Next Generation Bicycle Lock: Development of an Innovative Bicycle Lock Concept for Accell Group.

Master Thesis Industrial Design Engineering
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ACCELL GROUP

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Acknowledgement

This master thesis was about designing a new bicycle lock for Accell. I wanted to experience how it is to work in the bicycle industry, and Accell is one of the leading companies in the Netherlands within the bicycle industry. I wanted to experience this since I am a big cycling enthusiast and I wanted to know whether working within this industry sparked the same passion as practicing the hobby, to see if I want to become active within this industry in the future. Besides being active within the cycling industry, Accell is also a company that has a lot of experience with product design. I have not yet been active within a large company with such a focus on product design, so that was a good learning experience as well to get a glimpse of how things work within such a company. The assignment also appealed to me because due to the longer timeframe of the assignment I was able to follow a more complete design process from research to a first working prototype which was used for user tests. Within the limited timeframes of the assignments on the university you would often not be able to move past a still rather vague concept whereas working this out further and developing the prototype is where things become more difficult and more concrete. It was nice to finally be able to answer a lot of questions that were present in the beginning of the design process in the further stages and with the prototype. I would like to thank Accell, and more specifically Rutmer Tjeerdema for offering me the opportunity to do my master assignment at Accell Group. I also want to thank Rutmer for the time and effort he put into guiding the assignment and offering valuable feedback during the weekly meetings we had. I also want to thank Roy Damgrave for supervising the assignment on behalf of the university of Twente and for offering helpful feedback after all design phases. Also, all other Accell employees that participated in the user test or had a chat about the project at some stage offered great insights which I want to thank them for. Lastly, I want to mention stichting ART who offered me the change to look into some important documents that are not publicly available for this project. They did not have to do this but were very keen to help me out with setting some important requirements for the assignment. I am happy to finish of this assignment and my master program as planned even though we have been battling with the corona restrictions for a long time over the course of 2020 and 2021, and even during the first couple of months of this assignment.

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Abstract

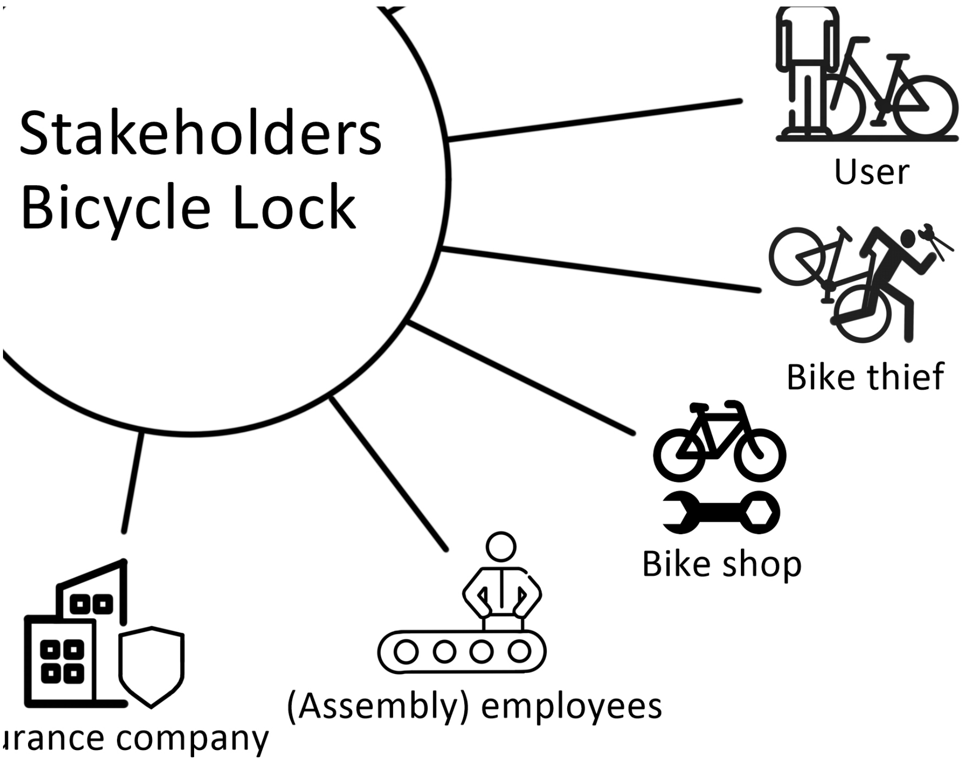
During the analysis, research is done to create a knowledge base for the rest of the assignment. It is concluded that bike thieves have four main methods to steal bikes: break the lock, pick the lock, lift the bike away, and steal parts. To prevent thieves from stealing bikes this should be made impossible or unrewarding. There are four main principles that can be used to achieve this: Locking the bike, deterring the thief, making the bike useless after theft, or by tracking the stolen bike. Locking the bike with an ART approved lock is required by the insurance companies, this means that the lock should prevent the bike from being rolled away when locked. Locking the bike to the world makes it harder for the thieve to steal the bike since it cannot be lifted away. Deterring the thief can be done with alarms. This is done often in new innovative locks. For this assignment not much focus was given on alarms since it is more like an additional function that can be added to almost any concept rather than a locking concept itself. Making the bike useless can be achieved by integrating the lock into the bike design. The aim of this method is that breaking the lock means breaking the bike itself making it useless for thieves to sell. Tracking a stolen bike will not prevent your bike from getting stolen but it will help you with finding it back. There are however a lot of third-party companies that offer tracking, so it is not deemed to be a requirement for the new lock to have tracking. Together with a stakeholder analysis, an analysis of all the current trends, a competition analysis, and an analysis of the use case of the current locks a list of requirements is made for the new concept that has four main pillars: anti-theft resistance needs to be improved, the user friendliness needs to be improved, the lock needs to be better integrated with the bike design, and the business case should be feasible. During the ideation phase a lot of ideas were created which were grouped into 11 main idea directions. With the help of the requirements from the analysis phase these idea directions were given scores. This was done more on feeling than on facts since the ideas were still very undefined. This scoring together with a discussion has led to three idea directions being chosen to develop into preliminary concepts. These were: a lock pin integrated in the dropout pad, a lock which is operated by the kick stand, and a chain lock which is stored over the rear carrier with a lock pin to lock the rear wheel. During the conceptualization, these three ideas are worked out further into preliminary concepts. The focus in this phase is on the technical aspects of the concepts mainly to find out if the idea is possible and feasible to produce. The lock pin in the dropout pad turned out to be less compact than hoped, and there will be a relatively easy method to break this lock open without damaging anything. This together with a relatively high cost price means that this concept is not selected. The kickstand lock turned out to be more like a switch for an electronic lock which could be coupled to for example the dropout pad lock. It was not selected because it offered limited added value for the increased cost price. The integrated chain lock was a much more feasible option that will be possible to make. The main downside is the limited chain length, but it was the only concept that could be locked to the world and give a high level of security. The cost price increase was also the lowest of all concepts and it has the highest potential to improve the user experience. Therefor this concept was chosen as the final concept. In the final development phase this concept was further improved, and a prototype was built. With this functional prototype, user tests and real-world tests could be performed to give realistic insights in how this lock would function. It showed that the concept indeed has good potential by being faster than the current ring lock with chain lock during the user test and it scored higher on ease of use and looks. It also ticks off a lot of the requirements. There are however also some points of improvement, meanly with the chain itself and the lock pin holder. The main concern of this concept remains the limited chain length which gives problems when parking the bike in a bicycle rack.

Introduction

The ring lock and chain lock as we all know it has been around for a long time already. With the current trend within the bicycle industry that is focussed on more integration and more use of electronics this leaves an opportunity for improvement. Accell group wants to explore their options to modernise the bicycle lock for brands like Batavus, Sparta, and Koga.

The goal of this assignment is to come up with a concept for an innovative bicycle lock that will fit the current trends. To do so the process starts with a research phase to better define the assignment and get familiar with the current situation, the problem, the competition, and to set the boundaries for the new concept. This is done by looking at the current locks, research bicycle theft, define the stakeholders and their interests, describe the current trends within the industry, do a competitor analysis, describe the bike the lock will be part of, and by describing the use case of the current lock. This leads to a design direction and requirements for the concept. This is used to set boundaries during the ideation phase. In this ideation phase a broad range of ideas are created which are then grouped into idea directions. For each idea direction also a short use case is created to see how the user would interact with the lock. The requirements of the research phase are then used to help select the three most promising idea directions. These three ideas are then further worked out into preliminary concepts. During this conceptualization phase the focus is on technical feasibility. The locking mechanisms are worked out in more detail and the first rough models are made to fit all components in place and check for fit and interferences. This leads to a better understanding about the limitations of all three concepts to be able to make a well-grounded decision for the best concept direction. In the final development phase the final concept for this assignment is created. The concept from chapter 3 is streamlined into a better looking package with better defined functionality. Besides creating the final concept, a first working prototype is build which closely resembles the looks and functionality of the final concept. In this final phase a lot of focus is on testing this prototype both in a user test as well as doing real-world tests to find its strengths and limitations and give insights that a computer screen cannot give. With this knowledge a realistic value proposition can be given with recommendations for further developments of the concept.

1 Analysis



During the analysis the knowledge base for the remainder of the assignment is discussed as well as concept requirements before entering the ideation phase. This chapter starts with defining what a traditional bicycle lock is as an benchmark. After this an explanation about bike theft is given by looking at how thieves work and what can be done to prevent bike theft. A stakeholder analysis is done to look at all interests of the stakeholders involved. The internal and external market trends in the lifestyle bicycle market are briefly discussed and a competition analysis of new innovative locks is discussed in which other tactics against bicycle theft are used more often. The bicycle anatomy is shortly touched upon, and the use case of the traditional bicycle lock is explained. This chapter is concluded with a SWOT analysis and a list of concept requirements and a design direction.

1.1 Bicycle lock

In the Netherlands most people will be familiar with a bicycle lock. With the number of bicycles in the Netherlands and the level of bike theft a large amount of Dutch people has, and uses a bicycle lock on their bike. The function of the bicycle lock is to prevent the bike from getting stolen. Stichting ART, who represents the ANWB, RAI vereniging, BOVAG, and Dutch theft insurance companies is responsible for testing bicycle locks in the Netherlands and describes a bicycle lock as 'an anti-theft provision for two-wheeled vehicles which prevents to ride or push the two wheeled vehicle and offers the possibility to prevent free movement of the wheel(s)'(stichting ART, 2019). There are multiple types of bicycle locks that try to prevent bicycle theft. In the Netherlands we are most familiar with the ring lock and the chain lock, but in other countries other types of locks are more popular. The most well-known 'traditional' bike lock types as described by stichting ART are:

Cable lock (*fig. 1.A*): a cable made of steel wire, in a single or spiral loop, with one end fixated to the lock housing or consists of a cable and a separated padlock/U-shackwle lock.

U-shackle lock / ring lock (*fig. 1.B*): lock housing with (partially or totally) detachable U-shaped shackle.

Folding lock (*fig. 1.C*): a number of bars, connected to each other by pivoting points, on one end fixated to the lock housing.

Anchorage element (*fig. 1.D*): an element provided with an eye or ring or similar, which can be used to connect with a chain, a locking system or bike frame, assuming that the object itself is permanently connected to the "fixed world" (wall, floor). Anchorage elements may include a lock.

Brake disc lock (*fig. 1.E*): a lock housing suitable to enclose a part of the brake disc; one of the (ventilation) holes in the brake disc is used by the blocking mechanism.

Chain lock (*fig. 1.F*): a chain combined with a padlock, U-shackle lock, or fixated lock housing.

Ring lock (*fig. 1.G*): a frame lock with a circular shackle, enclosing the cross section of the wheel rim totally when closed.

Figure 1: Types of bicycle lock

1.2 Bicycle theft

Every year a lot of people in the Netherlands lose their bike because of bike theft. According to BEKE (2020), in 2019 alone there where around 466.000 victims of bike theft with a total loss of around €600.000,- , making it the most frequent property crime in the Netherlands. Although the trend is that less bikes get stolen, the prices of bikes are increasing due to the increased popularity of e-bikes. According to a questionnaire of the ANWB in 2018, 29% of the respondents owned an e-bike (compared to 9% in 2013) and 47% of all bikes were more expensive than €1000,- . Another problem with bike theft is that the change of being caught is relatively low and the consequences are relatively low when being caught, making it a safe and lucrative crime to commit (BEKE, 2020). Both the questionnaire of the ANWB as well as the research of BEKE show that bike theft for some people is a reason to keep their bike at home. Most popular locations for bike theft are large (student) cities, stations, shopping areas, squares, sheds, and gardens. Also, the border regions of the Netherlands are popular among thieves since it is easy to reach Germany or Belgium (and from there Poland and such) from these regions. The research of BEKE (2020) distinguishes three types of bicycle thieves:

1
Casual Thief

The casual thief steals bikes at random when they 'feel like it'. They often steal cheaper bikes which were not locked properly for their own use or for a quick sale. These thieves are often students whose own bike is just stolen or addicts who need a bit of money. These types of thieves are not that relevant for this assignment since they do not target expensive e-bikes. This type of bike theft is also becoming less comon.

2
Professional Local Thief

The professional local thief works more professionally and is well prepared to pick or break a lock open. They steal bikes more regularly and remove or change frame numbers before selling the bike. They sell the bikes locally, often from home. It also happens that they check the market place before stealing the bike to see which bikes are most wanted which means that they target very specific bikes when stealing.

3
Organised Gangs

These organised gangs often steal multiple expensive bikes at once. They are well prepared and sometimes also work together with local thieves or industry insiders for information. The bikes that are stolen by these gangs are transported and sold in other countries, mainly in eastern Europe.These bikes are also prepared before selling the make them harder to trace back to the original owner.

The casual thief is not much of a concern for this assignment. These thieves target the cheaper and easy to steal bikes. Expensive e-bikes with good quality locks will not be their target. The professional thief and the organised gangs on the other hand are more of a concern. They are aware of the bikes they want to steal to get a good price when being sold again. They target the more popular and expensive models. The way these thieves work is explained in figure 2. They scout the second-hand market for models with a lot of demand and scout locations and bikes to steal.

The actual stealing is done by either lifting the bike and carrying it away or in a van. Also picking the lock is a popular method. Some thieves even have runner keys which they often received from contacts within the industry. Locks are also broken loose with tools and a last method is stealing only parts like the battery of the e-bike. There are also stories of bike jacking where people were forced of their bike with violence, but this is not common.

After the bike is stolen these are sometimes parked somewhere else just to make sure the bike is not being tracked via GPS. The bikes are then prepared to be sold. Some thieves remove the frame number, which is often only a sticker under the clearcoat, and replace it with a new number which is not registered as being stolen. Then the bikes are either sold locally by the thief or are transported to another country to be sold on another foreign market.

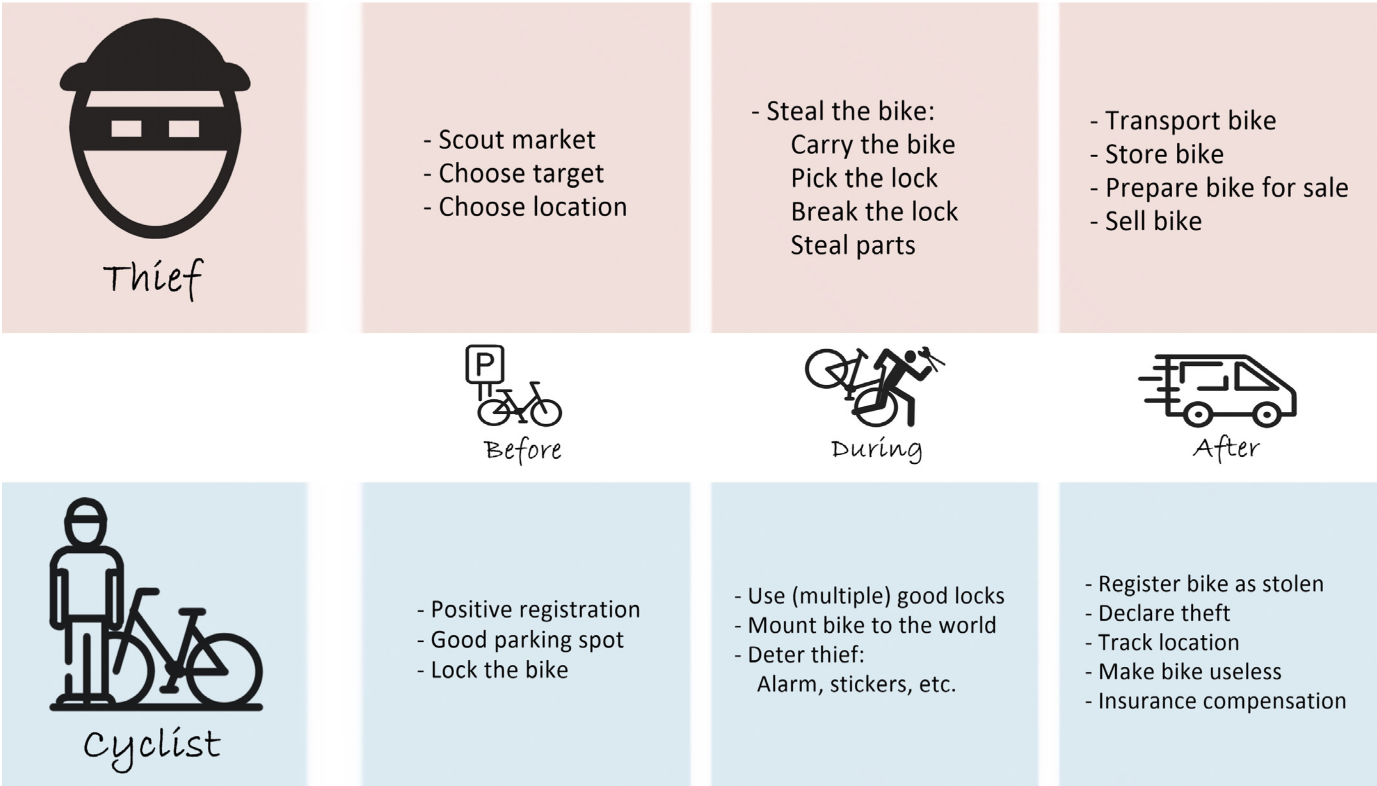


Figure 2: Bicycle theft roadmap

The bicycle theft roadmap in figure 2 also shows possible solutions to prevent bike theft. The traditional measure against bike theft is of course using a good bike lock. This should make it harder for the thief to take the bike away. And although using a good lock is obviously very recommendable almost everyone agrees that all locks can be opened when the thief really wants to. Another often heard measure is to lock your bike ‘to the world’ by using an additional chain lock. The questionnaire of the ANWB (2018) showed that 63% of the respondents said they lock their bike to the world. This questionnaire also showed that in 46% of the most recent bike theft cases the respondents had their bike locked to the solid world. This indicates that it indeed reduces the change of your bike getting stolen when you lock your bike to the world. However, it also shows that it is not a perfect solution.
Other solutions against bike theft are taking care of where you park it. Choose a place where there is more surveillance and good lights in the dark etc. Another solution is to register your bike on your name before it gets stolen, such that it is connected to your name. This is called positive registration. It should also be registered when the bike is stolen so that the frame number is known as being stolen when someone looks it up, and you can declare the theft at the police. This last measure is even more effective when the bike is also equipped with a tracking device such the police knows where the bike is. Usually when a bike theft is declared the police cannot do much to get the bike back but when they know the location of the bike, they can get it back much more easily.
The bike thief can also be deterred by using alarms when the bike gets stolen or by using stickers that indicate that your bike has a tracking device installed. You can also deter the thief by personalizing your bike with stickers or paint such that it is more recognizable. Another popular measure is getting your bike insured. This does not prevent the theft itself, but when your bike does get stolen the financial consequences are much less and you can buy a new bike. Especially with the increasing prices of bikes these insurances become more popular.
One last measurement that is not used a lot currently but that starts to emerge in new innovative bicycle locks is making the bike useless for the thief. Some electric bikes have electronic lockdowns when it gets stolen such that the thief cannot use the bike as an e-bike anymore and cannot sell it either. There are also locks that are integrated in such a way that breaking the lock means breaking the bike.

Conclusion:

The casual bike thief is not of much relevance for this assignment, the professional thieves are. Professional bike thieves target specific models which are easy to sell. Bikes are stolen by either lifting the bike, breaking the lock, picking the lock, or by stealing components. All locks can be broken. When you want to get your bike back it is important that you know where it is. Other measures are deterring the thief, registering the bike, make the bike useless after theft, or getting insurance. Locking your bike to the world also reduces the change of it getting stolen.

1.3 Stakeholders

When designing a new bicycle lock there are multiple stakeholders to consider. In the case of a bicycle lock there are quite some stakeholders involved both during the design and production as well as in the use phase and later during the disposal. Although not all stakeholders have the same amount of interest in the design it is still important to look into the interest off all these stakeholder groups.

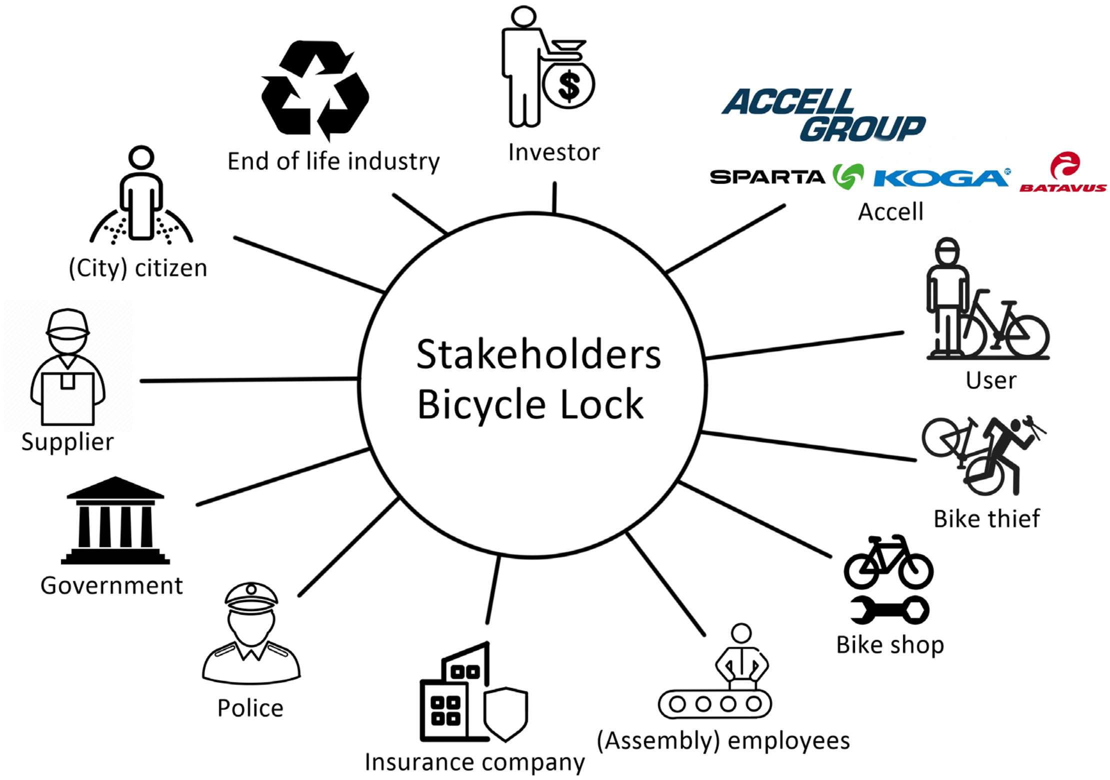


Figure 3: Stakeholders

Accell Group:

From the introduction it is already clear that Accell focusses heavily on e-bikes. In fact, in 2020 they already sold more electrical bikes than traditional bikes (472 thousand vs 425 thousand bikes) (annual report 2020). They even expect that in the long-term traditional bikes will only cover 8-10% of total nett sales compared to 12% in the first half of 2021. To put this into perspective, e-bikes already covered 53% of total nett sales in that period (2021 H1). Accell focusses on e-bike innovation and on smart technology (IoT) and urban mobility solutions. They also want to innovate and experiment to minimise material usage through re-use and end-of-life solutions. Safety is another topic Accell focusses on in the development of new products. They believe that the lack of safety while cycling for some people is the reason not to cycle. Therefor they want their bikes to become safer (Annual report 2020). Accell Group houses many cycling brands. However, since this assignment focusses on lifestyle bicycles and the Netherlands, only the premium brands that sell these bikes in the Netherlands and that are therefore relevant for this assignment are discussed:

Sparta:
Sparta produces e-bikes only, the focus of this brand is on the urban commuter.

Koga:
Koga produces high end sports bikes and commuting (e-)bikes. This brand is focusing on delivering the more premium bikes compared to Batavus and Sparta. Sports bikes are not their core business but help to create the premium brand image.

Batavus:
Batavus focuses on regular city bikes as well as e-bikes and cargo bikes. This brand focuses on making bikes for the whole family.

There is also a conflicting interest within Accell Group when designing a new bicycle lock. since bike theft also stimulates the sale of new bikes, creating a new innovative and effective bicycle lock will be good in a competitive point of view but can also potentially reduce bike sales.

The user:

Unfortunately, it is not advisable to leave your bike unattended in public without a proper lock. Bicycles can be expensive, especially the popular e-bikes, and the last thing you want is that your bike gets stolen. Therefor most people will use a bike lock to try to keep their bike safe from theft. But bike locks can also be annoying to work with. For consumers it is important to have an easy-to-use lock that keeps their bike from being stolen. Easy to use could mean all kinds of things like easy to carry around, fast to (un)lock, easy to reach, low operational strain, low maintenance, clear use instructions, few operational steps, and few things to do wrong. Also, some locks offer the opportunity to trace your bike back when it is stolen. Then there is the price of the lock, the lock should be as good as possible for the lowest possible price. Lastly, a lock should also have an appealing look, or even be invisible. the lock has also a contribution in the looks of a bike. For some consumers the looks of the bike is off influence when buying a bike.

Bike thief:

This stakeholder group is very important to keep in mind since they are the ones a bicycle lock is designed against in the first place. The goal is to make it impossible or unrewarding for thieves to steal bikes. In Chapter 1.2 bicycle thieves were discussed in more detail.

Bike shop:

Bike shops need to sell the new lock to the market. When the lock brings advantages and features to the market that differentiate it from the competition this can make it easier for the bike shops to sell bikes from Accell Group. It is important to keep in mind that often bike shops do not only sell bikes from Accell but also from other brands. And since a lot of customers ask for advice at the shop it is also important that the shop employees themselves like the new bicycle lock. For them it is important that the bike lock is easy to instal and maintain with the available knowledge and that it is reliable. Shop owners do not want problems on bikes they sold, especially when it should be covered under warranty.

(Assembly) Employees:

For employees it is important that the new bicycle lock has a positive effect to the market to promote sales to guarantee their employment in the long term. But on a more direct scale it is also important for manufacturing and assembly employees that the lock can be produced and installed in a technically and ergonomically feasible way. The production of bikes with such a new lock system may also not cause increased safety risks in the work environment. It is also important to see whether the new design requires additional knowledge within the company either through education of the current human resources or by employing new people with this skillset.

Insurance company:

Keeping the bike from being stolen is the obvious goal of using a bike lock. However, bikes can get stolen and in such a situation some cyclists have a bike insurance. In that case the lock needs to be approved by the insurance company. Most insurance companies require customers to use an ART-2 bicycle lock to get paid after their bike is stolen. They need to be able to proof that the bike was locked when it was stolen. Often the bike also needs to be locked in the shed. The insurance does not require an additional second chain lock to lock to bike ´to the world´ as is often recommended in the Netherlands. The new generation of keyless electronic locks can also be used with most insurances if they are also ART-2 classified (consumentenbond, 2021). Stichting ART is responsible for testing the locks and giving out the certification to lock manufactures. They test the lock on their strength, durability, weather resistance, and do an attack test to ensure the bike is difficult to open. There are many technical requirements for a lock to meet to receive an ART-2 classification. But one of the most important requirements before entering the concept phase is that the lock needs to prohibit the thief from rolling the bike away. Locks that block the bottom bracket, pedals or steering can therefor only be ART-2 classified in combination with an additional locking aid (stichting ART 2019).

Police:

Solving bike theft is one of the many tasks of the police. This is often not on top of their priority list and therefor bike theft is often not solved when reported at the police (BEKE, 2020). However, knowing the location of the stolen bike greatly increases the willingness of the police to act and bring the bike back to its original owner. This can be done with tracking devices inside the bicycle. Because of the high workload at the police and the low priority of bike theft some companies also rely on private security companies to trace the bikes and take them back. This needs to happen according to the government rules. It is not always allowed for these private companies to break into someone’s property to take the bike back. However, a good bicycle lock that prevents bicycle theft from happening is a positive effect for almost all stakeholders including the police since there will be much less bike theft cases to solve.

Government:

The bicycles that will be sold with the new locks will end up on the streets where rules apply. This means that the lock needs to be conform those rules which can also be different depending on the country you are in. When using electronic locks with communication protocols it is important to keep in mind what kind of data this collects and what happens with this data, especially with the new stricter privacy rules of nowadays. Also, the safety of the people involved with the bike needs to be granted. City councils should be able to remove abandoned bikes or bikes that are not parked correctly and bring them to a city depot without all kinds of alarms going off for a long period of time.

Supplier:

Accell Group does not own the whole supply chain from raw materials up until the completed bicycle. Therefor, at some point, they need suppliers to supply materials, components, or even assemblies. It is important that the input needed by Accell can be delivered by suppliers in a way that fits Accell.

(City) Citizen:

Citizens are often not in direct contact with someone else his bicycle lock. However, in busy city environments it can still cause annoyance. For example, bicycle locks with audio alarms sound like a great idea, but when a substantial amount of all bikes have such an alarm, hearing these alarms in daily live will become inevitable. And when these alarms are then also very sensitive and tend to go off easily this can cause annoyance among citizens. This can ultimately create bad reputation for Accell Group when it concerns their bikes as well. Also, trying to move a bike that is badly parked is daily practice in some places, when this is not possible due to alarms or to good of an bicycle lock this can create minor problems as well.

End of life industry:

With the increased environmental awareness both worldwide as well as within the Accell Group, it is also important to consider the end of life of the bicycle lock. What happens when the product is not used anymore? Is it recycled or does it become landfill? And who is going to do that? At this stage these are questions that can not be answered yet, but they do need to be considered once a concept is created. Some connected bikes also use subscribtions, what happens when these expire?

Investor:

For investors it is important that the Accell Group keeps a good brand reputation and that there is a healthy grow in bikes sales as well as profit. Good quality and innovative products that differentiate from competitors can help with that and a new bicycle lock can be such a selling point. Besides making money some investors also like to have some 'moral' in their investments and a product that reduces bike theft can be a good pitch in keeping investors involved. However, just like for Accell Group itself and the bike shops, bike theft also stimulates the sale of new bikes. So, having an amazing lock which eliminates bike theft all together might also reduce bike sales and profit.

Conclusion:

A lot of stakeholders are involved when designing a new innovative bicycle lock. Important factors to consider while designing a new bicycle lock are that the main focus of Accell Group will be on e-bikes. They want to focus on urban mobility. For the user the ease of use is important as well as the price of the product and the looks of it. To be effective the lock needs to prevent the bike from being stolen or make it unrewarding to steal. It is important that a new bicycle locking mechanism can differentiate in a positive manner from the competition to stimulate sales. It should be feasible to produce and easy to work with as well as being reliable. The lock needs to be ART-2 certified which also includes that it should not be able to roll the locked bike away. For the police it is important to know the location of stolen bikes. Alarm systems might cause problems in city environments and the end of life of the lock also needs to be considered when designing the lock.

1.4 Lifestyle bicycle trends

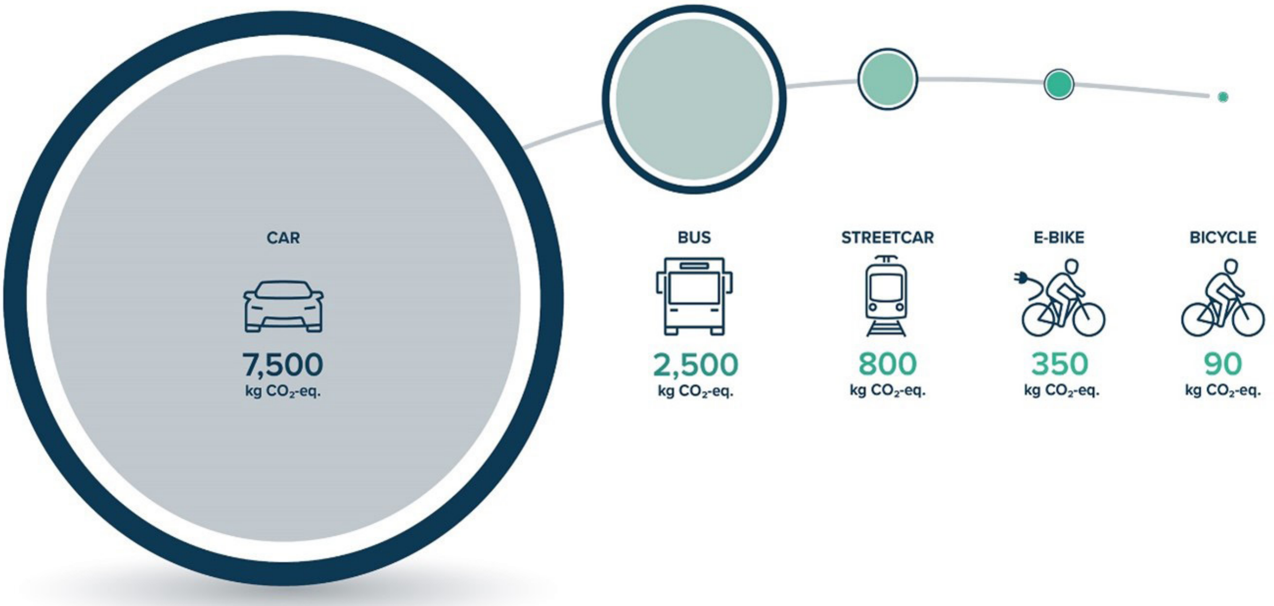


Figure 4: Transportation methods environmental footprints (Annual report Accell, 2020)

External trends:

Investments in the electrification of bicycles will be the biggest growth driver for bikes in the long term. E-bikes make cycling less physically demanding which makes it attractive for a larger group of consumers and for other forms of transport, such as parcel services. The environmental impact of an e-bike is higher than a regular bike, but it is still much lower than other forms of transport (see fig 4). The electrification of bicycles also creates opportunities for more effective security against theft and an improved traffic safety. Across Europe, cycling is seen as a solution for city transport in the future. Therefor a lot of governments are making subsidy schemes to stimulate the use of (e-)bikes in the city environment. Besides this, there are also a lot of investments into cycling infrastructure to stimulate the use of bicycles even further. This should lead to more use of bicycles which stimulates safer city transport, CO2 reduction, and a healthier lifestyle. Besides this also bike sharing is becoming increasingly popular within cities. It is more common nowadays to lease, rent, or share a bike instead of buying one. This is expected to boost the bike market growth as well.

Internal trends:

It was already stated that for Accell Group the e-bikes will be the main focus for the future. Regular bikes will also still be sold but in terms of nett sales the e-bike is expected to have a much higher share than regular bikes.

When looking at the more technical trends within lifestyle (e-)bikes that appear within the market and are seen within the product portfolio of Accell Group itself, there is a trend of using mid engines for e-bikes as well as integrated batteries (in-tube batteries).

Accell Group uses mainly Bosch engines for their e-bikes. A development that is expected for the upcoming years is that some brands will also come with e-bike engines with build in gears making the use of internal gear hubs redundant.

There is also a growing share of bikes that come with belt drive instead of a chain. This should reduce the needed maintenance and is said to give a smoother ride quality. The more expensive bikes will come with these belt drives.

The traditional men's frame with the high toptube is becoming less popular in favour of the low / easy step through women's frames.

Almost all proper (e-)bikes come with disc brakes instead of drum brakes or rim brakes like they used to have. These brakes are hydraulic making them more powerful and easier to modulate.

One interesting trend is that within the Netherlands it is most common for city and commuter bikes to come with internal gear hubs whereas the rest of the world more often uses a derailleur system. Gear hubs require less maintenance than a derailleur system. With the increased popularity of e-bikes also the specced gear hubs change. Efficiency of the e-bike is becoming less important since the motor can easily compensate for that. Instead manufactures start speccing less efficient but stronger gear hubs like the Shimano nexus 5 speed and the Enviolo hubs that are stronger and don't break down that easily under the power of the motor.

Using these stronger hubs, mid engines and integrated batteries also result in heavier e-bikes.

Weight is becoming less important because of the electrical assistance of the e-bike. To neatly integrate the batteries into the downtube these downtubes are even casted instead of extruded and hydroformed giving more design freedom.

Another development within Accell group especially applicable for the Dutch market is that Accell starts making more and more components themselves and do not attach much value to well-known aftermarket brands anymore. People simply buy a 'Batavus' or a 'Sparta' instead of all the individual components that are mounted to the bike, similar as with cars.

Innovations are also shared across different Accell Group brands, and this will probably happen even more often in the future. Some identical frames are even sold under different brands to increase the economy of scale and therefor create a more competitive price point.

Conclusion:

For the new lock to fit the upcoming trends it needs to work on a low step through e-bike with a mid- engine and in-tube battery using disc brakes. The weight of the bike is not as important as it used to be. Accell produces a lot of components themselves which can also be an opportunity when designing a new lock.

Figure 5: The Sparta C-GRID ULTRA, an e-bike that is according the latest trends: mid engine from Bosch; an in-tube battery; using a belt drive instead of a chain; having a low step through frame; using hydraulic disc brakes; and using an internal gear hub (Sparta, n.d.).

1.5 Competition analysis

In Chapter 1.1 the common types of traditional bicycle locks were briefly discussed. During this assignment the aim is to find an innovative way to lock a bicycle. In the last couple of years there were more companies that tried to accomplish this with mixed results. In this Chapter some of the interesting examples of the new breed of innovative bicycle locks are discussed. Traditionally the bicycle lock was meant to lock the bike and therefor make it harder to take the bike. But as is clear now, all locks can be broken loose. So, a lot of these innovative locks also try other tactics like deterring the thief, making the bike useless after theft, or tracking the bike down when it is stolen.

VanMoof kick lock:

Figure 6: VanMoof kick lock (VanMoof, 2018)

This lock consists of multiple layers of protection. First, there is the mechanical lock which is located at the rear brake disc. An additional disc is placed in front of the brake disc that contains slots where a pin can be locked into to stop the rear wheel from spinning. This pin is integrated in the rear non-drive side dropout and can be 'kicked' into the slot with your feet after aligning the marks on the rear hub. The kick lock is connected to the electronics and battery inside the frame by a cable running through the chain stay and the kick lock unit can also be swapped may it break down at some point. To unlock the pin the lock uses a Bluetooth connection with your smartphone. When your phone is near the bike the kick lock can be unlocked with a simple push on the button at the steering wheel. When you do not have your phone with you, or its batteries are empty this button can also be used to press a code to unlock the lock. There is no dedicated physical key anymore.
Besides this mechanical lock there is also an electronic defence mechanism. By locking the kick lock the electrical defence mechanism is automatically also activated. When the bike is being moved an alarm goes off to warn the thief and the surrounding. If after two minutes the bike is still moving the complete bike goes into lockdown. This means that all electronics are shut off, making the bike useless for the thief, and the tracking systems starts. This tracking system works with GSM and RFID to give an accurate location of the bike in the app, you can even use Apple Find My. When the customer also paid for the VanMoof piece of mind theft protection service the VanMoof bike hunters will get your bike back or else you will get a new one within the first three years after purchase.
So, although the lock itself is rather simple and offers little protection. With the added electronical defence system, it is supposed to give enough protection against theft. And the lock is neatly integrated in the bike and easy and fast to use.

Mobilock:

Figure 7: Mobilock (Dynteq, n.d.)

The Mobilock is unique in that it has the ART-4 classification while most bicycle locks have an ART-2 classification. This means that this lock is more secure than the typical bicycle lock. It uses a combination of a ring lock and a chain lock. The chain lock is not ART-4 classified but ART-2, since this enables a lighter, and for bicycles, more suitable chain. This lock is designed for share bicycles programmes and is electronically operated. It is locked manually by inserting the lock pin in the lock. The lock can be unlocked using the app on your smartphone. By using LoRa and Bluetooth low-energy connection the lock achieves a battery life of 3 years which means that it can be easily used on all kinds of bikes. However, if your smartphone runs out of battery there is no back up like most locks have and you can't unlock the bike.

Linka:

The Linka original was one of the first electronic bicycle locks to get the ART-2 classification. The Linka is based on a ring lock which can be both locked and unlocked electronically with your smartphone using a Bluetooth connection. You can also operate the lock using a password on the lock itself may your phone run out of energy or is not around. You can lock it by touching the lock in a certain location and you can use auto unlocking which means that it will automatically unlock when your phone gets near the bike. The locks also have an alarm which goes off when someone is trying to steal your bike. This will also give a message in your app. The newer and more expensive version, the Linka Leo, also has a GPS tracking system to see where your bike is located. The Linka has a build in battery which lasts around 3 months in auto unlocking mode up to 16 months. It will give a warning when it is running low. The battery can't be removed, so charging means that the bike needs to be located near a power outlet. There is also a chain available which can be used in combination with this lock to create some extra theft protection.

Figure 8: Linka (Linka, n.d.)

I LOCK IT:

The I LOCK IT electronic ring lock is very similar to the Linka lock. It can be connected to an app on your smartphone and has an auto-unlocking function that will unlock your bike when the lock is connected to your phone via Bluetooth. It will also activate an alarm when someone tries to steal the bike by using accelerometers just like the Linka. Again, there is a more expensive version that also has GPS tracking for when your bike gets stolen. This lock can also be used in combination with a chain lock and the integrated battery should last one season and can be charged through micro-USB just like the Linka. This lock is not ART-2 rated but I LOCK IT offers an insurance in combination with this lock so you can still insure your bike against theft.

Figure 9: I LOCK IT (I LOCK IT, n.d.)

Pentalock:

Pentalock is a more modern and refined version of the concept Blulocks once had. It is a bottom bracket module which locks the crank axle in place. Breaking this lock means breaking the bike which makes it useless for thieves to sell. It has keyless locking and unlocking with an app and a remote key using Bluetooth. An alarm will go off when someone tries to steal the bike. When it is used in e-bikes it can also lock all electronics like the motor, battery, and display. For the non-e-bike version it uses 4 AA batteries that should last 2 years. This lock is only just available to manufacturers but will be introduced in some brands the coming years.

Figure 10: Pentalock (Pentalock, n.d.)

Bosch E-bike lock:

Bosch has built in a premium function in its Kiox and Nyon displays which enables electronical locking of e-bikes. When this function is installed, the display will act as a key. When the display is removed from the bike the motor is deactivated and only when the same paired display is connected to the bike again, the motor will be activated again. This makes it harder for thieves to sell the stolen bike since the motor does not work anymore and when pairing a new display to it you will get a notification that the bike has been stolen

Figure 11: Bosch E-bike lock (Bosch, n.d.)

Greyp locking system:

Figure 12: Greyp locking system (Greyp, n.d.)

Another E-bike brand that has a built-in electronic locking mechanism is Greyp. Their bike has built in internet which is always connected to your phone. The app will give a warning when the bike shows suspicious movement. The motor and battery of the bike can be remotely deactivated in case of theft, and it can also be tracked via the app. You can even send messages to the display to warn the thief as well as make pictures with the build in cameras.

Blulocks:

Figure 13: Blulocks (newatlas, 2015)

BluLocks was a start up from Delft that designed an integrated locking mechanism in the seat tube of the bike that could both lock the crank axle as well as a chain lock. By fixing the crank axle it became impossible to ride the bike and breaking open this lock would mean breaking the seat tube which would make the bike useless. This lock never came into mass production but still the idea of integrating a lock in a way that means breaking the bike to break the lock is an innovative thought.

N-lock:

Figure 14: N-lock (n-lock, n.d.)

N-lock offers a completely different approach for locking your bicycle than any other lock. This lock is located in the stem and disengages the handlebar from the steerer tube making it impossible to steer and therefor ride the bike. This can also be convenient when storing the bike in tight spaces since you can twist the handlebars to make the bike less wide. It still uses a key, and the bike can still be moved relatively easily after (un)locking the stem. The aim is to make the bike unrideable and therefor useless. The bike can be locked with the available additional integrated cable lock for some added security.

Interlock:

Figure 15: Interlock (kickstarter, 2016)

Another Kickstarter campaign from a couple of years back was the Interlock. This is a cable lock which is integrated in the seat post which makes it easy to store and bring along and gives the bike a neat look. Apart from the integration in the seat post it was just a regular cable lock.

Location tracking:

In the competitor overview in figure 16 there are multiple different technologies used for tracking bikes. The tracking technologies are the following:

GSM:
GSM tracking has the advantage over GPS that it also works inside buildings and does not need a free line of sight. It works via triangulation by connecting to multiple GSM towers and then an indication of the location of the transmitter can be determined. This is however not as precise as GPS, so you cannot locate the exact address the bike is located. For that you need an additional low range radio frequency technology like VanMoof does as well be combining GSM with RFID to trace their bikes back.

Apple Find My:
Apple Find My works by making a Bluetooth connection with Apple phones that are near the bike. This phone then sends its location. This technology is relatively simple, but it only works when you have an iPhone and when there are other Apple product around the stolen bike. It does not give an live location but only a last seen location. It is also not publicly known what Apple charges to use this technology.

GPS:
GPS is the best-known technology to track a location. It is however not perfect. First, it does not work well within buildings. It is even a problem to transmit the signal through a bike frame so you cannot just put an GPS receiver inside a bicycle. It is also relatively expensive. Sparta used to sell bikes with GPS but they do not offer this anymore because of the costs. The GPS unit itself is somewhere around €50 up to €150 and then you still need a sim card to send the data.

LoRa:
LoRa is a relatively new technology which can be a cheap alternative to GSM and GPS tracking. It also works by making a connection to a near-by connection point just like GSM, so it also works inside but is a lot more precise than GSM. You do need a LoRa network. This network is already provided by KPN in the Netherlands and its worldwide coverage is fast growing. It costs somewhere between €20 up to €40 to run for 5 years. And it needs only very little power. Mobilock uses LoRa and the ANWB also offers LoRa chips in combination with their insurance. If you only want to use location tracking this offers the best price performance ratio.

What happens though regarding tracking devices in bicycles is that these are also often offered by external parties. There are for example bicycle insurances that come included with a tracking chip or there are GPS units that can be bought separately and installed as an aftermarket add-on. This means that tracking does not necessarily has to be integrated into the bicycle lock but can also be seen as a separate product.

Conclusion:

New innovative bicycle locks often add multiple layers of protection against theft. Besides the often-traditional locking of the bike the lock can also deter the thief by using an alarm. The bike can be made useless to sell by integrating the lock in such a way that breaking the lock means breaking the bike or by adding an electronic lockdown to the e-bike. And a lot of these locks can use location tracking. When using location tracking in a bicycle lock without further functionality LoRa is the most cost and energy effective way to track the location of the bike. However, location tracking does not necessarily need to be integrated into the lock but can also be seen as a separated system. Most of the successful locks in this list are either ART classified or offer their own insurance system.

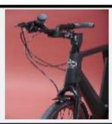
Lock:		Approach	Type	Insurance	Location tracking	Alarm	Auto Unlocking	Battery life
VanMoof kick lock		Lock, Track, Useless	Electronic	VanMoof Piece of mind	GSM, RFID, Apple Find My	Yes	No	N.A.
Mobilock		Lock, Track	Electronic	ART-4	LoRa	No	No	3 Years
Linka		Lock, (Track)	Electronic	ART-2	optional GPS	Yes	Yes	Up to 16 months
I LOCK IT		Lock, (Track)	Electronic	I LOCK IT 360°	optional GPS	Yes	Yes	Up to 7 months
Pentalock		Lock, Useless	Electronic	No (only in Denmark)	No	Yes	Yes	2 years
Bosch E-bike lock		Useless	Electronic	No	No	No	No	N.A.
Greyp locking system		Track, Useless	Electronic	No	GPS	No	No	N.A.
Blulocks		Lock, Useless	Mechanical	No	No	No	No	N.A.
N-lock		Useless	Mechanical	No	No	No	No	N.A.
Interlock		Lock	Mechanical	No	No	No	No	N.A.

Figure 16: competition overview

1.6 Bicycle components

Figure 17: overview of bicycle components that can be used for locking a bicycle.

Traditionally in the Netherlands a ring lock is used which puts an u-shackle in between the spokes of the rear wheel. However, there are a lot of moving parts in a bicycle whose movement can be blocked which makes it impossible or harder to ride the bicycle. There are also static components which can still be used to lock the bike by connecting it to something else, by using for example a chain lock. In figure 17, an overview of components is given which can be used to lock a bicycle. What was already discussed in Chapter 1.3 in the part about insurance companies and stichting ART, is that for a bicycle lock to receive the ART-2 classification it must prevent the thief from rolling away the bike. Not all components listed in figure 17 can achieve this, therefor during the concept creation the possible components which can be used for locking the bicycle is limited to the following lists:

Moving components:

- Wheelset
- (Rear) Gear hub
- Front hub
- Stand
- Brake disc
- Brake caliper
- Brake lever
- Tires

Static components:

- Frameset
- Seatpost
- Handlebar

This does not mean that all other components shown in figure 17 cannot be used in the concept. However, in that case it should probably be in combination with other components or it acts as an additional defence.

1.7 Use cases

The use of bike locks in daily practice impacts the design of a new bicycle lock. In this section the current use case of bicycle locks will be discussed.

Finding a location:

Before locking the lock, already some steps need to be done. First, a suitable location needs to be found and this will have a big influence on how the bike can and will be locked. On busy locations, like for example at train stations, finding a free place itself is sometime already a challenge. When you squeeze your bike in between two others this also makes it harder to reach the lock to lock your bike. Some locations offer the opportunity to lock your bike to the world, while sometimes there is nothing to lock your bike to. Another location is at home, where also a lot of bike thefts take place. Most insurance companies also require the bike to be locked in the shed.

Figure 18: This bike is not properly parked.

Parking the bike:

Often the bicycle stand is used to park the bike, while sometimes the bike is parked inside a rack, and there is no need to put the bike on its stand.

Locking the bike:

Most bikes in the Netherlands come with a ring lock. These are easy to lock. Slide the knob down while turning the key and making sure it clears the spokes. When it is closed the key can be pulled out and the bike is locked. This does require you to bend over you bicycle since the knob and the key are not on the same side of the bicycle. Especially in tight busy parking spots this can be a bit uncomfortable. A lot of people also use an additional chain lock to lock the bike to the world. This prevents the thieves from lifting the bike and walking away with it. Sometimes the bike rack also offers a loop to put the chain through. When locking a chain lock it is important to loop the chain properly. It preferably needs to pass through the frame, a wheel, and a fixed item while also trying to keep the chain off the ground. This needs to be done in such a way that the chain cannot simply be lifted of the fixed item, not all users do this correctly. Looping a chain lock can be difficult in tight spaces and takes much more time than locking the ring lock. When people are in a hurry or only leave their bike for a short period of time, they often only use the ring lock.

Figure 19: correctly looping a chain lock can be difficult.

Storing the keys:

After locking the lock(s), the user needs to store the keys in a place where they do not loose it. When coming back to the bike finding the bike and the keys sometimes causes problems with people losing the keys or not knowing where they parked the bike.

Unlocking the bike:

Hopefully the bike was not stolen. You have found the bike and your keys and now the bike needs to be unlocked again. When in busy places it is sometimes a real challenge to reach the lock to unlock the bike, since people have placed bikes next to yours which were not there before. especially with chain locks which are often looped through the bike rack which is in the front of the bike. This can make it hard to unlock the bike and to get your bike out of the rack. When a chain lock was used this needs to be stored somewhere as well. Some people put it in a bag, but most will loop the chain around the bike again and lock the lock. Again, this takes much more time than unlocking a ring lock, which is simply a matter of inserting the key and turning it. Be careful though, bike keys are often rather soft and bend or break easily. When the lock is not turning the smooth, this needs to be done carefully or the key will break while it is inserted, making it impossible to unlock the lock even with the reserve keys.

Riding away:

All locks unlocked and stored away again, the bike can be removed from the rack, or the stand can be folded back in again. The keys are in the locks, so these cannot get lost.

Conclusion:

Locking and unlocking a ring lock is much easier and faster than a chain lock. That is why people not always use a chain lock when in a hurry or when only leaving the bike unattended for a short period of time. The location where the bike is parked has a major influence on how easy it is to reach the lock and how easy it is to loop the chain lock. Difficulties during locking and unlocking a bicycle are: reaching the lock and keys; looping the chain lock correctly; not loosing the keys; remembering where the bike was parked; and storing the chain lock while cycling.

Figure 20: Reaching your bike can be hard in this situation.

Figure 21: Correctly parked bike, using two locks and connected to the world.

1.8 Conclusion & design direction

Before entering the ideation phase the analysis needs to be concluded. This is done with a SWOT analysis which gives a quick overview of the strengths, weaknesses, opportunities, and threats of Accell Group in relation to this assignment.An conclusion of the whole analyis is given as well as a list of concept requirements which is supposed to give direction to the ideation phase. The Chapter is finished with the design direction.

SWOT:

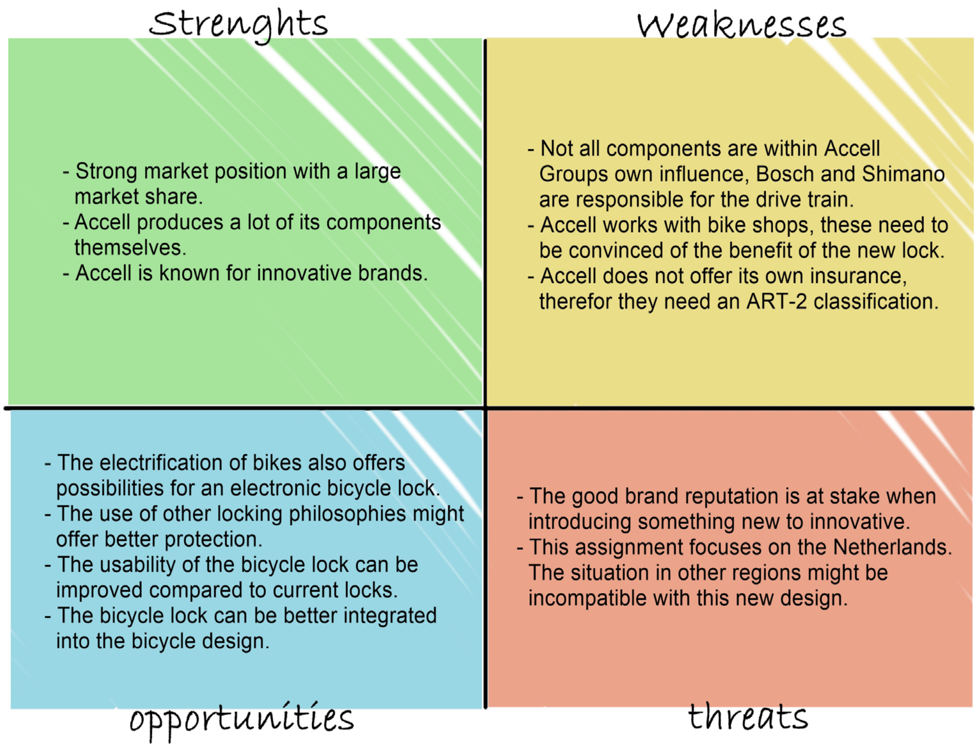


Figure 22: SWOT analysis

Analysis conclusion:

Professional thieves target specific models. They steal the bike by breaking or picking the lock, lifting the bike, or by stealing components. To prevent theft, it should be made impossible or unrewarding. This can be achieved by four principles: Locking the bike, deterring the thief, making the bike useless after theft, or by tracking the stolen bike. Locking the bike from being rolled away is needed to get the bike ART-2 classified and therefore insured. Tracking is also available as a separate solution. The new bicycle lock should be compatible with low step through, mid-engine, in-tube battery e-bikes with disc brakes. The lock should be easy to use. Use problems with current locks are the reachability of the lock, correctly using the lock, losing the keys, and storing a chain lock when riding the bike. The price and looks of the lock are also important for the customer. The new lock also needs to differentiate itself from the competition to promote sales. Accell produces a lot of components themselves which can be an opportunity for integrating the lock into the bicycle design.

Concept requirements:

- The lock should be ART-2 classified for insurance purposes; this entails that the bike should be locked in the traditional sense that it should not be able to role the bike away on its wheels.
- The lock should offer better anti-theft protection than the current ring lock and chain lock. Locking alone is not sufficient against bike theft, therefor the lock should offer additional protection by either deterring the thief, tracking the bike, or making the bike useless to sell.
- The lock should offer improved usability than traditional bicycle locks (ring lock in combination with chain lock). This can mean a combination of for example being faster, easier to reach, impossible to operate incorrect, or impossible to lose keys.
- The lock should fit the core bicycle archetype for the coming years, meaning it should work well with a mid-engine e-bike with low step through, in-tube battery and disc brakes. Other bicycle archetypes which are applicable are a bonus.
- The lock should be both financially and technically feasible to produce.
- The lock should be safe to use.
- The lock should have an appealing look.
- The lock should differentiate itself from the traditional bicycle lock to stimulate bicycle sales.
- Accell Group should have influence on the design of the lock, meaning it should not rely on large companies like Bosch or Shimano.

Design direction:

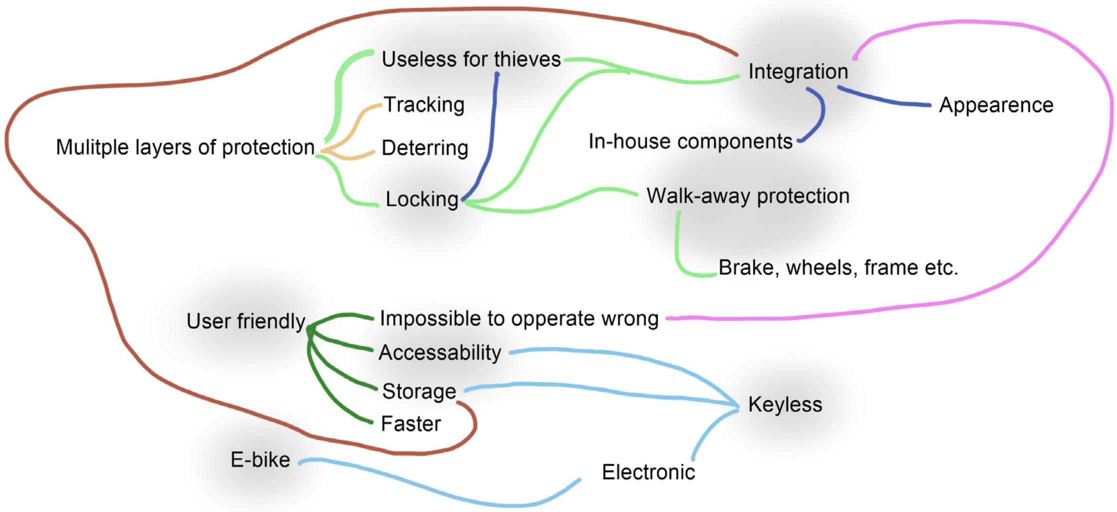
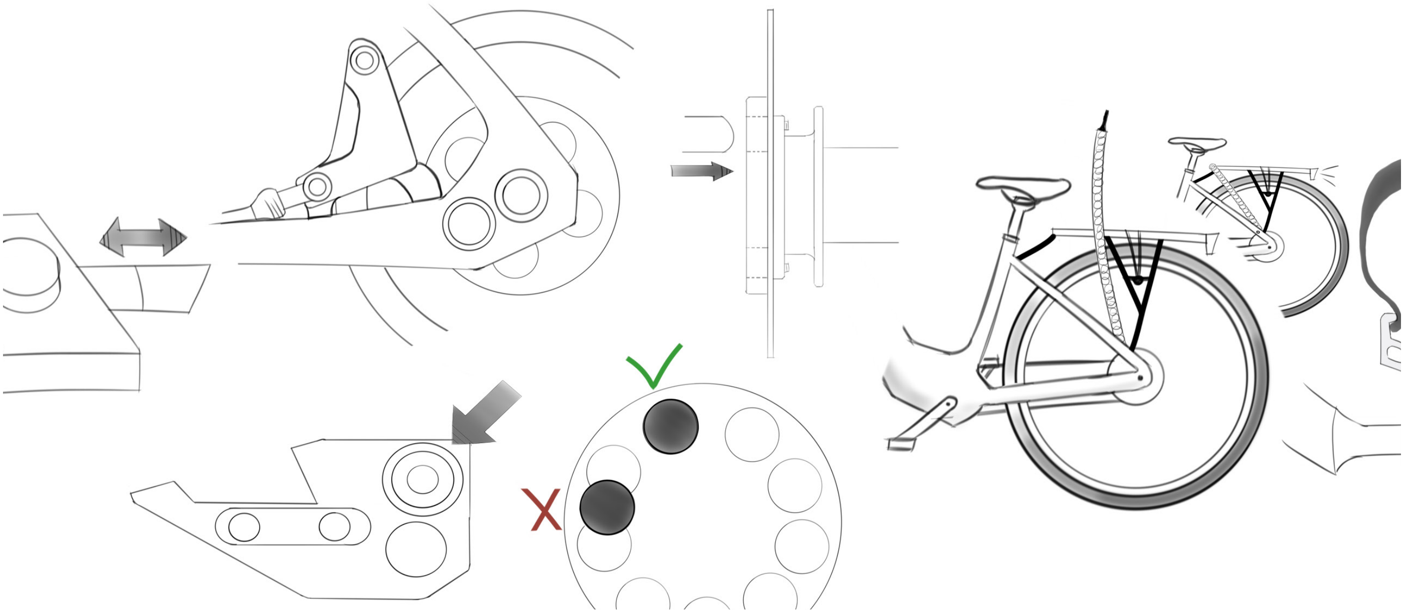


Figure 23: Design direction flowchart

In figure 23 some connections are made between possible design that can be combined. these combinations lead to the following design directions that will be pursued during the ideation phase:

- The design offers a combination of locking the bike as well as making it useless to sell for the thief.
- An integrated design offers many possibilities to achieve the above, as well as improving the looks and solve the storage problem. Therefor the aim is to come up with an integrated design. The integration can also take place in main components that Accell produces itself besides the frame.
- The design prevents the wheel(s) from turning or locks the bike to the world.
- The accessibility of the lock can be guaranteed by either fitting the lock in an easy to reach location, or by making use of a keyless/remote controlled electronic lock.
- To further improve the user-friendliness, the design needs should aim to be fool proof. This can be done by having only one way, the correct way, to operate the lock.

2 Ideation



During the ideation phase, the concept requirements from the analysis are used to steer the idea generation. Creative techniques like a mindmap and a brainstorm session are used to come up with ideas which are categorized to form idea direction boards. The three most promising idea directions are selected to further develop during the conceptualization phase by using the requirements and taking the traditional ring lock as a benchmark. The chapter is concluded with the three selected ideas.

2.1 Ideation process

Figure 24: Brainstorm session

The analysis in the last chapter was concluded with a concept direction. This direction acts as a guideline during this ideation phase. Using the concept direction reduces the scope of the assignment making the ideation more manageable and efficient since according to the analysis the other directions a lock can be developed in are less relevant.

During the ideation the focus is on the locking mechanism. In the analysis also alarms and location tracking were discussed, but this can be added regardless of the locking mechanism and is therefor not considered in this phase. Making the bike useless after theft is being kept in mind during the ideation since this is also dependent on the design of the locking mechanism.

Multiple techniques were used to come up with ideas for concepts. A mindmap was constructed which could act as inspiration for new ideas and a brainstorm session was held together with Rutmer Tjeerdema and Marten Hiemstra who work in the development team for Sparta and Batavus. The ideas were visualized in sketches.

Figure 25: mindmap

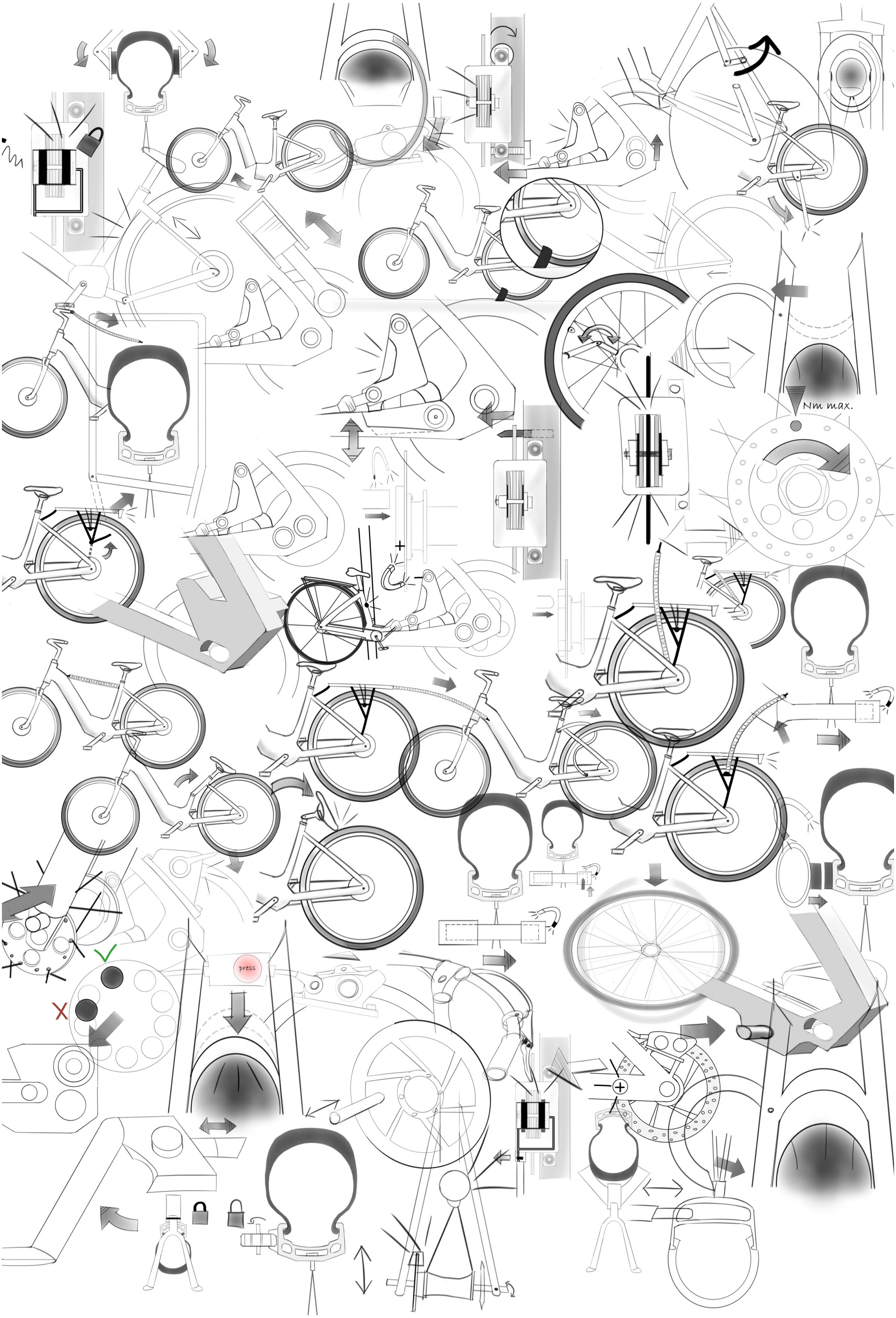


Figure 26: ideation sketches

Since a lot of ideas were similar, they were categorized into idea directions from which idea boards were made. Within the idea boards a preselection is already made to select the more promising ideas which are used during the concept selection later in this phase. This preselection is made since not all ideas are of the same quality and a lot of them will not actually by possible in real life. Yet these ideas sometimes sparked other, better ideas which is why they were kept in the idea boards as inspiration.

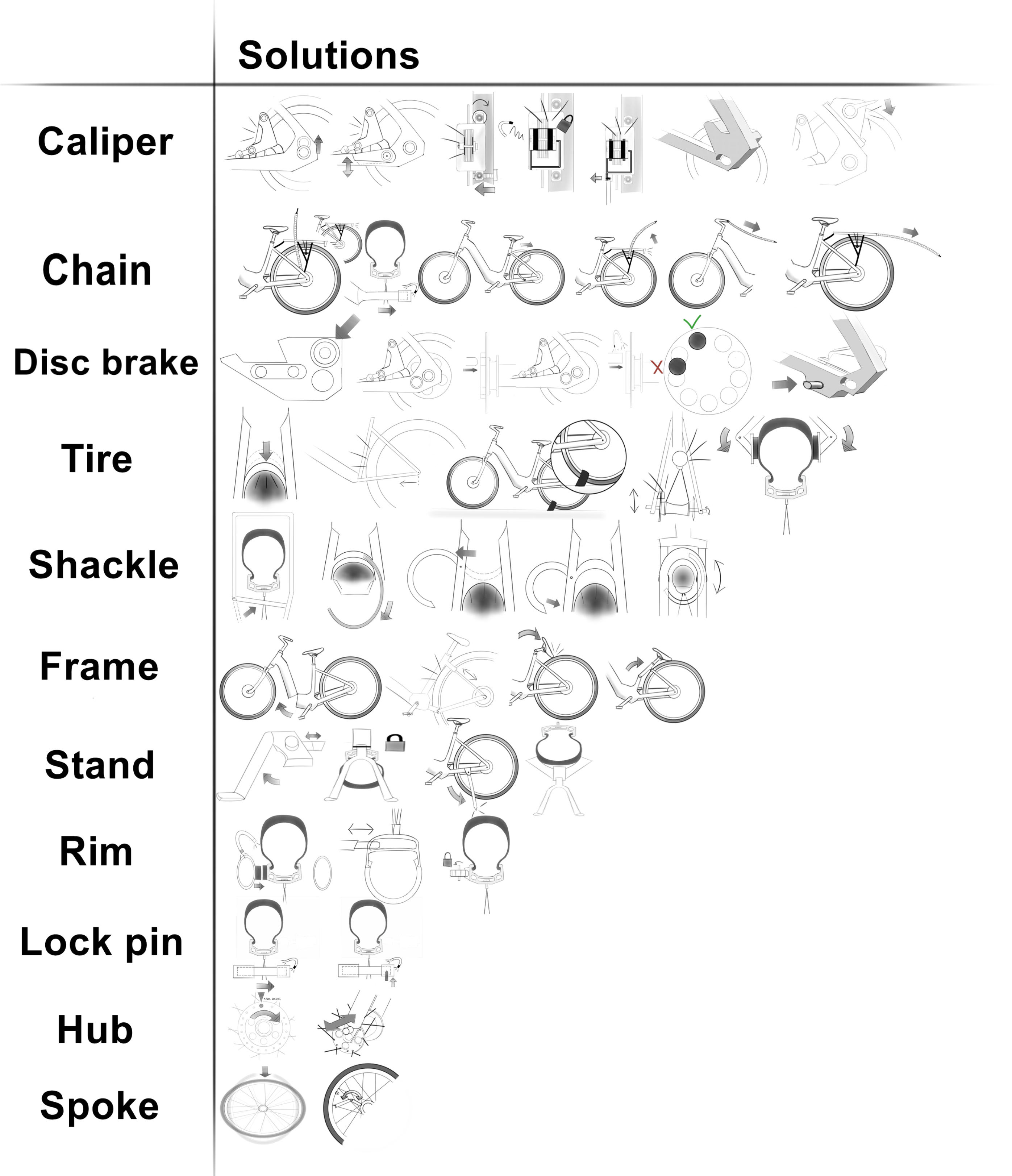


Figure 27: idea categorization

2.2 Idea directions

Kickstand lock

When parking a bike, often the kickstand is used to keep it upright. The kickstand is operated by swinging it with your feet. Since this is an action that is already done when putting away the bike, it would be nice to combine this with the action of locking the bike to improve the user friendliness of the lock. The kickstand can be used to operate a lockpin which will prevent the rear wheel from turning. With a double kickstand this concept might also work by locking the stand itself. The rear wheel will then be lifted off the ground making it impossible to simply roll away. However, not a lot of e-bikes use these double-sided kickstands since it is hard to fit these to an e-bike frame. In figure 27, the use of the kickstand lock is explained. This is the strong point of this concept. However, one point worth mentioning is that not in all situations you need a kickstand. For example, when there are bike stands, in such situations you would still need to use the kickstand to lock the bike.

Locking

1. The user finds a place to park the bike.
2. The bike is parked by folding the kick stand out. This automatically locks the bike. Also, when the bike is parked in fixed bike stands, the bikes own stand still needs to be used to lock the bike. There is no key involved.
3. The bike will give a signal that the bike is locked.
4. When the user wants to secure the bike to the world, an additional chain lock needs to be used.

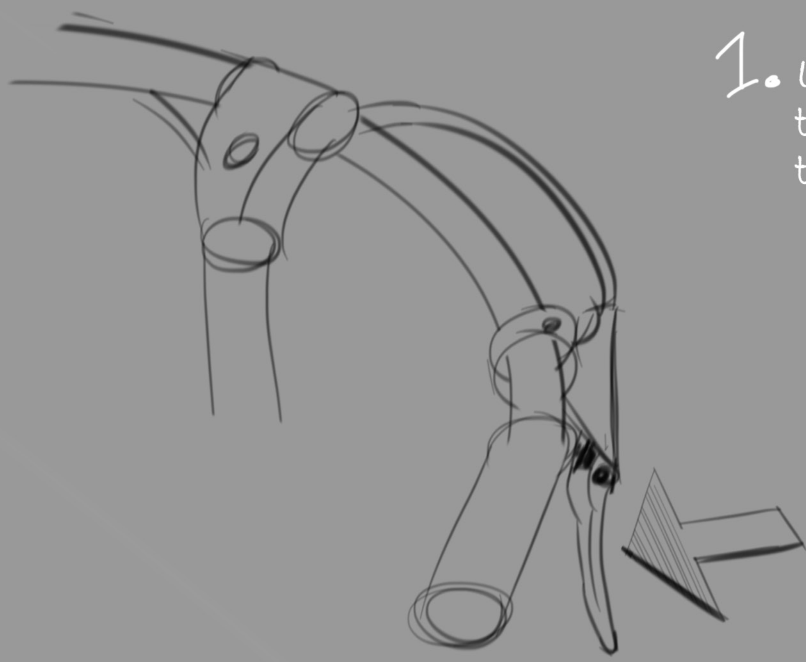
Unlocking

1. When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at the handlebar. The bike will give a signal when there is a successful connection.
2. Then the kick stand can be folded back in, and the bike is simultaneously unlocked.

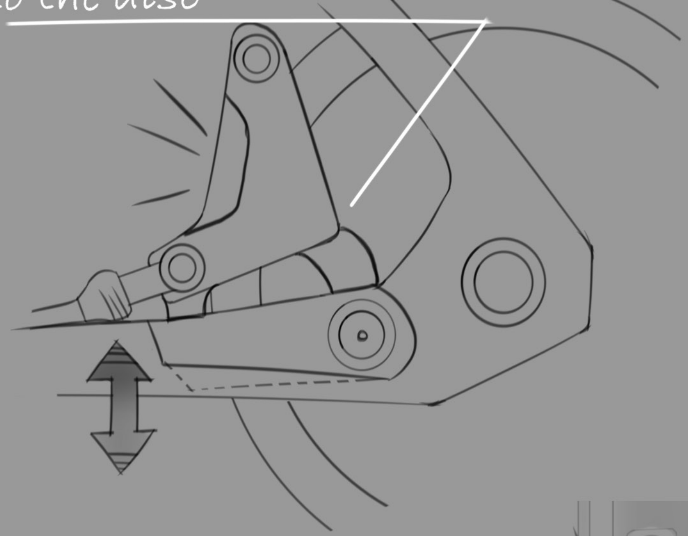
Figure 27: use description kickstand lock

Brake Caliper Lock

Locking the bike by using the brake caliper to lock the brake disc.

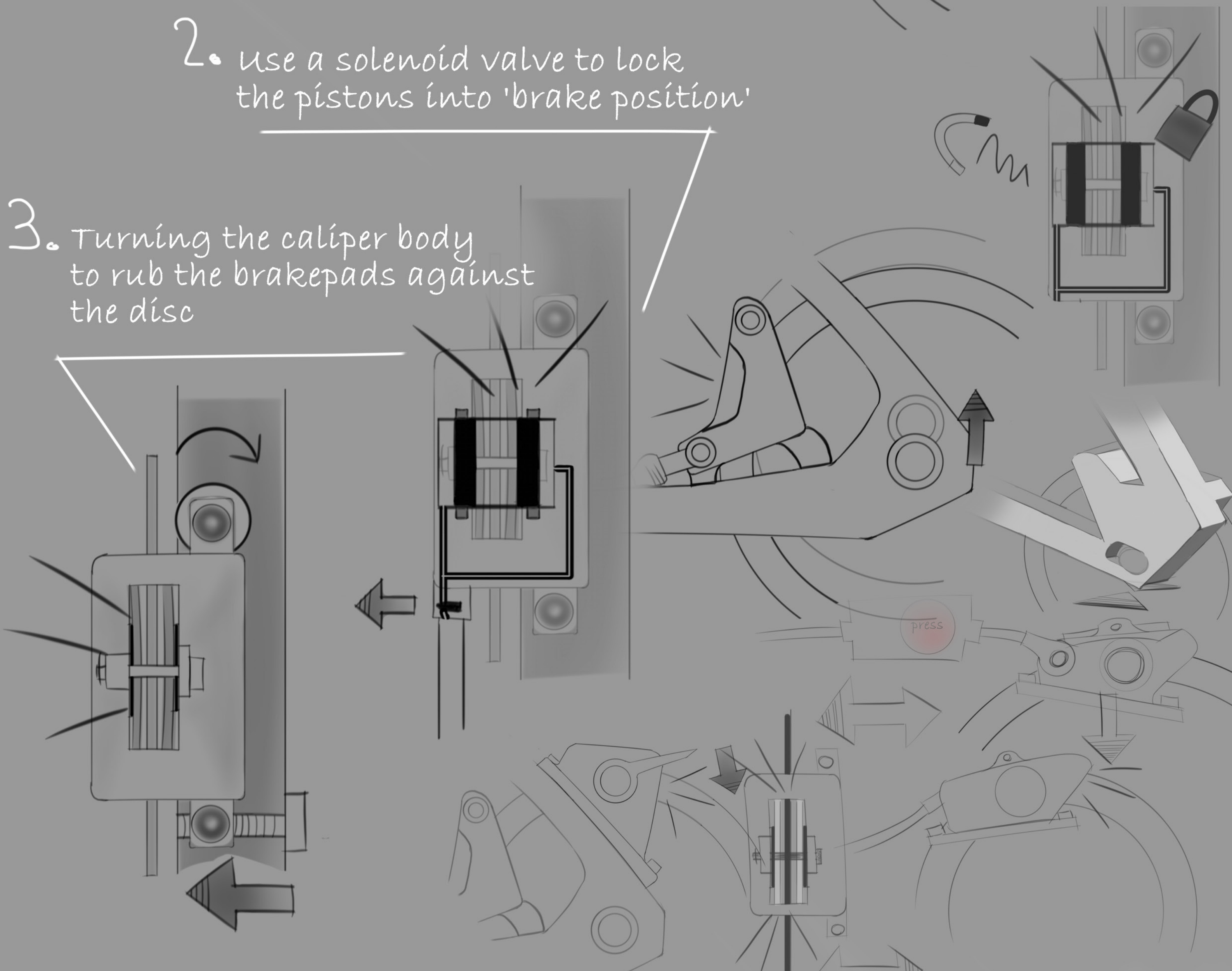


1. Lowering the caliper mount to fixate the caliperbody to the disc



2. Use a solenoid valve to lock the pistons into 'brake position'

3. Turning the caliper body to rub the brakepads against the disc



Brake caliper lock

The rear brake is already used to prevent the rear wheel from turning. What if the brake is also used to lock the bike? This offers a possibility to integrate the lock into an existing component. There are two ways to achieve this. The first is by applying oil pressure just like when braking and then locking that pressure, such that the brake pads are kept against the disc. This however needs to happen in or directly against the caliper, otherwise simply cutting the brake hose would unlock the bike within a second. Solenoid valves can be used to block the oil flow within the brake caliper. Another way to use the rear brake as a lock is by making the brake pads and caliper body rub against the disc by misaligning the caliper. This can be done by moving the brake mounts. This way of locking the bike relies more on friction instead of having a pin in a hole. This might make it harder to pass the ART tests.

In figure 28, the use of the brake caliper lock is explained. When blocking the oil flow in locked position there first should be oil pressure before it is locked. This means an additional step and this pressure needs to be high enough to prevent the rear wheel from turning.

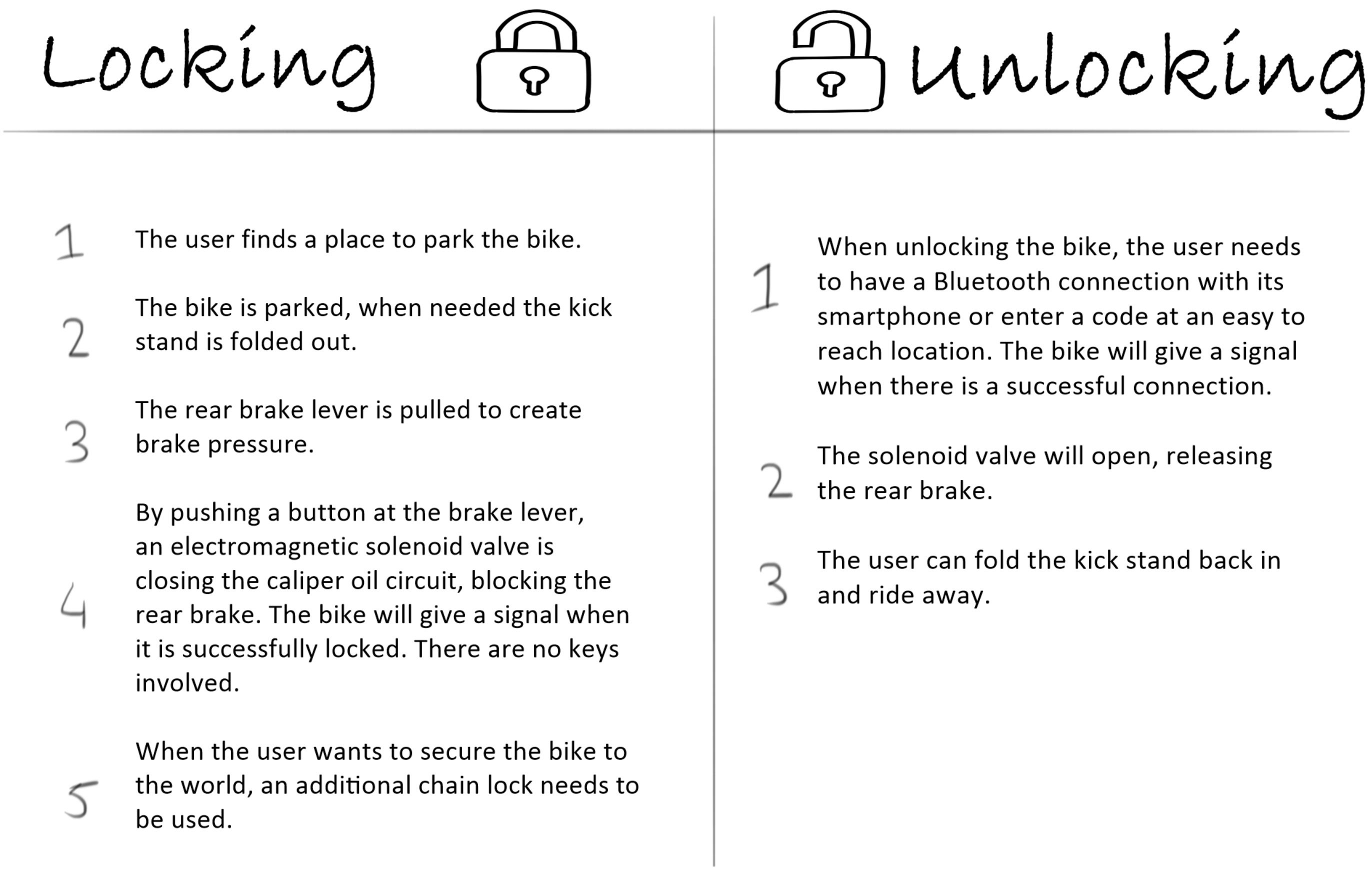
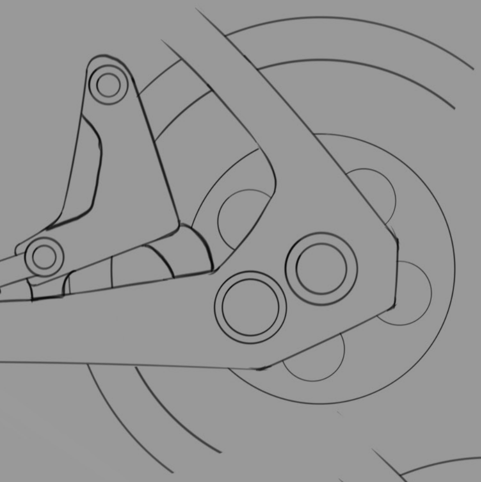
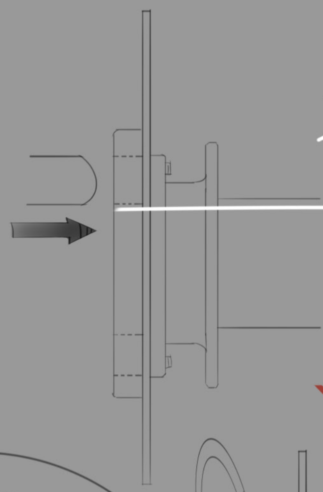


Figure 28: use description brake caliper lock

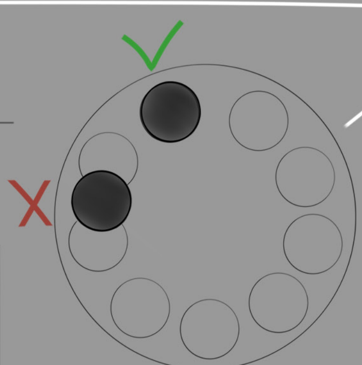
Brake Disc Lock

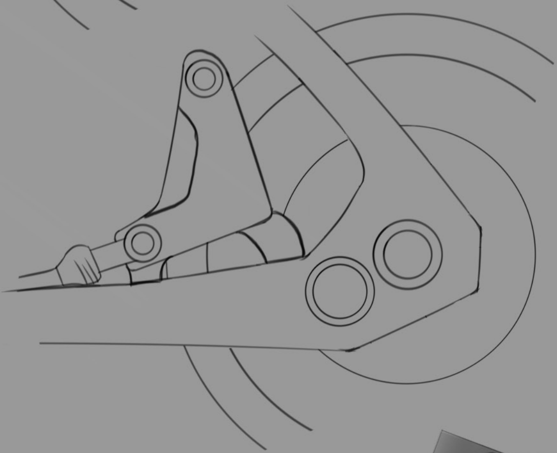
Preventing the brake disc from turning aside from the rear brake

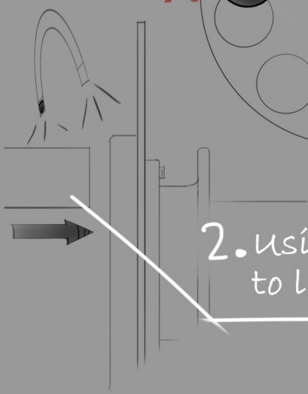




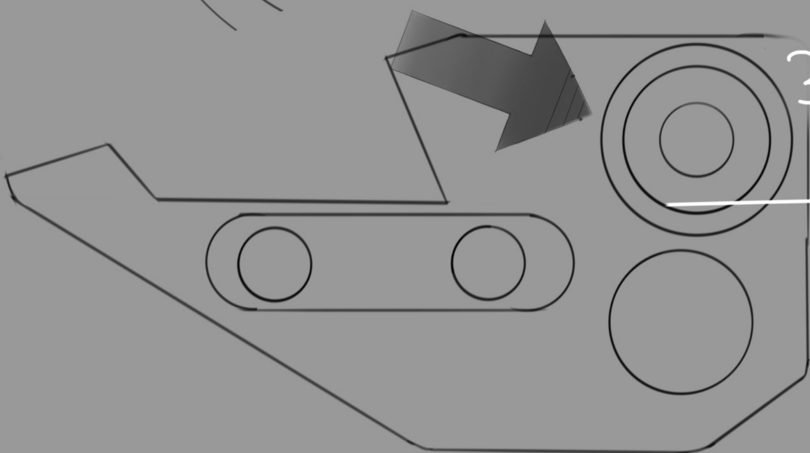
1. Using a lockpin to lock a disc. Using a lockpin patern it might be possible to always hit a slot



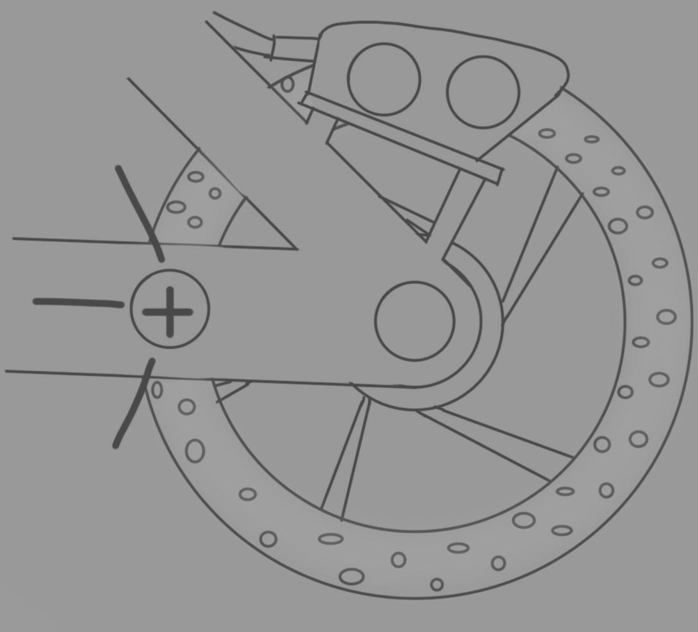


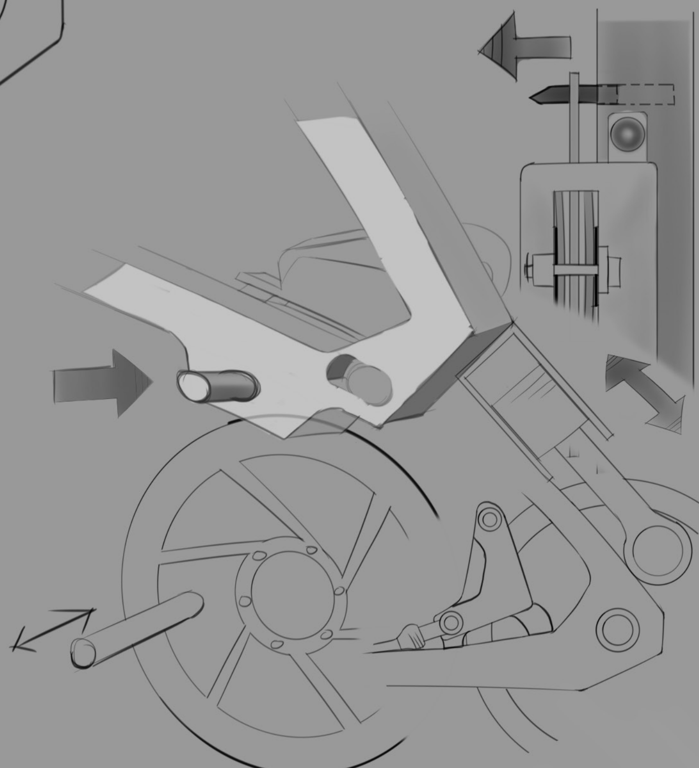


2. Using an electromagnetic lockpin to lock the disc



3. Integrating the locking mechanism into the sliding dropout for easy compatability





Brake disc lock

Besides locking the brake disc by using the brake caliper, there is also the option of adding an additional lock to the disc. Just like VanMoof does with their kick lock. This can be integrated in the frame dropout. However, Accell uses the same sliding dropout pads on a lot of frames. By integrating the lock in this dropout pad instead of the frame itself it is easy to implement the lock instantly on a lot of different models. Besides this, by integrating the lock into the dropout pads they are always aligned with the rear axle. The disc can be locked by either pushing a lockpin through the holes in the brake disc. However, this might create the risk of bending the disc. By adding an additional disc this problem can be solved. And by creating a slot pattern in this disc together with two lockpins it is possible to always have one pin hit a slot, which means the rear wheel does not have to be aligned. The lockpin itself can operated electronically by using electromagnets or small electromotors or actuators.

The use of the brake disc lock is explained in figure 29, by fully automating the lockpin and using a slot pattern this is a user-friendly solution which can be neatly integrated into the frames sliding dropout.

Locking

1. The user finds a place to park the bike.
2. The bike is parked, when needed the kick stand is folded out.
3. The slots in the disc need to be aligned with the lock pin in the dropout.
4. By pushing a button on an easy to reach location, an electromagnetic lock pin is locked in the slots in the disc. The bike will give a signal when it is successfully locked. There are no keys involved.
5. When the user wants to secure the bike to the world, an additional chain lock needs to be used.

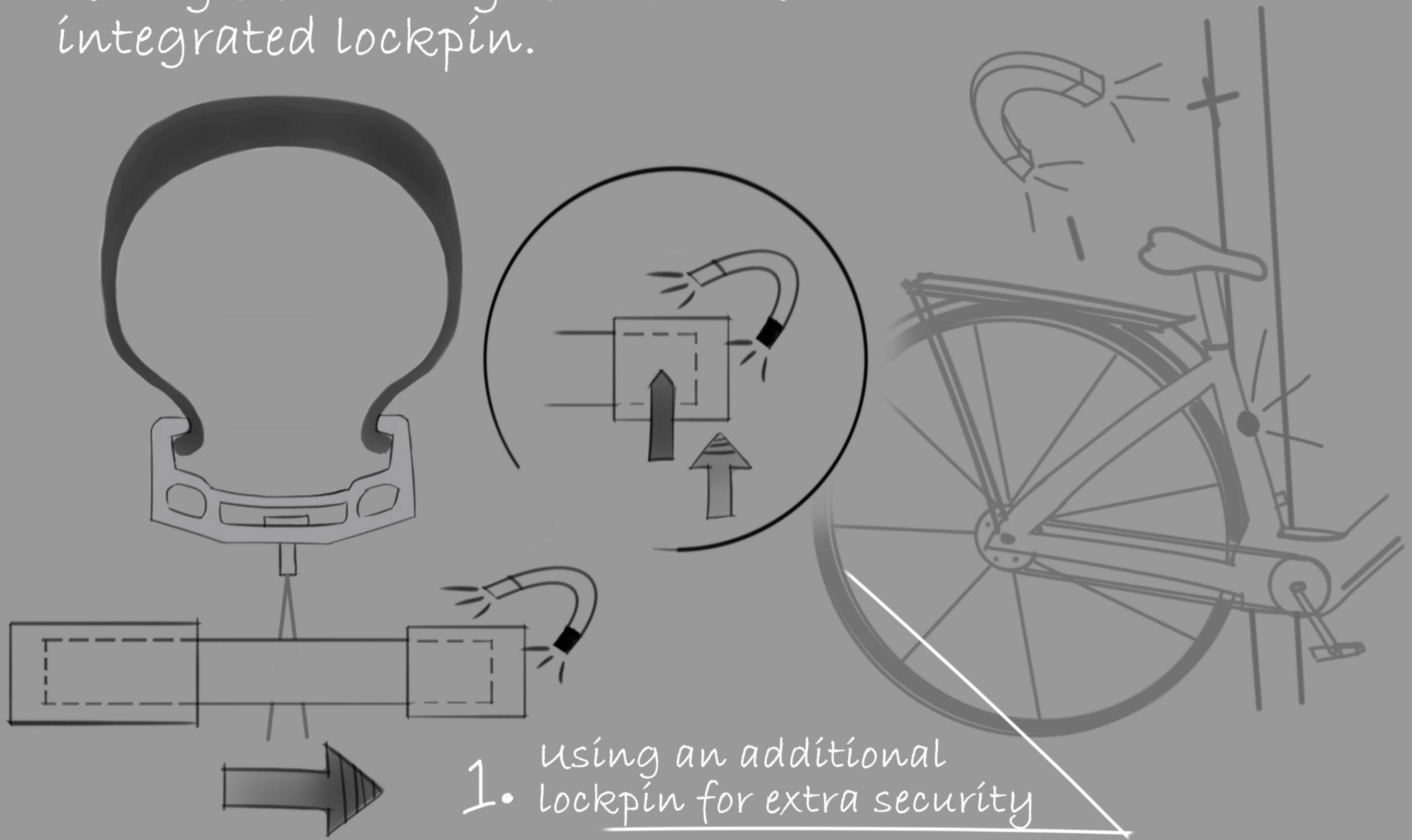
Unlocking

1. When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at an easy to reach location. The bike will give a signal when there is a successful connection.
2. The lock pin will automatically retract.
3. The user can fold the kick stand back in and ride away.

Figure 29: use description brake disc lock

Electromagnetic Lockpin

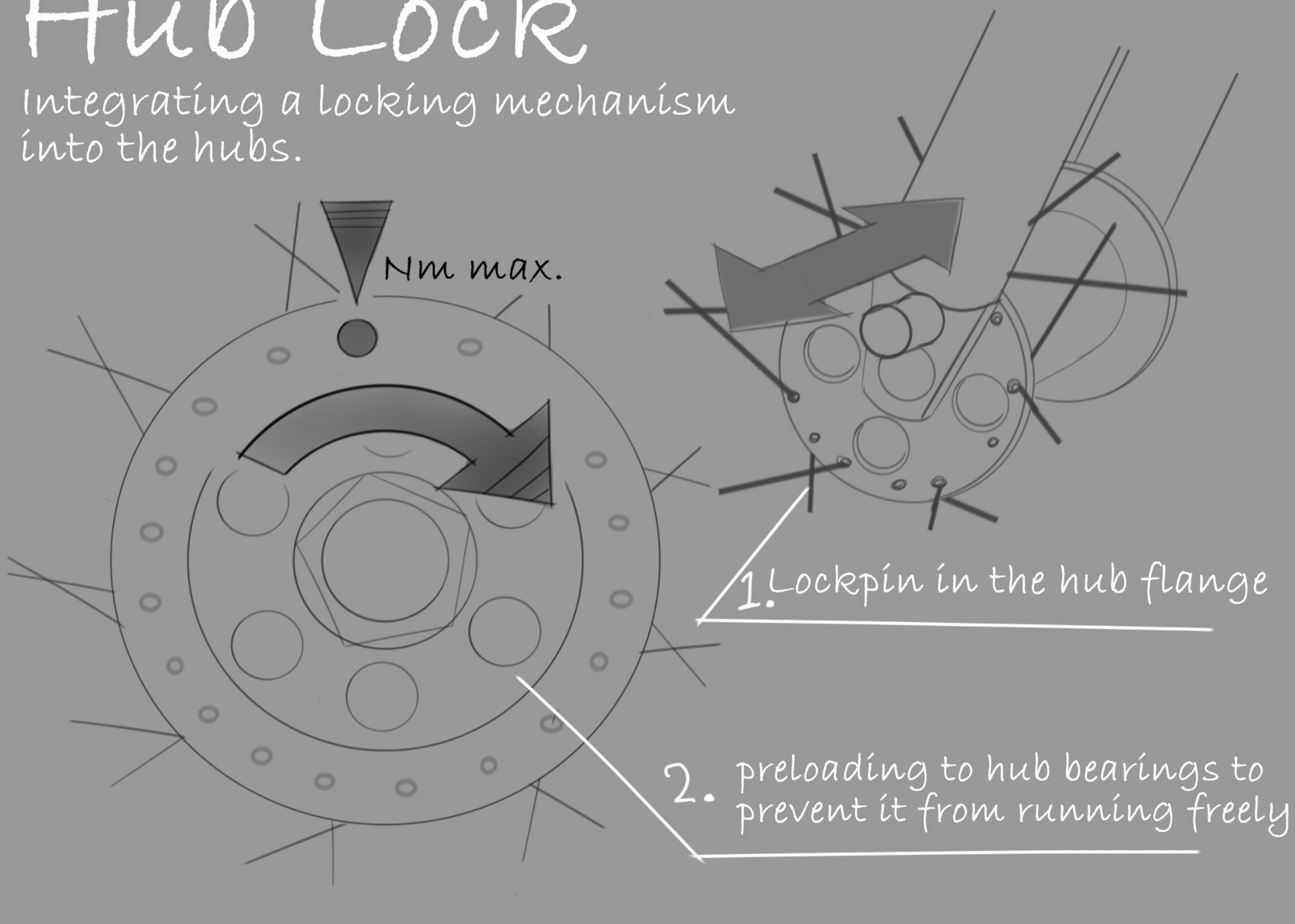
Using electromagnets to lock an integrated lockpin.



1. Using an additional lockpin for extra security

Hub Lock

Integrating a locking mechanism into the hubs.



1. Lockpin in the hub flange

2. preloading to hub bearings to prevent it from running freely

Electromagnetic lockpin

This concept uses electromagnets to operate a lockpin which goes in between the spokes. There are two types of electromagnetic locks, one that locks when it is powered, and one which opens when it is powered. For bikes it will be best to choose the last since a bike usually spends more time standing still then riding. Another way to reduce the needed electricity is by using an additional mechanical lockpin which secures the electromagnetic lockpin in place after it is closed. This way the lockpin only needs to be powered when opening and closing the lock.

In figure 30, the use of this lock is explained. There is no key and the locking and unlocking will happen without physical actions of the user. However, this lock does need power to work, so it will be important to keep the battery charged. It is also not as innovative and integrated as some of the other ideas since it is still a pin in between the spokes.

Locking

1 The user finds a place to park the bike.

2 The bike is parked, when needed the kick stand is folded out.

3 By pushing a button on an easy to reach location, an electromagnetic lock pin is locked between the spokes. The bike will give a signal when it is successfully locked. There are no keys involved.

4 When the user wants to secure the bike to the world, an additional chain lock needs to be used.

Unlocking

1 When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at an easy to reach location. The bike will give a signal when there is a successful connection.

2 The lock pin will automatically retract.

3 The user can fold the kick stand back in and ride away.

4 To unlock the bike, the user needs to charge the battery before the emergency battery is empty. Without power, the lock pin will automatically lock. The bike will warn the user in time so they can charge the battery.

Figure 30: use description electromagnetic lockpin

Hub lock

Often city bikes use conus bearings in the hubs. These bearings are tensioned by tightening a nut on the axle. When this nut is turned to tight the bearings cannot turn anymore. So, by adding a mechanism on the axle that can (over)tighten the conus bearing the wheel can be locked. However, from a mechanical point of view this is not a favourable method since it can damage the bearings. Another way would be to add slots to the hub flange where a lockpin can fall into. This would only work on the front-right hub flange since all other flanges are blocked by the drivetrain or the brakes. And locking the front wheel might create safety issues. Besides, drilling holes in a hub flange is also not really mechanical favourable because the high spoke tension might then pull the flange apart.

In figure 31, the use of a hub lock is explained. Also, in use this will not be a very good solution since you would probably need to reach for the hub which is not easily accessible. There is also not enough space to create a proper hole pattern, so you would need to align the holes on the hub flange with the lockpin.

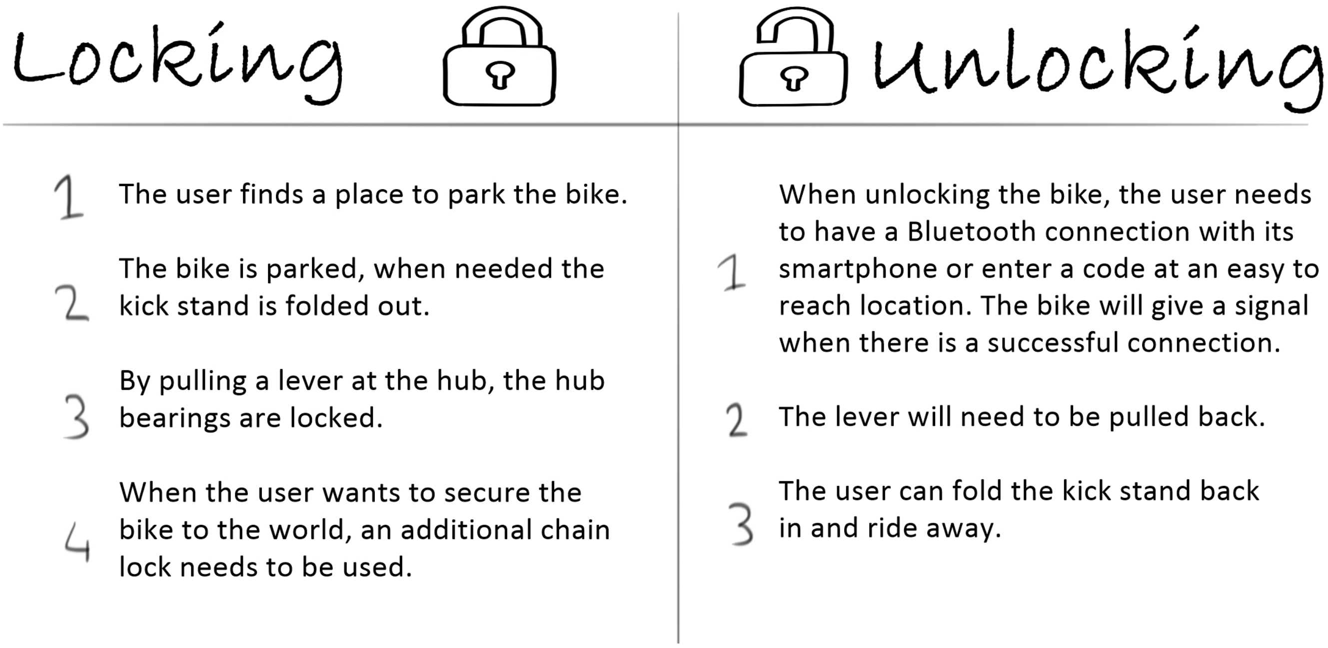
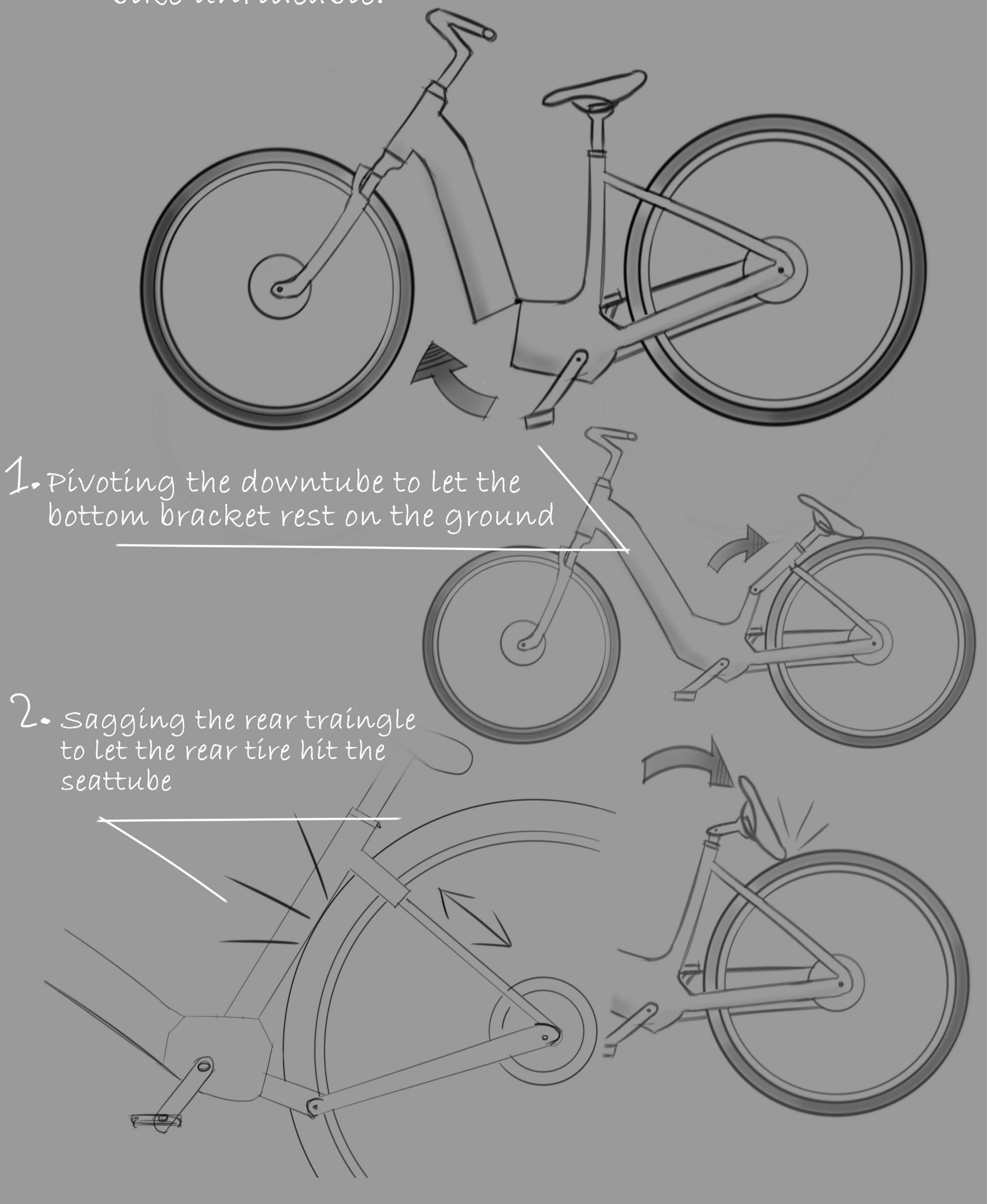


Figure 31: use description hub lock

Frame Pivot Lock

Using integrated pivot points to make the bike unrideable.



Frame pivot lock

This is a bit of a wild idea. It is inspired by folding bicycles. When there would be a pivot point in the downtube the bottom bracket would rest on the ground and the bike cannot be rolled away. The rear triangle of the bike can also be built in such a way that it sags down like a full suspension mountainbike which will eventually lead to the rear tire hitting the seat tube or the mud guards. However, this is off course not a very secure anti-theft mechanism and it asks for a lot of mechanical modifications of the frame which will add a lot of complexity and costs without much benefit.

In figure 32, the use of the frame pivot lock is explained. This is not a user-friendly alternative to the ring lock since it works more like a folding bike. Considering that nowadays e-bikes are getting close to 30kg this is not user friendly to operate at all.

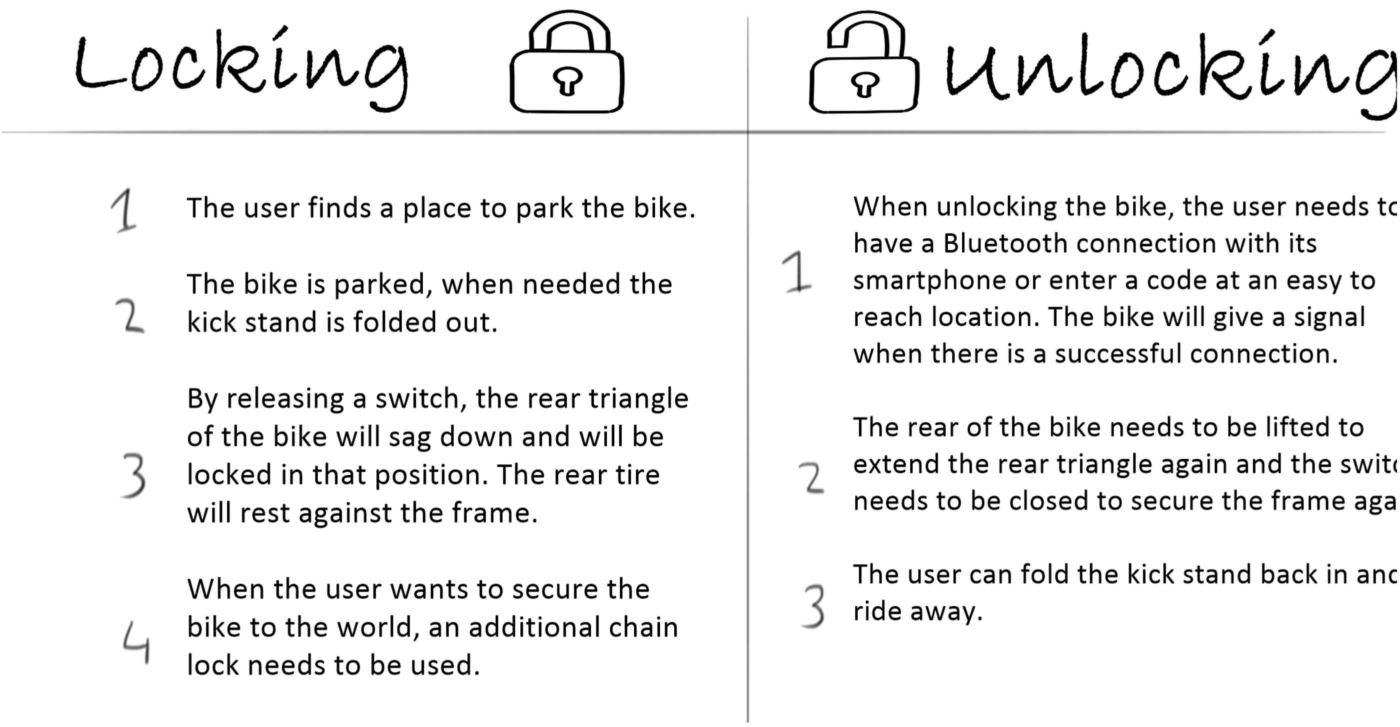
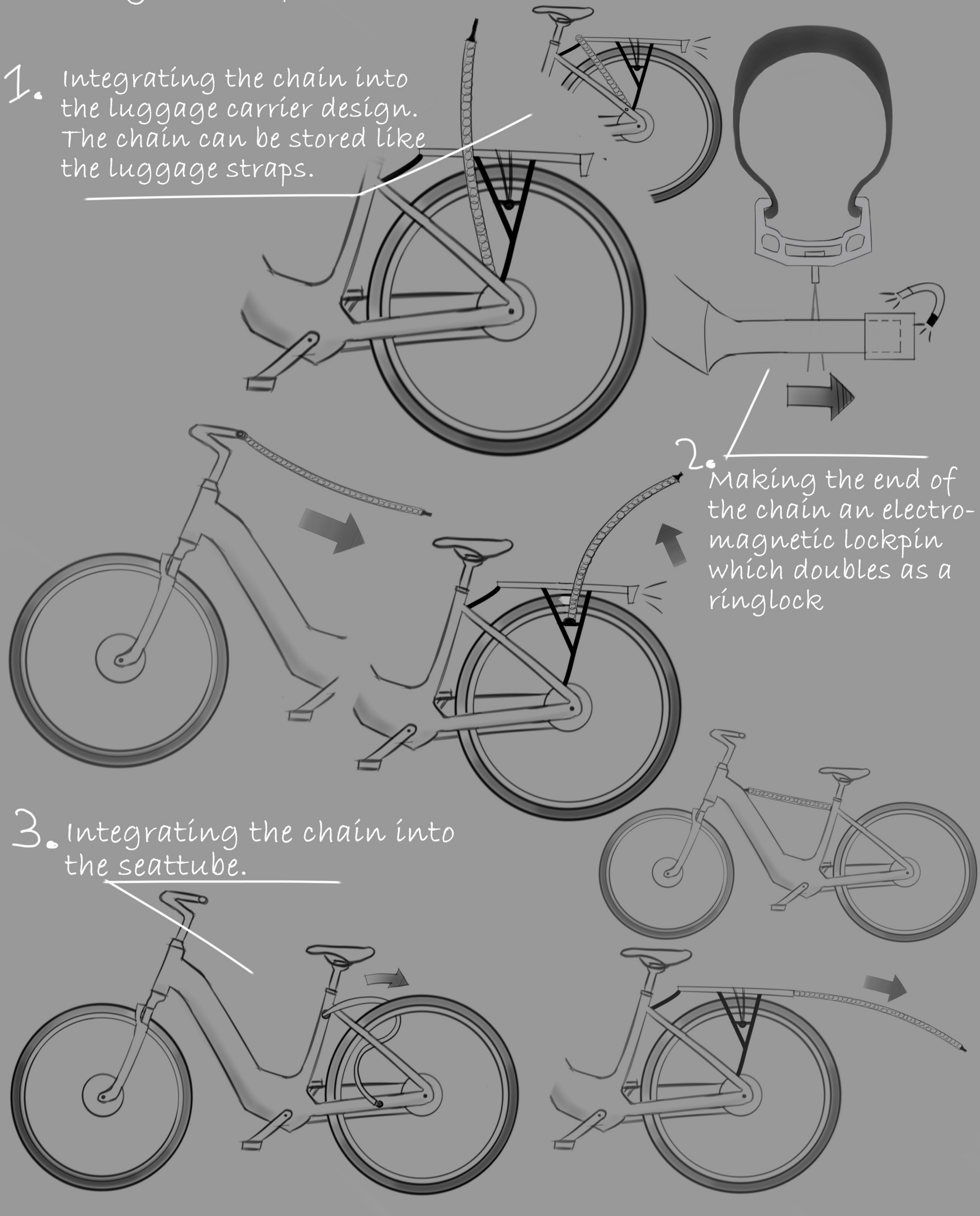


Figure 32: use description frame pivot lock

Integrated chain lock

Integrating a chain lock into the bicycle frame or bicycle components.



Integrated chain lock

The chain lock is seen as the most secure way to lock a bicycle. With a chain lock you can lock your bike to the world, making it hard for thieves to lift your bike away. However, a chain lock as also wholesome to store while not in use. There are a lot of tubes on a bicycle where a chain can be stored in. However, for this a retracting mechanism will be needed. The chain lock can also be integrated into the design of the rear carrier where the chain can be stored as if it was a carrier strap. This would be a neat way to store the chain and has around the correct length. The end of the chain can be a lockpin which can be inserted into a slot in the seat stays, which also locks the rear wheel, like the Mobilock. By always having the same start and end point it becomes a lot easier to loop the chain and storing the chain will become much faster when there is no need to wrap the chain around the frame. These steps are also explained in figure 33. There are still some steps that the user needs to perform but compared to a traditional combination of a ring lock and a chain lock this will be faster and easier and look neater as well.

Locking

1 The user finds a place to park the bike.

2 The bike is parked, when needed the kick stand is folded out.

3 The chain is removed from its luggage carrier holder and looped around the objects the user wants to connect the bike to.

4 The pin at the end of the chain is inserted though the spokes and into the connection in the seatstays. The bike is locked (to the world). There are no keys involved.

Unlocking

1 When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at an easy to reach location.

2 The bike will give a signal when there is a successful connection.

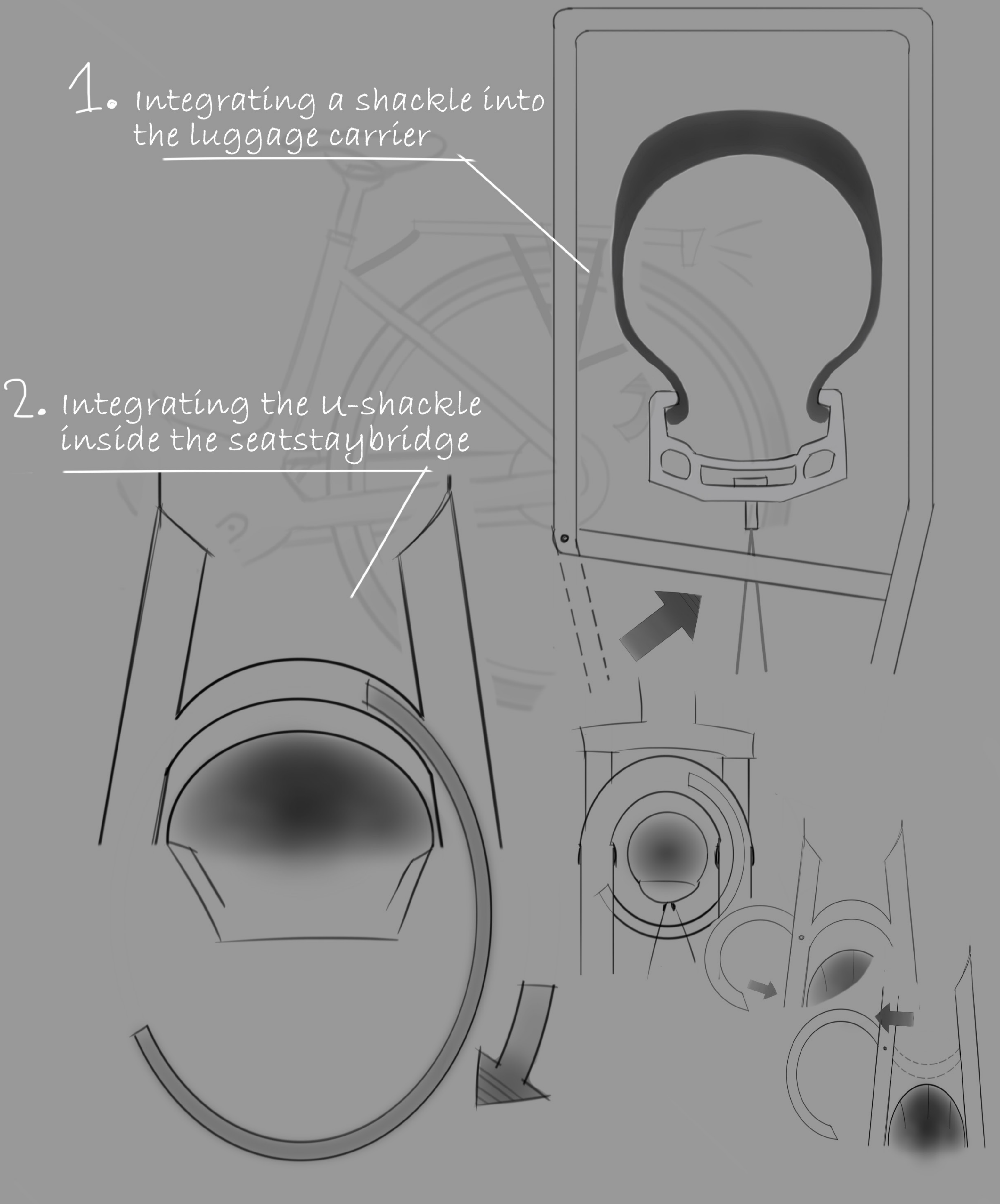
3 The lock pin can be retracted, and the chain can be un-looped and stored away in the storage carrier holder.

4 The user can fold the kick stand back in and ride away.

Figure 33: use description integrated chain lock

Integrated Shackle Lock

Integrating the traditional ringlock into the bicycle design



Integrated shackle lock

This idea takes the mechanism of the traditional ring lock and integrates this into the seat stay bridge. By integrating the lock into the frame, breaking the lock means breaking the frame. This makes the bike a lot less attractive to thieves. However, as we can see in figure 34, in terms of use there is not a lot of innovation compared to the ring lock. By making the operation electronic some physical actions can be replaced by a motor. Also, each frame will need to be adjusted for this lock to be fitted. Compared to some other concepts this makes compatibility harder.

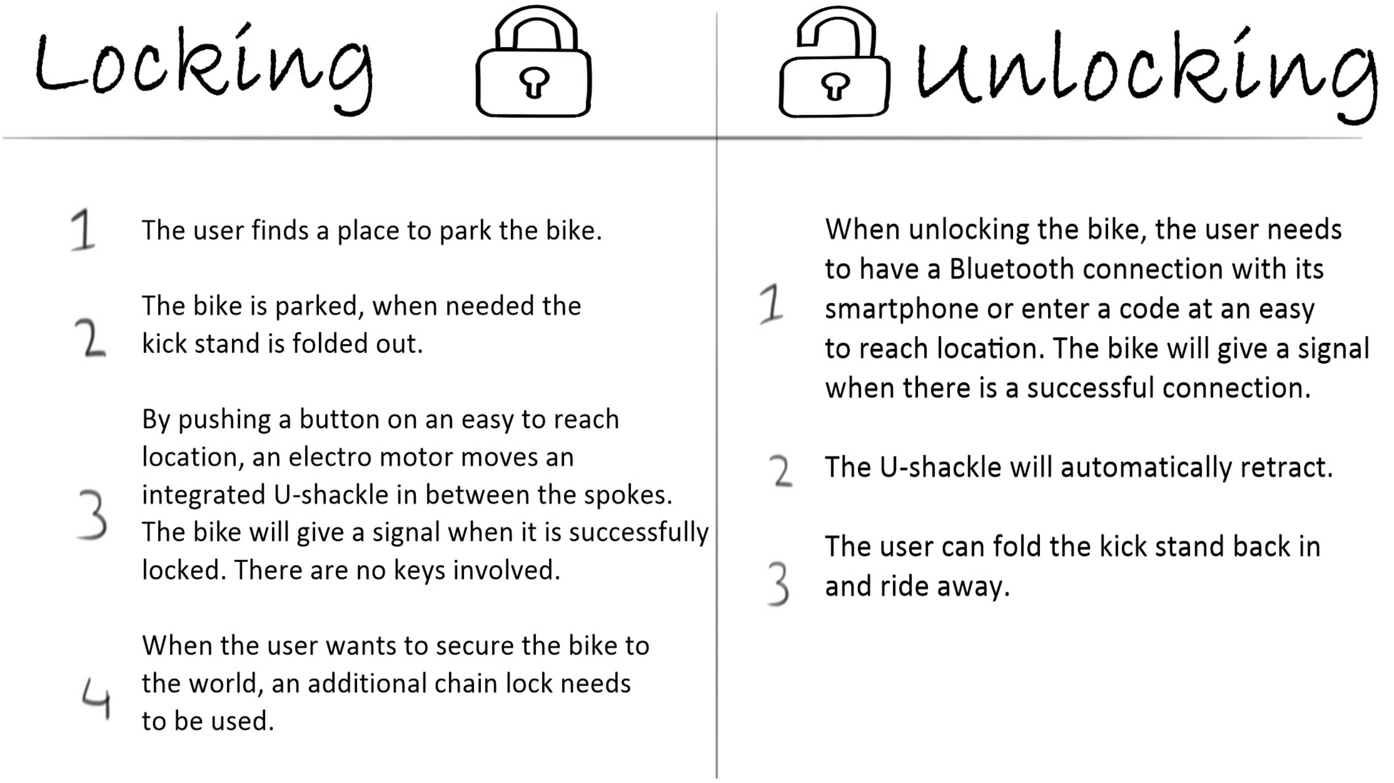
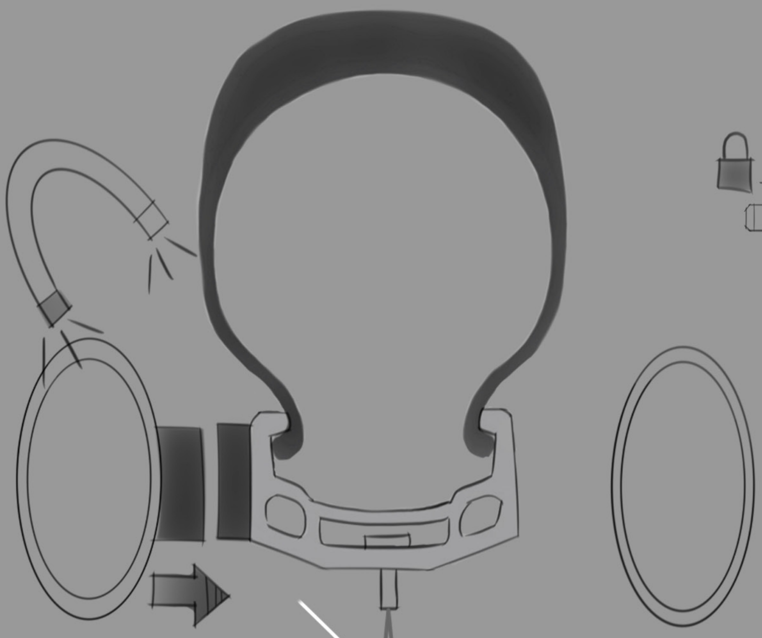
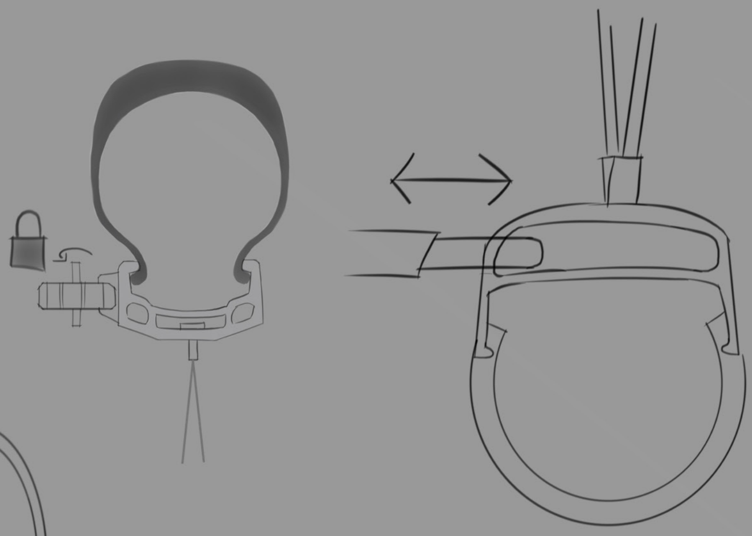


Figure 34: use description integrated shackle lock

Rim Lock

Using the rims to lock the wheels from turning.



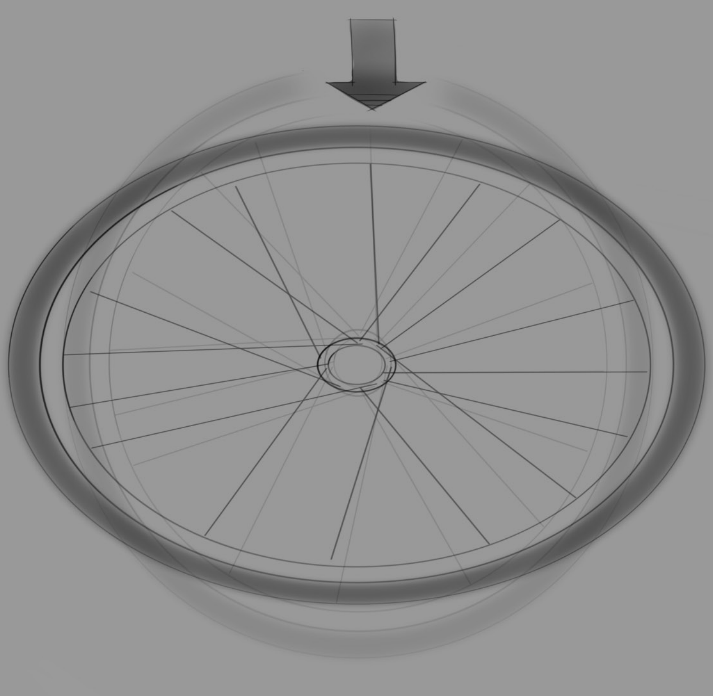


1. An electromagnetic rim which is being held in place by an opposite pole at the chainstays

Spoke Lock

Using special spokes that can lock the wheels.

1. Instead of pushing a pin between the spokes, bending a spoke between the frame



Rim lock

The rim lock uses electromagnets or lock pins at the rim. The rim needs to be adjusted for this to have slots for the pin or by having electromagnets. The last will add a lot of weight to the rim, while the rim is, due to rotational weight, a component that should not have unnecessary weight. Drilling holes is possible. However, these holes then need to be aligned with the lock pin, with the risk of damaging the rim when the pin is not correctly aligned. And a rim is an expensive and difficult component to replace. So, this concept is not very feasible.

In figure 35, the use of this concept is explained. It does not offer any advantages to the other concepts. So, there are better alternatives.

Locking

1. The user finds a place to park the bike.
2. The bike is parked, when needed the kick stand is folded out.
3. The slots in the rim need to be aligned with the electromagnetic pin in the chainstays.
4. By pushing a button on an easy to reach location, the electromagnetic lock pin is locked in the slots in the rim. The bike will give a signal when it is successfully locked. There are no keys involved.
5. When the user wants to secure the bike to the world, an additional chain lock needs to be used.

Unlocking

1. When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at an easy to reach location. The bike will give a signal when there is a successful connection.
2. The lock pin will automatically retract.
3. The user can fold the kick stand back in and ride away.

Figure 35: use description hub lock

Spoke lock

This idea turns things around. Instead of pushing a pin in between the spokes, a spoke is put in between the frame. This would however mean that the wheel would need a special spoke which makes it hard, if not impossible, to lace the wheels automatically. There is also no real benefit in pushing a special spoke in between the frame instead of the other way around.

In figure 36, the use of this concept is explained. Because the mechanism is placed on the rotating wheel it is more challenging to electrify this system and spokes are also hard to reach for physical locking and unlocking the spokes. Therefor this is not a strong concept.

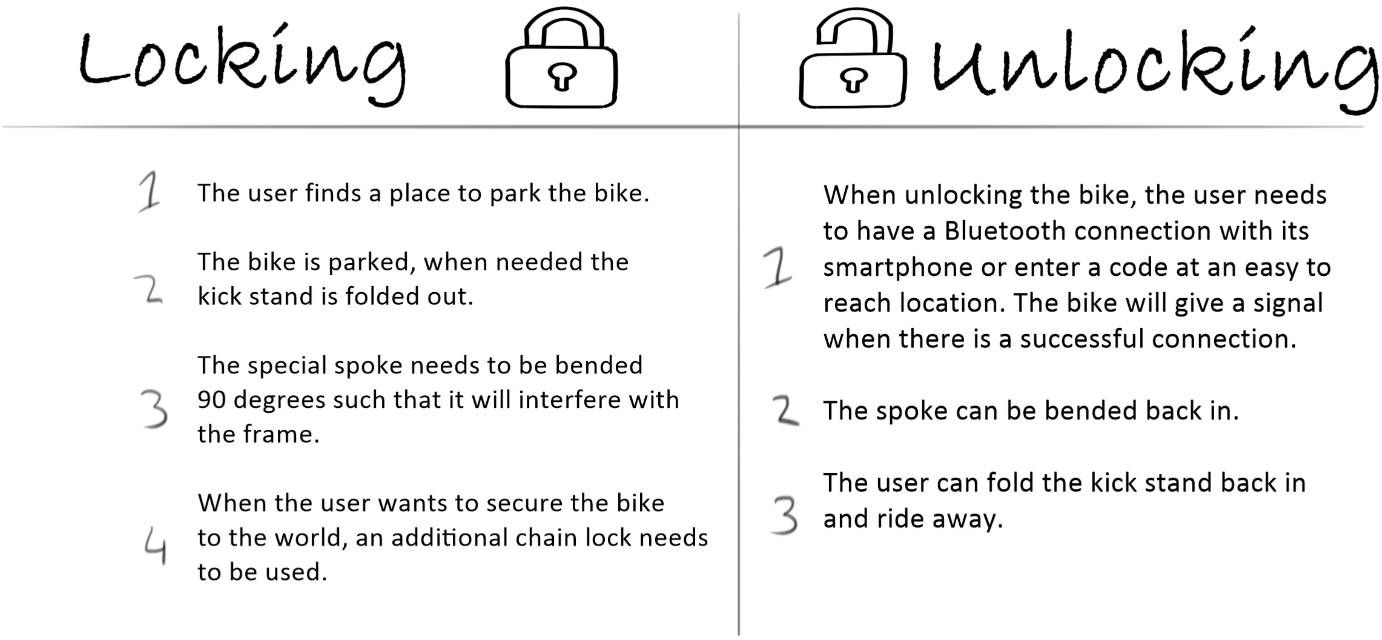
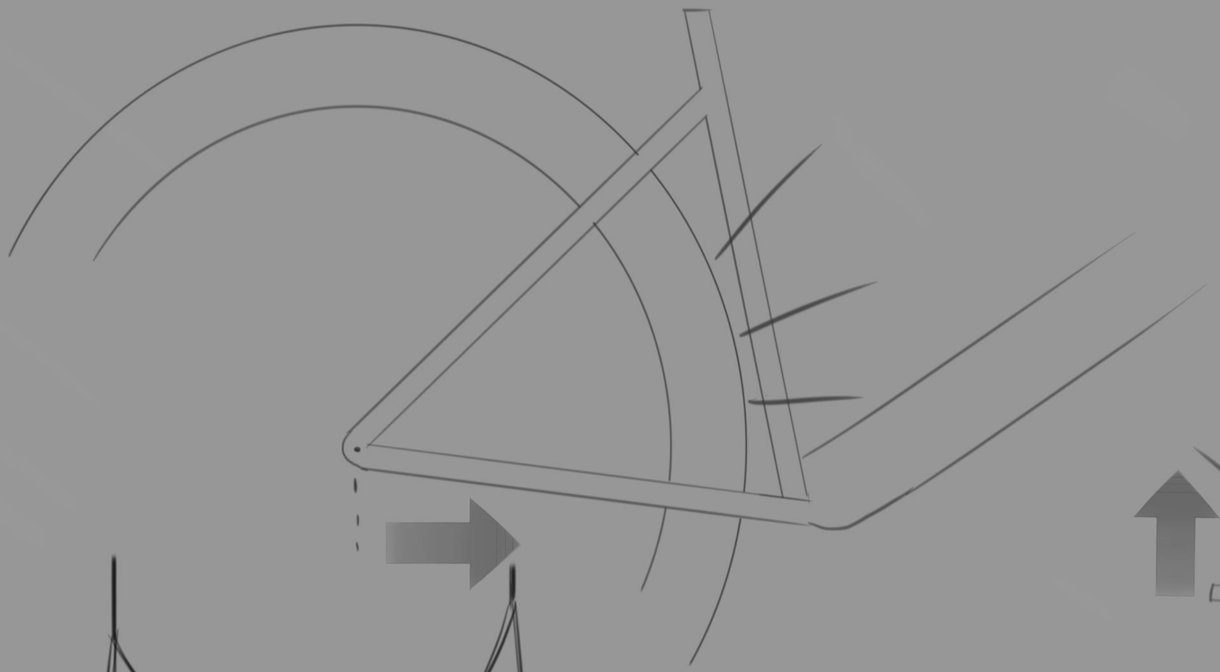
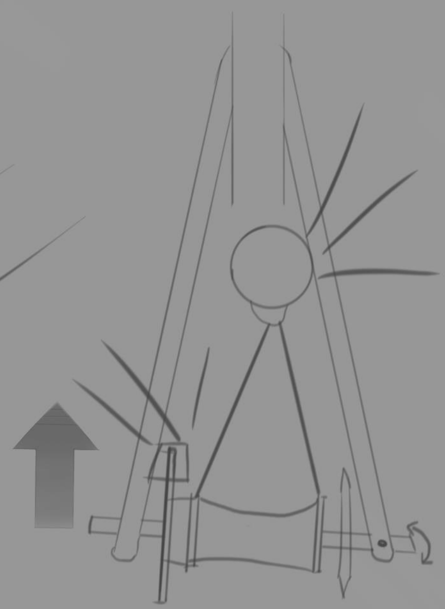


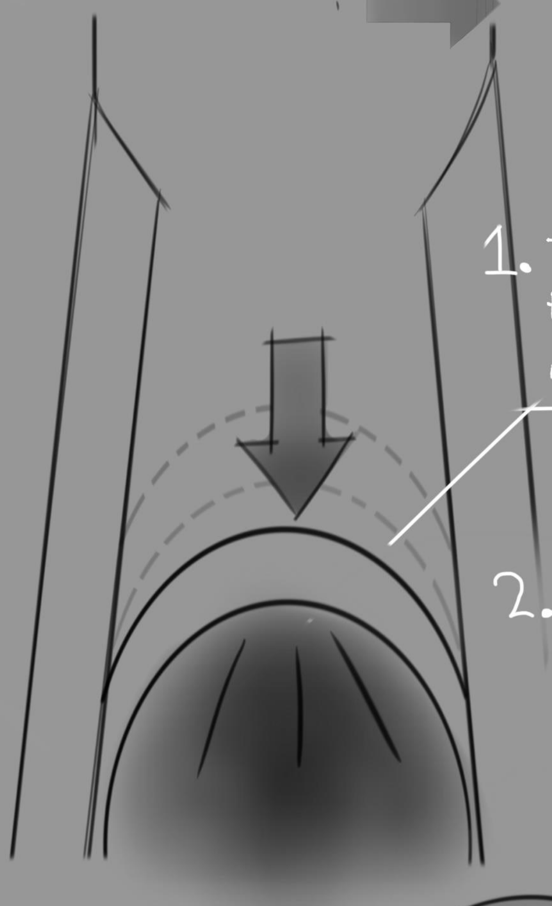
Figure 36: use description spoke lock

Tire Lock

A tire lock should prevent the tires from turning.

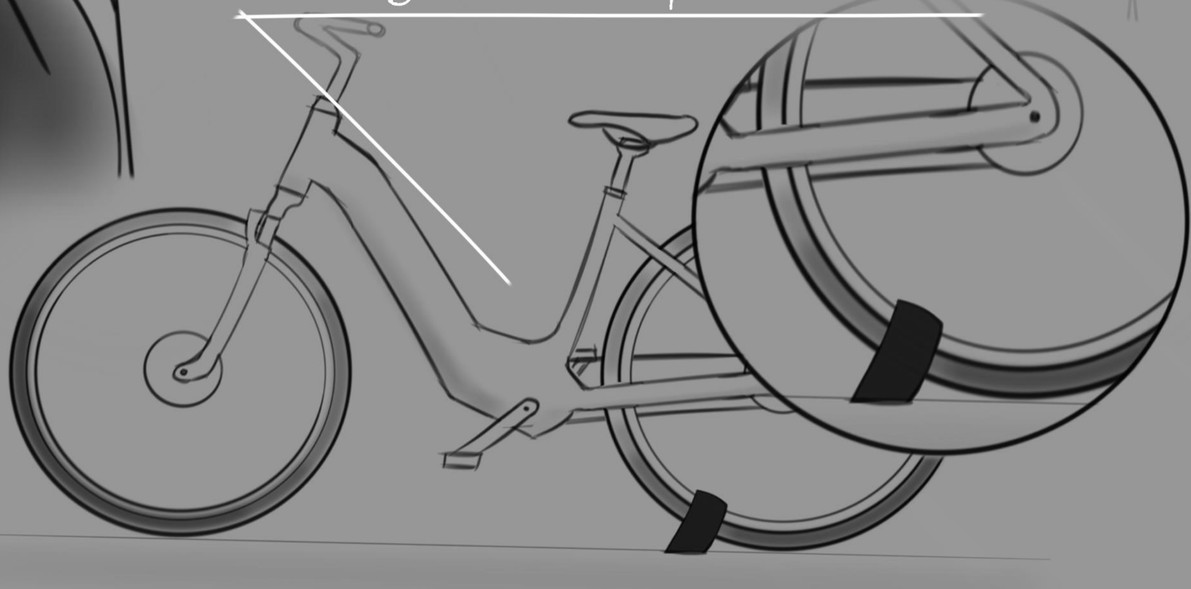






1. Blocking the tire by pushing the seatstays or chainstays against the tire.

2. Prevent the tire from turning by adding a tirestop to the wheel



Tire lock

This concept pushes a stop block against the tire. This is a relatively easy way to lock the wheel, although just like the brake caliper lock it relies on friction instead of interference. There is also a really easy way around this type of lock by simply deflating the tires. Therefor this concept will probably not make it through an ART test. The use of this concept is explained in figure 37, there is no unique use case compared to a lot of the other concepts. Therefor this is not such a strong concept.

Locking	Unlocking
1 The user finds a place to park the bike.	1 When unlocking the bike, the user needs to have a Bluetooth connection with its smartphone or enter a code at an easy to reach location. The bike will give a signal when there is a successful connection.
2 The bike is parked, when needed the kick stand is folded out.	2 The lever can be pulled back, releasing the blockstop stop from the tire.
3 By pulling a lever, a blockstop is pushed against the rear tire.	3 The user can fold the kick stand back in and ride away.
4 When the user wants to secure the bike to the world, an additional chain lock needs to be used.	

Figure 37: use description tire lock

2.3 Idea selection

To select the best idea direction to work on further during the conceptualization, the ideas are ranked against the weighted requirements. The requirements that are used come from the analysis. Also, the design direction can be linked back to these requirements:

- Making the bike useless for thieves is related to anti-theft protection.
- The looks of the lock are related to appealing looks.
- The storage, accessibility and 'fool proofness' of the lock is related to the usability.
- Preventing the wheel(s) from turning or locking the bike to the world is related to roll-away protection.

The requirements are weighted on a three-point scale with 3 being the most important requirement and 1 being the least important. Then all ideas are rated on each requirement on a five-point scale:

5: The idea fully meets the requirement.
4: The idea meets the requirement reasonably well.
3: The idea reasonably meets the requirement.
2: The idea does not sufficiently meet the requirement.
1: The idea does not meet the requirement.

The points are then multiplied by the weighting factor and added to give a total score for each idea. To compare the ideas to the current situation the table is also filled in for the ring lock as a benchmark. The scores are off course arbitrary since the concepts are not defined in detail yet and the scores are therefor somewhat opinion based. The outcome was discussed with the supervisor at Accell, and it was agreed upon that the three highest scoring ideas were selected for the next phase.

Requirement	Weight	Kickstand lock		Brake caliper lock		Brake disc lock		E- lockpin	
		Assesment	Score	Assesment	Score	Assesment	Score	Assesment	Score
The idea prevents bike from being rolled away.	3	4	12	4	12	4	12	5	15
The idea offers improved usability over current locks.	3	5	15	4	12	4	12	4	12
The idea fits the ´core archetype bicycle´.	3	5	15	5	15	5	15	5	15
The idea seems technically feasible.	3	4	12	3	9	4	12	3	9
The idea offers a safe to use solution.	3	4	12	4	12	5	15	5	15
The idea offers improved anti-theft protection.	2	3	6	4	8	3	6	4	8
The idea seems financially feasible.	2	4	8	3	6	4	8	2	4
The idea differentiates itself from the current locks.	2	3	6	4	8	3	6	3	6
The idea is compatible with other types of bicycles.	1	5	5	3	3	4	4	3	3
The idea seems to offer an apealing look.	1	5	5	4	4	5	5	4	4
The development of the idea is within Accell's influence.	1	5	5	3	3	5	5	5	5
	Total:		**101**		**92**		**100**		**96**

Requirement	Weight	Hub lock		Frame pivot lock		Chain lock		Shackle lock	
		Assesment	Score	Assesment	Score	Assesment	Score	Assesment	Score
The idea prevents bike from being rolled away.	3	4	12	3	9	5	15	5	15
The idea offers improved usability over current locks.	3	3	9	2	6	3	9	3	9
The idea fits the ´core archetype bicycle´.	3	5	15	3	9	5	15	5	15
The idea seems technically feasible.	3	2	6	3	9	5	15	4	12
The idea offers a safe to use solution.	3	5	15	3	9	5	15	5	15
The idea offers improved anti-theft protection.	2	2	4	3	6	5	10	3	6
The idea seems financially feasible.	2	2	4	2	4	3	6	2	4
The idea differentiates itself from the current locks.	2	4	8	5	10	3	6	3	6
The idea is compatible with other types of bicycles.	1	5	5	5	5	4	4	2	2
The idea seems to offer an apealing look.	1	4	4	1	1	3	3	4	4
The development of the idea is within Accell's influence.	1	1	1	5	5	5	5	5	5
	Total:		**83**		**73**		**103**		**93**

Requirement	Weight	Rim lock		Spoke lock		Tire lock		Ring lock	
		Assesment	Score	Assesment	Score	Assesment	Score	Assesment	Score
The idea prevents bike from being rolled away.	3	4	12	3	9	3	9	5	15
The idea offers improved usability over current locks.	3	4	12	3	9	3	9	3	9
The idea fits the ´core archetype bicycle´.	3	5	15	5	15	4	12	5	15
The idea seems technically feasible.	3	3	9	2	6	3	9	5	15
The idea offers a safe to use solution.	3	5	15	3	9	4	12	5	15
The idea offers improved anti-theft protection.	2	3	6	2	4	2	4	2	4
The idea seems financially feasible.	2	3	6	2	4	2	4	3	6
The idea differentiates itself from the current locks.	2	3	6	5	10	3	6	1	2
The idea is compatible with other types of bicycles.	1	4	4	4	4	4	4	5	5
The idea seems to offer an apealing look.	1	3	3	2	2	4	4	3	3
The development of the idea is within Accell's influence.	1	4	4	3	3	5	5	1	1
	Total:		**92**		**75**		**78**		**90**

Table 1: selection table idea directions

In table 1 the scoring table can be seen with all allocated points. The selected ideas are:

1. Kickstand lock

This idea is selected since it scores good in feasibility and offers an innovative and improved usability. Combining the kickstand with the lock is something not thought about before and looks promising to improve the usability of the current locks.

2. Brake disc lock

This idea is selected especially because off the idea to integrate the lockpin in the sliding dropout pad which would make it easily compatible with a lot of bikes Accell makes. A proper integration of this idea can also give a better theft protection than a traditional ring lock. The idea also seems technically and financially feasible. When establishing a lockpin pattern and making the lock electronically operated it can also be more user friendly than comparable current offerings.

3. Integrated chain lock

This idea is the only concept which can be used to connect the bike to the world. Therefor it is a replacement of not only the current ring lock but also off the chain lock in once. The ideas feasibility is already largely proved by Mobilock which is technically similar. However, the idea of storing the chain as a luggage strap and providing a fixed start and endpoint of the chain is an innovation in user friendliness as well as in looks.

The electromagnetic lockpin also scored rather high. However, there are some technical concerns especially with the distance the lockpin would need to bridge compared to the lockpin of the brake disc lock. Besides, it is not as innovative as the brake disc lock can be since it is still a pin through the spokes and the goal of this assignment is to come up with a new innovative bicycle lock.

Conclusion:

The three selected ideas are the kickstand lock, the brake disc lock, and the integrated chain lock. These ideas are chosen because they scored high on feasibility and scored well against the other requirements as well. All these ideas have something new and innovative and have the potential to improve the anti-theft protection as well as the user friendliness. During the next phase, the conceptualization, these three ideas will be developed into concepts.

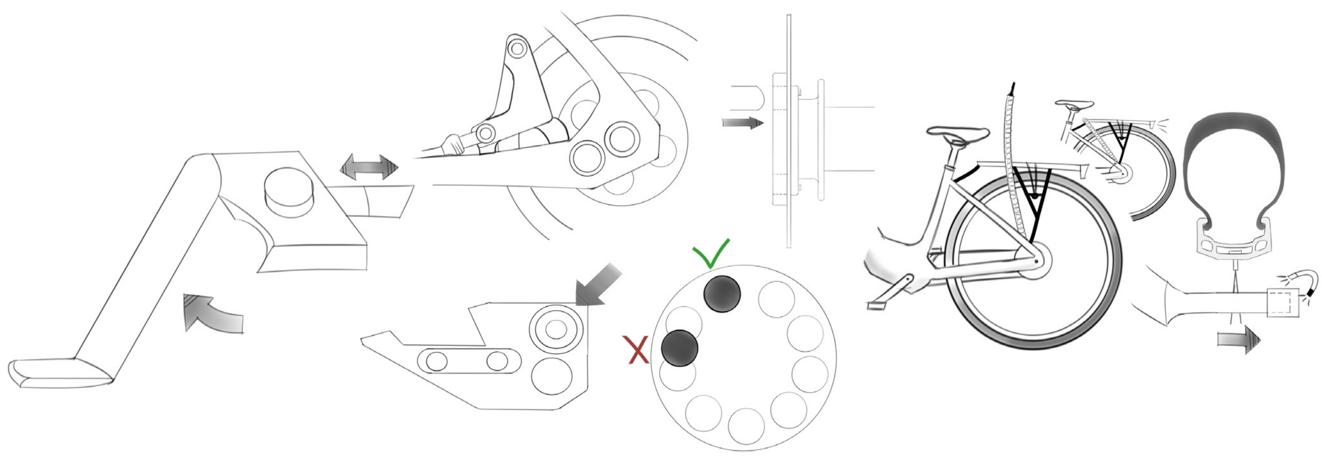


Figure 38: selected idea directions

3 Conceptualization

In the ideation phase multiple idea directions were thought off. The best directions were selected to be developed into concepts. In this phase the three idea directions are worked on to come up with realistic concepts. The technical components for the lock's mechanism are developed or selected, and a 3D model is made to test fit all components and visualize all concepts in renders. The user actions are defined, and the strengths and weaknesses of all concepts are discussed. Also, a cost price estimation is performed. At the end of this conceptualization phase the most promising concept is selected which will enter the development phase to be developed into a final concept and a prototype.

3.1 Disc Brake Lock

This concept makes use of lock pins at the dropout that fall into the holes of a slotted disc. This is very similar to the concept VanMoof has with their kick lock. However, the aim of this concept is to be more user friendly than the VanMoof kick lock. This should be achieved by reducing the actions the user needs to perform to lock the bike. Kicking the lock pin should therefore be automated. The VanMoof lock needs to be aligned with the slots since it only has one lock pin. This concept will use electronic lock pins that work in a pattern that ensures that always one of the two pins will fall into a lock hole. To make the lock easily compatible with a lot of bikes it will be integrated into the sliding dropout pad of the bike. This is a standardized component within the Accell Group and therefor integrating the lock into this interface makes it possible to mount it on a wide range of bikes without changing the frames of these bikes.

Lock pin mechanism:

To create a lock pin pattern at least two lock pins are needed. Since the space is limited, this means that the lock pin mechanism needs to be as compact as possible. When looking into solutions to electronically drive compact lock pins solenoids are a logical choice because of their small size and linear movement. There are different kinds of solenoids that would work differently within this concept. Linear motors were also considered but these were not as compact as solenoids.

(Regular) Linear solenoid:

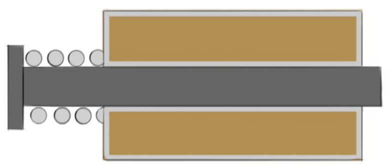


Figure 39: Solenoid cut through

This is a ferromagnetic core pin with copper windings around it. When current goes through the wires it creates a magnetic field and the core pin moves. A retracting spring pulls the core pin back when not powered.
When powered for a longer time, the copper windings get hot. Therefor they can only be powered with a limited voltage when turned on for long periods of time (i.e., anything longer than a couple of seconds). Also, the force the solenoid can exert, and the stroke are then limited. When only powered for a short period of time, the same solenoid is much stronger and has a larger stroke. The force is related to the stroke of the solenoid, the higher the stroke, the lower the holding force of the solenoid. This is because the core pin has less surface where the magnetic field pulls on when extended. The holding force of small solenoids can even be as low as just 1N at 1mm of stroke when powered for a long period of time (Geeplus, 2019).

Power consumption of small solenoids that are constantly powered will be limited. The battery of a regular e-bike can power such a solenoid for somewhere over 200 hours depending on the solenoid used (Appendix A). So, the range of the e-bike will not be decreased too drastically.

Bistable latching solenoid:

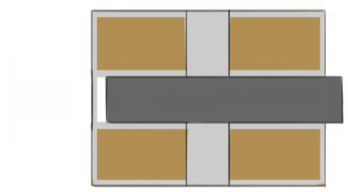


Figure 40: Bistable latching solenoid cut through

These solenoids have a double set of copper windings and a magnet. The windings pull or push the core pin and the magnet keeps the core pin in place. There is no retracting spring. These solenoids hold position in between pulses. Therefor it does not need to be powered constantly in one position and there is no problem with overheating. Therefor these can also be stronger in a smaller size. However, due to the lack of a retracting spring it is possible to push the core pin back in by hand and it will than hold that position.

One of the requirements is that the lock needs to pass the ART requirements for insurance reasons. One of the requirements is that for electronic locks the status of the system may not change when the battery is changed or removed. The latching solenoid will keep its position. However, the regular solenoid will lock when it was in unlocked position and the battery is removed. This is a change of status and therefor this might be a problem when using regular solenoids. With these two types of solenoids the following mechanisms were thought off:

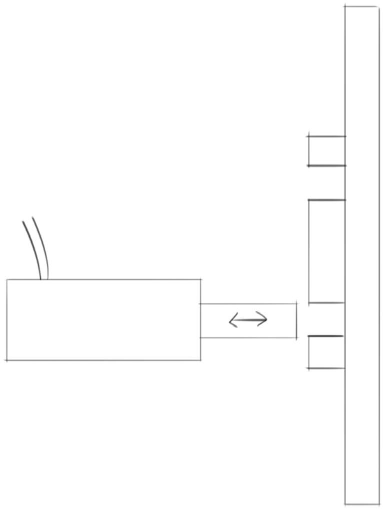


Figure 41: Lock pin is linear solenoid

Lock pin is linear solenoid core:

Advantages:
- Compact, simple design
- Linear solenoid already acts as spring loaded, lock pin pattern or other mechanism for aligning not needed. When it does not fit a hole, it will once the wheel starts turning.

Disadvantages:
- Overheating: to prevent this, only a low force and little stroke can be used.
- Constant power needed in unlocked state, but a bicycle battery can last over 200 hours when powering a solenoid, so this will not influence the range too much.
- When unlocked and the battery is removed, it will lock. This is not in line with ART regulations.

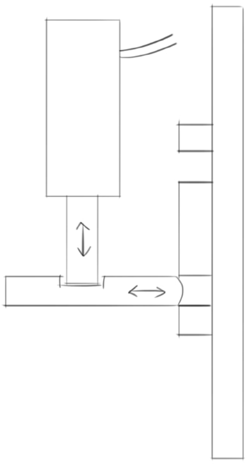


Figure 42: Solenoid is used to lock the lockpin

Solenoid is used to lock the lock pin:

Advantages:
- No overheating of the solenoid, larger stroke, and force available and less power consumption.

Disadvantages:
- How is the lock pin operated? This can be done manually but then you end up with an VanMoof kick lock.
- Hard to make this spring loaded, so two lock pins are needed or you need to allign the lock pin.

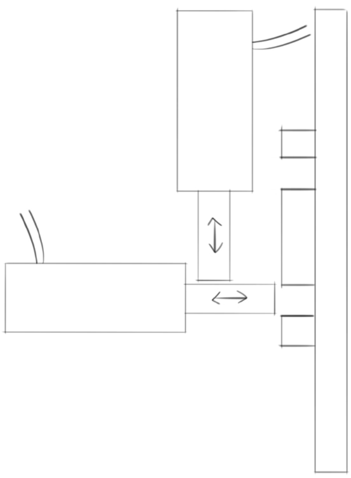


Figure 43: Two solenoids in combination

Two solenoids in combination:

Advantages:
- One solenoid is locked in place by the other, short ‘ON’ time so no overheating and full force and stroke available.
- Less power consumption due to the short ‘ON’ time.

Disadvantages:
- Two solenoids needed, this takes up more space and is more expensive.
- Hard to make this spring loaded, and 4 solenoids will not fit, so a lock pattern is not an option. This means that the user needs to align the slots.

Indirect hydraulic solenoid:

Advantages:
- Short stroke and low force can be converted into a longer stroke.
- Lock pin will be spring loaded.
- Solenoid can be located more freely away from the slotted disc.

Disadvantages:
- More difficult to engineer and more expensive construction.
- When unlocked and the battery is removed, it will lock. This is not in line with ART regulations.
- Maintenance risk, seals might start leaking.

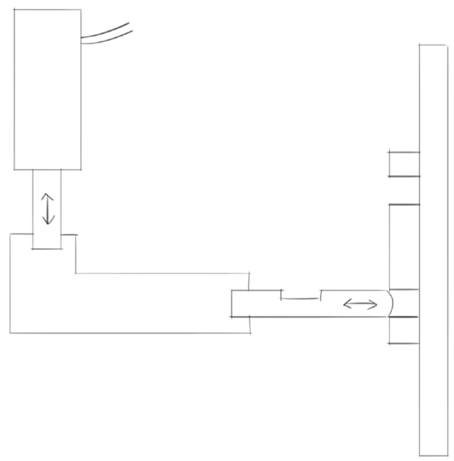


Figure 44: Indirect hydraulic solenoid

Lock pin is bi-stable latching solenoid:

Advantages:
- No power needed in stable positions.
- No overheating.
- Higher hold force and longer strokes possible.

Disadvantages:
- Lock pin is not spring loaded, so two solenoids are needed.
- Can be slightly bigger than a regular linear solenoid.
- Bi-stable latching solenoids are more expensive than regular solenoids.

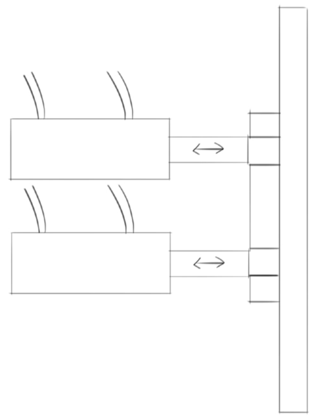


Figure 45: Lock pin is bistable latching solenoid

Indirect (bi-stable) latching solenoid:

The latching solenoid is used to operate a hydraulic circuit that operates two lock pins simultaneously from which always one fits.

Advantages:
- No alignment needed
- Orientation of solenoid is free

Disadvantages:
- Difficult to engineer
- More components are more expensive

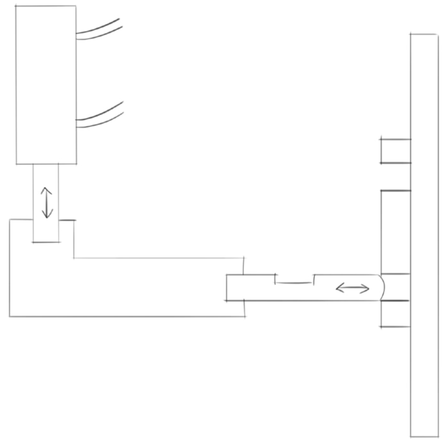


Figure 46: Indirect latching solenoid

Using regular linear solenoids is not preferred since those are too limiting in terms of force and stroke. Using two solenoids in combination will take up too much space and giving up on the requirements of not having to align the slots and having automatic lock pins will not have the desired outcome. Bi-stable latching solenoids are a better option. Using them directly will be preferred for simplicity reasons.

Slotted disc design:

The slotted disc also has some design constraints. Since bistable latching solenoids are used it is important that the holes are blind, otherwise the pin can be pushed back from behind. The specific solenoid used for this concept has a holding force of 40N (Geeplus, 2019b)., this is sufficient to push the lock pin into the slot, but with a screwdriver or similar tools it will be possible to push the pin back into the solenoid. And because it is a bistable solenoid it will then stay in that position because of the internal magnetic field. When the disc has blind holes, it will not be possible to push the pin back from behind and because there will only be very little room between the disc in the dropout pad it will also not be possible to push it back from the side. Achieving blind holes can best be done by making a special brake disc which is closed in the centre. This way it is possible to make two metal discs without blind holes which can be laser cut. Another constraint is the diameter of the disc. Because of the design of brake calipers, the brake caliper mounting holes come out towards the brake disc near the outer diameter of the disc as can be seen in figure 47. At this point there is only very little space between the brake disc and the dropout pad, not enough to fit another disc in between. The disc can therefore not have a larger diameter than 80mm. In the middle of the disc are the hub axle and the bolt holes of the disc. This is an industry wide standard, and the holes are located on a diameter of 44mm from the centre of the axle. This means that when adding an additional disc in front of the brake disc the usable space is roughly between 50 and 80mm diameter (figure 48). Another option would be to use the space behind the brake disc. However, in the centre and at the brake surface the disc cannot be thicker. This would mean that a multi-thickness brake disc needs to be made which is a lot harder and more expensive to produce since it cannot be laser cut anymore. This would however enable the lock holes to be located on a diameter larger than 80mm (figure 49).

Figure 47: Dropout pad to brake disc clearance

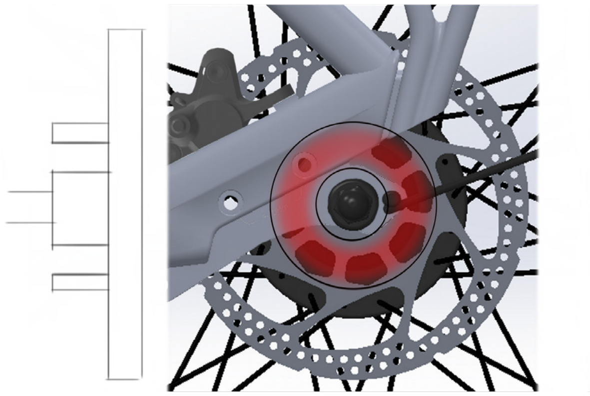


Figure 48: small slotted disc in front of brake disc

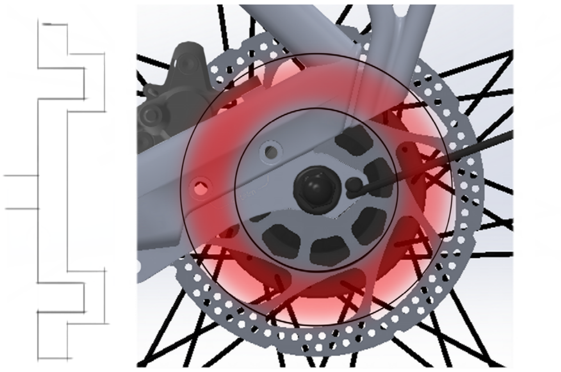


Figure 49: Multithickness brake disc with slots

Other design constrains:

The dropout of a bike is a rather tight area with a lot of components coming together. Of course, there is the frame itself which covers a large part of the dropout pad. The dropout pad can also slide back and forward around 20 milimeters, so this also needs to be taken into account. As mentioned before there is the brake disc which gets close to the dropout pad on the inside. The axle of the rear wheel is mounted into the slots of the dropout. To enable the rear wheel to be taken out it is important to keep a slightly forward-facing slot free of obstacles. It needs to be facing forward to release chain or belt tension to remove the rear wheel. Also, the wheel nut needs to fit over the axle. On the back of the dropout there is also a setscrew located for tuning the chain tension. This screw needs to be accessible to reach with an allen key. The luggage carrier is also often mounted to the frame near the dropout and sometimes the mudguards are also mounted to the dropout pad. The locking mechanism needs to be designed around all these components.

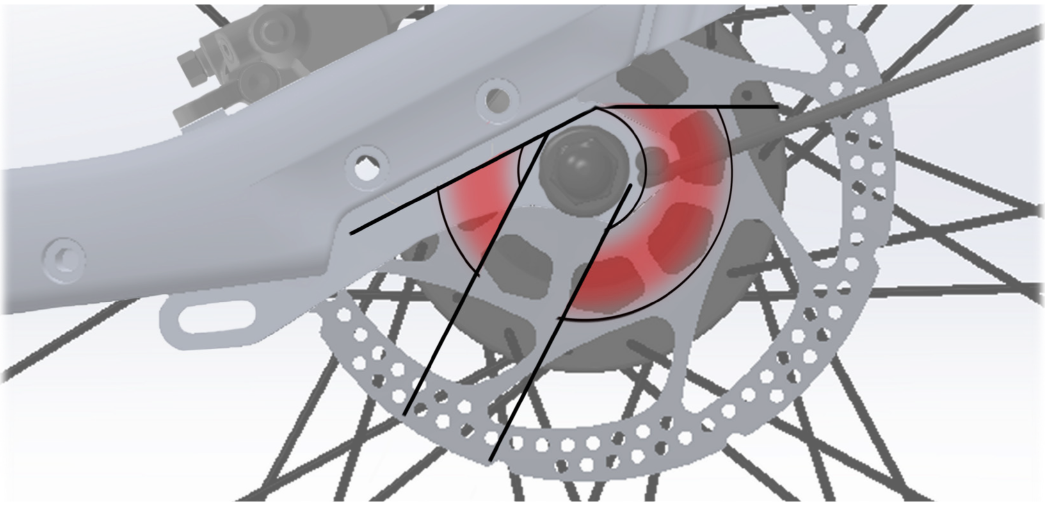


Figure 50: Lockpin mechanism interferences. Only the red areas are free off obstracles.

Lock pin pattern:

Two latching solenoids are used as lock pins. For this concept a Geeplus RD2L-0932 latching solenoid was chosen (Geeplus, 2019b). since this one is relatively compact and still has an holding force of 40N. The height and width of this solenoid are both 25mm. When integrating two of these in the available space discussed in figure 50, the most obvious choice would be to place them next to each other on a diameter of 65mm from the axle as shown in figure 51. This would only mean that the mudguard mounting point must move, but this is an easy component to change compared to all other parts.
To create a lock pin pattern were always at least one of the two lock pins enters a slot a simulation is drawn in a 3D model and a slotted disc is designed. The slots are kept as small as possible with this layout to create the least amount of momentum from turning the wheel which will limit the shear force which can be exerted to the lock pins. In figure 52 the design of the slotted disc is shown. As can be seen, when pin 1 reaches the next slot, pin 2 is still in the previous slot. And when pin 2 reaches this slot, pin 1 is still there. So, at least one pin is always aligned with a slot.

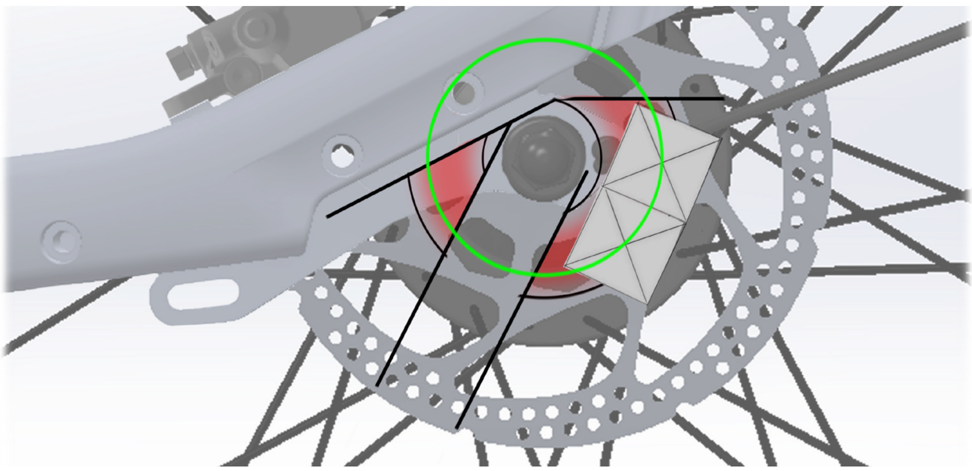


Figure 51: Lock pin layout

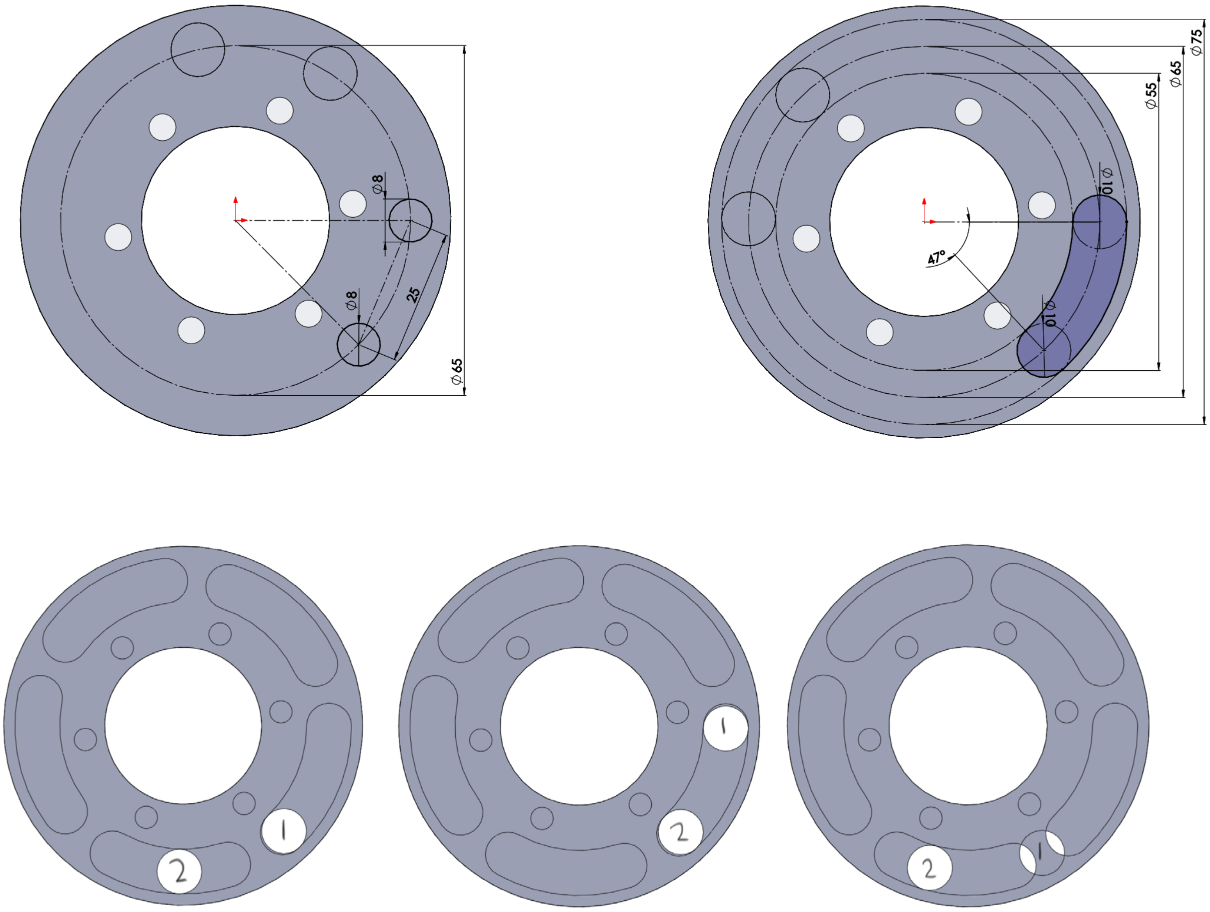


Figure 52: Slotted disc design and lock pin pattern

Electronics:

To operate the lock there is more needed than just the two latching solenoids. These need to be controlled as well. This lock will be operated with an wireless device such as a smartphone or a key fob using a radio signal or Bluetooth. For this a receiver is needed. To ensure sufficient security against hacking it also needs a rolling code protocol just as is used in car keys. This rolling code is generated by a small processor which is connected to the receiver. Power comes from the e-bike battery and the lock will run on the same voltage as the lights, 12 volts. The electronics cannot be fitted inside the dropout because of a lack of space to neatly integrate this. Therefor the electronics are located in the motor bracket inside the frame. Since the motor is covered with plastic covers the RF signal should be able to pass through to the receiver. A cable will run through the chain stay from the motor bracket to the dropout where the solenoids are located. To make it harder for thieves to cut the cable and operate the solenoids with an external power source the cable runs in between the dropout and the brake disc inside a small channel where it cannot be reached with a cable cutter before it enters the frame.

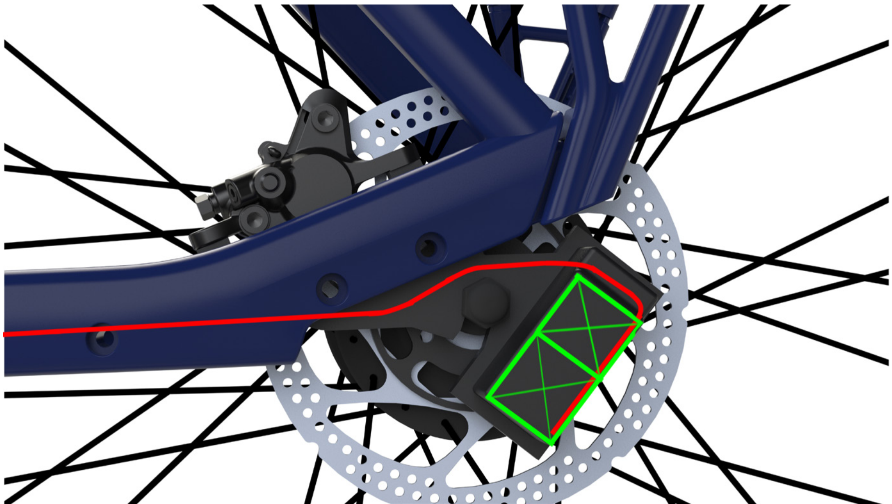


Figure 53: Cable routing sketch

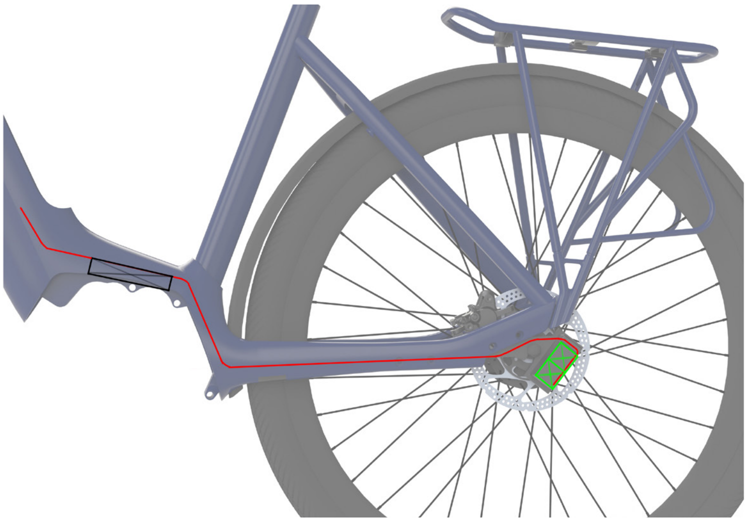


Figure 54: Cable routing and electronics layout

Housing:

The solenoids are just an open frame with the electric components inside. This is not weatherproof and will not withstand an attack. Therefor a housing is needed that protects the solenoids and hides the cables. Hiding the cables is important because in theory when the cable is cut an external power source can be added and the receiver and processor can be bypassed enabling the thief to unlock the bike without the digital key. Since the solenoids are sticking out of the current dropout pad it will never be a nice integrated shape together with the frame. Therefor, the shape of the design is kept simple to not draw too much attention to it. To keep the manufacturing of the housing simple the dropout just has a hole in it where a hardened steel 'solenoid box' will be bonded in. This means that the dropout pad can be made as the current design with a bit more material and an additional hole. The solenoid box can be casted, or CNC machined, and then heat treated to create enough protection against an attack. The solenoids can then be mounted inside the solenoid box and the cables can pass through this box to exit behind the pad near the axle where it can run though a small recess in the dropout pad to hide it from cutters before the cable enters the chain stay. In figure 55 an exploded view of this is shown. Further a cover is needed to shield of the back of the solenoid box. This cover needs to have seals where the lock pins pass through. The lock pins itself will be 8mm in diameter and made of hardened steel and screw over the 4mm pins of the solenoids.

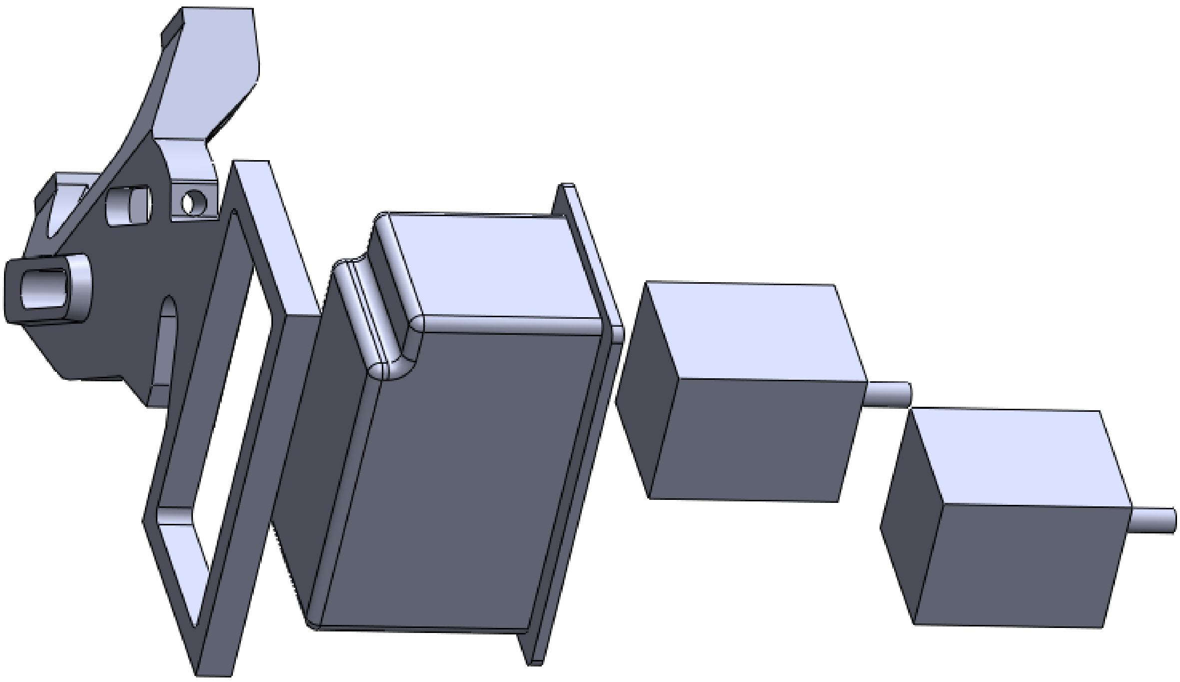


Figure 55: Solenoid housing design

Renders:

Figure 56: This render shows the brake disc lock concept with the solenoid box integrated in the dropout pad and the slotted disc in front of the brake disc.

Figure 57: Close up of the brake disc lock. As can be seen, the wheelaxle can still be removed from the dropout pad without toughing the solenoid box.

Figure 58: Rear view of the brake disc lock. As can be seen there are two lock pins and there is still clearance between the slotted disc and the dropout pad.

Design weakness:

There is a weakness of the lock as it is designed currently. Because of the flex of the frame and the limited insertion (4-5mm) of the lock pin in the disc, it will be possible to remove the rear wheel to unlock the bike. The following needs to be done to achieve this:

- Loosen the caliper bolt to release the brake caliper from the disc.
- Loosen both wheel bolts.
- While bending the frame ‘open’ at least 4-5mm, removing the rear wheel from the bike.
- Either push the lock pins back into the dropout pad or removing the additional slotted disc in front of the brake disc.
- Removing the disc means removing the 6 disc bolts, removing the disc, and the reinstalling the brake disc with 6 bolts.
- Reinstall the rear wheel into the dropout.
- Tighten the wheel bolts.
- Re-align the brake caliper and fastening the caliper bolts.

A small test at home showed that the time estimated to achieve this is below 2 minutes. Off course, this does not necessarily mean that this is not a good concept, a ring lock will not last long against an angle grinder or a strong cutter. However, for the ART testing this might be a problem to pass the test. A mechanical minded thief who knows this method might be able to unlock the bike in 2 minutes without causing damage to the bike. This thief is then only left with a useless lock and a rather strange dropout pad which might cause questions when selling the bike. For this concept particularly it might be useful to combine it with an alarm or electronic lockdown when the thief starts messing with the lock in locked position to add an additional level of security. Designing the dropout in such a way to prevent the wheel from being taken out will most likely make it unacceptable hard to instal and remove the rear wheel and to tension the chain or the belt. Therefore, the design is left as it is for now.

3.2 Kickstand Lock

This concept focusses on the user friendliness of a bicycle lock. When looking at the use case of parking a bicycle the kickstand is most often used when the bike is not stored in a bicycle rack. By combining the action of folding out the kickstand with locking the bicycle this will save a use step making it more appealing to lock the bicycle.

Mechanical options:

First the options of using the kickstand as the lock itself will be discussed. The problem with this is that there is not one type of kickstand but many. These are all fundamentally different and will each need a different mechanism to function as a lock. The three main types of kickstands and the options with them are:

Double sided kickstand:

Figure 59: Double sided kickstand (Ursus, n.d.)

This kickstand is mounted central behind the bottom bracket. It has two legs and when folded out it these legs keep the bike upright while lifting one wheel from the ground. This will be the easiest kickstand to use as a lock because it lifts one wheel off the ground. Because of this, locking the stand itself will make it impossible to ride or push the bike away. It can then only be lifted away just as with a ring lock. However, not a lot of mid-engine e-bikes use this type of kickstand because the space behind the bottom bracket is often filled by the motor.

Rear kickstand:

Figure 60: Rear kickstand (Ursus, n.d.)

This kickstand is mounted to the left chain stay. It is located next to the rear wheel so it will be possible to create a mechanism to lock the rear wheel. This is not easy however since a traditional stand moves parallel to the rear wheel. So, this movement needs to be translated into something that moves in between the spokes. One concept that was once released removed the pivot point and instead let the leg of the lock arc through the wheel to the right side of the bike. This looks nice when locked but once unlocked the leg is sticking out to the left and has a rather big form factor whereas an traditional stand folds down underneath the chain stays blending in with the lines of the frame. Also, locking this stand is simple, but unlocking it will be much more difficult since it needs to be pulled up and is harder to reach then a ring lock.

Figure 61: Rear mounted kickstand lock concept by Quick (Seth, 2013)

Central kickstand:

Figure 62: Central kickstand (Ursus, n.d.)

This stand is mounted in the same place as a double-sided kickstand, but it has only one leg. It does not lift a wheel off the ground, and it is also not located next to the rear wheel, so there is no easy way to use this type of stand as a direct lock. It will prevent the cranks from turning when the leg is locked. However, this still enables the thief to roll away the bike which is not allowed for an ART certification.

Figure 63: Kickstand with integrated push sensor

As can be seen, using a kickstand as a direct bicycle lock is not as easy as it seems. The double-sided kickstand has potential, but the rear mounted kickstand will end up being a large poorly integrated stick and for the centre mounted kickstand it is even the question whether it is possible. There is however also the option to use the kickstand as an indirect bicycle lock. In this case the kickstand acts more as a switch for the lock mechanism. This can be done by either using a cable actuated lock (or hydraulic), but these locks will be prone to cutting the cable. In the other concepts this has turned out to be a threat for the anti-theft security of the lock. It can also be done electronically by integrating a sensor in the kickstand which gives a signal to an electronical lock to lock or unlock. This can be combined with the brake disc lock described previously to create a lock that locks and unlocks by only using the kickstand. This sensor can also be integrated into all three types of kickstands giving more design freedom when designing and speccing a bicycle frame. Push sensors are rather small off the shelf items which with a little change in the design of the kickstand can be integrated into the base of the kickstand. In one position the leg of the stand will push the sensor which will give this signal to the processor of the electronical lock.

Figure 64: Kickstand with integrated push sensor in folded position

A flowchart of the locking protocol will look the following:

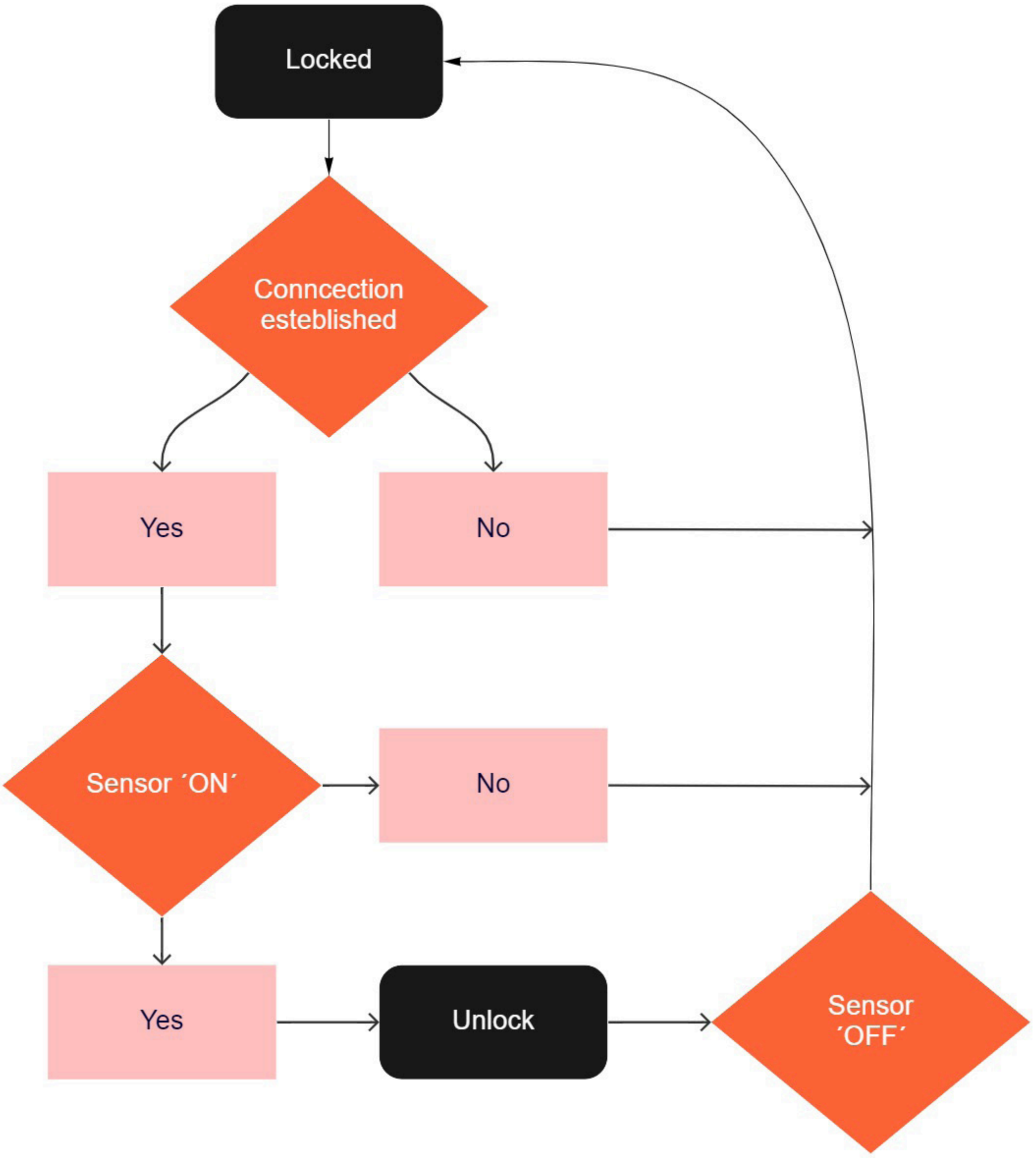


Figure 65: Flowchart of electronic unlocking protocol of the kickstand lock

For unlocking the lock an additional connection via Bluetooth or with a radio controller needs to be established to create the lock's security. However, a Bluetooth connection can be established automatically when the phone has been paired with the lock. This would mean that once you stand next to the bike and fold in the kickstand the bicycle is unlocked without touching the mobile phone.

One drawback of this concept is that it is not always needed to use the kickstand. When placing the bike in a bike rack as is often the case at train stations and such the kickstand is not used. With this concept this would mean that you would still need to use the kickstand in a bike rack. This can be done without a problem in most cases but still seems like a strange thing to do. Another option would be to lock the bike with your phone of key fob, but this would take away from the whole purpose of the kickstand switch for these situations.

3.3 Integrated chain lock

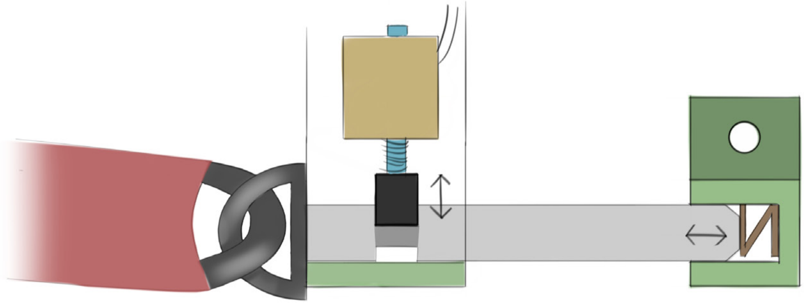


Figure 66: Integrated chain lock locking mechanism

Lock mechanism:

The chain will be connected to a lock pin at the end. This lock pin will have a tapered head to make it easier to insert and to push the locking wedge up. Near the end of the lock pin there will be a recess with a smaller diameter to enable the locking wedge to fall into. The locking wedge at the right side of the lock will be spring loaded by the internal spring of the linear solenoid. At the left side the lock pin will not be locked. It will only fall into the housing and push against a spring. Locking the lock will only involve pushing the lock pin through the housing holes. The wedge will be pushed up by the tapered head of the pin and fall into the recess once it is inserted far enough. When unlocking the lock pin, the linear solenoid to which the wedge is connected will be activated and pull the locking wedge up against the internal spring load for a short period of time. The spring at the tip of the lock pin will then push the lock pin back far enough such that the locking wedge is not aligned with the recess. The lock pin can be pulled out then. The locking wedge is located on the right because when the lock pin is cut in two, the chain is still locked. And depending on the play on the left side it might also still block the pin from falling out the housing. This would mean that a thief needs to cut the pin one or two times as well as the chain to steal the bike. This means that the pin is inserted from the right side of the bike. This is most logical since most people are used to stepping off their bike on the left side since that is where the bike stand is located. If you then want to lock your bike to the world you put it with the right side against the object. To be most efficient with the chain length it is then most logical to start and end with the chain on the right side of the bike, this also prevents the user from having to step around the bike to put it against the object.

Lock housing:

The housing of the lock has multiple functions. The most obvious is to protect the locking mechanism. Therefor it is important that it is made from a strong material and has a strong structure such that you cannot easily break it and reach the internal mechanism. The second function is to mount the locking mechanism to the frame. When using the existing mounting points on frames, the mechanism needs to be lowered with respect to these holes to clear the rim. So, the mounting holes need to be positioned above the locking mechanism. It should not be possible to remove the lock from the frame when it is locked. The lock pin already ensures this but when also integrating the mounting screws inside the housing and forming the housing cover around the lock pin holes it becomes even more difficult to remove the lock from the bike, even when the lock pin itself is cut in two. In current ring locks there is a bridge between the two sides to house the shackle. With this lock it is not technically necessary to have this connection between the left and right side since the right side will only be a spring. However, not using a bridge will mean that the two sides need to be aligned correctly. Therefore, using a bridge to connect to two sides still has advantages. The receiver that is inside of the housing also needs to be able to catch the signal. Therefor the cover cannot be made of metal entirely. To solve this the backing plate is made of metal and the internal mechanism will be protected inside a metal subframe. The cover can then be made of plastic.

Chain:

The first challenge is to mount the chain to the bike in such a way that it is hard to remove it. Bolting it to the frame or the luggage carrier will always give to opportunity to unbolt it again by the thief, making the chain less efficient against bike theft. Welding it to the frame or luggage carrier is also not feasible both for Accell as well as the customer who cannot decide to change it then afterwards. One simple but effective way to solve this problem is by looping the chain around the frame at the seat stay just like you would loop a plug-in chain around an object currently, figure 67 shows how this can be done. This also enables the chain to be moved around a bit or be removed altogether to be looped around an object which gives more freedom in tight situations where maximum length is needed. Also people who prever to store their chain in their pannier bags have this option. Because the chain is looped around the frame, the weakest point is the chain itself and not the mounting point, it also generates a bit of extra length. This is needed because the length you get from storing the chain along the luggage carrier is limited to about 90cm. This is also the minimum length that is usable as a chain lock. The chain itself can be a regular ART2 certified plug-in chain with the lock pin at the end being bigger than normal to fit the lock and the ring at the other end being coated with a softer material like rubber or plastic to protect the paint of the frame. The chain holder at the rear carrier can be a simple clip-on extension where the chain can lay in. To maintain enough chain length, this clip needs to be as high and as far to the front as possible and as wide as possible while still integrating nicely with the carrier. Another reason why it needs to be in front of the rear carrier is to clear the pannier bags or the child seat. Making it a clip-on holder creates better compatibility with current parts.

Figure 67: Example of how the chain will be mounted to the frame by looping it around the seat stay

Figure 68: Test setup to test wheter the chain will slap around during cycling.

Pin holder:

When the bike is not locked the chain is stored over the rear carrier. The lock pin is then hold in place inside a holding case. This case should hold the lock pin in place without locking it. In figure 69 multiple options to achieve this are sketched. Option 3, the leaf springs, is the preferred option since this is both the cheapest and the most compact option. This is because the leaf spring is both the spring as well as the gripper whereas the other options use multiple components to achieve this. The lock pin can also be held in place by only using friction, for example by using a rubber lining inside the storage tube. However, this will result in a less positive feeling when placing and removing the lock pin in the holder and this will also wear out over time. This can mean that after a while the lock pin is not gripped properly anymore. Another option would be to use a spring clamp. This would be much smaller than a complete holding case. However, the risk exists that when riding the bike, the lock pin will be pulled out of the clamp and then the chain might swing into the spokes which can cause accidents. When using a tube housing the pin can also shoot out of the clamp but it is then kept inside the tube.

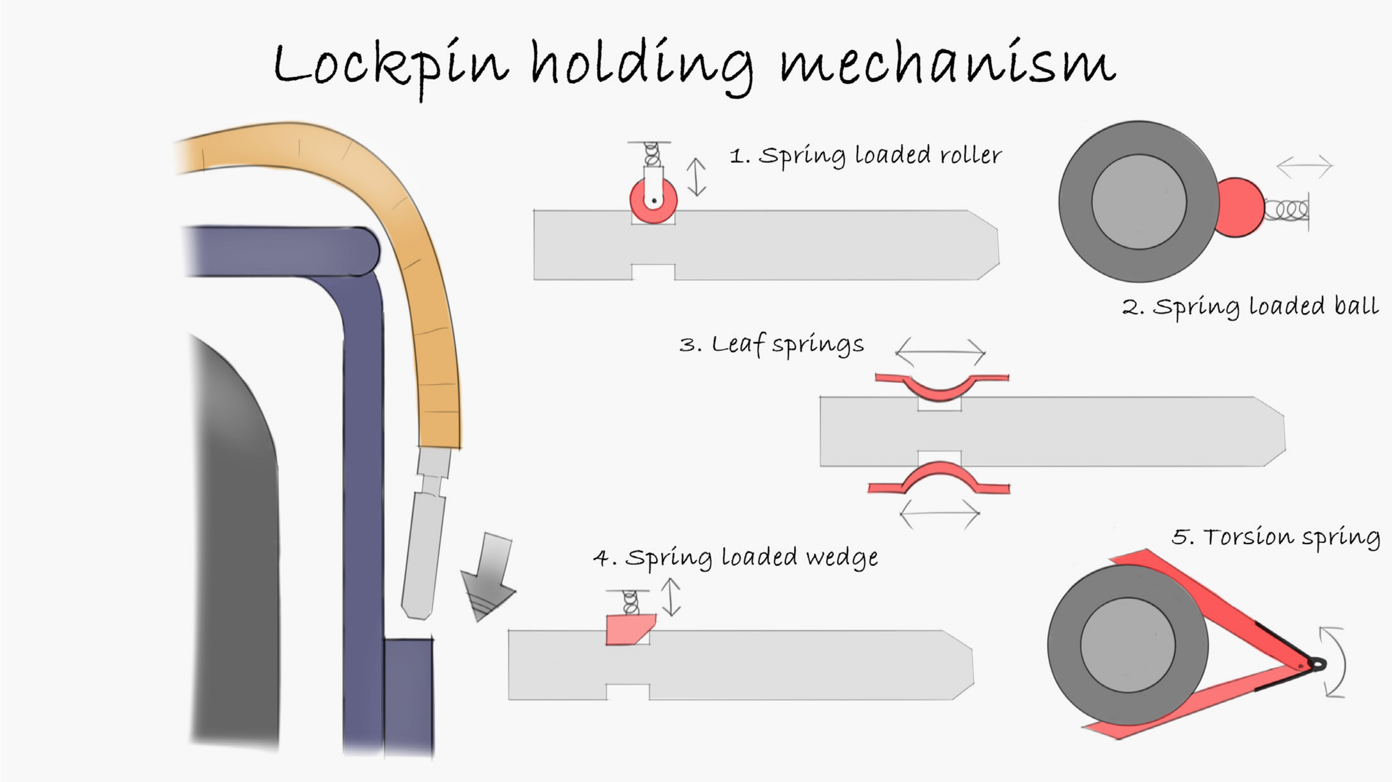


Figure 69: lock pin holding mechanism ideation sketches

Electronics:

This lock only shortly uses a solenoid to unlock the lock. Locking it will happen mechanically by pushing the lock pin into the lock. The power for the lock can come from the cable of the rear light which often runs under the mudguard and thus close to the lock. The receiver and processor can be fitted inside the lock itself since there is sufficient space. The cable entering the lock does not have to be protected against cutting in contrast to the brake disc lock because the controlling of the solenoid happens inside the lock. Only the cable running from the chip to the solenoid needs to be hidden from cutting through. The protocol is as simple as pushing a button on a key fob or smartphone which will then activate the solenoid shortly to release the lock pin. Off course, a secure connection between the key fob or the smartphone with the lock needs to be established to prevent hacking.

Renders

Figure 70: Left side render of the integrated chain lock concept with the chain holder, the pin holder and the lock itself.

Figure 71: Right side render of the integrated chain lock concept with the chain holder, the chain looped around the frame and the lock itself.

Figure 72: close up renders of the seperate components of the integrated chain lock concept with the chain holder, the lock itself, and the pin holder.

3.4 Concept selection

Recommended key protocol:

Before selecting the best concept first the key protocol is left to discuss. Since all locks are electrical there is no need for a physical key. However, there still needs to be something to unlock the bike. There are many possibilities to do so but the most common are infrared signals or Bluetooth. Bluetooth can work with your mobile phone and has the benefit that there is no key required anymore. The disadvantage of this technology is that some devices can have problems to connect to each other and that the battery of your phone can be dead. Therefor electronical locks which rely on Bluetooth often have a backup code which can be pressed. This is however often a simple 3 letter code which is prone to hacking. Infrared signals are more applicable to an electronic key, often called key fob. This is more reliable than Bluetooth but still requires the user to carry the key fob with them. Both methods work fine but combining them together can mean the best of both worlds. People who do not encounter problems with Bluetooth and trust their phone can make use of this more practical method without the need to carry a key. People who do not trust this method can still use a key fob. By putting the responsibility at the user, the need for a backup also becomes less apparent because there is always a backup key in the form of either the key fob or your phone. And if you decide to not carry the key fob this is the responsibility of the user. By eliminating the backup code, it also becomes less likely that the lock can be hacked.

Concept overview:

	Brake disc lock	Kickstand lock	Integrated chain lock
Benchmark			
Locking	Park the bike and push the key fob or lock with smartphone.	Park the bike with kickstand	Park the bike, take the chain from the holder, and wrap around object, insert lock pin.
Unlocking	Push the key fob or use your smartphone and ride away.	Have a Bluetooth connection or push the key fob, fold the kickstand and ride away.	Push the key fob or use your smartphone, de-loop the chain and insert the chain and lock pin in the holder and ride away.
Strenghs	No need to align slots or to perform a physical action, this solution can be used in each situation.	Fully automated and you cannot forget to lock the bike.	A complete solution that saves the most time compared to its benchmark and offers improved anti-theft protection.
Weaknesses	This lock offers limited protection, so there is still the need for a chain lock.	This lock offers limited protection, so there is still the need for a chain lock. A kickstand is also not normally used in a bike rack.	The chain cannot reach near the front wheel.
Added cost price (est.) (difference to benchmark)	€17,-	€25,-	€14,-

Figure 73: concept overview

In figure 73 the three concepts are compared in a comprehensive overview. It is important to note that the concepts have different benchmarks, The brake disc lock and the kickstand lock are compared to a ring lock whereas the integrated chain lock is compared to a ring lock with a plug-in chain. This difference in benchmark is also considered in the cost price estimation. The outcomes presented in this overview are the added costs compared to the benchmark, so for the integrated chain lock the chain of the regular lock is also subtracted from the costs. Furthermore, the actions the user must take to both lock and unlock the lock are described as there are some subtle but important differences there and the strengths and weaknesses of each concept are briefly mentioned. A more detailed calculation of the cost prices presented can be found in appendix B.
Another point worth mentioning is that after the analysis phase, Kingpolis decided to make the use of a secundairy chain lock required for bikes over 3500,- euro (Kingpolis, 2022). This might become a trend for insurance companies to require the use of chain locks which is in favour of the chain lock concept.

Concept selection:

To select the most promising concept to continue working on, the same matrix is used as at the end of the ideation. Only the requirements are more strictly formulated and divided into 4 categories: anti-theft security, usability, integration, and business case as these are the four main pillars of this assignment were the concept need to score well on.

The requirements are weighted on a three-point scale with 3 being the most important requirement and 1 being the least important, these weights are kept the same from the ideation. Then all concepts are rated on each requirement on a five-point scale:

5: The concept fully meets the requirement.
4: The concept meets the requirement reasonably well.
3: The concept reasonably meets the requirement.
2: The concept does not sufficiently meet the requirement.
1: The concept does not meet the requirement.

For some requirements, the concept is compared to its benchmark, with the benchmark being a score of 3, so if it performs better, it will score higher and when not matching the level of its benchmark it will score lower.

	Concept:	Brake disc lock		Kickstand lock		Chain lock	
Requirements:	Weight	Assesment	Score	Assesment	Score	Assesment	Score
Anti-theft resistance							
The concept can pass ART regulations.	3	2	6	2	6	5	15
The concept offers improved anti-theft protection over applicable benchmark. (3=benchmark)	2	2	4	2	4	4	8
User friendliness							
The concept offers improved usability over applicable benchmark. (3=benchmark)	3	3	9	4	12	4	12
The concept is safe to use.	3	5	15	5	15	4	12
Integration							
The concept fits the ´core archetype bicycle´.	3	5	15	5	15	5	15
The concept has an appealing look.	1	3	3	3	3	3	3
Business case							
The concept is technically feasible.	3	3	9	3	9	4	12
The concept is financially feasible.	2	3	6	2	4	4	8
The concept differentiates itself from current locks.	2	3	6	4	8	4	8
The concept is compatible with other types of bicycles.	1	2	2	2	2	3	3
The development of the concept is within Accell's influence.	1	3	3	3	3	4	4
	Total:		**78**		**81**		**100**

Table 2: concept selection table

The points are then multiplied by the weighting factor and added to give a total score for each concept. The scores are off course arbitrary since it was only filled in by me and not all requirements are measurable already. Therefor the outcome is somewhat opinion based. However, all concepts were developed into enough detail to get a good sense for how it will work out. The outcome has been discussed with the supervisors to agree on the outcome.

When comparing the outcome of table 2 to the outcome after the ideation, only the integrated chain lock concept keeps a high score. The brake disc lock and kickstand lock score considerably lower than before. This is because they offer only limited anti-theft protection and are relatively expensive compared to the added usability. These two concepts only replace the ring lock while that is an easy-to-use lock. The integrated chain lock also replaces a regular chain lock which has much more potential to gain on usability, so this concept has gained relatively more in terms of usability for less costs while also offering good anti-theft protection. Therefor, this is the most promising concept which will continue into the development phase.

Conclusion:

All three selected ideas were further developed to have enough level of detail to assess them on the requirements for the lock which can be divided into four main pillars: anti-theft protection, usability, integration, and business case. The concepts have different benchmarks because realistically the brake disc lock and kickstand lock can only be compared to a ring lock whereas the integrated chain lock offers more protection and can be compared to a ring lock in combination with a plug-in chain. The integrated chain lock is selected as the most promising concept that will be developed further in the development phase because it is a more complete solution that scores well on all four pillars. It offers good anti-theft protection while gaining relatively the most in terms of usability. Its added costs compared to the benchmark are also estimated to be lower than the other concepts.

Figure 74: selected concept, the integrated chain lock

4 Concept development

After finishing the last phase there was already a clear picture of what this concept should be. However, some aspects still need to be better defined and some aspects of the concept are changed. First the requirements are made more specific for the chosen concept direction. Then the concept itself is further developed. This concept is divided into two main items: the locking mechanism and the rear carrier. The final concept is explained and showed with renders and pictures. The cost price estimation from the last chapter is also updated following the changes in the design. A functioning prototype has been built which is used for user tests and real-world testing. This also leads to a realistic use case description and is used to define the pros and cons of the concept as well as recommendations for further development.

4.1 Requirements

There was already a list of requirements to help with selecting the best concepts. Now that the final concept direction is known these requirements can be described in more detail for this concept.

Anti-theft resistance

The concept can pass ART regulations:

- The lock can withstand -10°C
- The lock can withstand a corrosion test
- The lock can withstand a dust test
- The lock pin can withstand at least 55 kN of cutting force
- The lock can withstand at least 5 kN of pulling force at the lock pin
- The lock and remote still function after 50 free falls from 1 meter
- The lock can withstand a vibration test
- There should be at least one type of chain available for this lock that is ART rated:
  -The chain can withstand at least 15 kN of tensile force
  -The chain can withstand at least 55 kN of cutting force
- The lock can withstand the attack test
- The lock should still function properly after 5000 use cycles
- It shall not be possible to generate, within 24 hours with a chance greater than 1 %, the correct code that can unset the system.
- To prevent reading the signal in the air, the code used for unsetting of transmitting devices shall change “in random order”
- At least a 32 Bits (binary) encryption code shall be used for transmitting devices.
- At least 20 times before malfunction due to an empty battery of both the lock or remote control the user shall be informed (no matter how, except light signals from the lock).

The concept offers improved anti-theft protection over a ring lock in combination with a chain lock.

User friendliness

The concept offers improved usability over a ring lock in combination with a chain lock:

- The lock is faster in use then the current combination of a ring lock with a chain lock.
- The lock scores higher on ease of use then the current combination of a ring lock with a chain lock.

The concept is safe to use:

- The lock pin will not get caught in the spokes while cycling.
- The chain loop will not get caught in the spokes while cycling.
- The user will not hit the chain while cycling.

Integration

The concept fits the ´core archetype bicycle´:

- Mid-engine e-bike
- In-tube battery
- Disc brakes

The concept has an appealing look:

- The lock scores better on looks then the current combination of a ring lock with a chain lock.

Business case

The concept is technically feasible:

- The lock can be produced with current manufacturing methods and materials.
- The product can be mounted in a timely manner within the assembly line.

The concept is financially feasible:

- The estimated cost price should be in-line with the added value.

The concept differentiates itself from current locks.
The concept is compatible with other types of bicycles.
The development of the concept is within Accell's influence:

- Accell can bring this concept to the market itself. Third parties may still be used for subcomponents.

4.2 The locking mechanism

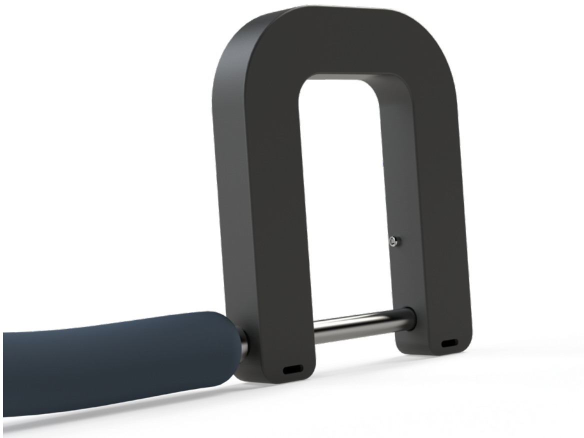


Figure 75: The final concept locking mechanism

The basis mechanism used to lock the bike has not changed. A solenoid with a wedge is used to lock a lock pin. After unlocking, a leaf spring will push the lock pin slightly back such that the wedge will not lock the pin anymore. For the final concept, a battery is added to the electronics to function as a back-up battery in case the e-bike battery is empty or removed. By adding this battery, it also becomes possible to use this concept for non-e-bikes. A hub dynamo can then charge the battery while cycling and since the lock only uses a small amount of power the battery only needs to be charged very little during cycling.

The solenoid can be screwed into a little plate which will be welded onto the base of the lock. This plate also covers up the wedge of the solenoid which makes sure that this cannot be pushed up manually after the cover is removed or broken into. Another plate is added to the base between the solenoid and the receiver to cover up the cables while still allowing the mounting bolt to go through. This prevents the thief from cutting these cables and using an external power source to open the solenoid. The main cable powering the lock does not have to be protected since it sits before the receiver. This cable will enter the lock under the mud guard. The cable can be routed under the mud guard to the bottom bracket area where it can be connected to the battery of the e-bike.

The mounting slots for the lock have also changed. On traditional ring locks there are usually three slots to allow adjustment for different bikes. These slots would then be in the base of the lock and face upwards meaning that rain and dust can come into the lock. Since this lock will be an Accell product a standard interface for the mounting holes is chosen where all frames should adhere to. Just like Accell uses standardized dropout pads and such across all their bikes. In this way the bolt head will cover up the hole meaning that water cannot come in from here. This is also the reason that the receiver and the battery are in the top of the lock to prevent water that comes in from collecting at the electronics. The water will run down to the bottom where two little slots are located where the water can exit the lock again.

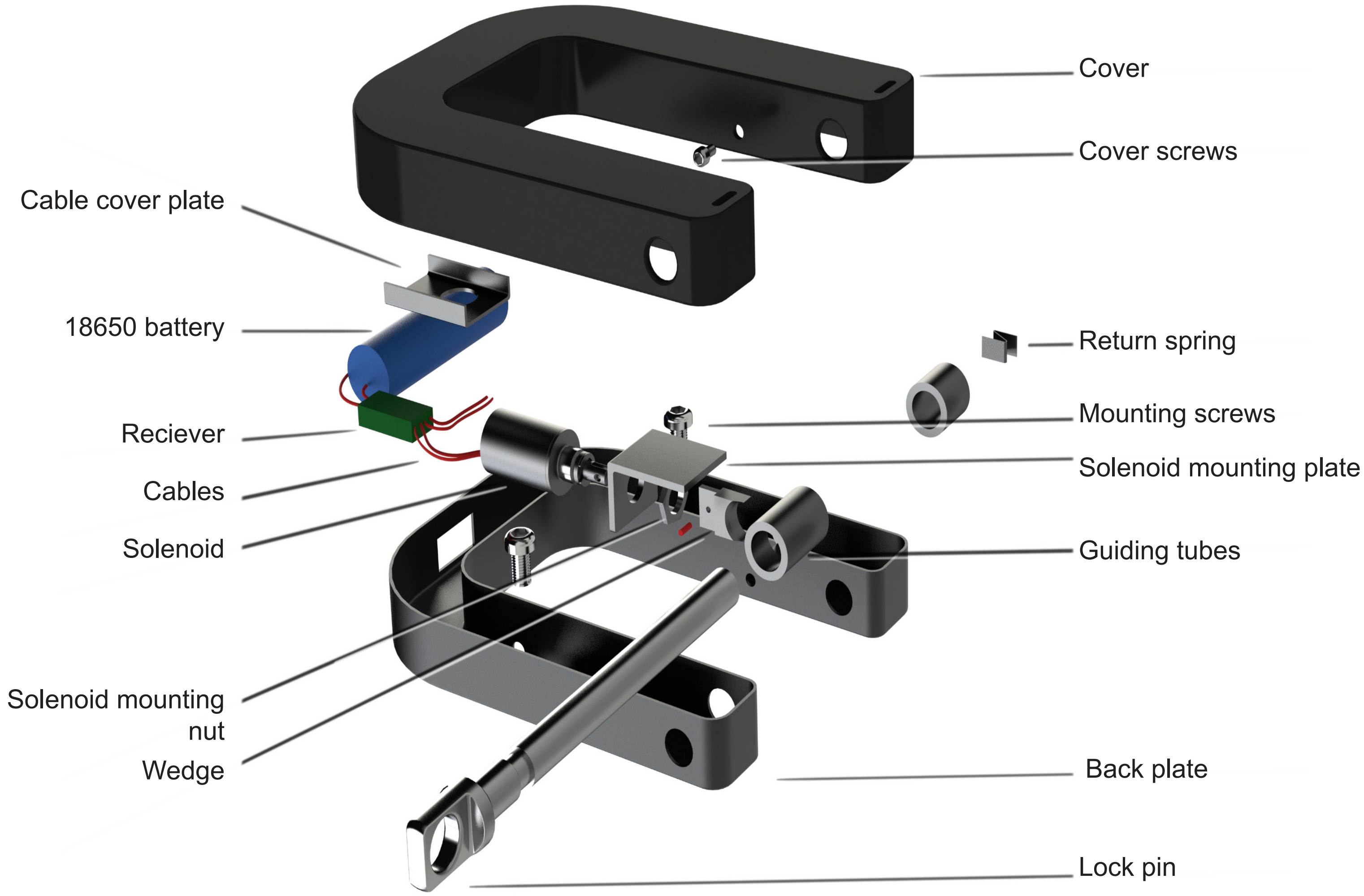


Figure 76: exploded view locking mechanism

Back plate

- Material: hardened steel
- Production: casting, heat treatment

Cover

- Material: polypropylene
- Production: injection moulding
- Assembly: build in clip and screws

Guiding tubes

- Material: steel
- Production: extrusion, cutting
- Assembly: welding / brazing

Solenoid mounting plate

- Material: hardened steel
- Production: Stamping, heat treatment
- Assembly: welding

Solenoid wedge

- Material: hardened steel
- Production: forging, heat treatment
- Assembly: mounting pin

Cable cover plate

- Material: hardened steel
- Production: Stamping, heat treatment
- Assembly: welding

Lock pin

- Material: hardened steel
- Production: forging, heat treatment

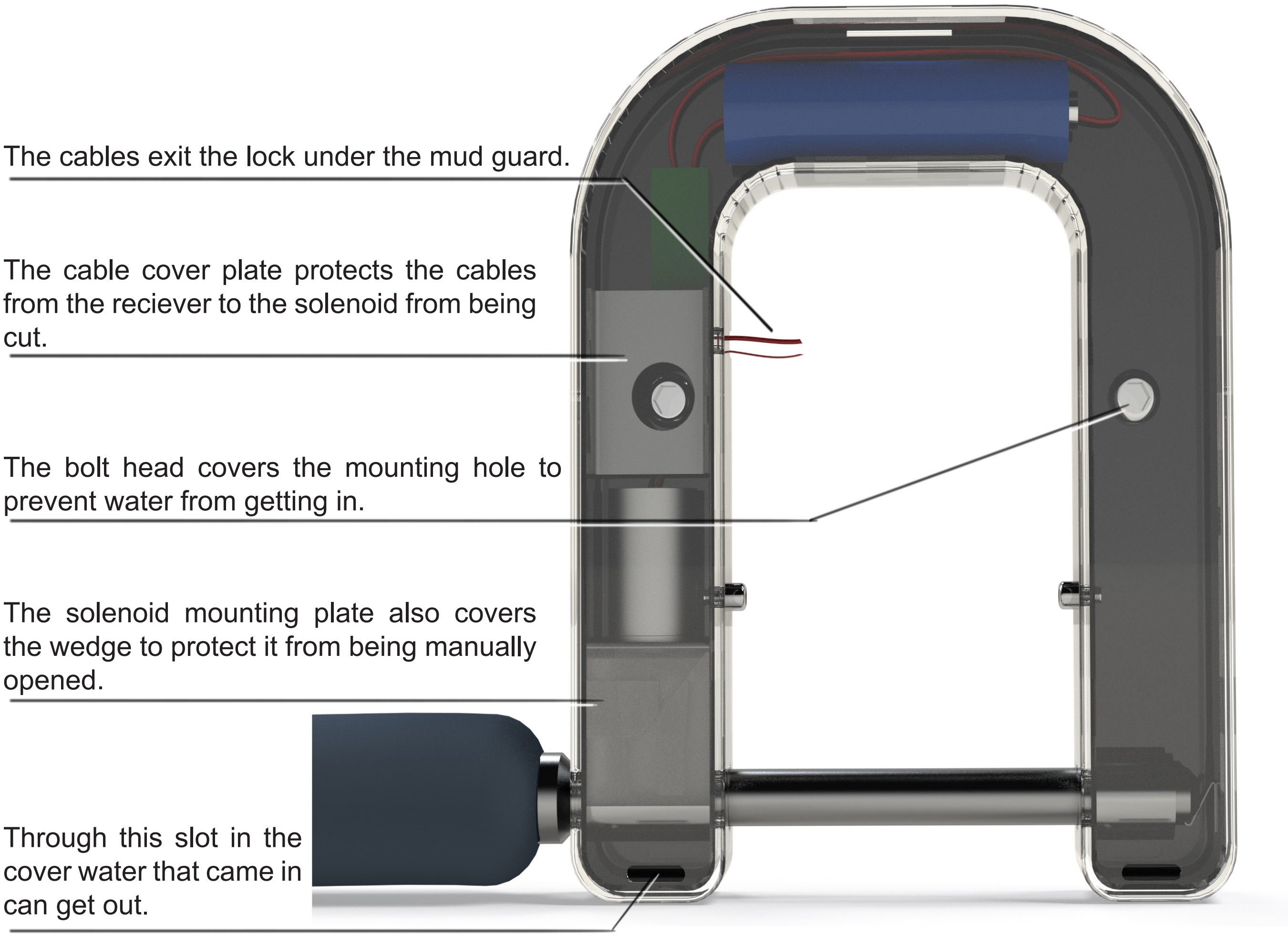


Figure 77: Internals of the locking mechanism

4.3 The rear carrier

The rear carrier sees the most updates compared to the previous preliminary concept. There it was decided to make clip-on holders for the chain and the lock pin and loop the chain around the frame. This was done to keep the current carrier. However, it resulted in a cluttered look with unnecessary big add-ons. The chain was not running parallel on both sides either and when the whole concept is reduced to add-ons there is a higher risk of competitors copying the concept. Since Accell makes their own rear carriers there is also the possibility to make a dedicated carrier within their own portfolio whereas this will be harder to do for a lot of competitors giving them a competitive advantage to protect this concept. What this means concretely is that the chain is now looped around the carrier instead of the frame. This is done to factor out different chain lengths for different frames. Now the carrier can always use the same chain. The carrier itself is a blindly mounted carrier which is screwed to a metal plate under the mud guard. This bolt cannot be reached if the rear wheel is in place, and the rear wheel cannot be removed when the bike is locked. This ensures that the carrier cannot simply be bolted off the bike by thieves when locked which would make the chain useless.

The chain holder is also a much more simplistic bended plate which is welded to the frame of the carrier, which is much easier and cheaper to produce than a bolt on clamp. Also, the pin holder is now connected to the carrier instead of the rear axle, making for a much cleaner look. It is a little tube welded to the carrier with a leaf spring bolted inside to hold the pin in place. All parts are designed in such a way that the chain can now run parallel on the left and on the right along the tube of the carrier except for the chain loop which is bulkier than the rest of the chain. This again makes for a much cleaner looking concept.

Figure 78: The rear carrier with chain looped and stored on the carrier. The chain loop can be seen on the left and the lock pin holder is on the right.

Figure 79: The carrier without chain. The chain holder sits under the bend in the deck and the pin holder is welded to the tubes of the carrier. A small leaf spring is bolted in there to keep the lock pin in place.

Another part that was further developed was the loop ring at the end of the chain. Since a thick 8mm ART-2 chain is used for this concept, using a standard ring will end up in a big bulky chain loop around the carrier that is not only not nice to look at, but it will also stick out which might cause problems with the spokes of the rear wheel. Multiple designs were tested with the aim to create a ring that better follows the tube of the carrier. The idea was to 'fold' the ring around the tube. However, when the ring was bended too much the chain links could not be looped through it anymore. Therefor a design is chosen with a mellow bend which still follows the tube a bit while allowing the chain to be looped through. It is made triangular to create a larger opening where the chain needs to loop through and become smaller where it connects to the chain to avoid unnecessary bulk. This ring needs to have a soft (rubber) coating to let it grip the tubes and prevent paint damage on the rear carrier.

Figure 80: The chain loop ring, a slightly bended triangle.

4.4 The final concept: the chain carrier lock

Figure 81: The final concept on the Batavus Velder.

Figure 82: The final concept on the Batavus Velder.

Figure 83: The final concept on the Batavus Velder.

Cost price estimation:

In the last phase a cost estimation was made to help with concept selection. This cost estimation can be found in appendix B. For the chain carrier lock this estimation is updated following the further development of the concept, as can be seen in table 3. The carrier is now also added to the cost price estimation. However, this is also a component that falls in the savings category. In the end the estimated difference between the current situation and the new concept is €0,50 less then before, mainly thanks to the carrier which is easier to produce. However, the added battery adds costs to the concept. The estimated added costs are €13,50 , which will result in an upcharge of around €45,- for the customer. For reference, an ART-2 certified electric Linka lock with an ART-2 plug-in chain costs around €200,- which is more than €100,- more expensive than a non-electric ART-2 ring lock with chain lock.

Chain carrier lock				Savings			
components	price	pcs.	total	components	price	psc.	total
back plate	2	1	2	ring lock	15	1	15
cover	3	1	3	chain lock	15	1	15
solenoid	2	1	2	carrier	15	1	15
reciever + processor	3	1	3				
wedge	1	1	1				
return spring	0,50	1	0,50				
chain + lockpin	20	1	20				
custom carrier	18	1	18				
internal frame	0,50	4	2				
battery	2	1	2				
cables			3				
assembly			2				
Total			€ 58,50				€ 45
					Δ=€13,50		

Table 3: Cost estimation chain carrier lock

4.5 Prototype

To be able to test and demonstrate the concept, a functional prototype has been build. This has been fitted to a working bike such that it can be used for real-world prototype testing to get a better understanding of the concept. The design of the prototype has been altered such that components could be 3D printed and could house easily accessible electrical components to create the wireless locking function. The rear carrier has been built on basis of an existing carrier making it a bit different than the concept carrier. Still the locking mechanism, the functionality, and the looks of the prototype gave a good representation of the final concept with the main differences being that the printed nylon is a bit rougher and less stiff than metal components would be and that the components were bulkier to fit all components and give enough strength to the printed parts.

Figure 84: The prototype bike.

Figure 85: Drive side with the chain loop and the insertion hole of the lock mechanism.

Figure 86: The chain loop around the carrier tube.

Figure 87: The chain holder.

Figure 88: The chain holder.

Figure 89: The insertion hole of the locking mechanism.

Figure 90: The non-drive side of the carrier.

Figure 91: The lock pin holder.

Figure 92: The chain loop from behind.

Figure 93: A bike bag still fits on the carrier.

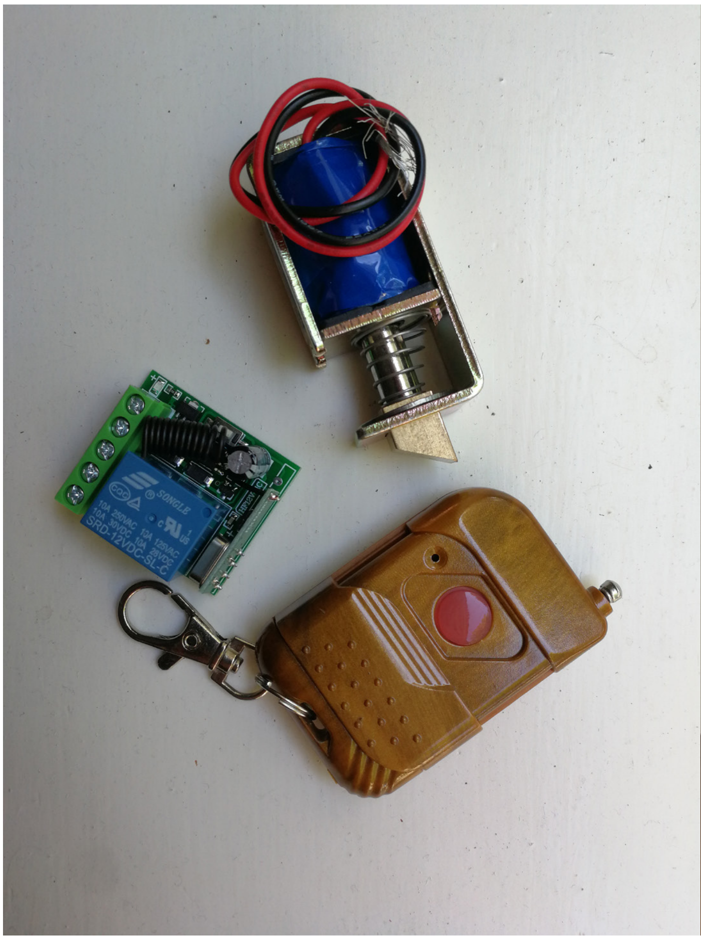


Figure 94: Electrical components used for the prototype.

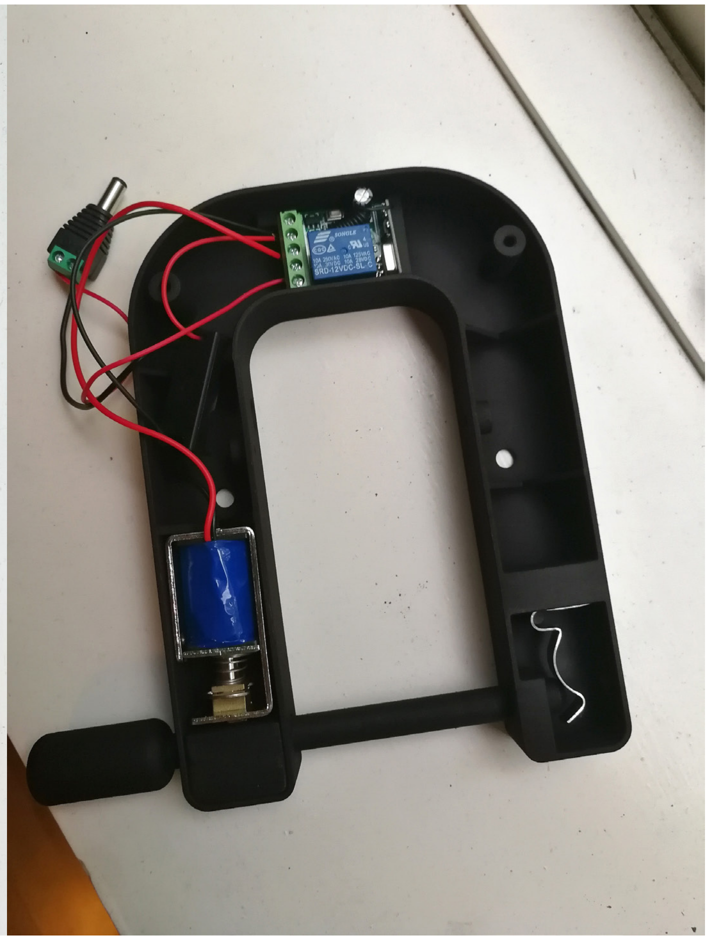


Figure 95: Inside the prototype locking mechanism.

4.6 Prototype user test

With the functioning prototype a user test could be done. The objective of this user test was to see whether the prototype was faster to lock and to unlock and whether users found it easier to use this lock compared to a ring lock with a plug-in chain. Also, the looks of the new lock were part of the requirements and was asked about during the test. To test this a test set-up was made with the prototype bike and a benchmark bike fitted with a ring lock with plug-in chain. The users were people working at Accell who were not involved in the project. They first got a practice run with the benchmark bike after which they did a timed run. Then the same was done with the prototype bike. After this a little interview was held. The full test report can be found in appendix C. The test did not only provide quantitative data in the form of scores and times, but also observations and remarks were noted down during the test.

N	Tb lock (s)	Tb unlock (s)	Tb total (s)	Tp lock (s)	Tp unlock (s)	Tp total (s)	Δ lock (s)	Δ unlock (s)	Δ total (s)	Score use	Score looks	Δ use	Δ looks
1	34	36	70	8	11	19	26	25	51	7	8,5	2	3,5
2	22	22	44	14	18	32	8	4	12	7,5	8	2,5	3
3	25	28	53	7	15	22	18	13	31	8	8	3	3
4	12	14	26	6	10	16	6	4	10	8,5	9	3,5	4
5	12	17	29	5	7	12	7	10	17	8	6	3	1
6	20	29	49	4	8	12	16	21	37	8	8	3	3
7	21	18	39	5	12	17	16	6	22	8	8	3	3
8	8	7	15	7	10	17	1	-3	-2	3	6	-2	1
9	8	8	16	3	6	9	5	2	7	7	7	2	2
10	12	7	19	6	10	16	6	-3	3	9	8,5	4	3,5
11	12	11	23	6	8	14	6	3	9	8	7	3	2
12	13	9	22	6	8	14	7	1	8	7,5	8,5	2,5	3,5
13	20	18	38	4	14	18	16	4	20	8	8	3	3
14	19	20	39	5	10	15	14	10	24	8	7	3	2
15	17	20	37	5	9	14	12	11	23	8	9	3	4
16	27	15	42	3	7	10	24	8	32	8,5	6,5	3,5	1,5
avg	17,63	17,44	35,06	5,88	10,19	16,06	11,75	7,25	19,00	7,63	7,69	2,63	2,69
min	8	7	15	3	6	9	1	-3	-2	3	6	-2	1
max	34	36	70	14	18	32	26	25	51	9	9	4	4
						%	-66,67	-41,58	-54,19			52,50	53,75

Table 4: The quantitative data collected during the test session.

The conclusion of the test was that the new concept is faster to lock and unlock to a pole than the ring lock with a plug-in chain. Within the test pool it was even 54% faster. The users also found the prototype easier in use than the benchmark. It could also be observed that the users had much more difficulties with looping the plug-in chain than the prototype chain. The less experience people had with chain locks, the more they seemed to benefit from the prototype lock. The participants also thought that the new lock looked better, even though it is still rather bulky it fits the bike better and looks more purposeful now that the chain has a dedicated place.

Other important points of feedback that came up during this test was that a lot of people missed a clear click as feedback in the lock pin holder. Also, when twisting the chain, it becomes shorter. This means that the pin would not always be fully inserted into the pin holder. Some users also mentioned that they would like to have more feedback when the lock is locked. Also putting the lock pin in the locking mechanism and in the lock pin holder is a bit harder than with the plug-in chain because the lock pin is longer. Another concern that was shared during the test session was that with the chain mounted to the carrier thieves might cut the carrier open to remove the chain. The full list of observations and remarks can be found in the test report in appendix C.

4.7 Prototype real-world test

To get a good understanding of how this lock functions in the real world the prototype bike is used for a real-world test. A loop of over 20 km is ridden on the bike to test how the chain behaves on different types of surfaces and in different parking situations that you might come across in the city. The findings made during this test are discussed in three phases: riding, locking, and unlocking.

Riding:

Multiple aspects of the lock were tested while riding the bike. First of was whether the chain was in the way during cycling. This is one of the major benefits of this concept. The chain is stored in a good position out of the way of your legs and feet during cycling whereas a chain that is wrapped around your frame or seat post can rub against your legs.

Figure 96: The chain is not in the way while cycling.

Secondly, the noise made by the chain was tested. A regular chain lock wrapped around the frame can rattle against the frame, even damaging the paint. No put holes were avoided during testing and bad cycling lanes with uneven tiles were incorporated. The prototype lock did only rattle against the carrier tubes once when cycling through a deep hole behind a speed bump. This was far from a gentle impact and the whole bike made noises when going through this hole. For the rest of the test the chain stayed in place and did not rattle against the tubes. What did happen though was that the chain itself could rattle a bit. Especially when the chain was hanging a bit lose the links of chain could rattle a bit against each other. This did not make a lot of noise, the chain and cables of the bike made more noises, and it only happened on impacts. It was also a rather subtle noise. It was not really annoying since the rest of the bike made more noises. However, the chain was not 100% quiet.

The third thing that was tested was whether the chain stayed in place while cycling. The chain did not fall out of the holder at the top of the carrier during the test. Even under heavy impacts the chain stayed in place. Another concern was the lock pin. The pin should stay in the holder so that it cannot get caught by the spokes of the rear wheel. When it was in the correct position it did not came lose at all. Also, when it was deliberately not inserted correctly with the pin only inserted a little bit and the chain therefor hanging very loose the chain stayed in place and the pin did not come out of the holder under impacts.

Locking:

Firstly, the bike needs to be parked. This immediately shows the biggest downside of this new lock. The chain length is limited due to the placement on the rear carrier. On the prototype the chain worked out to be 90cm long, which is on the shorter side of the chain length spectrum. Also, the location of where the pin needs to be inserted is fixed on the bike so there is less freedom than with a regular chain lock to lock it. This also means less thinking because there are less options but in practice it means that this lock cannot be mounted to the world in as much situations as you would with a regular chain lock. While testing multiple situations poles and fences did not pose any problems. Only bicycle racks were a problem because there the chain loop is at the front wheel, which was too much of a stretch for this lock while with a regular chain lock you can simply put it through the front wheel or the front of the frame. With current plug-in chains you have often the same problem. But they can be ordered in different lengths and the longer ones can sometimes reach far enough to reach the loop of the rack. When parking the bike in a rack there are three options. You can lock the bike only with the pin and let the chain just hang lose. You can also loop the chain through the rear wheel and then insert the pin, then the bike is still double locked but not to the world. If you really want to have your bike locked to the bike and a rack is your only option, you can still do this but then you need to park you bike backwards in the rack. This looks a bit unconventional and is slightly harder than parking it with the front wheel in the rack. But still, it is perfectly possible to do so and now you can lock the bike to the rack. How much of an issue this is depends on how the user want to use the bike. These bicycle racks are most often found at train stations and bus stops, in the city centre you almost always have other options to park your bike as well. This concept is aimed at the more expensive (e-)bikes. When looking at the bicycle parkings at such stations you rarely see these bikes. People often use older, cheaper, bikes to park there. But nevertheless, this new concept is more limited than a regular chain lock when you want to lock your bike to the world.

Figure 97: Fences do not give any problems while locking the bike.

Figure 98: Locking the bike to a pole works fine ass well.

Figure 99: A regular chain lock can lock the frontwheel to the bike rack.

Figure 100: This lock can not reach the rack, but it can be looped through the rear wheel.

Figure 101: Also these bigger loops cannot be reached.

Figure 102: Parking the bike backwards is an option to still lock the bike to the rack.

Unlocking:

After the bike has been locked it needs to be unlocked as well. The prototype could be unlocked with a remote, just like you would with a key fob. For the real concept unlocking would be possible with both a key fob as well as a smartphone. This gives the user the option to keep the key fob at home if they do not like keys or to use the key fob if they find it difficult to use the smartphone for unlocking the bike. When the lock is unlocked a click can be heard and the pin can be picked out of the lock. One surprising thing that the prototype testing showed was that chain length will change if the chain is twisted or not tightly placed around the corners. In practice this means that although the chain is tightly wrapped over the rear carrier the lock pin will not always end up at the same insertion depth. This can give problems when an indexed click is added to the pin holder. This is an issue that needs to be looked at in further development. Besides this the process is relatively straightforward.

Figure 103: As can be seen in this picture, the lock pin is fully inserted in the lock pin holder while still having some slack left in the chain.

Figure 104: With a twisted chain the length changes. Here the chain is tight over the carrier but there is still a gap of 2cm until full insertion in the lock pin holder.

4.8 Storyboard use case

Storyboard locking:

1. Parking the bike

Find a suitable place to park the bike. Preferably next to a pole or a fence. Make sure that the bike is parked with its drive side facing to the object, this will be naturally since most people step off the bike on the left.

Figure 105: Park the bike next to the object you want to lock it to.

2. Line the bike up

To make locking the bike easier it is best to line up the pole slightly after the chain holder, with the pole being located between the lock and the chain loop. This leaves the most chain length available to wrap around the pole. Because of the long lock pin, it will also be harder to insert when pole is in front of the lock.

Figure 106: Line up the bike with the pole between the chain loop and the locking mechanism.

Figure 107: Parking the hole in front of the pole will make it harder to insert the long lock pin.

3. Take the lock pin out of the lock pin holder

The lock pin can be pulled out of the holder on the left side of the bike. The chain can then be picked out of the chain holder.

Figure 108: Take the lock pin out of the holder.

4. Wrap the chain around the object

When the bike was parked properly this will be easy to do.

Figure 109: Wrap the chain around the object.

5. Insert the lock pin into the lock

The lock pin can be pushed into the locking mechanism, a click from the solenoid can be heard when it is properly inserted, and the lock will be locked.

Figure 110: Put the lock pin in the insertion hole.

Figure 111: Push the lock pin all the way in. Then the lock will be locked.

Storyboard unlocking:

1. Push the keybutton

This can be either on the key fob or on your smartphone in the final concept. When the button is pushed the mechanism will make a clicking sound and the lock pin will be pushed slightly out of the lock.

Figure 112: Push the key or use your smartphone to unlock the bike.

2. Pick the lock pin out of the lock

The solenoid will close again after 5 seconds, but because the lock pin has been pushed back it will stay unlocked also after those 5 seconds giving the user all the time to pick the lock pin out off the lock.

Figure 113: The lockpin can be picked out of the lock again.

3. Wrap the chain over the chain holder

In the current design you need to make sure that the chain is not twisted and that you guide it nicely around the corners to make sure that the pin will achieve full insertion depth. This is a point of attention for further development since it adds unnecessary complexity to the use experience.

Figure 114: Wrap the chain over the chain holder of the carrier.

4. Push the lock pin in the lock pin holder

When the chain was wrapped correctly in step 3, the pin will slide all the way in until the click. The chain is now safely stored away during cycling.

Figure 115: Put the lock pin in the lock pin holder.

Figure 116: When the chain has been correctly guided around the carrier it can be fully inserted into the holder.

4.9 Requirements check

At the beginning of the assignment requirements have been defined for the concept. After choosing the final concept direction these requirements have been further defined to fit the concept. Now that the final concept for this assignment is finished and the prototype tests are completed it is time to check whether the concept adheres to the requirements.

Anti-theft resistance

- **The concept can pass ART regulations.**

Since these are technical specifications, these could not be tested with the prototype. These requirements are important for the further development of the concept into a product ready for market introduction.

- **The concept offers improved anti-theft protection over a ring lock in combination with a chain lock.**

In essence this concept is similar to the benchmark. However, the locking mechanism is very similar to that of Mobilock. They managed to get their lock ART-4 certified, which means that it is better resistant against theft. If Mobilock managed to get their lock ART-4 certified this gives good reasons to think that this mechanism should also be able to pass those tests when done right. Another aspect that came across during testing was that people noticed that this lock 'forces' you to use the chain, whereas in the current situation people often only use the ring lock when in a hurry or when they think it is a safe place to park their bike. Bicycle racks form an exception though because most people will not lock their bike to the rack with this concept whereas this is possible with an regular chain lock.

User friendliness

- **The concept offers improved usability over a ring lock in combination with a chain lock:**

  - The lock is faster in use then the current combination of a ring lock with a chain lock.

The user test proved that the prototype was faster when locking the bike to a pole. The same will probably be true for fences. In the case of a bicycle rack this cannot be compared.

  - The lock scores higher on ease of use then the current combination of a ring lock with a chain lock.

The prototype scored higher on ease of use when locking the bike to a pole. The same will probably be true for fences. In the case of a bicycle rack this needs more testing.

- **The concept is safe to use:**

  - The lock pin will not get caught in the spokes while cycling.

The real-world test showed that the lock pin stays in the holder, also when not properly inserted and riding across bad road surfaces.

  - The chain loop will not get caught in the spokes while cycling.

The real-world test showed that the loop will not hit the spokes.

  - The user will not hit the chain while cycling.

The real-world test showed that the chain is far away from your legs and feet while cycling.

Integration

- **The concept fits the ´core archetype bicycle´:**
  - Mid-engine e-bike
  - In-tube battery
  - Disc brakes

The concept is designed around this bicycle archetype. The concept works fine on those bikes.

- **The concept has an appealing look:**

  - The lock scores better on looks then the current combination of a ring lock with a chain lock.

The prototype scored better on looks than the benchmark lock during the user test.

Business case

- **The concept is technically feasible:**

  - The lock can be produced with current manufacturing methods and materials.
  - The product can be mounted in a timely manner within the assembly line.

There are no overly complex components in the concept. Also, Mobilock has a similar locking mechanism. Mounting the lock to the bike is similar to a ring lock only with the added electrical cable which runs under the mud guard. However, there is often also already a cable for the rear light so this will not be a difficult cable routing.

- **The concept is financially feasible:**

  - The estimated cost price should be in-line with the added value.

The cost price is higher than the benchmark. However, compared to an electronic Linka lock it is cheaper. The lock also offers added value in the form of user friendliness and looks compared to the benchmark which should weight up against the added cost price.

- **The concept differentiates itself from current locks.**

The locking mechanism is similar to Mobilock, but this is not commercially available to buy so it will still be new to consumers. Integrating the chain with the rear carrier in this way is a new concept that is not available yet.

- **The concept is compatible with other types of bicycles.**

By adding the back-up battery to the locking mechanism this lock can probably also be used for other lifestyle bikes with a hub dynamo and a rear carrier.

- **The development of the concept is within Accell's influence:**

  - Accell can bring this concept to the market itself. Third parties may still be used for subcomponents.

The carrier can be produced by Accell itself. The locking mechanism probably as well although they will need some external expertise for this as well. The chain is a component that can be outsourced to companies specialized in producing chains. Still, the overall concept can be bought to market by Accell and it will be hard for other companies to copy this concept as a whole because of all the different components involved.

4.10 Pros and cons

To finish off this last phase of this assignment a value proposition in the form of a list of pros and cons of the final concept is given as well as the conclusion on the final concept.

Pros

- One operation for both the chain lock and the lock pin through the rear wheel instead of two separate locks.
- Carrier bags and carrier straps can still be used.
- The chain has a dedicated place to sit which looks neater and is not in the way while cycling. The chain will also not damage the paint on your frame anymore
- Because of the electronic lock the user can choose between a key fob or their smartphone to unlock the lock.
- Using an app on your phone to unlock the bike also offers the potential to create a bike sharing platform with friends.
- The lock does not need to be charged separately.
- The electronic lock does not have a keyhole anymore which is often used to pick the lock by thieves in case of bike theft.
- The key and the keyhole can also not seize or break anymore over time.
- The actions to lock the bike are more intuitive than with a regular chain lock.
- The lock is faster in use in the case of locking the bike to a pole or a fence than a ring lock with a chain lock. During the user test it was even more than twice as fast.
- This concept is easy to spec on different kinds of lifestyle bikes without modifying the frame.
- This lock encourages people to also use the chain lock and not only the ring lock / lock pin. Insurances are probably going to demand the use of chain locks on expensive bikes.
- The locking mechanism has the potential to become ART-4 certified.

Cons

- Chain length is limited to 90cm, which is too short to reach bike racks.
- Taking the chain of the carrier to gain a bit of extra length takes time and has only very limited effect in practice.
- The electronic lock might fall victim to hackers.
- The lock is more expensive than a regular ring lock with chain lock.
- In the current form the lock is not integrated into the frame, meaning that breaking the lock does not make the bike useless.
- Although not loud, the chain links can still rattle a bit against each other.
- When storing the chain over the carrier the chain length can differ a bit due to twisting of the chain.
- Inserting the lock pin in the lock or the mechanism is a bit harder because of the length of the lock pin.

Conclusion

The chain carrier lock has been further developed. The chain is now better integrated in the carrier to make production easier and to make it better looking. Also, the locking mechanism has had some updates with an integrated battery. The functional prototype enabled user tests and real-world test. These gave some good insights. In general, this concept has some good potential to be introduced to the market. It was more intuitive to use than a regular chain lock and it was also faster in use. It also offers some practical benefits with the option to use your phone as a key and the chain which has a dedicated place where it will not damage the frame or will be in the way of your legs. There are however also some problems that need to be solved before bringing this concept to the market. The lock pin holder needs to be looked into. It needs more feedback and the insertion depth of the chain in the holder changes. The current design cannot accommodate this. The fact that this concept does not work well with bicycle racks is another concern. There is no good insight yet how much of a problem this would be for the target group.

5 Conclusions and recommendations

Bike thieves steal bikes by breaking or picking the lock, lifting the bike, or by stealing components. To prevent theft, it should be made impossible or unrewarding. Four main principles can be used to achieve this: Locking the bike, deterring the thief, making the bike useless after theft, or by tracking the stolen bike. Locking the bike with an ART certified lock is required to get your bike insured against theft. Bike trackers were not considered during the design phases of this assignment since those are already offered as separate products and sometimes even offered by the insurance company. Therefor this is not necessarily a function for the lock. Deterring thieves is often done by alarms. This can be very useful to integrate into the lock but was also not considered during this assignment because it is not related to the locking concept itself, it is rather an additional function which can be added to almost any kind of lock. The lock had to fit the ART requirements though for customers to be able to get insurance for their bike. One of the key requirements for passing ART regulations is the bike cannot be rolled away when locked. The lock also had to fit the current core archetype bike, which is a mid-engine e-bike with an in-tube battery and disc brakes. The goal of this assignment was to come up with a concept for an innovative bicycle lock which would differentiate itself from other locks. The lock should also offer better usability and improved theft protection. In the end the chain carrier lock was selected as the final concept because it best fitted these requirements of all the ideas created during the ideation and the conceptualization phases. Integrating the chain lock with the rear carrier and combining the lock pin of the locking mechanism with the chain makes for a more integrated approach which is more intuitive to use than a ring lock in combination with a chain lock. It also turned out to be significantly faster to lock the bike to a pole with this lock. Because the locking mechanism itself has the potential to be made up to ART-4 standards it makes it harder for thieves to steal the bike. Picking the lock is also not possible anymore because there is no keyhole. This concept also forces the user to use the chain, making it more likely that the bike is locked to the world which will probably also become more important for insurance companies in the future. By using a chain to lock your bike to the world it becomes impossible for thieves to lift the bike away to a quite place to open the lock. However, this lock is not integrated with the frame itself meaning that breaking the lock does not mean making the bike completely useless. This could be changed in future developments but is too much of a risk to do immediately at the first market introduction because all frames need to be adopted for this. The biggest drawback of this concept is the limited chain length which means that locking the bike to a bike rack means parking the bike backwards, which not a lot of people will do. How much off a problem this is for the target group still has to be investigated. The concept did score better on looks than the traditional ring lock with chain lock because the chain had a dedicated place on the bike. This also offers other advantages. There are however still some points of attention that came up during testing that need to be fixed before the concept is ready to be introduced. These will be discussed in the recommendations. All in all, it can be said that the chain carrier lock offers good potential to be introduced to the market. There are still some design aspects that need to be improved and a good market research is needed to see which target group will benefit from this type of lock. In the correct use cases this lock is faster and more intuitive than current ring lock with chain locks. It is also a better integrated solution.

Recommendations:

During the design process and the testing, some points of attention came up that need to be considered before introducing this concept. Below is a list of recommendations that I believe Accell should investigate in further development.

- The lock pin holder should offer the user feedback. The current concept has a single leaf spring which would offer a click. However, the insertion depth of the chain varies due to the twisting of the chain. Therefore, if a chain is used the lock pin holder should offer multiple clicks to accommodate these different insertion depths.
- By looping the chain around the carrier as is the case in the current concept, the tubes of the carrier become the weakest part of the connection. A thief might cut the carrier open to release the chain and carry the bike away. Accell might consider strengthening the carrier.
- The chain loop around the carrier turns out to have very limited added value in practice. The additional freedom that was one of the reasons to do it with a loop is rarely used because the effect is limited. It is also not very convenient to use. This together with the previous point makes me recommend Accell to reconsider whether looping the chain around the carrier is the best solution. Maybe another connection that is fixed and hard to break is better.
- Experiment with a cable instead of a chain. This has been discussed before during meetings, since a cable might look and feel nicer than a chain lock. However, cable locks, especially thick ART ones, have a limited bending radius compared to chains. This would not be suitable for looping the cable around the carrier which is why a chain was chosen. Following the previous point of not using the chain loop, this also opens up the option again to use a cable like for example the Tex-Lock instead of a chain. The cable will also not rattle while cycling and will not twist like the chain does. This means that the problem of various insertion depth of the lock pin holder will most likely also disappear.
- The lock should give more feedback when it is locked. The current click is too subtle, and users were not always sure whether they locked the bike. Either to click should be louder or a visual clue like a led should be implemented into the design.
- A metal prototype of the locking mechanism should be made and tested. The 3d printed prototype was a nice proof of concept. It was however too rough, and it flexed too much to get a good feel of the lock. Also, the lack of a click in the previous point could be a result of the lock pin being made of nylon. Also, it turned out that the strength of the solenoid and the spring force of the return spring should be tuned accordingly to get the lock pin to release nicely, this can only really be tested when the mechanism is made out of metal.
- In the current design the locking wedge is a separate part connected to the solenoid. However, when considering large quantities, it might be worthwhile to order custom solenoids where the wedge of part of the solenoid pin itself. This reduces the number of parts and an assembly step.
- An alarm can be integrated into the locking mechanism to deter thieves.
- Tracking should be kept separate from the lock. It adds significant costs while there are a lot of third-party options available. Also, integrating tracking in the lock means that you lose the tracking when the thief has removed the lock from the bike and replaced it with a new one to sell again.
- For the first market introduction I would keep the locking mechanism separate from the frame as it is designed in this concept. If it turns out that it is an successful product Accell might want to consider integrating the locking mechanism into the frame itself. This will significantly reduce the form factor of the lock and it also offers more protection against theft. Since the lock is than a structural part of the frame, breaking the lock means breaking the frame. This makes the bike useless for the thief. It does require all frames to be designed around this lock though and you cannot fit a traditional ring lock anymore.
- Before introducing this concept to the market, more market research might be needed to make sure that the bicycle rack problem will not be a dealbreaker for too many people. I reckon that this is mainly a problem when parking your bike at a station, in city centres there are almost always other options to park your bike. The target group is probably not using their expensive bikes as a regular train station bike. Still, it is important to be sure about this because this might be the biggest dealbreaker of this concept.

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Appendix

- Appendix A: Solenoid energy consumption
- Appendix B: Cost price estimation
- Appendix C: Prototype user test report

Appendix A: solenoid energy consumption

Most bicycle batteries nowadays have a capacity of 400 or 500 Wh. A 24V solenoid that is powered constantly at 20°C has a power of 1,5 W (Geeplus, 2019).

(400 Wh) / (1,5 W) = 267 Hours.

So, an e-bike battery can power a solenoid constantly for over 200 hours, if that would be the only thing it would power. This means it consumes relatively little power and that it would not have a large negative effect on the range of the e-bike.

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Appendix B: Cost price estimation

To help with selecting the best concept and to rate whether the added value add up against the costs, a cost price estimation for all the concepts is made. The aim of this estimation is to come up with the added costs compared to the relevant benchmark that the concept will be replacing. This will be either the ring lock or the ring lock in combination with a chain lock. Defining the cost price in this stage of development can be hard as not all aspects are well defined, and this is not the stage yet to get quotes from manufactures. Also in the current market, prices change rapidly. Therefor this really is nothing more than a rough estimation.
Three strategies were used to define the estimated costs of parts:

- When an (comparable) part was available on consumers sites, the sales price was divided by three to get an estimation of the cost price of that part.
- When an (comparable) part was available on AliExpress, this price was taken as an estimation of the cost price of that part.
- When the options above did not work, a guestimation was made on how much it would cost to produce such a part. Material, volume, complexity, and production method were considered in the guestimation.

For all concepts, all parts were added on the left side of the table. On the right side the savings were subtracted, this is the benchmark that the concept will replace. The differences are calculated.

Brake disc lock				savings			
components	price (est.) €	Pcs.	Total	components	price	psc.	total
dropout pad	6	1	6	brake disc	5	1	5
latching solenoid	4	2	8	dropout pad	3	1	3
custom brake disc	6	1	6	ring lock	15	1	15
slotted disc	6	1	6			total:	23
lock pin	0,5	2	1				
cover	1	1	1				
reciever + processor	3	1	3				
electronics cover	1	1	1				
solenoid cover/box	3	1	3				
cables			3				
assembly			2				
		total:	40			difference:	17

Integrated chain lock				savings			
components	price (est.) €	Pcs.	Total	components	price	psc.	total
back plate	2	1	2	ring lock	15	1	15
cover	3	1	3	chain lock	15	1	15
magnet / solenoid	2	1	2			total:	30
reciever + processor	3	1	3				
wedge	1	1	1				
chain + lockpin	20	1	20				
pin holder	3	1	3				
chain holder	2	1	2				
internal frame	3	1	3				
cables			3				
assembly			2				
		total:	44			difference:	14

Kickstand lock				savings			
components	price (est.) €	Pcs.	Total	components	price	psc.	total
Kickstand	13	1	13	kickstand	10	1	10
push sensor	2	1	2			total:	10
cables			2				
assembly			1				
		total:	18			difference:	8
						difference with disc lock:	25

Figure B.1: cost price overview.

Appendix C : Prototype user test report

Objective:

During the design of the new lock the following requirements had been defined:

The concept offers improved usability over a ring lock in combination with a chain lock:
- The lock is faster in use then the current combination of a ring lock with a chain lock.
- The lock scores higher on ease of use then the current combination of a ring lock with a chain lock.

The concept has an appealing look:
- The lock scores better on looks then the current combination of a ring lock with a chain lock.

The objective of this test is to see whether the prototype meets these requirements. The hypothesis is that the prototype will meet all three requirements.

Furthermore, by performing this test with people that were not involved in the development of the concept, new insights can be gathered on how people interact with and experience the lock. This can help with defining recommendations for further development.

Test protocol:

Two bikes were prepared for this user test. One was the prototype bike with the new prototype lock and the other was a regular bike with a ring lock with a plug-in chain.

Figure C.1: The prototype bike next to the pole on the left and the benchmark bike with ring lock and plug-in chain on the right.

As can be seen, the bikes are not the same. This would have been better for testing the looks, but this was not practically possible.

The test situation was to double lock the bike both with the lock pin / ring lock as well as with the chain around a pole. The bikes were already parked next to the bikes in a suitable position for both bikes, meaning only the locking and unlocking itself was tested and not the parking of the bike.
The test takes around 5-10 min for each participant and is divided into three phases:

Phase 1: benchmark testing

- The bike with ring lock and plug-in chain wrapped around the frame / seat post is parked next to the pole.
- The participant is given a practice run to lock and unlock the bike and find a way of wrapping the chain that they find most convenient. This run is not timed but observations can be made.
- The participant is asked to lock the bike to the pole, the time this takes is measured.
- The participant is asked to unlock the bike and wrap the chain around the bike again in a way that is suitable to cycle with. The time this takes is measured.
- Observations are made during this test.

Phase 2: prototype testing

- The bike with the prototype lock is parked next to the pole.
- The participant is given a short explanation about the new lock and is given a test run to lock and unlock the bike. This run is not timed but can be used to make observations.
- The user is asked to lock the bike to the pole, this run is timed.
- The user is asked to unlock the bike and store the chain again, this run is timed.
- Observations are made during this test.

Phase 3: interview

- Ask for general feedback / reactions on the new lock:
    - What did they like about the prototype?
    - What did they did not like about the prototype?
    - Other remarks?
- On a scale from 1 to 10, with 1 being difficult and 10 being easy, which score would you give the prototype lock on ease of use given that the benchmark lock would score a 5.
- On a scale from 1 to 10, with 1 being ugly and 10 being nice, which score would you give the prototype lock on looks given that the benchmark lock would score a 5. Make clear this it is about the lock only and not about the bikes they are mounted on.

Outcomes:

On Tuesday the 14th of June the user test was performed at Accell with employees that were not involved in the development of the prototype. The test was performed by 16 participants. The quantitative data that was collected is given in the table below:

N	Tb lock (s)	Tb unlock (s)	Tb total (s)	Tp lock (s)	Tp unlock (s)	Tp total (s)	Δ lock (s)	Δ unlock (s)	Δ total (s)	Score use	Score looks	Δ use	Δ looks
1	34	36	70	8	11	19	26	25	51	7	8,5	2	3,5
2	22	22	44	14	18	32	8	4	12	7,5	8	2,5	3
3	25	28	53	7	15	22	18	13	31	8	8	3	3
4	12	14	26	6	10	16	6	4	10	8,5	9	3,5	4
5	12	17	29	5	7	12	7	10	17	8	6	3	1
6	20	29	49	4	8	12	16	21	37	8	8	3	3
7	21	18	39	5	12	17	16	6	22	8	8	3	3
8	8	7	15	7	10	17	1	-3	-2	3	6	-2	1
9	8	8	16	3	6	9	5	2	7	7	7	2	2
10	12	7	19	6	10	16	6	-3	3	9	8,5	4	3,5
11	12	11	23	6	8	14	6	3	9	8	7	3	2
12	13	9	22	6	8	14	7	1	8	7,5	8,5	2,5	3,5
13	20	18	38	4	14	18	16	4	20	8	8	3	3
14	19	20	39	5	10	15	14	10	24	8	7	3	2
15	17	20	37	5	9	14	12	11	23	8	9	3	4
16	27	15	42	3	7	10	24	8	32	8,5	6,5	3,5	1,5
avg	17,63	17,44	35,06	5,88	10,19	16,06	11,75	7,25	19,00	7,63	7,69	2,63	2,69
min	8	7	15	3	6	9	1	-3	-2	3	6	-2	1
max	34	36	70	14	18	32	26	25	51	9	9	4	4
						%	-66,67	-41,58	-54,19			52,50	53,75

Figure C.2: Quantitative test outcomes.

Within this test pool, locking the bike went 67% faster with the prototype lock. Unlocking was 42% faster and the overall time was 54% faster with the prototype lock. The fastest times of the prototype were faster than the fastest times of the benchmark lock and the slowest times of the benchmark were slower than the slowest times of the prototype. Only one participant managed to be faster with the benchmark lock than with the prototype lock. On ease of use the participants gave the prototype lock a score that was 53% higher than the benchmark lock and on looks the prototype scored 54% higher than the benchmark lock.

Remarks on the test method:

- The situation created to lock the bikes was ideal for both locks. The bikes were parked close to the pole in the correct orientation. In other situations, the outcomes may become different. The most obvious being situations where you would need to unloop the chain from the carrier. However, this also yields partly true for the plug-in chain which is often looped around the frame by the user and kept there during locking and unlocking.
- Due to practical reasons the locks were not mounted on the same bikes. This made comparing the looks of the locks a bit harder for the test persons. Also, the chain used as plug-in chain was a thinner, non-ART, chain whereas the chain used in the prototype resembles a thicker ART-2 chain. This also has an influence on the looks and the feeling of the lock.
- Some people had prior experience with using plug-in chains, others not. No one had experience with the prototype lock. Therefor the practice run was used for both locks. It was however obvious that people with prior experience with plug-in chains did better in this test than people without prior experience. In the ideal situation people would have had more time to practice with both locks. However, to keep test times acceptable for the users this method was chosen.
- The test set-up and the questions asked could have influenced the opinion of the participants while giving the score. This could have resulted in higher scores for the prototype.

Hypothesis testing:

To confirm that the hypothesises are indeed correct the data collected during the user test was also used to perform hypothesis testing. 5 tests are performed to test the locking time, unlocking time, total time, use score, and the score on looks. T-tests are used for this. Since for the times two times are compared that were set by the same person in the same setting a paired T-test was used. For the scores, a single T-test was used to test whether the score was higher than 5, which was the benchmark.

Time locking (paired T-test):

The null hypothesis is that Time benchmark minus the Time prototype is equal to zero. With a 99% confidence interval this test proved that Tb-Tp is greater than zero, meaning that the prototype was faster to lock.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Tb lock	16	17,63	7,25	1,81
Tp lock	16	5,88	2,58	0,64

Estimation for Paired Difference

Mean	StDev	SE Mean	99% Lower Bound for μ_difference
11,75	7,17	1,79	7,09

μ_difference: population mean of (Tb lock - Tp lock)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
6,56	0,000

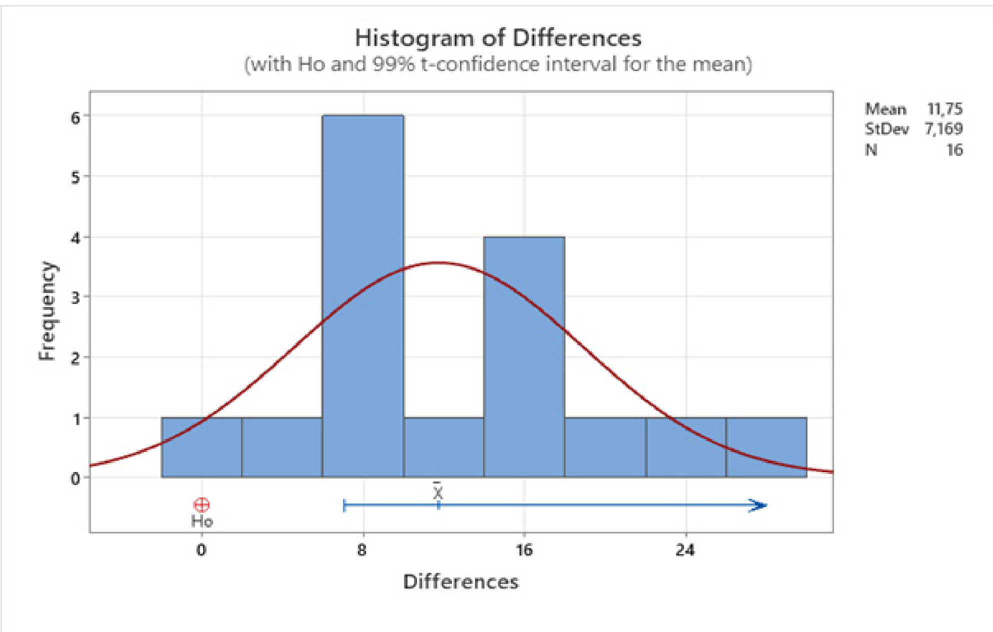

Figure C.3: Hypothesis test locking time.

Time unlocking (paired T-test):

The null hypothesis is that Time benchmark minus the Time prototype is equal to zero. With a 99% confidence interval this test proved that Tb-Tp is greater than zero, meaning that the prototype was faster to unlock.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Tb unlock	16	17,44	8,41	2,10
Tp unlock	16	10,19	3,23	0,81

Estimation for Paired Difference

Mean	StDev	SE Mean	99% Lower Bound for μ_difference
7,25	7,72	1,93	2,22

μ_difference: population mean of (Tb unlock - Tp unlock)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
3,75	0,001

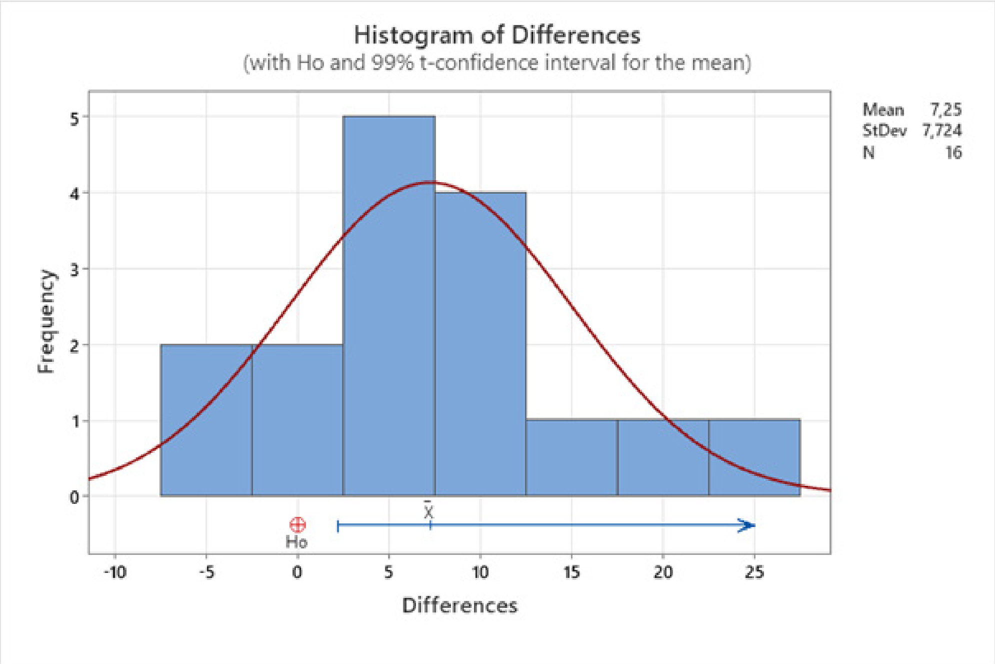

Figure C.4: Hypothesis test unlocking time.

Time total (paired T-test):

The null hypothesis is that Time benchmark minus the Time prototype is equal to zero. With a 99% confidence interval this test proved that Tb-Tp is greater than zero, meaning that the prototype was faster in total. Since one time was on the edge of the normal distribution in favour of the alternative hypothesis, another test was performed where this measurement was deleted. This test still gave the same outcome.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Tb total	16	35,06	14,98	3,75
Tp total	16	16,06	5,40	1,35

Estimation for Paired Difference

Mean	StDev	SE Mean	99% Lower Bound for μ_difference
19,00	13,92	3,48	9,94

μ_difference: population mean of (Tb total - Tp total)

Test

Null hypothesis H_0: μ_difference = 0
Alternative hypothesis H_1: μ_difference > 0

T-Value	P-Value
5,46	0,000

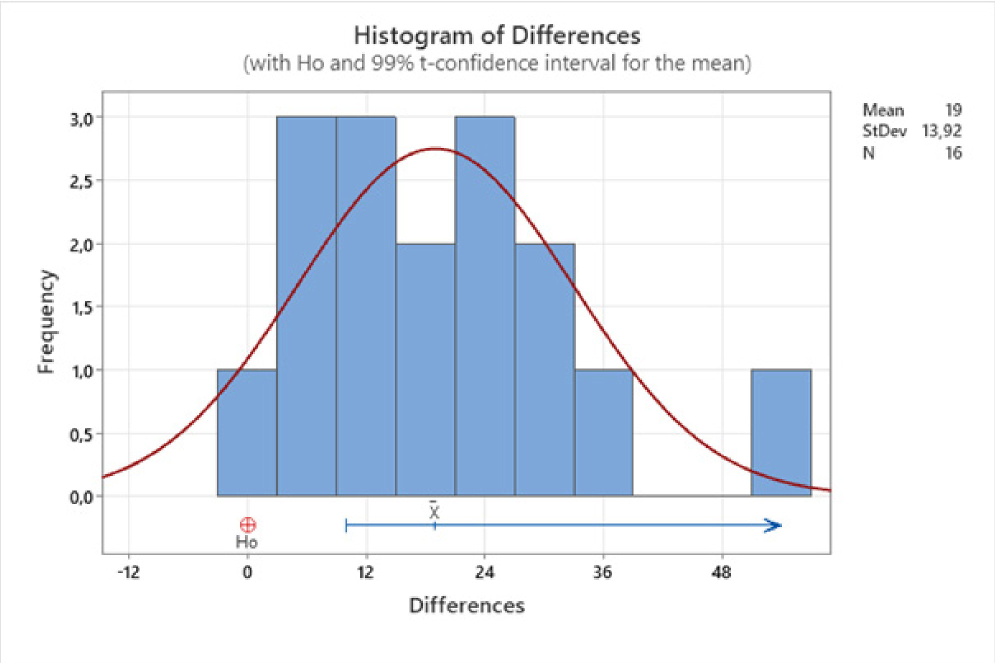

Figure C.5: Hypothesis test total time.

Test with outlier removed:

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Tb total	15	32,73	12,14	3,14
Tp total	15	15,87	5,53	1,43

Estimation for Paired Difference

Mean	StDev	SE Mean	99% Lower Bound for μ_difference
16,87	11,39	2,94	9,15

μ_difference: population mean of (Tb total - Tp total)

Test

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference > 0

T-Value	P-Value
5,74	0,000

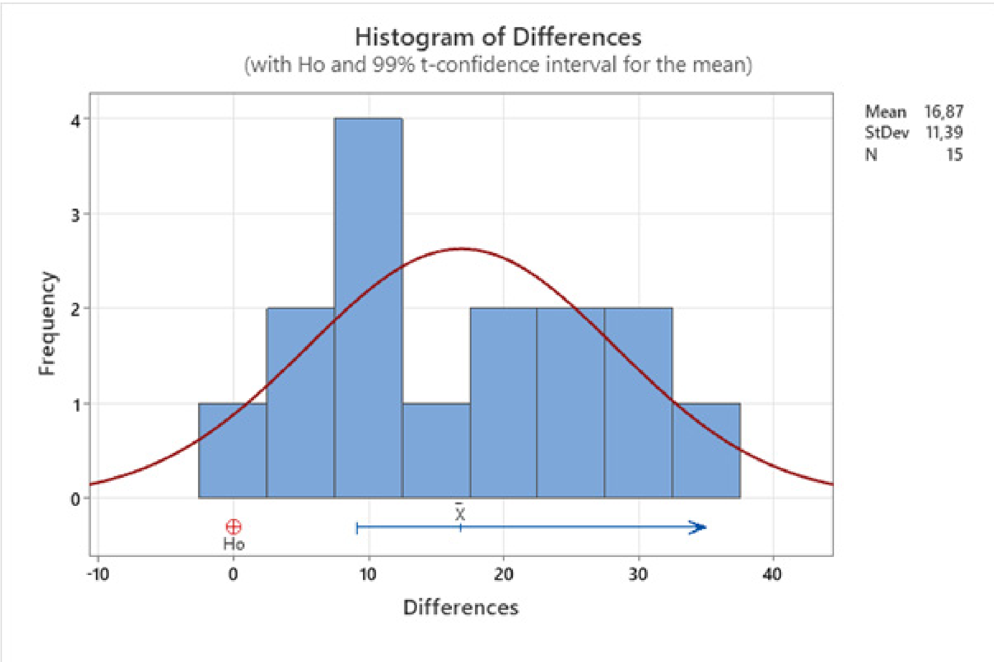

Figure C.6: Hypothesis test total time without outlier.

Score usability (single T-test):

The null hypothesis is that score on usability is 5. With a 99% confidence interval this test proved that score on usability was higher than a 5, meaning that the prototype scored better on usability than the benchmark lock.

Descriptive Statistics

N	Mean	StDev	SE Mean	99% Lower Bound for μ
16	7,625	1,335	0,334	6,756

μ: population mean of Score use

Test

Null hypothesis H_0: $\mu = 5$
Alternative hypothesis H_1: $\mu > 5$

T-Value	P-Value
7,86	0,000

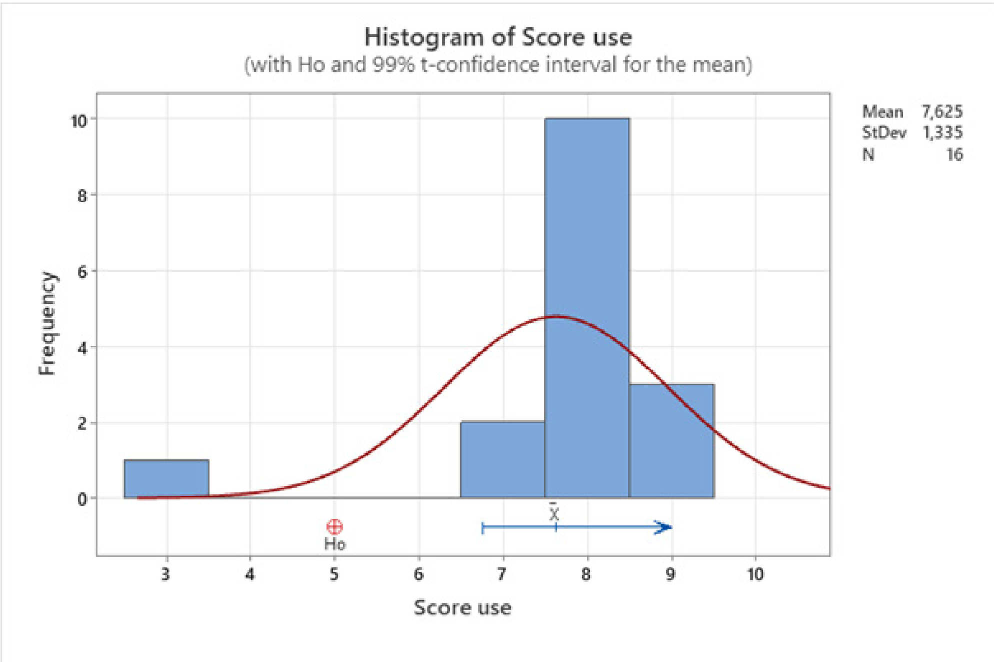

Figure C.7: Hypothesis test use score.

Score looks (single T-test):

The null hypothesis is that score on looks is 5. With a 99% confidence interval this test proved that score on looks was higher than a 5, meaning that the prototype scored better on looks than the benchmark lock.

Descriptive Statistics

N	Mean	StDev	SE Mean	99% Lower Bound for μ
16	7,688	0,981	0,245	7,049

μ: population mean of Score looks

Test

Null hypothesis $H_0: \mu = 5$

Alternative hypothesis $H_1: \mu > 5$

T-Value	P-Value
10,96	0,000

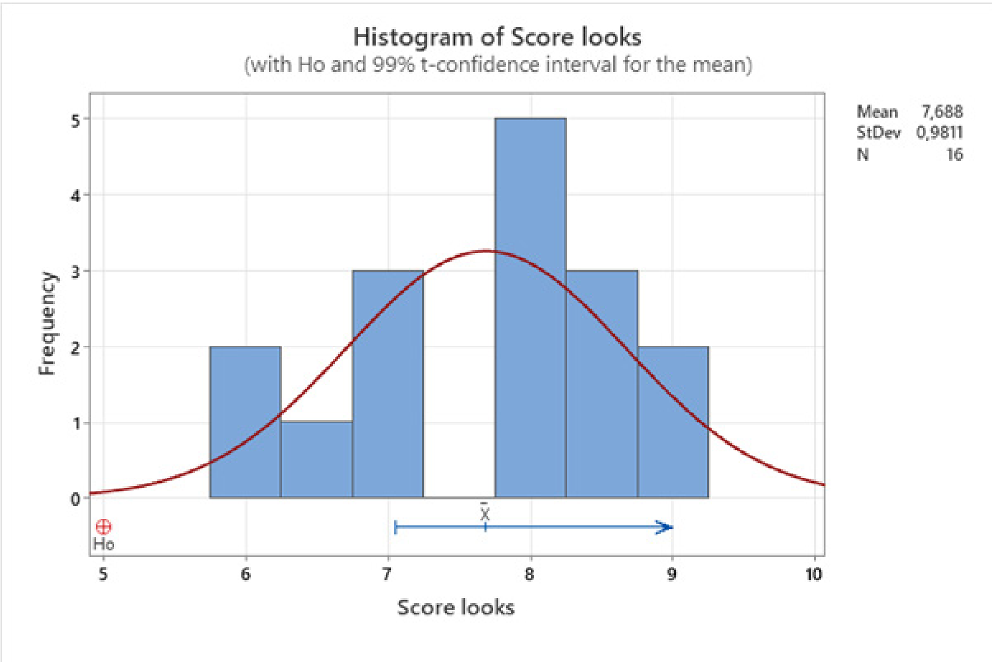

Figure C.8: Hypothesis test looks score.

Use remarks and observations made during testing

While testing observations were made and feedback and remarks were given. This qualitative data is summarized in the following section.

- Multiple people mentioned that they missed a ‘click’ when inserting the lock pin back into the lock pin holder on the rear carrier. This click was designed into the prototype but was not clearly present due to the material used. Besides this, not everybody reached the click, which leads to the following point:
- The length of chain is also dependent on how the links of the chain fall around the corner and whether or not the chain is twisted. There can be up to 3 cm of difference in where the lock pin ends up with an equally tensioned chain. Getting the chain to fold around the corner in the right way asks for some getting used to and takes longer to do.
- Multiple users also mentioned that in practice they also often only use the ring lock when they deem the risk of getting their bike stolen low or if they want to be quick. With this combined lock this also means having to deal with the chain (whether this is then secured to the world or not). This was seen both as an advantage because it stimulates the use of the chain, but also as a disadvantage because in these situations it will take longer and more effort to lock the bike.
- In this concept it is also possible to use the chain as a styling item by using different fabrics on the outside.
- One user mentioned that for this concept the electronic component of the lock has little added value over a mechanical mechanism. The unique selling point of the concept is mainly in the carrier with the chain in a convenient location.
- However, a lot of users mentioned that they liked the electronic key. And they also imagined that it would be nice to use your smartphone to unlock the bike. Some even mentioned to like the idea of keyless entry, similar as with current car keys.
- One user was also exited by the fact that this electronic key will not wear out, whereas mechanical key cylinders can get stuck over time.
- Two users also said that they liked to have more feedback when the lock was locked. The current click it gives is very limited in providing this feedback.
- Multiple users also mentioned that it was hard to get the lock pin back into the holder because you need to aim it in the hole.
- Because the lock pin is longer than with the benchmark chain, someone mentioned that it was harder to insert into the lock, especially when the pole was in the way of the insertion hole.
- Some users did not get the chain into the chain holder the first time right. The remark was also made by some that it could be bigger to make this easier.
- Some people liked that compared to the benchmark the chain has a dedicated place where it is not in the way while cycling. Also, people said that chains wrapped around the frame damage the paint and in this regard this new concept is also better.
- When using a plug-in chain with a ring lock there is also the risk of the lever hitting your finger when unlocking the bike, this can be painful and can not happen anymore with this new concept.
- The remark was made that by looping the chain around the carrier instead of the frame, it becomes easier for thieves to cut the carrier to open the chain. Therefor, some users thought it would be better to mount the chain to the frame. This would give them a safer feeling.
- The looks of the concept were also point of discussion. In general, everyone thought that the prototype looked better than the benchmark. Some really like the looks; others would have wished that the chain was more hidden (i.e., inside tubes etc.) or a bit neater by using a cable lock instead of this bulky chain. Also looping the chain around the carrier was not as neat as some would have liked. Someone also stated that with the benchmark the locks are stored more compact together whereas with this concept the components are more spread around the bike. This concept makes the lock look bulkier but that was not necessarily annoying, in fact, someone also mentioned that it also looked reassuring to have such a bulky lock. It gave a sense of security. Not having a chain dangling around your frame was seen as a big positive by most. Almost all people thought that the bulk of this lock should fit with the bike it is mounted on. On the prototype bike it looked nice, but on the slender steel tube frame of the benchmark bike it would not look nice. For the intended purpose, e-bikes, people thought it would be fine to use this lock.

- The time saving for people with experience with plug-in chains was much smaller than for people without experience with using plug-in chains. There was a large variation in how people used the plug-in chain whereas with the prototype everyone had a similar method. This indicates that this new concept is more intuitive to use than the plug-in chain of the benchmark.
- One especially striking observation with the benchmark lock was that a lot of people locked the ring lock again after plugging the chain back in the lock after looping it around the frame while the task was to unlock the bike. Apparently, putting the chain in the lock is associated with locking the ring lock while this is off course not needed when unlocking the bike. This again indicates that the benchmark lock is not that intuitive to use.
- Some people needed to get used to the idea of not needing the key to lock the prototype.
- Users were especially enthusiastic with how fast it was to lock the bike, for unlocking this was a bit less the case.
- There seemed to be no apparent relation between how enthusiastic people reacted and how much faster they were. Some people were only a bit faster and were really enthusiastic with the prototype while others saved a lot of time and still had all kinds of doubts and questions about the lock.

Conclusions:

The conclusion of this user test is that the prototype meets the set requirements when locking a bike to a pole. The prototype was both faster to lock and unlock than the benchmark. The users also scored the new lock higher on ease of use and on looks compared to the benchmark. The prototype also seemed more intuitive to use with inexperienced users struggling a lot with the chain of the benchmark lock and not so much with the prototype lock. There are however points for improvement, especially the lock pin holder should be looked at.