Screwless mounting of cover for sensor

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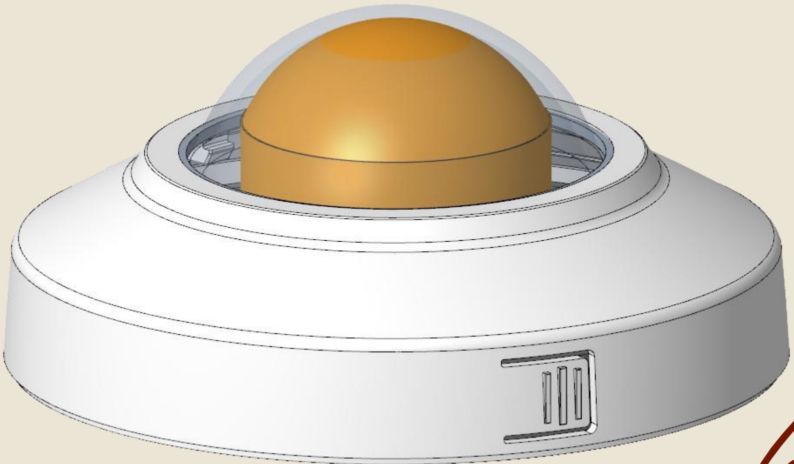
MASTER THESIS



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Finding the best solution to attach a plastic cover onto a metal chassis

Cover figure: 3D-rendering of final concept with a button. (Otto Reerslev)

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Abstract

This report covers the development process of finding the best attach method for a plastic cover to a metal chassis of a sensor. Several manufacturers of electronic equipment use screws as a semi-permanent way of attaching a cover to their product. However, this method is not always appreciated as it takes up volume in the product and makes the exterior of the product unattractive.

The project has iteratively explored several possible methods for attaching two parts and proceeded to create prototypes of three different methods. The prototypes were created by 3D-printing and thus allowed several physical tests to be carried out. By using workshops as a tool for evaluation, the prototypes were iteratively improved. Though, as this project seeks to find the best solution, there was a single concept which turned out to be superior and thus being the result of this thesis project.

The final result of this thesis is a concept utilising a snap-fit attachment mechanism for attaching the two parts. Whilst a button press is required for releasing the snap-fit and thus also the parts.

The thesis concludes that the best solution with a snap-fit and a button release for the cover of a sensor would make the installation simpler given the fact that the assembly requires fewer steps, shorter time and no tools. Even though the solution was not proven to be more intuitive than a screw solution, it was still intuitive to install and disassemble.

Keywords: Screwless attachment, sensor, plastic cover, chassis, installation, product development

Sammanfattning

Denna rapport sammanfattar arbetet av att finna den bästa fästmetoden för en plastkåpa till ett metallchassi för en sensor. Många tillverkare av elektriska föremål använder skruvar som en semi-permanent metod för att fästa kåpan mot produkten. Detta är dock inte alltid uppskattat då det nyttjar volym i produkten och utsidan av produkten kan uppfattas som oattraktiv.

Projektet har iterativt utforskat flera möjliga metoder för att fästa de två delarna och har fortskridit till att skapa prototyper som nyttjar tre olika metoder. Prototyperna skapades genom utskrivning i 3D vilket möjliggör att flera fysiska tester kunnat utföras. Genom att använda workshops som ett verktyg för att utvärdera prototyperna har de iterativt förbättrats. Dock, eftersom detta arbete söker den bästa lösningen var det endast ett koncept som visade sig överlägset och är således resultatet av detta examensarbete.

Det slutgiltiga resultatet av arbetet använder ett snäppfäste för att fästa de två delarna. Medan en knapp används för att frigöra snäppfästet och därmed också delarna.

Arbetet konkluderar att den bästa lösningen med ett snäppfäste och en knapp för att frigöra sensorkåpan skulle göra installationen enklare då den kräver färre steg, mindre tid samt inga verktyg. Även om lösningen inte visade sig vara mer intuitiv än en skruvlösning, var den ändå intuitiv att installera och demontera.

Nyckelord: Skruvfri fästanordning, sensor, plastkåpa, chassi, installation, produktutveckling

Acknowledgments

We want to thank all of the people who helped us with this thesis. There have been several valuable sources of information, feedback and opinions that have helped us to compose this project.

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We are grateful for all those who took their time to participate in our workshops. This includes students at the department of product development as well as participants attending the installation experience center workshop. These occasions have brought new ideas on how to improve the project further which has been of great value to us.

Lastly, a warm thank you to our company administrator, Daniel Åhman and supervisors Nina Bergius and Jimmy Bengtsson for supporting and challenging us throughout the project.

Lund, May 2021

Michael Lindberg & Otto Reerslev

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1 Introduction

1.1 Problem description

1.1.1 Background

The development of modern lifestyles has changed public areas and workspaces to become smarter and safer with the use of technology. There are several electronic devices which can be fitted onto walls and in ceilings to operate for several consecutive years. It could be devices for fire security, air conditioning, motion sensors, wireless connectivity et cetera. Lately these devices have increased in numbers resulting in a high demand of certified installers for such. This means that the ease of installation and serviceability of these devices are becoming increasingly important to consider. The need for a fast, easy, and intuitive way to install and disassemble the devices are therefore requested.

When attaching two parts together there are several aspects to consider, including the materials, forces acting on the parts, possibility to detach, ease of attaching, tools required and more. An attachment method should thereby be chosen upon the requirements given of the specific purpose of the attachment. Regarding the installation of the devices mentioned earlier, they are usually set up to fit a cover over the device and then to secure the cover. When disassembling the fastening must first be released for then to be able to separate the two parts.

1.1.2 Example product to use as a base model for improvements

By using a specific product as a reference model, the development process can easier be applied. This master thesis has been carried out in collaboration with a company manufacturing sensors, upon their request. Hence, is the example product subject to this thesis project, a small sensor of their product series suitable for indoor and outdoor operation. This product may be mounted on walls or ceilings and its power is supplied through a cable. The sensor itself is fragile and thus covered by a plastic cover, which is secured onto the chassis using two screws. Though, screws have the disadvantage of taking up a relatively large volume inside the chassis. This as the screw thread holder must enclose the full screw and provide sufficient support for withstanding the forces acting on it. Furthermore, the outside of the product may be regarded as unattractive since the screws have another colour than the rest of the plastic cover and that it breaks the otherwise, homogenous shape. The product consists of several parts where the key parts for this thesis is the plastic cover and the metal chassis, see Figure 1.

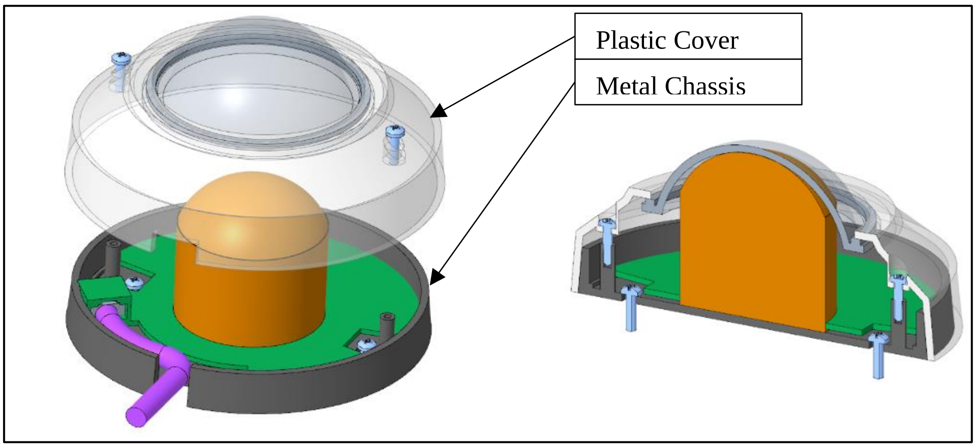


Figure 1 The example product is a small round sensor. The plastic cover is mounted with two screws onto the chassis after the cable has been installed. The product contains a circuit board.

1.1.2.1 Chassis

There are several different styles for the chassis of these sensors, depending on its purpose, manufacturer and model. This means there are several variants as they aim to hold different hardware components and operate in different environments. The chassis of this product has the purpose to serve as a platform onto which the sensor may be mounted. The chassis also holds the electronics and has two holes for the cable to supply power. One hole is situated on the circumference of the chassis while the other is just adjacent but on the bottom side of the chassis.

1.1.2.2 Plastic cover

The plastic cover is the outermost part of the product and is covering the metal chassis, setting the esthetical outside of the product. The plastic cover serves as a protecting barrier for dust, water and collisions. It has an outer diameter of approximately 10 centimetres and holds the dome in its centre which is protecting the sensor. There are two holes in the cover to fasten the screws for the cover to the chassis. The screws require nine full revolutions to be fully fastened.

1.1.2.3 Installation process

Firstly, the sensor and printed circuit board (PCB) are fitted into the chassis and secured to it using screws. Then the chassis is attached to the selected mounting surface, such as a wall, using screws. The sensor inside the chassis can then be adjusted to fit the situation. Next, the plastic cover is attached onto the chassis, covering the sensor and finalizing the installation.

1.1.3 Products for benchmarking

The product described above will be used as a reference model for benchmarking new concepts throughout the project. An additional product produced by the same company will also be used when evaluating the new concepts. This additional product has a snap-fit attachment that uses the flexible cover to pass over the catches whilst a bayonet twisting motion is required for releasing the two parts.

1.1.4 Goals

This master thesis seeks to develop the best concept for mounting a plastic cover onto a ceiling-mounted sensor. The final goal is to design a 3D-model and a prototype of the best attachment method for the plastic cover of the sensor. The example product with screws for mounting will be used as a reference when benchmarking the new concepts.

Another goal is to thoroughly investigate what possible attachment methods that may be used for similar applications. By doing so, the outcome of this project will serve as a foundation for the development of future products.

1.1.5 Assumptions

The product is assumed to be of a round shape of roughly Ø100mm and the cover should completely enclose the whole chassis, except for the bottom side. The plastic cover is assumed to be produced by injection moulding and made from a relatively stiff plastic of the same material as the example product. The chassis is assumed to be produced in cast aluminium due to the necessity of conducting heat from the electronics. The chassis will hold a big sensor in the middle and be mounted to the selected surface using screws. The typical product is assumed to be produced in high volumes. The cover is assumed to be lightweight and can be held in one hand. The cover can be mounted and dismounted multiple times. The cover is also assumed to have a hole on one side to allow side cabling.

1.1.6 Delimitations

As this thesis is focusing on electrical sensors which have a limited lifespan, the products must be serviceable and thus requires a non-permanent attach method for the outermost cover. Consequently, the thesis will not look into any permanent attach method. In addition to this will the thesis not alter the sensor itself nor substitute it for another. Hence the chassis, cover and dome will therefore need room for a sensor of equal size to Figure 1. Furthermore, the plastic cover should be kept as one complete part since splitting it gives more parts which can be troublesome for an installer to handle. Also, this thesis does not aim to develop a full attachment solution where simulations and functional tests have been carried out. The thesis is also delimited from assigning full dimensions and performing cost analyses of the planned concept.

1.2 Individual contributions

The development was conducted together as a team, see Appendix A for a detailed time plan. The development includes brainstorming, construction of screening and selection matrices, preparation and execution of workshops. The contributions of documenting the workshops were made entirely by Michael, while the preparations of the prototypes for the physical workshop were made by Otto exclusively.

2 Methodology

2.1 Ulrich and Eppinger's product development process

According to the project description, this project's purpose is to rethink and improve the attachment of a cover for future products. By using the product development methodology suggested by Ulrich and Eppinger (U&E), one or a few new solutions may be generated. The methodology provided by U&E was used as a foundation, though slight modifications were made to better fit this assignment. According to their book, the generic product development process can be divided into six phases as depicted in Figure 2. (Eppinger & Ulrich, 2012, s. 9)

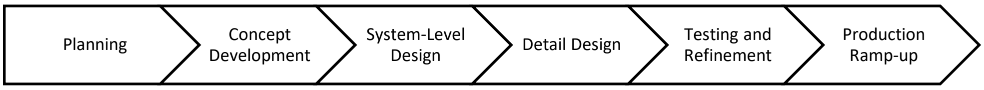


Figure 2 The generic product development process's six phases according to Ulrich & Eppinger. Courtesy to Ulrich & Eppinger.

This project focuses on the concept development phase, which is the part of the product development process where new design concepts are viewed, tested and analysed. The concept development phase is described by (Eppinger & Ulrich, 2012, s. 15) as "In the concept development phase, the needs of the target market are identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing."

According to studies by (Boothroyd, 1996) (Porter & Knight, 1994) the concept stage is significant since it involves several important decisions which have a large impact downstream on the final cost of the product.

According to U&E, the generic concept development process is divided into the seven front-end activities depicted in Figure 3. It is clarified that the activities are ordered roughly in this sequence, while the activities rarely proceed in a sequential fashion in reality. Instead, the activities do often overlap and new information at a later stage may require stepping back or to iterate an earlier stage. (Eppinger & Ulrich, 2012, s. 16)

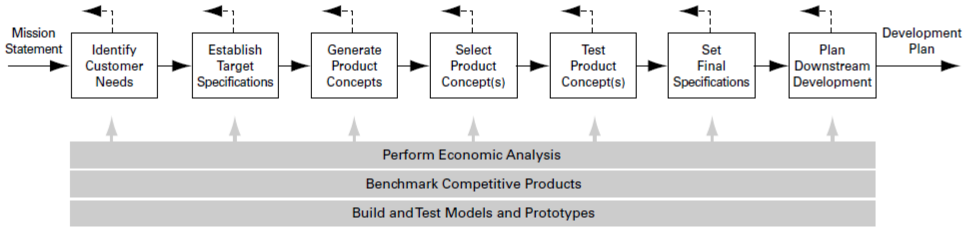


Figure 3 The generic concept development process according to U&E. Courtesy to Ulrich & Eppinger.

2.1.1 **Identify Customer Needs**

In order to ensure that the product is focused on the customer and to ensure that no customer is missed, U&E suggests that a method for identifying customer needs should be followed. This five-step method is also used to identify latent, hidden and explicit needs. Furthermore, the method facilitates the development by unifying the team's view of customer needs. The steps provided by (Eppinger & Ulrich, 2012, s. 75) are as following:

- Gather raw data from customers.
- Interpret the raw data in terms of customer needs.
- Organise the needs into hierarchy of primary, secondary and tertiary needs.
- Establish the relative importance of the needs.
- Reflect on the result and the process.

2.1.2 **Establish product specifications.**

Product specifications are defined by what the product has to do in a detailed, measurable way. Each specification consists of a metric and a value. Even though the product specifications do not explicitly tell the development team how to address the customer needs they serve as a tool of what to achieve in order to satisfy the customer. Ideally, U&E suggests establishing the product specifications early in the project and then work thoroughly to meet every single specification. The proposed process by (Eppinger & Ulrich, 2012, s. 95) for establishing the product specifications is:

- Prepare the list of metrics.
- Collect competitive benchmarking information.
- Set ideal and marginally acceptable target values.
- Reflect on the results and the process.

2.1.3 Concept generation

Since the success of a product largely depends on the quality of the underlying concept it is of great importance for the development team to find a promising concept. Though it may neither be expensive nor time consuming compared to other development phases it shall still be done extensively to generate a sound concept (Eppinger & Ulrich, 2012, s. 118). The foundation of the concept generation process is the customer needs and product specifications established previously. Then, the process follows the ensuing five-step process:

- Clarify the problem.
- Search externally.
- Search internally.
- Explore systematically.
- Reflect on the solutions and the process.

2.1.4 Concept selection

The process of concept selection is described in (Eppinger & Ulrich, 2012, s. 144) as: "Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development." There are two main approaches to the concept selection process. Either through use of concept screening where concepts are tested relative to a reference concept or concept scoring in which the selection criterions are weighted depending on their relative importance to the concept. Both these two approaches use the following six-step method:

- Prepare the selection matrix.
- Rate the concepts.
- Rank the concepts.
- Combine and improve the concepts.
- Select one or more concepts.
- Reflect on the results and the process.

2.1.5 Concept testing

A great way of determining which of a few potential concepts to proceed with is by using the concept testing method described by (Eppinger & Ulrich, 2012, s. 166). Though, prior to testing, it is required that the number of alternatives are reduced since is only feasible to test out one or a few concepts with customers. The seven-step method for the concept testing is as follows:

- Define the purpose of the concept test.
- Choose a survey population.
- Choose a survey format.
- Communicate the concept.
- Measure customer response.
- Interpret the results.
- Reflect on the results and the process.

3 Theory

3.1 Injection moulding of plastics

Injection moulding is a manufacturing process which can be used with several different materials ranging from metal to plastic. Injection moulding of plastics is a very effective production method allowing complex parts with small or large volumes. However, since the moulding machines and moulds are relatively expensive, the producing volumes must typically be large to be profitable (Bruder, 2015, s. 111).

Typically, an injection moulding machine consists of an injection unit and a clamping/locking unit. The process starts by melting the plastic material to liquid state and then inserting the correct amount into the clamping unit. Two mould halves create a cavity or cavities inside the clamping unit in where the liquid plastic is inserted under pressure. One of the halves is fixed to the injection nozzle while the other halve is mobile and often attached to a hydraulic piston. (Bruder, 2015, ss. 112-114)

When designing plastic parts for injection moulding, there are several design aspects to consider for the part to be manufacturable. There are handbooks and design guides given out by the raw material suppliers, such as (DuPont, 2000) (LANXESS Corporation, 2007) (Dutch State Mines, DSM, 2021), with design considerations for their materials. Even though the details may differ between these guidelines, the general rules of thumb are the same. Hence, the following three rules are referenced from (Bruder, 2015).

The first rule for a successful manufacturable part geometry, is to have a uniform wall-thickness. As liquid plastic shrinks during solidification, uneven cooling or uneven wall-thickness leads to uneven shrink that can produce internal stresses and warpages. Some variation of wall-thickness is allowed throughout the design if the transitions are not abrupt. The even wall-thickness constraint makes it necessary to design ribs, bosses and corners with certain care, and should be done within recommended limits from raw material suppliers, to prevent sink-marks and warpage. (Bruder, 2015, ss. 151, 238-259)

The second rule is to avoid sharp corners as plastics are sensitive to stress concentrations and could break at moderate loads. It is recommended for corner radius to be at least 0.5 times the wall thickness, while it is important to know that the sensitivity is heavily dependent on the material used. Sharp corners also have poor flow characteristics when filling the mould. (Bruder, 2015, ss. 151, 251-259)

A third rule for a manufacturable part is that the geometrical shape must not prevent the mould halves from releasing the part at the end of a cycle. Draft is essential for ejection of the part, especially as the plastics shrinks it could adhere on to the mould. Draft should be added to the whole design including walls, ribs, bosses etc. A minimum draft angle of 1-2° is needed for smooth surfaces, while etched surfaces should have larger draft-angles. (Bruder, 2015, s. 138) The ejection is typically assisted with an ejector system, where pins, a rail or a plate will push out the part at the end of the cycle. (Bruder, 2015, s. 137) With the use of slides added to the mould, the design may be more advanced and still allow the part to release. Slides allows the manufacturing of cavities and ribs that needs a perpendicular separation-direction compared to the mould's separation-direction (Bruder, 2015, s. 124).

3.2 Bonenberger's snap-fit development process

The snap-fit development process described by Bonenberger in his book: The First Snap-Fit Handbook, is a systematic process for developing a mechanical attachment (Bonenberger, 2016). The methodology was originally intended for developing snap-fit interfaces, but it is stated that "[…] the design principles here can, and should, be applied to all mechanical attachments and interface designs." (Bonenberger, 2016, s. 10).

The process originates from design for assembly (DFA) and turned out as a handbook containing tools, nomenclature, equations and methods for the product designer to use not only in DFA. The most important take-away from the book is that the term snap-fit is not defined as a flexing piece of plastic that locks an attachment but is instead defined as the entire attachment interface composed by locators, locks and guides.

3.2.1 The snap-fit development process

The snap-fit development process consists of six phases that stretches from the decision to use a snap-fit attachment and ends with a completely designed application ready for production. The first phase begins with defining the basic functionality of the application, defining the basic shapes involved and by specifying general requirements and conditions. This phase is followed by a technical benchmarking to study similar snap-fit applications to acquire both inspiration and understanding of the application. The third phase is where various conceptual ideas are generated and compared to each other. This phase is described to be one of the most important phases, as it includes a set of critical decisions of which engagement direction (ED), assembly motion (AM) and constraint pairs to be used. The third stage ends by selecting the best concept. The fourth phase is where the features are designed in detail. An important part of this phase is to determine the dimensions related to assembly forces, separation forces, retention strength, acceptable stress & strains etc. By the end of this phase, a first design could be produced as prototype. The fifth phase is where the design is confirmed by a first production. An initial evaluation of the concepts design is done and ideas for improvements are noted. The sixth and final phase is to fine-tune the design even further, which leads to a complete design ready for production. The reader is referred to the book for further details. (Bonenberger, 2016, ss. 204-232)

3.3 Prototyping using 3D-printers

To transform research and ideation into a physical product is described as a critical feature by (Hanington & Martin, 2012) as it allows for concept testing to be carried out. However, the model itself does not have to be physical as it can be in digital form but relevant to this thesis, the prototyping will focus on physical prototyping, specifically 3D-printing as it enables more accurate evaluation.

Low fidelity prototypes will be used in an early stage to test out concepts and specific mechanisms. Gradually, the fidelity will increase to finally have prototypes with relatively fine tolerances.

To develop 3D-models can be both time consuming and costly. However, the cost is in most cases regained, several times over, as the cost of identifying flaws in the early stages are much less costly than finding them and fixing them later in the development process. This is true according to the 1-10-100 rule first presented in 1992 (Labovitz, Chang, & Rosansky , 1993, s. 183), see Figure 4.

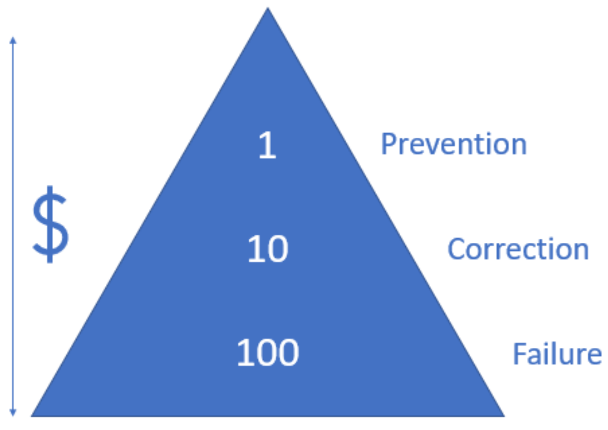


Figure 4 The 1-10-100 rule. (Michael Lindberg)

4 Identify customer needs

4.1 Data gathering

4.1.1 First installation workshop

An installation workshop was conducted with the purpose of mimicking an installer's or customer's interaction with the product. The reasoning for selecting a workshop as a source of data is due to it being one of the proposed ways to gather raw data by observing the product in use, according to (Eppinger & Ulrich, 2012, s. 77). Two electric devices consisting of a metal chassis and a plastic cover were therefore used. One had screws for fastening the cover while the other had a snap-on and twist off solution. Additionally, there was a hole for the cable supplying power and both could be mounted in the ceiling or on the wall with the use of screws. The presence of different tools such as a manual screwdriver and power tool but also several wall materials for fastening, like soft tile and wooden plates made the outcome of the workshop extensive.

The installation provided experience about the ergonomic positions of the installer, the tool usage and the forces needed. It was also evident that the main stakeholder to consider for this development process is the installer since it is the installer who is handling the product in nearly all cases. During the workshop it was also noted that the cabling makes the installation more troublesome and is therefore an important aspect to take into consideration. By letting someone install the device without instructions for the first time, the process reveals whether the installation is intuitive or not. The time it takes to install was also valuable information which was heavily influenced by technique and training. After mounting and dismounting the products a couple of times the time required for completing an installation was greatly reduced. Conclusively, the workshop indicated that a positive overall perception from handling the product is important. Yet, more notable was the find that the installer must feel that the product is intuitive not only to install but also to disassemble.

4.1.2 **Discussion with experienced engineers**

To better understand the example product and its potential improvements, several discussions with experienced engineers were held. The essential points were that it is important to focus the development on the user. Who is the main user, how will he or she use the product and how often? Another important aspect was to make sure the product is feasible to manufacture. This is relevant for this thesis since complex parts and mechanisms may be created easily in 3D-printers but are difficult and costly to injection mould in plastic. The third and final point was that a producing company always seeks to improve existing products and to maintain their reputation amongst customers. It is therefore important to consider the quality aspect of the concepts developed.

(Experienced engineer Jimmy Bengtsson & senior engineer Nina Bergius, company manufacturing sensors, Lund, Sweden, personal communication, 13 January 2021)

4.1.3 **Discussion with a product owner**

During a video meeting with the product owner for a product applicable to this thesis, the project group had the possibility to get confirmation on the information extracted from the workshop conducted previously.

During the discussions with the product owner, it was confirmed that this type of sensor is intended for use indoors where a small visual footprint and a low price are important properties for the end customer. It was also confirmed that these products are mainly mounted in ceilings, where the soft-tile installation is most troublesome. When discussing the stakeholders, the end-customer was clearly pointed out as most important. However, the person installing the product should also be noted as a key stakeholder, especially regarding the mechanics of the sensor. By satisfying the person installing the sensor, the end-customer will most likely share the same opinion since it means the product has been installed quickly and without issues.

The product owner stated that the products are mostly sold to a professional market. The concept will thereby most often be handled by professional technicians, with a few exceptions. There are smaller businesses that occasionally install the products on their own, and thereby the concept cannot be too advanced. The installer should thereby be viewed as both professionals and non-professionals.

(Martin Jensen, company manufacturing sensors, Lund, Sweden, personal communication, 15 February 2021)

4.1.4 Discussion with a product specialist

During a video meeting with a product specialist for a product applicable to this thesis, additional information and confirmation was provided. The product specialist is responsible for knowing the details of the product while it is out on the market.

The discussion brought light upon the feedback customers had submitted in regard to the alternative product with a snap on and twist off attachment. According to this, supplemented with information from installers of the product, there are potential for improvements regarding both the mounting and dismantling. The feedback did not state in a clear way the exact problems of dismantling but was instead summarized as not being easy enough. Some customers didn't appreciate that they needed to hold a hand behind the soft-tile in order to install the plastic cover. Another customer had got a few soft-tiles damaged during installation, which was connected to the problematics of attaching the plastic cover. Additionally, the product specialist stated that it is recommended to have a wooden plate on the backside of the soft-tile. The reason is because the two screws that will attach the chassis into the ceiling will need something to attach into and a soft tile may not be compact enough.

When discussing if the end-customer is affected by the installer, it was stated that a time-consuming installation will keep the end-customer waiting and could thereby increase the installation-cost.

(Jacob Shamekhi, company manufacturing sensors, Lund, personal communication, Sweden, 16 February 2021)

4.2 Product Lifespan

The products lifespan, the time from when it is manufactured to when it is recycled, was analysed to further understand the product. By introducing phases that the sensor goes through during its lifetime, such as manufacturing, installation, operation and service, different areas of interest can be found. This tool was used for organizing customer needs and to rank the criteria. The phase-analysis reveal how a concept must compromise between certain criterion from different phases. An example would be a concept that is positive because the ease of installation, but the concept is visually ugly which gives a negative value for the operation-phase.

The result of the lifespan analysis is shown in Figure 5. The typical sensor product is mainly constructed for fulfilling a specific function. It is typically installed once and then in operation for many consecutive years. The most important phase to consider is therefore the operation phase since it has the longest duration. Yet, for this thesis the installation phase will be of great interest as well. After some time in operation the sensor may need service or is uninstalled as its time in operation has come to an end. Given that it is a technically advanced product, pre-assembling the parts into the chassis is necessary prior to distribution. The products lifespan ends by disassembly and recycling. Note that the lifespan analysis was made mainly to visualise the products lifespan and are based on assumptions and not on data.

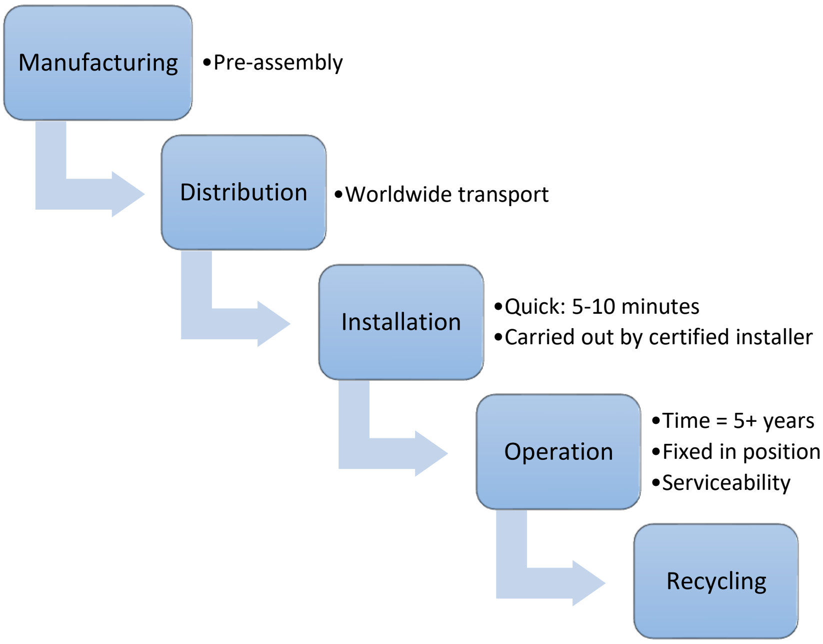


Figure 5 The lifespan of a typical sensor where five phases are covered. (Otto Reerslev)

4.3 Define stakeholders

In order to fully identify the customer needs for the product subject to this thesis, it is necessary to understand who the customer is. Therefore, an explanation of the stakeholders is hereby presented. It is noteworthy that a complete sensor-product has a specific function to fulfil for the end-customer, whereas this project focuses on the mounting of the cover.

There are two primary stakeholders to this product, the installer and the end-customer. In regard to this thesis, the installer is the principal stakeholder to take into consideration as the process of mounting and detaching the plastic cover to chassis is mainly carried out by the installer. The end-customer will nevertheless be the paying stakeholder, who wants the sensor to fulfil the desired function. This stakeholder will not be as interested in the specific attachment solution, as long as the product is functionally fulfilling the requirements.

Though it shall also be mentioned that there are additional stakeholders which will not be considered in detail in this thesis. These stakeholders, which will be named secondary, could sometimes be considered when selecting a concept but are not rated as high compared to the primary. One such stakeholder is the person who is in the same room but never physically in contact with the product.

4.4 Define user cases

A user case will be defined as any time a person is physically handling or interacting with the cover together with the chassis. By including expected future use of the product early in the development process it is easier to plan for the forthcoming phases of the development which is highly desirable for products with critical functional elements (Eppinger & Ulrich, 2012, s. 61). The user cases are closely related to various installation cases, but have been extended with cases relevant during procurement, maintenance, troubleshooting and disassembling.

4.4.1 Components for user cases

A number of installations were decomposed into a number of categories, to systematically explore the physical handling of the plastic cover and the chassis. By combining different components, a variety of different user cases can be constructed. The categories and components can be seen below:

Situations when handling the product Handheld testing (during design & procurement), new installation, during maintenance, disassemble the product.

Stakeholder interacting with product: Installer, end-customer, product designer.

Surface behind while mounting/demounting: In hand, on wall, in ceiling.

Material mounting to: Concrete, wood, plaster wall, soft tile, brick wall.

Cabling alternatives: No cabling, see second alternative in Figure 6, cabling from side through cabling hole without hole cover piece, see first alternative in Figure 6, cabling from side through cabling hole with cover piece, see third alternative in Figure 6, cabling from behind or underneath, see Figure 7.

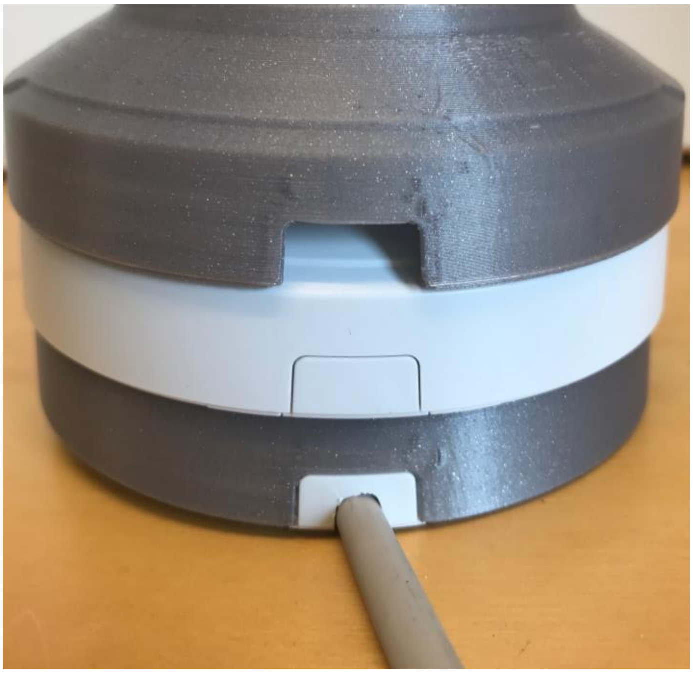


Figure 6 Side cable hole alternatives. From above; without cable hole cover piece, with intact cable hole piece cover, tailored cable hole cover piece. (Michael Lindberg)

4.4.2 **Four typical user cases**

Four of the most important user cases are discussed briefly below.

4.4.2.1 Handheld interaction without any surface for mounting

While discussing the product at a retailer's shop, or handling the plastic cover at a design meeting, either an installer, a customer or an engineer is interacting with the plastic cover to get a feeling of the product. These occasions are important as this interaction will affect stakeholders' thoughts of the product.

These occasions do not include a surface to mount the sensor and most often without a cable. With a downscaled situation, this is however the time when a customer often decides whether to invest in this product or not.

4.4.2.2 New installation in a soft-tile ceiling

Installation of a sensor in a ceiling is typical and needs the installer to work with both their hands over one's head, which is exhausting after a while. The installation is often done on a ladder or similar height above the floor. One common ceiling-installation is the installation in a soft-tile in the ceiling. This installation is complicated because a soft tile has no additional force other than its own weight keeping it in place.

When mounting sensors in the ceiling, it is common to exit the cables through the ceiling and then use the intended cable hole on the back of the chassis, see Figure 7.

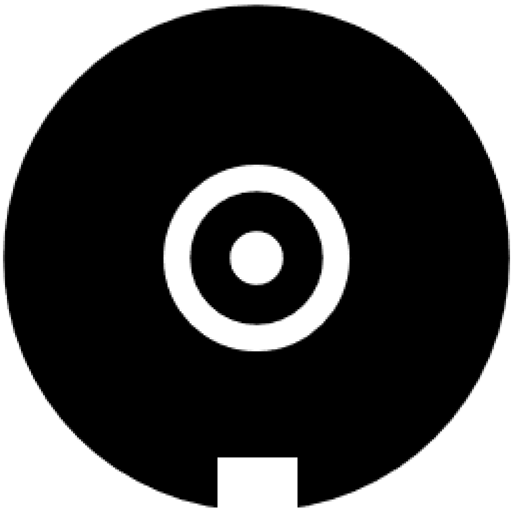


Figure 7 A hole in the chassis back allows cabling to exit the product through the ceiling/wall. (Michael Lindberg)

According to measurements conducted, a square soft-tile of approximately 592x592x15 mm weighs 450g. In the case of an added chipboard behind the soft-tile, for screws to attach firmly, an additional 1450g may be approximated to be added. Thereby a force acting upwards on a soft-tile should be ~18,65N maximum to not lift the tile up, while a force downward could be higher. Twisting motions are also allowed as it has support around all four edges.

4.4.2.3 New installation on a wall

Installing a sensor on a wall is rather straightforward compared to the ceiling mount. The wall gives support upon pressure which means a sensor can be held in place by a pushing force. If the cabling should be installed along the wall, the hole cover piece should be either removed or modified depending on the number of cables that enters the sensor.

4.4.2.4 Disassemble of sensor in ceiling

While an already installed sensor does usually not require it to be interacted with. However, there are some occasions due to maintenance where it is required to disassemble a sensor. For an installer who has not been in touch with a sensor for a long time, a quick and intuitive disassemble is preferred.

4.5 Customer needs

From the data gathering and the user cases, the following customer needs were identified. However, the customer needs were set up for a general product, not the example product to allow usage for similar products. The customer needs were set up for the plastic cover, chassis and the attachment solution according to the project's delimitations.

According to U&E, the customer needs should be organized into a hierarchy with a set of primary needs that are further described with underlying secondary needs. This has been implemented and the relative importance of the needs have been defined by marking each need as either desired or needed. (Eppinger & Ulrich, 2012, s. 75)

The customer needs have been interpreted from the data sources. Both the details and the essence that were mentioned in the discussions provided a look into past experiences. Moreover, the customer needs have been provided with the source of the need which can be of great importance for further discussions and investigations. Each need was marked desired or needed based on the interpreted understanding of the relative importance of the need compared to the others. Furthermore, it did become clear that these needs and their weighting are subject to change if they were intended for another application.

The needs from each individual stakeholder are all necessary to consider in order to find the best solution. Therefore, the cover's summarized customer needs are presented in Table 1.

Table 1 Customer needs divided by type of stakeholder. Sources are abbreviated according to; I – first installation, D1 – discussion with experienced engineers, D2 – discussion with product owner, D3- discussion with product specialist. The customer needs are set up for the cover, the chassis and the attachment of the cover, not the whole sensor product.

No.	*Source*	*Customer Needs*	*Installer*	*End-customer*
		The plastic cover is easy to mount/dismantle		
1	I	Allows mounting & dismantling	N	
2	D1	Is quick to mount/dismantle	N	
3	D1	Is intuitive to mount/dismantle	N	
4	D2	Is ergonomic to mount/dismantle	D	
5	D3	Has few steps	D	
6	D3	Can be mounted/dismantled with one hand	D	
7	D2	Easy to mount/dismantle correctly	N	
8	I	Gives feedback when mounting/dismantling	N	
9	I	Know when mounting/dismantling is done correctly	D	
		The plastic cover allows cabling		
10	I	Attachment not affected by cabling	N	N
		The product with cover feels good in the user's hand		
11	D2	Induce a robust feeling	N	N
12	D1	Induce a feeling of good quality*	N	N
13	D3	No loose parts	D	D
		The plastic cover is protective		
14	D1	The product withstands being hit		N
15	D1	Protects from outside elements		N
16	D1	Protects from tampering*		D
		Product gives good value for money		
17	D2	Lasts a long time		N
18	D2	Affordable price		N
19	D3	Produced in a sustainable way		D
		The sensor is aesthetically appealing		
20	D2	Is aesthetically discrete		N
21	D2	Looks like a professional product		N
22	D1	Allows repainting		N
		** Needs have not been translated into product specifications*	D = Desired	N = Needed

5 Product Specifications

5.1 List of metrics

A list of metrics could be generated by going through the list of needs step by step and considering what measurable characteristic of the product that correlates to the desired needs (Eppinger & Ulrich, 2012, s. 95). However, the full product specifications will be directly presented in the following section.

5.2 Product specifications

The list of metrics was adjusted by adding columns for importance and ideal values, see Table 2. The importance for each specification was based on the data gathered from the installation workshop and the input from experienced engineers, product owner and product specialist. It was stated that the solution must successfully fulfil the basic functionality, to protect the sensor from hits and outside elements which is typically measured in industry through Impact protection (IK)- and Ingress protection (IP)-classifications according to EN 62262. IK-classifications declare how well the product can withstand mechanical impacts while IP-classifications are the ability to withstand particles and liquids. The attachments must also be good for the service technician, where the mounting and dismantling should be intuitive, foolproof and give feedback to the user. The importance was weighted high for these specifications.

Note that the specifications and the ideal values are greatly dependent on the specific product and the circumstances it will operate in and are thereby not final. The proposed product specifications could however be helpful when determining product specifications for similar products.

Table 2 Product specifications with need numbers indicating which customer need that was the source for the requirement. The ideal values are indicating a marginal that the product should comply with.

No.	***Need Nos.***	***Metric***	***Importance***	***Unit***	***Ideal Value***
	Installation				
1	1, 17	Product cover can be mounted and dismantled	4	# of times	100
2	2	Time to mount	3	Seconds	5
3	3	Intuitive to mount	5	Subj.	Yes
4	3	Intuitive to dismantle	5	Subj.	Yes
5	3	Tools required	1	Number	0
6	4	Manual torque required	3	Nm	0.46**
7	4, 12	Manual force required	3	kg	5***
8	5, 12	Required mounting steps	3	Number	2
9	6	Hands required	1	Number	2
10	7, 12	Plastic cover can be mounted in	5	# positions	1
11	8, 9, 12	Plastic cover gives feedback in	4	# of ways	3
12	10, 12	Interference with cabling when mounting	4	Binary	No
	Technical requirements				
13	13	Number of loose parts except cover & chassis	3	# of parts	0
14	14	Withstand appropriate IK-classification	5	Binary	Pass
15	15	Operate in humidity	2	% humidity	0-100
16	-	Operate in temperatures	3	°C	5-50
17	15	Withstand appropriate IP-Classification	5	Binary	Pass
18	17	Time mounted without problem	4	Years	10
19	11, 12	Bending stiffness	4	GPa	2.3*
	Manufacturing				
20	18	Complex parts	3	Number	0
21	18	Manufactured using injection moulding	4	Binary	Yes
22	18	Have a production cost	4	Low/mid/high	Low
23	-	Take less room inside chassis	2	% Volume	5
24	19	Produced in a sustainable way	2	Binary	Yes
	External requirements				
25	20, 21	Be Aesthetically appealing	4	Subj.	Yes
26	22	Repainting possible of externally visual parts	4	Binary	Yes
27	-	Have hole for cabling	5	Binary	Yes

*According to ABS statistics provided by (Sastri, 2010, s. 220)
**Based on 1/5 of the sexes' average torque when mounting on ladder in (Mital, Kilbom, & Kumar, 2000, s. 118)
***Based on 1/5 of the sexes' average strength from position 5 in (Mital, Kilbom, & Kumar, 2000, s. 117)

6 Concept generation

6.1 Clarify the problem

According to (Eppinger & Ulrich, 2012, s. 120) the first part of concept generation lies in clarifying the problem and dividing it into subproblems if necessary. For this project, the described task of attaching a cover to the product chassis, was decomposed into a few subtasks.

The clarified task was defined as:

- Attach the plastic cover on the metal chassis with a non-permanent attachment.

6.1.1 **Decompose into subproblems**

Even though the main task was of simple character, it was decomposed into a set of subproblems. The decomposition did not make use of any systematic method but was instead the result of discussion and logical thinking. The subproblems were defined as:

- Physical protection
- Mounting onto metal chassis
- Disassemble from metal chassis
- Method for fastening the cover
- Guiding while mounting & disassembling
- Feedback to installer

With a decomposed task, it was decided to focus on the most critical subproblems, as suggested by (Eppinger & Ulrich, 2012, s. 123), in order to produce the best competitive end-product. Conforming to this, the project group pointed out the subproblem of mounting, dismounting and fastening the plastic cover to the metal chassis as most important.

6.1.2 **Clarify the problem according to Bonenberger**

As the task is defined as an attachment, it was decided to complement the clarification of the problem above with tools described by Bonenberger.

6.1.2.1 Define the application

With the use of four binary questions from (Bonenberger, 2016), the functionality of the attachment can be described in short, see Table 3. The answers for the first three questions were obvious. The last question however, regarding if the attachment should be self-releasing or need a manual action, could potentially be any of the answers.

Table 3 Functionality questions according to Bonenberger.

Question	***Answer***
Should the attachment be fixed or movable?	Fixed in position
Should the attachment be temporary or final?	Final
Should the attachment's retention be permanent or releasable?	Releasable
Should the attachment be self-releasing or need a manual action?	Either answer is possible

The basic shapes of the mating-part (cover) and the base-part (chassis) was described to clarify the ingoing geometries, see Figure 8. The project group defined the cover to have the basic shape of an enclosure as it looks like an open box with flexible walls. The chassis was also defined to have the basic shape of an enclosure, due to the higher walls on the chassis perimeter. However, this combination is not a common combination, as it, according to (Bonenberger, 2016, s. 49), is rare for the base part to be shaped as an enclosure. The chassis could alternatively be defined as a cylindrical surface because the outside of the chassis will be non-flexible.

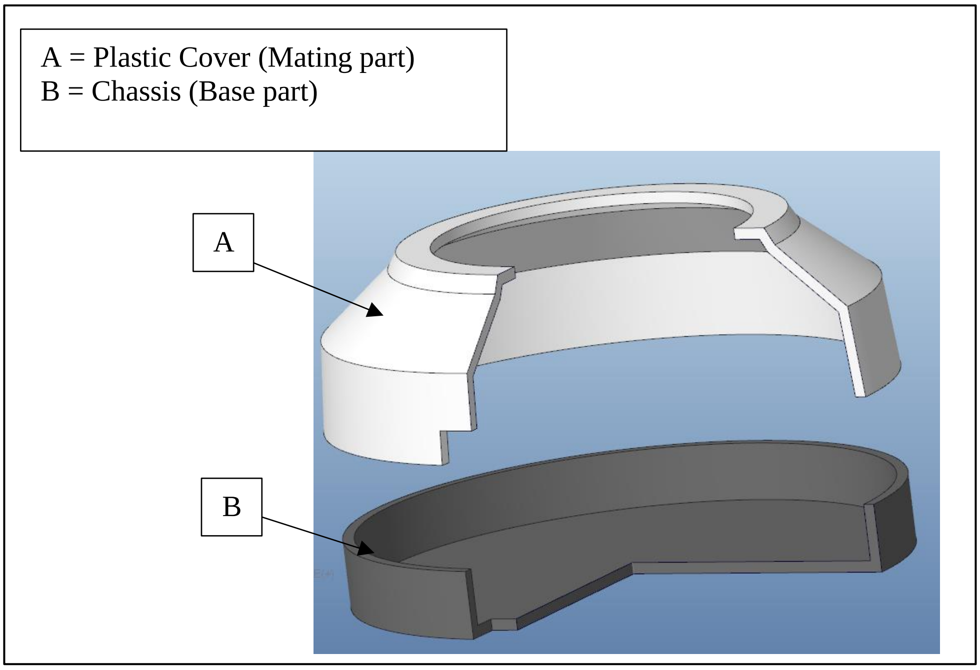


Figure 8 The basic shape of the mating part is an enclosure that has a slight conical form. The basic form of the base part is also an enclosure, as the electronics and sensors will cover the inside.

6.1.2.2 Combination of EDs & AMs

By introducing a cartesian coordinate-system and systematically combining every possible ED with a set of AM, a complete analysis is conducted as proposed by Bonenberger (Bonenberger, 2016, ss. 210-213). An ED is defined as the final direction of which the attachment is locking. This is important as the separation direction is most often the opposite direction of the ED and it will determine the lock features orientation and mechanism. The final movement to engage the lock, is defined as the AM. The five proposed motions to investigate are push, slide, tip, spin and pivot.

A cartesian coordinate-system was defined on the metal chassis, where the x-axis was defined in the direction of the cable, see Figure 9. The analysis of allowed ED resulted in eleven possible and one impossible ED, see Table 4. Out of the eleven possible, merely three were seen as non-problematic and obvious. The eight problematic directions were rotations and translations with regards to the x- and y-axis, as they will be constrained by the chassis cylindrical shape and because the cover should be firmly attached around the chassis.

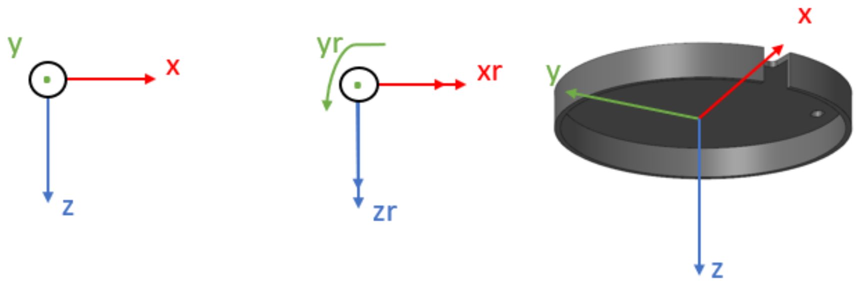


Figure 9 The defined cartesian coordinate-system showing translation, rotation and how it is applied on the metal chassis.

Table 4 The allowed EDs according to the analysis. Three directions are viewed as obvious and non-problematic, while four possible directions are slightly constrained by the chassis cylindrical shape.

Is the ED allowed?	***ED***
Impossible	+z
Possible but problematic	+x, -x, +xr, -xr, +y, -y, +yr, -yr,
Possible and not problematic	-z, +zr, -zr,

The five proposed AMs were then tested in theory for each of the 11 allowed ED. This process was quite tricky to do in theory, and thereby the resulting analysis should not be viewed as final, but instead as inspiration for the concept generation. The conducted analysis resulted in 10 different AMs, spread on the four types of EDs, see Table 5. The most promising candidates were to revolve around an axis, the linear push in z-direction or the tip around the xr- or yr-axis.

Table 5 The allowed AMs in combination to each allowed ED.

ED	***AMs allowed***
-z	Push, slide, tip, push+spin
+zr & -zr	Spin, push+spin
+x, -x, +y, -y	Push, slide
+xr, -xr, +yr, -yr	Tip, pivot.

6.1.2.3 Preliminary Snap-fit constraint worksheet

The snap-fit constraint worksheet was originally made by Bonenberger as a learning tool for developers to improve their understanding of constraining a part in 12 directions, according to (Bonenberger, 2016, s. 134). A similar, but not identical, worksheet was filled in to organize the applied forces and constraints to clarify the problem further. The worksheet was developed for an installation in the ceiling, see Table 6. A constraint in the worksheet is defined as preventing the motion of the mating part. Based on the three most promising candidates of AMs, the worksheet was filled in with versions A, B and C where these resemble:

A = Engagement by a pushing motion in -z.

B = Engagement by a spinning motion around -zr (Righty-tighty).

C = Engagement by a tipping motion around +xr.

A few constraints based on the basic shapes of the parts were exemplified in the worksheet, but these constraints should not be seen as final as the design of the individual parts do not reinforce these completely. This exemplification does however show the directions that are easier to constraint with the help of the basic shapes.

Table 6 A preliminary snap-fit constraint worksheet for a product installed in the ceiling. The worksheet is filled in with the three assembly motions A, B & C, corresponding to the assembly with a linear push -z, a spin around -zr and a tipping around +xr. The constraints from the basic shapes are not final, because they could be removed by altering the ingoing parts design.

			Translation						***Rotation***					
Applied forces			***+x***	***-x***	***+y***	***-y***	***+z***	***-z***	***+x***	***-x***	***+y***	***-y***	***+z***	***-z***
		Force(s) due to accelerations and part mass					✓							
		Functional/applied force(s)												
		Other forces	✓	✓	✓	✓	✓	✓					✓	✓
		Assembly force (in the engage direction)						A	C					B
		Intentional separation force					A			C			B	
		Forces due to thermal expansion/contraction	✓		✓		✓							
Locator and lock-pairs (Constraints)														
Basic Shape	Enclos -Surfa	Cylinder cover around cylinder chassis	1	1	1	1								
Basic Shape	Enclos -Surfa	Cover conical shape around chassis						1	<1	<1	<1	<1		
Needed Locator		Needed constraints (A)											1	1
Needed Locator		Needed constraints (B)					1							1
Needed Locator		Needed constraints (C)					1						1	1
Lock		Lock engagement					1			1			1	
		Degrees of motion in total	0	0	0	0	0	0	0	0	0	0	0	0

<1 marks direction that are not completely fixed.

6.2 Searching externally

To find inspiration for new concepts, an external search was conducted. By looking at several different products, several possible methods for mounting and detaching were found.

The external search was organized in a systematic approach where a set of categories were researched, see Table 7. The table includes a list of attachments that were not looked into because they were either permanent, did not allow multiple attachments and detachment or seemed unfit for the task by other reason. It shall also be noted that the external search was conducted using online searches.

Table 7 Categories for systematic external search.

Category	***Alternatives***
Common non-permanent attachment-methods	Screws, snap-fits, threads, bayonet mounts, ball catch lock, toggle latch, hooks, buckle clips, magnets, hinges
Related products with similar purpose	Smoke detectors, wireless network access point, lamps, cameras, kitchen equipment, loudspeakers, motion detector
Other things that connect	Cables (Ethernet, USB, HDMI), coupling
Ideas not investigated	Carabiner, vacuum, velcro tape, zip-tie, knots, glue, welding, using flexible strings, zipper

6.2.1 Non-permanent attach methods

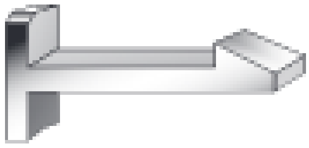
6.2.1.1 Screws

A common way of assembling two parts is using one or more screws, see Figure 10. It is considered a reliable and affordable method of attaching the two parts together which can be done multiple times (Shah, 2019).

Figure 10 Screw and bolt. (OpenClipart-Vectors, 2017)

6.2.1.2 Snap-fits

A snap-fit is a flexible assembly where two parts get pushed into an interlocked position. This method has a great economic advantage while also profiting from enhanced external appearance and no need of tools (Bonenberger, 2016, s. 1). See examples in Figure 11 and Figure 12.



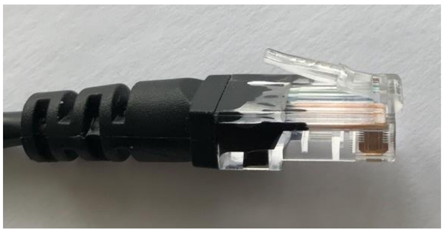


Figure 11 Cantilever snap-fit. (Bonenberger, 2016, s. 8)

Figure 12 Ethernet cable with 8P8C (RJ45) connector. (Michael Lindberg)

There are a variety of snap-fits and the most common design style is a cantilever one displayed in a few variants in Figure 13Figure 11 below.

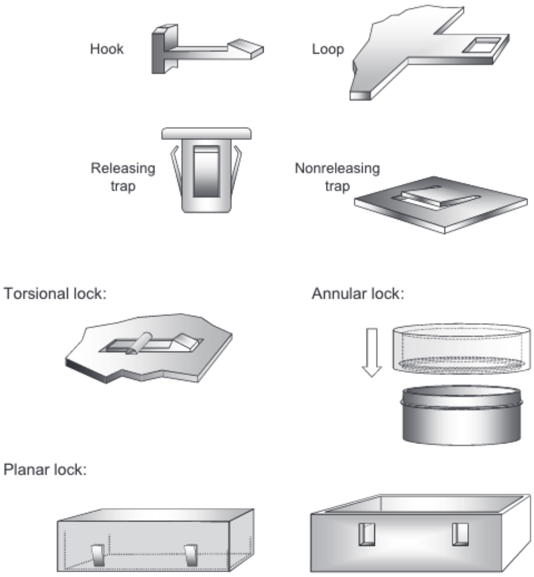


Figure 13 Beam-based locks. (Bonenberger, 2016, s. 80)

6.2.1.3 Threads

Threads are another idea used for assembling two parts. With inspiration from bottle caps, lightbulbs and metal-lids on glass jars, the use of threads for interlocking two parts were found. Through a twisting motion, threads will interlock with a tight seal, see Figure 14 and Figure 15.

Figure 14 Threaded bottle cap. (Michael Lindberg)

Figure 15 Light bulb with threads. (Horell, Edison screw fitting)

While looking at metal-lids for glass jars, a new version was found. By dividing the lid in two parts the difficulties of opening and closing jar lids were diminished. The first part, a flat metal lid, simply acts as a protection for the jar content whereas the other part is an outer ring attached around the lid, holding it in place, while also connecting to the threads on the jar (Crown Cork, 2020), see Figure 16 and Figure 17 which are similar.

Figure 16 An innovative lid consisting of two parts. (Otto Reerslev)

Figure 17 Threaded glass jar with lid. (Otto Reerslev)

6.2.1.3.1 Pill jar

A pill jar is a common product, produced at high volumes and at low costs. It is designed to be opened several times during its lifetime without breaking. Furthermore, the opening and closing is required to be intuitive for everyone since there is no specific target group of the product. An interesting solution found on a pill jar on the Swedish pharmacy market combines threads with a bayonet mount and a flexible lid. The lid may simply be screwed onto the jar until a clicking sound is heard, indicating the bayonet catches has interlocked. To open, it is required to press on the two pads on opposite sides of the lid, indicated with ribs as seen in Figure 21. When pressed the bayonet catches on the lid expand out, see Figure 22, allowing to pass the corresponding catches on the jar, see Figure 19. While pressing, a anticlockwise rotation is required to unscrew the threads.

Figure 18 Jar with threads and two bayonet catches, marked with red circles. (Michael Lindberg)

Figure 19 Close up of a bayonet catch. (Michael Lindberg)

Figure 20 Flexible plastic lid with threads and bayonet catches. (Michael Lindberg)

Figure 21 Lid with instructions. (Michael Lindberg)

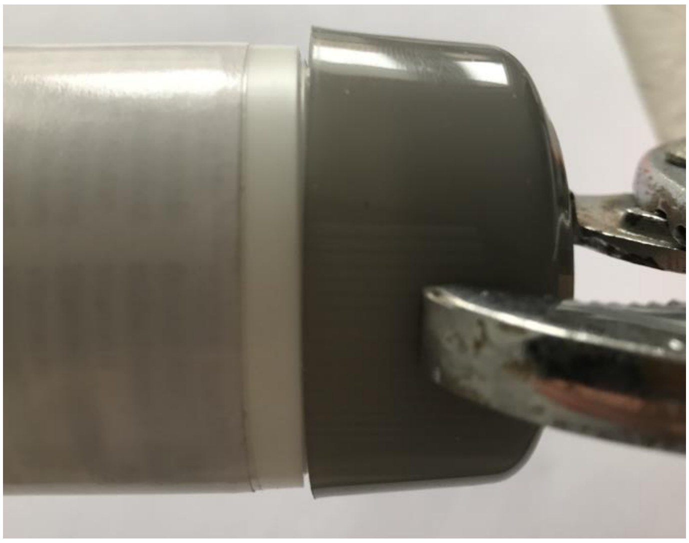


Figure 22 Lid squeezed on pads allowing to bypass the bayonet catch due to the flexible cap. (Michael Lindberg)

6.2.1.4 Bayonet mount

A bayonet mount is a method for interlocking two parts together using a relatively short twisting motion (Nationalencyclopedin, u.d.). A simple bayonet connector consists of a male part with circular pins that fits into an L-shaped female receptor with a matching diameter, see Figure 23 and Figure 24.

Figure 23 Bayonet mount for a light bulb. (Horell, Science Photo Library, & Universal Images, Bayonet fitting)

Figure 24 A camera lens with bayonet mount. (Science Museum)

6.2.1.5 Ball catch lock

The concept of a ball catch lock also known as a bullet catcher consists of a small metal ball attached to a spring, see Figure 25 and a metal strike plate with an indent for the ball to catch, see Figure 26, (DoorCorner, 2020). The two parts, ball and plate are fitted to the parts which are to be locked together. When the two parts are aligned the ball can be pushed into the indent by applying a force greater than the spring force holding the ball. The advantage of using a ball catch lock is that there is no need for rotation upon attaching and detaching the two parts (Direct Door Hardware, 2021). There are also roller latches which operate similarly. Though a roller latch has a roller rather than a ball attached to a spring which hinders movement along the roller axis.

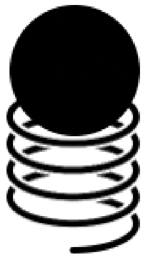


Figure 25 A ball attached to a spring. (Michael Lindberg)

Figure 26 Mortise strike plate for catching the ball. (Michael Lindberg)

6.2.1.6 Toggle latch

A toggle latch, also known as a draw latch or tension latch, uses its latch to hook onto its keeper and pull the two surfaces together (McMaster-Carr, 2019). These locks can be found on ski-boots, buckles on trailers, kitchen cabinets, glass jars and more, see Figure 27 & Figure 28.

Figure 27 A bottle with a swing top. (Michael Lindberg)

Figure 28 Marmalade jar with a toggle latch. (Michael Lindberg)

6.2.1.7 Hook

By using a bent piece of metal or other stiff material to attach the hook on the backside of the target attachment. This application is for instance used by logistic companies to hold the sides in place when shipping goods in two-sided roll cages. Additionally, consumers use bungee cords for attaching various things to backpacks or bicycle luggage carriers, see Figure 29.

Figure 29 Bicycle luggage straps. (Lfuhr, 2018)

6.2.1.8 Buckle clip

A buckle clip can also be named as a side release buckle or even parachute buckle. It consists of a male hook and female insertion part. The male usually has a centre rod and a spring prong on either side, see Figure 30. These are inserted into the big opening on the front side of the female part which also has holes on the side corresponding to the spring prongs so that they may interlock. To release the side spring prongs are pressed while applying a pulling force on the two parts (CustomTieDowns, 2021).

Figure 30 Buckle clip. (Michael Lindberg)

6.2.1.9 Magnet

Two separate assembly pieces can be held together by the attraction force of two magnets with opposite polarity. To use permanent magnets would be preferable since they have a constant magnetic field and opposed to electric magnets a permanent does not require any power supply (Cavette, 2020). See an example of a magnetic attachment in Figure 31.

Figure 31 A Magsafe charger held in place by a magnet. (Library)

6.2.1.10 Hinge

A hinge is a leaded attachment allowing movement radially with origin of rotation in the rod of the hinge (Nationalencyklopedin, 2020). A hinge is a viable solution for holding two parts together and allowing easy open and closing of the product. Though, it requires an additional method for attaching and detaching the other end of the product, see Figure 32 and Figure 33.

Figure 32 Hinged bottle cap. (Horell, Science Photo Library, & Universal Images, Bottled mineral water)

Figure 33 Door hinge. (Michael Lindberg)

6.2.1.11 Press fit

The concept of press fit, or interference fit as it may be called, is when two pieces are held together by friction, see Figure 34. The force required to fasten the pieces depends on the interference, or allowance, between the two joining parts (Childs, 2014).

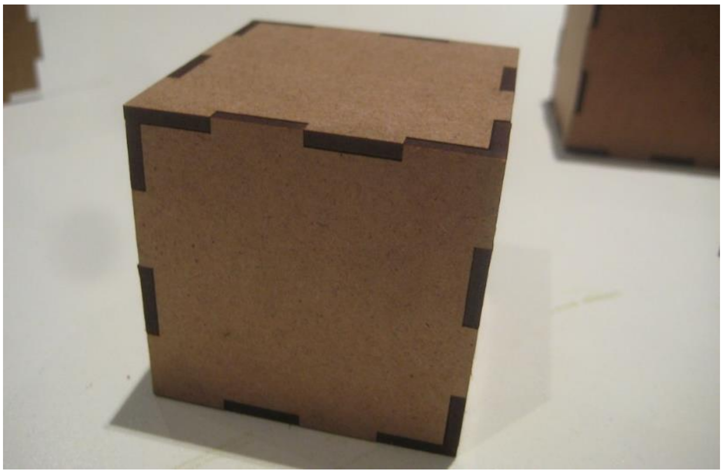


Figure 34 Press fit kit. (Zero One 000111)

6.2.1.12 Push opener

A push opener is a part often found in kitchen cabinets which eliminates the need for knobs as the door is opened and closed through a push, see Figure 35. The inside of the cabinet is provided with a rod attached to a spring. When the rod is pushed, the spring gets compressed and then rotates the rod through tracks in the casing to a new locked position which is either in the inner or outer position depending on the previous. The same mechanism can be found in modern mass-produced ballpoint pens, where a single click extends the ballpoint and a second click contracts the ballpoint into the pen casing again.

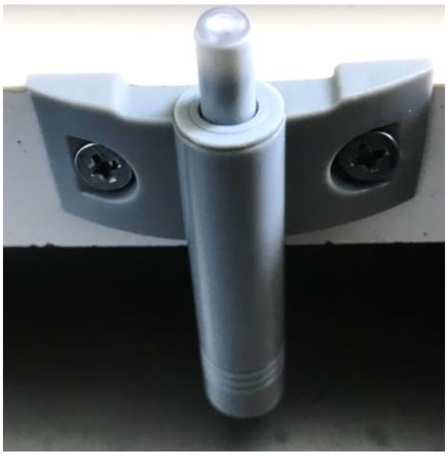


Figure 35 A push opener mounted in a kitchen cabinet. (Michael Lindberg)

6.2.2 **Similar products**

By investigating products of similar shape and purpose, inspiration was gathered. Several similar products are hereby presented with a short note of typical attachment methods they use. The vast number of similar products makes a complete analysis impossible and the following list presents only a small share of ideas.

The research showed that many ceiling-mounted products have a base-plate which is installed first, and the device is then attached to the base-plate with a bayonet lock. It also showed that some products have two-parted plastic covers, which this project is delimited from using, see Figure 42. Screws are used for many similar products, but are sometimes only used to lock the part in place, see Figure 43. The investigation of kitchen equipment showed that various shapes of a bayonet mount's track and protrusion are used, which induce different feelings to the user.

Figure 36 A fire alarm which is fitted using a bayonet mount onto a base plate. (Michael Lindberg)

Figure 37 A recessed loudspeaker attached in a soft tile ceiling which is held up by radially extended arms above the ceiling. (Michael Lindberg)

Figure 38 An access point for a wireless network is fitted using a bayonet mount onto a base plate. The ethernet cable is placed in a tailored cable hole on the backside of the access point. (Ihennen, 2020)

Figure 39 A surveillance camera mounted on a pole hanging down from the ceiling. (Peggy_Marco, 2015)

Figure 40 A spotlight which may be recessed up into the ceiling and is held up by radially extended arms. (毛, 2014)

Figure 41 A permanently wall mounted motion detector capable of detecting movement in front of it. The outer cover may be detached by prying it off using a screwdriver. (Otto Reerslev)

Figure 42 A fire alarm fitted with a bayonet mount and a securing screw. The cover is two-parted and black stripes was added afterwards to display the parting-line.
(Otto Reerslev)

Figure 43 The cover for a wall-mounted RFID-reader is secured with a screw located under the product, out of sight for users. (Otto Reerslev)

Figure 44 A kitchen blender fitted with a bayonet mount. Symbols are indicating the locking direction. (Otto Reerslev)

**Figure 45 The blender has an L-shaped lock and a corresponding catch, which gives feedback for both locking and unlocking.
(Otto Reerslev)**

**Figure 46 Another blender with a boot-shaped bayonet. The round protrusion is squeezed into a locked position.
(Otto Reerslev)**

**Figure 47 A big food processor with a bayonet lock, where radial catches prevents the container from unlocking.
(Otto Reerslev)**

6.3 Brainstorming 1

A brainstorming session was conducted where basic concept ideas were sketched on paper. The paper sketches were a convenient tool for expressing and communicating ideas within the team. The procedure was to focus systematically on a specific attach method at a time and to sketch possible variants of that method. Most methods from section 6.2.1-Non-permanent attach methods, were covered in brainstorming 1, except for hook, press fit and push opener methods. Then each sketch was presented and discussed to highlight advantages and disadvantages with the concept. See sketches in Appendix B.

There were a couple of interesting discussions during the brainstorming session, regarding several topics. These discussions include:

- A couple of ideas would affect the visual outside of the product, including the use of buttons or screws. Whilst a physical marking on the outside would be intuitive for an installer, such a solution would also affect the aesthetical outside of the product. It was decided that if the solution alters with the products outside, it may only be allowed if the product function end up being much better. A slight compromise with the appearance should be at least considered if the product were to be more intuitive.
- Some ideas will require the cover top to flex during installation and dismantling. By gripping and applying a pressure on two sides of the cover top, a slight oval shape allows snap-fits or small catches to get into position. Though a flexing cover top will not induce a robust feeling as opposed to the customers' demands and there may not even be enough space around the chassis to enable flexing since there is such a tight fit. On the other hand, the advantage would be a quick installation, with the risk of being unintuitive.
- A couple of ideas include a button on the outside of the cover top. If a button would be chosen, it should be taken into consideration that repainting the product will also need this button to be repainted. A button may also bring the hazard of letting dust into the product.
- Whatever solution that will finally be chosen, the concept must be strong and safe enough for many years ahead.

6.4 Brainstorming 2

After completing brainstorming 1, some time was intentionally left to pass before considering new potential concepts. Therefore, when finally embarking on brainstorming 2, ideas were generated with ideas from looking at similar products and challenging the limitations of the project scope, see Appendix C.

One potential concept was based on the push opener part which requires a push both to open and to close. But this solution does not include a way to hold the cover top fastened in its inner position. Thus, the push openers are each mounted in a 45-degree angle to the loosening direction of the cover top which then holds the cover top in place when the rods are fully extended.

6.5 Explore systematically

According to (Eppinger & Ulrich, 2012, ss. 130-131), the vast number of possibilities for each individual subproblem should be explored in a systematic manner in order to organize and synthesise the possible solutions. For this project however, the most important subproblem was focused directly and no systematic exploration of concepts was done. The product development process thereby continued into the first concept selection phase.

7 Concept Selection 1

7.1 Method for selecting concepts

For this first selection, the concept screening methodology as described by (Eppinger & Ulrich, 2012, ss. 149-150) was followed. Each concept category have been evaluated based on the selection criteria, where a bad fit would give a "–", while a neutral, nor good or bad would give a "0" and a good fit would result in a "+" for that specific criterion. The total sum is then calculated and compared to the reference model. Depending on the achieved score the concept category gets eliminated or passes the first selection and continues to the next iteration.

7.2 Selection criteria for concept selection 1

The chosen selection criteria were focused on the fundamental key issues identified from the customer needs and product specifications. The final selected criteria were easy installation, cheap manufacturing, externally appealing, high quality feeling and impact resistant will cover the important subproblem.

There should however be some clarification to the criteria as they may be more inclusive than the name suggests. An easy installation is regarded as a summary of the installation process as well as the dismounting process. In such a manner is the time, intuition and force covered for the installation process. Similarly do the manufacturing process contain other aspects than cost such as manufacture viability and packaging. On the contrary is the criterion externally appealing self-describing. Meanwhile a high-quality feeling is based on a number of subjective perceptions such as stiffness, feedback, material, tolerances and more. Finally, the criterion impact resistant does not simply indicate if the concept is resistant to outer forces but also dust, water and whether it leaves any gap between parts.

7.2.1 **Concept categories**

The concepts categories that were generated are presented in Table 8.

Table 8 Concept type sketch reference matrix.

Type	*Sketch reference*
Screws (Ref)	B1, B6
Snap-fit	B1, B4, C1, C2, C3
Threads	B1, B3, B4
Bayonet	B2, B3, B4, B6
Ball catch	B2, B4, B6
Toggle latch	B2, B4
Magnet	B2, B3, B5, B6
Push opener	C1, C2
Press fit	B2, C1, C3

7.2.2 **Concept screening**

The results from concept screening of the categories in Table 8 are presented in Table 9 and Table 10.

Table 9 Concept screening matrix.

Selection criteria	*Ref*	*Snap-fits*	*Threads*	*Bayonet*	*Ball catch*
Easy installation	0	0	0	+	+
Cheap manufacturing	0	+	0	0	-
Externally appealing	0	+	+	+	+
High quality feeling	0	0	0	+	0
Impact resistant	0	-	-	0	-
Sum	0	+1	0	+3	0
Rank	-	2	3	1	3
Continue to develop?	Y/N	Y	N	Y	N

Table 10 Concept screening matrix continued.

Selection criteria	*Ref*	*Toggle latch*	*Magnet*	*Push opener*	*Press fit*
Easy installation	0	+	+	+	+
Cheap manufacturing	0	0	-	-	+
Externally appealing	0	-	+	+	+
High quality feeling	0	0	+	+	0
Impact resistant	0	0	-	-	-
Sum	0	0	+1	+1	+1
Rank	-	3	2	2	2
Continue to develop?	Y/N	N	Y	Y	Y

7.3 Reflection on the result and the process

A reflection on the results and the process is hereby provided, as suggested by (Eppinger & Ulrich, 2012, ss. 149-150). This first selection was done to sort out the concepts that would not be worth investigating and was therefore rather aggressive. The process of giving +, 0 or – for each selection criteria is not a precise measurement and will never show the whole picture, but the process does still give insight to the concepts. Each concept does obviously have both advantages and disadvantages which will be presented later in this section.

The choice of having a short list consisting of broad criteria was intentional as it would give good discussions. For example, the full installation and dismantling processes were discussed with advantages and disadvantages. This gave a chance for arguments of both sides to be ventilated.

The result should also be taken with slight caution as the decisions were singlehandedly decided from the project group’s opinions and no external source.

7.3.1 **Concept-types continuing to next phase**

The arguments that were highlighted while processing the concept screening matrixes are hereby presented for each concept-type that is continuing to the next phase.

7.3.1.1 Screws

The use of screws is seen as an intuitive, fool-proof, impact resistant and reliable way of mounting the plastic cover. The linear mounting is good for handling the cabling. The major disadvantage was the esthetical outside of the plastic cover with visible screws along with the longer installation time.

7.3.1.2 Snap-fit

The use of snap-fits has good potential if designed properly as it does not affect the aesthetic outside and because the installation could be done quicker. It also has the potential of a cheaper production. The major disadvantages were related to the weaker attachment that can be problematic for impact, the problem of not being intuitive for dismantling and that a snap-fit solution hardly generates a high-quality feeling to the product.

7.3.1.3 Bayonet

The use of bayonet connection was regarded as a solution that can be made quite professionally. The major advantages were that the aesthetical outside is not being affected, the solution provides a quick, guided installation, ideally with feedback and a fixed end position resistant to outer forces. The major disadvantage was the need of a twisting motion that can be problematic for cabling, and perhaps not being intuitive while dismantling.

7.3.1.4 Magnet

The magnetic concepts had advantages of being hidden on the inside of the cover top. However, fitting magnets on both the chassis and plastic cover part could be relatively costly but more prominent is the additional volume added to the otherwise thin cover top part. On the other hand, the magnet solutions provide an intuitive mount and dismount along with good feedback but are subject to deterioration due to time, tear and wear.

7.3.1.5 Push opener

The push opener concept is advantageous since it allows a clean outside of the plastic cover. It also provides a high-quality feedback when a new position successfully has been reached. However, it requires relatively large space inside both the chassis and cover top to operate as intended.

7.3.2 **Concept-types eliminated during selection**

The arguments that were highlighted while processing the concept screening matrixes are hereby presented for the eliminated concept-types.

7.3.2.1 Threads

The use of threads ended up being eliminated as it proved worse than screws on several points. The main advantages of not affecting the aesthetic outside and being intuitive is shared with the bayonet method. Though the major disadvantage was the need for a relatively long twisting motion which is difficult with cabling in place. Additionally, the mounting needs to be strong enough for impacts and vibrations which is tough to achieve as there are only weak threading frictions holding the cover top in place.

While discussing the solution of dividing the cover top into two parts where one uses threads, the installation appeared to be more complicated with two parts and of lower quality which led to this idea being dismissed.

7.3.2.2 Ball catch lock

The use of ball catch lock is seen as a quick installation with guiding and feedback, without affecting the aesthetic outside. The major disadvantage was the higher cost of production together with a solution not being strong enough for impacts and possibly having a small glitching from side to side. This concept was eliminated because a snap-fit would possibly be both stronger and cheaper.

7.3.2.3 Toggle latch

The toggle latch is seen as a unique idea with potential of being quick and strong. The major disadvantage is that the aesthetic outside would be affected in a negative way. However, it could be integrated into the cover top but that would require quite a lot of development to make it fit smoothly together with the cover top. The other disadvantages include expensive manufacturing, the problem of being designed small and thereby troublesome for the installer to work with. This solution was eliminated because of the aesthetic outside.

8 Concept selection 2

8.1 Method for selecting concepts

When conducting the second selection of the concepts, only the ones proceeding from Concept Selection 1 were considered. The process was to involve two experienced mechanics designers from a manufacturing company of electrical sensors, in a workshop to help decide which concepts that were promising. In practice this meant having a virtual meeting where the concept categories were explained verbally. Following this, a few open questions were asked to understand the reasoning of the mechanic designers. The questions were in different variants of the ones seen in Table 11.

Table 11 Discussion questions for concept selection 2

Discussion questions
What would your impression of installing this concept category be?
Please consider the following aspects when answering the question above: Time Intuitively Simplicity
What is your quality feeling for this concept category?
What potential do you see for this project?

The categories continuing from Concept Selection 1 were reorganised to better represent the scope of each category. Thus, the snap-fits were divided into two subcategories, snap-fits without release mechanism which requires a pulling action to disassemble meanwhile snap-fits with release mechanism require an action other than pulling, such as pressing, doing a rotation or a lift to enable disassembly. The release mechanism can also be dependent on a tool such as a screwdriver, a credit card, coin or similar. Another new category was introduced, for concepts that require a flexible cover that is pinched as it is mounted over catches.

With the feedback received from the mechanics designers a concept scoring matrix was filled out.

8.2 Reasoning for weight distribution of concept selection 2

Since the installation process is considered of great importance it was given a weight factor of 28%, see Table 12 and Table 13 on page 62. This was also the case for the disassembling with the same reasoning. In total this gives the installation process a weight factor of 56%. Moreover, the installation was divided into intuitively, quickness and simplicity. These were weighted 8, 10 and 10 whereas the same categories were weighted 12, 6 and 10% for the disassemble process. The reasoning for this is that an installation is not required to be as intuitive as a disassemble since the user may get clues from looking on the inside of the product when installing but has to figure out the disassembling by only looking and feeling on the outside of the sensor. In contrast it is desired to have a quick installation process as the customers are not happy awaiting. While it is acceptable if the dismantling takes longer time as the customer's expectations are not as high and possibly is the facility where the sensor is present no longer in use. The simplicity relates to how easily the process may be completed without issues and the effort required. A weight of 10% were assigned to the simplicities because of the bad emotional feeling which may appear if either process is considered inconvenient or troublesome.

When considering quality, which is of importance to maintain a competitive brand, this category was given a total of 20% divided onto; robust feeling, not fragile and no loose parts with 6, 10 and 4% respectively. The product must not break easily as this would be troublesome to the end customer, thus it was given half of the quality category weight. Still, when looking at and when handling the product, the user should ideally get a high-quality feeling. This is somewhat more important than the last quality criterion, to limit the number of parts the product has. A product with many loose parts may be considered bothersome and is therefore undesired.

The final criteria are covering the technical requirements about protection with a 24% weight of the total criteria. The two protection criteria, impact and environmental protection are both fundamental for the product to function.

8.2.1 Feedback from experienced mechanic designers

In this section a summary of the key points covered with the mechanic designers will be presented.

It was obvious that a key point for making a concept intuitive or not is to provide it with proper guidance. This feature can be added at a late stage to improve an already promising attachment concept.

Many of the concepts presented were considered to have a quick installation due to the few steps needed, for example, magnets, snap-fits, press fit and bayonet. Though, this does not compensate for an unintuitive concept.

A snap-fit solution had a drawback of having the plastic snap-fits exposed without much support. This poses a threat to breaking the snap-fits when shipping and installing the product.

The product's protection against impacts, dust and water was a recuring concern as several of the concepts had a weaker attach method. This mainly applies to the press fit solution and the push opener concept but was also mentioned when discussing magnets and snap-fits.

The original concept using screws were discussed as intuitive and robust. With pre-attached screws there are no loose or fragile parts. However, the negative aspects remain regarding the external aesthetics and taking up volume inside the product.

The push opener concept was considered an innovative way of solving the attachment problem while having the benefit of being intuitive. Yet, the concept was criticised due to the risk of unwanted dismantling as the action for releasing, to push on the cover top, may be carried out too easily or as a consequence of a small impact.

In theory the concepts appear to work out well but, according to the experienced mechanics designers, most concepts suffer from smaller problems that surface along the way or end up not working at all. This applies to the press fit concept which is great in theory but should be discarded as the friction holding the plastic cover in place is diminished after time and wear.

Even though the self-releasing snap-fit has potential, its shortcoming is to find a good balance of the force required to snap on versus the force required to detach the part. From experience this is not easily done as it requires several iterations but more importantly the pushing force for snap-on is heavily limited in this case due to the mounting in soft tile-ceilings.

(Experienced engineer Jimmy Bengtsson & senior engineer Nina Bergius, company manufacturing sensors, Lund, Sweden, personal communication, 25 February 2021)

8.3 Concept selection matrix

Based on the feedback received, the concept selection matrix has been filled out.

Table 12 Concept selection matrix.

Criterion	*Weight (%)*	*Snap-fit with release*	*Snap-fit without release*	*Flexible cover over catches*	*Original screws on top*
Easy to install	**28**				
Intuitive	8	8	8	7	9
Quick	10	9	8	7	3
Simple	10	7	6	6	6
Easy to disassemble	**28**				
Intuitive	12	5	7	3	9
Quick	6	6	8	7	3
Simple	10	6	7	7	6
Quality feeling	**20**				
Robust feeling	6	6	5	3	8
Not fragile (Breakable)	10	5	6	6	8
No loose parts	4	7	9	9	6
Technical criterion	**24**				
Withstands IK	12	8	6	5	10
Withstands IP	12	6	6	5	9
Sum	1-10	6.62	6.76	5.68	7.28
Rank	1-8	5	4	7	1
Continue to develop?	Y/N	Y	Y	N	N

Table 13 Concept selection matrix continued.

Criterion	*Weight (%)*	*Press fit*	*Magnet*	*Bayonet lock*	*Push openers*
Easy to install	**28**				
Intuitive	8	5	8	7	5
Quick	10	6	10	7	8
Simple	10	6	8	5	5
Easy to disassemble	**28**				
Intuitive	12	8	7	7	6
Quick	6	7	8	7	8
Simple	10	8	8	7	5
Quality feeling	**20**				
Robust feeling	6	4	8	8	5
Not fragile (Breakable)	10	3	6	8	4
No loose parts	4	9	7	9	6
Technical criterion	**24**				
Withstands IK	12	5	4	6	5
Withstands IP	12	5	4	6	5
Sum	1-10	5.88	6.88	6.80	5.54
Rank	1-8	6	2	3	8
Continue to develop?	Y/N	N	Y	Y	N

8.4 Concluding concept selection 2

Concept selection 2 resulted in four concepts that were further investigated and four concepts that were dropped.

8.4.1 **Concepts with least potential**

8.4.1.1 Press fit

Due to the loose fastening of the press fit concept, this category was eliminated from the development process. Furthermore, the concept has a requirement of rather high tolerances and may hence be costly to produce.

8.4.1.2 Push opener

The concept with a push opener was considered an interesting concept due to its simplicity. However, it had a major drawback as it probably would not sustain an impact without the plastic cover detaching from the sensor's chassis. Furthermore, the concept is worrisome as every end step requires the push opener to re-expand out a bit in order to get into a fixed position. This implies the plastic cover cannot be constructed in a way that is in direct contact with the metal chassis when attached.

8.4.1.3 Flexible cover over catches

Even though a flexible cover provides a smooth way of both installing and dismantling the cover it was eliminated since the part may fall off when struck with an impact. Additionally, it is difficult to get the material flexing enough to pass by the catches.

8.4.1.4 Original screws on top

The original screws concept got the most points in the concept selection matrix. Nonetheless it will hereby be excluded from the development process. The reason for this is that this thesis aims to find a screwless option and that there are many similar products on the market which use a screw solution.

8.4.2 **Concepts continuing to digital workshop**

The four screwless concepts with the most points from the concept selection matrix were, in the following order, magnets, bayonet lock, snap-fit self-releasing and snap-fit with release mechanism. These concepts continued to the next phase.

9 Digital workshop

9.1 A digital workshop as a tool for evaluation

The purpose of the workshop was to visualise the concept ideas. Due to the current restrictions regarding the Covid-19 pandemic, it was decided to conduct a digital workshop as that would eliminate the need for physical contact. The goal of the workshop was to receive feedback both from several individuals but also from more experienced designers. Lastly, the digital workshop was chosen since it has a much shorter lead time for the 3D-models compared to a physical workshop with real prototypes. The expected outcome was to dismiss one or more concepts based on the feedback received.

9.2 Method for the workshop

Upon preparing for the workshop, 3D-models were created for each concept category described in section 8.4.2. As two 3D-models were generated from the snap-fit with release mechanism category, this made a total of five models subject to evaluation during the digital workshop. The individual parts were then assembled to show the fitting and interaction between the parts. A digital whiteboard was prepared beforehand with stations of each concept along with pictures. A short summary of the concepts was also sent out two days prior to the workshop. The attendees were five experienced mechanical designers from a manufacturer of electrical sensors. The procedure for the workshop was to present a 3D-model of each concept and then let every member write down positive and negative thoughts as well as questions and possible improvements for the concept on digital post-it notes. An open discussion was then initiated, and interesting or unclear notes were brought up to discussion so that they may be explained and conversed in group.

9.3 Feedback from workshop

The format of the workshop gave room for both individual thinking and collective discussions. The five attendees provided feedback based on past experiences for each design. A brief summary is hereby given.

9.3.1 **Bayonet**

The concept of bayonet mounts had an advantage of already being well-tested. Previous experience says that it is possible to design so that it would give a nice feeling and still be cost-effective which makes it a viable solution for the problem. However, it was argued that past experiences have shown complications when combining a bayonet-mount with cabling. A product with a cable pointing straight out is not hortatively expressing a twisting motion should be applied. The proposed design was also argued to be non-intuitive as the key to opening is hidden within the product and no signs or indications of a twisting motion is shown on the outside, see Figure 48.

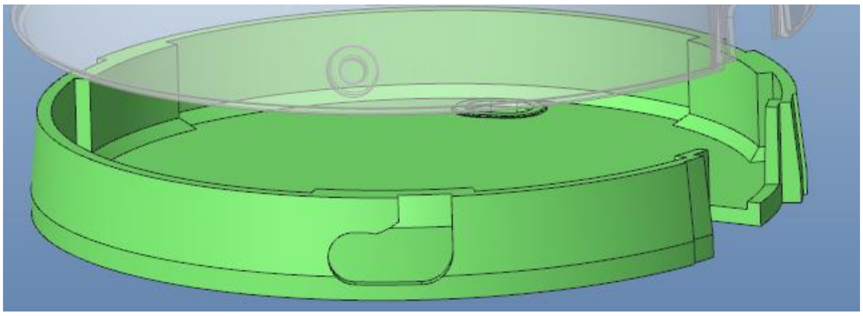


Figure 48 The bayonet concept presented during the workshop.

9.3.2 **Self-releasing snap-fit**

The pictures presented at the workshop are shown in Figure 49 and Figure 50. The concept of self-releasing snap-fits, where the whole plastic cover needs to flex was marked as the least favourable concept. Past experiences of testing this concept have shown that the design counteracts the individual, as you grip on the outside and press the plastic cover together while the cover needs to flex outwards. The proposed design with 3 snap-fits was thereby explained as a potential problem where 2 snap-fits would make use of the flexing cover in a better way. It was also suggested that an external indicator of the pressing location could diminish this problem. There was also a mention of a tilt problem, where the plastic cover gets wedged stuck in a tilted position when one snap-fit is released while two are not yet released.

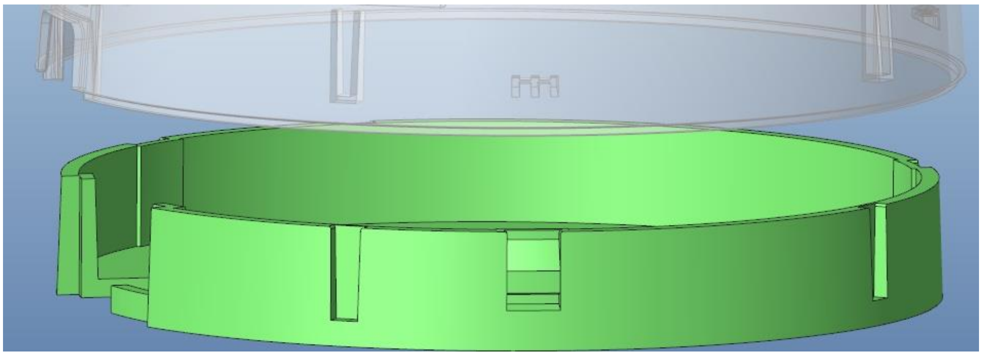


Figure 49 The self-releasing snap-fit concept presented during the workshop.

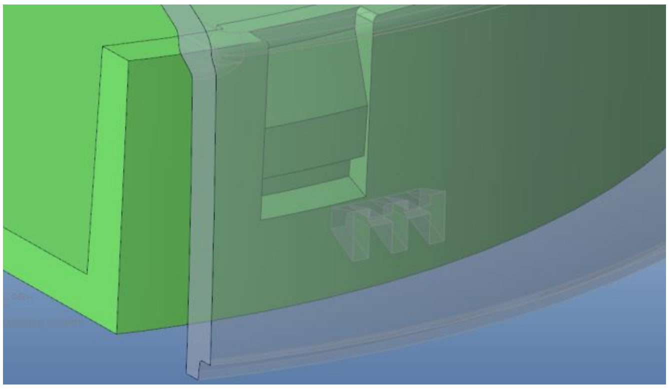


Figure 50 The catches on the cover's inside are designed to allow self-release by pulling the cover in with a high enough force.

9.3.3 Snap-fit with release button

The pictures presented at the workshop are shown in Figure 51, Figure 52 and Figure 53. This concept faced several questions. The designers were worrying that one button might not be enough, that the button may be placed facing a wall or that the button may be hit during IK-testing and thus releasing the cover top unwillingly. These questions resulted in that there are some concerns regarding the design, however the idea has potential. Small details such as the button and snap-fits are fragile parts which may not be durable enough. Additional concerns were raised of how the product may be manufactured as small details are difficult to produce. However, given the potential it was clear that the concept needed further work and to be iterated a few times before reaching its full potential. Thus, two improvements were mentioned. First to turn the button upside down and secondly to affect the aesthetic outside so that it looks intuitive.

Figure 51 View from outside. (Otto Reerslev)

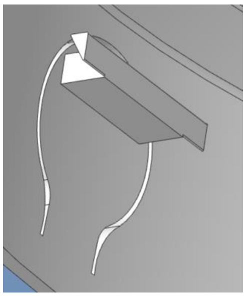


Figure 52 View from inside. (Otto Reerslev)

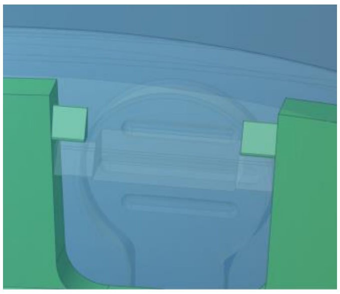


Figure 53 The locking mechanism. (Otto Reerslev)

9.3.4 **Magnets**

The pictures presented at the workshop are shown in Figure 54 and Figure 55. The concept of using magnets received attention as it is very easy to install. Despite that, the ease was also considered a possible threat as such an easy disassembly means also unauthorised individuals simply may remove the cover and temper with the exposed sensor inside. In that sense, an additional locking mechanism was proposed to prevent such an action. Another benefit is that there are already several products which feature magnets. Still, it is necessary to investigate the electromagnetic capability (EMC), in other words how the electronics function in the presence of magnets but also how to avoid electrostatic discharge (ESD), a sudden discharge that may erupt between two electrically charged objects, often due to a short, which in turn, may induce sparks. Overall, magnets are a promising concept, though it requires a lot of testing and tweaking to make it work smoothly.

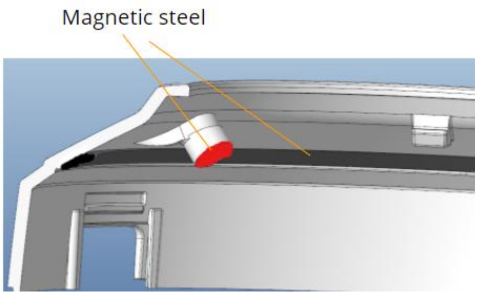


Figure 54 The cover was presented with magnetic steel attached on the inside. (Otto Reerslev)

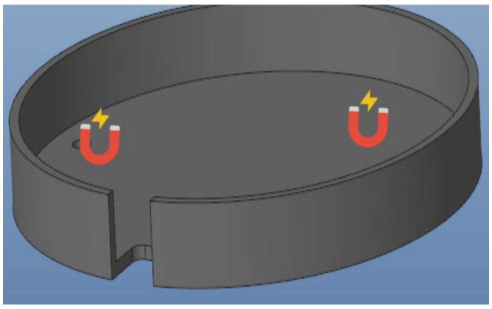


Figure 55 The chassis was presented with magnets to attract the magnetic steel. (Otto Reerslev)

9.3.5 **Plastic chassis snap-fit**

The picture presented at the workshop is shown in Figure 56. The fifth concept was also met with questions since the mechanism is somewhat complicated. The feedback received was mainly positive due to the innovative idea to insert a plastic part into the metal chassis to make it flexible. Additionally, since it is an insert, it may be altered depending on the individual customer’s demands. Thus, it was recommended to continue developing the concept and to investigate if a pressing action could trigger a separation between the two parts.

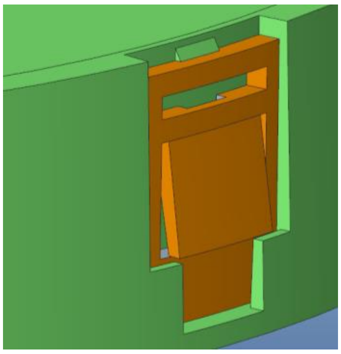


Figure 56 The plastic snap-fit inserted into the chassis, as presented during the workshop. (Otto Reerslev)

9.4 Concluding the digital workshop

A lot of useful feedback was received, and several undiscovered problems were highlighted during the digital workshop. The most promising concept was the bayonet as it would perform the best at this stage. However, there were concepts that had greater potential compared to the bayonet but had yet not been developed to meet its full potential. These were the two concepts based on a button functionality, the snap-fit with button release and the plastic chassis snap-fit, along with the magnet concept.

10 Prototyping

10.1 The design iteration preceding prototyping

The concepts from the digital workshop were thus adjusted, according to the feedback received. However, before printing the 3D-models, a few questions had to be dealt with regarding the concepts. For instance, how to make a pushing force of a button release the two parts? Moreover, the fitting method for the magnets in the corresponding prototype were to be determined. Finally, how to provide guidance for the bayonet concept to easier find the bayonet's entry points.

When developing the button release concept further, it became clear that the most difficult problem to solve was how to make a pushing force release the plastic cover in the z-direction. To this problem there were several suggestions such as fitting a seesaw on the inside of the cover top, see Figure 57, or to make the chassis go on the outside of the cover top for it to lock, see Figure 58.

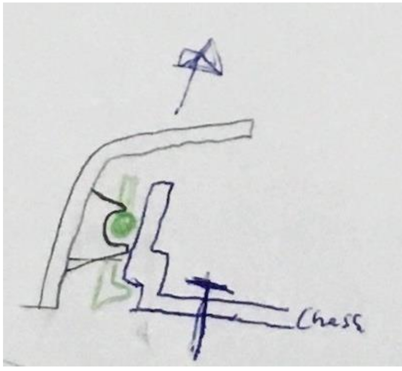


Figure 57 Sketch of seesaw on the inside of the cover, which would allow a pushing motion to release the lock. (Otto Reerslev)

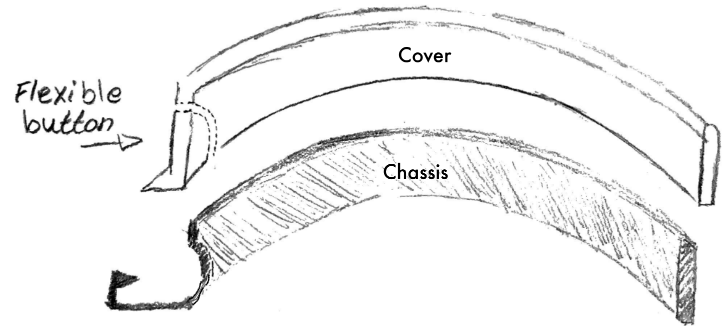


Figure 58 The locking mechanism where the plastic cover goes on the outside of the chassis but locks on a beam which is on the outside of the cover. (Michael Lindberg)

The most promising of these two was considered the seesaw option or a lever to separate the two parts upon a button press. The previous concept of having a plastic insertion piece in the chassis could be an alternative way of fitting this mechanism into the prototype. Hence, the release button concept and the plastic chassis snap-fit concept were explored further through making various 3D-models of both the button and the insertion piece in the chassis. These two concepts were then merged to form the, henceforth called, button concept.

10.2 Produce prototypes

The first prototypes to be printed were the magnet concept and a simple variant of the button concept which had a plastic insertion in the metal chassis. Both concepts were printed in plastic by a 3D-printer supplied by a spool of filament and thus lacking the characteristics of the metal chassis. The insertion piece was considered the most fragile piece of the prototypes and was therefore printed in several exemplars so that it could easily be replaced if broken.

Concluding the prototyping stage there were a total of four prototypes produced. The magnet concept, the bayonet and two iterations of the plastic insertion, all of which will be described in detail below.

10.2.1 **Magnet concept prototype**

Even though the magnetic attraction force may be calculated with high precision, it is difficult to know the practical force for a physical prototype as there are many variables affecting its magnitude. Thus, the prototype was designed with room for two different magnet sizes distributed around the sensor at four places. This made it possible to find the optimal attraction force by sequentially increasing the number of magnets. The magnets were glued into slots around the sensor in a plastic piece which is attached to the chassis with screws, see Figure 59.

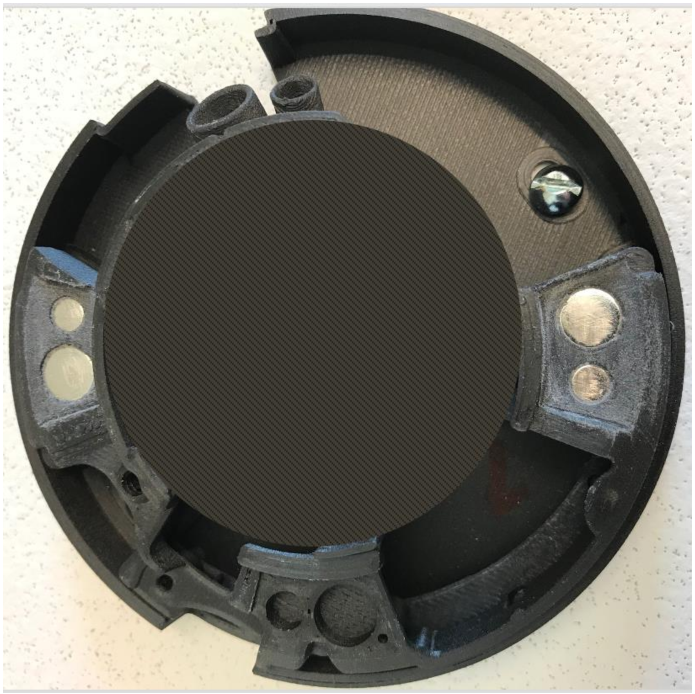


Figure 59 The chassis with four magnets glued into its plastic inner piece. (Michael Lindberg)

On the plastic cover piece, there was not enough room to fit magnets. Therefore, steel plates were cut into appropriate shapes and glued onto the cover on designated surfaces parallel to and matching the four positions on the chassis plastic piece, see Figure 60. In the end, only two positions out of four were fitted with magnets but each position held two magnets, adding up to a total of four magnets.

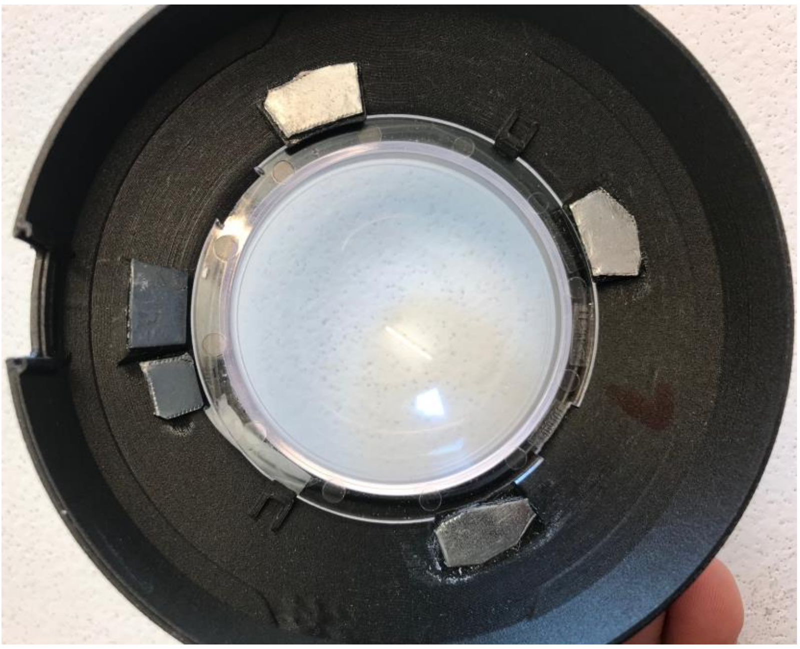


Figure 60 The cover with four cuts of a steel plate glued onto its designated places. (Michael Lindberg)

10.2.2 Bayonet concept prototype

The bayonet prototype was produced with three round male protrusions on the plastic cover's inside that will interlock with female L-shaped trails in the chassis, see Figure 61. The male-female-pairs are separated with 115 degrees angle to prevent the cover from being attached in the wrong direction. The male protrusions were kept simple, with a circular profile which won't get stuck in any edges while handling. The male protrusions will prevent the cover from sliding down the chassis walls, except when they reach their respective female trail. The female trail was made with wide guiding chamfers at the top, to guide the user to the trails entrance. The trail was designed with an L-shape to only need a horizontal movement and not a vertical movement when locking the parts, in order for the cover to stay in level with the chassis base. The trail was designed to minimize the twisting motion so potential problems with cables were diminished. In that manner was the final prototype designed to twist merely 6-degrees. The parts are locked together with a small hump in the trail, that is smaller than the diameter of the circle and requires the male protrusions to squeeze past the small hump. So, when the twisting torque is high enough, the cover is permitted past the hump, whereupon a notable clicking sound is heard and then the twisting motion is stopped.

Figure 61 The bayonet prototype, with a circular male protrusion on the inside of the cover and a female trail in the chassis. (Otto Reerslev)

10.2.3 Button concept prototype

This concept is based on a cantilever snap-fit beam with an underhook catch on one side of the chassis. This side may be released through the push of a button. Meanwhile on the other there is a combination of a knob and a hinge.

The button itself is flexible and the same is for the plastic insertion which can be seen in Figure 63.

Figure 62 The side with a snap-fit beam, underhook and a button. (Michael Lindberg)

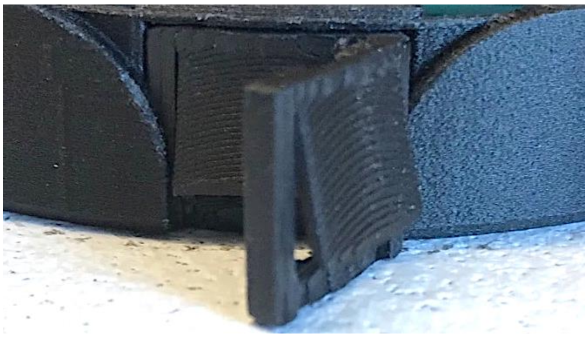


Figure 63 The plastic insertion piece which is flexible. (Michael Lindberg)

Figure 64 The side with hinge and knob. On top is the inside of the cover which is to match with the corresponding chassis holder seen on the bottom. This holder features a vertical guidance for a smooth fitting in the z-direction. (Michael Lindberg)

10.3 Physical workshop to evaluate prototypes

A workshop for testing the produced prototypes was conducted in a simulated environment suitable for the sensor. This was arranged to focus on user-testing, where each person attending was asked to act as an installer. Each attendee conducted the workshop individually, without anyone around and was instructed to first dismantle and then to reinstall each of the prototypes and finally to fill out a paper questionnaire. The prototypes were installed in a soft-tile ceiling and there was no cabling included. To facilitate their task, there was a ladder, a set of screwdrivers and a power tool available for use. The people attending were experienced mechanic designers from a company manufacturing sensors, of which some had previous experience from installing this type of sensor. The focus of the workshop was put on the installer since this is the primary stakeholder.

Five concepts were mounted in the ceiling before the workshop started. The order in which the attendees were ordered to disassemble the sensor concepts were the snap-on and then the screw concept, both of which are in the product range of this company. Proceeding this, was the magnet concept followed by the bayonet and finally the button concept.

Figure 65 The soft tile before installation in the ceiling, with the three prototypes and the two reference models. Each model was marked with A-E to indicate the order for disassembly, without explaining the underlying concept. (Otto Reerslev)

10.4 Workshop outcome

A total of eleven people conducted the workshop and provided their view of the proposed concepts. The opinions diverged and no apparent favourite concept could be chosen out of the five proposed. This was anticipated as subjective opinions are different for each individual person. The installers' reactions, verbal communication and opinions from the questionnaires have been summarized in Table 14. The questionnaire can be found in Appendix D.

Table 14 The feedback from the physical workshop based on reactions, verbal communication and notes from the questionnaires.

Concept	*Source*	*Feedback from installers' reactions, verbal communication and questionnaires.*
Dismantle approach	R	* If a visual indication was noticed, the installer tried to use it.
	R	* If no visual indication was seen, the approach was to pull or twist the cover.
	R	* When dismantling & installing for the first time, an intuitive concept is essential.
	R	* After a few dismantles/installations, an intuitive concept is less essential.
A: Snap-on	V	+ Feels secured when locked in place.
	R	- Need opposite force from above during installation
	R	- Needs to be in the correct position to snap on
	R	- Quite challenging to dismantle if not completely installed.
	R	* Some people dismantled with ease, some did not.
	V	* Installation was quick when knowing how to do it correctly.
B: Screws	R	+ Most intuitive dismantling because it visually shows the screws.
	R	- A bit time-consuming, where 20-30 s were required for unscrewing and 25-35 s for fastening the two screws.
	Q	*Overall highest score in questionnaire.
C: Magnet	Q	+ Easiest to install, no force was required for installation.
	Q	+ Easiest to dismantle, as it had the lowest separation force.
	R	+ Magnets are cool and gives a wow-factor
	V	- Separation force was too low! Assumed to be a problem for impact tests.
	V	- Several components required.
	Q	- Lowest score in questionnaire for how viable this concept would be.
	R	* The prototype could be attached in the wrong direction.
D: Bayonet	V	+ Good clicking-noise when assembled correctly.
	Q V	+ Was arguably the most reasonable concept to produce, as it could be done directly in plastic.
	V	+ Same motion for installation & dismantling, felt intuitive.
	Q	+ A late rotational click indicates the installer is assembling correctly.
	V	- Was too easy to dismantle. Could perhaps need a secondary lock?
E: Button	V	+ Quick installation with a feasible assembly force.
	V	+ Feels like the cover is attached firmly.
	V	- Needs trimming, to give a higher clicking-sound at assembly, to give correct assembly force and to pass impact tests.
	V	- Want more feedback when the button is pressed at dismantling.
	V	- The buttons affect the visual appearance, could perhaps be integrated better?
	R	* Was only intuitive if the person noticed the button!
		+ is positive, - is negative, * is other **R=Reaction, V=Verbal communication, Q=Questionnaire**

10.4.1 **Data collection through questionnaire**

The questionnaire was answered by all eleven testers. The data from the four quantitative questions were displayed in a box and whisker chart, see Figure 66.

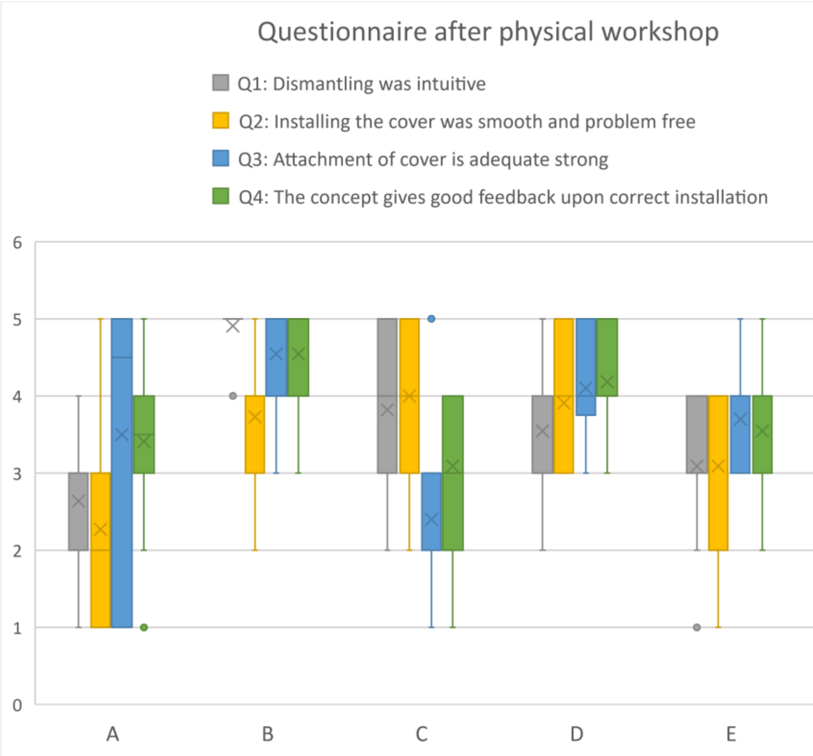


Figure 66 Box and whisker chart of data from the questionnaire. The box marks the lower and upper quartile. The mean value is marked with an X. The whiskers show the data outside the upper and lower quartiles. Any point outside the whiskers is assumed to be an outlier. The quartile calculations are made exclusive of the median. The data is based on eleven attendees' answers.

The first question which addressed whether the installation process was intuitive or not got extremely homogenous and high responses for the B concept with screws. Moreover, the second question: if the installation of the cover was smooth and without trouble, got the widest spread of all the questions, possibly indicating both appreciators and pessimists among the testers. Regarding the third question, if the cover was attached strong enough, there was the widest range, from 1 to 5, in the reference model A with the snap-on and bayonet off. This could mean that some people succeeded to do as the developer of this product had intended whilst others did not. Finally, the fourth question that addressed the feedback of the concept if it is installed correctly, got an interesting result for the C concept with magnets. It had the lowest mean and extreme value of all the concepts.

10.5 Iterating the chosen concepts

With the feedback received from the physical workshop, the decision was made to continue developing the bayonet and the button concept but to drop the development of the magnets as it would not withstand the impacts required for the sensor in relation to the price of the magnets required. The new iterations were printed and tested within the project group, similar to the workshops conducted earlier.

The button concept was developed further by replacing the hinge mechanism with a button just as on the other side. This change not only made it possible to separate the two parts linearly but also attach its two sides in any order, because they were symmetrical. A prototype was printed to test this concept in practice. However, it proved to be more complex to dismantle, because two synchronised actions were needed to release the cover.

The bayonet concept on the other hand did not receive as much feedback since it was functioning relatively well during the live workshop. However, there were still ideas of how to improve it. For example, to create a 45-degree tilted bayonet track to prevent a pushing force of the cover but instead attach it using the twisting motion. Another idea was tested, where additional catches were added that expanded in the radial direction. These would increase the torque required, both for fastening and releasing the cover. Upon testing this it was proved that the radial catches were not consistent, as they depended on the position where an installer grips on the cover. Nevertheless, two radial catches were included in suitable places on the cover resulting in a sturdy bayonet concept.

The two concepts were closely inspected and tested out physically to see which had greater potential and more importantly which one that proved to fit the best for the scope of this thesis. The concepts' similarities and differences were summarized in a table, see Table 15.

Table 15 Comparing the bayonet and a button concept. The similarities are followed by the differences.

Classification	***Similarities***
I	* Allow quick mounting & dismantling (in most conditions). * Few steps for mounting & dismantling. * Is equally intuitive when mounting. * Requires only one hand. * Requires no tools. * Is guiding the cover while mounting. * Gives feedback through sound and feeling when correctly mounted. * Can only be mounted in the correct orientation. * Mounting requires low force in -z direction.
T	* Could operate in the same temperature range.
M	* Contain no complex parts. * Potentially have low production costs. * Saves space in the middle of the product.

Classification	**Differences**	***Bayonet***	***Button***
I	Assembly motion	Rotation around the z-axis.	Pushing motion in z-direction.
I	Cable interference	Difficult with a small cable hole.	Installation barely affected by the cable.
I	Intuitive to dismantle	Non-intuitive if no visual or tactical indication.	Intuitive if button is found.
T	Time mounted without problem	The bayonet lock is assumed to persist the full lifetime of the product.	It is unknown if the insert persists pressure during the whole product lifetime.
T	IK-classification	A firm rotational lock grants persistence against impacts.	The cover prototype is flexing and risks releasing the lock.
T	IP-classification	Twisting lock provides tight seal for IP-protection.	The button cut out may let dust and water inside.
M	Extra parts	No additional parts needed.	The insert adds a new, small part.
O	Aesthetically appealing	Does not affect the outside.	Affects the outside as the button requires breaking the cover.
O = Other	**I=Installation**	**T=Technical Requirements**	**M=Manufacturing**

Some clarification is necessary to paint the full picture regarding some of the points covered in Table 15. At first, the bayonet concept was heavily affected by the cabling during installation. It is particularly difficult to install the cover with a tailored cable hole piece, re-examine alternative three in Figure 6 . Additionally, a stiff cable may prevent a simple installation or even unscrew the lock by itself. This aspect is important as the sensor requires a cable to operate, and all installations will include cable handling. As mentioned in section 4.1.3, most of the sensors are installed in soft tile ceilings which allows the cable to exit from the backside hole. However, as there are cases when the cable exits from the side, the chosen concept must work in these circumstances as well. Hence, the button concept's linear assembly motion was advantageous, and also the insert required only such a small assembly force so that the soft tile remained unraised upon installation. Concerning the button concept, it has the disadvantage of breaking the outside of the, otherwise, homogenous cover piece through integrating a flexible button in the concept. Moreover, the insert is required to withstand large forces during the IK testing and this capability is more difficult to predict for years ahead when the insert has been under constant pressure. It is uncertain how the design will cope with impacts on different regions of the cover. The prototype showed some flexing when pressed upon specific weak points without support from the chassis underneath.

The conclusion was to choose the button concept as a final concept, based on the feedback from the workshop, further testing of the iterations and comparing the differences. The reasoning was that, given the assumption that a tailored cable hole cover piece will be used, the assembly direction is disadvantageous to be rotational around the z-axis. If the cable would not intervene during installation, the bayonet concept would be a viable option.

11 Results

11.1 The concept design

The final concept is the button concept which will be presented in more detail.

The concept has, as previous versions, an insertion piece which may be permanently mounted into the chassis using a press fit attachment. The piece can be made from either plastic or metal. When producing this piece, small variations of the snap-fit beam or the frame can be modified to achieve different properties such as stiffness, durability, easy release and so forth. This snap-fit cantilever beam is upon installation, snapped into a locking position to the catch on the inside of the cover as can be seen in Figure 68, which produces a clicking sound at a correct installation.

The button on the cover is already included in the plastic as it is simply a button shape that is cut out in the cover piece, see Figure 71. The button is thus flexible and bends around a single fastening point on the cover. On the button outside there are three protruding ribs that indicate an action to the installer both visually and tactually. Additionally, there is a protrusion on the inside of the button to simplify the pressing on and releasing of the cantilever beam.

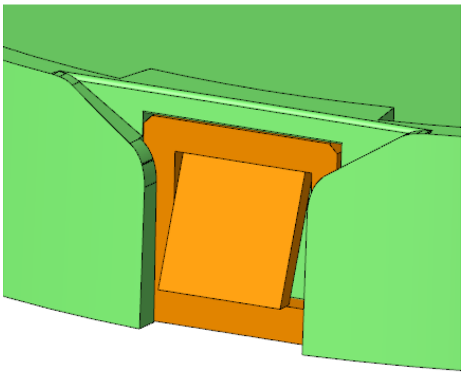


Figure 67 Close up of chassis and insert piece. The chassis is built inwards slightly, and the wide chamfers on the chassis introduce guiding of the cover during installation. (Otto Reerslev)

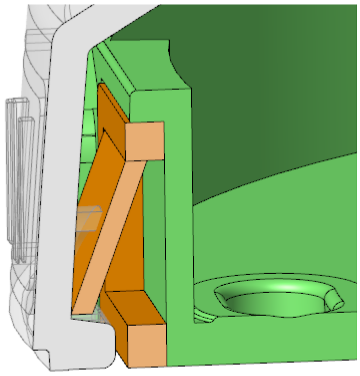


Figure 68 Section showing insert piece's cantilever beam locking the cover's catch. The protrusion on the inside of the button will simplify the release of the lock. (Otto Reerslev)

On the opposite side from the button is the hinge which has two features. First is the lower guiding pin which helps the user to find the correct assembly position for the hinge, see Figure 69. This pin is located low down on the inside of the cover and glides on top of the sloped edges of the chassis leading down to the hinge catch position in the centre of the slopes. Then, the hinge mechanism which is constructed by two catches that are slightly rounded. The chassis features a concave round while the cover has a convex round, which joins smoothly enabling a revolve of the hinge, see Figure 70.

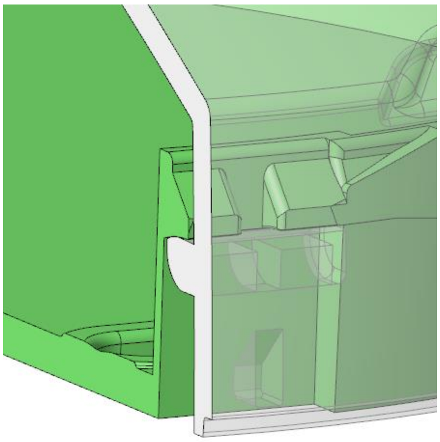


Figure 69 Close up of hinge-side. The lower guiding pin will guide the cover during installation. The catches are designed as ribs. (Otto Reerslev)

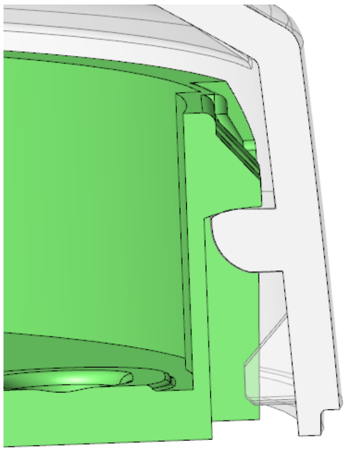


Figure 70 Section showing hinge-side in profile. The cover's catch is designed to act as a hinge-mechanism together with the catch of the chassis. (Otto Reerslev)

The final concept is created with the rules for injection moulding, mentioned in section 3.1 in mind. This means the prototype mostly has got rounded edges to avoid sharp corners, a constant wall thickness and drafted angles allowing a smooth ejection. The design will require two slides on the inside of the cover, one for the button side and one for the hinge side.

The cover is thereby attached on two points on opposite sides of the chassis and the installation is performed by a tipping motion in the -z ED. Down below is the final prototype displayed with important features in focus, see Figure 71-Figure 73.

Figure 71 The final prototype of the button concept. (Michael Lindberg)

Figure 72 Inside of the button on the cover. (Otto Reerslev)

Figure 73 The hinge on the opposite side from the button. (Otto Reerslev)

11.2 Specifications

In order to ensure that the resulting concept is working, it was compared to the initial list of product specifications. Table 16 shows each specification and marks how well the concept works for each specification. It shall be noted that there are several specifications in Table 16 that are assumed to be fulfilled rather than tested. This is due to the fact that the change from the initial reference product, which fulfilled these specifications, are small or can simply be foreseen.

Table 16 Reviewing the resulting concept with regard to the product specifications.

No.	***Metric***	***Importance***	***Unit***	***Ideal Value***	***Fullfilled?***
	Installation				
1	Product cover can be mounted and dismantled	4	# of times	100	Yes*
2	Time to mount	3	Seconds	5	Yes
3	Intuitive to mount	5	Subj.	Yes	Yes
4	Intuitive to dismantle	5	Subj.	Yes	Yes
5	Tools required	1	Number	0	Yes
6	Manual torque required	3	Nm	0.46	-
7	Manual force required	3	kg	5	Yes, lower.
8	Required mounting steps	3	Number	2	Yes
9	Hands required	1	Number	2	Yes
10	Plastic cover can be mounted in	5	# positions	1	Yes
11	Plastic cover gives feedback in	4	# of ways	3	Yes (Sliding, impact, sound)
12	Interference with cabling when mounting	4	Binary	No	Yes
	Technical requirements				
13	Number of loose parts except cover	3	# of parts	0	Yes
14	Withstand appropriate IK-classification	5	Binary	Pass	To be tested
15	Operate in humidity	2	% humidity	0-100	Yes*
16	Operate in temperatures	3	°C	5-50	To be tested
17	Withstand appropriate IP-Classification	5	Binary	Pass	To be tested
18	Time mounted without problem	4	Years	10	To be tested
19	Bending stiffness	4	GPa	2.3	Yes*
	Manufacturing				
20	Complex parts	3	Number	0	Yes
21	Manufactured using injection moulding	4	Binary	Yes	To be tested
22	Have a production cost	4	Low/mid/ high	Low	Cost analysis not performed
23	Take less room inside chassis	2	% Volume	5	Estimated -40%
24	Produced in a sustainable way	2	Binary	Yes	Yes*
	External requirements				
25	Be Aesthetically appealing	4	Subj.	Yes	Plausible
26	Repainting possible of outwards visual parts	4	Binary	Yes	Yes*
27	Have hole for cabling	5	Binary	Yes	Yes

***specification assumed to be fulfilled**

12 Discussion

12.1 Data gathering

Since the report is neither based on material directly from customers nor installers, it is difficult to fully assure all needs are identified. However, the data gathered is believed to be reliable as it is not collected from one single source nor single-handedly based on findings from one workshop opportunity.

12.2 Identified needs and specifications

The experience from the installation workshop gave insight to several of the installer’s needs. It should however be noted that it was not carried out by experienced, nor certified service technicians. The discussions in section 4.1.2-4.1.4 pointed out other significant needs to consider, related to the end-customer and manufacturing. Even though this method for data gathering is not ideal, it still sheds light on the needs of the end-customer which has been difficult to reach directly during the circumstances of the Covid-19 pandemic.

The identification of needs could potentially be improved by interviews or discussions with end-customers or service technicians, which was unfortunately not conducted due to lack of contact with end-customers or experienced service technicians. However, the physical workshop provided an opportunity to ensure the needs that had been identified earlier were adequate. The presented needs were organized to be used for similar products that are installed in ceilings and on walls, and to be extended with new needs for a specific case.

As the product specifications were constructed by thinking through every customer need and setting up measurable metrics to describe that need, there is a risk that specifications were missed. Product specifications are more specific than customer needs and must be tailored for an individual product. The proposed product specifications should thereby be regarded with this in mind for this general case. The list should be extended with further specifications and the ideal values would require a higher precision if intended to a specific product.

A couple of needs were not translated into product specifications due to the uncertain way of measuring them by quantity. One example was need #12, to induce a feeling of good quality when handling the product, which is a critical need to ensure that the product is competitive. To enable a translation of this need to a specification, it could either be rephrased or split up in several more specific needs. Though, this was not done since the outcome would be too many specifications that would disrupt the unity of the need itself.

An interesting perspective of the customer needs and product specifications which has not been analysed thoroughly is one based on the phases of the product's lifespan, covered in section 4.2. By considering the different phases of the product's life, different aspects are rated differently. Some of the aspects to consider in the phases can be; cost, time in operation, number of interactions with stakeholders et cetera. By mapping this, the relative importance of the aspects can be examined and then compared based on the corresponding phase. All of which to give a complete perspective of the product specifications in regard to its lifespan.

12.3 Stakeholders with contradictory interests

In this thesis there have been different stakeholders to take into consideration. For example, the screws were a topic which divided the customer and installer into two parties with opposite opinions. On one hand, the screws were appreciated as it gave clear indicator for the installer how to disassemble the product while the customer thought they were ugly. To decide which way to go, one of the two stakeholders had to be prioritised. Since the thesis focused on an easy installation, the installer was determined to be the prioritised group. Accordingly, the moral of this is that the outcome may have looked differently if the priority of the stakeholders were chosen differently.

On the same topic it shall be mentioned that there have been discussions with the experienced engineers of a company manufacturing sensors regarding the trade-off between the protection of the cover versus how easily it can be dismantled. These two are contradictory making the development difficult as a priority must be determined. For this application, the project chose to put focus on the ease of dismantling, thus not putting much effort into preventing tampering of the product.

12.4 Concept generation

Concept generation was a central part of the project. New and innovative ideas were necessary for finding the best solution. Through tools such as brainstorming and external searches, several conceptual ideas were generated. The predetermined assumptions regarding shapes and manufacturing affected the innovative capabilities and decreased the number of concepts slightly. A concept's viability was greatly affected by the form-factor of the product, which in this case was restricted to a relatively small volume.

It was clear that all concepts could not be investigated in detail, which is why a selection eventually was necessary. The concepts were arranged in groups prior to concept selection 1. The process of grouping concepts simplified the handling of the ideas but was counter-productive for the innovative mind. By grouping ideas into boxes, the mind gets stuck in a uniform thinking pattern, resulting in mental boundaries that are introduced to the concepts and thus preventing new creative ideas.

Moreover, the concept generation could have been done differently on a couple of points. An increased number of concepts could have been generated by further external research or by exploring the clarified problem in a group. The concepts were only generated within the group, instead of communicating with people with other backgrounds, experiences and ideas. This was a direct consequence of this thesis being conducted during the COVID-19 pandemic. Ideally, more time could have been put into sketching or building low-fidelity-prototypes for the various concepts, prior to the development in CAD, but was limited by the time plan of the thesis.

12.5 Concept selection

The purpose of concept screening was to filter out ideas that did not seem applicable for the task or had less strengths compared to other concepts. There is a possibility that the filtered-out concepts had more potential than anticipated as they had not been investigated thoroughly this early in the project.

Conducting concept selection 2 showed that weighting, rating and ranking is a time- and energy-consuming process where several vague decisions are made that directly affect the outcome of the project. The process has its advantages, as it clarified the most important specifications and the resulting matrix also gave insight into the differences and compromises between the concepts. However, it is too complex to construct a selection matrix with every criterion, hence the matrix will not give a complete analysis where every feature is compared.

Note that the scores for each concept in the selection matrix are based on a verbal evaluation of the conceptual ideas. The involvement of two experienced engineers gave input that were subjective as their arguments were based on their experiences. Additionally, when considering the selection criteria, note that the evaluation of the subjective criteria and the considerations whether they have been fulfilled or not are simply based on subjective decisions by the team.

The concept selection could have been done differently, for example by developing the concepts further before conducting concept selection 2. The selection would then be done with more details already in place. Another thing that theoretically would be better, to use a bigger, more detailed selection matrix. However, this did not seem appropriate for this project, because of the simple task, to attach two pieces, and that focus was put on the later development stages such as constructing prototypes and testing them out in practice.

12.6 Prototyping

An early insight was the advantage of an iterative and relatively quick development process enabled through 3D-printing. Though, criticism towards printing several concepts early on may be the cost of the prototypes, the time and materials used. Additionally, it is common that for each new iteration there may surface new, undiscovered problems, which has not yet been taken into account for the time planned. Also, as concepts must be constructed in a CAD-programme prior to printing, the prototyping can take longer than planned. Another issue that appeared when prototyping was the limitations to the fidelity depending on the printer used. The reduced fidelity resulted in a worse functionality than planned, especially compared to a finished product. In the same manner does the material properties differ from not the finished product.

Since the best way to test out one or several moving parts' functionality is to physically experiment, all the promising suggestions should ideally be 3D-printed and tested. Though, as there were numerous of these suggested solutions, not all could be printed in full size, so the functionality was tested out first on a small 3D-printed part which only held the necessary part to test the functionality. This may have affected the evaluation of these concepts as it may not have the same properties when produced in smaller sizes.

Conclusively, since the resulting concept is a function of the proposed and tested concepts, an increased number of prototyped concepts would be favourable, to achieve a more competitive product.

12.7 Workshops

Despite trying to arrange the physical workshop in the most realistic and productive way possible, there are some aspects that were not covered. As opposed to a real installation, the conducted did not include any cabling which simplified the installation process for several of the concepts. The reasoning for this is that all of the prototypes were installed in a soft tile, whereupon the cable is usually exited through the chassis' backside hole and therefore barely interfering with the installation of the plastic cover. Additionally, the workshop could not include every possible installation, but focused on the most critical installation. The installation process started out by disassembling the prototypes rather than assembling them. This was intentional as an installer may arrive at a scene where a product is already installed and requires service. Additionally, whether the concept is intuitive or not is tested out better this way since the installer cannot examine the attachment mechanism on the inside of the product prior to disassembling but must rely on other factors. More importantly is the simplification that was made to the sealing of the dome. During the physical workshop there were no sealing attached to the plastic cover which in turn made it easier to attach the cover. In addition to this was the plastic prototypes prior to the workshop attached to a soft tile using screws. Yet, the chassis could not be fastened fully as that made the prototypes' chassis bend which in turn made the attachment more difficult.

All feedback received during the physical workshop was affected by the prototype's quality and the result would be different if the prototypes were constructed differently. The quantitative data from the questionnaire, presented in Figure 66, indicates that the opinions are similar for some questions, but varies for others. The variation of opinions could depend on subjective opinions or that each person experienced different events during the workshop. The low number of testers affect the results, and clearer results might occur from testing with more people.

12.8 The resulting concept

Due to different circumstances, assumptions, customer needs and product specifications, the best attachment method is directly depending on the specific application of the product. The final concept was chosen as the best screwless option for the given conditions, but it should be noted that it still has its drawbacks. Even though the team have benchmarked with products of a single company that is manufacturing sensors there are no guarantees that the result is better than all sensors on the market.

The resulting concept proved, through testing of prototypes, to be a quick, intuitive, and simple concept to handle during mounting and dismantling, because of the guided, linear assembly which requires only a small assembly force and the button to manually release the lock. The concept relies on one additional part which is permanently attached to the chassis to add the manual release-feature, resulting in zero loose parts.

The similarities of the resulting concept to an attachment using screws, is the absence of rotation to the cover during assembly. Both affect the aesthetic look of the cover's outside, whereas it is a matter of taste of which visually looks better than the other. An attachment using screws is presumably more durable and stronger compared to the proposed concept since the friction of a tightly fastened screw is higher than a thin cantilever beam in the plastic insertion piece. Though, even more concerning when comparing it to the screw concept, it was not proven to be more intuitive. On one hand, could this mean that one of the goals of the project was not successfully achieved. But on the other hand, the button concept was still considered intuitive when conducting the workshop and since the task of the thesis was to find the best screwless mounting, the goal can be regarded as successfully achieved.

When reviewing the concept with the list of product specifications, a couple of technical requirements were not tested. The most critical specification to be tested is operation during a long time and for IK-testing. Verifying these specifications is required before integrating this concept in a product. Even though the number of analyses carried out on the final concept was restricted, this meant more focus could be put on developing a better final attachment concept.

The assumptions affected the choice of concept, as it removed some of the design freedom. If the product would be designed with other constraints, then other design solutions would be applicable. By redesigning the product and introducing a second layer of the cover as shown in Appendix B.4, the cabling would not be an issue when installing. If the chassis was made of a flexing material the snap-fit might be integrated in the chassis. The size constraint not only limits the possible volume of the solution but also affects the mechanical properties, as the cover will not flex similarly as covers for larger sensors. Thereby a solution cannot be scaled down directly from a bigger sensor.

Since this solution is not only applicable for this specific product it may be used for other similar products. This can be of advantage not only for the manufacturer of the specific product but also for society as a button concept may be more ergonomic and requires no tool, thus allowing more people to independently service their equipment of similar kind.

12.9 Evaluation of process and methodology

The systematic development process provided by U&E, had its advantages and disadvantages. The process simplified the organizing of the necessary specifications and features for achieving a successful product. By researching the customer needs & product specifications early, the important features and properties for the final concept were known prior to concept generation and selection. The needs acted as a set of criteria for selecting concepts prior to prototyping. Working early with product specifications did, however, turn out to be one of the drawbacks of the methodology, as the list of criteria influenced the innovative thinking when generating concepts. Another drawback to face the product specifications early is that the decisions made at that stage form the future of the project. Thus, as the insight in the project and problem at that stage is somewhat limited, decisions may be unsubstantiated.

When the developer should focus on new innovative ideas, the process did not provide enough innovative tools for overcoming old conceptual ideas and testing new boundaries. The tools from Bonnenberger's snap-fit development process did clarify the problem regarding the attachment's characteristics and assembly motions, but similar to U&E, it did not provide much innovative inspiration to new conceptual solutions.

13 Conclusions & Future work

From this thesis, it can be concluded that there are several possible methods for fastening a cover to a metal chassis that do not make use of screws. A notable conclusion made from the Bonnenberger method is that the number of viable assembly directions for this application are no more than three.

Furthermore, it can be concluded that subjective criteria are more difficult to handle. As opposed to technical requirements, are they difficult to quantify and therefore challenging to assure they are fulfilled.

The final conclusion that is drawn is that this thesis project has come a long way to develop an alternative method, using a snap-fit for fastening a plastic cover to a metal chassis and a button to release it. This method is considered intuitive and simple to handle with cabling and in soft-tile installation. Still, this solution is not fully developed as there are some issues that are addressed in more detail in section 13.1 Future work, presented below.

13.1 Future work

There are several areas to investigate prior to integrating the final concept in a product ready for the market. To begin with, the proposed concept could be further iterated to be tailored for the specific product. By redesigning the insert, the locks functionality could be achieved with other materials that allow a stronger and cheaper design. It is also encouraged to develop better guidance, both visually and tactually. This will enhance the overall impression of the product.

The future work includes a strain analysis to ensure that the proposed design will withstand external forces and the temperature variations. A mould flow analysis of the chassis and the cover should be done, to ensure the manufacturability of the given concepts. Additionally, this analysis should also include an IK-test to ensure that the specified IK-classification are met.

A cost analysis should be performed to ensure that the concept could be produced within a competitive price-range. This was not done as a cost analysis is depending on many variables such as number of products, initial costs of tools/dies.

Conclusively, the proposed concept needs to be tested out by service technicians, to get their input regarding the handling of this solution.

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Appendix A
Time plan and outcome

A.1 Planned Gantt chart

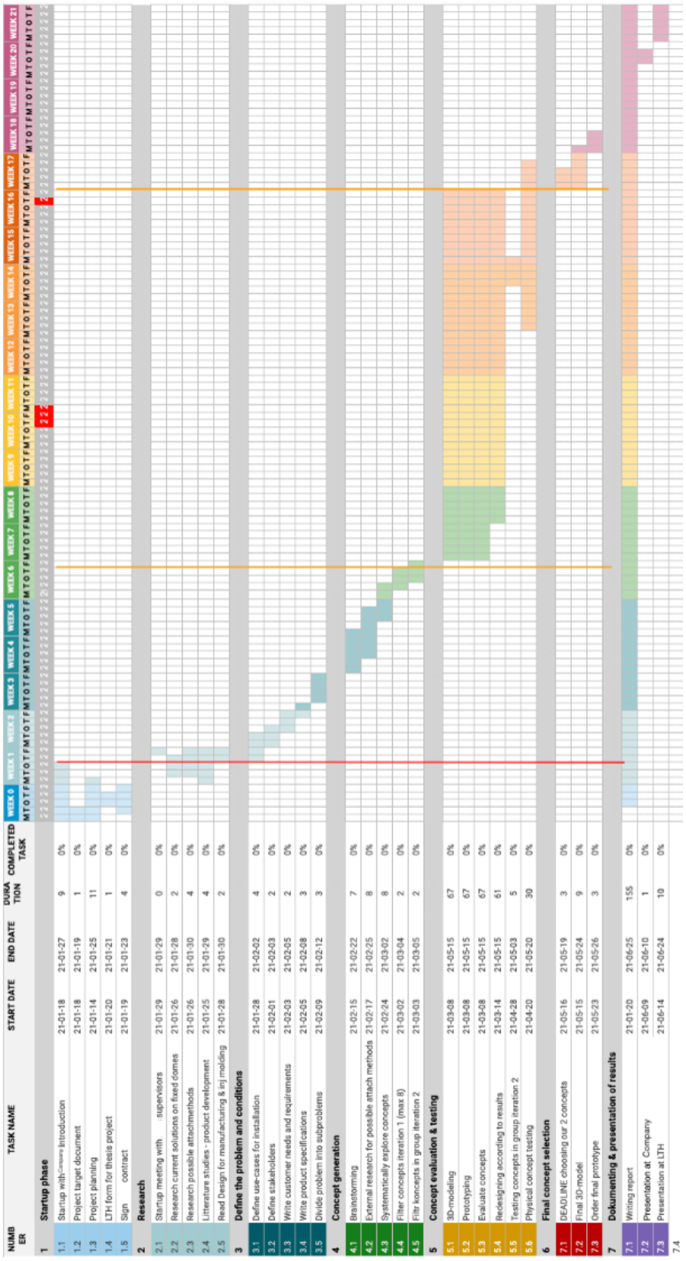

Figure A.1 The initial Gantt-chart for the project plan.

A.2 Executed Gantt chart

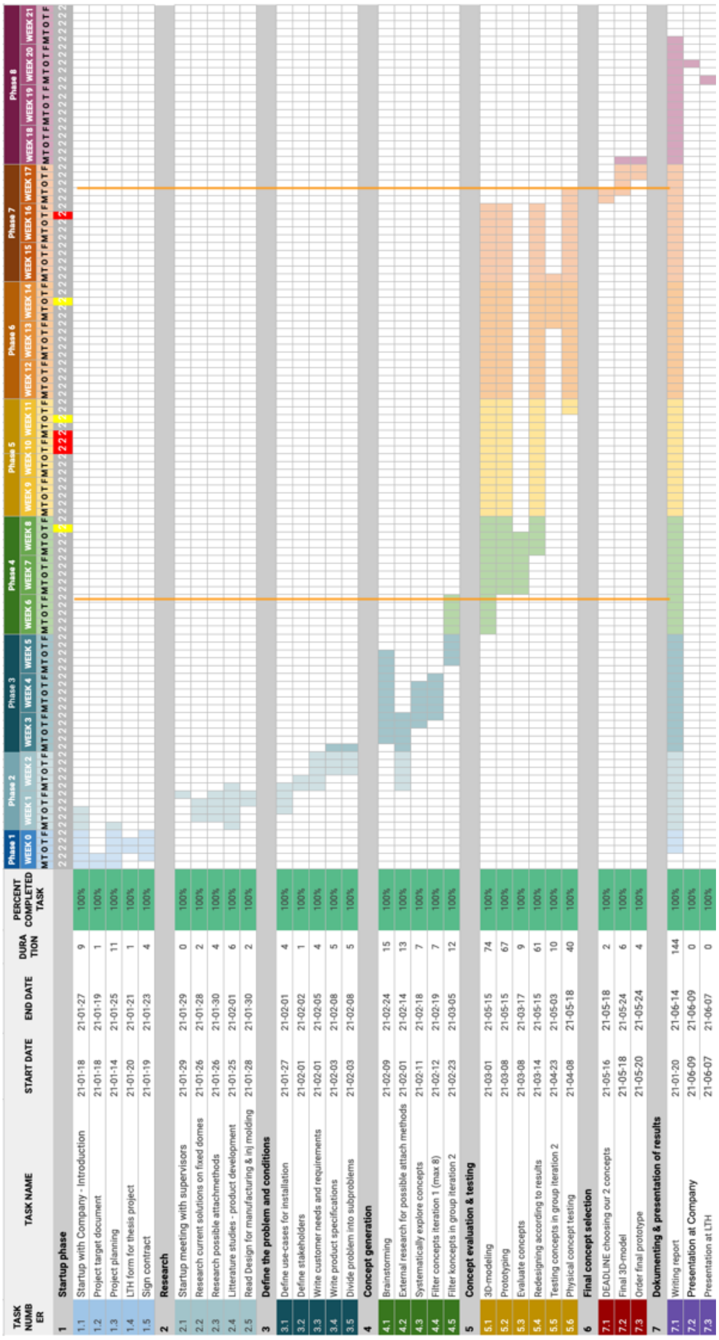

Figure A.2 Executed time plan.

Even though are a few differences between the planned and executed time plan, on the whole, the team managed to follow the plan relatively well. One major difference is the time required for brainstorming of the concepts which was underestimated beforehand. Also, the evaluation was completed in shorter time than originally planned.

Appendix B Brainstorm sketching A

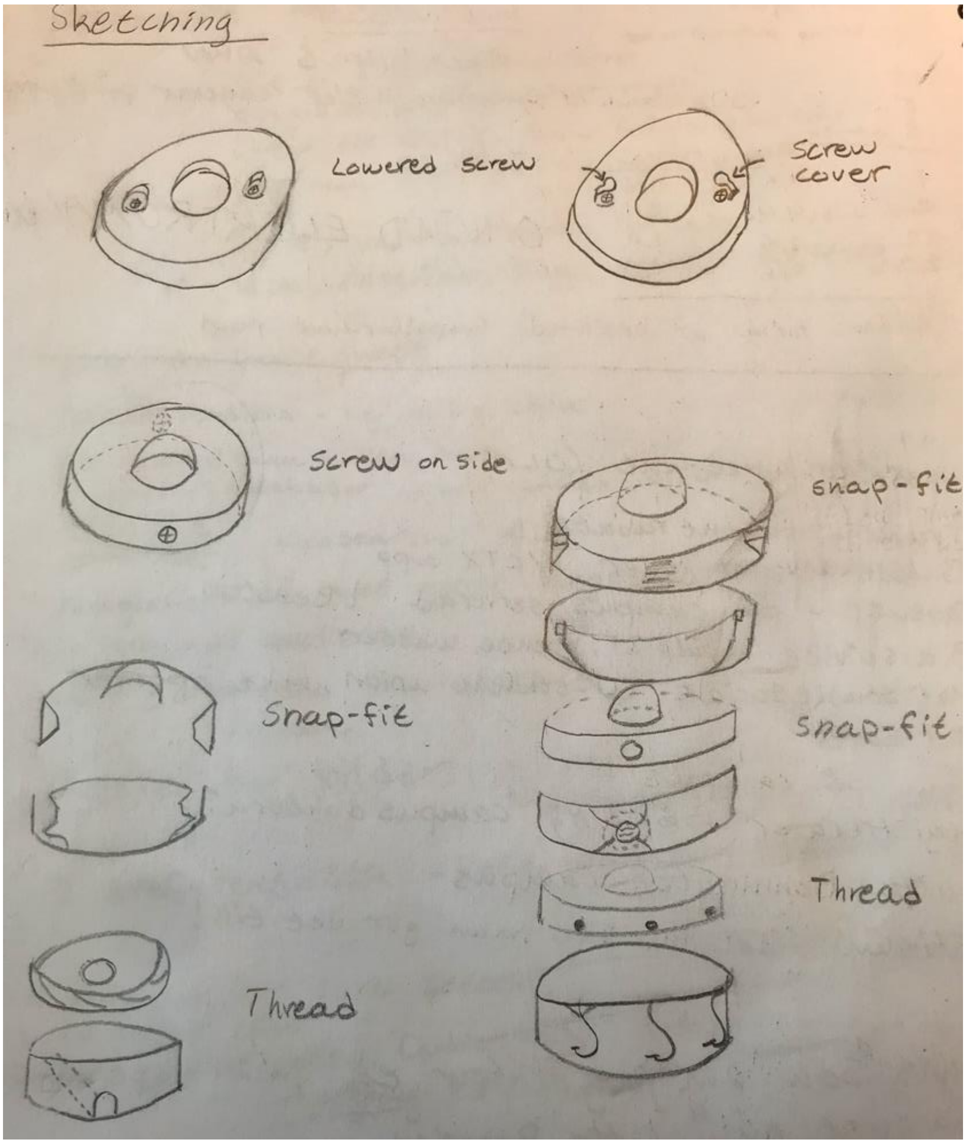

Figure B.1 First sketch.

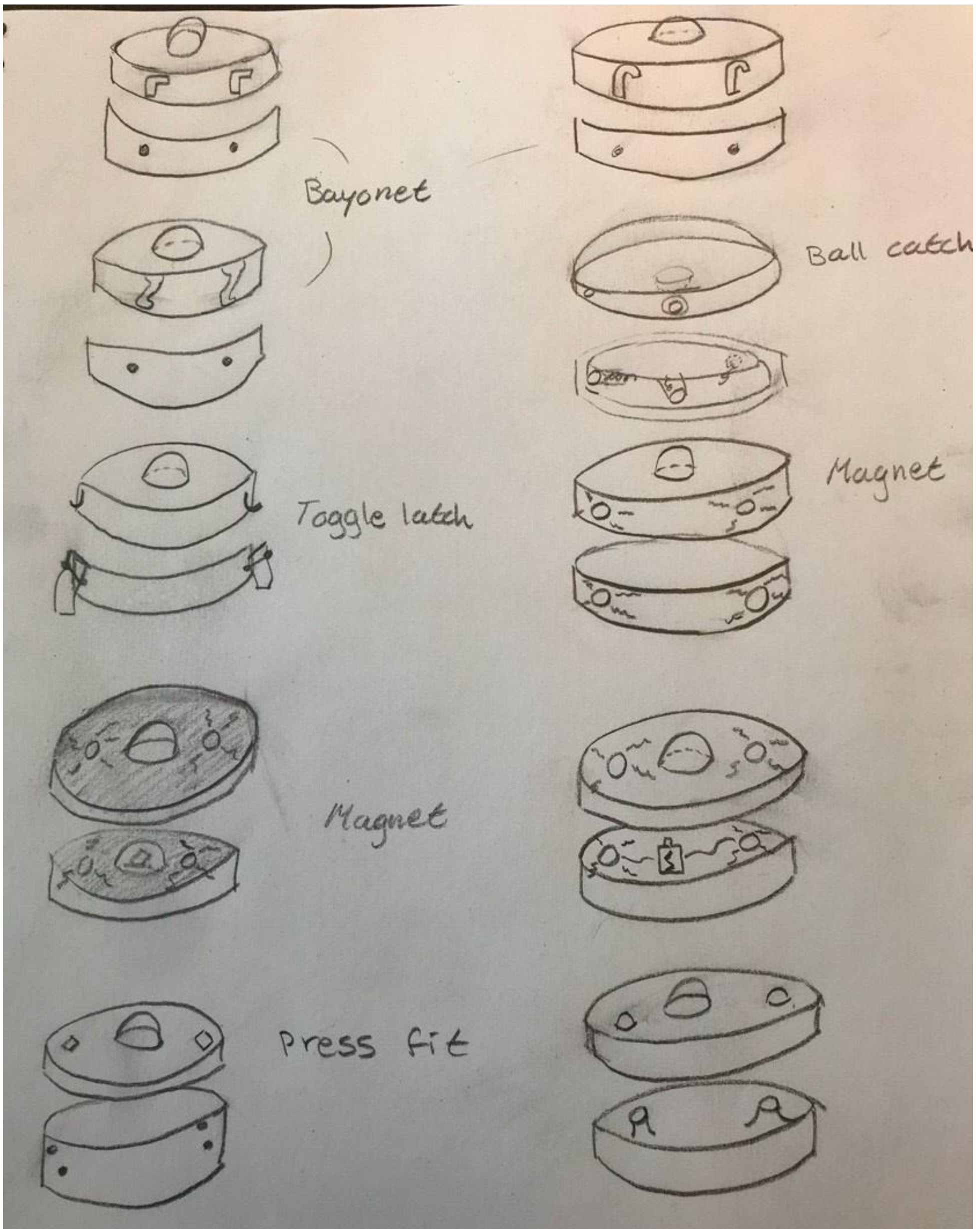

Figure B.2 Second sketch.

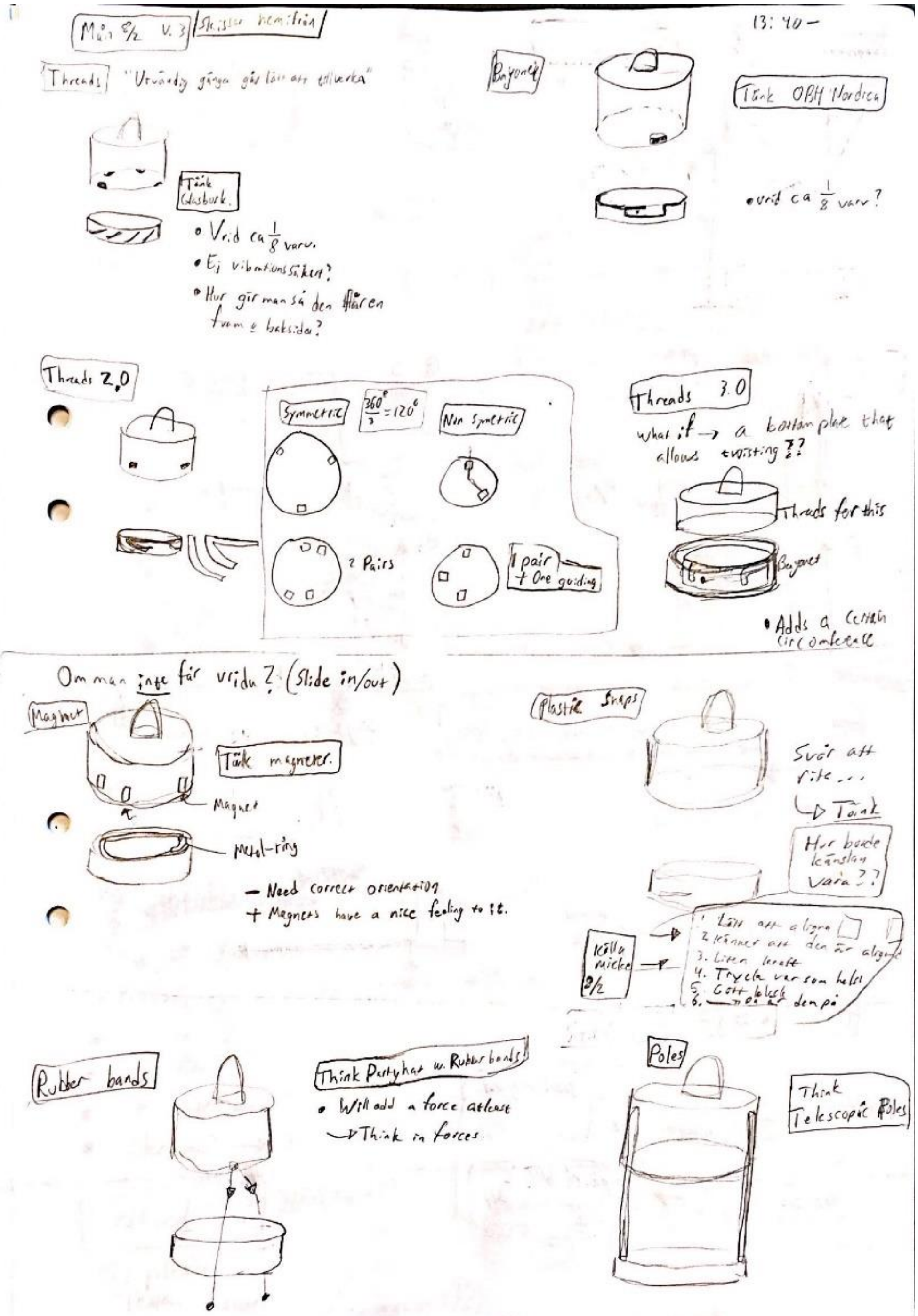

Figure B.3 Third sketch.

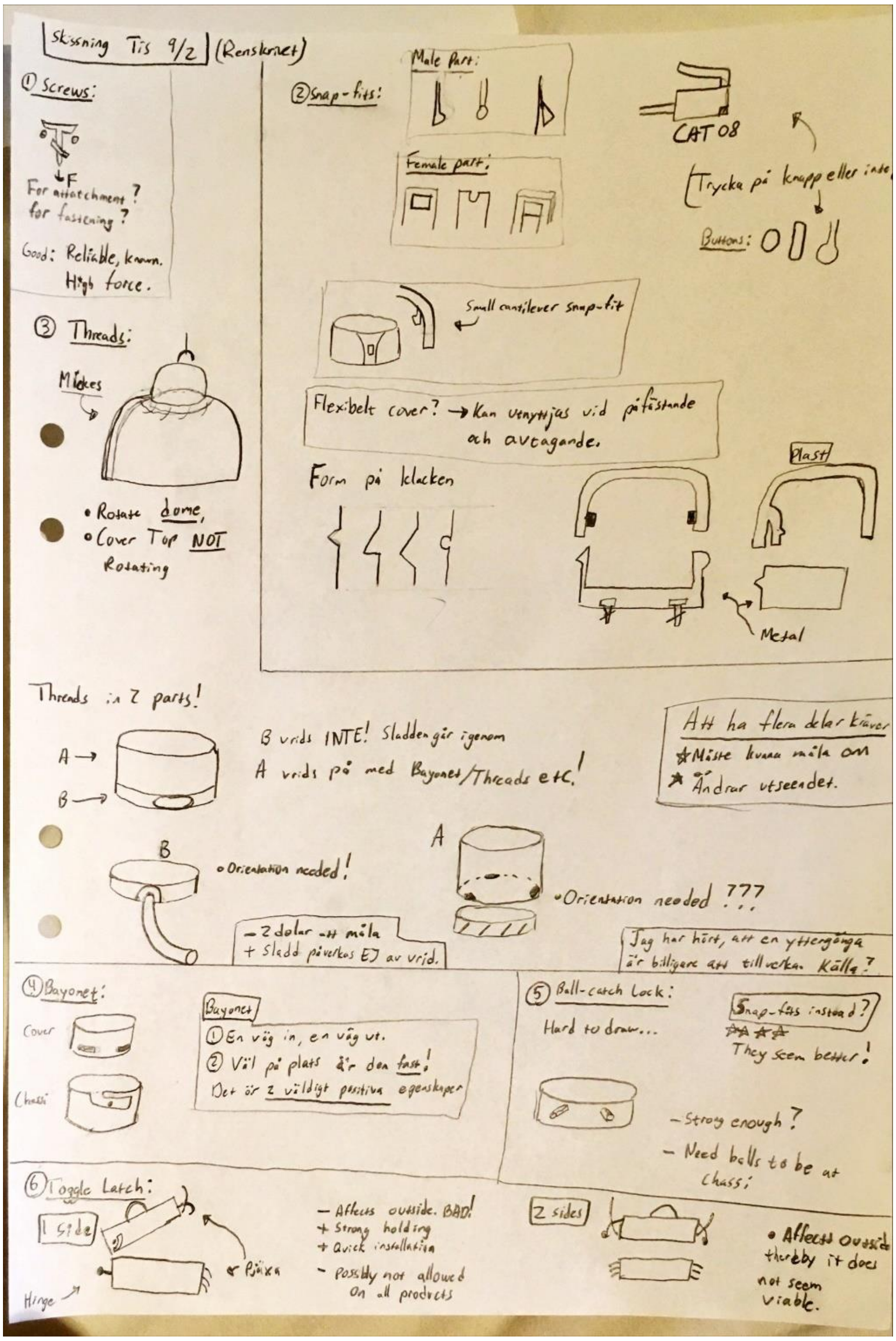

Figure B.4 Fourth sketch.

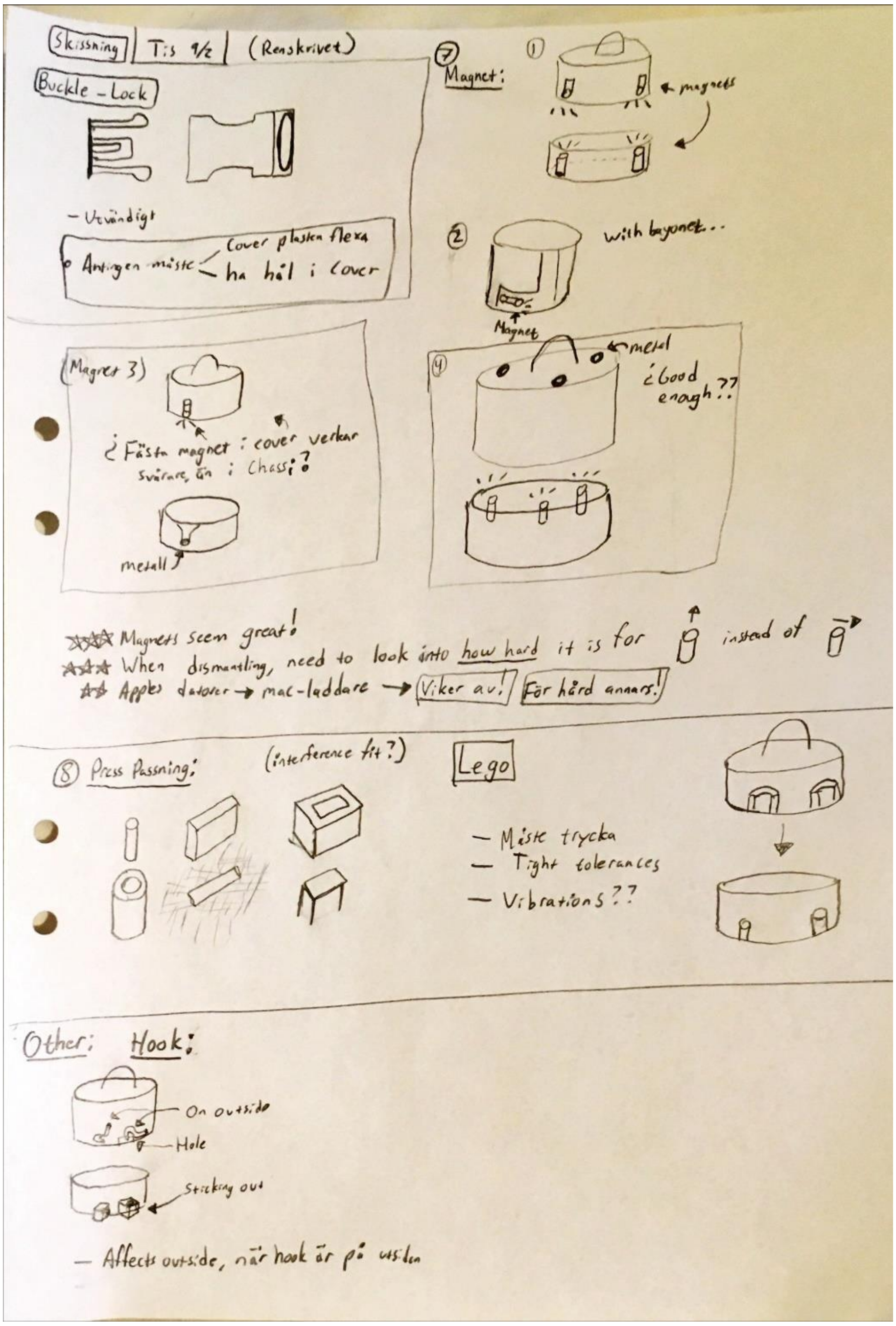

Figure B.5 Fifth sketch.

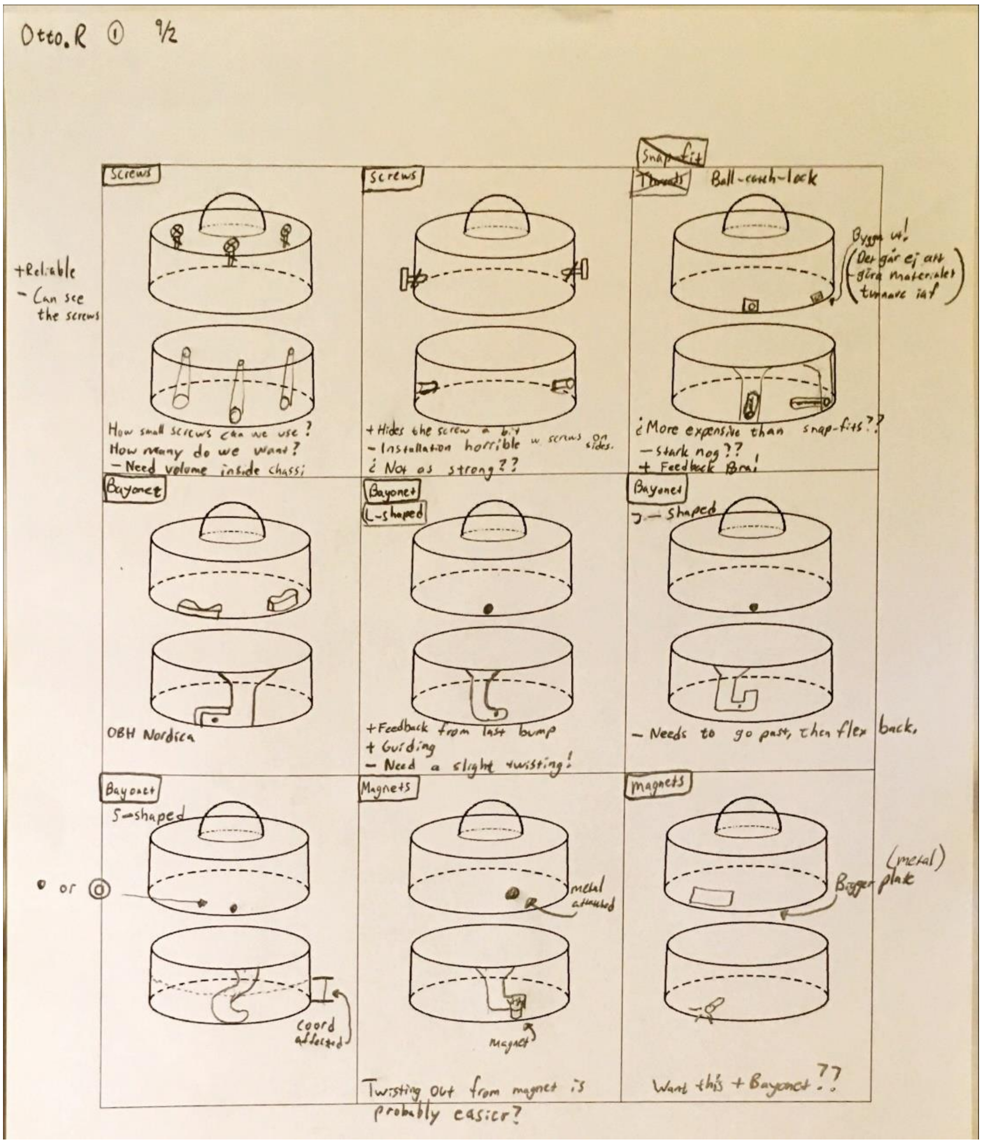

Figure B.6 Sixth sketch.

Appendix C Brainstorm sketching B

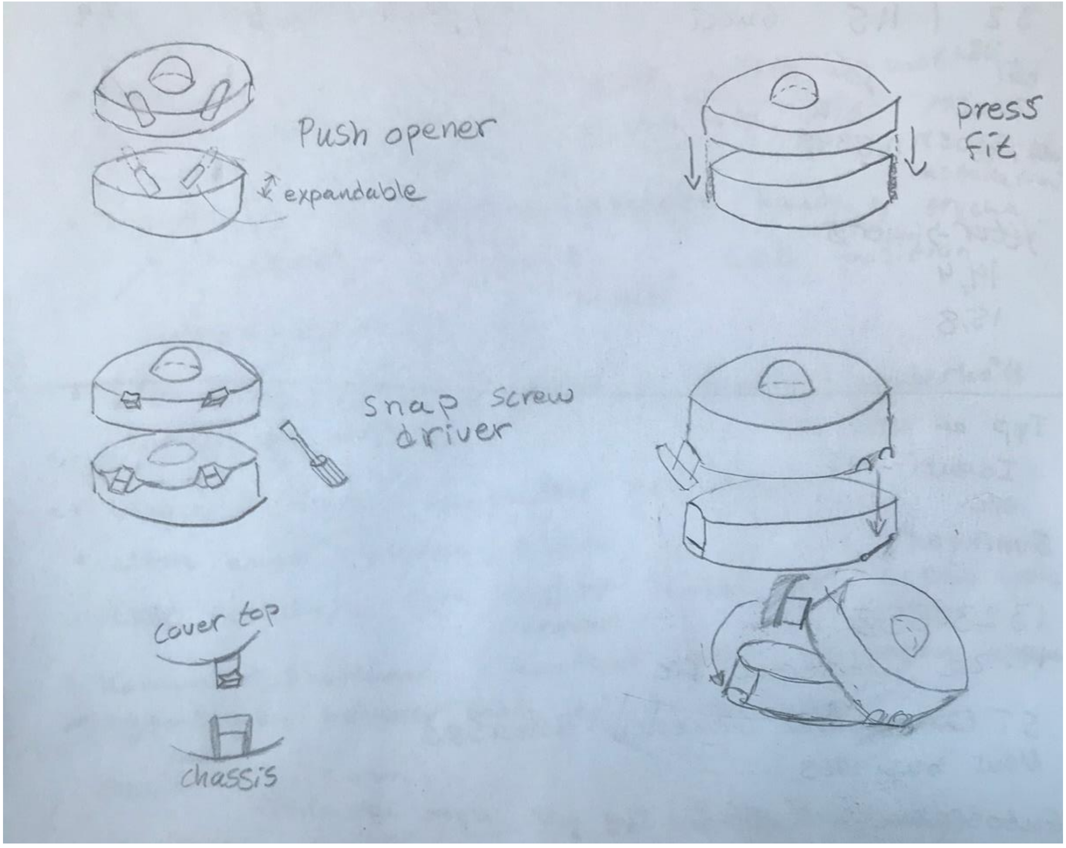

Figure C.1 Seventh sketch.

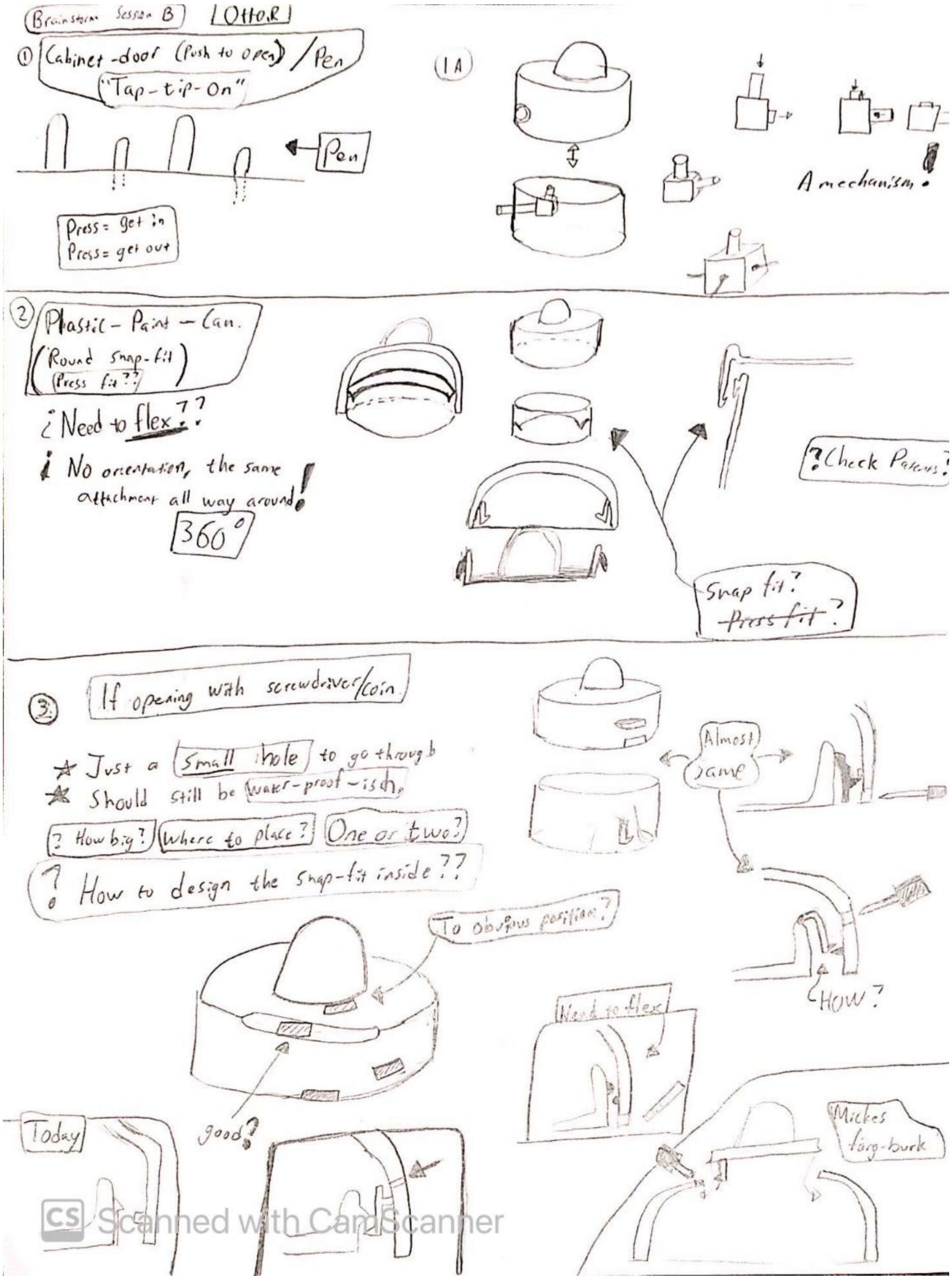

Figure C.2 Eighth sketch.

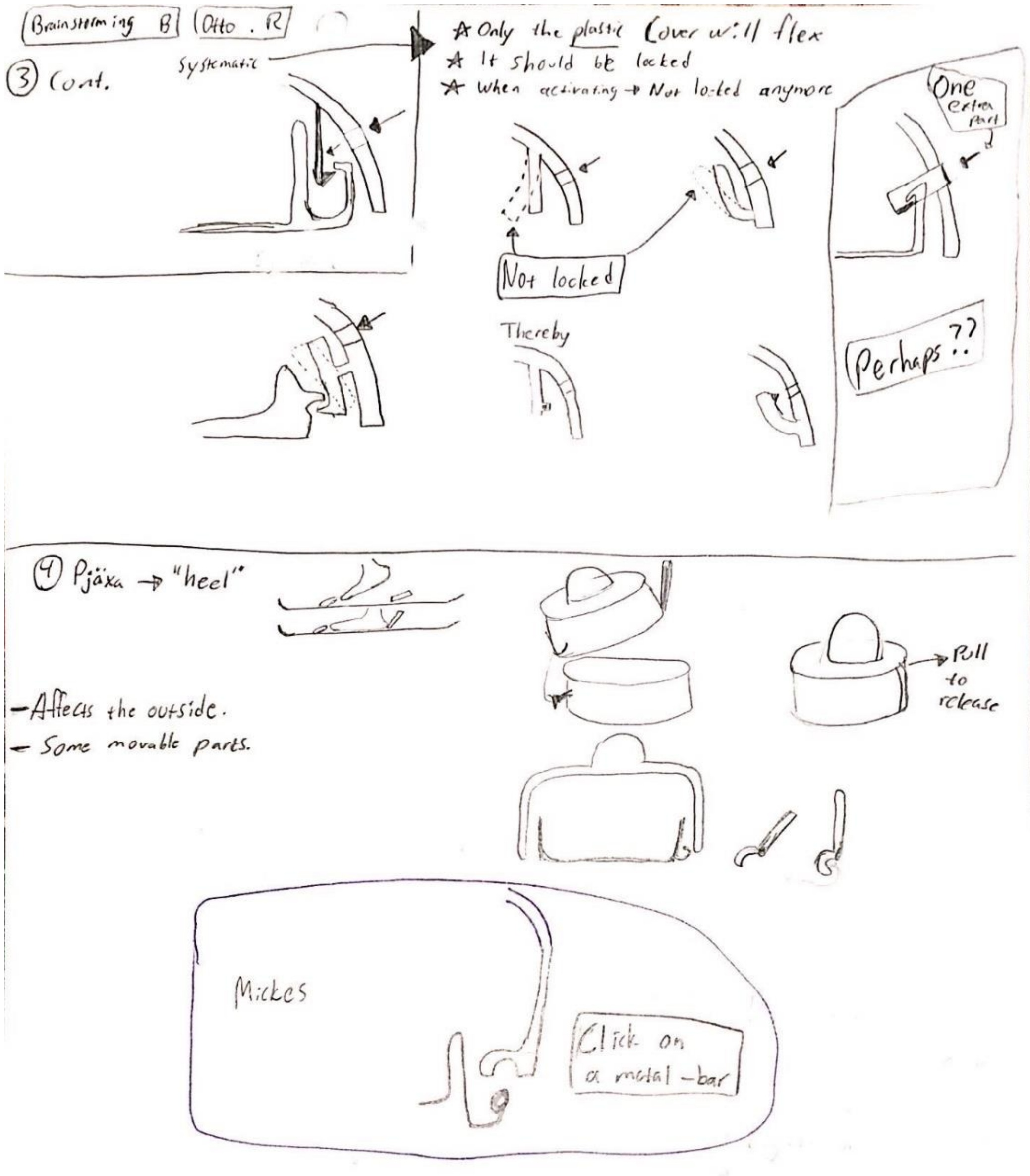

Figure C.3 Ninth sketch.

Appendix D Questionnaire for installation workshop

The questionnaire that was used during the installation workshop. The participants were asked to fill in the questionary after they had tested the five concepts.

Enkät efter Installations workshop

Yrke: ……………………………………………………

Du har nu testat 5 olika koncept för att fästa Cover på Chassi:

A = Snäpp på, vrid av
B = Skruvar
C = Magneter
D = Bajonett
E = Knapp och snap fit

1.	Vilket koncept gillade du bäst, och varför?
2.	Vilket koncept tycker du har minst potential, och varför?
3.	Vilket koncept känns mest realiserbart?
4.	Vad skulle du vilja ändra på med det koncept som du anser mest realiserbart?

Figure D.1 The physical workshop questionnaire page 1 of 2.

Svara på följande påståenden med ett tal mellan 1–5: (5 = Instämmer helt och 1 = Instämmer inte alls)	A = Snäpp på, vrid av B = Skruvar C = Magneter D = Bajonett E = Knapp och snap fit				
	A	**B**	**C**	**D**	**E**
(Exempel) Prototypen består av få antal delar	5	3	1	5	3
B hade skruvar… C kräver många delar…D samt A behöver inga delar…					
(1) Demonteringen var intuitiv					
Kommentarer.					
(2) Installering av cover var smidig och problemfri					
Kommentarer.					
(3) Cover sitter lagom hårt					
Kommentarer.					
(4) Konceptet ger bra feedback vid korrekt installation					
Kommentarer.					

4.	Övrigt. Ditt helhetsintryck. Feedback på workshopen. Skriv av dig!

Figure D.2 The physical workshop questionnaire page 2 of 2.