant 5
When this participant placed the bike in the rack, he accidentally struck the prototype with the center of the crankarm instead of the pedals because he leaned the bike slightly left, as shown in figure XXX. As a result of the prototype's movement, he noticed its ability to flexibly move back and forth. However, in a later interview, he mentioned that he initially anticipated the prototype to be completely rigid, given the design of the flexjoint.

Appendix O: User testing interview transcriptions

This appendix contains the transcriptions of interviews conducted after user testing the final prototype. As all participants were Dutch, these interviews were also held in Dutch.

Participant 1

Interviewer: Oké wat was je ervaring of je gedachten bij het plaatsen van de fiets in het rek zoals het nu is?

Participant: Ja, het is eigenlijk net als een normale fietsenstandaard. Het enige is dat je door die laadpaal dat je trapper daar tegenaan kan komen. Dat je daar rekening mee moet houden, maar het is heel simpel, je zet je fiets erin en het is klaar. Met bijzondere of speciale ophanging. Het is vrij makkelijk.

Interviewer: En dat je trapper er tegenaan zou komen, is dat iets waarvan je dacht... Oh, dat is iets wat ik niet wil of dat is iets wat vervelend is?

Participant: Nou ik zou wel bang zijn dat ik dat ding beschadig.

Interviewer: Ja, de fiets of de oplader?

Participant: De lader, ik weet niet hoe stabiel dat ding staat?. Maar ik denk dat als zo ontworpen wordt dat hij een stootje kan hebben.
Ik zou het wel fijn vinden als ik er geen rekening mee hoef te houden. Dat ik niet mijn trapper omhoog hoef te positioneren.

Interviewer: Oké bij jou kwam hij nu toevallig perfect uit. Hij is namelijk inderdaad zo ontworpen dat als je met je trapper tegenaan komt, dan gaat hij plat, dan gaat je trapper er overheen.
Maar bij jou ging hij zowel bij vooruit als achteruit, dan kwam je trapper er niet tegenaan. Ik weet niet of dat iets was wat je, specifiek zelf aan het mikken was. Ja, hij scharniert plat om je fiets er overheen te laten gaan.

Participant: Er is wel al goed overnagedacht dus

Interviewer: ja, dat is wel, dat is het idee achter de oplader inderdaad.
En inderdaad, ik had eerst een idee met dat hij gewoon blijft staan, maar op een gegeven moment gaat iedereen gewoon z'n fiets er tegenaan rijden en dat ding gaat gewoon kapot, dat overleeft ie niet.

Participant: Ja inderdaad wel slim gedaan.

Interviewer: Zijn er aanpassingen of toevoegingen waarvan je denkt dat zou het gebruik makkelijker of beter maken van zo'n draadloze oplader?

Participant: Ja hoe zou dit werken als er meerdere naast elkaar hebt staan? Omdat je dan ook zo klappen kan krijgen, bijvoorbeeld.
Interviewer: Dat die vanaf opzij er tegen aan komt?

Participant: Ja als dicht naast elkaar staan, dat je dan een andere misschien raakt met het afstappen.

Interviewer: Ja, in principe, is dit natuurlijk een heel kort stukje uit een dubbel laag fietsrek.
Normaliter heb je natuurlijk een hele rij en zit er een laag boven, maar in principe kan je normaal niet zelf naast het rek komen,

Participant: Oke

Interviewer: Daar zitten er inderdaad andere fietsen voor de rest van het rek. En als er een fiets naast staat zodra die in principe gewoon in de goot gaat, kan die het niet raken.

Participant: Dan zou ik in principe niks toe te voegen hebben.

Interviewer: Nog andere feedback over het gebruik van of het ontwerp van het ding?

Participant: Nee, ik vind het een heel slim idee. Het zou echt wel een toevoeging zijn.

Interviewer: Oké thanks. Dan was dat het voor nu.

Participant 2

Interviewer: Wat was je ervaring of wat waren je gedachtes bij het plaatsen van de fiets in het rek?

Participant: Het ziet er een beetje breekbaar uit. Het is meer toen ik erin fietste en als ik in mijn fiets in het rek zet, ga ik niet opletten hoe voorzichtig ik ermee moet doen. Dus als ik mijn fiet gewoon erin ram zeg maar, dan kan het zijn dat je, zeker aangezien dat ding ook wel dikker is dan normale standaard, dat je er een beetje tegenaan zit, zodat hij een beetje kan gaan buigen. Maar voor de rest, prima.

Interviewer: Je tilde op een gegeven moment de fiets op, over dat ding heen. Waarom was dat?

Participant: Over welk ding bedoel je precies?

Interviewer: Op een gegeven moment toen we hem erin zette, toen tilde je de hele fiets als het ware erin. Is dat bewust of zet je altijd op die manier je fiets in het rek?

Participant: Dat is automatisme, ja. Ik kom aanrijden ik zet mijn voorwiel gewoon erin en dan rij ik hem gewoon op die manier erin

Interviewer: Zijn er aanpassingen of toevoegingen die het gebruik van het rek met die oplader makkelijker zouden maken in jouw ogen.

Participant: Ik heb niet het idee alsof de oplader per se in de weg staat. Als je met een kettingslot zit, ja, dat ding waar je hem vast maakt, zit aan de andere kant. Dus dat is ook geen probleem. , Ik zou hem misschien iets verder weg zetten, dat hij er niet tegenaan stoot als je bezig bent. Maar ik weet niet hoe dat zit met de draadloze oplader.

Interviewer: Ja, uiteindelijk moet hij wel een beetje contact maken. Er kan wel een beetje een air gap tussen zitten, maar hij moet eigenlijk wel in range zijn natuurlijk.

Participant: Ja, of je moet ergens met iets van een feedback spring in, dat je dan wel een beetje resistance hebt, maar dan wat voor speling kan creëren op die manier.

Interviewer: Toevallig tilde jij hem dus inderdaad er overheen maar het hele ding waar hij op staat is flexibel. Dus hij kan helemaal plat en hij kan ook opzij bewegen.

Participant: Dat is wat ik net heb gezegd. Dan is het prima. Dan hoef je nergens zorgen om te maken denk ik.

Interviewer: Maar dat was dus niet iets waarvan je verwachtte dat hij dat zou doen?

Participant: Nee, hij ziet er gewoon op die manier rigide uit als je er tegenaan drukt.

Als ik nu beter kijk, dan zal er wel ergens een rotatiepunt zitten, maar je zou denken dat het makkelijk te breken is, zeg maar.

Interviewer: Ja het is nu ook een prototype, dus deze is ge-3D-print. Je hoort ook dat hij een beetje hol is als je tegenaan botst.

Dat is natuurlijk niet hoe hij in het echt zal zijn, maar dat is wel de behuizing.

Participant: je kan de layer lines wel zien inderdaad

Interviewer: Heb je nog overige feedback over het gebruik of het ontwerp zelf van de oplader?

Nee, niet echt. Dit was het wel.

Interviewer: Top, dan was dat hem.

Participant 3

Interviewer: Wat was je ervaring of je gedachtes bij het plaatsen van het fiets in het rek met de oplader?

Participant: Het leek best wel op een normale fiets in de rek plaatsen, maar toen opeens zat die trapper die kwam er tegenaan. Die moest ik even verder trappen, maar dat ging vrij soepel eigenlijk en hetzelfde bij het eruit halen.

Voor de rest voelde het hetzelfde als een normale fiets in de rek plaatsen.

Interviewer: Zijn er aanpassingen of toevoegingen waarvan je denkt, dat zou het makkelijker maken of beter maken om met deze oplader een fiets in het rek te zetten? Vooral aan de kant van de oplader.

Participant: Ja, die kan je niet echt onder de trapper zetten, dat wordt die wel heel laag.

Misschien daar iets mee dat hij niet tegen de trappen aankomt, maar voor de rest niet.

Interviewer: Ja, dat hij niet er tegenaan zou botsen

Participant: Ik had het nu eigenlijk ook eerst niet door, toen botste hij tegenaan.

Interviewer: Het is wel interessant dat je het zegt inderdaad want hij is gemaakt om de trapper tegenaan te laten botsen Misschien zag je ook wel dat hij een beetje heen en weer bewoog net, toen je hem naar achter haalde . Als je met de trapper er tegenaan komt, kan hij in principe helemaal plat. Dan kan de trapper er overheen.

Participant: Oh, dus ik heb hem helemaal verkeerd gebruikt ook.

Interviewer: Nou ja, dat is dus ook deel van de test. Hebben mensen door dat dat kan? . Of gaan mensen de hele tijd lopen pielen met de voeten om de trapper goed te zetten.

Of hebben mensen er het vertrouwen indat het vanzelf gaat. Je wil natuurlijk niet dat bij elke oplader iemand moet gaan staan met een soort instructiebordje met 'he je mag hem er gewoon tegenaan rijden'.

Participant: Ja, ik was een beetje bang dat ik hem kapot zou maken.Je wilt het nooit riskeren ofzo. Je kan er wel vanuit gaan dat het meebuigt, maar voor het weten is die kapot.

Interviewer: Ja precies. Maar dat werd er nog niet zelf uit duidelijk ?

Participant: Nog niet helemaal, nee.

Interviewer: Oké, top. Heb je nog overige feedback over het gebruik of het ontwerp van de oplader?

Participant: Het ziet er heel simpel uit. Het ziet er niet heel ingewikkeld uit. Dus dat is goed, I guess. Nee, niet echt.

Wel een leuk idee, ik vind het een leuk idee.

Thanks. Ja.

Interviewer: Dan waren dat alle vragen.

Participant: Nou, perfect.

Participant 4

Interviewer: Wat was je ervaring of je gedachtes met het in het rek plaatsen van de fiets?

Participant: , Ik had eerst het gevoel van moet ik die standaard nog naar beneden doen ofzo, maar toen zag ik dat hij er wel netjes op aansluit. Dus toen, was dat prima. Ik merkte wel toen ik hem eruit pakte dat de trapper er tegenaan kwam en dat hij daardoor een beetje bewoog ook.

Maar ja, verder ergerde ik me daar niet aan of zo.

Interviewer: En dat die trapper er tegenaan kwam en dat hij daardoor heen weer ging, voelde dat als, ik ben het nu aan het slopen?

Participant: Hij bewoog gewoon mee, dus nee eigenlijk niet. Ja, precies. Maar het voelde wel een beetje alsof het niet de bedoeling was, zeg maar.

Interviewer: Oké. Ja, want het is inderdaad dus wel de bedoeling. Daar is het inderdaad voor ontworpen dat als je er met de trappers tegenaan komt, dat hij gewoon uit de weg kan bewegen, zodat niet dat ding kapot rijdt.

Zijn er nog aanpassingen of toevoegingen aan deze setup die het gebruik ervan makkelijker of beter zouden maken?

Participant: Misschien kan je dat scharnierende mechanisme maken dat het iets duidelijker in beeld is , zodat je gewoon ziet dat hij ook echt kan bewegen. Of misschien iets erop tekenen ofzo, een plaatje, weet ik niet, zoiets misschien.

Interviewer: Ja, want nu was het nog van tevoren niet helemaal duidelijk dat hij kan bewegen?

Participant: Nou, nee.. Ja, misschien als ik wat beter had gekeken, waarschijnlijk wel, maar dat had ik nog niet gedaan. Maar ik denk wel, als je dit één keer gebruikt, dan snap je het ook wel. Dus dat is het nu. Ik snap het nu. Nu is het niet meer vreemd.

Interviewer: Ja. Maar als je het voor het eerst gebruikt?

Participant: Ja, dan is het even wennen denk ik.

Interviewer: Heb je nog andere feedback over het gebruik of het ontwerp zelf van het ding?

Participant: Kan ik even wat dichterbij kijken?

Interviewer: Ja, tuurlijk. Ja zeker.

Participant: Ja, je moet natuurlijk oppassen, dit staat op de grond dus mensen gaan er misschien wel keer op staan ofzo. Misschien dat het trouwens ook wel meevalt als je hier nog een rek hebt. Maar , je moet natuurlijk oppassen dat het wel tegen een stootje kan denk ik. Dus misschien moet hij ook in deze richting kunnen scharnieren ofzo.

Interviewer: Dat kan hij ook inderdaad. Dus deze kant op heeft hij wat flexibiliteit, maar hij is vooral in deze richting flexibel. Het is polyurethaan wat ik heb gegoten.

Participant: Dat is het zelfde material als skateboard wielen toch?

Interviewer: Ja, dit is dan een wat zachtere variant

Participant: Ja ik vind het eigenlijk gewoon wel een heel goed ontwerp als dit gewoon sterk genoeg is, dan zou je er niet heel veel meer mee moeten doen.

Interviewer: Ja hij is nu ge-3D-print, maar uiteindelijk wordt hij natuurlijk niet ge-3D-print. Uiteindelijk willen we hem gaan maken van sheet molding compound, dus dat is ook waar autobumpers van worden gemaakt.

Dus dat kan dan wel tegen een beetje impact. Dit natuurlijk, als je hier vol gas tegenaan fietst, dan gaat hij gewoon kapot omdat het een 3D print is.

Participant: Ja, nee, dat zit goed denk ik. Ik zou wel een soort van, dingen waar ik dan aan zou denken is, dat ik zelf bij die rekken af en toe het gevoel heb dat die sensoren heel slecht werken, omdat dan staat er, er zijn nog honderd plekken vrij en dan is er echt niks zeg maar, dus misschien dat je hier iets aan kan toevoegen dat je het wel echt door hebt als er een kapot gaat dat je hem dan kan vervangen zeg maar. Dat je bijvoorbeeld een soort stroomsterke meter hebt ofzo, dat als het dan op nul staat, dat je het dan door hebt.

Interviewer: Ja, dus dat je kan zien , stel je hebt er 100 naast elkaar staan, welke het nog doen...

Participant: Op een gegeven gaat er natuurlijk gewoon een keer iets kapot en dan moet je dat wel in de gaten kunnen hebben.

Interviewer: Ja, zeker. Nu met de tegels, die zijn ook verbonden met een cloud systeem. Die kun je dus met een dashboard uitlezen.

Participant: Ja, dat is ideaal natuurlijk.

Interviewer: Dus in principe is het idee om dezelfde technologie hier in te stoppen. En dan zou dat op die manier ook werken.

Participant: Ja nee, ik denk dat het prima kan werken.

Interviewer: Oké

Participant: Leuk project.

Interviewer: Top. Nou, dat waren voor mij de vragen.

Participant: Oké

Participant 5

Interviewer: Wat was je ervaring of je gedachtes bij het plaatsen van de fiets in het rek met deze oplader?

Hoe vond je de ervaring?

Participant: Ik dacht dat ik mijn fiets er gewoon in zou kunnen zetten en er gewoon doorheen zou kunnen rijden. Alleen het was leuk om te zien dat hij zo flexibel was en heen en weer bewoog.

Interviewer: Oké maar dat was dus iets wat je niet verwachtte?

Participant: Als ik er zo naar zou kijken, zou ik niet 1, 2, 3 verwachten dat hij heen en weer beweegt.

Interviewer: En zijn er aanpassingen of toevoegingen die het gebruik van deze oplader beter of makkelijker zouden kunnen maken naar jouw mening?

Participant: Ik denk dan inderdaad kijken naar dat het overkomt als flexibeler dus wat ik zelf vond is dat de onderkant een beetje glimt en zwart is waardoor het voor mij een beetje leek op iets van staal of metaal achtig dus daardoor misschien wat minder flexibel leek. Dus misschien daar een aanpassing in maken dat het wat flexibeler wordt, of lijkt in ieder geval voor de mensen.

Interviewer: Dat hij meer uitstraalt dat het flexibel is?

Participant: Ja, want ik vond de flexibiliteit er juist heel leuk in. En goed om te weten.

Interviewer: En heb je nog andere feedback over het gebruik of het ontwerp zelf van de oplader?

Participant: Ik vind het een mooi design. Het is clean en ook klein, best wel modern. Dus ik vind dat het wit en zwart tegelijkertijd ook wel weer juist een hele mooie look. Alleen de flexibiliteit dat is het goed om mee te nemen. Maar los daarvan vind ik het heel mooi design.

Interviewer: Oké dan dank je wel.