GRADUATION REPORT

UNIVERSAL CHARGER FOR SHARED E-BIKES

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Abstract

The market for shared mobility has seen massive growths in recent years. Pollution and congestion requires us to rethink how we move around and new technologies make sharing continuously easier and more convenient. Society is slowly moving towards a mindset that values access over ownership, and this is also the case for (urban) mobility. Research has shown that convenience is the most important factor for people to engage in shared mobility and the rising demand leads to all kinds of light electric vehicles popping up in our streets. Especially e-bikes gain market quickly, both in the form of publicly shared vehicles as well as within corporate fleets.

But with operating shared mobility programs also come challenges, and keeping all those vehicles charged is definitely a major one. Free-floating vehicles are often charged by manually swapping its batteries, while dock-based schemes rely on its users connecting the charger after use of the service. Docking stations for e-bikes exist that combine locking the bike in a physical dock with charging its batteries, but they are often expensive, take up a lot of valuable (public) space and are bike-specific. Next to that, contacts suffer from breaking, mechanical wear and corrosion.

The start-up TILER is currently developing a universal wireless charging solution for e-bikes, however the physical form of a charging tile with an accommodating kickstand is not considered as the ideal physical form to apply wireless charging to shared vehicles. Therefore, a graduation project was set up to explore alternative solutions and design a universal and convenient charger for shared electric bicycles.

The result of this project is the TILER Click, a product that makes charging an integral part of retrieving and returning shared e-bikes from their hub. The easy alignment in combination with a simple yet efficient clicking mechanism make the TILER Click so simple to connect and disconnect that it is no longer an effort to charge the bike. Placement of the receiver on the rear of the electric bicycle make the product extremely universal and versatile, regardless of bike geometry.

The TILER Click offers a convenient, simple and reliable way of keeping e-bike fleets charged. With that, it not only enhances the experience of charging itself, but also has a positive impact on the user experience of the entire system. Being able to charge shared e-bikes in a uniform and simple way can play a crucial role in the future of (shared) mobility.

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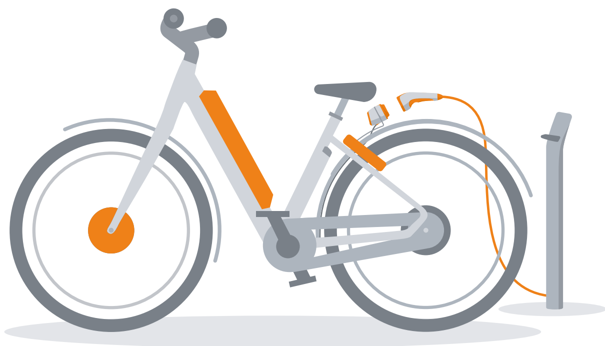


figure 1.1 The first ever wireless charging tile by TILER was installed in Delft in December of 2020

1 Introduction

The use of electric bicycles has seen massive growths in recent years. More than a quarter of all cycled kilometers in the Netherlands last year are accounted for by e-bikes, equalling over 4,1 billion kilometres (De Haas & Hamersma, 2020). Especially in the age group below 50, e-bike usage is increasing rapidly and commuting on e-bike has become popular.

People perceive all kinds of benefits of using electric bicycles. A riding bike requires about 28 times less space than a driving car (De Haas & Hamersma, 2020), e-bikes are usually quicker through the city (Zoelen, 2016) and using the bicycle to travel to work has shown beneficial to both physical and mental health (De Haas & Van den Berg, 2019). This shows that the electric bicycle is here to stay and will play an important role in the future of mobility.

Next to consumer e-bikes, the market for B2B e-bikes is expanding as well. Bike fleets that are shared by multiple users are growing and Nieuwsfiets.nu (2019) estimates that by 2022, there will be over 300.000 B2B e-bikes in the Benelux alone.

A major challenge in running these e-bike fleets is to keep the batteries charged (Fellin, 2020). Companies struggle with keeping track of when batteries need to be charged (Mobility Lab, 2020) and charging batteries inside causes serious risks for companies and resulted in fires at among others Stella and Domino's (NOS, 2018; Stolk, 2019).

Next to corporate shared bikes and consumer e-bikes, the publicly shared e-bike and other light electric vehicles show a steady uprise in society. A combination of new technologies and a shifting mindset that values access over ownership make shared e-bikes and other Light Electric Vehicles (LEVs, figure 1.2) an excellent alternative for the car. Especially for improving reachability and air quality in the city, sharing electric vehicles come forward as a promising solution (Beemster et al, 2020).

Charging these shared vehicles still poses serious issues, says Hagels, Managing Director at shared e-bike provider Urbee (personal communication, 27-10-2020) and has a negative impact on reliability of the system towards users. Charging is seen as one of the major hurdles in operating shared micro-mobility services (Gauquelin, 2020; Fellin, 2020; Hasenberg & Schönberg, 2020) and current solutions are often large and bike-specific (Veenman, 2021; N. Hagels, personal communication, 20-01-2020). Charging of free-floating shared vehicles like Felyx' mopeds and Lime's scooters e-bikes even happens by manually swapping the batteries (e.g. Felyx, n.d.), which financially impacts the services.

TILER is currently developing a system that can charge e-bikes wirelessly and outside through a special kickstand in combination with a charging tile integrated in the pavement (figure 1.1). The system developed by TILER prevents corrosion, mechanical failure or congestion of connectors and their smart electronic system prevents overcharging or overheating the batteries. Keeping track of real-time battery levels allows providers and users to keep overview on which bikes are fully charged and thus can be used.

Publicly shared bicycles pose a promising application of TILER's technology of wireless charging, though the combination of tile and kickstand might not be the best physical form in this scenario. With scarcity in space, the amount of bikes that can be parked per meter is important (D. Basta, personal communication, 19-10-2020) and using the kickstand requires more space between bikes. A double kickstand limits choices for providers and the kickstand is one of the parts of the NS OV-fiets that has a relatively short life cycle (A. de Hoogd, personal communication, 19-09-2020). Furthermore, the tricky alignment of the kickstand with the tile might not be in line with the convenience that attracts people to shared e-bike systems (Fishman, 2016).

To further explore the application of the charging technology of TILER for shared e-bikes, a product has been developed as part of a graduation project. This report outlines the outcome of this project. A thorough research into the context of shared mobility, current and future solutions for charging shared LEVs and the promising technology that is wireless charging has been used as input for a universal charging solution that benefits both providers and users of shared e-bikes.

This process resulted in the TILER Click: a simple to use and universal charging solution for shared e-bikes (cover image). The concept offers an intuitive and recognizable way of charging vehicles, while making connecting and disconnecting the charger an integral part of returning and retrieving a bicycle. Its clever placement on the bike allows for easy and convenient alignment of the charger.

With the TILER Click, a full battery is guaranteed. Therefore, the product not only improves the experience of charging a shared bicycle itself, it can also positively impacts the perception of the entire MaaS system.

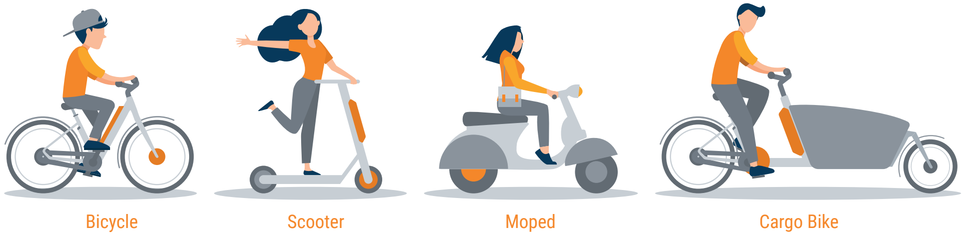

figure 1.2 Typical types of light electric vehicles (LEVs) often seen in shared context

Context Analysis & Research

part I

2 Context

Congestion and local pollution requires us to rethink how we engage in mobility (Deloitte, 2018; Avital et al, 2015). In the future, more vehicles like cars, mopeds and bicycles will be shared. Ideally, these vehicles are carbon neutral to fit in with Europe's future vision on carbon neutral cities (Nu.nl, 2020).

The sharing of electric vehicles asks for systems to book a vehicle, but it also requires hubs to store the vehicles. Furthermore, it requires a reliable charging infrastructure to ensure a full battery for every trip. New technologies, demographic developments and cultural changes all contribute to an important role for shared mobility in the future. Appendix A outlines the factors that drive the growth of shared mobility, though the most important trends and developments are also discussed in this chapter.

2.1 A Brief History

The first ever bike sharing program was the White Bicycle Plan in Amsterdam, introduced in 1965 (Pacheco, 2015) (figure 2.1). The initial purpose: lower the amount of cars in the city (Koops, 2018). Though multiple parties – including the municipality of Amsterdam – showed interest in the concept, theft and vandalism led to the termination of the plan.

Mobility as a Service (MaaS) systems have grown steadily through the years, with a massive growth in recent years (Pacheco, 2015) as new technologies like smart locks and GPS tracking diminish issues with theft and vandalism. Bike sharing has always been one of the major forms of shared mobility, with bike sharing programs in cities worldwide. The dock-based systems that can be found in e.g. Paris, New York or Taipei are likely the most well-known examples (figure 2.2).

Sharing is seen not only in mobility, but an entire new 'Sharing Economy' is arising: from taxi rides to laundry machines and from clothes to music. This is fed by a changing mindset that values access over ownership (Leung, Xue & Wen, 2019; Schönberg, Dyskin & Ewer, 2018).

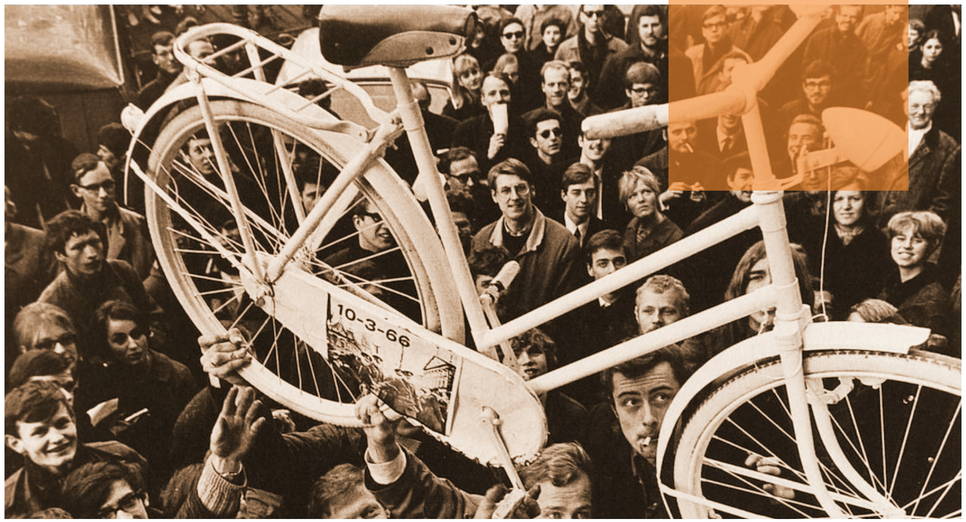

figure 2.1 The White Bicycle Plan is viewed as the first ever shared bicycle program

figure 2.2 Docked bicycle sharing scheme in London, United Kingdom

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The six key success factors for MaaS-systems, determined by Roland Berger (Schönberg, Dyskin & Ewer, 2018):

High-density network

Highly concentrated and comprehensive networks of vehicles and widespread program coverage ensure high accessibility.

Multimodal integration

Integration of infrastructures, information structures and payment with other mobility services enables convenient transfers.

Simple handling

User-friendly, app-based rental processes and no advance registration increase usability and reduce entry barriers for new users.

Smart data analytics

Use of data-driven applications optimizes pricing and operations while creating additional revenue streams.

High-quality vehicles

Easy-to ride but also sturdy and weatherproof vehicles ensure a comfortable riding experience and reduce maintenance costs.

Support of local authorities

Support of local authorities, e.g. in terms of bike lanes, accessibility of public spaces and links to public transport can boost success.

2.2 Convenience of Sharing

Research institute Roland Berger has composed a list of the six key success factors for shared mobility (insert) (Schönberg, Dyskin & Ewer, 2018). Convenience was found as the most important reason for people to engage in MaaS-systems (Fishman, 2016), with the distance to available vehicles as a close second. The importance of convenience for the success of shared bicycles is also mentioned by founder of the OV-fiets Ronald Haverman: “If we want people to share bicycles, we have to make it as easy as possible” (Slütter, 2018). The importance of making sharing simple was also mentioned by Sylla, founder of Deelfiets Nederland (personal communication, 02-10-2020).

As part of the conveyed convenience, the density of MaaS-systems is crucial to its survival. Free-floating systems are popular because proximity to a dock or hub – on both sides of the trip – does not have to be considered. Current systems usually work with a back-to-one principle, where vehicles need to be returned to the same hub as where the trip started. A large density of hubs and a solid user base allows back-to-many systems, as natural distribution will occur (Urbee, n.d; Schönberg, Dyskin & Ewer, 2018).

2.3 Mobility Hubs

One of the most important developments in future mobility is the Mobility Hub (Heineke, Kloss & Scurtu, 2019; Schönberg, Dyskin & Ewer, 2018; Unsense, 2019). These hubs offer multiple modes of shared transportation at tactical and near-by locations via a single platform (figure 2.3 and 2.4). Such hubs are currently being piloted in different cities throughout Europe (Interreg NWE, n.d.) and according to CTO of Amsterdam’s Innovation Team, Diederik Basta, the first results show remarkably promising (personal communication, 24-09-2020). The municipality of Amsterdam is planning a high-density network of small, minimal hubs throughout the city and rather has multiple hubs of e.g. five e-bikes and a cargo bike each than one larger hub with over twenty e-bikes (figure 2.3).

figure 2.3 Mobility hub from Hely in Delft offers users different forms of shared mobility, e.g. cars, cargo bikes and e-bikes

Though shared e-bikes are seen as most promising for the Dutch markets (D. Basta, personal communication, 19-10-2020), global markets have shown to be driven by demand and prone to changing when customers' mobility needs shift. As an example, the current COVID pandemic causes a significant drop in mobility demand (N. Hagels, personal communication, 20-01-2021; Appendix I1). This means if demand for different vehicles increases, so does the supply (Vuocolo, 2019; Peddie, 2019). This shows that the market of shared micromobility, despite already being around since the 1960s, is far from mature (Leung, Xue & Wen, 2019). It also shows that companies can only survive if their services are flexible and respond best to customer demand.

2.4 Conclusions

The charging of shared e-bikes needs to be convenient to enhance the user experience. Convenience is marked as the most important factor in using shared mobility and convenience is one of the main factors driving technological development in this field. Therefore, a charging solution that requires high mental or physical effort has little chance in being adapted widely. Providers of shared e-bikes would be crazy to integrate systems that decrease convenience for users of their services.

As people will often be using vehicles from different providers (e.g. in different cities), a universal system is crucial. Universality of the charging system can ensure that people use it correctly as they are used to it from experiences with other providers in the past.

Global markets have shown that the market of shared mobility is one that is constantly changing. Providers grow fast, but might lose market share even faster if new, more convenient alternatives come in play. As charging requires infrastructure, only a truly universal infrastructure can provide a promising future that is worth paying for.

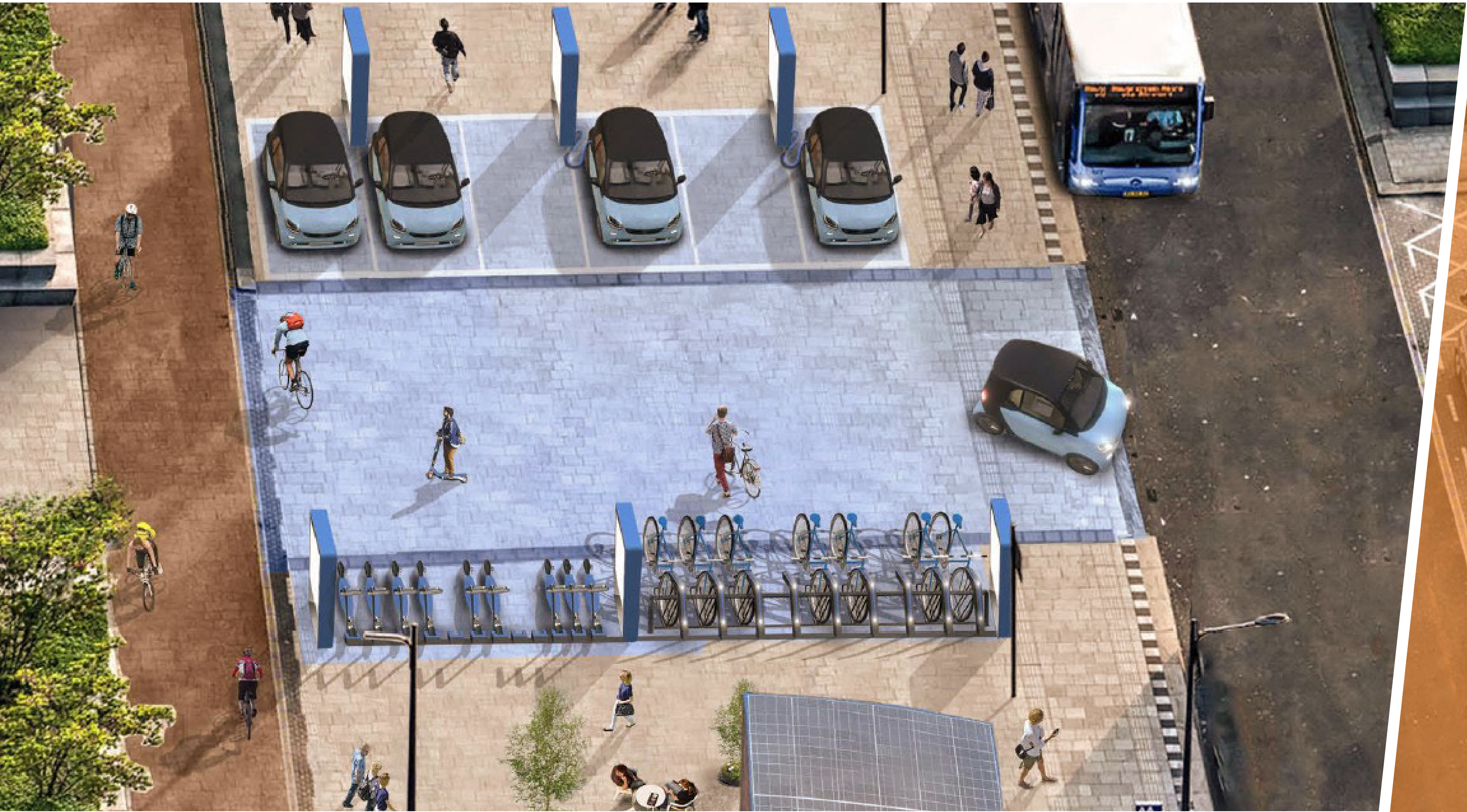

figure 2.4 The municipality of Waalwijk envisions a crucial role for shared mobility in keeping their city reachable and connecting surrounding towns and cities

3 Current Solutions

New technologies make sharing of light electric vehicles easier and more reliable, but the charging infrastructure for said vehicles seems to lag behind. Charging remains one of the main issues in exploiting shared electric vehicles and seen as a key element in lowering operation costs (Fellin, 2020). Different options are currently available, but are often expensive, not user friendly or not universal (N. Hagels, personal communication, 20-01-2021). Based on Fellin (2020) and Veenman (2021), charging solutions can be roughly divided into a number of categories that are characterized by different pros and cons and excel in different situations (table 3.1). This chapter also discusses some interesting individual cases that are currently on the market.

3.1 Case Studies

KingMeter - Wireless Charging Dock

What system do they use?

KingMeter uses a docking station for the entire bike (figure 3.1) that utilizes wireless charging (figure 3.2).

Main benefits?

Charging through wireless charging reduces mechanical wear of contact points (Treffers, 2015; Fellin, 2020). Combining this with a dock ensures correct alignment without asking significant effort of the user. The dock-based system also provides locking the bicycle to the environment, thus lowering risk of theft.

Main drawbacks?

Despite offering a reliable charging solution, the concept of a dock brings along some major drawbacks. Installing docks is expensive (the cost-price of the KingMeter dock is €800; appendix I2) and not flexible and the amount of bikes that can be parked per meter is limited (D. Basta, personal communication, 19-10-2020; N. Hagels, personal communication, 20-01-2021; Veenman, 2021). Next to that, the system is bike-specific (Veenman, 2021) and requires customers to use KingMeter bicycles both now and in the future (N. Hagels, personal communication, 20-01-2021; Appendix I2).

figure 3.1 ▲ KingMeter offers docks with wireless charging, but these require a lot of space and are far from universal

figure 3.2 ▶ A receiver coil is placed on the bike's front fork that aligns with a transmitter coil placed in the dock

Public Solutions for Shared LEVs				Public Solutions for Consumer LEVs		
Regular DC Plug	Docking Station	Battery Swapping	Vehicle Swapping	Socket	Regular DC Plug	Battery Locker
Cable with a regular plug, usually consumer grade plugs.	*Structure on the street to park the vehicle into. Locks the vehicle while also charging its batteries.*	*Depleted batteries are swapped in the street by provider, then charged elsewhere. Often used for free-floating systems.*	*Entire vehicle is taken from the street to charge elsewhere, either by provider or third party. Mainly used with (lightweight) scooters.*	*Regular wall socket built into wall box, bike rack or poles to which users can connect their own charger. Sometimes combined with locker.*	*Cable with DC plug that plugs into the battery.*	*Locker that fits battery and charger, often fitted with a standardized wall socket inside.*
Small and versatile solution that is easy to integrate, even in existing parking spaces.	*No effort from user required to connect charger.*	*Allows free-floating systems without worrying about charging.*	*Taking a scooter from the street can be done fast.*	*Universal solution, as all chargers fit into a standardized wall socket.*	*Users do not need to carrry their own charger around.*	*Anti-theft solution for both battery and charger.*
Up-front investment is low.	*Significant decrease in theft and vandalism, as bike and battery are locked completely.*		*Charging can be outsourced to locals to save costs compared to battery swapping.*	*Easy to integrate in design.*	*Unique selling point for vehicle brand.*	*Decreases chance of vehicle theft (less interesting without battery attached).*
Prone to breaking and mechanical wear.	*Prone to mechanical wear and failure due to bumping.*	*High personnel costs.*	*High personnel costs.*	*Users have to bring their own charger, which is heavy and can be forgotten.*	*Only accessible for vehicles that operate with the specific plug (not universal).*	*Users have to bring their own charger, which is heavy and can be forgotten.*
Relies on users plugging in after use of the vehicle.	*High up-front investment and installation costs.*	*Investments in extra batteries.*	*Not suited for larger or heavier vehicles.*	*Problems with theft of chargers (if charger cannot be placed in locker).*		*Battery needs to be taken out of the vehicle on the spot.*
No communication with battery or feedback on battery status.	*Often not mobile or versatile and takes up a lot of (scarce) space in the public domain.*	*Requires special and fire-proof charging utilities in every operation region.*		*Not possible for shared vehicles.*		*Too cumbersome for shared vehicles.*
Low reliability negatively impacts user perception of the entire system.	*Requires complicated permits in most cities.*	*Easy accessibility to battery required, but increases chance of vandalism/battery theft.*				
High maintenance costs due to breaking plugs on both charger and vehicle.	*Not universal, thus limiting vehicle choice (now and future) for clients.*					

table 3.1 Comparison of different available charging solutions currently on the market with their benefits and drawbacks

Urbee - Regular DC plug

What system do they use?

Urbee is a spinoff of the e-bike brand QWIC and uses mainly rebranded QWIC bicycles for their MaaS system. This means they also use the regular chargers that come with the bicycle (figure 3.3), although their hubs include a steel container that houses the adapters (figure 3.6).

Main benefits?

In their newest hubs, Urbee replaced the black cable with a red one (3.6). This attracts the user's attention, making it more likely the user will connect the charger after use of the e-bike, but more importantly, also disconnects the charger before use.

Main drawbacks?

As mentioned by Hagels (personal communication, 19-10-2020 and 20-01-2021), the current system used by Urbee shows multiple drawbacks and requires a massive improvement. First of all, replacing plugs on the bicycle when damaged is expensive and often needed, as the plug gets damaged when users forget to disconnect the charger before use and suffers from mechanical wear. Next to that, position of the plug on the battery is hard to reach (figure 3.4). An extra plug is placed behind the lock, which is easier to reach but also poorly visible. Lastly, Hagels mentioned that in their corporate sharing program, sometimes different bicycles are used in a single hub that require different plugs for charging, which leads to users simply not charging at all when finding the right plug is too much effort (personal communication, 20-01-2021). Some users just do not seem to get it at all (figure 3.5), illustrating the need for a solution that is harder to misuse than it is to use.

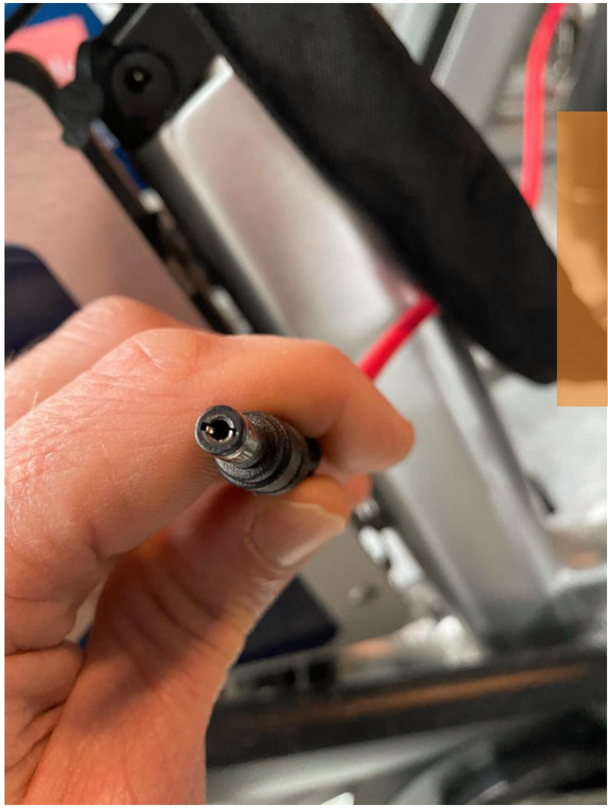

figure 3.3 Urbee uses a regular consumer-grade DC plug for charging, but experience numerous problems with wear, damage and unwillingness of users

figure 3.4 The charger plug on the battery is relatively hard to reach, especially when space between vehicles is limited

figure 3.5 The current system is not reliable, as users do not always understand how to use it (as observed in a Rotterdam hub)

figure 3.6 Stainless steel containers protect chargers from weather influences, red cables draw attention to the chargers

Deelfiets Nederland - Load & Lock

What system do they use?

Deelfiets Nederland has developed their own Load & Lock system in which the plug for charging is placed right next to the plug-in lock on the AXA Electronic Ring Lock (figure 3.7). This means users automatically connect the charger once they insert the locking plug that is anchored to the hub.

Main benefits?

Once the user inserts the double plug into the vehicle, it is both locked and charging. According to Sylla, founder of Deelfiets Nederland, this eliminates a step in the process and makes the system more convenient for its users (personal communication, 02-10-2020).

Main drawbacks?

Deelfiets Nederland's Load & Lock system still requires users to actively connect and align the plug, thus still being a separate step in the process of using the service (O. Sylla, personal communication, 02-10-2020). As the plug functions as both a charger and a locking system, alignment becomes crucial. Since a regular DC plug is used for charging, it is prone to wear over time, while misalignment by users can speed up this process due to the pin bumping into the bicycle.

3.2 Conclusions

Though many promising charging solutions exist, a universal product that can be directly integrated in existing services seems lacking. Docks seem to offer the most reliable and easy charging solution, but limit clients in their choice in bicycles and come with large drawbacks in flexibility, required space and cost. Somewhat universal systems exist (e.g. Deelfiets Nederland), but are often based on existing plugs that do not fit the needs of the sharing economy (e.g. convenience and reliability) and require users to take the initiative to disconnect the charger before or connect the charger after use.

The ultimate charging solution offers the ease of use and reliability that is offered by docks while also being universal and adaptable for different types of bicycles. It needs to integrate seamlessly and logically in the process of taking the vehicle from and returning the vehicle to a hub to ensure it is always disconnected before use and again connected afterwards.

figure 3.7 Deelfiets Nederland placed their charging plug right above the lock and combined its charging and locking plug into a double plug

4 Stakeholders

To gain a better insight in what values and criteria are important in the design of a wireless charger for shared e-bikes, a stakeholder analysis has been performed. The initial selection of stakeholders was inspired by the seven interest groups in the shared economy coined by Leung, Xue and Wen (2019), though alterations and additions have been made to suit the more specific context of shared bicycles. All stakeholders have been analysed by asking the questions who, what and how, after which they have been placed in an interest-influence matrix (figure 4.1). Though appendix B shows a complete overview of the stakeholders, the most important ones have been discussed below.

4.1 Crucial Stakeholders

Users of Shared E-bikes

Who are they?

These are the people engaged in shared mobility and using the charging device designed in this project.

What do they want?

Fishman (2016) has shown convenience to be the most important driver for people in using shared mobility. Users want a reliable, high density system of shared e-bikes and the availability of fully-charged e-bikes plays an important role in their perception of the system. Though shared e-bikes will mainly be used for first- and last-mile transportation, a third of the users of the Hely Mobility Hub in Delft said to plan on selling their current first or second car (Kerssies, 2020).

How will they get it?

The success of shared mobility systems largely depends on the users. International markets have shown that if new systems that better suit the needs of the user enter the market, established systems need to adapt to keep users engaged (Vuocolo, 2019). Otherwise, users will simply embrace the new service, resulting in a fast drop of market share.

> *“If we want people to use more shared bicycles, we have to make it as simple as possible for them to do so.”*
>
> *R. Haverman, founder OV-fiets (Slütter, 2018)*

Providers of Shared E-bikes

Who are they?

Companies that provide shared mobility to users. These companies are the owner of the vehicles and the direct clients of TILER.

What do they want?

As these are commercial businesses, their main aim is to make money. To achieve this, they thrive for a solid and large user group and a dense network of available vehicles within cities. A system that provides in the needs of their users is essential to survive. The most important criteria for a charger solution are reliability of charging, the user never forgetting to connect the charger and live insights in the charging progress, agree both Niels Hagels from Urbee (personal communication, 27-10-2020) and Oumar Sylla from Deelfiets Nederland (personal communication, 02-10-2020).

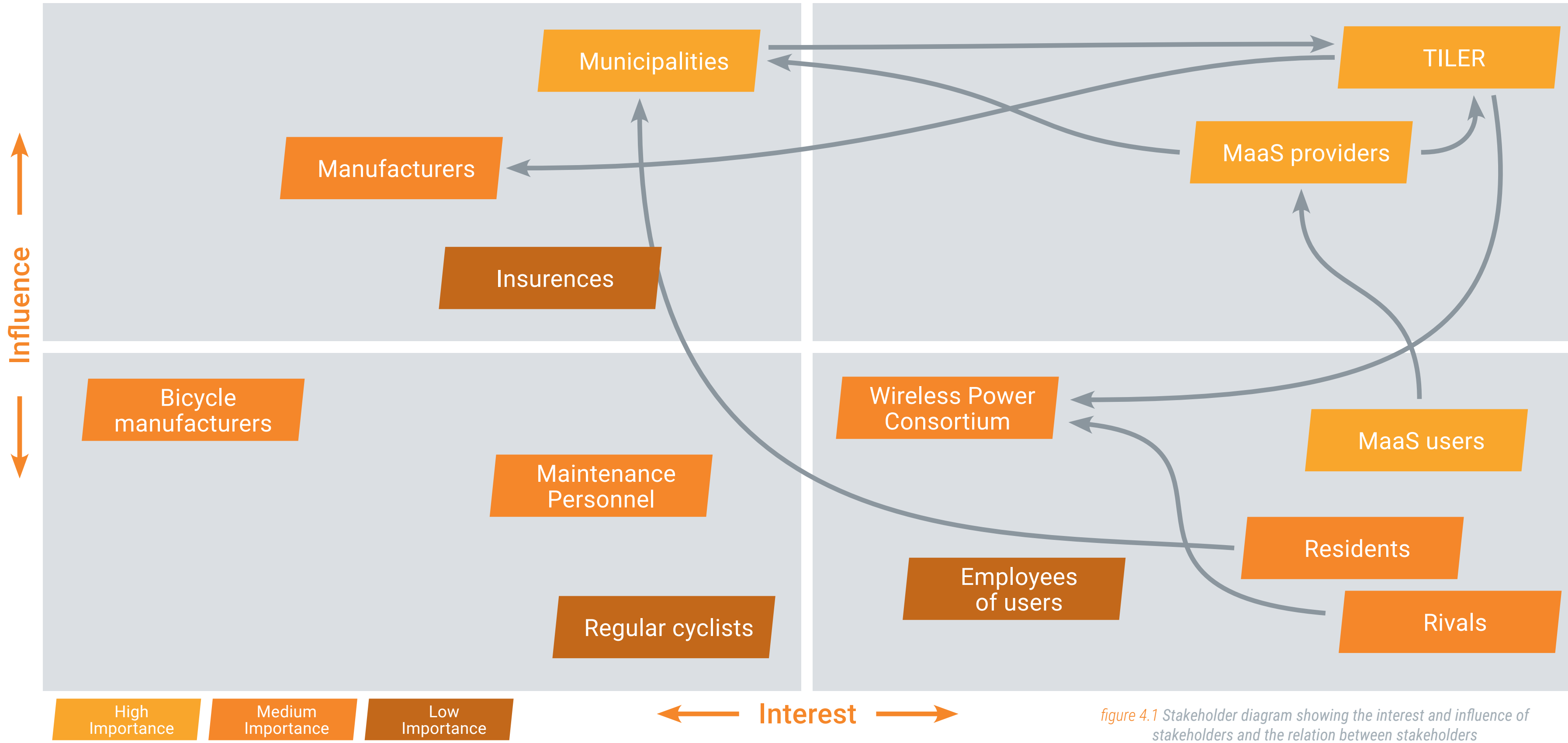

figure 4.1 Stakeholder diagram showing the interest and influence of stakeholders and the relation between stakeholders

How will they get it?

Though initial entrants of the free-floating market just flood the streets with their vehicles (Tuk, 2020), stricter regulations force providers to win over municipalities to allow their services in the cities (Gemeente Den Haag, 2019). Visibility and recognizability of their vehicles in the street is one of the major ways to gain attention of the users.

Governmental Institutions and Municipalities

Who are they?

Parties that decide on permits for shared mobility providers. This includes permits for placing docks or hubs on locations throughout the cities, and thus also permission to place the product developed in this project.

What do they want?

The main goal of municipalities concerning shared mobility is the liveability of the city. Cities engage in shared mobility as they see the potential in decreasing the amount of cars and making more efficient use of the available space (D. Basta, personal communication, 24-09-2020). The municipality of Amsterdam perceives the public space as a 'placid foundation of city life' (Gemeente Amsterdam, 2018) and Diederik Basta also noted that the visual impact and the number of physical objects in the public space is to be kept to a minimum.

How will they get it?

Municipalities work together with providers of shared mobility, e.g. in the Interreg Smart Hub project (Interreg NWE, n.d.). Governmental institutions can also provide funding to companies that they view as beneficial to a better and more liveable city. Their influence is relatively high, as they have to believe in and approve the product before it will be placed in the public domain.

Hagels noted that differences between municipalities can be high, as some rely on lingering and traditional commissions to approve hub placement, whereas other municipalities are more willing in adopting new innovations in their cities (personal communication, 27-10-2020).

> *"We are a lively city, there is a lot happening in our public space so we want to keep it as vacant as possible"*
>
> *D. Basta, CTO Innovation Team of the Municipality of Amsterdam (personal communication, 24-09-2020)*

4.2 Conclusions

It is important to notice that the people that are using the product are not the same as the ones responsible for buying the product. Users utilize the charging solution as part of a system, in which all elements come together in a joint verdict on the quality of their experience with the specific system. Therefore, a seamless integration of the charger solution with the other elements of the sharing system is important.

For providers of shared mobility – the direct client of TILER – the overall user experience is important as this results in happy customers and further growth of their business. They view added convenience for the user as most important in a charging solution, though note that reliability of the charging process plays a crucial role in providing the best user experience. The feedback on the charging process granted by the technology of TILER (e.g. live updates on battery level while charging) is also seen as valuable.

Although the users and providers are most important in determining the success of the proposed charging solution, it is essential to also note the influence of municipalities, as these governing bodies are responsible for the permits required to place and use the charging solution in the public environment. Their concerns on required space and visual impact will play an important role in paving the future for hubs with TILER chargers.

5 Wireless Charging

Wireless charging has become immensely popular in recent years. Proposals for wireless charging of vehicles go back over a century when French innovators Hutin and Leblanc patented a way of wirelessly charging an electric tram (US527857A, 1894). Wireless charging has been used in charging electronic toothbrushes for years and adaptions in wet environments and with moving parts have shown beneficial as well in preventing corrosion or mechanical wear (Treffers, 2015).

Only since the possibility to charge smartphones through wireless power transfer does the consumer see the convenience benefits of the technique. First prototypes and products in the '00s of this century evoked strong positive feedback from consumers, however high manufacturing costs made it unsuited for mass markets (Treffers, 2015). The Wireless Power Consortium was founded in 2008 in the belief that universality of wireless power transfer would help boost market demand and drop price levels. Since its introduction in 2010, Qi wireless charging has become the standard in mobile phones with over 465 million Qi-certified products sold globally in 2019 (Raskind, 2020). New applications in wearables and other small electronic devices show a grand future potential for wireless charging.

In general, wireless charging is based on Faraday's Law of Induction. By running a constant current through a coil (the transmitter coil), a magnetic field is generated around it. If instead alternating current is used, an oscillating magnetic field is generated (Mearian, 2018). Faraday's Law of Induction states that if another coil (receiver coil) is placed within this field, the changing magnetic flux generates an alternating current in the second coil, which can be converted to direct current and used to charge a battery (insert).

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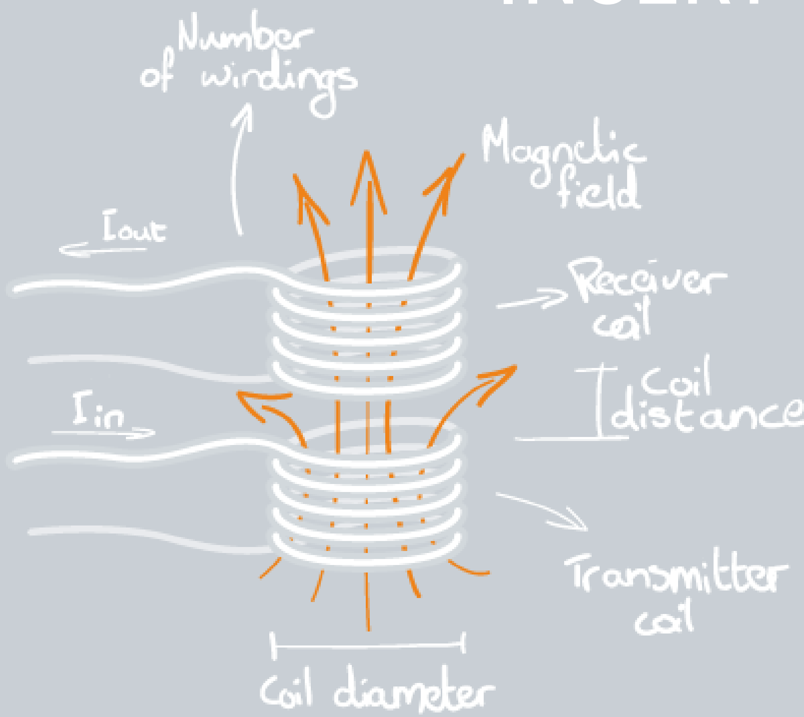


5.1 Coil-to-Coil Systems

The well-known Qi-standard is based on the principle of 'tightly-coupled' coil-to-coil charging. It consists of two flat coils (figure 5.1) – one on the transmitter side and one on the receiver side – that are placed close to each.

Though ideal for flat, small-space design applications (e.g. smartphones), coil-to-coil systems come with a couple of disadvantages. Ferrite shielding is required to contain the flux fields within the two cores and prevent heating up electronics behind the shield (figure 5.1) (Clark, n.d.), though according to TILER's electronics expert Ronald Kiewiet, the ferrite shielding is heated by the magnetic flux, which leads to lower efficiency (personal communication, 20-10-2020). Overall maximum efficiency of this technique is about 65% (Clark, n.d.). Slight misalignment of the coils also has a significant negative impact on the efficiency (figure 5.3), resulting in more heat dissipation. Making the two coils different sizes allows for some more misalignment in the product design, but also lowers efficiency.

figure 5.1 Flat coil with ferrite shielding


figure 5.2 Connected coil-to-coil system allows more alignment, but efficiency is still low if allignment of receiver coil is not exact with at least one of the transmitting coils

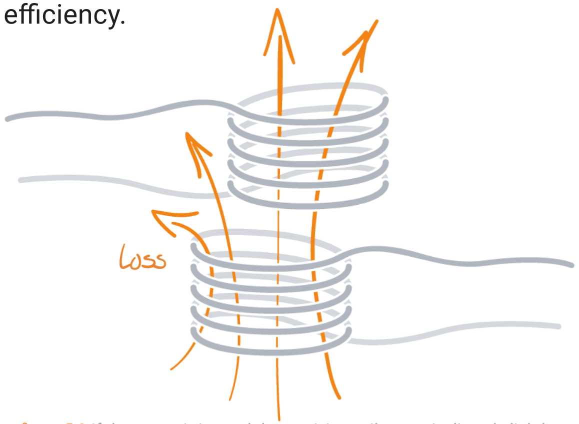


figure 5.3 If the transmitting and the receiving coils are misaligned slightly, a high loss in efficiency can be observed

An alternative for the coil-to-coil principle that allows more misalignment, is to use overlapping, connected coils on the transmitter side of the system (figure 5.2). This system couples the single coil on the receiver side with one of the coils of the transmitter, thus resulting in multiple 'alignment zones' to which coupling between two coils makes for the most efficient power transfer as possible with a coil-to-coil system. However, a drawback is that there is still space between these zones in which the coupling is lower and thus efficiency drops and more heat is generated (R. Kiewiet, personal communication, 20-10-2020).

5.2 TILER System

The patented system currently used by TILER (NL2019015B1, 2018) works much like a two-coil transformer (figure 5.4), where a ferrite core runs through two coils to increase or decrease the available voltage from I_{in} to I_{out} (Electronic Tutorials, n.d.). The system uses soft ferrite cores to guide the magnetic flux from one coil to the other (figure 5.5). The system is designed for the use in a double kickstand and requires a closed circuit.

Due to the steering of the magnetic flux, efficiency is much higher than traditional flat coil-to-coil systems as used in the Qi-standard. Efficiency of over 90% is possible while charging up to 200 watt at 4 amperes.

A large issue with this system is the vast amount of ferrite used in the product, making it both heavy and expensive. According to Van Nispen, founder of TILER, the ferrite in the current version of the tile with kickstand is responsible for approximately 200 euros of the total cost price of the product (personal communication, 24-11-2020).

The major benefit of the high volume of ferrite is that it creates a large surface area at which power transfer can occur (figure 5.5). This allows for the kickstand to be misaligned a few centimetres without significant loss of efficiency, as long as the contact areas of the transmitting area and receiving area are within their boundaries.

A variation of this system that has been explored by TILER is what they have coined ‘mushrooms’. In this principle, coils direct their flux through a much smaller ferrite core that closes its magnetic circuit via the air outside of the ferrite core (figure 5.8). Though the directional flux in this principle limits design freedom (R. Kiewiet, personal communication, 20-10-2020) and allowed misalignment is determined by the surface area of the ferrite, a clever design can drastically lower the amount of ferrite used in the system. By using readily available ferrite bobbins that are used for radio signal transmitting (figure 5.6 and 5.7), costs are kept to a minimum.

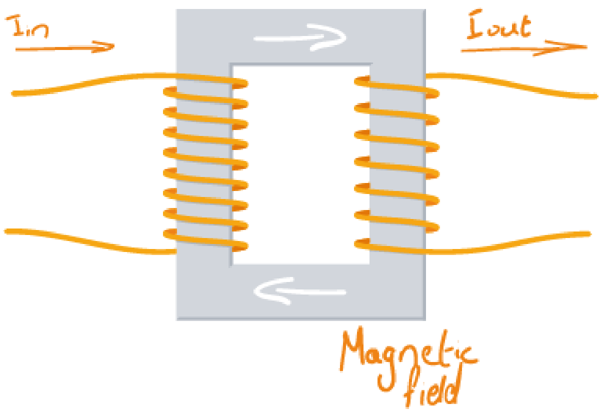


figure 5.4 A two-coil transformer uses a ferrite core to guide the magnetic field evoked by one (transmitting) coil into another (receiving) coil

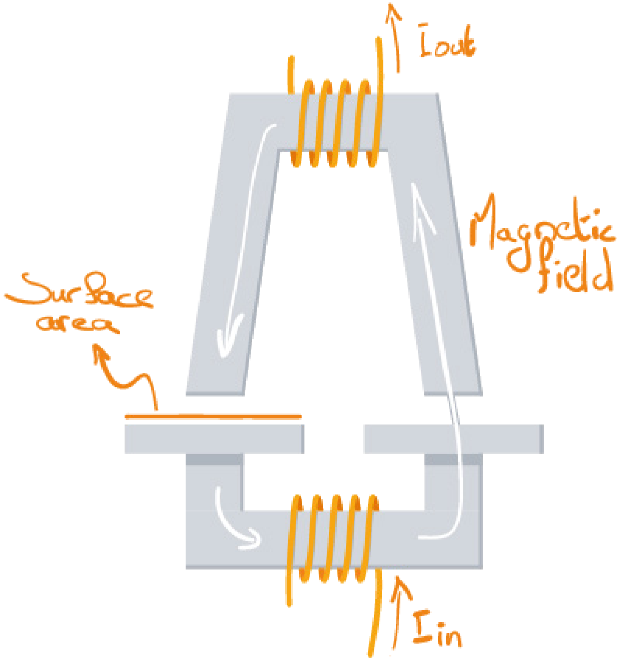


figure 5.5 The system patented by TILER allows misalignment without significantly influencing efficiency through the use of ferrite plates

In commission of TILER, magnetic experts at AE Magnetics have simulated the flux that is generated in the mushroom system and found that the magnetic flux being guided through the air impacts the efficiency (figure 5.8). A smart configuration of the ferrite or a standard core that guides the flux on both directions of the core can further boost the efficiency of the mushroom system.

The much smaller ferrite cores used in such systems are much lighter, easier to attain and cheaper than the current system of TILER. A negative effect, however, is that due to the much smaller contact area between the cores, alignment is far more important. This is because the contact area is an important determinant of the amount of power that can be transferred.

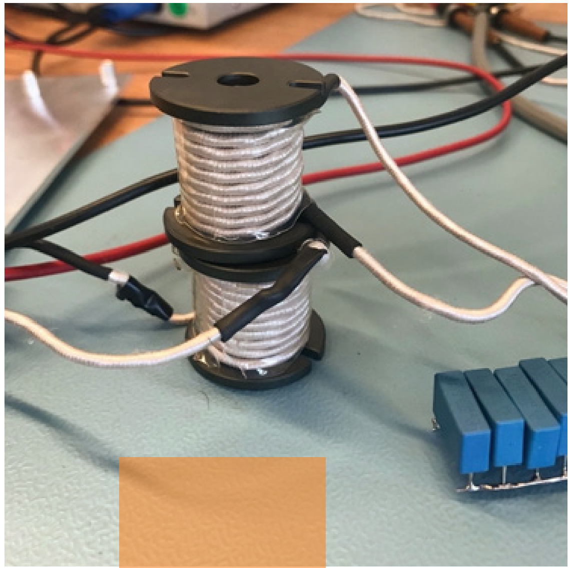


figure 5.6 ◂ Mushroom System, as tested by TILER's electronics experts

figure 5.7 ▾ The Mushroom System consists of coils placed around existing ferrite bobbins

It is also vital to mention that the 'air gap' (figure 5.8) between the cores impacts the efficiency of the charging process: a larger air gap decreases the efficiency, resulting in higher heat dissipation. The air gap is essentially the distance between the two cores, however this space is usually filled by the (non-ferrous) embodiment of the product instead of air. An air gap of just a few millimetres shows little impact on the efficiency, but the smaller the air gap, the better.

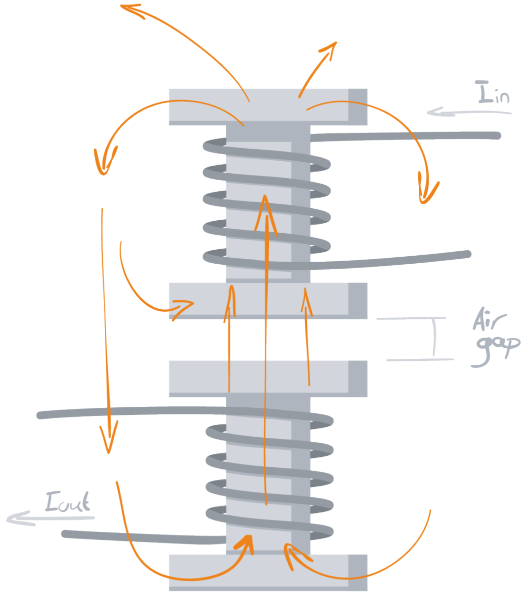


figure 5.8 A lack of ferrite guidance on the sides makes the Mushroom System less efficient

5.3 Conclusions

Its protection from corrosion and low sensitivity to wear and damage makes wireless charging ideal for charging shared vehicles in the public and outside environment. The technology developed by TILER shows grand potential in developing an efficient and universal charging solution that can be used under any circumstances and does not require precision or extreme care in connecting.

The wireless power transfer method used in the current product in development by TILER shows a high flexibility in parking due to its allowed misalignment, however high volumes of ferrite are required to achieve this freedom.
Though decreasing the amount of ferrite required for the wireless power transfer can drastically lower cost price, product weight and product size, it negatively impacts the amount of acceptable misalignment of the transmitter and the receiver side of the product. This means that if a large misalignment is desired for usability concerns, a high amount of ferrite cannot be avoided. On the other hand, eliminating the need for misalignment altogether theoretically requires a minimum volume of ferrite, as the entire surface area of the ferrite can be utilized for the power transfer.

figure 6.1 Insight in Urbee's maintenance centre at their headquarters in Amstelveen

6 Design Vision & Criteria

Analysis of the context has shown that convenience is not only the main driver for people to engage in shared mobility, but also drives innovations in this field. A seamless integration of the charging solution in the process of using a shared electric vehicle adds to the perceived convenience of the entire system.

Though convenience is important to all stakeholders, providers of shared e-bikes also benefit from the capabilities of the electronic systems behind TILER's charging system in terms of safety and reliability. The insights gained from live information contributes to a reliable system for their clients and instigates further growth of their business.

The research presented in the first part of this report has led to the following design vision:

*"Design a **universal wireless charging solution** for publicly shared e-bikes in city hubs that provides **safe and reliable charging** for MaaS providers while **requiring minimal physical and mental effort** of the user in the process of taking and returning the vehicle."*

Universal wireless charging solution

The product needs to provide the technique of wireless charging in a way that is universal to use for all e-bikes. The product will consist of two parts: the 'transmitter' which will be installed in publicly accessible hubs; and the 'receiver' which will be installed on the bicycle.

INSERT

The main criteria that are used in developing the ultimate charging solution for shared e-bikes:

1 *The complexity of use should be low to allow a convenient and seamless integration in the overall user experience. This means users have to be able to use the product intuitively.*

2 *The proposed solution needs to be universal for all regular e-bikes, allowing providers to install the product on their existing fleet regardless of the type of bicycles that are used.*

3 *No fragile parts are incorperated in the product to decrease the risk of vandalism or damage through misuse.*

4 *The product has a limited visual impact on the public space. It should not form a visual obstruction, especially when no vehicles are parked next to it.*

5 *The overall price of the product is low, including production (maximum €75), installation and maintenance.*

6 *The charging solution does not require significant extra parking space per e-bike compared to regular bike racks, maximizing the amount of vehicles that can be parked per meter.*

7 *The product should allow installation on-ground to allow usage in mobile or temporary hubs (e.g. for events or inside).*

Safe and reliable charging

The product utilizes smart technology in a way that prevents the batteries from overcharging and overheating. A reliable solution that ensures that the charger will be connected after each ride and avoids interruptions of the charging process boosts the availability of fully charged bicycles at all times, which improves the reliability of the entire MaaS-system.

Minimal physical and mental effort

The product is to be designed in a way that users of the e-bikes can park their e-bike intuitively in a way that the transmitter and receiver are aligned sufficiently. This goes both for physical effort (discomfort and number of steps) as well as their mental effort (how logical and understandable is the process). This allows the product to not only have a functional impact (easy and reliable charging), but also to have a positive impact on the entire process and perceived convenience of using MaaS in the first place.

The design vision is accompanied by a program of requirements (appendix C) to which the product need to comply. The most important criteria that are used for concept development have been listed in the insert to the left.

Concept Development

part II

7 Concept Explained

A broad ideation phase has led to a variety of ideas as to what physical form the perfect charging solution for publicly shared e-bikes would be. Through testing initial ideas and discussing with potential users, two concepts were selected that showed the highest potential. Appendix D outlines the ideation process, concept development and selection of a final concept.

From the different concepts, the paradoxically named 'Wireless Cable' was selected as the most promising for further development (figure 7.1). Its simplicity and recognizability in use and alignment make this concept the most convenient and versatile of the considered ideas. The low dependency on bike size and geometry make the concept exceptionally universal. The grand potential for future applications on consumer e-bikes or other (shared) light electric vehicles (chapter 14) only enhances this universality.

figure 7.1 The initial concept of the Wireless Cable is based on a movable transmitter coil, connected through a cable to a stationary charger pole

figure 7.2 Photo of the TILER Click installed on a shared electric bicycle

User testing and further refinements have led to the final concept: the TILER Click (figure 7.2), with a simple name to emphasize its simplicity in use. This chapter summarizes the product and explains its intended integration in the process of using shared e-bikes. Adjacent chapters elaborate on the details that are responsible for this user interaction, including the shape of the transmitter handle, placement of the receiver, connection of the charger and interactive electronics.

The product consists of a transmitter handle that is installed in the hub where the e-bike is parked and a receiver that is installed on the vehicle. To keep the project manageable within the given timeframe, peripheral equipment such as the charger pole has not been developed in detail. This is also because different providers have different requirements for their hubs, thus requiring different solutions for the form and installation of such a charger pole (e.g. hanging on the wall or from the ceiling might be options in some cases).

STORYBOARD I // Retrieve Bike

Step 1 User approaches the hub with the intention to use one of the vehicles

Step 2 Take out smartphone and open the app of the mobility provider

Optional If a user has already reserved a bike remotely, the application could assign the vehicle with the highest battery level and light its charger in a specific colour

Step 3 Based on the battery indicator on the charger, the user selects a bike with a sufficient battery level and reserves this bike in the mobile application

Step 4 Once a bike is reserved, an animated 'stream' of green light is shown to indicate it needs to be disconnected

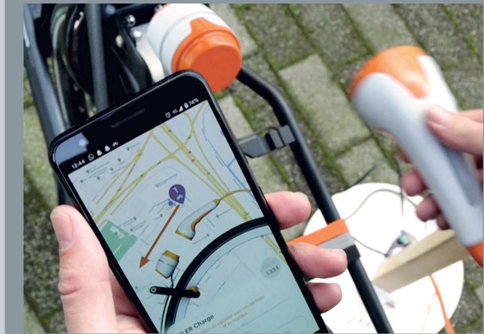
Step 5 The user disconnects the charger and places the transmitter handle back in its docking station that is installed in the hub, right next to the bike

Step 6 Once the charger is disconnected, the smart lock opens automatically, allowing the user to take the bike out of the bike rack

Step 7 Another happy user leaves the hub for a pleasant ride that starts with a full battery

STORYBOARD II // Return Bike

Step 1 When arriving at the hub, the user parks the bike in the rack at one of the free spaces



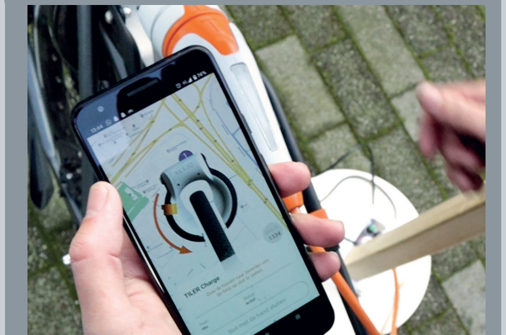
Optional The user can end his ride by connecting the charger without using the mobile application, though the application also has the option to end the ride

Optional If the mobile application is used to end the ride, the integrated lighting inside the receiver starts flashing to attract the user's attention towards the charger

Step 2 The user connects the charger manually by clicking the transmitter handle (handheld) on the receiver (installed on the bicycle)

Step 3 The charger recognizes that it is connected and verifies the vehicle's ID to make sure the vehicle is allowed to charge in the specific hub

Step 4 If verification of the vehicle is confirmed, the light element flashes green a couple of times to indicate that the look may now be closed



Optional If the mobile application is used actively during the return process, the screen provides a visual cue to now lock the vehicle

Step 5 Once parking is confirmed, the smart lock can be closed manually

Step 6 The light element indicates the current battery level, while the last LED is flashing to indicate it is charging

Step 7 The user has returned the bicycle succesfully and the vehicle is charging to provide the next user with the pleasure of a full battery as well

7.1 Seamless Integration in MaaS Systems

Charging batteries plays a crucial part in operating a successful and reliable MaaS system. Depleted batteries cause annoyance by users (e.g. Rieken, 2020) that is reflected in their perception of the entire MaaS system. Yet most charging solutions currently available are either cumbersome and expensive or fragile and unreliable (chapter 3).

With the TILER Click, charging becomes an integral part of retrieving and returning shared (storyboards pages 26-27). Through communicating with the smart lock and the mobile application, all that is left for the user to do is connect the charger.

Current systems require users to actively end their ride in the mobile application, but with the TILER Click, the smartphone can stay in the pocket. As soon as the charger is connected and the vehicle is recognized, the smart lock is activated. Once the user closes the lock, the back-end system automatically ends the ride. This further increases ease of use in similar way to AXA's 'pause-ride' button on their IN Electronic Ring Lock that allows users to pause their ride without having to use the mobile application (AXA IN, n.d.).

7.2 Familiarity & Simplicity in Use

In its most essential form, the Click works like chargers already used by many (e.g. car chargers, figure 7.3). The fact that the handle resembles known products with similar functions and interactions positively impacts the user-product interaction as well. People form conceptual models – simplified explanations of how something works (Norman, 2013) – based on how a product looks. Balancing novelty and familiarity in a design can play an important role in how well people interact with a product (Hekkert, 2006).

"It is recognizable, people understand what it is right away!"

N. Hagels, Managing Director at Urbee (personal communication, 20-01-2021)




figure 7.3 The TILER Click looks and function much like known electric car chargers, making the product instantly understandable and its interaction logical and intuitive

figure 7.4 An LED display on the back of the transmitter provides interactive visual feedback to the user

figure 7.4 Receiver location on the back of the bike allows easy access

Connecting and disconnecting the Click has been made simple and convenient to amplify the benefits of using MaaS systems. The effortless alignment of the transmitter handle with the receiver on the bicycle is one of the major functional strengths of the product. Because of the tapered shape of the receiver, initial alignment can be imprecise and the transmitter will be guided on the last millimetres to ensure a perfect alignment (chapter 9). A clicking mechanism consisting of two simple spring wires ensures the transmitter clicks in place (hence the name 'Click') while providing both haptic and audible feedback (paragraph 9.3).

The placement of the receiver on the rear of the bicycle (figure 7.5) plays an important role in this, as it is well-visible and reachable when standing behind the bike (e.g. in tightly packed bicycle racks).

7.3 Interactive Electronics

An LED display on the back of the transmitter provides interactive visual feedback to the user (figure 7.4) (paragraph 10.1). By using linearly placed RGB LEDs, the display can communicate when it is charging and what the current battery level is, but also when the charger is authenticating the bicycle to ensure it is allowed to charge there or when the charger needs to be disconnected before use. The light display functions in this way as a personal 'instructor' that tells the user what is going on in a simple and understandable way.

7.4 Stationary receiver

Many products that use wireless charging operate by having a stationary transmitter coil that is connected to the power grid to which a device with a receiver coil is aligned. This is true for electric toothbrushes and devices using the Qi standard (figure 7.6), but also for concepts that apply wireless charging to vehicles (e.g. Dumont, 2020; Throngnumchai et al, 2013; NL2019015B1, 2018).

The Click is unique in that it relies on having a stationary receiver on the bike to which the transmitter handle is aligned (figure 7.5). This way of reverse thinking allows for variation in the exact placement of the receiver on the bicycle, without having to compensate for misalignment caused by the difference in geometry among bicycles. Because alignment can always be perfect, the concept requires only a limited volume of ferrite, which is beneficial from both economical and sustainable perspectives (chapter 11).

As the transmitter device is a lot smaller than the vehicle housing the receiver, having to manually align the transmitter is also beneficial from a user perspective. Johansson et al (2001) have shown that vision is used to guide objects that are moved by hand past obstacles and to a goal. Future contact points and potential obstacles are the centre of attention and are monitored sequentially during the task (Bütepage et al, 2019), but unforeseen obstacles in the peripheral field (figure 7.7) can cause errors in this process, as the human brain is not skilled in detecting stationary obstacles in the peripheral vision (Vater, Kredel & Hossner, 2016). The compact size of the transmitter handle guarantees constant visual feedback on the trajectory, which supports the hand movement throughout the task of alignment and reduces the risk of unforeseen obstacles causing irregularities, as opposed to having to park the entire bicycle with perfect precision.

figure 7.6 Wireless charging is usually based on having a portable receiving device that is moved to align to a stationary transmitter

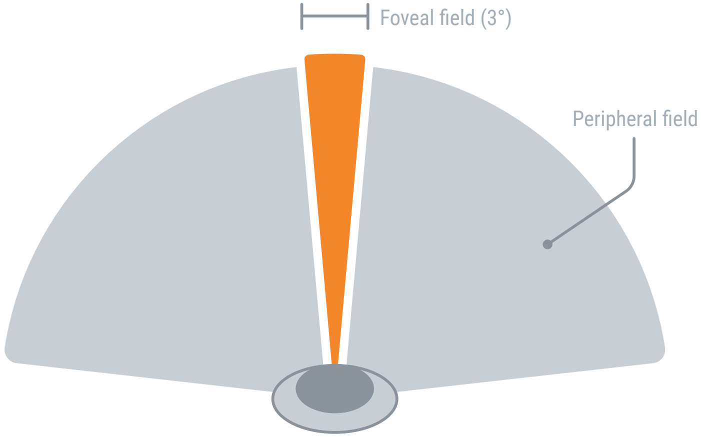


figure 7.7 The human eye can only focus in the foveal field, however stimuli in the peripheral field can also draw attention

8 Receiver Placement

For the placement of the receiver on the bicycle, three factors are important. Reachability is viewed as the most important factor in the placement of the receiver on the bike. A hard to reach receiver potentially leads to discomfort, as people need to overstretch muscles in order to connect or disconnect the charger. In line with that, the receiver needs to be visible once the vehicle is parked and identifiable as a charge-point. Lastly, placement of the receiver has to allow for easy integration with existing bicycles and connection to the bike's battery in a universal way.

The placement of the receiver right behind the bike's saddle was found as the most promising option (appendix E). It makes it easy to reach and well-visible whilst standing behind the e-bike, especially useful in tightly-packed bicycle racks where space between bicycles is limited (figure 8.1).

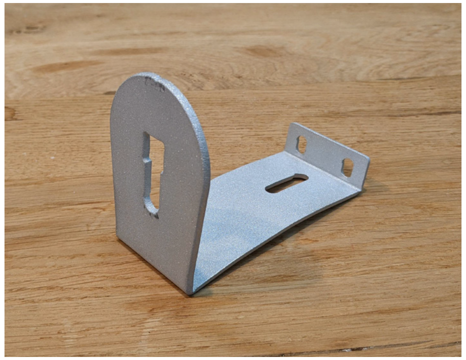


figure 8.2 Bike bracket that is used for the final prototype

figure 8.3 With custom-made brackets, placement on alternative mounting points is possible

figure 8.1 Receiver placement on the rear provides visibility and easy access from behind the bicycle, e.g. when no space is available between bikes

figure 8.4 For the e-bike used with the final prototype, mounting of the bike bracket at the rear carrier mounting points was the most simple solution

The receiver is attached to the bike by a custom aluminium bracket (figure 8.2 and 8.3) that is mounted to existing mounting points on the bicycle. For the bicycle used for the final prototype, the mounting points for the rear carrier provided the easiest integration (figure 8.4), but the lock mounting points are also an option (figure 8.3), as almost all shared e-bikes use electronic ring locks for which the mounting points are universal (AXA IN, n.d.).

The use of a custom bracket allows for adaption to different bikes. This means that a bracket has to be made specifically for the type of bike that a provider is using. The simplicity of the mounting bracket makes this easy and relatively cheap for both small and larger series.

The exact placement of the receiver and dimensions and mounting position of the aluminium bracket will have to be considered per case. A good example is a bicycle that has a small frame size and a battery integrated in the rear carrier (figure 8.5), where a sideways orientation or placement on the back of the carrier might be the best option.

A cable connects the receiver with the battery. With bicycles that have their battery placed in the rear carrier, this is only a short distance. For bicycles that have an in-frame mounted battery - such as the one used for prototyping - the cable can run under the rear fender towards the bottom, where it can either enter the bike's frame or run to the battery outside. This is also how cables for rear lights are often installed (figure 8.6).

Lastly, the receiver placement next to the lock is also beneficial from an interactive viewpoint. The area around the lock turns into a 'cockpit' for taking and returning the e-bike, as all physical interactions that are concerned with this process (charger connection and disconnection, changing seat height, locking bike, connecting and disconnecting chain lock) take place at this region of the bicycle (figure 7.4).

figure 8.5 Placement and dimensions of the bike bracket need to be reviewed per case, as some bicycles make the intended placement behind the lock challenging

figure 8.6 Rear-light cables often run below the fender, which is also how the cable from the receiver will run towards the battery (for frame-mounted batteries)

9 Transmitter Handle

9.1 Shape of the Transmitter Handle

The transmitter handle has been designed to fit well in the hand and to avoid discomfort during the process of connecting. To find the perfect shape, a variety of handle shapes and sizes have been tested and discussed with multiple potential users (n = 8) in an explorative research. The procedure of these tests are outlined in appendix F. The insights that have led to the design of the handle have been discussed in this chapter as well.

Participants in the explorative research showed a unanimous preference for a handle that is large enough to fit in the hand (figure 9.1). Participants said to like the feeling of added grip (n = 4) and that this also helped them in properly aligning the transmitter with the receiver (n = 3).

This is acknowledged by Lewis and Narayan (1993) in their research towards ergonomic hand tools: "the forces generated during use should be distributed on as large a pressure-bearing area of the palm as possible, while still being small enough to allow the fingers to wrap around the handle." Their research suggests that a handle that tapers towards the back is the most promising option to achieve this. A larger contact surface between the hand and the handle also lowers the peak forces (either pressure or shear force) on the skin, which leads to higher perceived comfort (Pheasant and O'Neill, 1975; Fransson-Hall & Kilbom, 1993).

Almost all participants (n = 7) preferred a handle that allows for alignment of the hand and the forearm. This is in line with the 'design principles' coined by Lewis and Narayan (1993) for the ergonomic design of hand tools. A handle shape that allows a neutral wrist position provides the greatest comfort (figure 9.1) (Flatt, 2000).

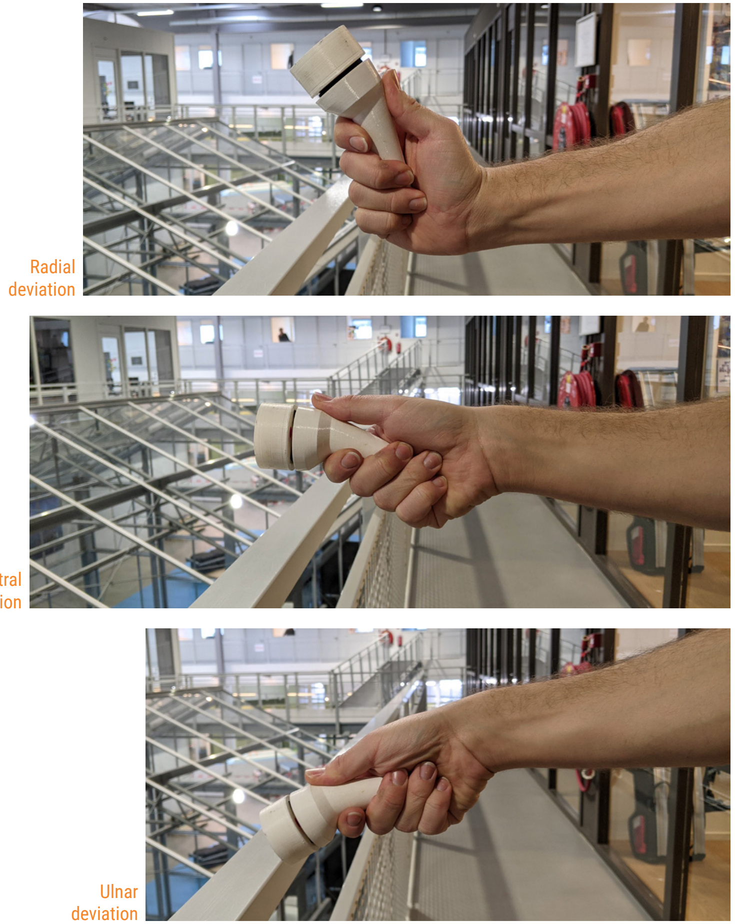


figure 9.1 Generally, people prefer a handle that fits well in the hand, but also allows a natural wrist position

figure 9.2 Iterations in the shape and dimensions of the transmitter handle have led to a comfortable and logical shape that fits well in the hand

figure 9.3 A linear connection mechanism simplifies the connection and disconnection processes

The final handle shape has been designed based on these insights. Iterations have been 3D printed, tested and adjusted (figure 9.2) to come to a shape that is perceived as comfortable by people with small hands as well as by people with large hands. While building and testing the final prototype, the most-heard comment from people that handled the prototype was that it fits well in the hand without being asked about it specifically.

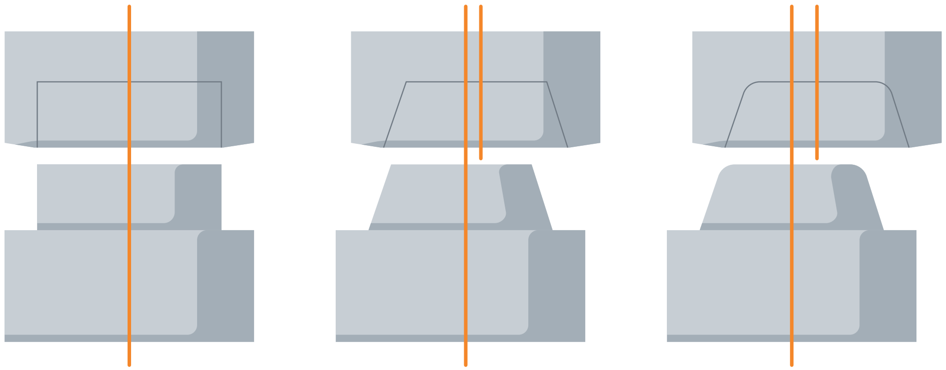


figure 9.4 A tapered and rounded shape allows more initial misalignment

9.2 Connection between Transmitter and Receiver

Part of the explorative research described in appendix F was to find the most easy and logical connection mechanism to connect the transmitter to the receiver. This mechanism needs to assist in a successful alignment.

Among the different presented connection mechanisms, all participants (n = 8) agreed that the linearly oriented examples offers the most convenient and fluent user interaction. This is due to the linear movement of bringing the transmitter handle towards the receiver being prolonged in the connection process (figure 9.3), thus not requiring any additional manipulation or actions as needed for considered alternatives.

The tapered shape of the receiver has been selected to assist the user in properly aligning the transmitter with the receiver, allowing for initial alignment by the user to be less precise. The rounded edge adds to this (figure 9.4). The tapered shape also plays a crucial role in the click mechanism (next paragraph).

9.3 Click Mechanism

In many power plugs, the friction between the male and female connectors ensure that the plug stays in the socket until pulled out. As the TILER Click has no such system, an alternative solution for this problem induced by gravity has been integrated. Appendix G shows a comparison of different explored options and the process that led to the spring wire mechanism explained below.

The integrated click mechanism consists of a spring wire on the top of the transmitter (figure 9.5) that locks in a groove on the receiver (figure 9.6). This piece of wire is enough to keep the charger connected when pushing moderately on the back of the transmitter handle (figure 9.7, top), yet due to the tapered shape of the receiver, the wire jumps out of the groove easily when slightly tilting the transmitter handle (figure 9,7, middle), which happens naturally when taking the handle by hand. When pulled sideways by the cable, e.g when someone trips over the cable, the spring wire jumps out of the groove, disconnecting the charger without damaging the cable (figure 9.8).

figure 9.5 A spring wire is integrated to make the transmitter lock in place on the receiver

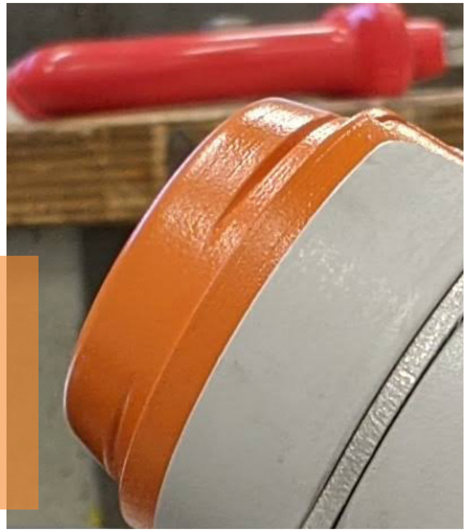


figure 9.6 The geometry of the upper groove differs slightly from that of the lower groove to allow easy disconnection

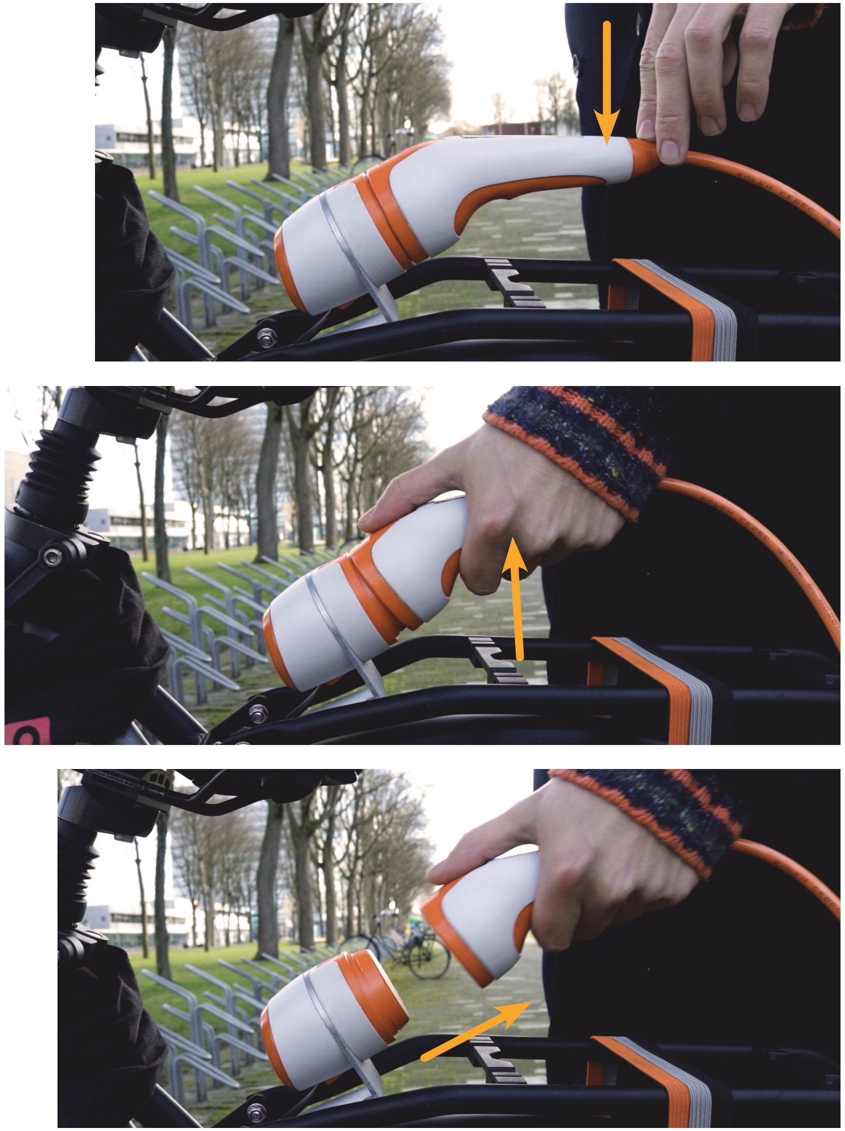


figure 9.7 The click mechanism locks the transmitter in place when pushed downward, but unlocks easily when slightly lifting the handle while disconnecting

figure 9.8 Though locked in place while charging, the clicking mechanism unlocks when the cable is pushed aside (e.g. when someone trips over the cable)

figure 9.9 A second spring wire on the bottom of the handle ensures feedback at all times

An added benefit of this spring wire mechanism is the multisensory feedback provided to the user when attached correctly. The spring wire is pushed aside by the tapered shape of the receiver and provides a clicking sound (audible feedback) and feeling (haptic feedback) when it jumps into the groove. Multiple participants of the explorative research (n = 3) noticed that a clear feedback moment when the connection was successful would be crucial. Donald Norman (2013), in his book 'The Design of Everyday Things', mentions clear feedback as one of five fundamental principles of interaction.

The tapered shape of the receiver has shown multiple clear benefits, but testing the spring wire mechanism showed that when the transmitter is attached under a slight angle, the wire is not pushed aside, resulting in the feedback described above lacking. Therefore, a similar spring wire has been added to the bottom of the transmitter (figure 9.9). By adjusting the angle of the groove on the bottom of the receiver, the bottom spring wire provides a slightly less noticeable haptic and audible feedback, yet does not interlock in a way that impacts the force required for disconnecting the charger (Jensen & Munch, 2015).

9.4 Style and Appearance

As the saying goes, there is never a second chance for a first impression. Research has shown that the appearance of products influences short-term comfort of use (Vink, 2019). Based on the function of the TILER Click in the MaaS system and the intended interaction, a number of keywords have been identified that summarize the intended appearance of the product (insert page 38). An accompanying collage was created to visualize the intended appearance and to be used as inspiration in the design of the charger (figure 9.10).

The most striking detail in the appearance is the orange colour. It acts as a reference to how the power is transferred from the grid, through the cable and the handle, into the receiver and from there to the battery.

The colour orange is associated with progress and elicits feelings of enthusiasm and fascination (Bruens, 2011). According to McLoad (2016), orange is a stimulative colour and can boost self-confidence. In the case of a charger, it has the potential to stimulate people to use the charger. The bright

figure 9.10 *Design moodboard representing the intended style in physical details*

INSERT

The keywords to which the appearance and styling of the product should satisfy:

Simple // Convenient

The appearance needs to communicate the simplicity with which the charger can be connected to and disconnected from the vehicle.

Innovative // Fresh

It is desired for the appearance to support the novelty and innovation of the product.

Friendly // Approachable

The product has to appear friendly and inviting to its users to ensure people feel attracted to the idea of using the product.

Remarkable // Surprising

The charger is closely related to known charger products, but surprising and remarkable details in its appearance should pull it away from that to emphasize the functional differences.

orange also adds a factor of surprise and novelty, as it pulls the product away of the shape-wise comparable car chargers, which mostly use (dark) grey tones, sometimes with blue details (figure 7.3).

The orange colour of both the charger and its cable also create a colour contrast with the surroundings, that will often be mainly neutral colours. This further reminds people of the fact that the charger is still connected, both in daylight and low-light conditions.

From a visual perspective, the outer sleeve (figure 9.11) protects the power transferring orange parts and acts as an insulation between the 'dangerous' electricity and the hand. It emphasizes the interaction with the product.

For the outer shell, a light grey colour was selected. A light and neutral colour was chosen to communicate the technical novelty and innovation that is in this product. Grey tones are associated with stability and reliability. Pure white can be perceived as sanitary (Bruens, 2011) and might be too clinical, but a light grey colour adds a serious touch to the playful and approachable orange.

The visual styling of the transmitter handle has been mirrored in the receiver on the bike, providing yet another visual cue that the two belong together and should be connected when returning the bike to a hub.

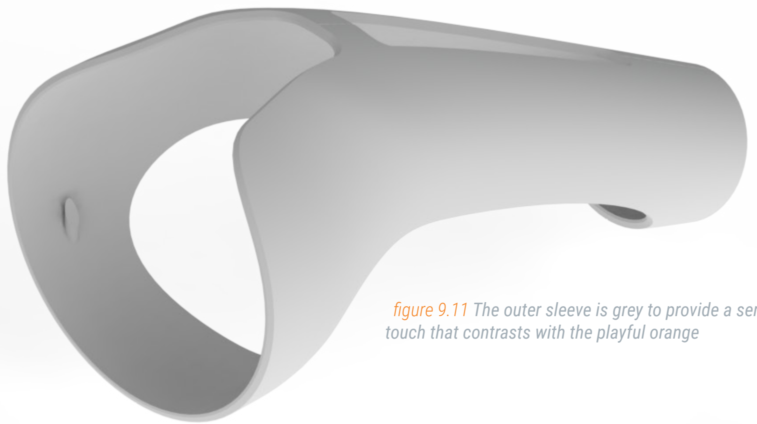


figure 9.11 The outer sleeve is grey to provide a serious touch that contrasts with the playful orange

figure 10.1 The interactive light surface is well-visible on the top of the transmitter and can be used for various communication purposes

10 Interactive Lighting

Both the transmitter and the receiver have integrated lighting that provide additional feedback. The use of electronics makes it possible for the product to respond to certain events in the process (e.g. when transmitter and receiver are connected) and enables visual communication towards the user that supplements the mobile application of the provider. This results in a seamless integration in the process of retrieving, using and returning a shared electric bicycle. The integrated interactive lighting is explained in this chapter.

10.1 LED Display on Transmitter Handle

An LED lighted 'display' has been integrated in the back of the transmitter handle as a means of visual communication (figure 10.1). The display is located on a place that is well visible from different directions when the charger is connected.

The display is basically a thin part of plastic that is lit from the back by RGB LEDs (figure 10.2). The different LEDs can be powered individually, which allows the implementation of animated patterns.

figure 10.2 Multiple LEDs light the light surface from a slight distance to generate a visually uniformly lit surface

One of the functions for which the display will be used is to communicate battery level and charging process. During the charging process, part of the display is lit blue and the 'next' LED will be flashing as to communicate that part of the battery is currently being filled. This way of communicating the battery level through multiple light points has been used in many products, including e-bike batteries, Bluetooth speakers and electric cars (figure 10.3), and therefore offers a recognizable and understandable way of communication.

In the process of retrieving a bicycle, users can reserve one up to 10 minutes before use. With the TILER Click providing the back-end system with real-time battery level, it would be possible to assign users the bicycle with the fullest battery. By lighting the light display in a specific colour, the user immediately knows which bicycle he is to take (e.g. the application showing 'Take the bike with the purple charger light'). This function has already been discussed in storyboard I (page 26).

figure 10.3 Using multiple LEDs to communicate battery level is fairly common in all sorts of applications

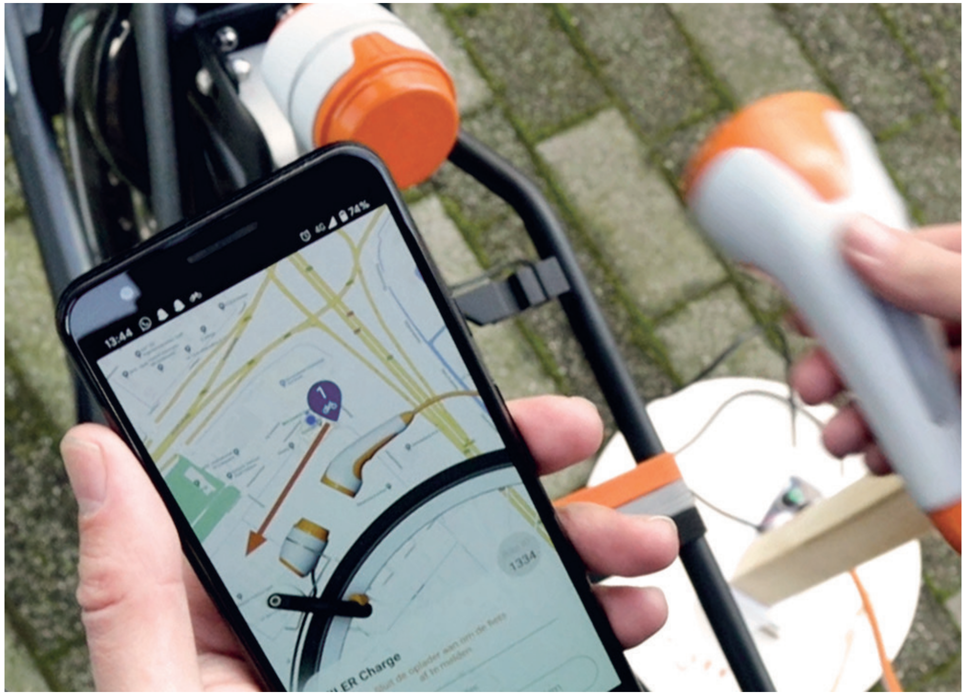


figure 10.4 The mobile appication can be used to support the user in the process and provide additional visual information

After reservation, the user will use the mobile application to unlock the bicycle, after which the LEDs will be lighted one after another to form a visual 'stream' away from the bike. This is an additional (active) visual cue to disconnect the charger before taking the bike for a ride. The light stream is lit in green to communicate to the user that he is good to go. This function was well-understood by users (chapter 13).

The LED display fulfils different functions in different stages of the process. As mentioned, the multiple LEDs allow for animated communication. A logical idea would be to implement a small screen instead of the LEDs, as it allows for more graphic communication and the use of e.g. text and icons. Though it would be hard to find a screen that is exactly the required size and a screen requires more complicated driving electronics and has a shorter life expectancy than LEDs, says Verwijmeren from Passives & Interconnect (personal communication, 11-10-2020), making it more prone to breaking.
It is worth mentioning that the charger will always be used in cooperation with the mobile application. This offers the opportunity to communicate more graphic or specific information as well, without impacting reliability and complexity of the charger (figure 10.4).

10.2 Integrated LEDs in Receiver

The receiver has been designed as a visually 'clean' product with limited number of details, yet it houses a light ring that acts as a reminder to connect the charger. Though it is not likely that the user will not see the light as the ring lock still has to be closed by hand, the flickering light ensures that the receiver also asks for attention when the user's view is not focussed on the vehicle but is instead in the peripheral vision (Vater, Kredel & Hossner, 2016), e.g. while using the mobile application or being distracted by something else.
The light element inside the receiver consists of a semi-transparent ring that is part of the embodiment (figure 10.6). A circular shaped PCB that houses the required infrared components for communication (chapter 12) is attached to the back of the ferrite core. This PCB will include LEDs on its edge that are directed outward and light up the beforementioned ring from the inside (figure 10.5).

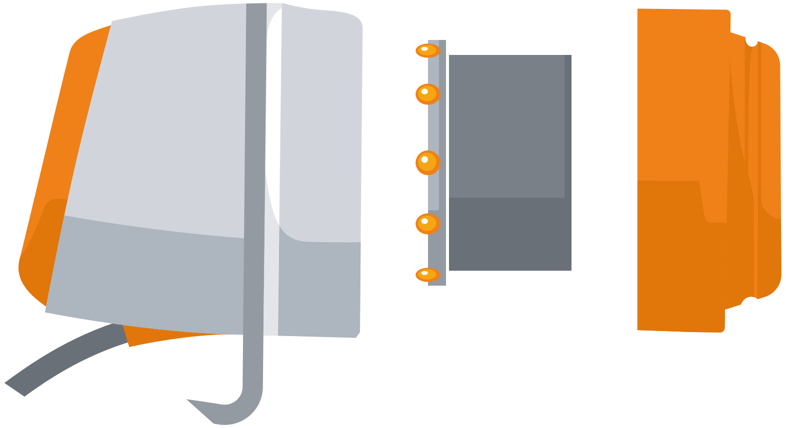


figure 10.5 The PCB that is mounted on the ferrite core (middle) is equiped with LEDs pointed outward to light the receiver lighting

figure 10.6 A light ring is integrated in the receiver to attract attention when the user needs to connect the charger or when a bike is stolen

10.3 Alarm Function

In theory, the charger should always be connected when a vehicle is parked at the hub and not in use. Therefore, when the charger is disconnected while the bicycle is not reserved, this implies unintentional disconnection or theft. This is when the alarm sequence will be started (figure 10.7).

The sequence starts after a few seconds with the flickering of lights on both transmitter handle (figure 10.8) and receiver (figure 10.6). This is to warn someone that disconnected the charger unintentionally that they have to reconnect it, but it can also indicate a stolen bike being dragged through the streets.

After about a minute, a notification will be sent to the owner of the hub so that they can check the GPS data of the specific vehicle and take actions if required. If the GPS data shows that the bike is left at the hub, but the charger has not been reconnected, the provider could decide to ask the next person to reserve a vehicle in the hub to reconnect the charger via the mobile application.

The alarm sequence will be terminated when the connection between the transmitter and the receiver is restored.

Further research is required to see if the alarm function is enough to replace the requirement of a physical fix to the hub or the need for a locking charger. Multiple providers of shared e-bikes have shown interest in such an alarm function (O. Sylla, personal communication, 2-10-2020; N. Hagels, personal communication, 27-10-2020), but Hagels also noted that retrieving a stolen bike is usually extremely hard despite its location being known and the expensive batteries are often already harvested when a stolen bike is found back (personal communication, 20-01-2021).

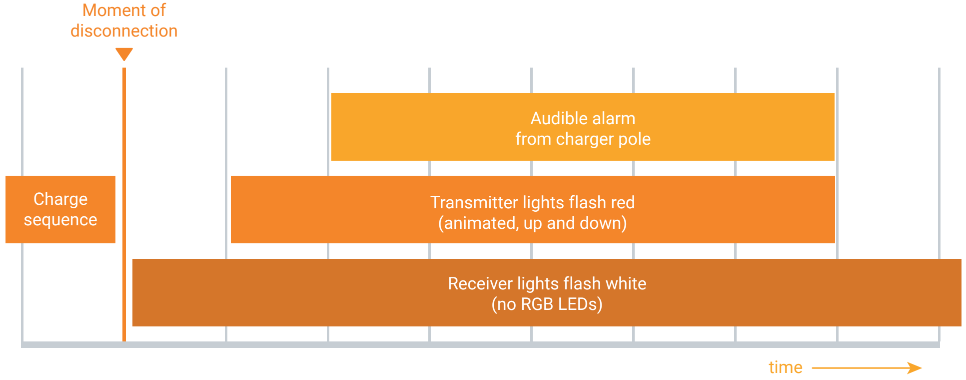


figure 10.7 The alarm sequence warns thieves and bystanders, but stops when the connection is restored or after a set time to avoid annoyance

figure 10.8 The light on the transmitter starts flashing red to notify something is wrong and the charger needs to be reconnected to the bike

11 Wireless Power Transfer

As mentioned in chapter 5, the technology to successfully charge any bicycle battery using wireless power transfer is one of the main assets of TILER. The current product of the company requires a large volume of ferrite to allow misalignment while parking, but the TILER Click eliminates this need. Therefore, an adaption of their system has been thought out for. This chapter outlines how the wireless power transfer works in this concept specifically, while also touching some of the peripheral features that has been elaborated on.

11.1 P-core

Within the scope of the project, it was decided to implement a buy-in core for the wireless power transfer. A brainstorm with electronics expert Ronald Kiewiet and TILER's former hardware designer Anamaria Grad has led to the selection of a Ferroxcube 42/29 P-core (figure 11.1, 11.2 and 11.4). Initial calculations of Ronald Kiewiet estimate that charging of at least 100 watt should be possible (personal communication, 3-11-2020). First experiments bij Kiewiet (figure 11.1) have shown that wireless power transfer is indeed possible, but tweaking the electronics and experimenting with different coil variables and ferrite alloys was not possible within the timeframe of this project.

The used P-core has an acceptable size that does not make the product look bulky. It fits well in the handle (figure 11.3) and keeps the size of the receiver on the bicycle acceptable from an aesthetic viewpoint.
Within the given outer dimensions, the used P-core might not be the most optimal shape for wireless charging. The surface area of the core allows for a high power transfer, but this limits the number of coil windings that fit, which

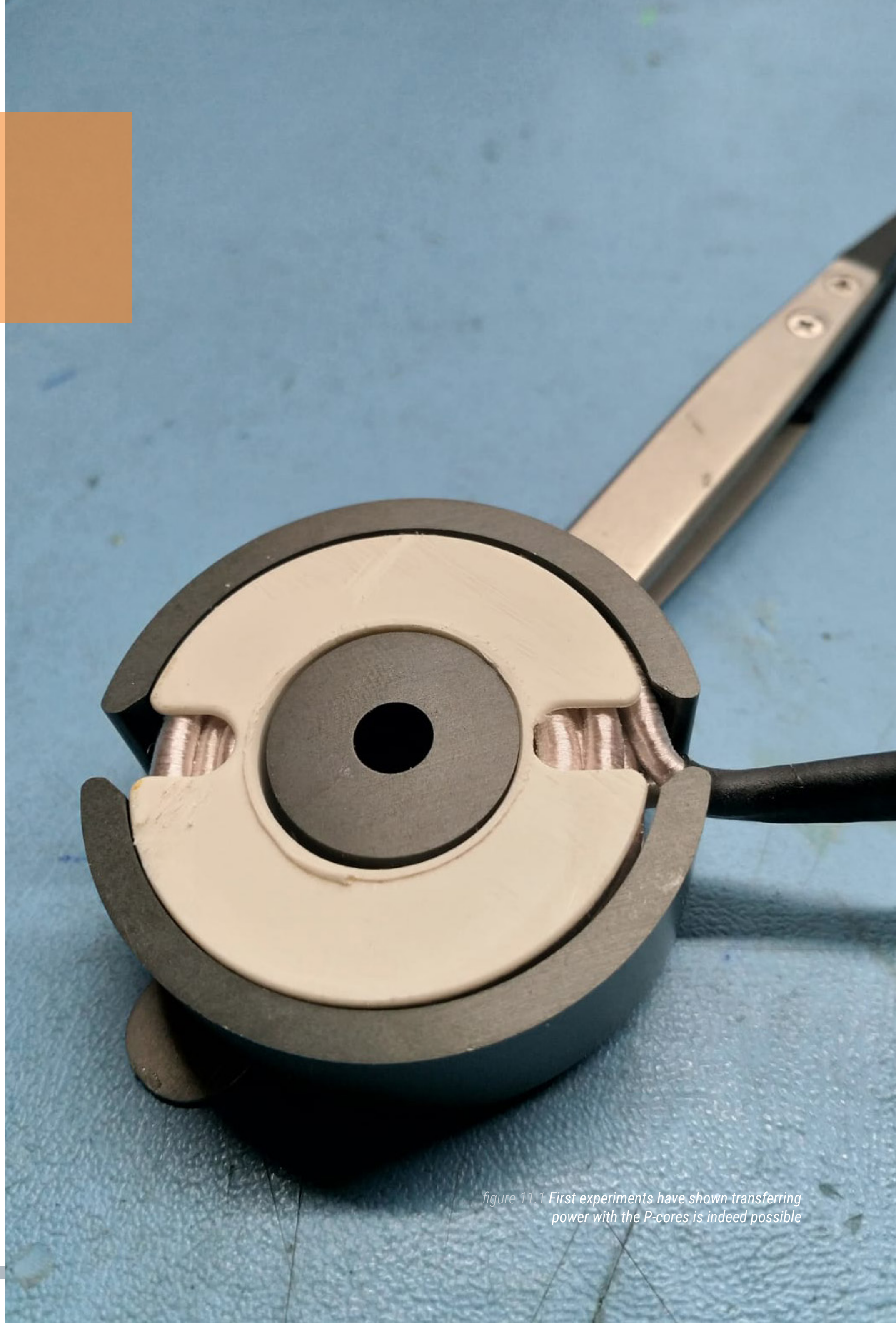


figure 11.1 *First experiments have shown transferring power with the P-cores is indeed possible*

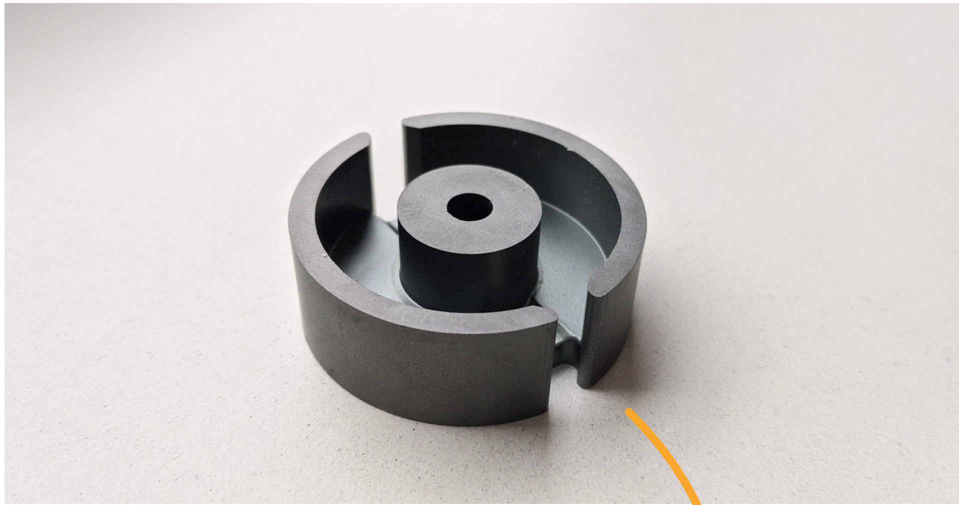


figure 11.2 The ferrite core used for wireless charging

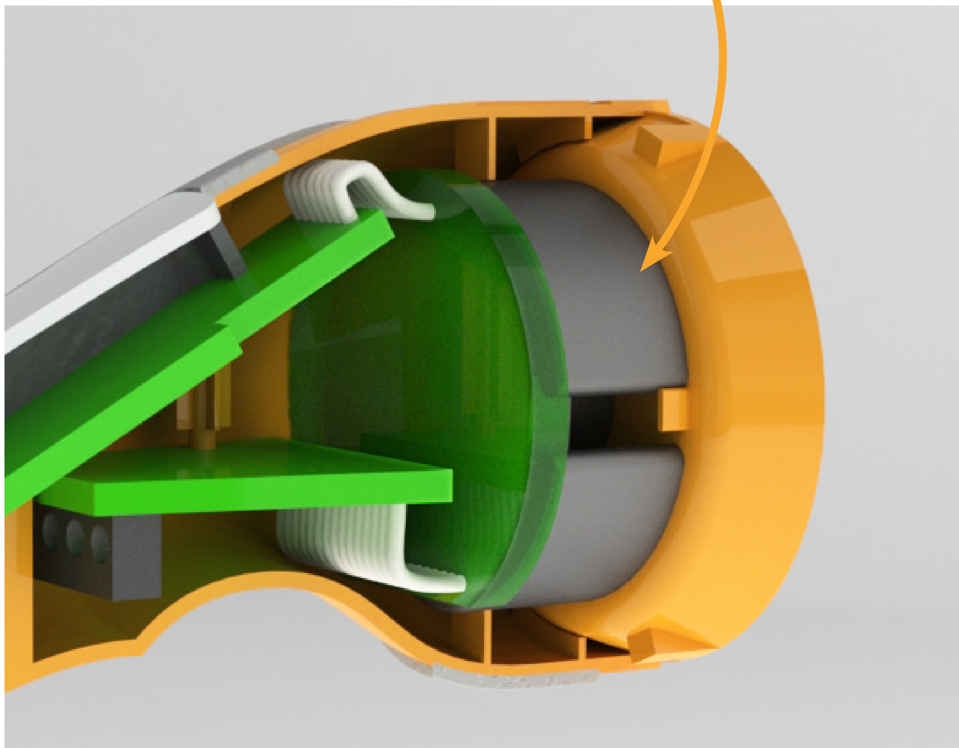


figure 11.3 The P-core fits well in the handle shape, without making it look or feel bulky or oversized (shown here with the required PCBs, see also chapter 12)

impacts the amount of power that can be instigated by the magnetic flux. A custom core could be an option for future iterations of the product to boost charging speed, though this asks for high investments both in development and production that are not worth the risk for a first version of the product. The proposed P-core is available from €5,02 per piece (based on 1.000 pieces, Digi-Key, n.d.).

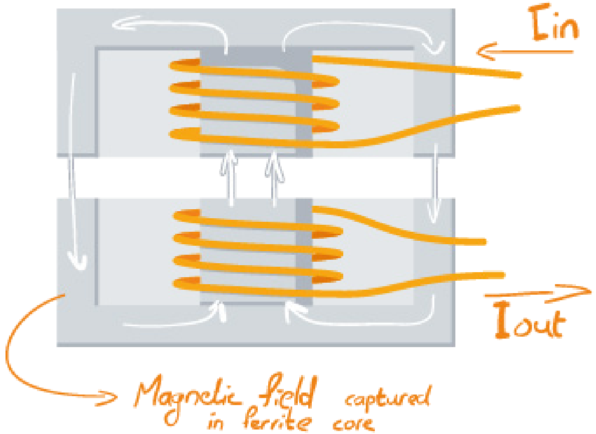


figure 11.4 Opposite to the Mushroom system (chapter 5), the P-core captures the entire magnetic field, resulting in lower loss and thus higher efficiency

11.2 Required Electrical Components

On the transmitter side, most of the components can be placed inside the charger pole. DC current from the power net is fed through a transformer to convert it to the required low-voltage and low-current for charging. As this process already happens inside the charger pole, it makes requirement for the transmitter cable less strict (R. Kiewiet, personal communication, 09-11-2020).

Inside the handle, the only thing that needs to be done is to convert the direct current to alternating current required for wireless charging. This is done through a so-called mosfet bridge that can control the frequency of the current, resulting in an optimal power transfer. Placing this mosfet bridge in the charger pole instead would mean that alternating current would have to travel through over one meter of cable, which results in fluctuating frequency and low power transfer.

figure 11.5 The bike electronics are currently still relatively large and require an extra container to place them on the bike

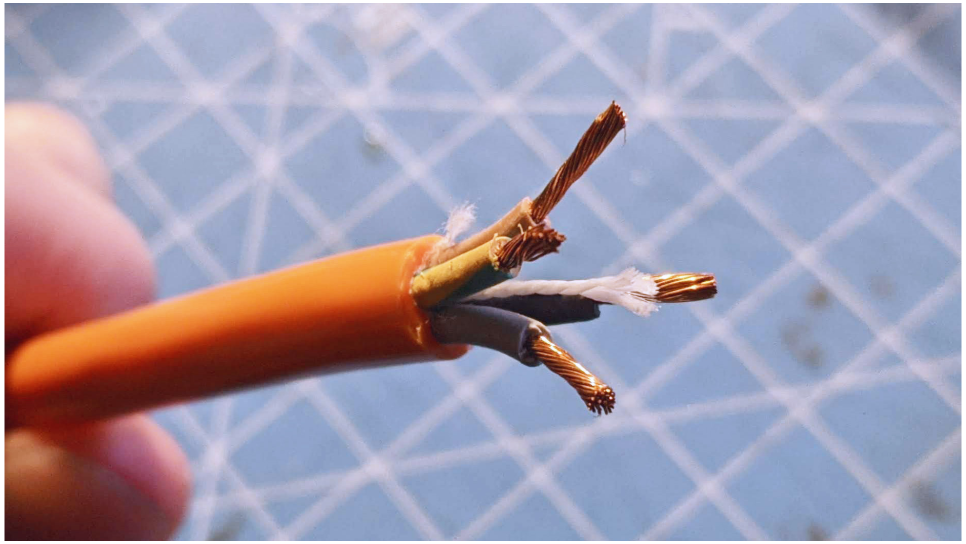


figure 11.6 A PUR cable with four conductors provides the desired mechanical strength and meets the electrical requirements

The receiver side is more tricky. The current electronics on the bike are too large to fit in the receiver. Therefore, TILER now uses a separate 'bike box' placed elsewhere on the bike to house the electronics (figure 11.5). TILER is currently working on sizing the electronics down to the point where it fits in the kickstand, making the bike box obsolete. Once this has happened, it should be possible to redesign the receiver to fit the electronics without significantly impacting its aesthetic properties.

11.3 Wire from Transmitter Handle to Charger Pole

A mechanically strong cable is required to transfer power from the charger pole to the transmitter handle. This cable has to withstand circumstances thrown at it in different environments, e.g. low or high temperatures, sunlight, bicycle wheels riding over it, pulling, etcetera.

According to Ronald Kiewiet (personal communication, 27-11-2020), the required wire will not have to transfer more than 5 ampere. J.S.T. Ltd. (n.d.) shows that a minimum conductor cross section of 0,52 mm2 is required to transfer this power without risking the insulation to melt. To play safe, a conductor size of 1 mm2 has been decided on. Four conductors are required for power transfer and communication (figure 11.6).

Felten WCS (M. Felten, personal communication, 27-11-2020) advised a PUR (poly-urethane) cable, as it can withstand environmental influences and are wear-resistant. They are often used for professional tools that are moved a lot (Wel, n.d.) and are ideal for use outside, repeated bending and scraping.

For future production, Felten WCS advises to invest in a custom-made cable (M. Felten, personal communication, 27-11-2020). This not only allows for making it in the exact desired colour with custom lettering, but also allows for e.g. implementing different diameter conductors or thickening the outer insulation layer to make the cable the exact desired thickness or flexibility.

Testing a sample of the required PUR cable has learned that its flexibility is high, which is desired in this situation. The thickness of the tested cable is 7.5

mm. A rubber cable grummet provides a transition from the hard plastic body of the transmitter handle to the soft flexible cable, but also adds a visual bridge between the thick body to the relatively thin cable.

Besides its mechanical characteristics, the proposed cable fulfils an aesthetic function. Thinner cables are available that are sufficient for the operational current, however a thicker cable makes the product appear less vulnerable.

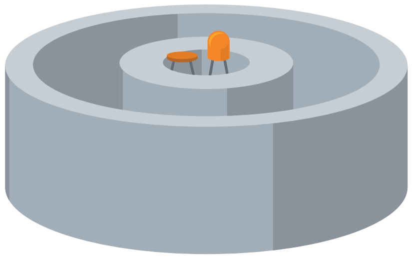


figure 11.7 Communication between transmitter and receiver happens through IR, located in the center hole of the ferrite core

11.4 Communication

The current concept of TILER uses a Bluetooth connection between the transmitter and the receiver to transfer data about bike identification, battery type, battery temperature and current voltage and amperage of the battery. It uses this data for safety reasons and for estimating the battery level.

In situations with just one bicycle, the Bluetooth connection is ideal as it does not require exact alignment of the sending and receiving device. Proximity is enough.

In the case of public hubs, however, a risk exists that the transmitter that is charging one bike is wirelessly communicating with the receiver from another vehicle. The exact alignment of transmitter and receiver in this product however allow for the utilization of a much simpler and cheaper IR communication system that is placed in the opening of the core, consisting of an IR transmitter and an IR receiver on both sides to allow bidirectional communication (figure 11.7). A common drawback of IR communication outside is the influence of sunlight, but this is not an issue in this case as the sunlight cannot access the IR receivers when the charger is connected.

One of the conductors in the cable from the transmitter to the charger pole will be used to transfer data to one central point per hub, including bicycle identification and live battery level. From there on, the data from the entire hub will be communicated to the owner of the hub via the GSM network (figure 11.8).

The most common electronic ring lock currently used with shared bicycles in the Netherlands is the AXA IN E-RL, which comes either with a Bluetooth connection or a wired connection that can be connected to existing intelligent systems already on the bicycle (AXA IN, n.d.). By wiring the smart lock to the TILER Click receiver, only one Bluetooth module is required to achieve the intended interaction between charger, lock and user (figure 11.8).

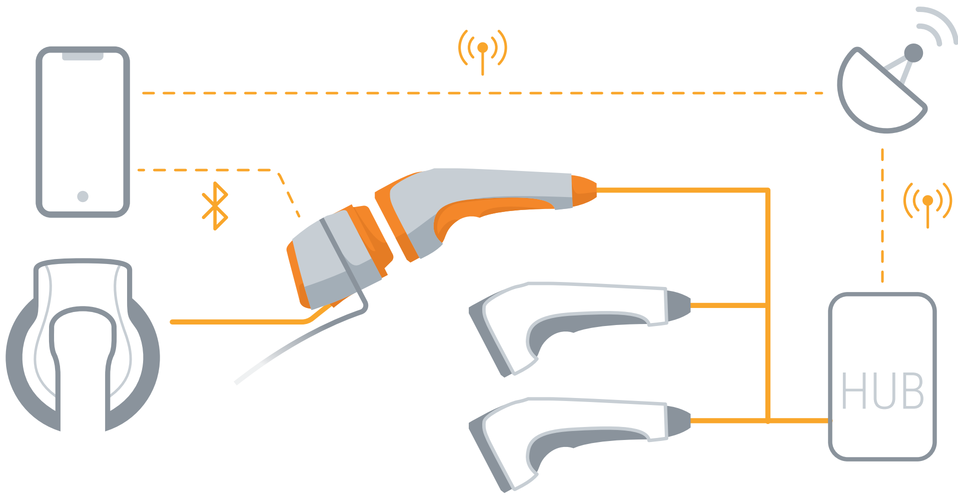


figure 11.8 Diagram explaining the different communication lines involved in the system

12 Production & Price Estimation

To further research the feasibility of the TILER Click, a first effort has been made to develop the embodiment of the product. Appendix H shows a full breakdown of parts (bill of materials) and estimated cost price.
The body of the transmitter handle has been designed in more detail to enable a more realistic estimation.

12.1 Production of the Transmitter Handle

The shape of the transmitter handle is relatively complex. Injection moulding was selected as the most promising production method for the body for multiple reasons. First of all, injection moulding is also possible with TPE material that feels like rubber, which is preferred for the outer shell as it reduces the chance of damage when falling on the ground or bumping into the bicycle. Secondly, the use of injection moulding allows integration of features for fastening or clamping other parts, which is ideal for assembly.
The use of injection moulding, however, comes with relatively high initial investment costs as the required moulds can be costly. This makes injection moulding less interesting for production of low quantities, but with the eye on future alternative versions and applications of the product (chapter 14), the initial investment will be worth it.

The transmitter body is made up of four main parts (figure 12.1). During assembly, all electronics will be attached to the upper inside body (figure 12.2), after which the other parts of the inside body are assembled. The ribs inside the body parts lock all other parts in place. The whole is now a water-tight container with all electronics and ferrite inside, yet it is still possible to

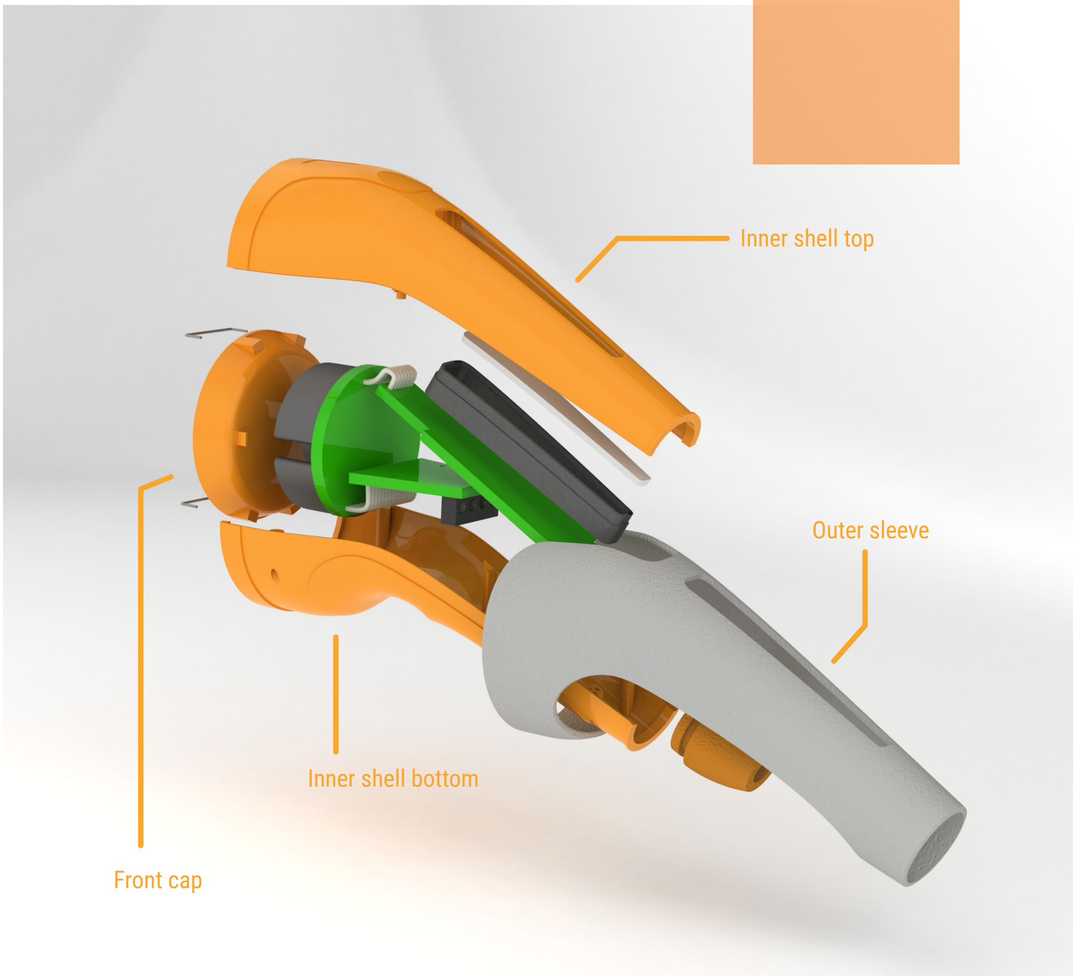


figure 12.1 The transmitter body consists of four main body parts

disassemble it if the electronics fail and need replacement or for recycling purposes. As the front part of the body is a separate part as well, the spring wires used for the clicking mechanism are locked in place during assembly and cannot fall out during use.

The last part that will be added (glued) is the outside sleeve, made of rubber. The geometry makes it lock in place and the countersunk fit ensures it will not come loose during use. The screws that assemble the inside body are also covered by the outside sleeve.

For the electronics, three PMBs are integrated that are connected through flexible wires (figure 12.2). The use of three PMBs allows for separation of the DC to AC converter, the communication between receiver and transmitter and the light element, ensuring the three separate functions will not interfere with each other (R. Kiewiet, personal communication, 19-01-2021).

12.2 Estimated Cost Price

A cost price is estimated based on a production of 5.000 pieces. This number is seen realistic for the use with shared bicycles, but higher production numbers might be possible if variations will be taken into consideration (chapter 14). Due to the timeframe of the project, it was not possible to discuss the project with actual production companies yet.

The total cost price (no assembly and transport) of the TILER Click is estimated on €115. This paragraph contains further argumentation for the estimations.

As mentioned in the previous paragraph, injection moulding was assumed as most feasible option. The design has been discussed with product designer Erwin van Veen, who has previously worked for an injection moulding company. He estimates the total cost price of the body to be somewhere around €15 for the combined four parts (personal communication, 26-01-2021). Based on this information and the fact the receiver does not require the use of TPE to counter impacts, the production price for the body of the receiver is estimated on €12.

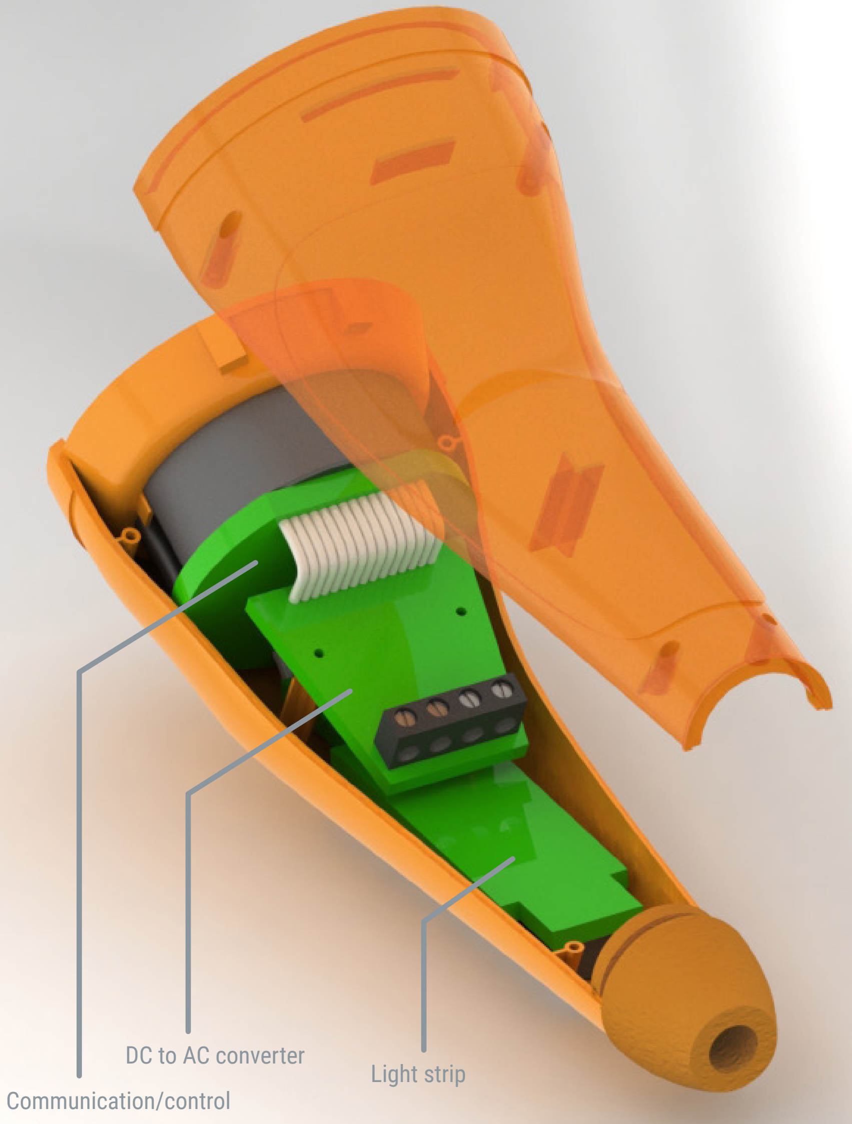


figure 12.2 All parts are assembled inside the inside top shell, after which everything is sealed by placing the bottom shell

The combined electronics will likely cost between 40 and 60 euros per charger (R. Kiewiet, personal communication, 28-01-2021), though prices can drop below €40 if a production of 10.000 per year is assumed. This does not include the ferrite cores (€5 per piece, of which two are required (Digi-key, n.d.)) and cables (the PUR cable costs €2 per meter if bought per 100 meter, but is likely cheaper for larger quantities).

The bike bracket is a part that can not be made in larger quantities. This makes estimation of a reasonable cost price difficult. For the cost price estimation, 10€ per piece is assumed.

Other parts include the spring wires, cable grommet and covers for the light box. Individual prices for these parts have not been estimated, but a combined price of €15 for all parts seems reasonable.

At a first glance, this might sound relatively expensive for a charger. However, as pointed out by Hagels (personal communication, 27-10-2020), a reliable charging solution allows the company to use batteries with a much lower capacity. Urbee currently uses 530 Wh batteries with a retail price of €700, but 300 Wh batteries provide sufficient energy for their users and cost 'just' €400. Hagels also lined out that their batteries often get stolen as there is a high demand for its cells. Using smaller capacity batteries might also make theft of Urbee's batteries less interesting for criminals, thus resulting in fewer broken or stolen bicycles.

Validation & Further Development

part III

13 Interactive Prototype

A realistic looking prototype of the concept has been built to validate the proposed interaction and finetune the interactive light elements in a realistic setting. The prototype focusses only on the interaction and therefore differs from the final product most importantly in that it cannot actually charge a bicycle. This chapter outlines how the final interactive prototype is built and tested, as well as some of the earlier prototypes that have sparked new insights and ideas.

13.1 First Interactive Prototype

To ensure the final prototype would function as intended, a somewhat simplified version has been made first (figure 13.1 and 13.2). This version houses three pinhole LEDs in the transmitter handle and uses a light-dependent resistor (LDR) to sense if it is connected to the receiver. The electronic components are driven by an external Arduino and separate wires replace the cable that would normally connect the transmitter handle to the charger pole.

This first prototype has been tested on a regular bicycle with some acquaintances, either through a live demonstration (n = 5) or a video demonstration (n = 2). As the prototype functions fairly similarly to the final product, some insights are valuable for this as well:

- The way people grasp the handle is as intended, though one person grabbed it further towards the wire. Upon asked, she mentioned that her hands are relatively small and she just liked that better due to the tapered shape of the handle, but she also mentioned that she would not consider disconnecting the charger by pulling the cord. This observation does not mean the shape is wrong, as offering multiple grasping options can improve the perceived convenience and simplicity of the product.

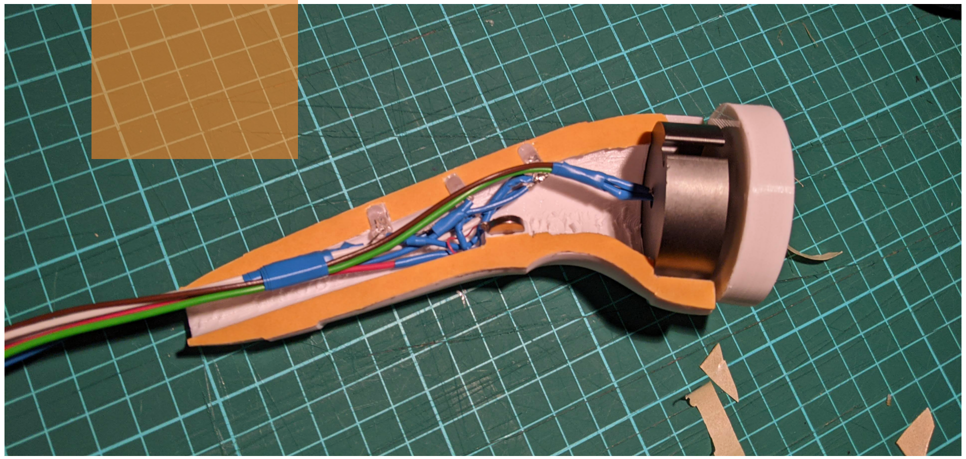


figure 13.1 A first prototype was built that houses a simplified version of the interactive electronics incorporated in the TILER Click (chapter 10)

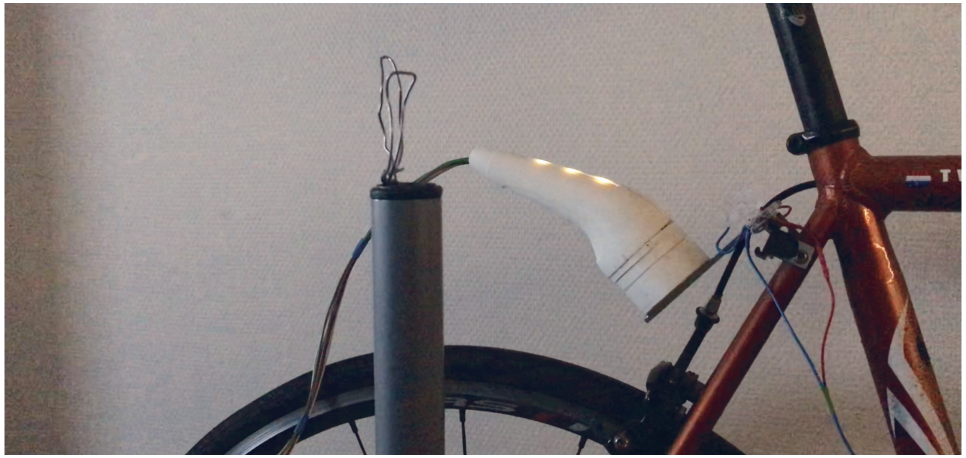


figure 13.2 A first interactive prototype was built on a regular bicycle, insights gained from building and using this prototype have been used in building the final prototype

- The placement of the lights makes them well visible when the charger is connected, as was envisioned in chapter 10.
- The lighting 'stream' to notify users to disconnect the charger before riding the bike was understood correctly. As one participant mentioned: "It looks like it [the handle] wants to be picked up, […], so that would work!"

The lighting in the receiver has not been tested with users in this prototype.

13.2 Final Prototype

Based on insights gained by previous prototypes, a final prototype was made that looks and functions like the final product (seen throughout this report). The prototype includes the intended lighting elements and a hall sensor that notices when the transmitter is connected to or disconnected from the receiver. Two Arduinos are used to run the prototype: one inside the transmitter handle and one on the charger pole. Using two Arduinos that communicate with each other allowed using the intended PUR cable, which only has four conductors. A full break-down of what went into making the final prototype can be found in appendix H, although figures 13.3 to 13.8 provide an interesting insight in the process of building it as well.

The physical prototype is accompanied by a digital copy of the X-bike application (figure 13.9), altered to include the role of charging in the process. Communication between the application, the lock and the charger is not included, but has been replaced by a switch on the receiver pole that changes the reservation status.

The final prototype has been installed on an e-bike that was made available by Urbee and has been tested with different stakeholders to validate the clarity and logicality of its interaction. The physical interaction was already tested plentifully with earlier prototypes, so

figure 13.3 The main body of the prototype was 3D printed in two parts, glued together and its surface evened

figure 13.4 Spray paint was used that comes close to the colours envisioned for the final product

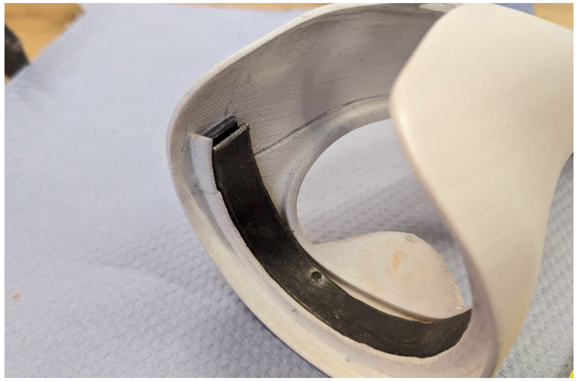


figure 13.5 Lead strips have been used in the front of the body to mimic the weight of the ferrite core and coil

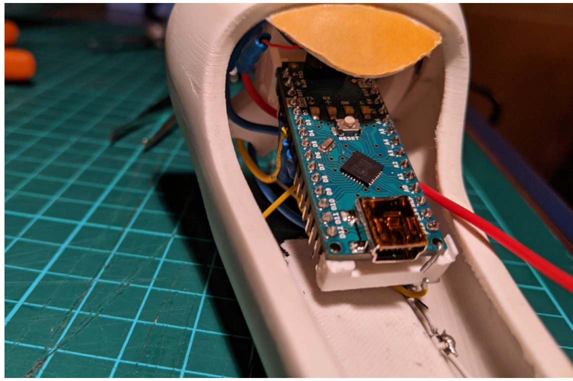


figure 13.6 An arduino and five RGB LEDs have been integrated to showcase the intended interaction

figure 13.7 Cardboard prototypes for the bike bracket were made to ensure correct placement and dimensions

figure 13.8 The final prototype was installed on an e-bike from Urbee, including running the receiver cable under the fender

no surprises are expected in that. This is, however, the first prototype that looks realistic and is built onto an e-bike, and it is also the first prototype that has all the interactive electronics working.

Though no structured testing or roleplaying has been done, the final prototype has been discussed with employees of TILER and peer students (as potential users, n = 10) on the following points:

- How do users perceive the physical connecting and disconnecting of the charger? Is it easy enough?
- Are the light elements understood correctly? (Receiver flashing, battery charging, disconnection cue).

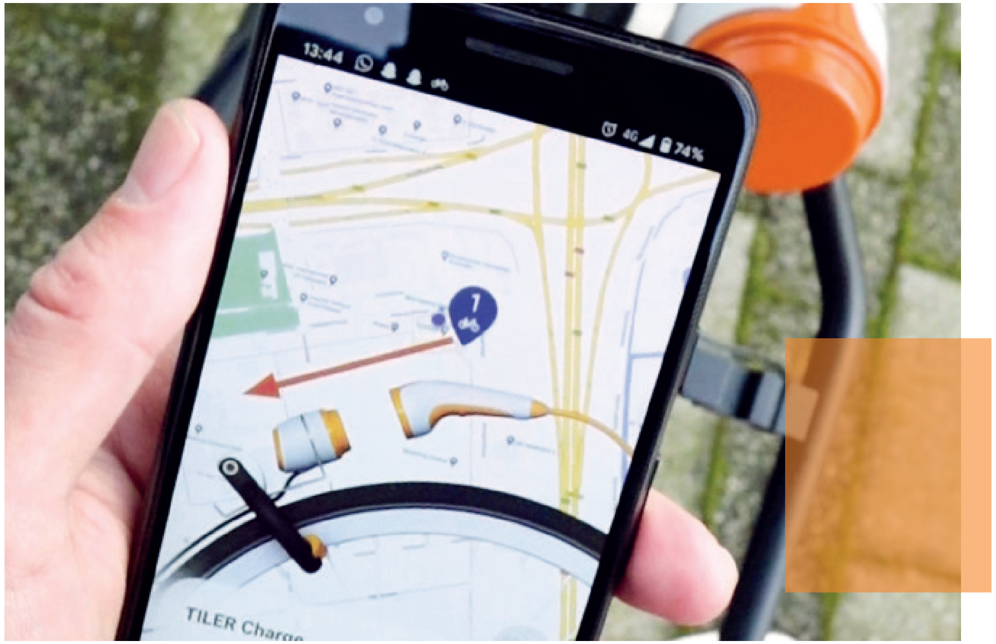


figure 13.9 A mock-up mobile application was made to showcase the intended integration of charging in the use of shared e-bikes

User testing gained valuable insights. As expected, the physical interaction was understood correctly by all and is good as is.

- The intended light element on the receiver was not properly visible when standing close to the bicycle. The intention was to light up a lightning bolt on the front-facing surface of the receiver, but it was found that this surface is only well-visible from a distance. Therefore, the lighting element in the receiver has been replaced in the concept by a lighting ring, as explained in chapter 12.
- The light display on the transmitter communicating the battery level was understood by all testers. Blue was perceived unanimously as the correct colour to communicate charging. The authentication process that occurs once the charger is connected, however, had all the LEDs light up for a few seconds as a confirmation. Some participants (n = 4) mentioned that they first thought the battery was already full. Therefore, the confirmation has been changed to flashing the LEDs green twice. This was understood properly by the five people that were asked afterwards.
- One participant found a flaw in the copy of the X-bike application, but was so focussed on the application that he missed the lighting 'stream' that communicates that the charger needed to be disconnected. This shows that people might be focussed on the application and might miss
- Two employees of a bike rental company tested the prototype and were surprised by the easy connecting and disconnecting, yet solid locking of the clicking mechanism. They also liked the sturdiness of the bike bracket.

Though all participants agreed on the concept and its integration in the process of using shared e-bikes being a good solution for charging e-bikes and the light display on the transmitter handle truly adding functionality

All participants agreed on the concept and its integration in the process of using shared e-bikes

figure 13.10 The prototype was tested by Urbee personnel, who reviewed the concept with their experiences from running a MaaS service

13.3 **Validation with Urbee**

Next to testing with potential users, the prototype was presented to and tested by both Urbee's managing director and operations manager (N. Hagels & S. Bijkerk, personal communication, 20-01-2020) (figure 13.10), who reviewed the product based on their practical experience with shared bicycles and its users.

First of all, Urbee showed highly enthusiastic about the TILER Click. Especially how the product integrates charging in the process of using shared e-bikes is seen as extremely valuable, as it can significantly boost reliability of charging. This also includes the use of lights in the transmitter, that play an important role in communicating the process that is now only done through the mobile application.

Next to that, physical interaction and the placement on the bicycle were perceived really good. The way the transmitter clicks on the receiver and the location of the receiver on the bicycle were highly valued and seen as a simple and convenient way of charging that is understandable and executable swimmingly by its users.

The universal mounting of the transmitter through a steel plate was also seen as a crucial part of the concept. Urbee often uses different bicycles in different hubs (and in some cases even different bicycles in a single hub), which makes a user-friendly charging infrastructure nearly impossible. They see the TILER Click as a promising solution for this problem, as it presents the user with the same charger every single time. This also goes for the use of their bicycles in hubs from Hely that also have cargo e-bikes from Cargoroo in them, where it would be ideal if all vehicles could be charged with the same charger.

Lastly, Hagels noted that he specifically liked the vibrant, yet serious appearance of the product.

The guys from Urbee did, however, viewed the lack of a locking mechanism as a drawback for using the TILER Click in the public environment. They expect the chargers to break easily if they drop on the ground often. Also, the fact that the bike can still get stolen easily makes them hesitant on using the product with their publicly shared e-bikes. Hagels sees the product more feasible and valuable in their corporate sharing programs, where bike theft and vandalism is less of an issue.

14 Future Variations

The product as described in this report has been aimed specifically at publicly shared e-bikes, but many of its elements can be used for future variations. This can massively boost potential production in the future and thus make investments in e.g. tooling more interesting.

A first possibility is to look further into the field of shared light electric vehicles and create adaptions for e.g. scooters and mopeds. Only changing the (bracket of the) receiver might be sufficient for some vehicles, but other vehicles might require a slightly larger version to accommodate faster charging of larger batteries. Much of the electronics in such a variations will be the same.

Next to that, as mentioned by Hagels from Urbee (personal communication, 27-10-2020), being able to charge different shared vehicles in the same recognizable way is extremely valuable in making users actually connect or disconnect the charger. Making the charger available for multiple different types of vehicles can further boost the position of TILER in the world of shared mobility.

Another example is a simplified version for commercial home use. Such a product would lack many of the interactive electronics that are added and might come with a power plug to connect the transmitter handle straight into the power net at home. A variation on this could be a 'wall box' comparable to that of electric vehicles that allows charging outside your house without having to plug into the power cord every time. This would be a good solution to those that have bought an e-bike with integrated battery (e.g. the VanMoof S3) that they cannot charge inside at their house, but combined with adaptions for different vehicles, it might also form a promising solution in the south of Amsterdam, where people charge their mobility scooter on the street (figure 14.1).

If such versions catch on, it feeds the possibility to set up an entire network of TILER chargers. This allows people to charge on the go, at work, when doing groceries or when parking a commercial bike at transferiums (e.g. train stations).

figure 14.1 In the area of Amsterdam Oud-Zuid, mobility scooters are charged by a charger placed in a wall-mounted locker

15 Further Development

The focus of this graduation project has been mainly on creating a seamless and convenient interaction between the user and the product. TILER has shown serious interest in taking the product further down the road, but its current state requires elaboration on the following things:

First of all, the embodiment is currently still in its idea phase. Injection moulding is currently seen as the most logical and beneficial choice as main production process for the embodiment. This (and alternatives) have to be further researched, also in collaboration with companies that specialize in this process. Contact has been established with Promoulding during the final week of the project, but this has not lead to useful results before the deadline of this report.

Secondly, the current state of the electronics is relatively cumbersome and requires a scale down. Considering the size of the current technology developed for the tile from TILER, it must be possible to fit the required electronics in the transmitter handle and charger pole. The receiver-side however requires further elaboration of both the electronics as well as the embodiment to ensure all required elements fit and no separate bikebox is needed (as is the case with TILER's current product).

Next to just scaling down the required electronics, the charging itself should be developed further to make it function properly and efficiently. First experiments by Ronald Kiewiet have shown serious potential (chapter 11), but further elaboration on the variables in this system requires more time.

Another aspect that needs to be developed is the wireless communication and integration with the provider's back-end system and mobile application. This is something that likely needs to be done together with an expert in this field, as well as parties such as AXA IN and X.bike that have developed products already in use in MaaS systems.

The charger pole is also a part that will require further attention. The way of placing the transmitter handle back on the pole has only be covered shortly in the final prototype and a more convenient and logical way might be possible.

As mentioned in chapter 7, different hubs or providers may have different requirements on how the charger is to be installed in the hub. It is advised, however, to further elaborate the 'docking station' for the transmitter handle in the way the user places and grabs the transmitter and the way the transmitter is locked in this docking station. Adding a magnet that attracts to the ferrite might be a good option to keep the transmitter handle in place. This is essential, as the docking station is an extension of the product and should therefore follow the philosophy of having a universal, logical and effortless way of connecting and disconnecting. Offering a convenient way of placing the transmitter handle in the docking station can prevent people from just dropping the transmitter handle on the floor after disconnecting it from the vehicle.

The docking station could be combined in one or two 'standardized' solutions for charger poles (e.g. so-called staples, a wall-mount or incorporated in a bike rack, as the power outlet in figure 15.1). Further hub-specific solutions could later be explored together with hub providers.

In the automotive industry, cars and charge poles often come equipped with an integrated lock that prevents people from disconnecting the charger while charging is ongoing. The main reason for this is that the high DC voltages can cause permanent damage to connector pins and may harm users when a charger is unplugged during charging (Khoury, 2020), but these systems also prevent theft of cables and prevents people from unplugging a charging vehicle to charge their own, while the previous user is still paying for it (Hachmang, 2018).

Though mentioned issues are not present in the use case of publicly shared e-bikes, a major problem is that the bikes might get stolen when not fixed to the environment. In 2020, almost 30% of Urbee's publicly shared e-bikes got stolen or had their batteries violently removed (N. Hagels, personal communication, 20-01-2021). A system that locks the transmitter and receiver as long as the vehicle is not reserved might be able to make the heavy chain lock currently used obsolete.

Beforementioned car chargers often work with a solenoid, a linear actuator that slides into a cavity in the charger cable handle. Whereas cars and charger poles have plenty of bodywork to integrate such a solenoid behind, the physical boundaries of the TILER Click makes a similar system complex to integrate. Further development of the concept could include the introduction of such a locking system to better suit the needs of the MaaS providers. In this case, the mechanical properties of the cable also need to be reconsidered.

User testing with the final prototype was not done in a fully realistic setting. The user tests as presented in chapter 13 show that the TILER Click has the potential to become a successful charging infrastructure for shared bicycles, and potentially also other shared light electric vehicles. This makes it worthwhile to invest in further development of the product, but testing in actual shared mobility hubs is advised before bringing the product towards production.

The current state of the prototype only mimics the interaction, but a next step would be to build a small series of prototypes that already incorporates charging and connectivity with the mobile application. With these prototypes, pilot studies can be done to gain more insights in how the TILER Click is used in practice and what requirements are important for the final product.

figure 15.1 Velopa offers regular power sockets on their bike racks that provide easy acces for connecting a bike charger

Conclusions

Over a period of five months, a universal charging solution for shared e-bikes has been developed. The wireless charging technology developed by TILER in their revolutionary charging tile was taken as a starting point, but a new and different physical form was considered to be better suited to the specific market of publicly shared electric bicycles.

The process of this graduation project included a broad yet deep analysis of the context that led to a clear understanding of the currently experienced issues by both users and providers of shared e-bikes and the expectations for the future. It was found that charging is one of the major issues in operating shared bicycles and that unreliable charging can lead to dissatisfaction among users. To come up with the ideal charging solution, a design vision was set up (chapter 6) that embodies the most important criteria for the charger solution, being universality, reliability and convenience.

The TILER Click fully integrates charging in the process of using shared e-bikes by providing a simple and intuitive way to connect and disconnect the charger. The resemblance to known charging products establishes a clear understandance of how the product works and what it is meant to do. The easy alignment in combination with a simple yet efficient clicking mechanism make the TILER Click so easy to connect and disconnect that it is no longer an effort to use the charger. This makes the product significantly more convenient in use than alternatives. Its connectivity with the electronic ring lock and the mobile application ensures the user disconnects the charger before using the e-bike and reconnects the charger again after use. This, together with the fact that wireless charging technology does not suffer from mechanical wear or corrosion, makes charging undoubtedly more reliable.

Placement of the receiver on the rear of the electric bicycle make the product extremely universal and versatile. Due to its small size and mounting through a custom bracket, it can easily be integrated on almost any bike, regardless of its geometry.

The TILER Click offers a convenient, simple and reliable way of keeping e-bike fleets charged. With that, it not only enhances the experience of charging itself, but also has a high potential positive impact on the experience of retrieving and returning the vehicles to their hub.

Its possible adaptions for other vehicles, as well as for other markets, show that the product has grand potential for future success. Being able to charge all shared light electric vehicles in a uniform way can play a big role in the future of (shared) mobility.

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Appendices

A Trend Analysis
B Stakeholders
C Program of Requirements
D Ideation
E Receiver Placement
F Explorative Research
G Click Mechanism Design
H Interactive Prototype
I Disclosed (only available to project team)
J Project Brief

APPENDIX A

TREND ANALYSIS

Demographic factors

Urbanization leads to larger cities. One of the major issues is congestion. Small, light vehicles play a role in lowering congestion, e.g. a driving car requires about 28 times the space of a riding bicycle. City infrastructure has always been aimed at car use, but is now slowly changing towards less space-intensive lay-outs.

Economic factors

More people are engaging in subscription-based services and leasing (e.g. Netflix, smartphone use, washing machines, etc.). These services require no up-front investment costs and no irregular maintenance costs. People want to pay more and more for what they use (pay-per-use) instead of also paying for products they do not use.

Shared mobility has a good potential in replacing 'second vehicles', e.g. second cars. These vehicles are standing still most of the time and thus sharing them is a financially healthy alternative.

Political factors

Municipalities are focussing more on alternatives to cars, as these require a lot of place. Some are also trying to avoid cars in the city altogether, having them parked outside the city centres and relying on smaller, more versatile modes of transportation for the last mile.

More strict regulations are forming for shared mobility, especially the free-floating variants. This forms new limitations, but also new opportunities (e.g. combination of free-floating MaaS with mobility hubs lowers visual impact to benefit residents, ensures availability for users and allows charging to lower costs for providers).

Municipalities focus more on the liveability of the city. Impact on city scape becomes increasingly important and how people use space as well.

Ecological factors

Vehicles with internal combustion engines are no longer welcome in cities. Using light electric vehicles in city centres decreases local pollution and increases liveability of the city.

Socio-cultural factors

A change in mindset can be seen that values access over ownership. A good example is Netflix, to which people pay monthly to view movies or series without owning them on DVD. The whole sharing economy and collaborative ownership is evolved around this idea.

Next to that, a growing demand for personal transportation is observed, which is only accelerated by the COVID-19 pandemic. Especially in combination with inter-city public transportation (e.g. trains), shared mobility is a very good alternative.

Technological factors

Access to vehicles via smartphone applications has made use more convenient for users, but also made it easier for providers to see who is using the bike. These applications work together with smart locks to further improve the experience of using the vehicle.

The next step in the mobile applications is to bundle vehicles of multiple providers in one application, also including public transportation.

GPS tracking of the bicycles has made use more versatile and lowers theft. It allows free-floating services. GPS geofencing allows municipalities and providers more control on where people are (allowed to) park and use the vehicles.

APPENDIX B

STAKEHOLDERS

Stakeholders have been identified and analysed by asking three questions. These questions help to identify the relations between stakeholders and their interest and influence in the product.

WAT? Who are they?
WDTW? What do they want?
HWTGI? How will they get it?

User of Shared E-bikes

WAT? Use shared e-bikes, mainly for work-related first- and last-mile trips combined with public transportation or cars parked outside the cities.

WDTW? Mainly convenience (Fishman, 2016). As for charging: an easy and fast system that does not require more physical and mental effort than necessary. Most users understand that charging is inevitable with electric vehicles (enquiries among e-bike users and people engaging in MaaS-systems, n=8).

HWTGI? Users have a big influence as they can simply decide not to use a MaaS-system if a more convenient alternative is on the market. If two comparable MaaS-systems utilize totally different charging solutions, users are more likely to use the one that offers the most simple solution in use.

Providers of Shared E-bikes / MaaS-providers

WAT? Provider of shared e-bikes or other shared means of mobility, e.g. Mobility Hubs. Also the direct client of TILER.

WDTW? Safe and reliable charging and a system that adds positively to the user experience of their service.

HWTGI? TILER needs to convince providers of the convenience and functional benefits that the product can bring them.

Governmental Institutions / Municipalities

WAT? Decide on regulations and permits for the use of shared mobility in their cities.

WDTW? Liveable cities and a system that blends in with the environment. High interest in shared mobility as it has a positive impact on the liveability in terms of congestion, pollution and both physical and mental health, thus also interested in peripherals that improve these services towards the user.

HWTGI? Governments need to approve the installation and use of the product in their city and will likely not do this if benefits to the liveability are too narrow or impact on the city scape is too large.

TILER

WAT? Initiator of the project and provider of wireless charging solution for e-bikes in various markets.

WDTW? A feasible and profitable product of which commercial viability has been verified.

HWTGI? TILER has a direct impact on the development of the product due to being the initiator of the project.

Bicycle Manufacturers

WAT? Manufacturers of e-bikes like Gazelle and Kruitbosch, but also manufacturers of e-bikes aimed for shared use like Urbee, Besv and ConnectBike

WDTW? Something unique to lead the market (J. van Winden, personal communication, 29-09-2020) and a reliable charging solution that is easy to integrate without influencing the overall visual appearance of their products.

HWTGI? Influence on how universal a system for shared e-bikes can be and influence on integration of the receiver side in e-bike frames in the future.

Employers of Users

WAT? Employers that stimulate their employees to engage in shared mobility.

WDTW? A good alternative for a more healthy and faster transportation than cars that are currently used. Some parties are even considering a 'mobility budget' so employees can decide which modes of (shared) transport they use instead of using a (leased) company car (Voermans, 2020; Urbee, 2016).

HWTGI? Fairly limited influence on the charging solution.

Residents

WAT? People that live in places where Mobility Hubs are located, but do not per se use them themselves.

WDTW? Limited impact on their street, both in terms of 'wild parking' of free-floating systems and the visual impact of Mobility Hubs or docks in the street.

HWTGI? Complain towards municipalities or providers of MaaS-systems if they are not content with current solutions.

Insurances

WAT? Companies that are paid to replaced stolen or damaged vehicles.

WDTW? High quality products on the street and low risk of vandalism or theft of (parts of) the MaaS-system, including vehicles and infrastructure.

HWTGI? Force MaaS-providers to improve in these fields and e.g. use chain locks as is the case with Cargaroo (M. Verheij, personal communication, 06-10-2020).

Regular Cyclists

WAT? People that ride privately owned (electric) bicycles.

WDTW? More available parking spaces that do not damage their own bicycles.

HWTGI? Limited influence on the developed product.

Wireless Power Consortium

WAT? Organisation behind the Qi-standardization in wireless charging for e.g. smartphones.

WDTW? Seeking for a standardization of wireless charging for Light Electric Vehicles such as e-bikes (Dumont, 2020).

HWTGI? Talk with various companies that are developing or will benefit from wireless charging solutions for LEVs.

Rivals

WAT? Other companies developing standardized charging solutions for (shared) e-bikes.

WDTW? An alternative that is preferred over the product developed in this project. This does not have to be a wireless solution per se.

HWTGI? Limited influence on the developed product, though good source of inspiration.

Maintenance Personnel

WAT? People that are responsible for cleaning and fixing the product and the hubs in general.

WDTW? Easy access and replacing of components that might break and no build-up of dirt or hard-to-clean spots and surfaces in the charging solution.

HWTGI? Though their influence is limited, their work is to be limited from a financial perspective from MaaS-providers.

Manufacturers / Distributors of OEM parts

WAT? Different companies involved in manufacturing the product.

WDTW? Large-scale production at their premises.

HWTGI? Offer advice in the development process to make the product more feasible.

APPENDIX C

PROGRAM OF REQUIREMENTS

1 Performance

1. Charging with at least 2 [A] should be possible.
2. Charging with 200 [W] for at least 4 hours straight should be possible.
3. Alignment of transmitter and receiver:
   - 3.1 Transmitter and receiver core should align when charger is connected.
   - 3.2 Maximum air gap between transmitter and receiver cores should be no more than 4 [mm].
4. Product should not damage bicycle in any way.
5. Should communicate to MaaS-provider when bike is charging, what bike is charging and battery level:
   - 5.1 Determine which bike is currently charging.
   - 5.2 Determine current battery level of charging vehicle.
   - 5.3 Communicate with provider at any given moment.
6. Should not break when falling on a concrete floor from a height of 1,5 [m].
7. Should not break if stepped on by a person of 85 [kg].

2 Size and weight

1. Installation should be possible in a 300 x 300 [mm] grid.
2. Maximum weight for installation equals 23 [kg].
3. If kickstand is used, maximum feet size of 50 x 50 [mm].

3 Environment

1. Internal temperature should not exceed 40 [ºC] in direct sunlight for over 6 hours.
2. Internal temperature should not go below 2 [ºC] with environmental temperatures of minimal -5 [ºC] for over 6 hours.
3. No build-up of dirt or water on connecting surfaces possible.
4. Product should have an IP-68 rating (dust and water resistance)
5. Prevent condensation on the inside in cavaties where ferrite or other corrosive materials are used.
6. Chemical resistance and resistance to salt water (e.g. when used in near-sea environment).

4 Standardizations, regulations and political implications

1. Corresponding to FietsParKeur regulations (Stichting FietsParKeur, 2019).
2. Should satisfy NEN-1010 norm.
3. No more than 48 [V] through the transmitter cable (low-voltage system).

5 Ergonomics

1. No chance of tripping when walking over.
   - 1.1 Transmitter should disconnect when pulling cable sideways.
2. Maximum pulling force to disconnect charger may not exceed 100 [N].
3. Any text, feedback and usecues need to be visible from a height of 1,8 [m] at an angle of 45 [º].

6 Materials

1. No use of conductive materials in a way which can interfere with the charging process.

7 Aesthetics, appearance and finish

1. Transmitter should have a soft finish to prevent damage to bike.
2. Aesthetics should be bright to catch attention.
3. Cable should be coloured brightly.

8 Life in service

1. Product should go at least 5 years without maintenance.
2. Product should not be able to be opened without special tooling.
3. Surfaces touching bike should be easy to replace by service personnel.

9 Maintenance

1. Access to and replacing of electrical components should be possible without having to permanently break the embodiment.
2. Rubber seals (for IP rating and insulation) should be replacable without having to permanently break the embodiment.
3. Cleaning of connecting surfaces should be possible with simple tooling (e.g. brush, plant sprayer).

10 Vandalism

1. Product should not have edges that allow opening with force (e.g. screwdriver, crowbar).

11 Target product cost and quantity

1. Production cost of charger should be no more than 120 [€], based on a production run of 5.000 units.
2. Production cost of charger should be no more than 75 [€], based on a production run of 10.000 units.

12 Transport and packaging

13 Installation and initiation of use

1. Product has to have a connection wire for connection to the Low Voltage net OR for a connection to the 230 [V] net (case-dependent).
2. Use of product in temporary/mobile hubs should be possible (i.e. installation on-ground should be possible).

14 Testing, reliability and safety

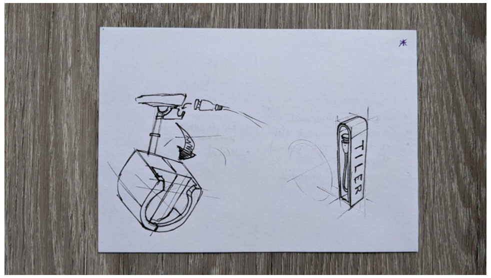
1. No materials or production processes used that pose health risks to production personnel and assembly personnel.

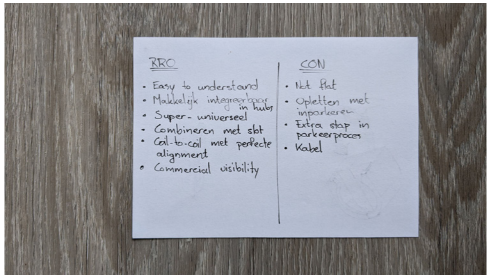
15 Re-use and recycling

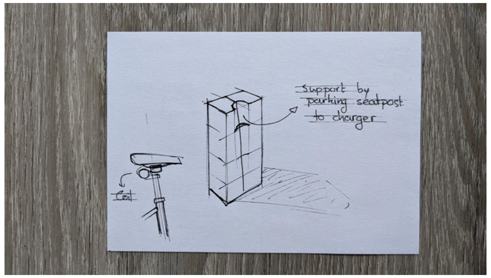
1. Product can be stripped down to parts/chunks of a single material at EoL scenario (except electronics).
2. Electronics may not be fixed permanently to housing parts.

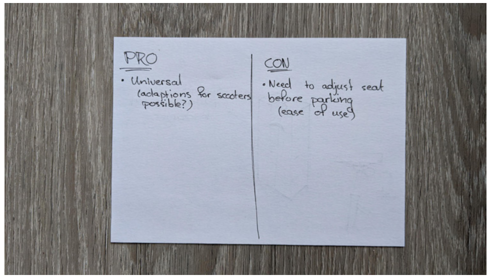
APPENDIX D

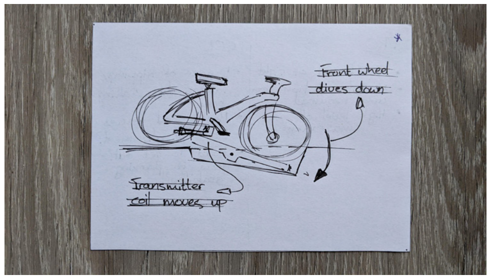
IDEATION

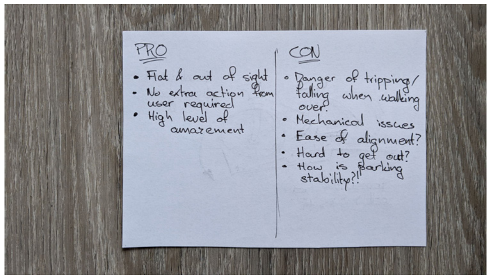


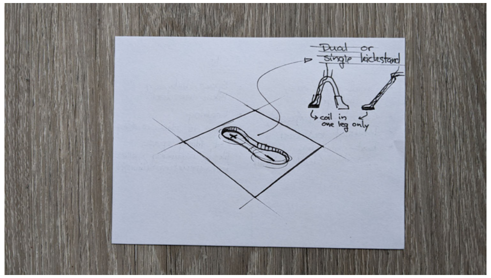


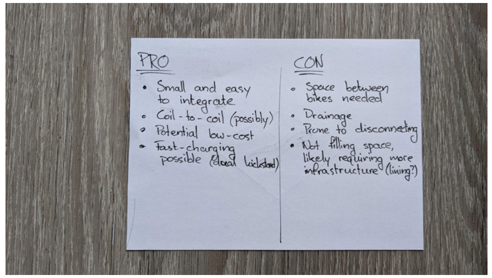


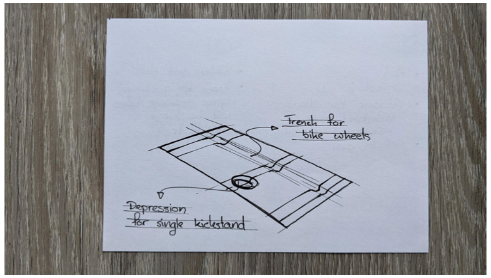


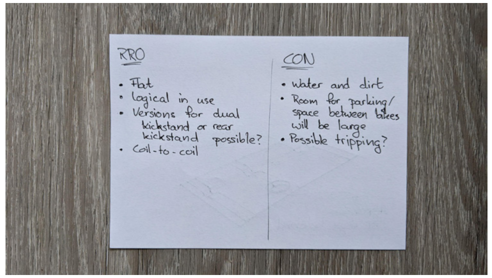


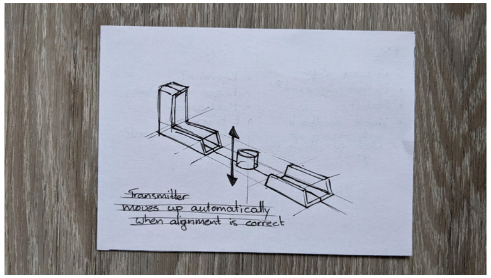


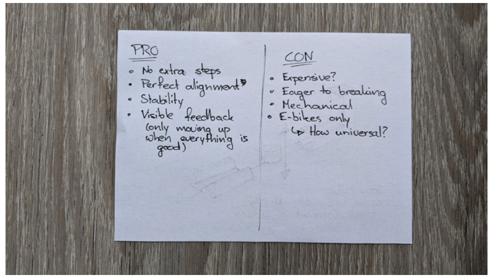


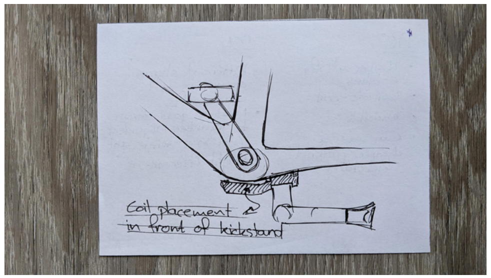


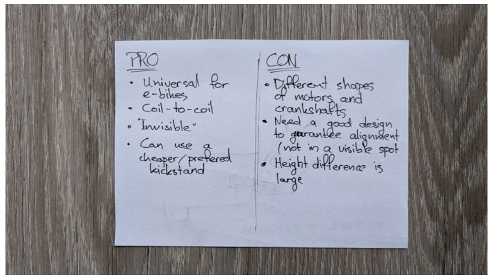


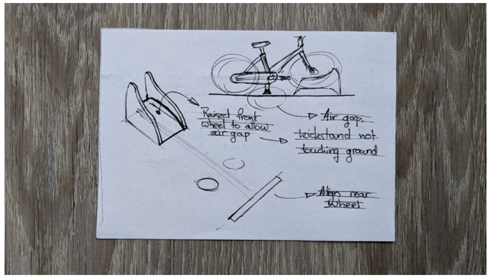


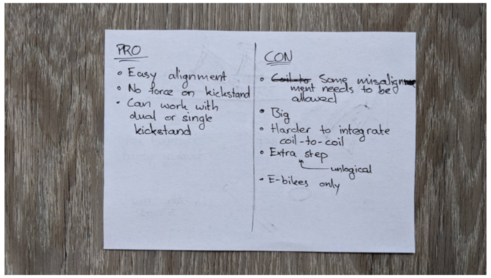


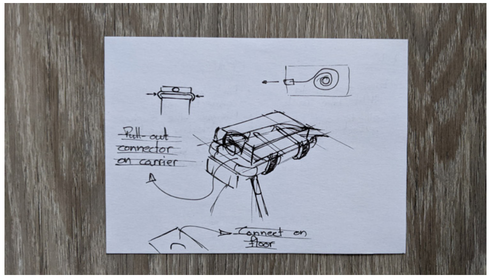


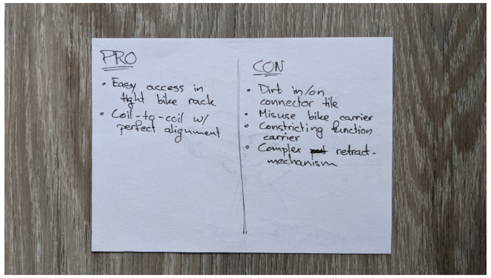


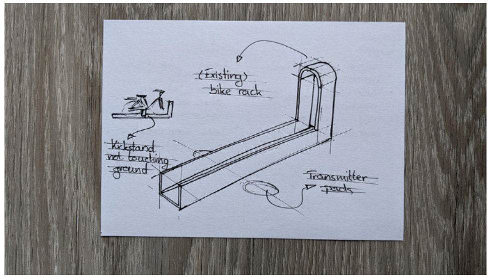


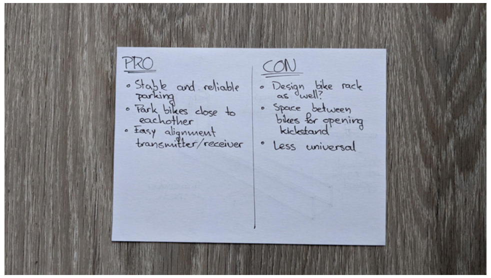

Raised front wheel to allow air gap
Air gap, kickstand not touching ground
Align rear wheel

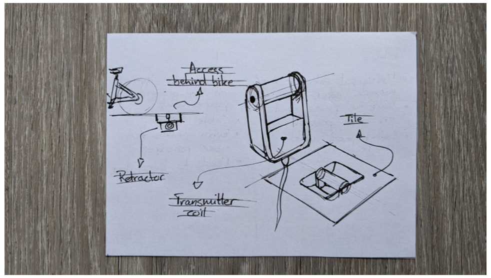

PRO
Easy alignment
No force on kickstand
Can work with dual or single kickstand
CON
Coil-to Some misalignment needs to be allowed
Big
Harder to integrate coil-to-coil
Extra step
unlogical
E-bikes only

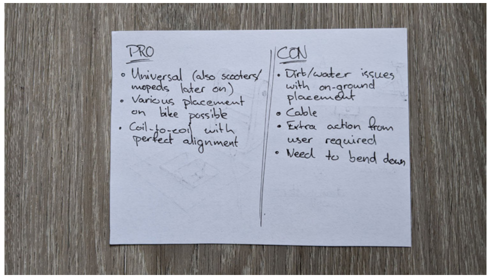

Pull-out connector on carrier
Connect on floor

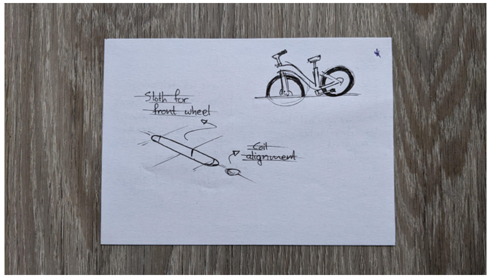

PRO
Easy access in tight bike rack
Coil-to-coil w/ perfect alignment
CON
Dirt in/on connector tile
Misuse bike carrier
Constricting function carrier
Complex pul retract-mechanism

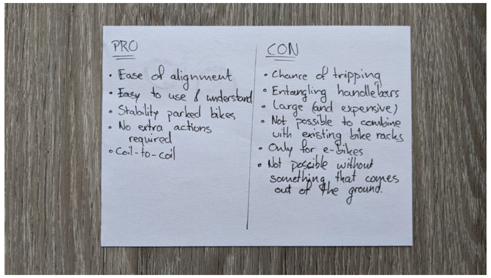

(Existing) bike rack
Kickstand not touching ground
Transmitter pads

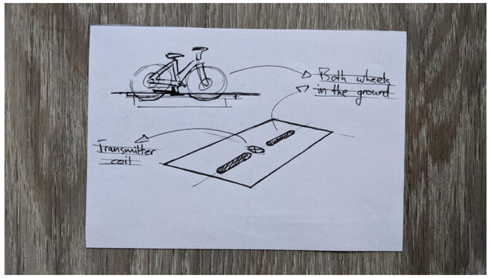

PRO
Stable and reliable parking
Park bikes close to eachother
Easy alignment transmitter/receiver
CON
Design bike rack as well?
Space between bikes for opening kickstand
Less universal

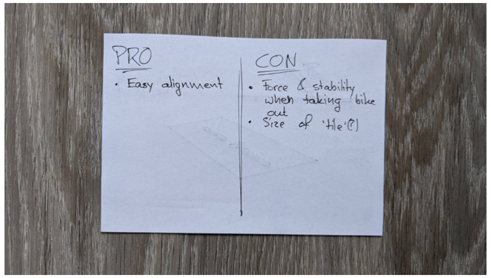

Access behind bike
Retractor
Transmitter coil
Tile

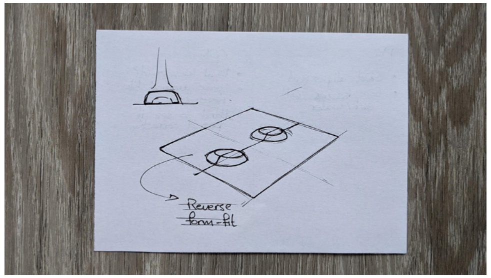

PRO
Universal (also scooters/mopeds later on)
Various placement on bike possible
Coil-to-coil with perfect alignment
CON
Dirt/water issues with on-ground placement
Cable
Extra action from user required
Need to bend down

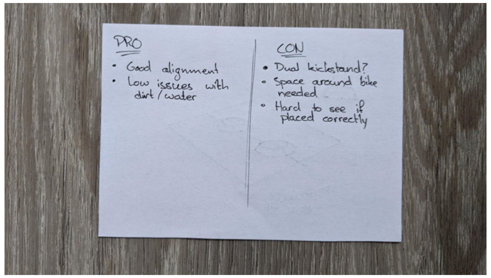

Sloth for front wheel
Coil alignment

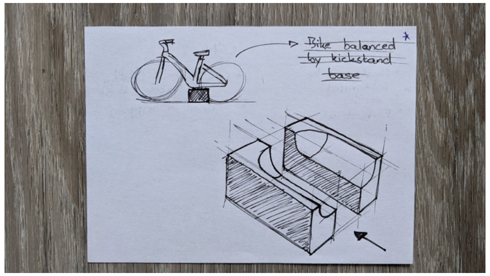

PRO
Ease of alignment
Easy to use & understand
Stability parked bikes
No extra actions required
Coil-to-coil
CON
Chance of tripping
Entangling handlebars
Large (and expensive)
Not possible to combine with existing bike racks
Only for e-bikes
Not possible without something that comes out of the ground.

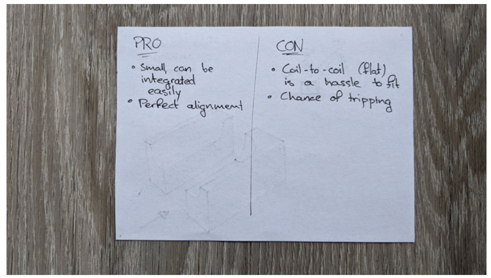

Both wheels in the ground
Transmitter coil


PRO
Easy alignment
CON
Force & stability when taking bike out
Size of 'tile'(?)


Reverse form-fit


PRO
Good alignment
Low issues with dirt / water
CON
Dual kickstand?
Space around bike needed
Hard to see if placed correctly


Bike balanced by kickstand base


PRO
Small, can be integrated easily
Perfect alignment
CON
Coil-to-coil (flat) is a hassle to fit
Chance of tripping

INTRODUCTION

Based on the research presented in this report, a broad exploration of ideas has been done (previous pages). The advantages and drawbacks of each ideas have been discussed. Comparing the ideas led to the selection of five feasible ideas that have been elaborated a bit further. Based on conversations with various potential users and other stakeholders and the pluses and minuses, two ideas showed more viable than the others. These two have been developed further into the two concepts shown in this appendix, after which a selection has been made by scoring the concepts on weighted criteria.

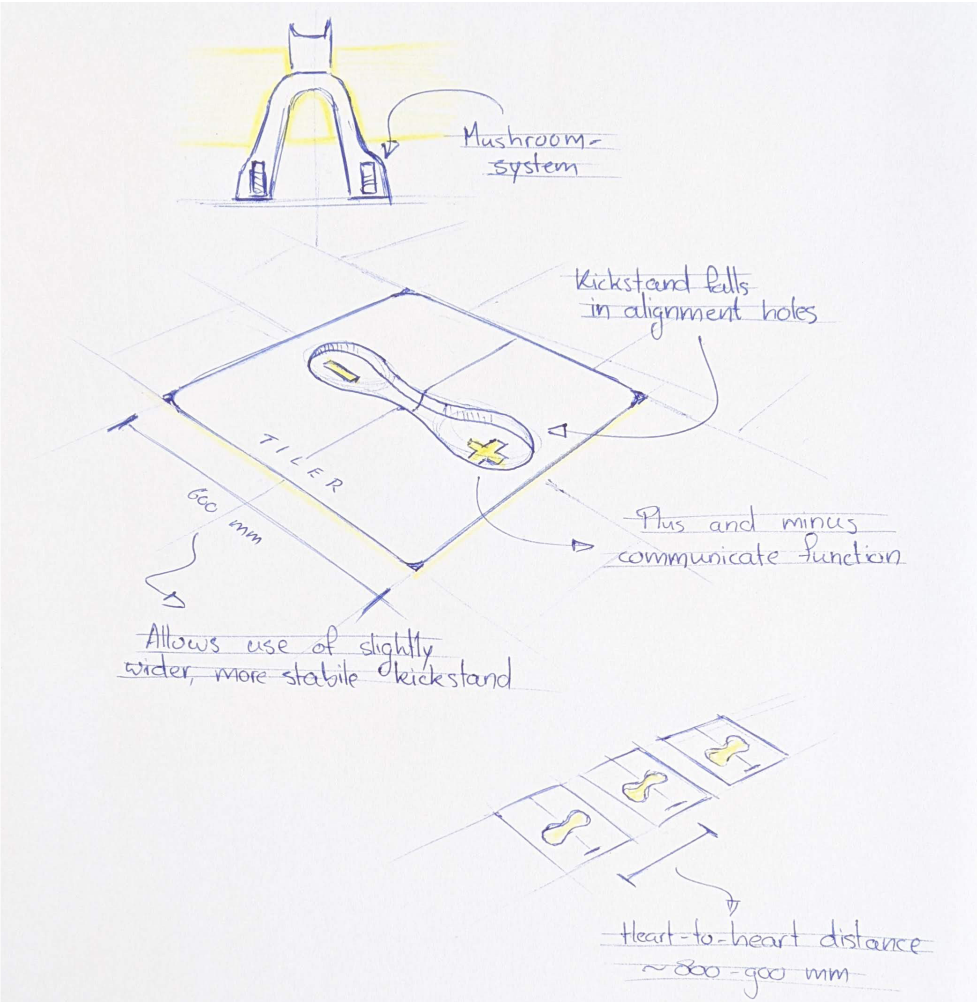


figure D.1 Idea sketch

IDEA GENERATION

Idea 1 – Traditional Tile

The first idea is based on the current product of TILER and consists of a flat tile. It was found that placing the bicycle on the kickstand causes dynamic forces that result in the kickstand moving slightly. Therefore, the idea has been elaborated with a guidance for the kickstand (figure D.1). Though cardboard mock-ups (figure D.2) did not help with placing the kickstand exactly in the aligning gaps, the beforementioned movement of the kickstand was slightly lowered. The mock-up showed that a complete 'hole' is required to sufficiently align the kickstand and further diminish the movement of the kickstand.

The largest benefit with the addition of the alignment holes is that shifting of the bike is decreased and alignment is improved. This allows for the selection of a wireless power transfer system that uses far less ferrite and is thus cheaper and less heavy.

One of the big issues with this idea in the context of shared e-bikes is that the space required in hubs is relatively large, as people are required to walk between bicycles to activate the kickstand. Furthermore, people bumping into bicycles when placing or taking another one could disturb the alignment or cause tipping over the entire bike. Also, this system limits providers of shared e-bikes to double kickstands.

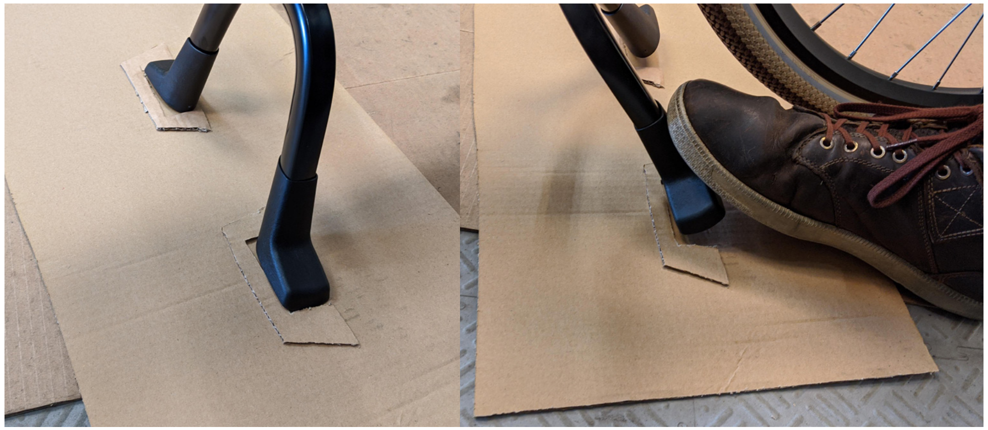


figure D.2 Cardboard model

Idea 2 – Sinkhole

This idea relies on the front wheel being steered onto a plate that is pushed down by the weight of the front of the bicycle (figure (D.3 and D.4). This action pushes up the transmitter like a seesaw. A receiver coil mounted on the side of the kickstand couples with the transmitter coil.

Though the idea would be far less complicated by having the front wheel dive deeper and not needing the seesaw mechanism, figure D.5 shows that this would not be possible due to the pedals and wider dimensions at the axis of the front wheel. Though the option with the rear wheel going into the ground (also portrayed in figure D.5) seems plausible, this would require backward parking which would disable access to the lock.

The idea has been tested with LEGO to see if this would be possible (figure D.6). Though dimensions differ from the LEGO model, the invisible bike rack by Milou Bergs (figure D.7) shows potential for this idea.

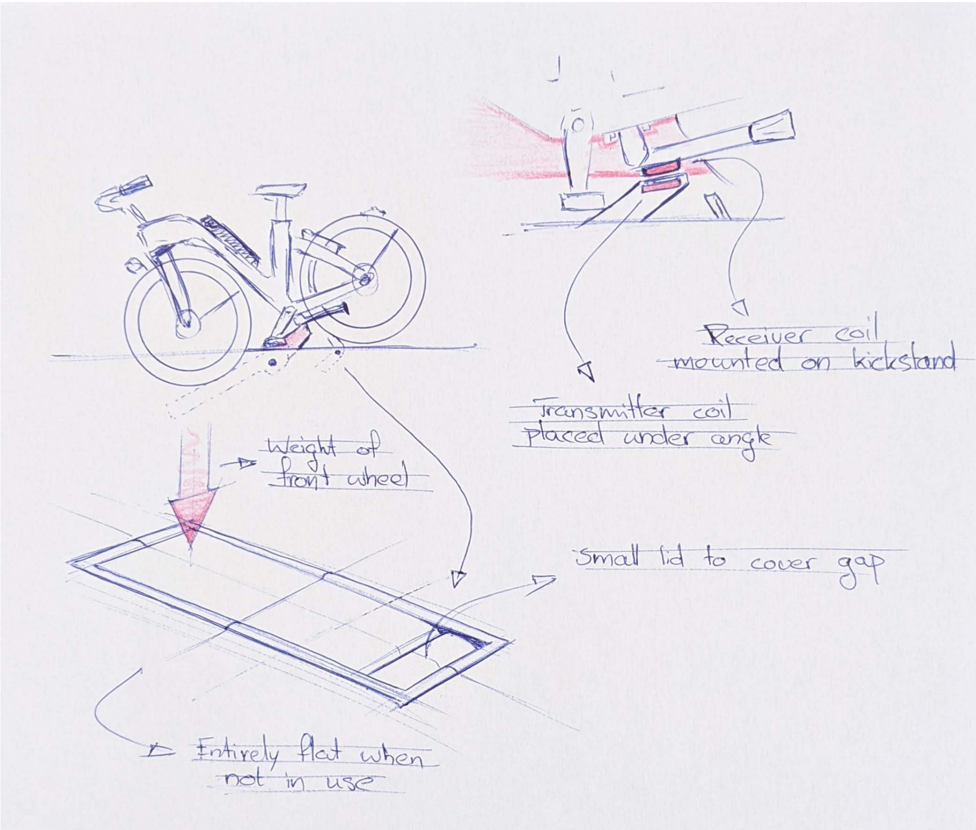


figure D.3 Idea sketch

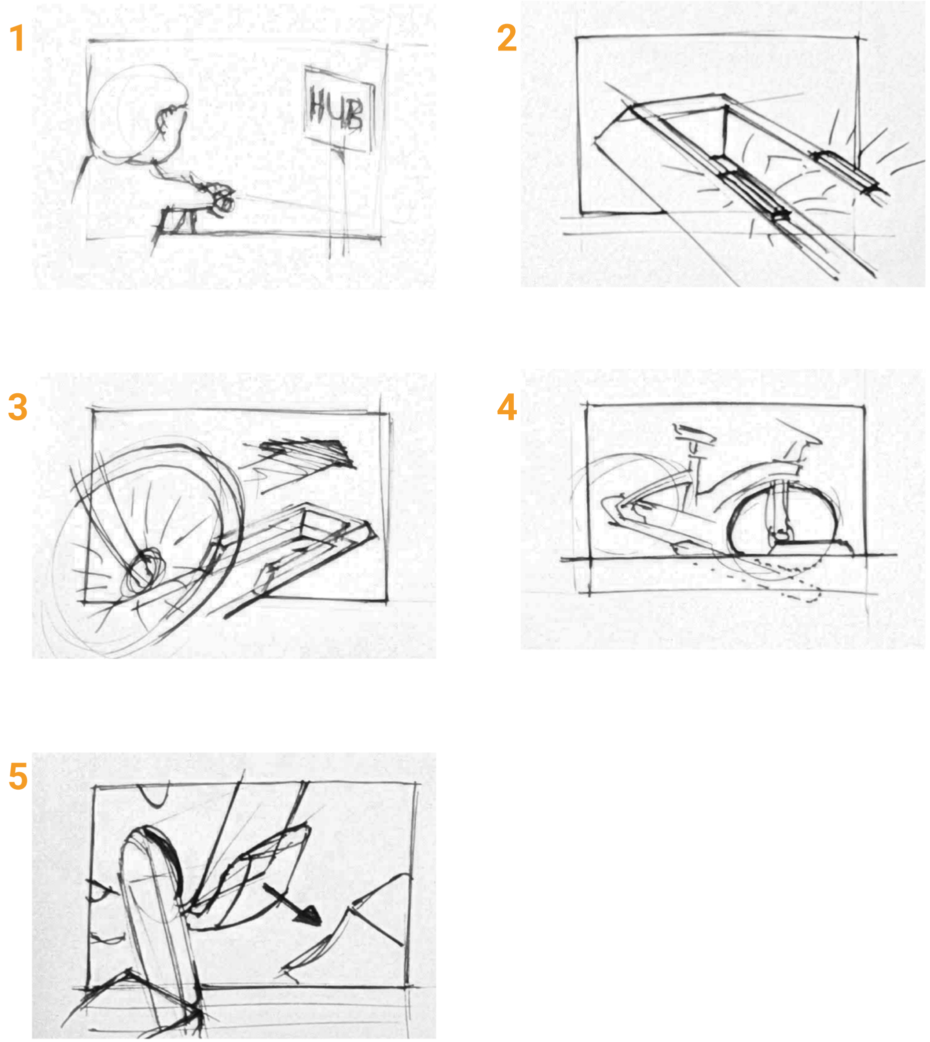


figure D.4 Storyboard of idea

figure D.5 Different options of receiver alignment

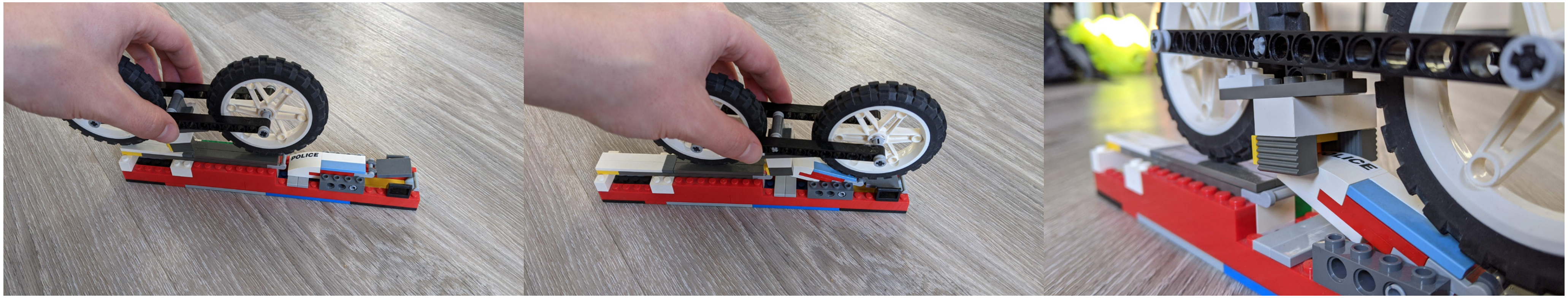


figure D.6 Proof of Principle through LEGO prototype

figure D.7 Invisible bike rack by Milou Bergs

Idea 3 – Coconut Dock

The third idea consists of a small ‘docking station’ on the ground that has coils on both sides (figure D.8 and D.9). The receiver is placed between the frame and the kickstand and uses the kickstand bracket that is welded to the frame, where it is shielded by the chain guard. The user is to steer the front wheel through the two sides of the dock and the shape of the receiver that is placed on the bike will ensure proper alignment.

Further development of this idea needs to take into consideration the geometry of electric bicycles. Especially the pedals and chainguard are likely to cause problems with alignment on this place.

A large benefit of this idea is that it does not require any bike racks to stabilize the bike, but is in itself a stabile system. It does not require as much space between bikes as with the traditional tile and ensures a structured and organized view when bikes are parked, though limits the visual impact when no bikes are parked because the footprint of the idea is relatively small.

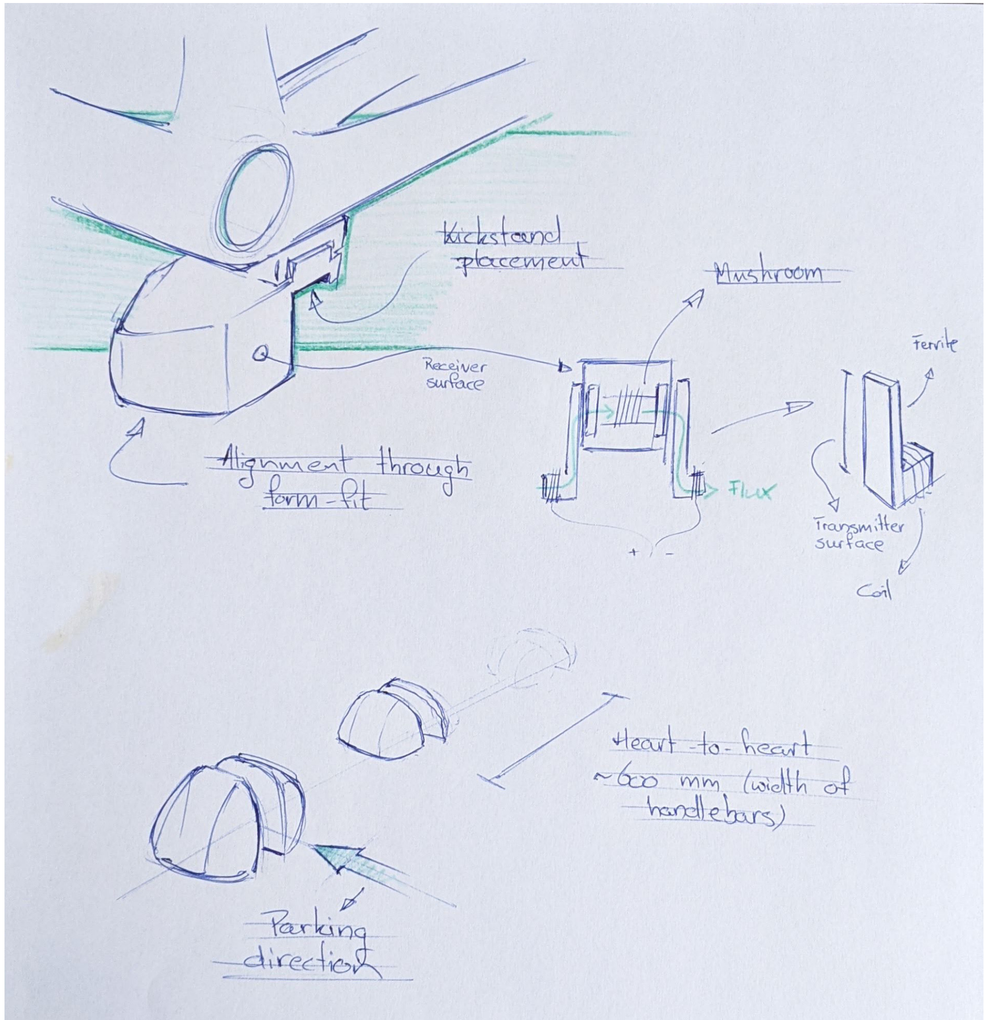


figure D.8 Idea sketch

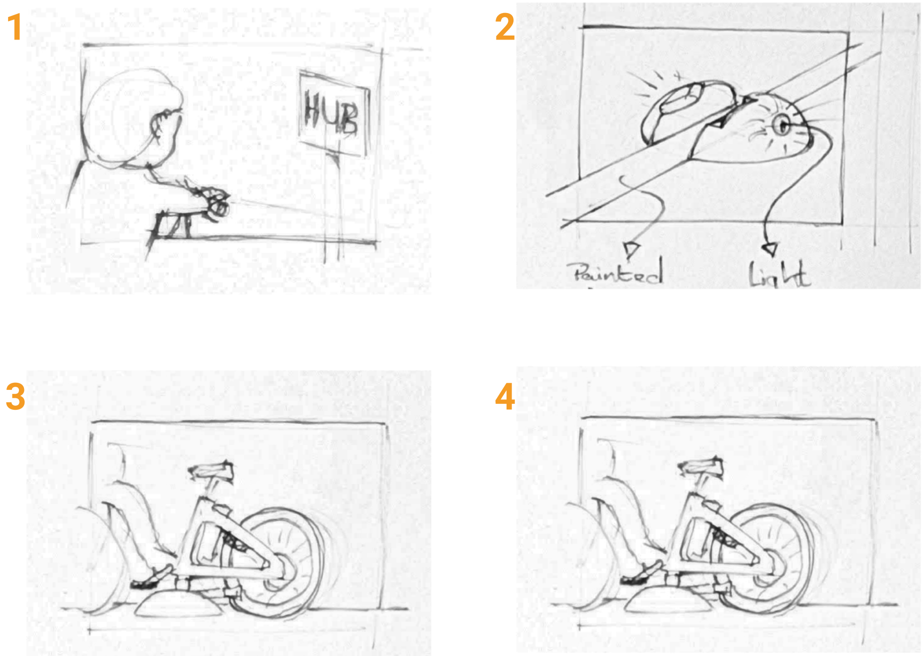


figure D.9 Idea storyboard

figure D.10 Traffic pole that can move up and down

Idea 4 – Jumper

The Jumper is inspired by the well-known poles that rise from the ground to block traffic (figure D.10). The transmitter coil is placed in the top of a similar (though smaller) pole that rises from the ground and connects to the receiver mounted underneath the crank shaft of the e-bike (figure D.11 and D.12).

A large benefit of this idea is that both the physical and mental effort required from the user are relatively low, especially when combined with a guiderail that lines out the wheels and a detection sensor that activates the Jumper automatically when the receiver is aligned with the transmitter in the direction that runs along the length of the bicycle.

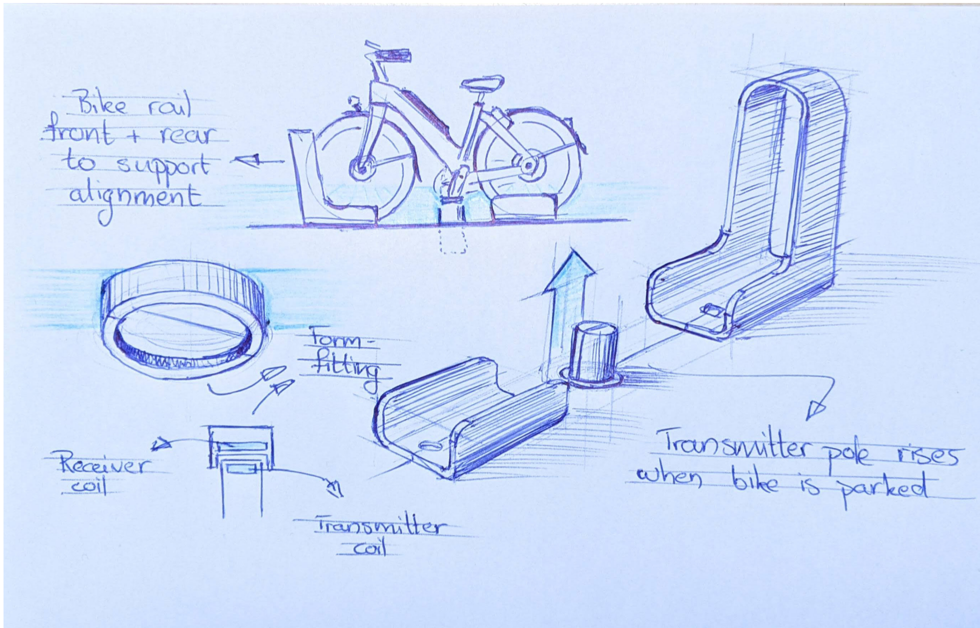


figure D.11 Idea sketch

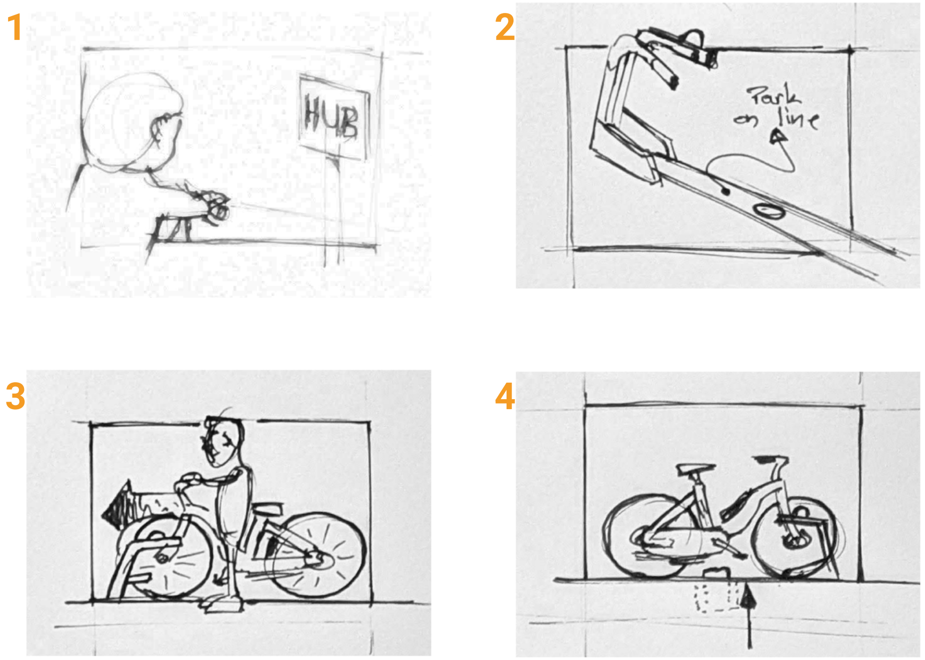


figure D.12 Idea storyboard

Idea 5 – Wireless Cable

The last idea consist of a transmitter coil in a handle at the end of a cable (figure D.13 and D.14). The cable is attached to a retractor system in the ground, comparable to those used in vacuum cleaners. After parking the shared e-bike, the users opens a lid with his foot that allows access to the transmitter. The transmitter is placed in the receiver below the bike seat.

Though this idea still contains a cable, it is believed that the hand-eye coordination and the direct access and visibility of this idea makes alignment of the transmitter and receiver extremely easy. Because the ease of alignment, a cheap, off-the-shelf wireless charging principle can be selected. Due to the shape, a flat coil-to-coil system seems a good option.

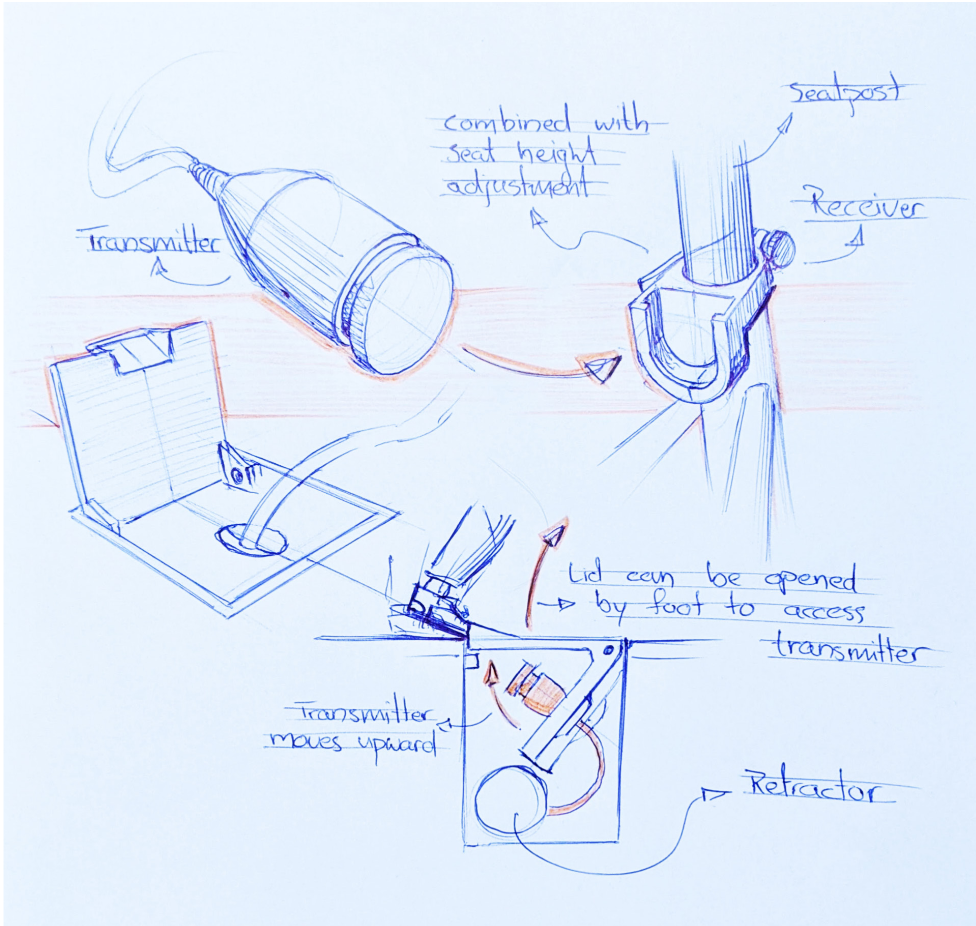


figure D.13 Idea sketch

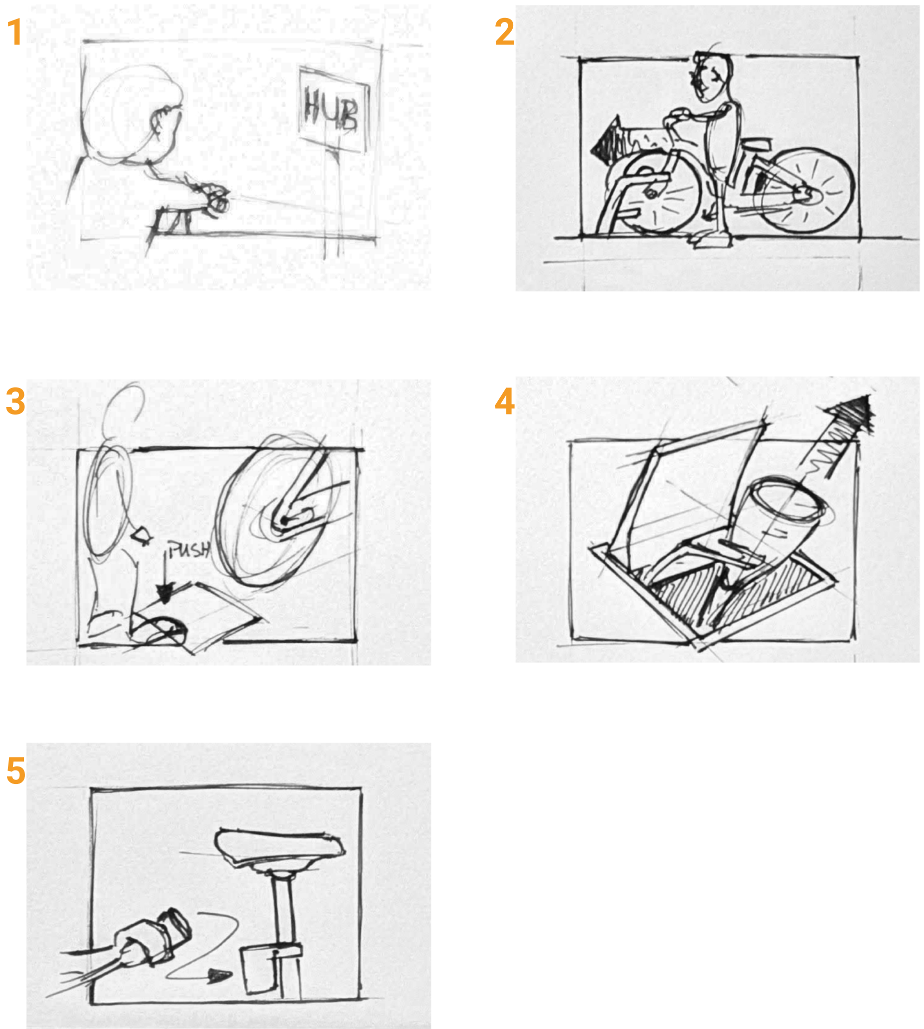


figure D.14 Idea storyboard

CONCEPT 1 - MICRODOCK

The first concept (figure D.15) is based on the idea of the Coconut Hub and consists of a small pole as the transmitter and a receiver that is mounted between the frame and the kickstand. The concept ensures that charging starts as soon as the bike is parked and the transmitter and receiver are aligned sufficiently. A storyboard is drawn to show the intended interaction* (figure D.16).

Transmitter pole
Testing with cardboard models showed issues with the original idea concerning space for the wheel, the front fender, the pedals and the chain guard (figure D.17), though it also learned that rotating the wheel around it generated more space between the left pedal and the front wheel (figure D.18). The coconut hub is therefore replaced by a small pole (figure D.15 and D.22). The top of the transmitter pole is coloured brightly to ensure visibility and prevent tripping.

**The storyboard has been drawn after the ideation phase and does not represent the concept in its current state!*

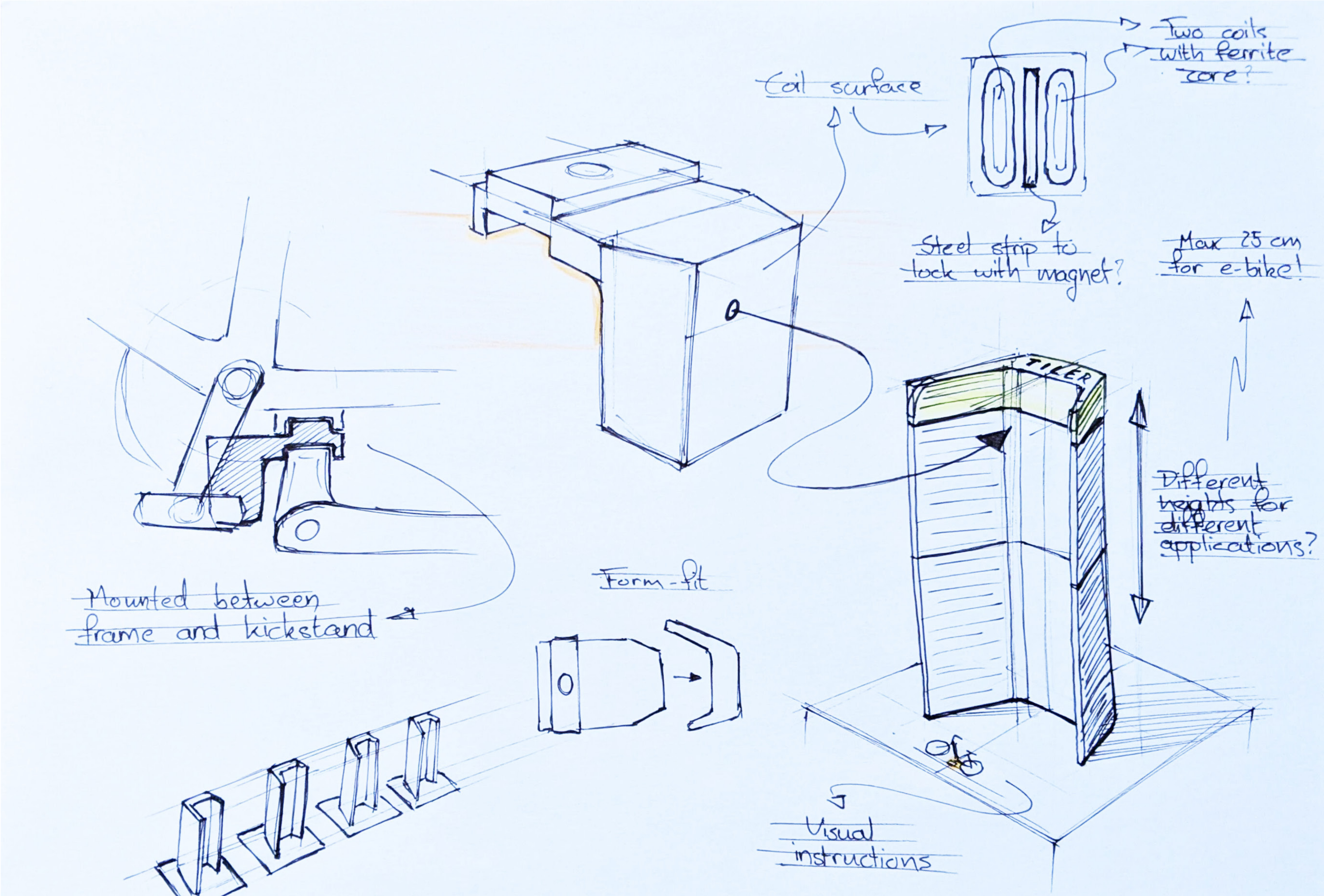


figure D.15 Sketch of the Microdock concept

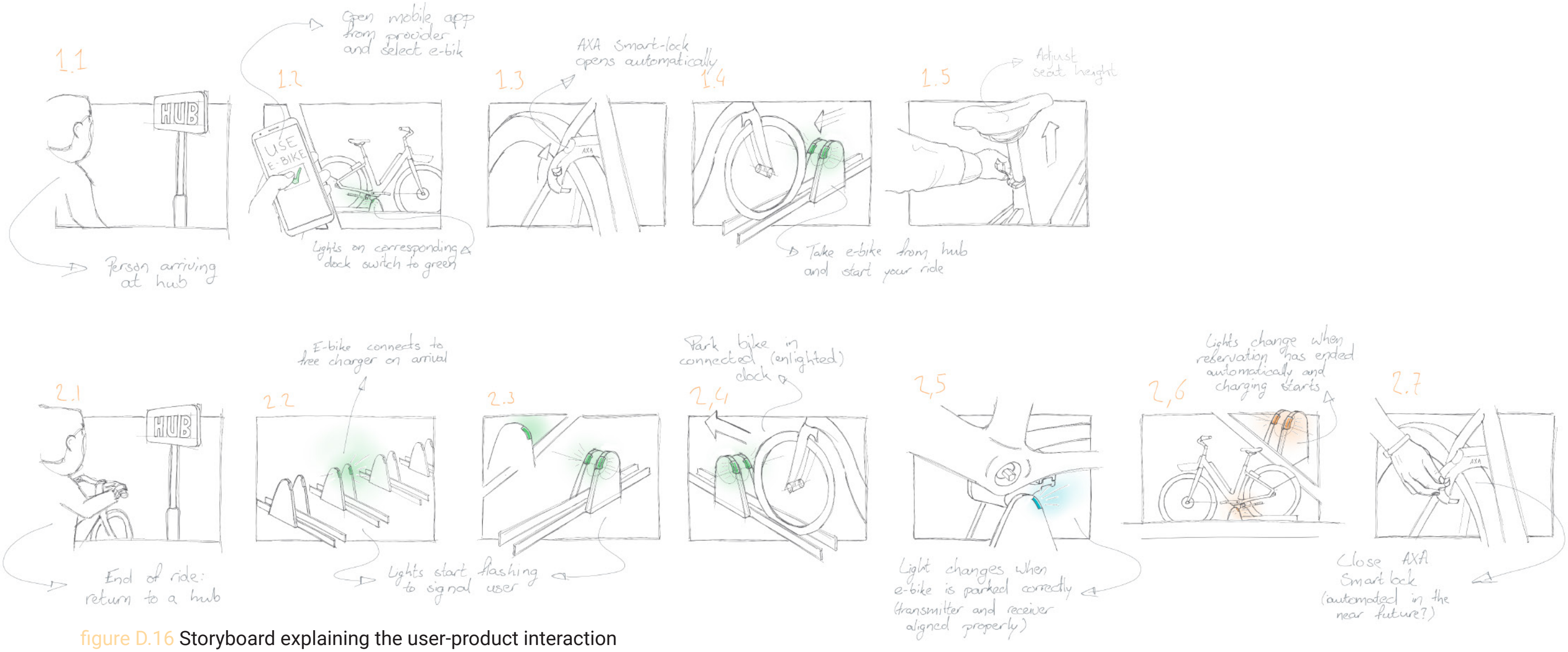


figure D.16 Storyboard explaining the user-product interaction

Placement receiver

The receiving unit will be placed on the bracket for the kickstand, after which the kickstand is placed on the receiver (figure D.19). This allows providers of shared e-bikes to use the kickstand they prefer (e.g. single or double kickstand) instead of forcing them to use a specific type.

The receiver can be placed in the open space beneath the frame, but behind the chain guard. This also ensures that it will not hit the ground e.g. when riding off sidewalks.

A drawback of this system is universality, as electric bicycles with the motor mounted on the crank shaft (mid-motor) offer less space behind the chain guard and require an adapted receiver to overcome the ‘belly’ of a mid-motor (figure D.17). Though most shared e-bikes now utilize front-mounted motors (e.g. Lime, Jump, Urbee), a gradual shift in consumer e-bikes towards mid-motor due to safety and convenience aspects predicts that future shared e-bikes will most likely use mid-motors as well. Note that this also requires a smaller transmitter, so a mid-motor e-bike would not be able to charge on a transmitter for front-motor e-bikes.

figure D.17 First proof of principle

figure D.18 Rotating the front wheel generates space

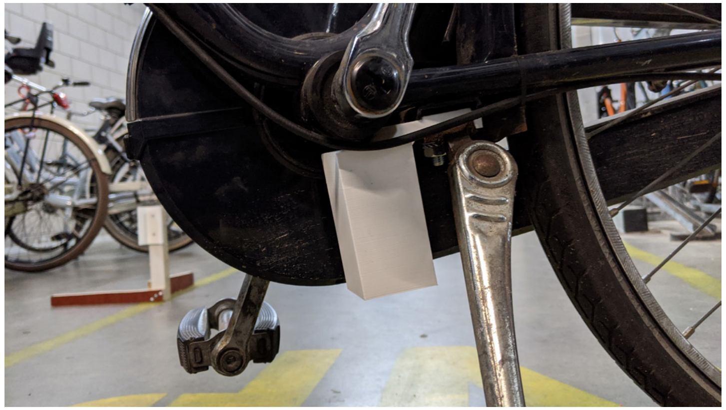


figure D.19 Placement of the receiver between frame and kickstand

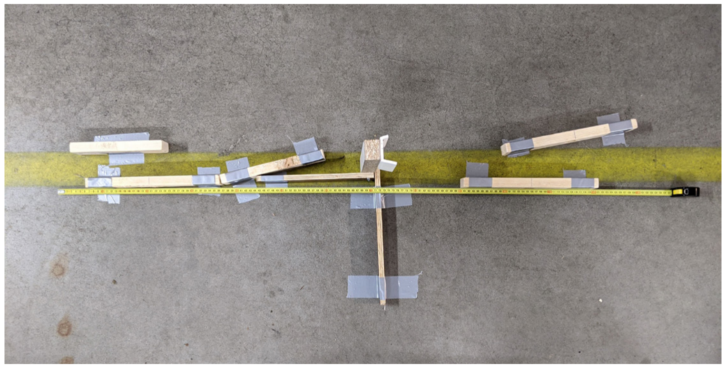


figure D.20 Required guardrails to align wheels with transmitter

Guardrails for wheels

During testing the ease of alignment, it was found that some guidance using the wheels is required for a proper alignment (figure D.20). It is hard to properly place the front wheel in line with the transmitter pole without this guardrail. An extra guardrail is placed for the rear wheel. The guardrails significantly ease alignment of transmitter and receiver. These guardrails will take the physical form of 'guidance grooves' in the platform (figure D.22).

Added benefit of the guardrails is that if someone bumps into the bike, forces are guided into the rails and the moment on the receiver is limited.

Wireless Power Transfer

The method for wireless power transfer in this concept needs to adjust for a slight height difference in bicycle geometry. According to Julien van Winden, product manager at Gazelle (personal communication, 29-09-2020), the height of the kickstand bracket on bicycles is not predetermined in the design process. The design team relies on the adjustability of the kickstand to counter slight differences in the height of the bracket, however the placement of the kickstand bracket is close to the drive shaft and thus variations in height are limited.

Measuring the height of the kickstand bracket on five random different bicycles showed that the height varies from 26 to 29 centimetres, so a variance of 50 millimetres will be accounted for in the wireless power transfer.

Consideration of various systems (figure D.21) showed that the combination of a ferrite plate with a coil in the transmitter and a 'mushroom coil' consisting of a ferrite bobbin with copper wire around it was judged as most promising, as it can overcome the height variance without much loss of efficiency.

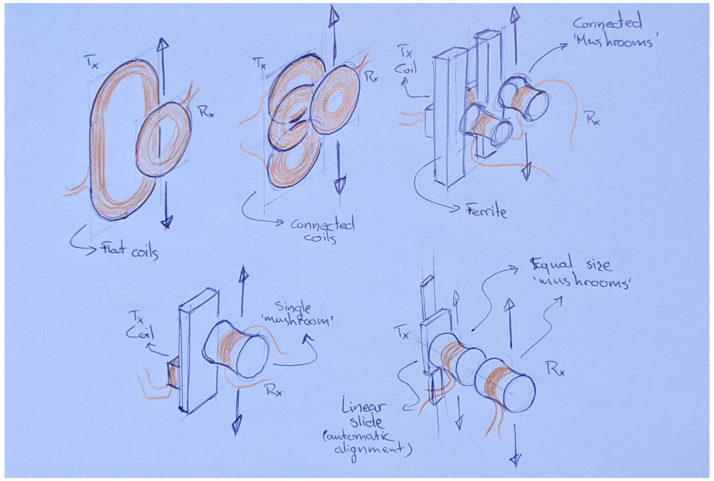


figure D.21 Different possible wireless power transfer systems

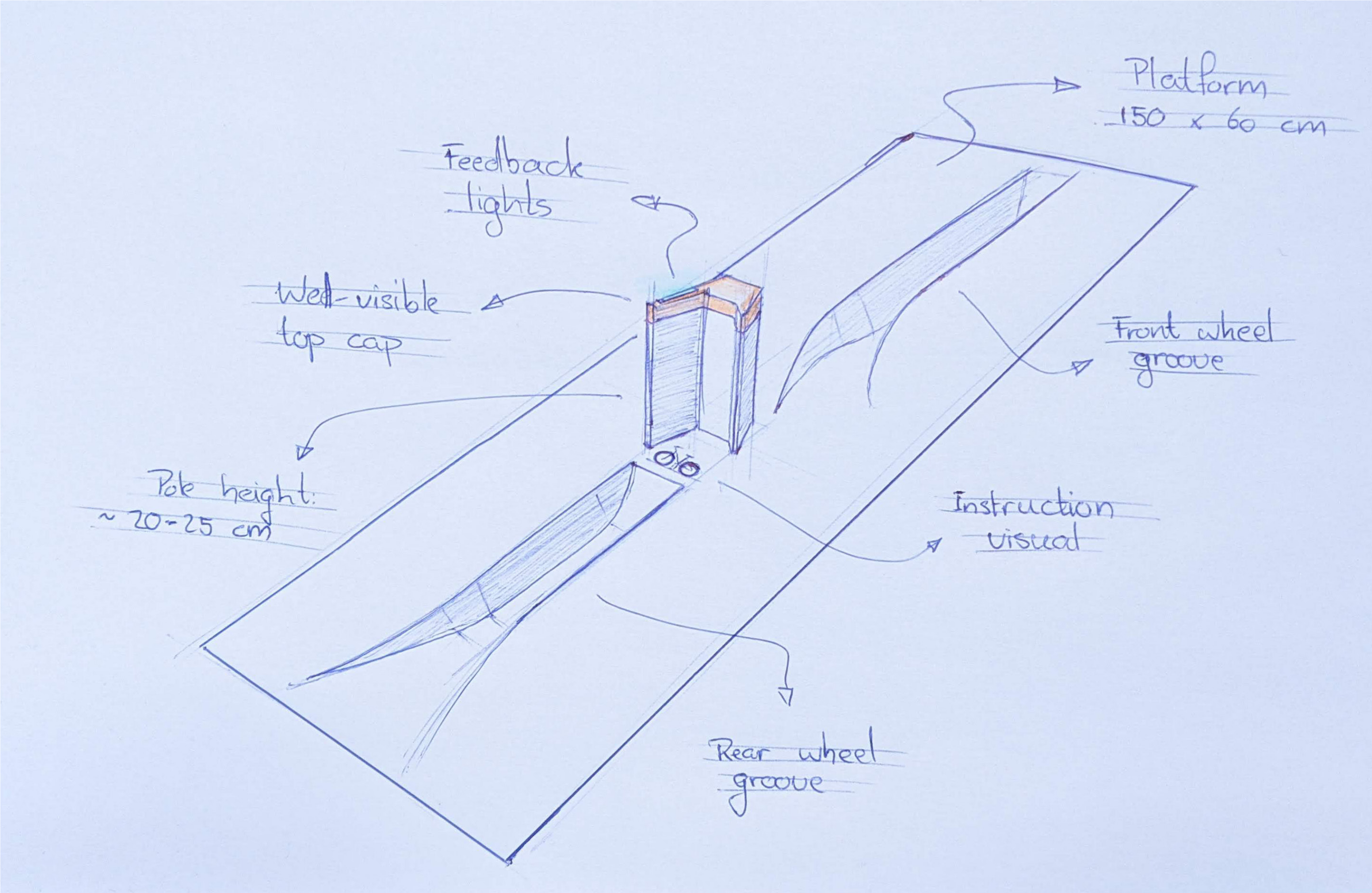


figure D.22 Sketch of the Microdock concept with guidance grooves

CONCEPT 2 - WIRELESS CABLE

The second concept is an evolvement of the Wireless Cable proposed in the chapter 'Ideation' (figure D.24). Though the proposed solution is not directly part of parking the bicycle, the handling is something that is fairly common for people and thus easy to understand. The mental effort required for placing the charger is limited. A storyboard of the intended interaction* can be found in figure D.23.

Charger pole

The initial idea was to have a retractor system integrated in the ground. First tests with a vacuum cleaner (figure D.25) showed, though people did not mind having to bend over to pick up the charger, they did not bend over to place it back after use but instead just dropped it on the floor. Proposed retractor system is also prone to issues with dirt and water, and thus the decision was made to implement the cable in a small pole instead (figure D.24 and D.26). This provides a more ergonomic and convenient user interaction.

**The storyboard has been drawn after the ideation phase and does not represent the concept in its current state!*

figure D.23 Storyboard explaining the user-product interaction

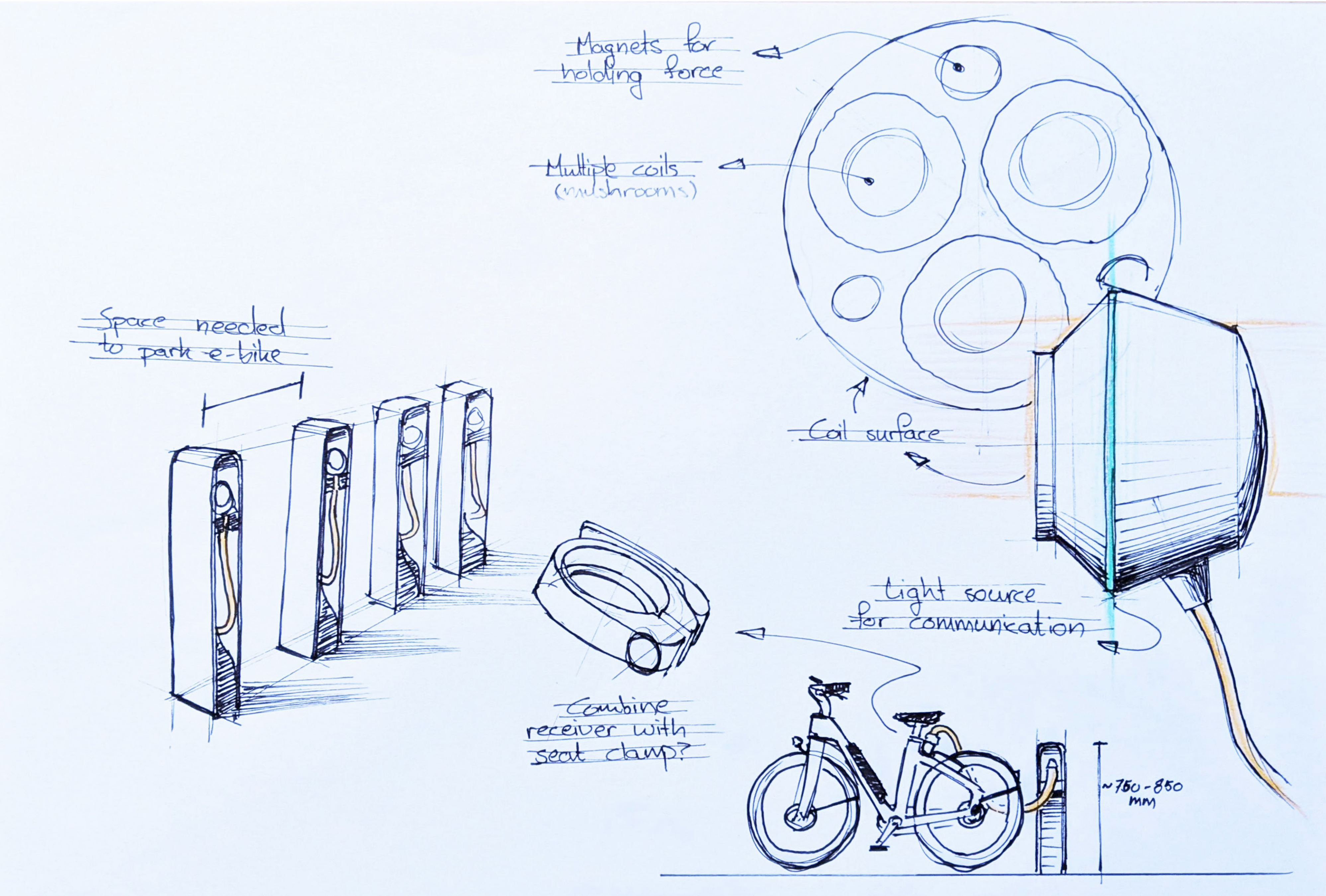


figure D.24 Sketch of the Wireless Cable concept

Parking the bike: limited space in the shed for activating kickstand, especially with the bike bags!

Stretching the cord. Bending over to pick it up was not experienced as an issue, though pulling the cord looked less fluent.

The end of an extension cable has been placed on the anticipated place of the receiver in the concept.

Placement of the receiver was experienced as logical well-visible. Participant had no issues in aligning the transmitter with the receiver visually. The bike bags again formed an issue with the cable, shown in the image by the participant having to hold the cable with the left hand.

Taking out the receiver again formed no issues. Retraction only started when pushing the button on the vacuum cleaner, but participant was asked to give a short pull after taking out the receiver to imaginely start the retraction.

During retraction, the participant did not bend to place the receiver back properly, but instead just let go of it and dropped it on the floor.

figure D.25 First user tests using a vacuum cleaner cord

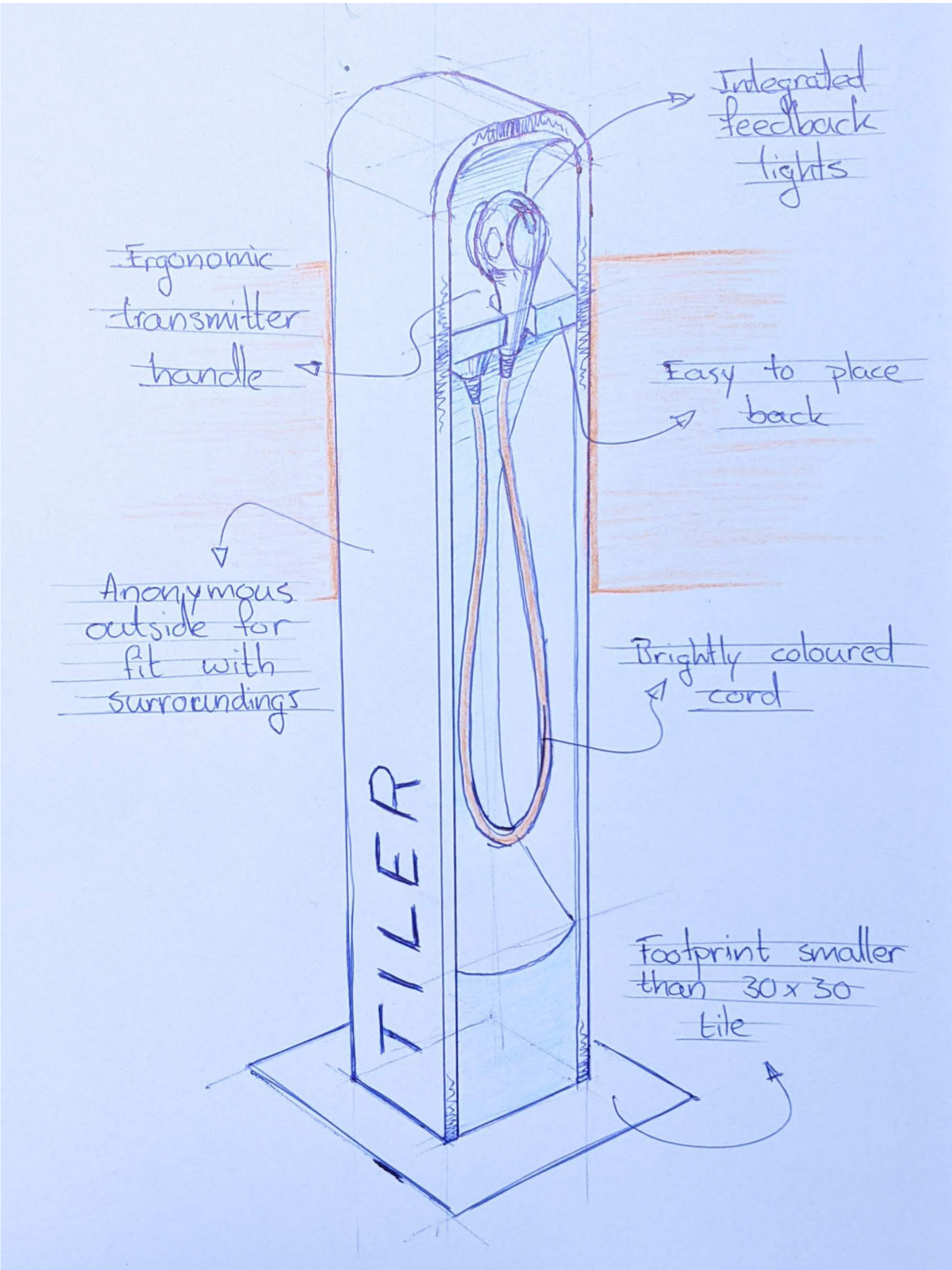


figure D.26 Illustration of a possible design for the charging pole

The visual impact of the charger solution is important for municipalities and residents. The municipality of Amsterdam perceives the public space as a 'placid foundation of city life' (Gemeente Amsterdam, 2018) and Diederik Basta, CTO of Amsterdam's Innovation Team, noted that the visual impact and the number of physical objects in the public space is to be kept to a minimum (personal communication, 24-09-2020).
Therefore, the design of the charger pole needs to fit in with the already existing street furniture and the general surroundings. This is something that requires attention in the remainder of the project. Inspiration can be drawn from Orange Power Systems' charger pole in an 'Amsterdammetje' (figure D.27) and other recognizable objects already nestled in the public space.

Receiver

The receiver is placed in a visible and reachable place on the bicycle. It is combined with a quick-adjust saddle-clip as in figure 8.6 and looks like the sketch in figure D.29.

figure D.27 Inspiration for a possible design direction for the charger pole

figure D.28 Quick-adjust seatpost-clip that is locked to the bike

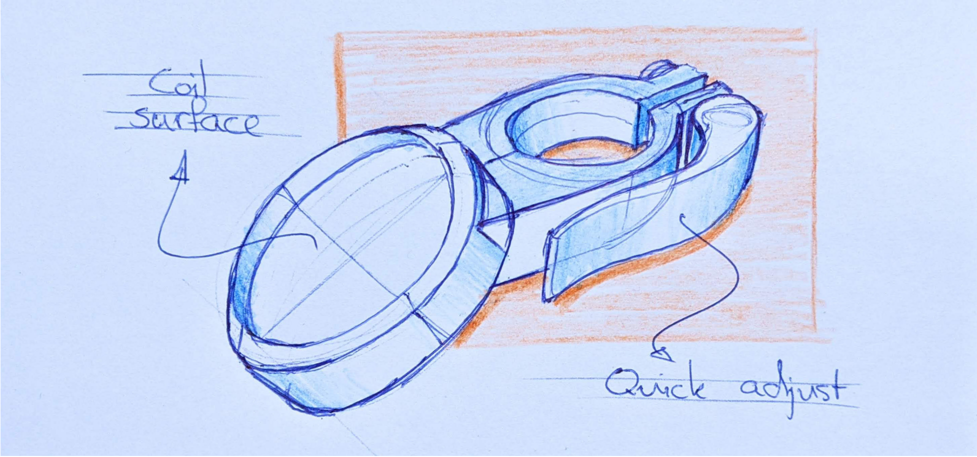


figure D.29 Sketch of the receiver placed on the bike

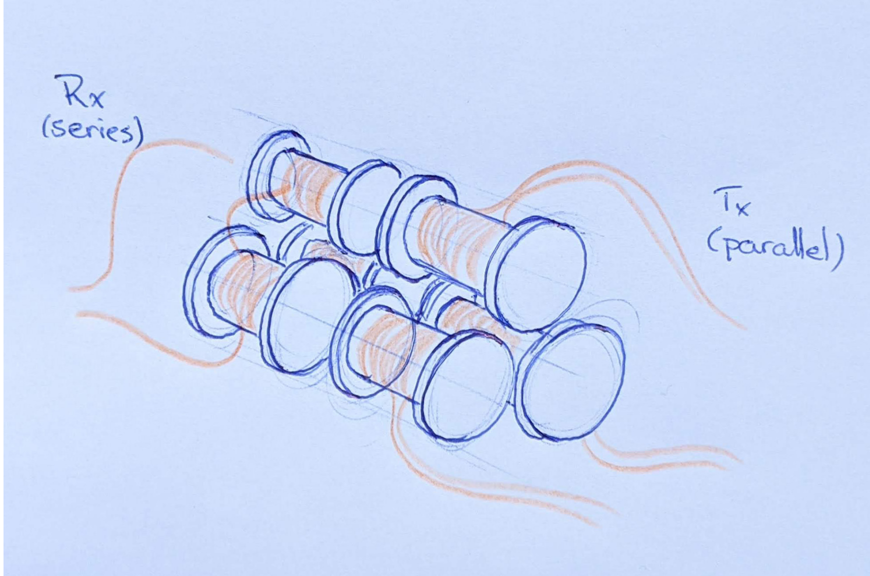


figure D.30 Wireless power transfer using three small 'Mushrooms'

Wireless Power Transfer

Though the ease of alignment in this concept allows for a cheap and off-the-shelve flat coil-to-coil system, these systems show drawbacks for application on e-bikes concerning low power transfer, low efficiency and heat dissipation (see also chapter 4). Therefore, a system that uses off-the-shelve ferrite bobbins is selected (Mushroom system). A system is though out together with TILER's electronics expert Ronald Kiewiet that utilizes three smaller bobbins that can transfer up to 100 watt each, instead of one larger one that can transfer up to the desired 200 watt (figure D.30). The largest benefit is that this makes the footprint of the connecting surface a lot smaller.

Another added benefit is that when the three bobbins are run parallel instead of in series, the product will still run at two thirds of its capacity if one of the coils burns out and is thus still able to charge the e-bike. Further research is required to reflect whether the added costs in electronics weighs against the likelihood of a coil burning out in practice.

Alignment magnets

In order to properly align and fix the transmitter to the receiver, three magnets are placed between the coil bobbins (figure D.31). These make sure that when the transmitter is placed slightly misaligned by the users, the magnetic force snaps the transmitter into the correct position. The use of three magnets – made possible by the use of three separate bobbins – forms a triangular dimension between them. This adds stability in the stickiness.

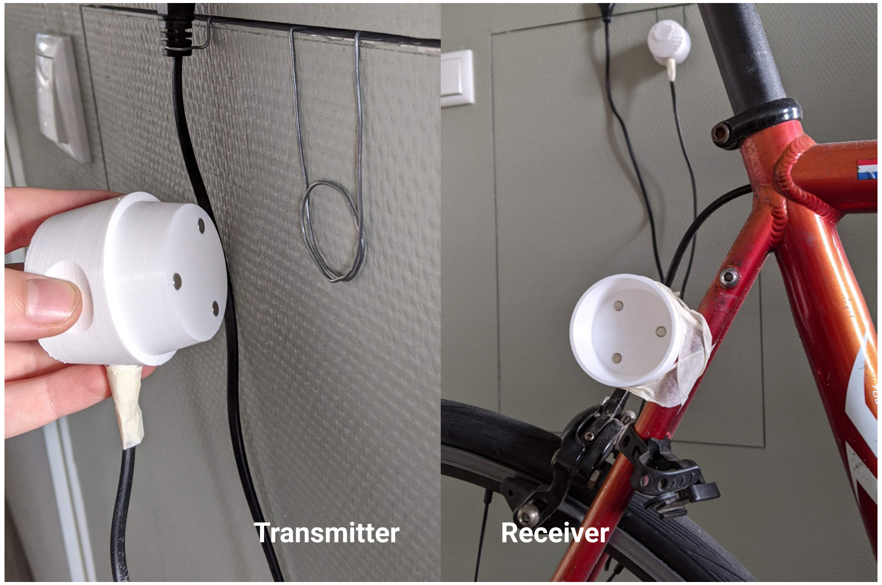


figure D.31 Prototype with magnets to align the mushrooms for optimal power transfer

CONCEPT SELECTION

In the previous chapters, two viable concepts are explained. A decision between these concepts has been made using the Weighted Criteria method. In this method, the criteria for the product are all given a weight according to their importance. Each concept is scored on the criteria, adding up to a final score.
The weight of each of the criteria is determined based on the research presented earlier in this report and on conversations with different stakeholders and potential users.

This shows that concept 2, the Wireless Cable, is preferred. This is mainly because the action of activating the charger is not new to people and alignment is easy both physically as well as mentally. The universality of the concept also outscores the other concept and opens future possibilities for integration on other types of (shared) Light Electric Vehicles as well.

CRITERIA

W1	Complexity of use (physical and mental effort)	**30**
W2	Universal system for all e-bikes	**18**
W3	Low risk of vandalism/damage	**16**
W4	Minimal impact on streetview	**12**
W5	Low overall price (incl. production and maintenance)	**12**
W6	Bicycles per meter (used space)	**6**
W7	Maximum sustainability	**6**
		100

FINAL SCORES

Concept 1	566
Concept 2	764
Current	534

CONCEPT 1

W1	**7**	210	High risk of having to lift the back of the bike. Limited vision on the pole while aligning. Large benefit is that it is fully integrated in parking flow
W2	**4**	72	Limited to e-bikes with space under the crank shaft (no mid-engine). Adjustment for each e-bike required.
W3	**5**	80	Large momentum on Receiver when someone bumps into bike. Generally larger forces on receiver. Low risk of conscious vandalism
W4	**7**	84	Pole is low and therefore limited impact. Some colour needed for visibility to prevent tripping. Guiderails for wheels look somewhat 'restless' and unorganized. Bikes are perfectly aligned when parked (benefit).
W5	**5**	60	Large platform with guiderails for wheels. Maintenance on cleaning (and sometimes replacing) Receiver.
W6	**4**	24	Width of handlebars determines space between bikes. One bike every 65 centimeters.
W7	**6**	36	Low use of ferrite, complexity in the system to allow use for bicycle of different heights.

CONCEPT 2

W1	**8**	240	Mental models already exist (e.g. charging devices or cars, fueling cars). Good vision on product during alignment. Quick to apply, only issue is that it is an extra step in the process
W2	**10**	180	All e-bikes, potential also for steps, scooters and more.
W3	**5**	80	Cable can be cut, adapters can be taken out as a joke. Actual chance of vandalism happening is relatively low.
W4	**7**	84	Slightly taller than the pole in Concept 1, but more opportunities in designing an 'anonymous' product that fits in the environment. Poles are far below eye level and therefore does not obstruct the view.
W5	**7**	84	High numbers due to universality means lower costs. Possible maintenance costs through damaged Transmitter or broken cables.
W6	**8**	48	Can be combined with existing bike racks if prefered. One bike every 37 centimeters (maximum).
W7	**8**	48	Limited use of ferrite, long term use due to universality. Lifetime of cable and Receiver might pose an issue.

CURRENT

W1	**5**	150	Limited vision on kickstand, especially right side. Bike tends to shift when placing on kickstand or when pushing accidentilly when parked.
W2	**5**	90	All e-bikes that have a kickstand bracket in the middle, only for people that want a double kickstand.
W3	**6**	96	Kickstand is prone to breaking (and expensive to replace). Tile is vandalism-proof (except for grafitti, but that is an issue for all).
W4	**9**	108	Only LEDs are visible
W5	**5**	60	High use of ferrites adds to price. Fragility of kickstand requires replacement more often: higher maintenance costs.
W6	**2**	12	Space between bicycle required to activate and align kickstand. One bike every 75 centimeters (self tested).
W7	**3**	18	High use of ferrites and limited lifetime of kickstand.

APPENDIX E

RECEIVER PLACEMENT

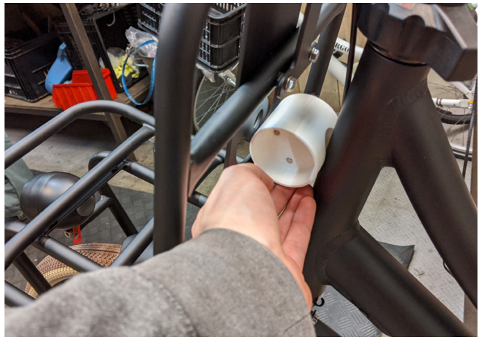
A Integration with seat clip
+ Universal
+ Easy access
- Usually the place of the chain lock

B Integration with seat clip - angled
+ Universal
+ Easy access
- Usually the place of the chain lock

C Under saddle
+ Easy access
- Cables

D Handlebars
+ Well visible
- Hard to reach from back of bike

E Handlebars - angled
+ Well visible
- Hard to reach from back of bike



F On frame - headset
- Hard to reach from front
- Looks strange

G On frame - front
+ Well visible
- Hard to reach from back of bike

H On frame - front - angled
- Hard to reach from back of bike
- Not universal

I On frame - front
- Not visible
- Low
- Not universal

J On frame - over kickstand
- Not universal
- Low

K On frame - below
- Different frame geometry (not round)
- Visibility
- Access

L On frame - below kickstand
- Not with every kickstand
- Low
- Access and visibility

M On frame - In rear fork
- Low
- Vulnerability

N On frame - On top of rear fork
- Vulnerability (extreme)
- No space for wheel covers

O On frame - seat post
+ Easy access
- Not a lot of space for some bikes

P Wheel axle mount
+ Easy access
- Low and vulnerable
- Cables

Q Between frame and lock
+ Use existing mounting option
+ Users also interact with lock, same place

R Rear fender - front
+ Below seat
+ Universal placement
- Cables of rear-mounted batteries?

S Rear fender - middle
+ Easy access
- Vulnerability
- Combination with rear carrier (could be +)

T Rear fender - middle
+ Easy access
+ Combination with rear light
- Vulnerability

U Rear fender - rear - angled
+ Easy access
+ Combination with rear light
- Vulnerability

V Rear carrier
+ Easy access
+ Replaces reflector/combination rear light
- Many bikes have no rear carrier (misuse)

APPENDIX F
EXPLORATIVE RESEARCH

A semi-structured explorative research has been performed to gain insights in what shape and size people prefer in the shape of a charger handle for charging an electric bicycle. The research was performed as part of a graduation project that was aimed at finding the most convenient way to charge publicly shared e-bikes.
The charger consists of two parts: the receiver, which will be placed on the bicycle, behind the saddle and above the ring lock; and the transmitter handle, which is connected to the power grid through a cable. The two parts are to be connected by the user of the e-bike to start the charging process and disconnected once the vehicle will be put to use.

The research presented in this appendix was aimed at answering the two following research questions:
1. What handle shape and size do people prefer?
2. What connection mechanism do people perceive as most convenient?
3. Which combination of handle shape and connection mechanism do people identify most as a charger?

This appendix is a short outline of how the research was performed. It includes raw results and conclusions, but must be read together with the chapters in the report to form a full view of the quality of the results.

Method
Based on the functional requirements that determine the contact area between the transmitter handle and the receiver, a total of 10 varying handle shapes have been designed in CAD software and 3D printed (figure F.1). The handles were designed to present a variety of angles and sizes.
Next to that, a brainstorm led to 8 different ways of connecting the transmitter to the receiver, again based on the functional requirements. These mechanisms were also designed in CAD software and 3D printed (figure F.2), each one consisting of two parts (e.g. A and A').

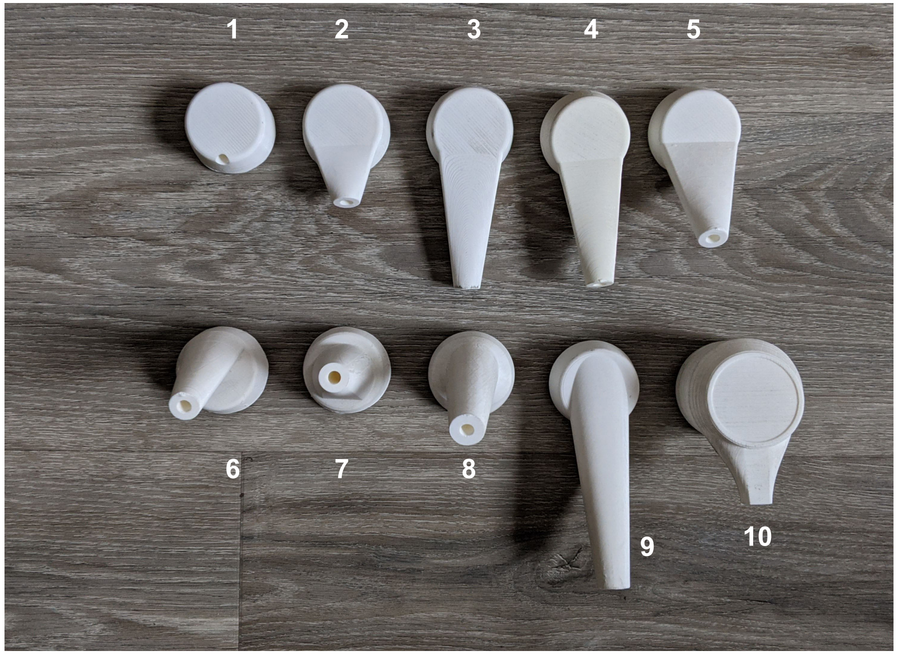


figure F.1 Tested handle design varieties

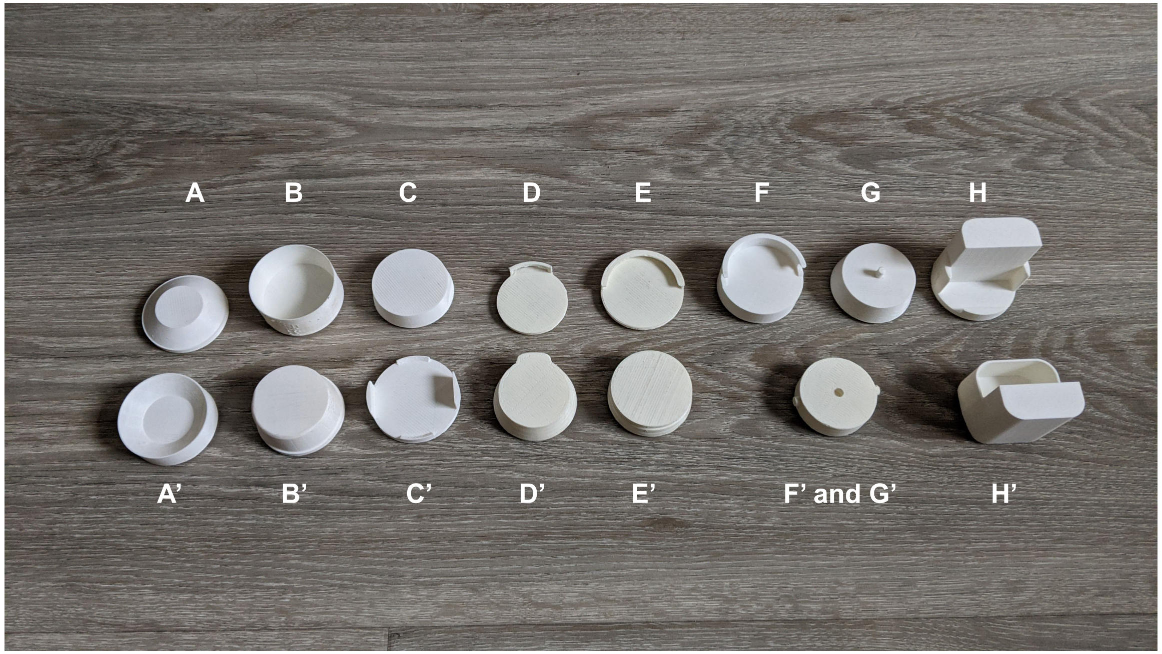


figure F.2 Tested connection mechanism varieties

All parts have been fitted with Velcro as to allow for multiple combinations. The total number of possible combinations is 160 (10 handles and 8 connection mechanisms with 2 configurations each).

As testing has occurred in different places, three different bicycles have been used during testing. All bicycles were fitted with an improvised mounting plate to which the receiver side of the connection mechanism could be fitted. All plates were mounted so that they are perpendicular to the arm when standing behind the bicycle and pointing towards the mounting plate (figure F.3).

8 participants participated in the research, all aged between 23 and 61 years old. One participant was female, all other participants were male. Exact hand size of the participants was not measured, but all participants said to judge their hands as average, thus concluding that no outliers contributed to the study.
From the participants, only 3 said to be experienced with e-bikes. All other participants know what an e-bike is, but never rode or charged one. Three of the participants have experience with shared light electric vehicles, of which one specifically with dock-based e-bikes and the other two with free-floating mopeds.

Testing all possible combinations with all participants would have costed too much time and fatigue would have led to unreliable results based on incomplete argumentation. Therefore, the different handles and mechanisms were spread on a table or on the floor (figure F.4) and participants were asked to experiment with them and form their own combinations. Participants were asked about their opinion and the researcher presented them with alternative handles and connection mechanisms based on their input to provide more input for forming their preferences.

figure F.3 Example of an improvised mounting plate

figure F.4 Photo of the test setup, as presented to participants

Results
A first result is that all participants (n = 8) preferred one of the three larger handles (8, 9 and 10). Participants mentioned that this gave them a nicer feeling due to the added grip. Multiple participants (n = 6) also mentioned that alignment of the transmitter handle with the receiver was easier with the larger handles, regardless the connection mechanism.
Three participants mentioned that the smaller handles made them feel as if they had to handle the transmitter handle with care, therefore preferring the larger handle.
Especially handle 8 was preferred (n = 7) (figure F.5) due to how comfortable it felt. The neutral wrist position added to the perceived comfort (n = 2).

Among the connection mechanisms, mechanism A and B were preferred unanimous (n = 8) due to its linear movement, prolonging the movement that is already made when moving the transmitter handle towards the receiver (n = 2) (figure F.5). Multiple participants (n = 4) mentioned that his was “just the most easy way”.
One of the main issues that participant noted were ‘too much fuss’ (n = 5) due to having to perform multiple actions (n = 2) (especially mechanism F) or alignment being too precise (n = 4) (mechanisms G and H, figure F.6). Observation in one instance where the time between connecting and disconnecting was significantly longer than the other tries showed that mechanisms that do not disconnect

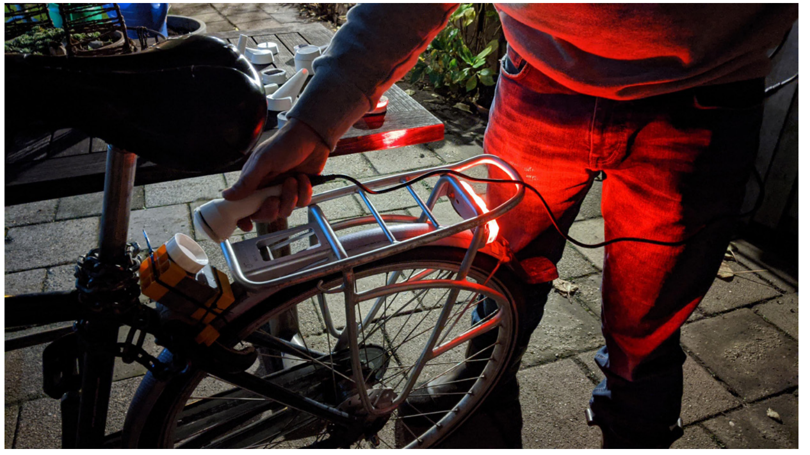


figure F.5 Handle design 8 with a linear connection mechanism that prolongs the movement of transmitter towards receiver in the connection

figure F.6 Connection mechanism H was disliked for its precise alignment

linearly are unexpected and can lead to annoyance. This specific participant pulled the mechanism straight out, but then reminded himself that the mechanism had to be lifted before taking out.
Many of the participants liked mechanism A due to its ideal alignment (n = 6), but some (n = 3) said to prefer mechanism B instead due to its clear feedback on when the charger is connected correctly (i.e. it does not go any further). The feedback is perceived as an important factor in the perceived convenience. One participant in specific mentioned that, despite its direction, precision and complexity not being preferred, mechanism H was liked for its clear click when attached.

Multiple participants (n = 4) mentioned to like the combination of handle 8 with connection mechanism B (figure F.7) most because it is "the most logical". This combination was also intuitively the first to be tested by 5 of the participants.

Conclusions

- Coupling and decoupling should be of a linear movement.
- Handle should be large enough to be perceived as solid and rigid, not as fragile. This also provides enough physical grip for an easy and assuring physical interaction.
- Handle should ensure a neutral position of the wrist.
- Coupling should have a clear 'coupling feedback', making the moment at which coupling is accomplished sensory noticeable. The most logical way is some sort of haptic feedback (e.g. physical 'locking' or a vibration motor).

figure F.7 Handle design 8 with connection mechanism B was viewed as most ideal and most logical by most of the participants

APPENDIX G

CLICK MECHANISM DESIGN

The need for a mechanism that holds the transmitter handle connected to the receiver during the charging process was discovered during testing of initial prototypes. The angle under which the two are connected and the gravity pulling on the handle and cable result in the handle falling off of the receiver quite easily.
The design of the click mechanism is limited by the size of the ferrite core required for the wireless charging process. To avoid further increasing the air gap between the transmitting and the receiving core, no more material can be placed between their contact surfaces.

Initial Learning from Magnets
Ideally, the click mechanism would be integrated behind the embodiment to offer the same benefits as wireless charging: complete protection of environmental influences. Tests showed, however, that relatively strong magnets are required to attach through the embodiment and still provide enough pulling force to hold the transmitter in place. The used magnets are neodymium magnets with a diameter of 6 mm and a hold force of 740 gram (Supermagnete.nl, n.d.). Neodymium magnets are the strongest magnets available, able to attract 1.000 times their own weight (First4Magnets, n.d.).
The issue with aligning multiple magnets along the edge (figure G.1) is that their magnetic field is added up, but not multiplied. The result is that the total force is larger, but the maximum air gap between the magnets remains the same. Using larger magnets would solve this, as they cause a stronger and bigger magnetic field, but it would strongly influence the design of the product in a negative way, making it bulky.
A magnetic ring that fits around the used ferrite core might be strong enough to hold the transmitter in place, but rings that have the exact dimension needed are hard to find, if not impossible. This means making a custom magnet would be the solution, but this is expensive. Besides, the magnets would require a lot of force from the user to disconnect the charger when pulled straight out.

figure G.1 Tests setup with multiple small magnets inside the embodiment that surround the ferrite core

Three alternatives
Three alternatives have been tested initially: one with a rubber ring, one with a latch that is pushed by a spring and one with three bi-directional click fingers.
The first alternative was tested with rubber rings of different thicknesses and diameters that are placed on the receiver and lock in a groove on the inside of the receiver (figure G.2). It was found that this is not a viable option, as it only works nicely when the transmitter Is placed under a slight angle (figure G.3). When placing the transmitter straight, too much force is required. As disconnecting with this mechanism can only be done linear, the needed force for disconnecting is always large, resulting in a dissatisfying interaction. Thinner rubbers decrease the required force, but also result in a less reliable connection.

figure G.2 Prototype with a rubber ring on the receiver and a groove on the transmitter side

figure G.3 Connection/disconnection often happens under a slight angle

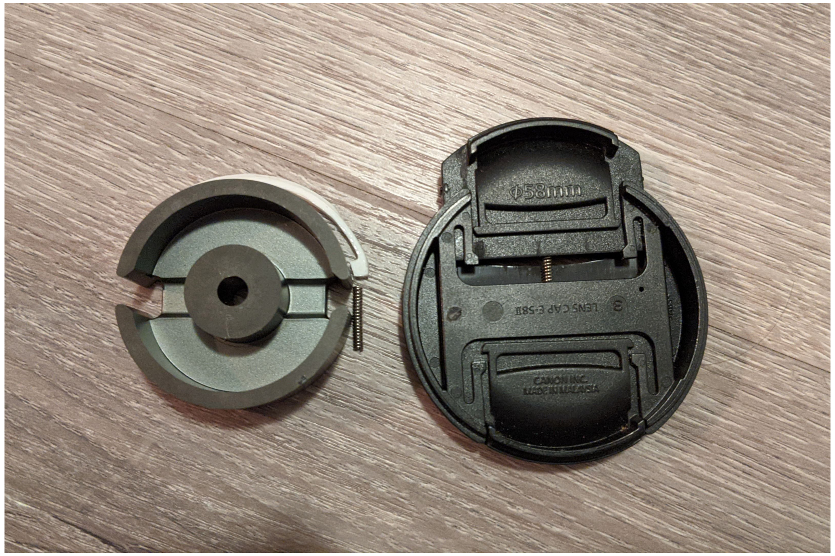


figure G.4 Lens cap inspired mechanism that is shaped around the ferrite core

The second tested idea is inspired by the lens cap from a camera (figure G.4), where two latches are slid aside by the fingers while placed and pushed aside by little springs to lock in the groove on the lens. The tapered shape of the receiver provides space for a small latch that forms around the P-core and has springs on the side of the core (figure G.5).
Testing this mechanism showed that the latch bends easily in the middle, thus not functioning as intended. The small and delicate parts also make this mechanism vulnerable, which is only emphasized by the fact that rain and dirt can find its way into the spring compartment.

The last mechanism consists of three plastic notches on the transmitter that lock into a groove on the receiver (figure G.6). The notches are placed on thin spring steel.
The shown prototype's bulkiness is because it was also intended to test with the length of the spring steel and the shape of the notch, but initial testing learned that the three click fingers often did not snap at the same moment because the connection does not always happen exactly linear. This resulted in an annoying feeling and wrong feedback.

The prototype did, however, learn that to counter the momentum caused by the gravity pulling on the handle, only the top of the connection has to be fixed. Blocking the lower two click fingers and using only one on the top (figure G.7) already worked a lot better. It also makes for the transmitter to unlock much easier, as the tapered shape of the receiver makes it unnecessary to overcome the required force to lift the click finger out of the groove. This works similar to the system with the rubber rings, where connection under an angle required significantly less force.

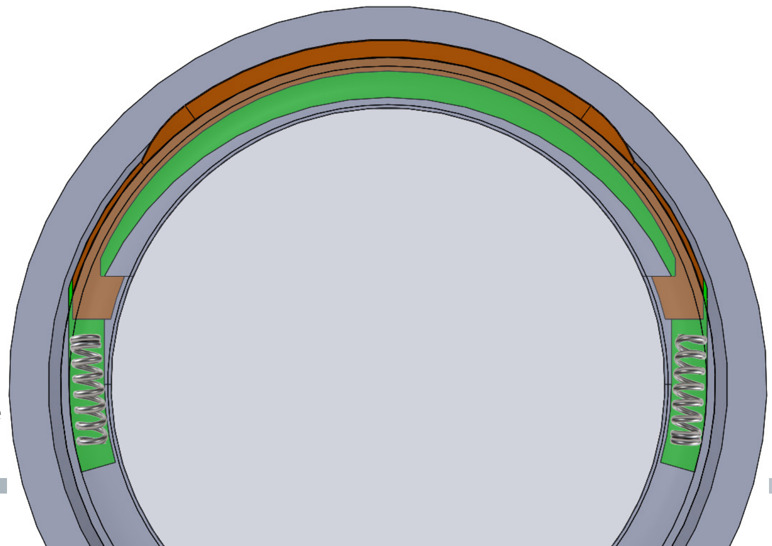


figure G.5 Spring and latch orientation around ferrite core

figure G.6 Mechanism with three click fingers does not provide the correct feedback

Spring Wire Mechanism

The findings from the three mechanisms discussed above have been put to use in another, simplified mechanism: a spring wire in the transmitter locks in a groove in the receiver. The first prototypes contained an iron wire that forms an entire circle around the transmitter (figure G.8). These have been discussed with Klaas Soeteman from Roveron (personal communication, 30-11-2020) to see what further optimizations where possible.

First of all, Soeteman urgently advised to replace the iron wire for spring wire in a production model, as it remains its original shape even after thousands of clicking cycles. Spring wire is made from steel that ‘remembers’ its shape. After being shaped, Roveron bakes the spring wire product in an oven to align the internal molecular crystal structure. This ensures that the product will always snap back to its original shape, as long as it is not deformed too extremely.
Next to that, it was found that the straight part that is in the top of the iron wire used was the only functional part needed. Therefore, the spring wire has been reduced to just this part (figure G.10).

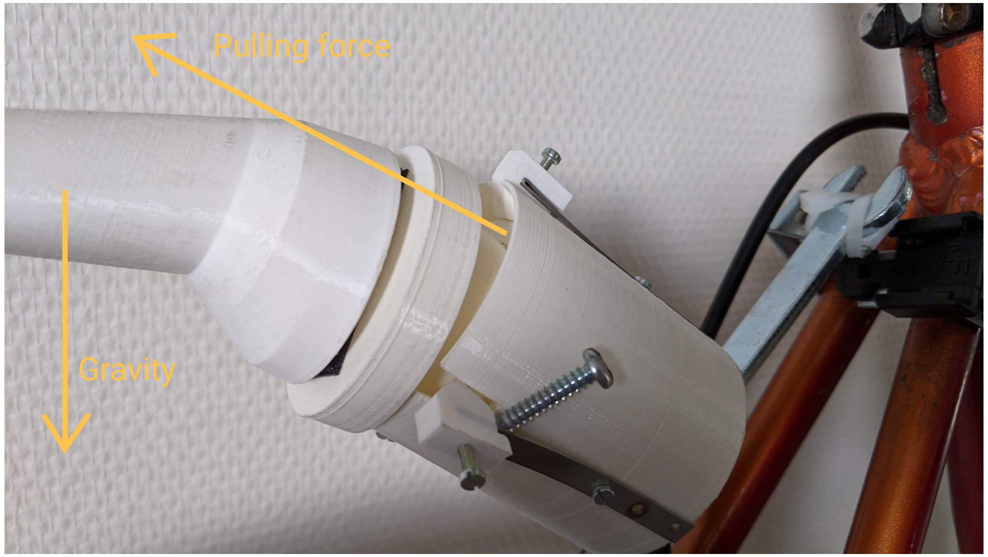


figure G.7 A mechanism with just one click finger showed sufficient to counter the pulling force caused by gravity

figure G.8 Spring wire mechanism in the transmitter is a simple alternative that solves issues in earlier ideas

figure G.9 Two spring wires of different thickness ensure correct feedback will always be given to the user

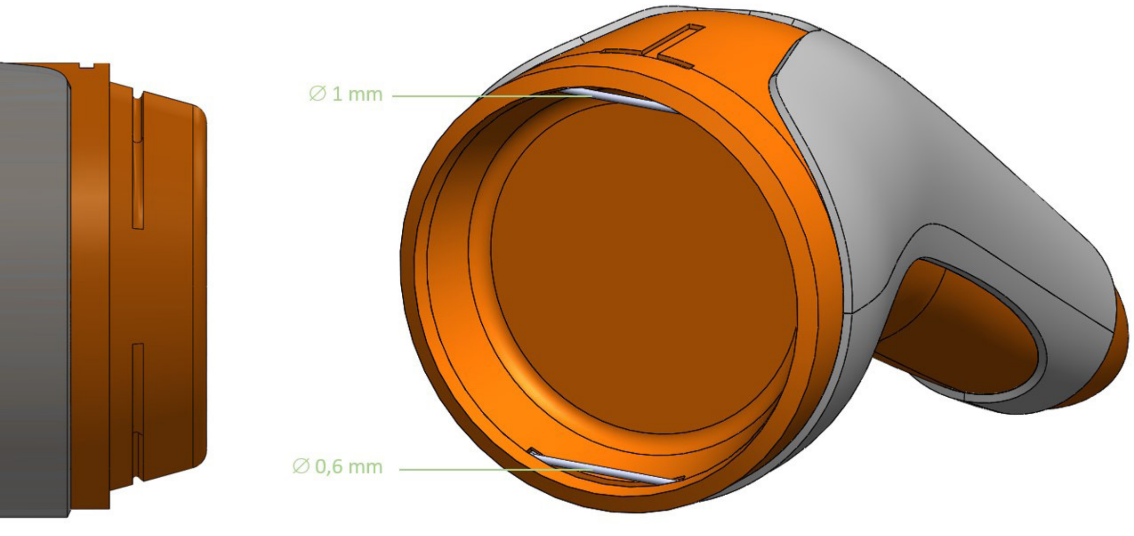


figure G.11 The dual spring wire mechanism shown in context

figure G.10 Minimal form of the spring wire to work properly

Lastly, Soeteman advised to use thinner material than the 1,2 mm thick iron wire that was used before. He estimates 0,8 to 1,0 mm should be good enough, as thicker material is more stiff and might cause problems with being pushed away by the tapered shape of the receiver during connecting.

Next to the thickness and the height of placement of the wire, the shape of the groove is essential for a successfully working mechanism. A steep edge provides a 'stronger' locking, but also requires more force for unlocking in a linear direction. The exact shape of the edge has been optimized in prototype, but so far has not been defined exactly.
The spring wire on the top provides a nice clicking sound and feeling when locking into the groove, which is perceived as a positive interaction. This feedback lacks when the transmitter is connected under a slight angle (figure G.3). Therefore, a second, thinner but otherwise similar wire has been added to the bottom to provide this feedback (G.9 and G.11). The shape of the groove must also be less steep to allow for easy disconnection (G.11, bottom groove). These slight differences result in the feedback being less obvious for this spring wire, but it is still there, thus adding a positive effect to the overall interaction.

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APPENDIX H

INTERACTIVE PROTOTYPE

The final prototype was made to look and function more like the final product. The body was made using 3D printing and its internal structure was altered to allow placement of an Arduino Nano (figure H.1). The prototype houses five RGB LEDs in its light display that can be programmed individually (figure H.2) and a Hall sensor that senses a magnetic field generated by a small magnet inside the receiver.
A vibration motor is also included that vibrates shortly when the handle is connected or disconnected, however user testing learned that the click mechanism already provides sufficient haptic feedback. The potential role of a vibration motor in the alarm function has not been tested.

Earlier prototypes included the ferrite core and weighed between 130 and 209 grams. The weight of the prototype was perceived positively by multiple people. The final prototype with its incorporated electronics weighs no more than 94 grams, so 68 grams of lead have been added to mimic the weight and centre of gravity of the ferrite (figure H.3).
The final prototype has been sanded and painted to look as much as possible like the real product (figure H.4 and H.5). A painted body looks and feels slightly different than an injection moulded one and especially the rubber sleeve intended for the final product feels different in this prototype, however the lack of comfort is not really noticed during user testing.

A simplified charger pole has been made of wood to make testing more realistic (figure H.6). A 3D printed 'dock' on the top end of the pole allows for effortless placement and grabbing of the transmitter, but testing showed that it also falls of easily. In the further development of the dock, placing a magnet that attracts to the ferrite might be a good option to keep the transmitter handle in place.

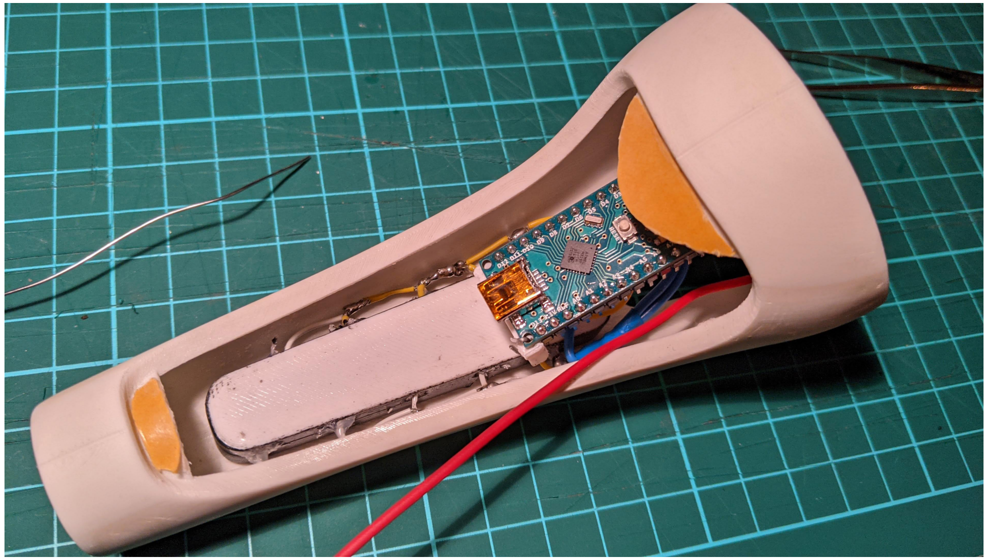

figure H.1 The transmitter handle is 3D printed and houses an Arduino Nano

figure H.2 Five Neopixel RGB LEDs are placed in line in the light display

figure H.3 Added lead mimics the weight of the ferrite core

figure H.4 The 3D printed body after sanding and surface finishing

figure H.5 The 3D printed body after paint

figure H.6 Semi-improvised charger pole

By using the software from Axure, the mobile application for shared mobility from X-bike has been copied and adapted to also include the role of the charger. A major difference, however, is that a connection between the application and the charger is not realised, but instead has been replaced by a toggle switch on the charger pole (figure H.7). A rotational potentiometer can be used to change the battery level displayed by the transmitter.
The charger pole also houses another Arduino Nano that communicates bidirectionally with the Arduino inside the transmitter handle (figure H.7). This second Arduino was required because the same PUR cable as intended in the final product was used, and this limited the number of available conductors. The Arduino on the charger pole also powers the LEDs in the receiver that is mounted on the bicycle through a cable. A simple DC connector was placed between the pole and the bicycle to allow easy transportation.

The light element in the receiver as presented in the storyboard in chapter 10 is based on an LED ring stretching around the receiver, but the initial plan was to light a lightning bolt on the charging surface instead (figure H.8). To keep the air gap between the transmitter and receiver ferrite limited, a system was developed that used a plate of thin acrylic with an engraved lightning bolt. When having an LED shine into the acrylic from the side, the light will only escape through the engraved area.

figure H.7 The charger pole houses a second Arduino and a switch button to simulate reservation status

Initial testing of this system showed genuinely promising, however after painting the receiver, the light emitted through the lightning bolt turned out to be not strong enough. Therefore, the system was replaced by four pinhole LEDs that shine through a cut-out lightning bolt, but while testing outside, the lights were still almost invisible. Next to that, the surface on which the light element was presented is placed under an angle, making it well-visible from a distance, but less so when standing close to the bike.
Due to its low visibility and the fact that it enlarges the air gap between the two ferrite cores, it was decided to abandon the idea of the lightning bolt and integrate the receiver lights in a ring instead.

The receiver is placed on a 3 mm thick bike bracket that was cut with a waterjet, bent by hand and sandblasted for a matte and uniform finish. Prototypes of 2 mm aluminium were made first to find the correct dimensions for application on the Urbee e-bike, but these lacked stiffness and did not make the prototype feel sturdy enough. Although just 50% thicker, the extra 1 mm makes the moment of inertia (and thus the stiffness) three times as large!

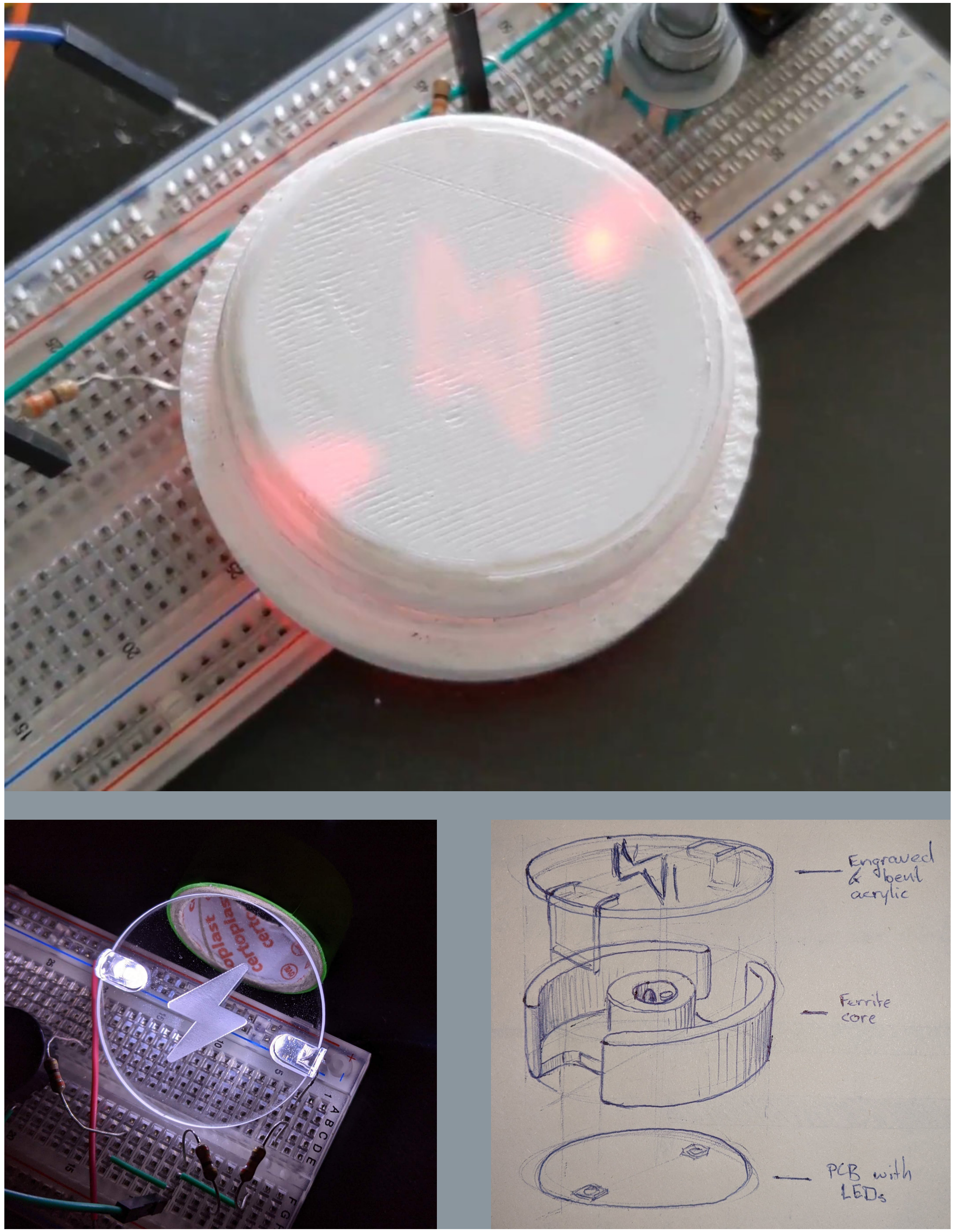

figure H.8 Working of the initially envisioned lightning bolt sign in the receiver

APPENDIX I

DISCLOSED

This appendix is disclosed and only available to the project team (TILER personnel and TU Delft coaches).

APPENDIX J

PROJECT BRIEF

The original project brief, as signed by the Board of Examiners on 15-9-2020, is found attached in the following pages.

Charging tile for electric bicycles in a TILER Network

project title

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

start date 31 - 08 - 2020

29 - 01 - 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The market for electric bicycles is on a rise. Where in 2007 only 6% of the total amount of sold bicycles in the Netherlands was an e-bike, the total share of e-bike sales has risen to 42% last year (Berg, 2020).
Not only consumer e-bikes are booming, other markets experience rapid growth as well. Additional tax liabilities allow companies to lease e-bikes for cheap (Business Insider Nederland, 2019) and food delivery e-bikes from Thuisbezorgd.nl and Domino's are replacing filthy delivery scooters in no-time (Cornelissen, 2019).
Another lucrative market is that of shared mobility. Electric share-scooters such as Felyx and Go Sharing gain in popularity in the Netherlands as an alternative for the automobile (Duursma, 2020). Uber has yet launched their Uber JUMP shared e-bikes in 31 cities worldwide (Putten, 2019) including Rotterdam and estimates that shared e-bikes will be accountable for a significant part of their net profit in the near future. Urbee in Amsterdam is also gaining popularity in the shared e-bike market.

One of the main drawbacks of electric mobility is the time and effort required for charging. Especially for shared mobility such as shared scooters and e-bikes, ensuring a full battery at all times is a major (cost) issue. As charging in the street is not possible, the provider of light electric shared mobility (be it scooters, be it e-bikes) needs to send someone out to swap the battery manually (Felyx, n.d.).

This is what TILER Charge (further referred to as TILER) is addressing with their wireless charging solution for e-bikes. The concept consists of a charging tile that is integrated in the ground and a specially developed kickstand that fits the bicycle. A coil in the charging tile generates energy, which is transferred wirelessly to the bicycle through a magnetic pole in the bike's kickstand (Wassink, 2020). This results in a high flexibility and an efficient yet powerful energy transfer (ca. 150-200 Wh).
TILER is currently focussing on corporate bike fleets that have the charging tile installed on their own grounds. The company is currently running a pilot test with Ahoy in Rotterdam (figure 1).

A future step for TILER is the TILER Network, consisting of publicly available charging tiles throughout the city. This has a massive potential impact on the market of shared mobility, as it promises to drastically lower the costs of providing a fully-charged e-bike at all times for companies like Uber JUMP and Urbee.

To be ready for such a network, TILER's charging tile needs to evolve. On a conceptual level, the interaction between the user and the charging tile needs to be reconsidered. The way people have to park their bicycle on the tile and the feedback the tile offers in return is essential for a positive experience. Especially when taking shared mobility into consideration – where the person charging the e-bike might not be the one using it later on – different user scenarios that might require a way of extrusive motivation to use the charging tile come into play. The pilot that is currently ongoing with Ahoy will offer a first guideline on improving the user-product interaction, but more user research will be required.
On a technical aspect, the charging tile needs to evolve from its current state as a glued black box to a product that is viable to produce in larger quantities and easy to install. TILER is already working on the embodiment of a series of charging tiles for a larger pilot, however conceptual changes for use in the TILER Network and regulations and certifications for installation in the public space and outdoor environment bring along new requirements.

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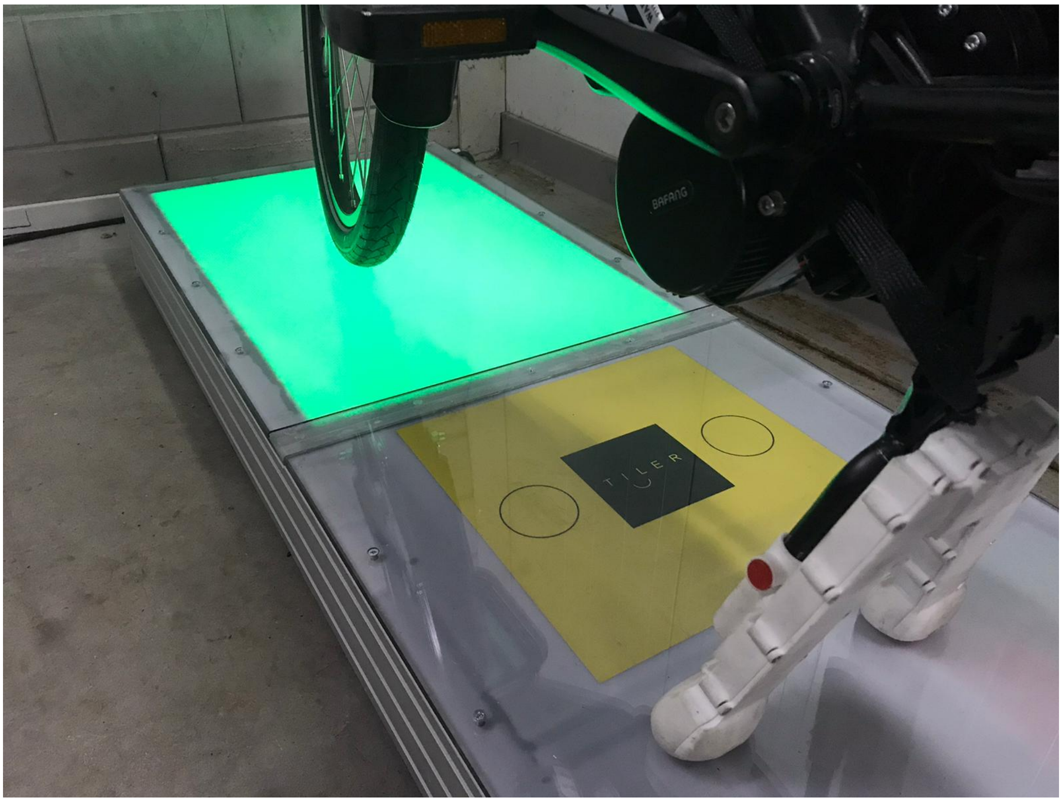

image / figure 1: Current prototype of TILER's charging tile

TO PLACE YOUR IMAGE IN THIS AREA:

- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:

- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
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image / figure 2:

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The current prototype of TILER's charging tile is more or less a glued box with the components required for charging inside. The prototype is mainly aimed at testing in practice, and however these tests will provide crucial insights for further development, the product is far from ready for larger-scale production and installation in the public space. The charging tile needs to be taken to a next level in terms of materials and production. TILER is currently working on a pre-production model of the current concept that enables larger-scale testing. Lessons learned in this process will provide useful insights in how to cope with internal heat build-up, but how the charging tile copes with water, dirt and other environmental influences also needs to be considered.

Designing a product for installation in the public space brings along new technical requirements. TILER has already done some preliminary research into these requirements, e.g. how the charging tile should be connected to and communicate with the power grid and the amount of magnetic flux that is allowed for a publicly available charging solution. Though mentioned requirements are on an electro-technical level and might have a limited influence on the embodiment design of the charging tile, a dive in regulations and certifications for public products is a must to prevent surprises in the end of the product. This will be done mainly through the connections of TILER.

In the test set-up of the current pilot study at Ahoy Rotterdam, an external LED panel is used to provide feedback to the user on when the e-bike is charging. The feedback on when the e-bike is parked correctly and is charging needs to be further explored to provide an all-in-one package. In terms of user feedback, converting the concept for use in the public space also brings along other new circumstances. For example: is it possible to know which (or who's) e-bike is currently charging to make the correct party pay for it? What happens when someone places another bicycle or object over it and can this be prevented in a positive way?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The main aim of this graduation project is to design the TILER charging tile for use and installation in the public environment. The charging tile will be designed on a conceptual level, taking the user-product interaction into consideration and on a technical level in terms of materials and production, while taking environmental influences and implications of design for public space into account.

The end result of this project will be a prototype of the charging tile that can be implemented in the public space and used in a broader TILER Network.

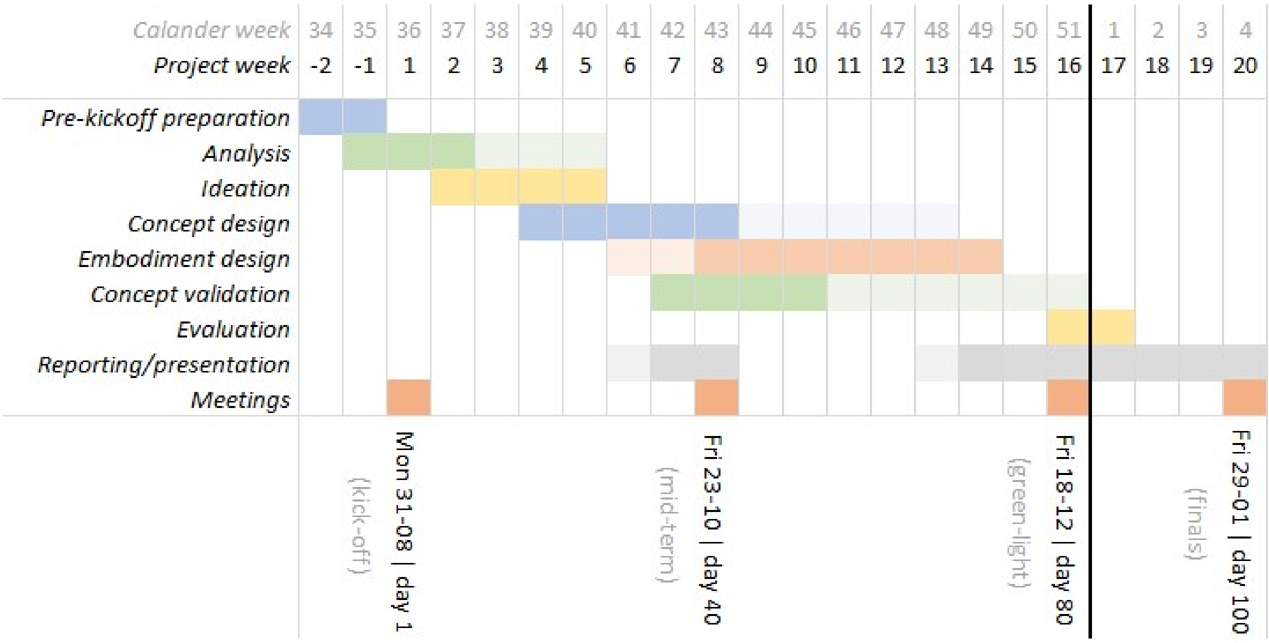
The expected outcomes of the project are as follows:
- Tested and verified concept for charging tile in a TILER Network
- Prototype to showcase new features that improve the user-product interaction
- Insight in use and users of the charging tile in public space and desired feedback to user
- Recommendations for further development of the TILER Network

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 31 - 8 - 2020

29 - 1 - 2021 end date



My approach will start with a thorough analysis of the current situation. This analysis will focus on both the technological considerations of the current charging tile, the requirements and limitations for the tile in the public domain and research into the potential user of the TILER Network.
A divergent ideation phase and a narrower concept design phase will lead to one or more conceptual designs for the charging tile. The result of this will be a concept that (potentially) meets all requirements on both a technical and a user-product interactive aspect.
After the mid-term meeting, the focus will shift from concept design towards embodiment design. Though the embodiment (in terms of materials and manufacturing) will already be taken into consideration during earlier phases of the project, this part of the project will be focused more on the details in making the charging tile into a feasible and reliable product that meets all demands and requirements in a satisfactory way.

Note the black vertical line between week 16 and 17. This represents the Christmas break, stretching two weeks from December 21 to January 3. No work will be done in this period of time.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Throughout my career as an IDE student, I have developed a strong interest in mobility, especially in relation to bicycles. I am an active cyclist myself and have been working in a bicycle store for almost six years. During a workshop with designers from Giant in Taiwan in the summer of 2019, I figured I could combine my passion for bicycles and cycling with my interest in (urban) mobility in my work as a designer. Teaming up with TILER offers me the chance to gain hands-on experience in this field of design.

Working with TILER also provides me an insight in the working environment of a young and innovative start-up. I have experienced the corporate culture of a renowned design agency during an internship earlier in 2020 and working with TILER enables me to experience a totally different culture. This gives me more insight in who I am as a designer and for what kind of company I want to work for after my graduation.

During the project, I want to evolve my skills in project management. I have little experience in managing a project like this and this will pose new challenges that will benefit me in my post-graduation career as a product designer. This also includes working on my planning and communication capabilities.

This project specifically also grants me the opportunity to evolve my knowledge on design for public use and the shared economy. This knowledge will be a valuable asset for a future where ownership is transitioning towards subscriptions.

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FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.