Master of Science in Mechanical Engineering
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Development of Modular Frames Intended For Sealing Cables

Modular Design and Mechanical Engineering

Sven Odin
Gustav Åsard

Faculty of Mechanical Engineering, Blekinge Institute of Technology, 371 79 Karlskrona, Sweden

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The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

Contact Information:
Author(s):
Sven Odin
E-mail: svod17@student.bth.se

Gustav Åsard
E-mail: guas17@student.bth.se

University advisor:
Adj. Prof Alessandro Bertoni
Department of Mechanical Engineering
E-mail: alessandro.bertoni@bth.se

Problem Owner(s):
Andreas Karlsson
Product Development Manager/PD & E Global Products
Roxtec International AB
E-mail: andreas.karlsson@roxtec.com

Daniel Sträng
Lead Innovation Engineer, Product Development & Engineering
Roxtec International AB
E-mail: daniel.strang@roxtec.com

Faculty of Mechanical Engineering	Internet :	www.bth.se
Blekinge Institute of Technology	Phone :	+46 455 38 50 00
SE–371 79 Karlskrona, Sweden	Fax :	+46 455 38 50 57

Abstract

When highly customer specific and specialized products needs quick and easy changes it might produce consequences which affects both the producer and customer negatively. A modular product could ease the financial burden and shorten increased time in production by offering a product which can be refined by a reseller close to the customer or by the customer themselves. This thesis serves as an investigative case study into the methods used for modular product development and how they fare against the case of highly specialized products. The first aim of this thesis is then the development of a modular product concept. The product is a cable sealing solution with the goal of protecting cabinets or act as a seal between two spaces, blocking from hazardous environments, liquids, dust and in some cases even fire. The second aim is to review the development and formulate a guideline to be available for third-party entities who themselves searches for a way of making modular products which does not necessarily fulfill the requirements for the typical methods used in *Modular Product Development.*

The study showed that using something like *Modular Function Deployment* as a framework and the tools with methods mentioned in regards of*Modular Product Development* is not suited for dealing with products that have the same basic functionality but share no physical commonality. For this, *Participatory Action Research* and *Agile Product Development* are shown to be far better suited.

The result are **three concepts**, two of which were considered interesting and made into functioning prototypes for testing ingress protection using standardized IP-tests for liquids. The prototypes scored fairly high, X4 and X5, considering them being the first iteration, showing that they have potential. But not without further work smoothing out existing and future issues along the way. A **guideline** was formulated based on the actions and activities that had an yield considered a tangible result, as well *Participatory Action Research* and *Agile Product Development.* The guideline is considered by the authors as useful when product functions are to be shared, but dealing with products housing no commonality.

Keywords: Modular Product Development, Modular Design, Agile Product Development, Mechanical Engineering, Participatory Action Research

Sammanfattning

När högt kundspecifika och specialiserade produkter behöver snabba och enkla förändringar kan det medföra konsekvenser som påverkar både producenten och kunden negativt. En modulär produkt kan lindra den ekonomiska bördan och förkorta den ökade tiden i produktionen genom att erbjuda en produkt som kan förädlas av en återförsäljare nära kunden eller av kunden själv. Detta examensarbete fungerar som en undersökande studie av metoderna som används för modulär produktutveckling och hur de står sig mot fallet med högt specialiserade produkter. Det första syftet med detta examensarbetet är då att utveckla ett modulärt produktkoncept. Produkten är en kabeltätning med målet att skydda skåp eller fungera som en tätning mellan två utrymmen, för att blockera mot farliga miljöer, vätskor, damm och i vissa fall även brand. Det andra syftet är att granska utvecklingen och formulera en riktlinje som ska vara tillgänglig för tredjepart som själva söker efter ett sätt att skapa modulära produkter som inte uppfyller kraven för de typiska metoderna som används inom *Modulär Produktutveckling*.

Studien visade att användningen av något som *Modular Function Deployment* som ett ramverk och de verktyg med metoder som nämns i samband med *modulär produktutveckling* inte är lämpligt för att hantera produkter som har samma grundläggande funktionalitet men som inte delar någon fysisk gemensamhet. För detta visade sig *Participatory Action Research* och *Agile Product Development* vara mycket bättre lämpade.

Resultatet är **tre koncept**, där två ansågs intressanta och gjordes till fungerande prototyper för att testa inträngningsskydd med hjälp av standardiserade IP-tester för vätskor. Prototyperna fick ganska höga poäng, X4 och X5, med tanke på att de är den första iterationen, vilket visar att de har potential. Men inte utan ytterligare arbete för att lösa existerande och framtida problem längs vägen. En **riktlinje** formulerades baserat på de åtgärder och aktiviteter som hade en retur som ansågs vara ett konkret resultat, samt *Participatory Action Research* och *Agile Product Development*. Författarna anser att riktlinjen är användbar när produktfunktioner ska delas, men hanterar produkter som inte har någon gemensamhet.

Nyckelord: Modulär Produktutveckling, Modulär Design, Agile Product Development, Maskinteknik, Participatory Action Research

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Contents

Acronyms

Term of Word	**Acronym**
Boundary Block Diagram	BBD
Design Structure Matrix	DSM
Electromagnetic Compatibility	EMC
Function Flow Block Diagram	FFD
Integral Design	ID
Minimum Viable Product	MVP
Modular Design	MD
Product Family	PF
Product Line	PL
Modular Frame	MF
Participatory Action Research	PAR
Ingress Protection	IP
Chemical Abstracts Service	CAS

Chapter 1

Introduction

Integral design, otherwise a product developed with integral design in mind is constructed by several functions, components or both which are themselves developed side by side for a perfect fit with each other. This usually means that the end-product may mostly house specialized and nonstandard components that are unfit to work with external products, because the highly specialized end-product is created for one or a very limited number of use cases. For example electronics. This can often be seen or heard as proprietary parts, a part that only fits the product and use case in question and nothing else without modifications done to the product by the end-user [14]. Products developed and produced after the idea of having a system or function based on *modular design* can often be seen using highly standardized parts and components to maximize the users ability to customize and change the product depending on the use case. A computer and the possible add-ons that can be purchased and installed are a modular system in the sense that the customer, most of the time, isn't bound to a certain producer's components or a component with a certain type of function. This is due to the fact that standards have been put in place and implemented regarding the connection interface between components [14].

When designing products integrally, and these products have the exact same main function with slight variations depending on the needs of the customer, a problem can occur. *The problem* that can occur is that due to these slight variations needed from the customer, it can lead to a larger demand for custom tailored products. This is not something that is inherently bad to a certain degree. It becomes a problem when the total amount of standardized product articles for the business is already large and a need for custom tailored products still remains, and grows with an expanding customer base. This is mainly harmful when an order has been made and a change in needs from the customer comes in the later stages of production. While the cost of the original order can be reimbursed the time spent in production can not and might cause a cascade effect of separate orders arriving late. The reason for not having a sizable inventory to prevent this stems from the large amount of product articles and the needs that often vary. Having a large catalog of products that is produced in high volumes has the disadvantage of not responding well to sudden changes regarding the production line. Accepting orders of highly customized products will require extra steps for finalizing the product, putting a strain on the regular production and demanding longer lead times due to prioritization issues that might arise. While some customized products might see a rise in sales afterwards making room for standardized production processes for the particular product, this is not common.

Having one product or a select few that suits every entity with its own requirements is challenging if there is not an established way or understanding of making products modular. One team responsible for product development at a company sees an opportunity for creating a slimmed-down product catalog. The idea of modularity has sparked their curiosity regarding the production of components applicable to a wider variety of base products. This is not a function that has been asked for by the clientele but internally by the producers themselves as they see the issues of large amounts of articles weighing more than the wider base of customer-specific and customized products.

The company providing the issue has not designed or produced a modular system based on their products. Currently, the frames are developed based on the needs of the customer for example the most common dimensions of holes, corrosion resistance, electromagnetic compatibility, and other specifications stated by the customer. If products that have been developed in this manner works for several customers, it becomes an established product. *The research done*, otherwise benchmark, on the competitors points to this method of development being commonly used. The reason being that the products provided by the competitors are presented in a similar manner which is that the user has to input their wants and needs into a software or sheet of choices. These wants and needs are then matched to a product that fulfills all of them or a new product has to be designed if no existing product can fulfill the customer's wants and needs. A modular design was found among one of these competitors where the user could choose between different parts resulting in a frame that is highly customized by the user themselves. However, this competitor still had separate products that served similar purposes which points to underlying needs that the modular product cannot currently fulfill. A large common design theme between the different producers could also be seen implying that the market is low on innovation or that there is not a lot of room for creativity. While some products could be seen as crude and not very innovative, but functional, other producers had products that were very much alike in both functionality and design. A couple of these products are larger frames allowing for a larger volume of cables, smaller circular solutions for smaller amounts of cable but also smaller frames with the functionality to be opened and retrofitted. The *wedge* used to compress the rubber modules inside the frame was also very similar. While the rubber modules which the cables are routed through are considered modular because they can be altered depending on cable width and exchanged for extended function, *none of the producers has declared their products to be modular* in other aspects. The products of the company providing the issue and the five competitors that were observed can be viewed below in appendix A.6, A.7, A.8 A.9 and A.10.

There are three existing products from three separate product families, with their own functions and traits that the problem owner seeks to incorporate into one singular product with the ability to switch between these traits depending on use case or customer need. These three different products have been distributed for investigation, analysis and to be used as references throughout the study, work and lastly development.

Table 1.1: The three reference products with the initial wanted traits

Product	Initial wanted trait
Product A A.15	• Lightweight • Cheaper to produce
Product B A.16	• Certified EMC capability • High-end
Product C A.17	• Openable • Retrofit • Certified fire protection

1.1 Objectives

The main goal of this thesis is to develop a late stage concept of a modular frame that has the potential of fulfilling the same needs as three existing types of frames that has different functions and areas of use. The objectives that are to be followed during the project are:

- Develop and evaluate a final concept of a modular frame based on the needs and requirements of the three reference products of different products families
- Document the strategy that was used to ease future modularization of existing products

1.2 Thesis questions

1. How can a modular design be implemented across a number of product families of highly customer specific and specialized products?
2. What is a suitable strategy, based upon existing methods, for developing modular design across product families of highly customer specific and specialized products?

Chapter 2

Background

The largest topics concerning the report or project are in regard of the design of the product and the work dedicated to analyzing the different entities closely tied to the product. To educate and nurture a better understanding of the topics and terms that are mentioned, some background information is needed. The four sections beneath will describe the different design methodologies, the importance of analysing stakeholders and needs, modular frames as well the ideas or justification of the report as a whole based on the previous three sections.

2.1 Agile product development

Agile product development is a methodology that aligns with the values and principles set forth in the *Agile Manifesto* [25]. Its approach centers around constructing products through short iterations, facilitating continuous feedback, and rapid improvement. Put simply, Agile product development empowers teams to stay nimble, respond to changes with ease, and produce top-notch products. Agile methodology breaks down projects into smaller tasks, prioritizing speed, flexibility, collaboration, and feedback. Unlike traditional methods, it allows for continuous evaluation and quick response to changes. Product development is typically broken down into iterative sprints, lasting anywhere from one to four weeks. During each sprint, cross-functional teams convene for a planning session to discuss and prioritize the tasks at hand. Each iteration is a mini-project covering all stages of product development, from discovery to release. The team presents a functioning MVP at the end of each sprint, aiming to improve it based on user feedback. It may take multiple iterations before the final product is launched [15].

Agile was popularized in 2001 with the publication of the Manifesto for Agile Software Development by a group of 17 software developers. Their aim was to streamline the software development process and swiftly detect and rectify issues [15].

The Agile Manifesto describes twelve core principles that act as the foundation for agile product development [24].

1. *Our top priority is to satisfy the customer by delivering valuable software early and consistently.*
2. *Agile processes harness change for the customer's competitive advantage. So it is important to welcome changing requirements, even if they arise late in the development process.*
3. *Software should be delivered frequently, with shorter timescales preferred, ranging from a few weeks to a couple of months.*
4. *To ensure the success of a project, it is essential that business people and developers collaborate and communicate with each other on a daily basis.*
5. *Projects are successful when motivated individuals are given the right environment, support, and trust.*
6. *The most effective way to communicate within a development team is through face-to-face conversations.*
7. *The primary measure of progress is the presence of functional software.*
8. *Agile development processes should enable sponsors, developers, and users to maintain a consistent pace indefinitely, promoting sustainable development.*
9. *Giving continuous attention to technical excellence and good design can significantly improve agility.*
10. *Simplicity is the art of accomplishing more by doing less. It is essential to maximize the amount of work not done.*
11. *The most effective architectures, requirements, and designs are developed by teams that organize themselves.*
12. *On a regular basis, the team engages in reflective exercises to improve their efficiency and effectiveness and adjusts their behavior afterward.*

2.2 Tools for modular design

Pareto front of maximum commonality is an example of a tool that is being used in the development of modular designs on preexisting products or product families and uses a *design structure matrix* (DSM) in conjunction with algorithms resulting in a modularity score to determine optimal modular design with maximized commonality. Examples of both tools respectively can be viewed below in appendix A.3 and A.5. DSM works by adding all the parts or elements of the product in the first row and column. If one of the elements in the first row is dependent on one of the elements in the first column to function, the columns element will then be crossed out in the row of the dependent element.

When all elements are evaluated, the rows and columns are then moved with the goal of clustering crossed out cells as close to each other and the diagonally line. The newly clustered elements are the ones considered most suitable for modularization. Pareto front of maximum commonality can also be seen described and used in a thesis which covers the concept of *modular function deployment* and its method and procedure used for designing a modular system based on a set number of products within a family. While the procedure isn't a general solution or applicable for the project at hand it can be useful for gaining insights [12].
The thesis describes the process used in steps:

1. *"Conduct research and needfinding"*
2. *"Analyze the results of research and needfinding"*
3. *"Formulate a strategy based on the analysis"*
4. *"Evaluate the strategy by applying it"*

Some examples of modular design implementation has used *Venn diagrams* and *product-component matrices* (PCM) to group the different components with their respective products. This isn't exclusively used to see the different parts of the products but more so to have an overview of shared or common parts and functionalities which helps with deciding the best course of action. In appendix A.2 and A.4 an example of each tool is shown. The use of a Venn diagram approach could be suitable in a project with a product family where the number of individual articles are low. While a PCM can be implemented in a family both low and high in the number of articles. In a PCM the different products are placed in the top row and all existing elements in the first column. All elements that are present in a certain product are then valued 1 and those which is not 0 [3] [9] [39].

2.3 Cable sealing frame

A cable sealing frame is a frame that houses a varying assortment of cables. The functionality of the frame varies depending on what the need for the frame is. In most cases the functionality of the frames, together with the sealing properties that it brings, is to transfer a cable between two environments without allowing airborne and liquid pollutants from one environment to contaminate the other. The design of the frame can vary heavily depending on what is demanded of the quality of the seal. This includes chosen material for the frame and the overall structural design. This also depends on the environment it is placed in and the environment it intends to shield while allowing the cables to pass through. An illustration of this is presented below in figure 2.1. In figure 2.1 there is a wall separating two environments with a hole connecting them. The cable sealer is attached to the wall in environment 1 which is filled with undesired pollutants. The cables are then pulled through and the neccessary components are fitted into the cable seal. The cables are now allowed to pass between environment 1 and 2 without allowing the pollutants to pass.

The compositon of a cable seal of the type that this thesis will cover includes a type of frame that is fastened to a wall, rubber modules that clamp around the cables which are housed inside the frame and if needed a compression module that is also housed by the frame. Some frames do not require a compression module because it can have some form of self compression included in the design.

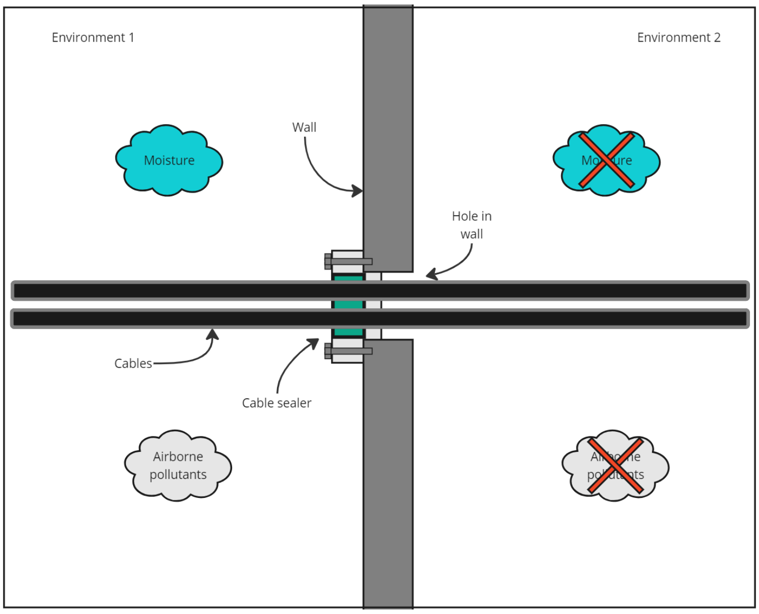


Figure 2.1: Illustration of cable sealer

2.4 Modular frame

A physical frame can be defined as a hollow structure, that can take on a variety of shapes, which is meant to contain something within. The most common examples of what is meant to be housed by frames is doors and pictures as an example [30]. What makes the frame modular can depend on a variety of different factors, which stems from what properties of the product the designer wants to make modular. An example of this could be that the frame allows for easy modification. This modification could be that the frame has the option of having an internal pressure gauge which can be easily attached to the existing frame. Another example could be a film that can be attached to the product in order to redirect a current passing through the frame. The modifications mentioned are designed in conjunction with the product and in a sense becomes a part of the product even though they are not always used. This in turn depends on what the customer requires of it. The frame that will be referred to in this report is designed to be mounted to walls as well as contain and transfer cables between two environments. Another thing that must be said is that the term modular frame is not an established title for what the product will become through modularization. The term modular frame is what the team decided upon when discussing what the generalized product could be referred to in name.

2.5 Chemical Abstract Service Registry

The Chemical Abstract Service (CAS) Registry is a chemical database of every known chemical substance [1]. A sequence of numbers, varying in size, is utilized to index the substances or materials [1]. The relevancy of the CAS registry in regards to this thesis lies in identifying potential harmful or toxic substances that should be avoided.

2.6 Standards

In this section the standards that are mentioned throughout the work is explained to provide the reader with relevant context. A total of two different types of standards are covered to some extent. These are Ingress protection and European standard.

2.6.1 Ingress protection (IP rating)

Ingress protection (IP rating) is an international standard for measuring the effective sealing capabilities of components and devices. IP rating is composed of two numbers in succession [22]. The first number indicates how well a component or device is protected against dust (airborne solids). The scale covers numbers 0 to 6 with 0 indicating no protection and 6 indicating that it is dust tight. The second number indicates the sealing capabilities of the device or component against liquids. The scale covers numbers 0 to 9 with 0 indicating no sealing capabilities and 9 indicating that it is protected against heated water jets. An example of this could be a device that has a rating of IP 34. The three indicates that the device is protected against airborne solids that have a diameter of 2,5mm or greater. The 4 indicates that it is protected against splashing water [4].

2.6.2 EN45545-2 and EN13501-1

EN standing for European standard is a collection of technical standards that can be applied to products processes and services [6]. The EN is followed by a varying amount of numbers that indicates which type of standard it is. In this thesis, two EN standards are referred to.

The EN45545-2 standard refers to fire protection on various types of trains. The standard considers various components and classifies them according to flame spread, heat release, smoke development and toxicity [33]. For the different aforementioned requirements, established test methods are listed which must be conducted to comply with the requirement [33].

The EN1305-1 standard refers to reaction to fire for products incorporated into buildings. The standard classifies the products according to fire resistance, smoke development and production of burning droplets or particles [5]. In order to attain a certain rating, established test methods must be conducted and passed [5].

Chapter 3

Related Work

3.1 Relevant content

Often seen cited, *Modular Function Deployment* is a doctorate thesis that was finished in 1998 by *Gunnar Erixon* at *KTH*. It covers the process of developing a modular product driven by a wide range of customer requirements that results in a large number of highly specific products. It also covers the issues concerning production planing due to the diverse product catalogue and the advantages of design for modularity. His use of modular function deployment can be seen in a variety of articles that he wrote in the late nineties and what is seen as very central and shared between Erixons works are the step by step guide on how to develop a modular concept [10] [11]. This guideline do change depending on the application of modular function deployment which can be seen in the introduction [12]. However the most common guideline used is when the function of modularity is highly module based [10].

1. *"Clarify product design specification"*
2. *"Select technical solutions"*
3. *"Generate concepts"*
4. *"Evaluate concepts"*
5. *"Improve each module"*

Øystein Eggen tailored his article to product design engineers seeking a thorough understanding of modularization and how it can enhance the concept generation process. It covers fundamental definitions and highlights the strategic benefits that can be achieved through the implementation of *modular product architectures.* The author presents a comprehensive approach to identifying concepts for modular product architectures by merging two key branches of literature into a cohesive model. The article suggests that combining Modular Function Deployment and heuristic methods can create a unified model with synergies [42].

Baylis et al. conducted research introduces a valuable approach for designers to efficiently pinpoint various component sharing possibilities. These possibilities are situated on a *Pareto front that optimizes both commonality and strategic modularity*. By exploring and refining the component sharing options along this front, designers can make informed decisions. The authors illustrate the efficacy of this method through a case study involving the selection of a product family platform for high-end and low-end impact drivers and electric drills. Quality analysis of the modular architecture for each product variant is conducted using a design structure matrix [3].

Pakkanen et al. highlights the lack of existing methods for developing modular product families from a re-design perspective [32]. The author's proceed to introduce the *Brownfield process*, which is a method that aims to cover all key engineering concepts used for developing a modular product family based on an existing product family. The Brownfield process has a total of ten steps which is noted by the authors as:

1. *"Target setting based on business environment"*
2. *"Generic element model of the module system"*
3. *"Architecture: generic elements and interfaces"*
4. *"Target setting based on customer environment"*
5. *"Preliminary product family description"*
6. *"Configuration knowledge: generic elements and customer needs"*
7. *"Modular architecture: modules and interfaces"*
8. *"Configuration knowledge: module variants and customer needs"*
9. *"Product family documentation"*
10. *"Business impact analysis"*

The reason for the brownfield process being of interest to this thesis stems from that the development that will be covered has it's roots in three existing products. From these three products, characteristics and individual unique functionality wants to be kept in the developed modular product. The new product will not be a re-design which the process is tailored for, but the approaches and methods described in the Brownfield process can be applicable since the modular product will be inspired by the existing products.

Table 3.1: Summary of related works in order.

Works	**Relevance**	**Thesis Characteristics**
Modular Function Deployment by G. Erixon [12] [10] [11].	Covers the development of modular products with the help of methods and tools. Also gives an example on how to tackle the issue from start to finish. heavy emphasise on products in one product family that shares common parts.	Product families, modularity, commonality, product development, concept generation.
Modular Product Development by Ø. Eggen [42].	Covers the development of modular products with the help of methods and tools. Also gives an example on how to tackle the issue from start to finish. heavy emphasise on products in one product family that shares common parts. Extends the work of Gunnar Erixon by combining it with a heuristic approach that extends the guideline for developing concepts.	Product families, modularity, commonality, product development, concept generation.
Product family platform selection using a Pareto front of maximum commonality and strategic modularity by K. Baylis et al. [3].	Deep dive into the methods and tools that is covered by Pareto front of maximum commonality and how these are used for identifying common parts and aspects of products.	Product families, modularity, commonality, product development.
Brownfield Process: A method for modular product family development aiming for product configuration by J. Pakkanen et al. [32].	Method specifically tailored for modular product development by re-design. Gives a detailed method consisting of ten steps that covers all phases of product development and how it can be applied via a case.	Product development, modularity, design process.

Chapter 4

Method

4.1 Approach

The approach for this Master thesis is based on mainly performing Participatory action research (PAR) throughout the development process. Other fields of knowledge was also utilized through the process as they were needed, such as methods derived from systems engineering to establish proper product requirements and needfinding to determine the ultimate needs of the modular product. This approach to development covers four common phases of product development which were worked upon in an iterative manner. These were reverse engineering, concept generation, concept selection and to some extent, prototyping and testing.

4.1.1 Participatory action research

Participatory action research (PAR) is an iterative process with the goal of building knowledge and solve problems [13]. PAR is built upon four key principles. The first being the value of direct experience, which implies the importance of involving individuals with first hand experience and knowledge in the perceived problem being worked on. The second principle addresses knowledge in action, which implies that new knowledge is generated through making changes often for actions taken throughout development. The third principle involves performing research transformatively. This implies that, a part from the outcome, there is value in the process utilized to arrive at the outcome. Lastly, the fourth principle highlights the need for constant dialogue. This refers to involving the aforementioned individuals mentioned in the first principal in a collaborative manner.

How PAR will be utilized throughout the course of the thesis can be summarized below in figure 4.1 which is called a PAR cycle. In figure 4.1 four general steps are present for each cycle. Defining a particular problem, determining an action to solve the problem, observing the results of the taken action and reflecting upon the outcome of the cycle. Defining a problem does not necessarily point to the entire problem the thesis aims to address as a whole, but rather one part of that problem such as; What are the needs of the modular product. This is then followed by taking action and following the same example of finding the needs, the action could be to conduct research on the current market or perform interviews with relevant individuals. The results of the action are then observed which in this case could be to compare the results of the research done and the information gained from the interviews. After the results have been observed it is then reflected upon, which in this case could be done by analyzing the results further and discussing whether more needfinding needs to be conducted. This can then lead to the redefined problem being that more needfinding needs to be conducted or that it is satisfiable for the moment and a completly new problem is defined and proceeded with. This cycle continues iteratively until the total outcome is satisfiable.

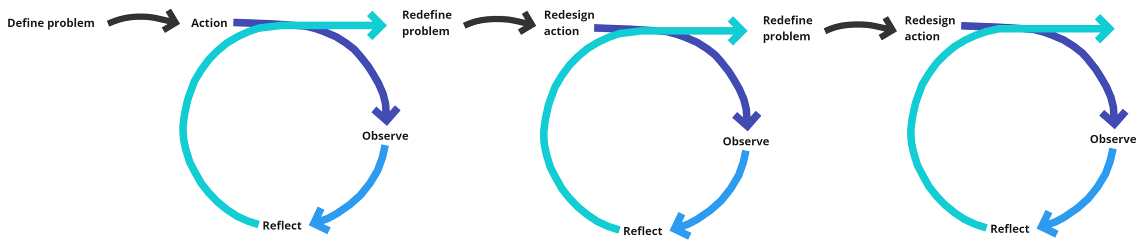


Figure 4.1: PAR cycles

4.2 General course of action

The first problem that was defined at the very start of the project was that some form of plan was required for the development of the frame as a whole. The following action to this was determined to make an initial plan that the work could be structured around and set realistic and attainable goals within the given time frame. After working with the tasks present in the initial plan during the early stages of the project it was determined, (observed), that it did not align well enough with the set goals of the project. After internal discussion, (reflection), it was decided that the plan needed to change and be elaborated upon. The problem was then redefined into needing a more flexible plan with room for correction and iteration as the project progresses. The action was then set as developing a new plan utilizing Agile [24]. The observed effects of the new plan through the development process was that it was less strict and necessary changes to it could be accounted for more easily. It was then deemed that no further larger changes needed to be made to the plan. The summarized par cycle's for this process can be viewed below in figure 4.2.

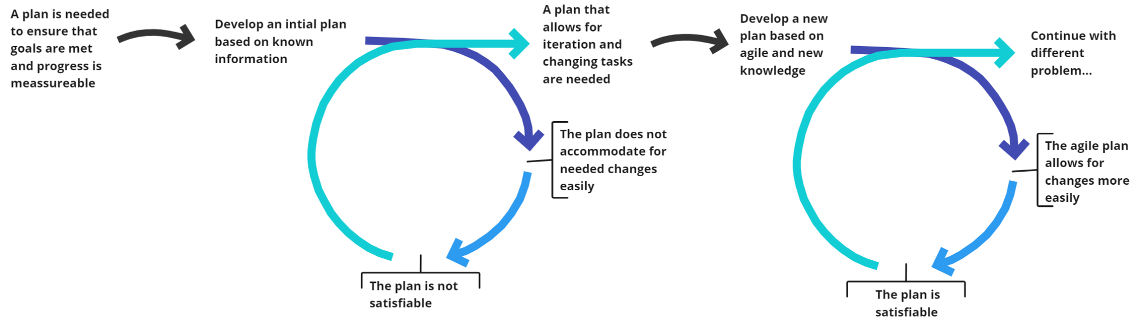


Figure 4.2: PAR cycle of planning the development

4.2.1 Initial plan

The first step in the thesis work will be to research the topic of modular design and collect data. The data will be acquired via scientific works on topics related to the main subject, product development, and established methods for the modularization of products. Data will also be collected via interviews with engineers and related personnel currently working on products with the aim of sealing cables. This will be done in order to determine product requirements based on needs, requirements and stakeholders. The collected data will be documented and used in the subsequent step in the project but also for evaluating and weighing the importance of the different stakeholders and their criteria.

The second step of the project consists of analyzing the compiled data from the previous step. A starting point would be to compare the different methods of general product development and modularization in correlation to their applicability to the reference product. Doing this would require listing the shared components that exist within the reference product families. Additionally, similar components should also be identified and listed. Having listed the shared and similar components the next step would be to determine which components need to be adapted or phased out. This will largely depend on the criteria of the stakeholders which will have to be taken into account while doing this. The last part of this project step is to then determine what would be a suitable method for making the family of products modular. In other words, determining the right strategy in order to take the existing product family and make it modular.

The start of the final phase of the project will be marked by applying a chosen method or, should it be the case, a combination of different methods for product development and modular design to make a concept solution of the modular product family. In this step, it will become apparent whether the chosen strategy is applicable, if changes to the strategy have to be made, or if there's a need to go back and reevaluate the strategy. There are ways of determining whether the chosen strategy is correctly chosen and well applicable. Examples of this could be if the resulting modular product family costs less in various ways, lessens the total number of articles required and lessens the total needed storage for both components and finished products. But the main contributing factor would be if the strategy does not cover the project from start to finish, covering the whole process and all its phases. There are surely other ways of determining the effectiveness of the strategy that will become more apparent as work on the project proceeds. Should the strategy fail in one or several aspects it will have to be iterated upon by going back to previous steps and changing it. If the strategy succeeds according to the established aspects or in most of them, the focus will be shifted towards documenting the results in a well-formulated report.

4.2.2 Agile plan

During the course of the project a second plan was formulated to cover different needed steps to create a comparable prototype, which can be viewed below in 4.3. As this is a plan that follows the agile methodology, the arrows present in the plan don't indicate a strict process that must be followed. The plan instead relies on going back and fourth between the listed tasks. The tasks marked in green consists of gathering information through various methods that will culminate into product requirements. Tasks marked in orange consists of different methods of analysis of the three given product lines. The tasks marked in blue is tied to ideation and using the information gained from the previous tasks in order to develop a comparable prototype. What is meant by comparable is that it can be compared against the three given product lines.

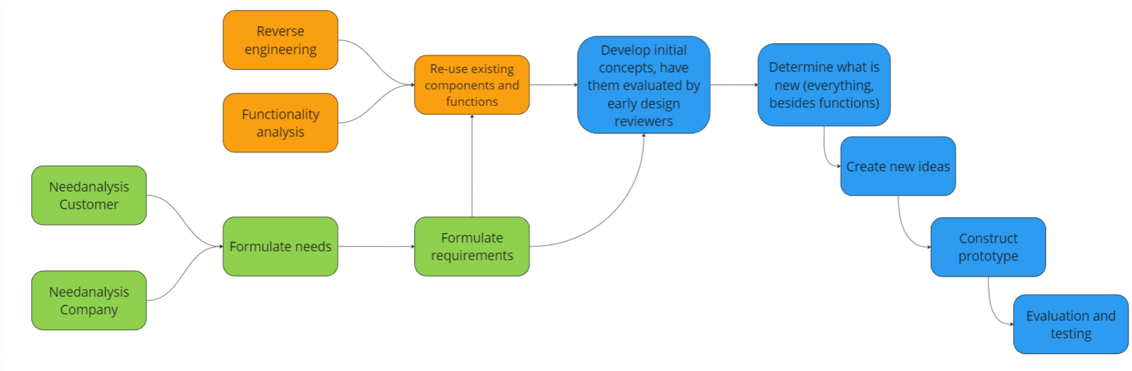


Figure 4.3: Agile plan

4.3 Stakeholder mapping

The analysis of stakeholders is done through interviews and mapping techniques. The important thing here is to be able to discern important stakeholders and those who are just observing [31]. This can be done through asking simple questions during meetings and by looking at the connection stakeholders has to the project. During the interviews in the report a simple list of questions was formulated beforehand and was constructed by questions regarding the product lines physical aspects, certifications, general and important needs and who or what are most dependent on the product. One regularly used technique for discerning stakeholders and their role in regards of the project is a simple stakeholder map in which all the different stakeholders are placed depending on their *influence* and *interest* regarding the product [40]. This is also what has been used in this project. What can be distinguished from figure A.1 is a basic graph with four zones representing different groups in which the stakeholders will be placed. *Keep informed* are those that might be interested in future purchases or financing depending on the reception of the solution. At this stage they are just onlookers, but needs information for the possibility of future co-operations. this group could also consist of smaller clients.

Manage thoroughly might be developers, subcontractors, large clients and those that risk the largest financial loss if anything don't go according to plan. *Minimal contact* could be subcontractors who isn't tied to the specific product and lastly *meet needs* could encompass financial backers who inherently are not specifically interested in the product, but mostly the growth of the company and could pull financial backing if their need regarding product sales are not met.

In terms of ranking the stakeholders, the ones that would be ranked high are those that are closest to the outer edge of *influence* and *interest* simultaneously. A stakeholder could have a lot of *influence* but low *interest*, in this case they would be ranked high but still lower than the first mentioned group. The same rule or logic goes for those that has high *interest* but low *influence*, these would be placed lower than the second mentioned group. Lowest rank is for those that are placed in the minimal contact group in the stakeholder map. A visual representation of what the ranking board could look like can be seen in appendix A.1. The amount of *ranks* and *groups* differs depending on the complexity and depth of the tool used as well the amount of stakeholders. The application of PAR in regards to uncovering and ranking the stakeholders can be viewed below in figure 4.4.

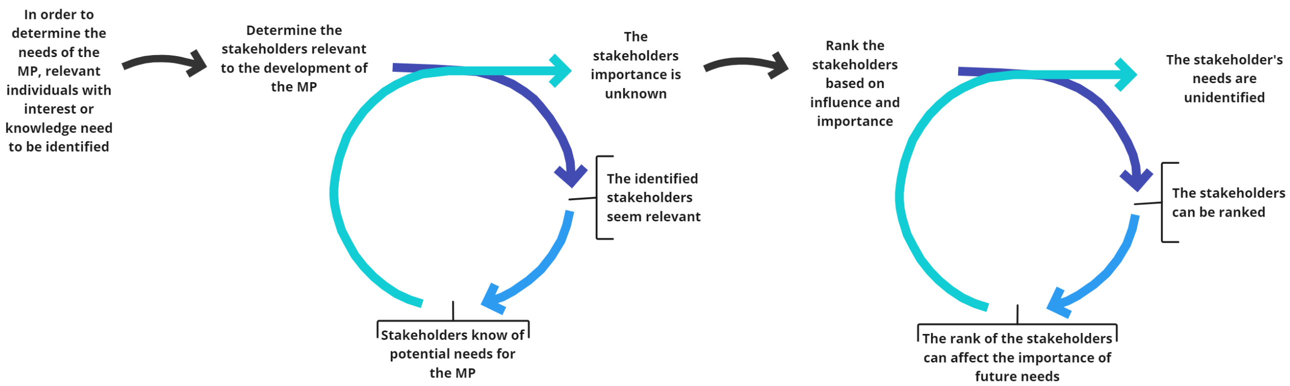


Figure 4.4: PAR cycle of uncovering and ranking stakeholders

4.4 Finding the product requirements

The first thing that was done, when determining the product requirements for the development of the modular product line, was to analyze the first given needs. These needs would be used as a basis of what would be required of the supposed modularized product line. The needs were noted down during a meeting that had been had with a key stakeholder with the position of Product development manager, the problem owner. These needs mainly consisted of physical properties of the different products within the product line that could vary.
The initial given needs were instated as the basis for the product requirements and used to formulate questions which would be used for interviews with relevant stakeholders. The template of questions that were used can be found in appendix A.2. Following this, four interviews where carried out with various stakeholders within the company. The four individuals that were interviewed were people that has close ties to the products in their design, manufacturing, sourcing and contact with customers. The interviews were carried out by mostly sticking to the prepared questions whilst stating new and follow-up questions when they came to mind. This method of conducting interviews is known as semi-structured interviews [2]. The interviews were recorded and notes were taken during them.

The next step consisted of analyzing the information collected from the interviews in order to find additional needs and gain an understanding of what to prioritize during development. This was done by listening to the recordings of the interviews whilst making bullet lists stating the question, the answers to the question and other interesting comments made during a particular timestamp. Having compiled the information gained from the interviews, a red line could now be identified from the answers. What is meant by this is that if a particular aspect or need comes up several times between separate interviewees it could be considered to be something that carries more importance.

With the information compiled from the interviews the needs were mapped and ranked. The needs were also elaborated upon and hence turned into proper requirements. This was done by making a mind map of the needs and drawing potential connections between them. The needs were ranked according to how frequent they were brought up and how important they were stated to be. Following this the requirements were formulated and placed in three different categories. These being functional and performance requirements as well as design constraints. The process as it pertains to par can be summarized below in figure 4.5.

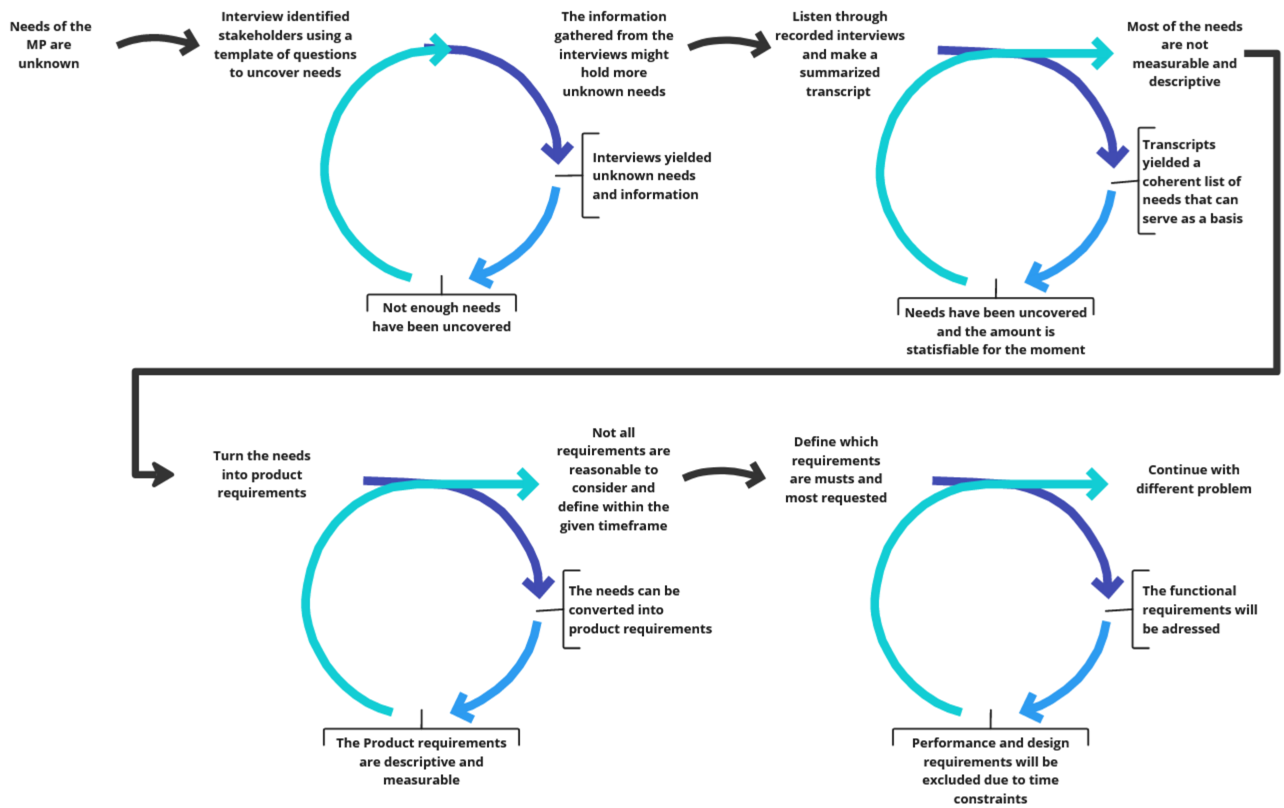


Figure 4.5: PAR cycle of determining product requirements and needs

4.5 Reverse Engineering

To get an understanding of the three reference products, A, B and C, and how they function during use and construction, reverse engineering tools were utilized. This is needed due the vast array of articles present in the catalogue that looks and feels like they're doing the same thing, but are stated to perform differently. The following sections will cover the tools and methods used for this particular case of mapping an overview of products that needs to be understood. The summarized par application for this section can be viewed below in figure 4.6.

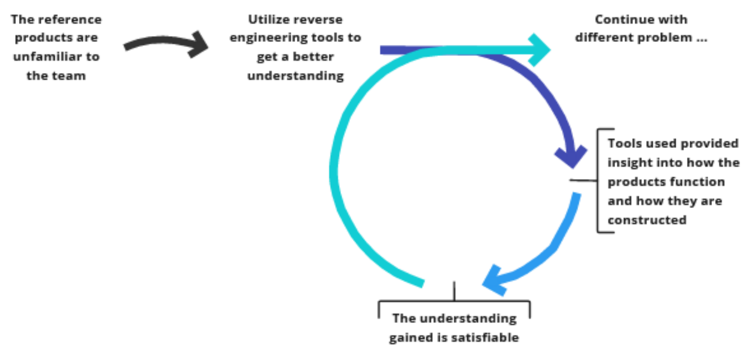


Figure 4.6: PAR cycle of performing reverse engineering tools

4.5.1 Functions and parts clustering

To get an overview of the different functions and parts of the products, some kind of dissecting and clustering needed to be conducted. *Functions clustering* refers to the process of using a Venn diagram with the three products represented by one area each. The main functions are then placed in relevance to the products to see what is shared and what is individually owned by them [3]. An example of a function cluster venn diagram can be viewed below in appendix 5.2. The *parts clustering* could be described as a two-dimensional exploded view with the relations of the different components mapped out [3]. An example of a component cluster can be viewed in appendix A.12.

4.5.2 Boundary block diagram

To illustrate the connections and relations between components, assemblies, and external systems, a boundary block diagram was used [34]. In appendix A.13 an example of a boundary block diagram can be viewed. The product was dissected into its main systems and components and connected with defined lines that have their distinct meaning for example, dotted lines represent data exchange while a full line shows that the components in question have physical contact. The lines can work in conjunction too each other. This can be seen in systems that have mechanical actions performed during operations that are actuated by using some kind of force, then it can be easily argued that both energy exchange and physical contact are required for operation.

4.5.3 Function flow block diagram

In appendix A.14, an example of a Function Flow Block Diagram can be viewed. While hard to discern from a boundary block diagram, a functional flow block diagram shows the relations between functions in their respective order of use when the product is in operation. Instead of showing how things happen, it focuses on what must be done and the order of it for the product to be functional as wanted [26].

4.5.4 Design structure matrix

To determine the potential modularity between the three reference products, a design structure matrix was used. A design structure matrix works by placing the components of a chosen product along the first column and row. This gives an equal number of cells for both rows and columns making the matrix uniform. Using appendix A.3 as an example, marks of some kind are then placed within cells indicating a dependency from one component to another. The mark present in row 1 column 3 indicates that component 1 depends on component 3 in order to function. Looking at row 3 column 1 the inverse dependency does not exist which indicates that component 1 depends on component 3 but component 3 does not depend on component 1 in order to function. The greyed out cells running along the diagonal of the matrix are never filled since it is the same components being assessed. What the diagonal

indicates depends on the placed marks proximity to it which in turn indicates the effect of changing that particular component [3]. Following this, matrices are made for all the products and then incorporated into one design structure matrix that incorporates all of them and their individual components.
This is done primarily to give an overview of which components are shared between them and give an indication of potential conflicts that could arise by changing or replacing them.

4.6 Ideation process

The information that has been gathered regarding the products are as earlier noted sifted through and ranked according to importance for the end goal. The product requirements and needs are then used for coming up with ideas and concepts for products that either fulfill all requirements or some aspects of them. This includes brainstorming sessions were the team sits down and sketches out different ideas that could solve the issues. In order to gain a better understanding of the solutions already present on the market, a benchmark of existing products were made. The reason for conducting a benchmark is to see what has already been done and to see if there are potential unseen needs that can be uncovered by looking at the competitors products [23]. The products were picked at random from different companies providing similar solutions to seal cables going from one environment to another. Using the provided information, given by the corresponding websites, the advantages and disadvantages of each product could be listed.

Apart from the aforementioned benchmark and utilization of needs and requirements to come up with ideas, a search of existing patents for different products was utilized. Sifting through patents acquired by various companies in the field of sealing cables gave inspiration and further insight into what works and what does not. Inspiration in this case refers to ways of solving a potential problem, fulfilling a requirement related to a concept or give new ways of thinking when generating concepts. It was also utilized to ensure that the ideas that were generated during the brainstorming sessions did not infringe on existing patents.

After a set of concepts has been drawn, they are then presented for a focus group during a workshop. The focus group consists of engineers and employees in direct contact with the three reference products which increases the chance collecting meaningful and viable information that might help iterate the concepts [27]. The process of agile product development plays a large roll here as the concepts are drawn and then changed according to feedback from important stakeholders. The altered concept are then under review and iterated as many times as needed in accordance with time constraints and satisfaction. Besides altering and improving concepts, the workshops are aimed at discarding those concepts that are found lacking in aspects such as functionality, performance, or viability, and bring forth the concepts that outshine these.

The first workshop was held and had a duration of one hour. The goal of the workshop was to get feedback on the concept ideas for different modular frames. A total of 10 different concepts were thought to be shown and discussed during the duration. The workshop was divided into three parts. The first part was thought to showcase the 10 different concepts and have the participants write pros and cons on post-it notes throughout.

The second part was thought to consist of the participants ranking the concepts together from worst to best. The final part was thought to be a discussion were the participants could combine the concepts that were ranked poorly and see if they would rank them higher. Due to time constraints the workshop only covered the first part and only concepts one to six. The workshops going forward would have the same arrangement, with the difference being clearer instructions and having participants discuss and write their answers together. A timer would also be utilized going forward to ensure that the planned steps would be completed.

The second workshop had a duration of eighty minutes and covered ten concepts. The goal of the workshop remained the same as last time, namely getting feedback on the generated concepts. The workshop was also divided into the same three aforementioned parts. Every concept was presented individually and in order. After one concept had been shown the participants were given 4 minutes for discussion and note-taking of potential pros and cons. The individuals were also allowed to ask for clarification about aspects of the concept during their discussion. After all concepts had been covered, the participants were given the option to discard or keep concepts based on viability and interest which resulted in a ranking of the concepts. The participants were lastly given the opportunity to combine concepts if they only liked a particular function or aspect of a concept which could lead to changes in the ranking. The concepts that survived the selection are to be reworked and conceptualized in greater detail with different ideas on how to solve the issues that came up during the workshop. A second selection is done internally without the influence of a focus group where the surviving detailed concepts are 3D-modeled and relayed to the focus group by digital means.

The third workshop consisted of openly discussing the refinements made to the concepts that were proceeded with. The main purpose of this was to further highlight potential improvements that could be made to the remaining concepts and pick out three final concepts. The decided three concepts would be picked based on their thought viability by both the development team and workshop participants. The chosen concepts would then go through a final design revision to incorporate the suggested improvements mentioned during the workshop. The entire process as it pertains to PAR can be viewed below in figure 4.7.

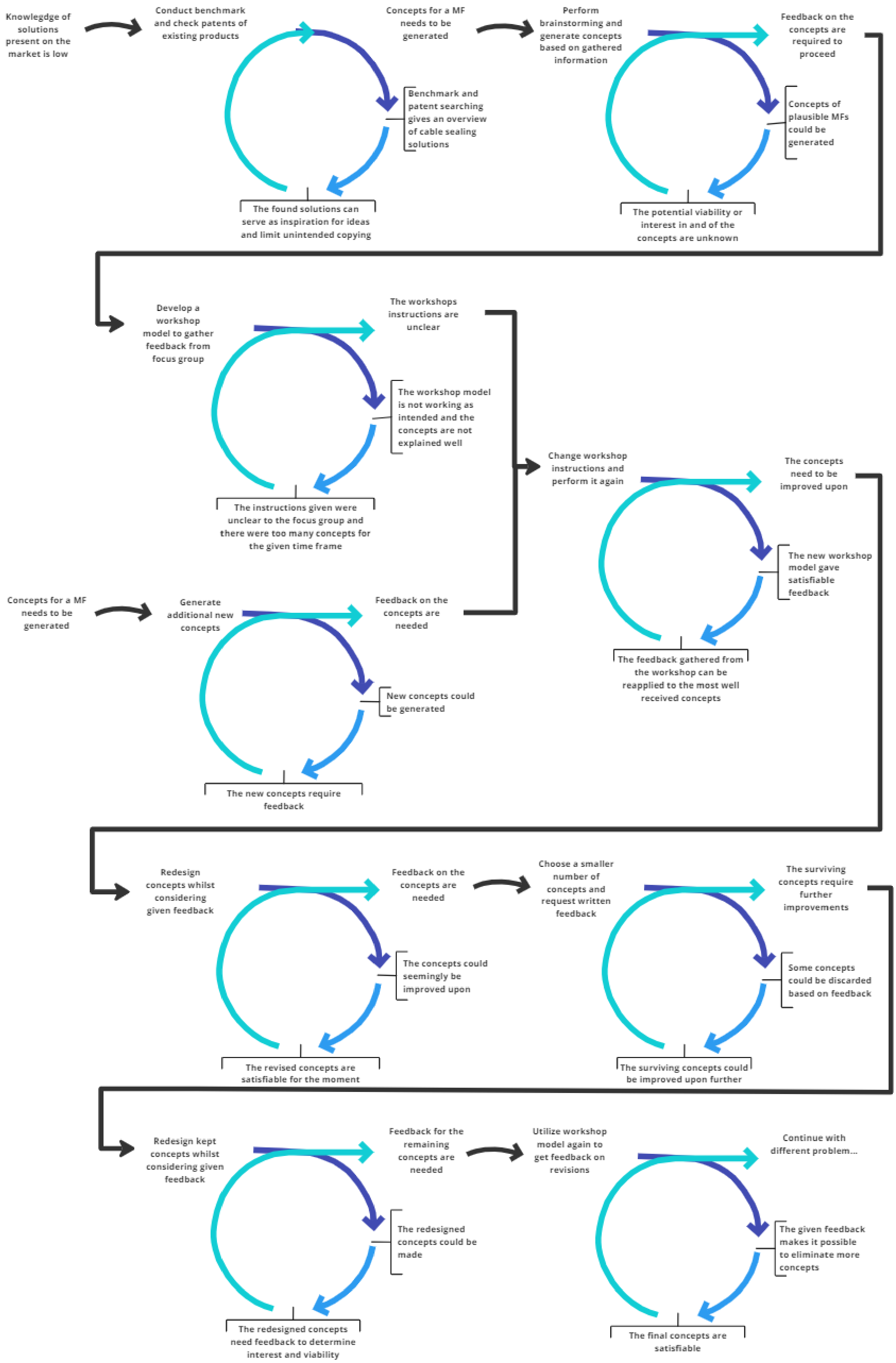


Figure 4.7: PAR cycle of the ideation process

4.7 Prototyping and testing

After showcasing the final iteration of the three concepts to the problem owner, it was decided to conduct a round of initial testing on two of the remaining concepts. The initial 3D-printed models of the concepts were only made to visualize them and give an idea of how easy they were to assemble. They were not, as they were, functional prototypes and had to be remade in a stronger material and with finer tolerances so that they could be tested. The testing would solely consist of Ingress protection (IP) testing that would determine to what degree the prototypes were resistant to water. The testing consisted of testing IP-X4, IP-X5 and IP-X6 for the two concepts. The X that comes before the number in the rating refers to the prototypes sealing capabilities in regards to dust. The X means that it is undefined or has not been tested. IP-X4 means that the prototypes were tested against an oscillating spray of water from all directions for a duration of at least 10 minutes. IP-X5 means that the prototypes were tested against low-pressure water jets, from varying angles, for a certain amount of time. The IP-X6 rate is similar to IP-X5 with the only difference being that the water jets used are more powerful. The testing and ingress for water rating were carried out by assembling the two prototypes and attaching them to a metal sheet with corresponding hole dimensions. Rubber modules and and compression modules were then fitted to the prototypes. The metal sheet was then fastened to a machine that contained the testing environment, were the three different IP-tests could be conducted. The process as it pertains to PAR can be viewed below in figure 4.8.

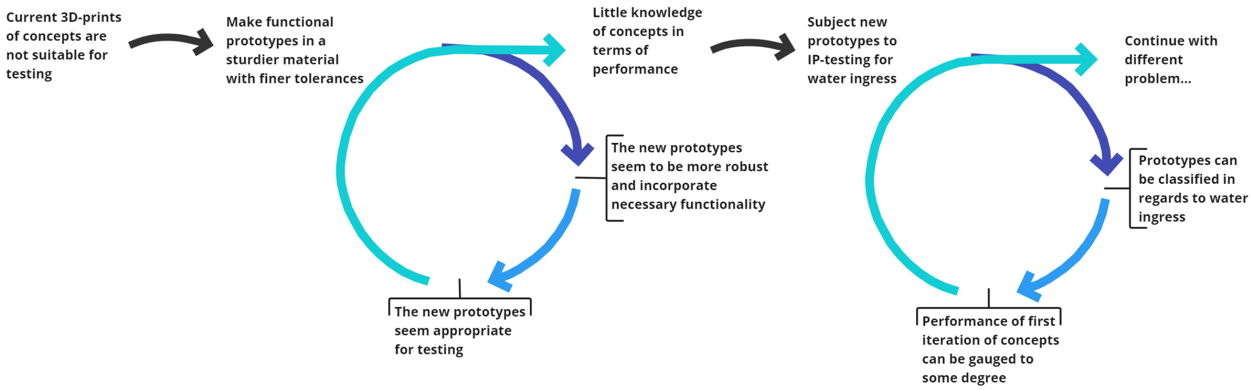


Figure 4.8: PAR cycle of the Prototyping and Testing process

Chapter 5

Results and Analysis

5.1 Stakeholders

The mapping of stakeholders resulted in the producer being of the highest authority due to the certificates and standards that are in place for the products. The need for a modular product where also asked for internally by the producer as a result of customers making changes in the later stages of the projects, resulting in longer processing and manufacturing times. Clients buy articles based on the certificates they need to cover with their installment e.g., fireproofing, water resistance, and electrical insulation, while the producer and subcontractors are the ones responsible for designing, developing, and testing as well as implementing the required certifications. The environment in which the product is installed also plays a major role in what kind of product the customer can expect. The producer and developer are in the end taken into larger consideration than customers and financiers, which will be discussed.

No financial backers or other entities that could be negatively impacted by bad reception to this particular project could be defined or named through the conducted interviews. This will inherently result in such stakeholders not being taken into consideration when mapping the rest. A compiled list of the defined and ranked stakeholders can be viewed below in table 5.1.

Table 5.1: Ranking of groups in the Stakeholder map.

Rank	Group	Stakeholder
1	Manage Thoroughly	Producer and Subcontractors
2	Meet Needs	Customers
3	Keep Informed	Potential Customers
4	Minimal Contact	Stock Owners and Financiers

For this work, only the first group is considered, namely the Producer and Subcontractor. In this specific case, the group consists of a problem owner, a lead innovation engineer, a sourcing specialist and a product engineer. The roles they serve for the project is grounded in asserting needs, give feedback on concepts and discussing potential problems that their knowledge can help alleviate. The remaining groups, namely the Customers, Potential Customers and Stock Owners and Financiers were not considered for this work. This is due to the scope of the project, which relates to time constraints and the nature of the problem being an internal want from the problem owner.

5.2 Preliminary product requirements

The initial requirements gained from the first meeting can be viewed below in a summarized list. These are high-level requirements that will steer and directly impact the concept generation. The order of the requirements does not imply their importance.

- The product shall be fire-resistant
- The product shall have grounding capabilities
- The product shall conform to the ingress protection standards that's already in place
- The product shall preferably not use a material unique to the three existing product lines
- The product shall preferably not require additional manufacturing methods in relation to the existing products
- The design of the product line shall preferably adhere to the size regulations of existing cabinet solutions

Following this four interviews were held. The individuals that were interviewed were people from within the company with different positions. These positions included a product engineer, the lead innovation engineer, a sourcing specialist and a product owner. The questionnaire used to conduct the interviews can be viewed below in appendix A.2. The results gained from transcribing the contents of the interviews can be viewed below in figure 5.1.
The resulting mind map highlights the needs gained from the interviews. The bubbles marked in red state problems, needs, or wants that were the most frequent to be brought up through all interviews. The yellow bubble indicates problems, needs or wants that were not brought up as frequently as the ones marked in red throughout the interviews. The orange bubbles give a stated reason for the problem. The white bubbles are either a stated consequence of the problem or a more specified reason for it. As seen in the mind map starting with functions, there was a unanimous need to keep the original function with the addition of having the modular frame be openable after installation. Two out of the people that were interviewed stated that there are positives to gain by having the refinement of the product moved closer to the customer, meaning that having a product that can be altered and modified by the customer is something that could be an interesting topic to look into. There was also a want for standardization since many of the products that were produced were custom versions of existing frames. This also ties into both the cost of the product going up as well as the lead times being extended since the existing product has to be custom made. Being able to have a higher production volume was something that was brought up frequently as well. The reason for this is also tied into the products needing to be custom made a lot of the times. The reason for this is that it becomes

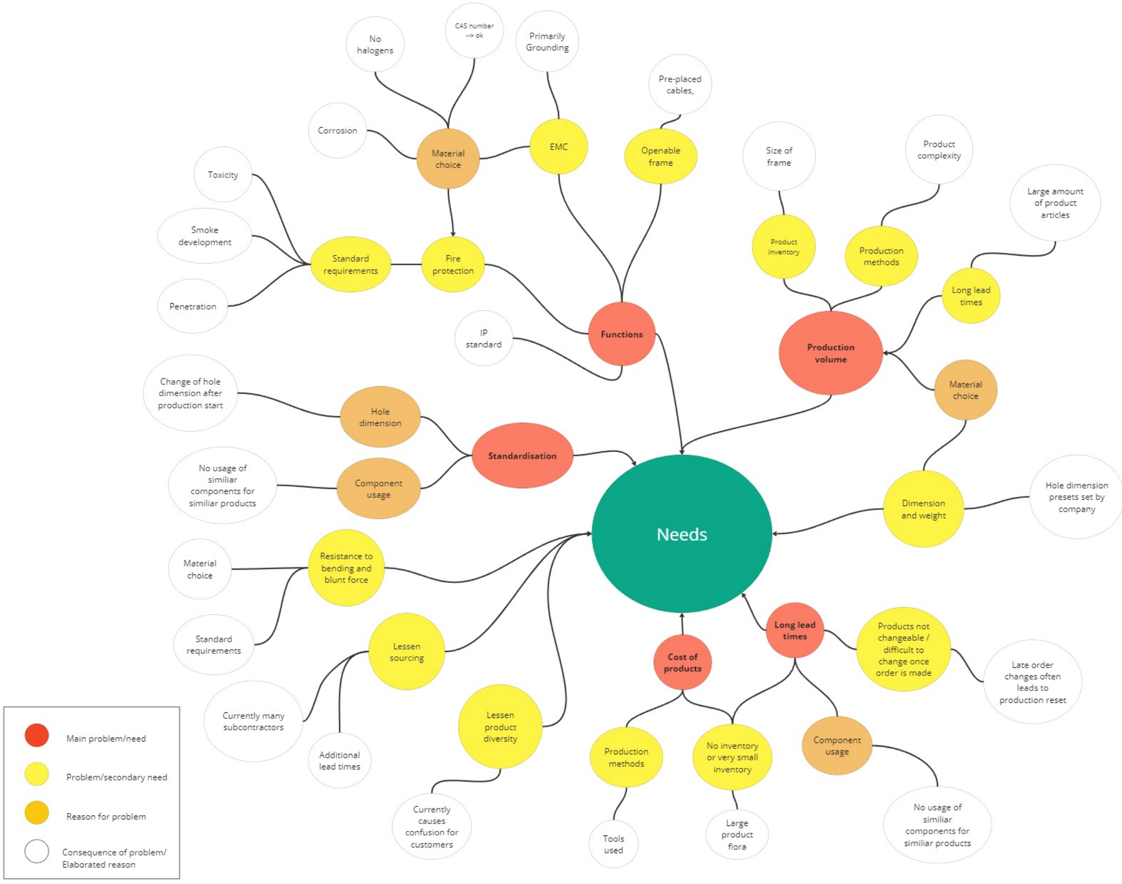


Figure 5.1: Needs mapped with respective correlations

difficult to keep a larger inventory of readied products due to the nature of demands and needs changing sporadically.

The resulting needs were then formulated into product requirements which can be viewed below. The list is categorized in three categories which are functional and performance requirements as well as design constraints.

Functional requirements:

- The modular frame shall be openable after it has been installed
- The modular frame shall use as many standardized parts between combinations as possible
- The modular frame shall have grounding capabilities
- The modular frame shall be customizeable to allow for different sizes
- The modular frame shall be able to be retrofitted

Performance requirements:

- The modular frame shall consist of standardized parts that can be assembeled into ¿ combinations

- The modular frame shall be able to handle a maximum voltage of ¿
- The modular frame shall be adaptable to holes between ¿ and ¿ in length
- The modular frame shall be adaptable to holes between ¿ and ¿ in width
- The modular frame shall be adaptable to holes between ¿ and ¿ in depth
- The modular frame shall be attached via ¿
- The modular frame shall be resistant to blunt force between ¿ and ¿
- The modular frame shall be resistant to bending between ¿ and ¿
- The modular frame's weight shall not exceed ¿
- The modular frame shall not release toxic substances into the air when heated according to the EN45545-2 standard
- The modular frame shall comply with the EN13501-1 standard in regards to smoke development
- The modular frame shall ensure that fire does not spread between two environments according to the EN13501 -1 standard
- The modular frame shall be resistant to corrosion stemming from exposure to water and air
- The modular frame shall have sealing capabilities according to IP code (Ingress protection code)

Design constraints

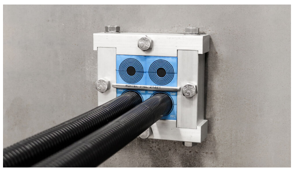
- The modular frame shall incorporate materials according to the CAS registry deemed as non harmful
- The maximum length of the modular frame shall be between ¿ and ¿ mm
- The minimum length of the modular frame shall be between ¿ and ¿ mm
- The maximum width of the modular frame shall be between ¿ and ¿ mm
- The minimum width of the modular frame shall be between ¿ and ¿ mm
- The depth of the modular frame shall be between ¿ and ¿ mm

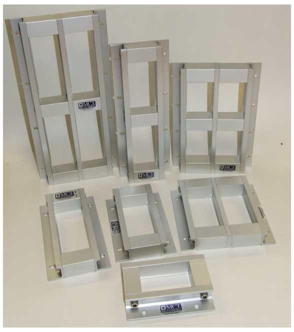
Due to the scope of the project not all of the requirements will be considered for the concept development of the modular frame. The requirements that the concept is certain to be designed around is mainly the functional requirements. The reason for this is due to many of the performance requirements being tied to both internal and third party testing to ensure that a certain standard is met. Examples of this is mainly tied to acquiring a certain fire rating, ingress protection code for sealing capabilities and short circuit testing for grounding capabilities. Regarding the design constraints, they will not be included since the size of the various parts included in the final or multiple final concepts might not be final. This is not to say that none of these requirements will be considered. If a material for the product is chosen, it will be chosen according to the CAS material list. No material will be chosen that has that has poor fire resistance capabilities, which potentially could lower the fire rating. In the list of requirements, many potential values are uncovered and thereby denoted with a ¿ symbol. The uncovered requirements are still kept since they are important to the development of the modular frame, but will be exempt in this stage of its development or only partially covered.

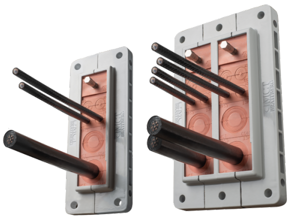
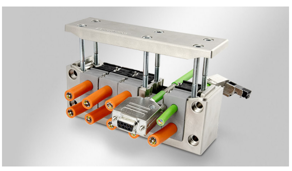
5.3 Benchmarking

The benchmark was conducted on ten different cable sealing solutions from various manufacturers. The goal of the benchmark was to see what types of solutions are present on the market currently to gain inspiration for ideas and lessen the risk of unintentionally copying existing solutions. The benchmark in its entirety can be viewed below in table 5.2. One of the main takeaways from performing the benchmark which was adapted into some of the concepts that were later thought of was that a sturdy frame could be constructed from very few parts as seen in product 8. Another take away that inspired concept 2, as seen in figure 5.14 was to build further upon standardized building kits as seen in product 6 and 7.

Table 5.2: Benchmark of chosen existing products (1-10)

Sol. No.	**Image**	**Advantages**	**Disadvantages**
1. Isotec KEL-ER CR [21]		• Retrofit • Lightweight • Cheap production • High IP-standard **IP54/55/64/65/66** • Certified corrosion resistance	• Plastic • Low fire resistance • No EMC capabilities • Lower wear and tear resistance than metallic products
2. Roxtec CRF 60x60/4 CM [35]		• Openable • Compact size • Lightweight • High IP-standard **IP66/67** • Easy install • Built in compression • **EN 45545** fire rating	• No EMC capabilities • Limited sizes • Since frame provides compression it might make retrofitting difficult

3. Seaview Progress RETROFIT Cable Seal [37]		• Retrofit • Cheap production • Lightweight	• Only one cable per module • Watertight but no mention of other sealing capabilities due to IPX rating
4. MCT Brattberg ALF EMC [28]		• Fairly cheap to produce • For cabinets • Lightweight • High IP-standard **IP66/67** • Retrofit • Metal • High corrosion resistance • Changeable size • EMC capabilities	• Needs to be anodized to compare to stainless steel • Anodized may still wear off and introduce corrosion • Anodize is susceptible to highly abrasive, alkaline or acidic materials or chemicals • No certified fire protection
5. Icotek KEL-DPZ CR [20]		• Very easy to install • Easy mounting of cable • Cost efficient	• Low rating for water sealing • Low resistance to bending and blunt force
6. Wall-Max Modular Frame WMF [41]		• Modular • Sturdy • Corrosion Resistant	• Galvanized steel, Heavy • Openable but seemingly difficult to retrofit • No standard mentioned/metric of confirmation for claims about product

7. MCT Brattberg RFCS Cabinet Seal [29]		• Retrofit • Fairly cheap production • Lightweight • For cabinets • Changeable sizes • Corrosion resistant • High IP-standard **IP65/67**	• No EMC capabilities • Limited size options • Not certified for fire protection
8. Hilti CFS-T SBO [18]		• FM fire approval • Sturdy construction • Few parts • Corrosion resistance • Openable	• Limited sizes • Openable but seemingly difficult to retrofit since its attached via casting • Difficult installation due to casting • No EMC capabilities • No mention of IP testing
9. Detasultra DES 24 [8]		• Retrofit • Lightweight • Cheap production • High IP-standard **IP66** • Corrosion resistant • Ex certified	• Plastic • Low fire resistance • No EMC capabilities • Lower wear and tear resistance than metallic products
10. Icotek EMC-KEL-DS [19]		• EMC capabilities • No need for conductive braids. Conductive capabilities built in to the rubber modules • Compact • Certified fire protection	• Low IP-rating compared to other products **IP54/55** • Limited sizes

5.3.1 Patent search

One product that was found were an openable aluminium frame with stated EMC-capabilities that was seen as a possible source of inspiration. Product 4, as seen in table 5.2, did not separate itself from the rest of the market but did very much resemble an early idea that had come to fruition during the establishment of product requirements. Being able to take inspiration from a product some boundaries needs to be set based on active patents for eliminating any risks of patent infringement. The research on products and the patents from the producer resulted with no findings of an active patent regarding the product. This inspired the concept seen in figure 5.14.

5.4 Reverse engineering

The section presents the results of various reverse engineering activities. The methods used dissect the three reference products physically and functionally for a better understanding how the different systems work during operation and what they consist of parts wise.

5.4.1 Functions and parts clustering

The clustering of functions and parts resulted in the following figures seen below in 5.2, 5.3, 5.4 and 5.5. The Venn diagram showed that quite a lot of functions are shared between two or three products, with the outlining being fire rating, EMC capabilities, cost, rodent resistance, robustness against environmental impacts, and complexity. The two functions that were shared between two of the products, in this case, product C and A models, are a lightweight construction. Between the product B and A models are corrosion resistance and the allowing of pre-terminated cables.

The mapping of components and assembly of the three products resulted in the acknowledgment of how different the products are considering their complexity. Product A requires a small amount of parts for installation due to the solid plastic frame that has zero moving parts besides the compression mechanism. The product B model has a solid frame just like product A, but comes with parts that are meant to be situated on the other side of the wall that the frame is mounted on. There are also compression modules that are situated inside the opening of the frame instead of being incorporated into the structure. The product C model has the largest number of separate parts that need to be assembled to be functional and comes from the need for it to be able to be open and retrofitted around already installed cables.

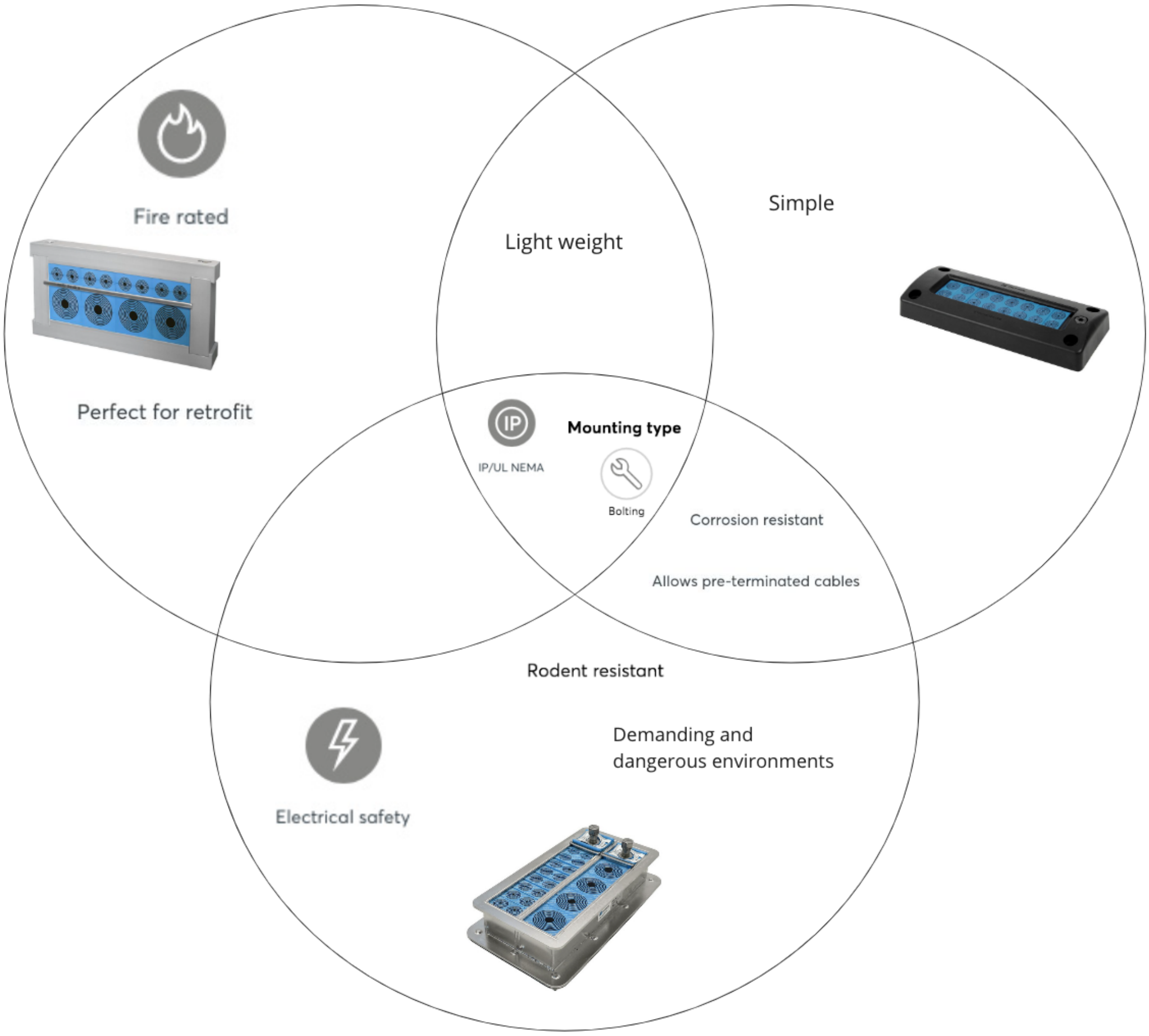


Figure 5.2: Function cluster of the three reference products

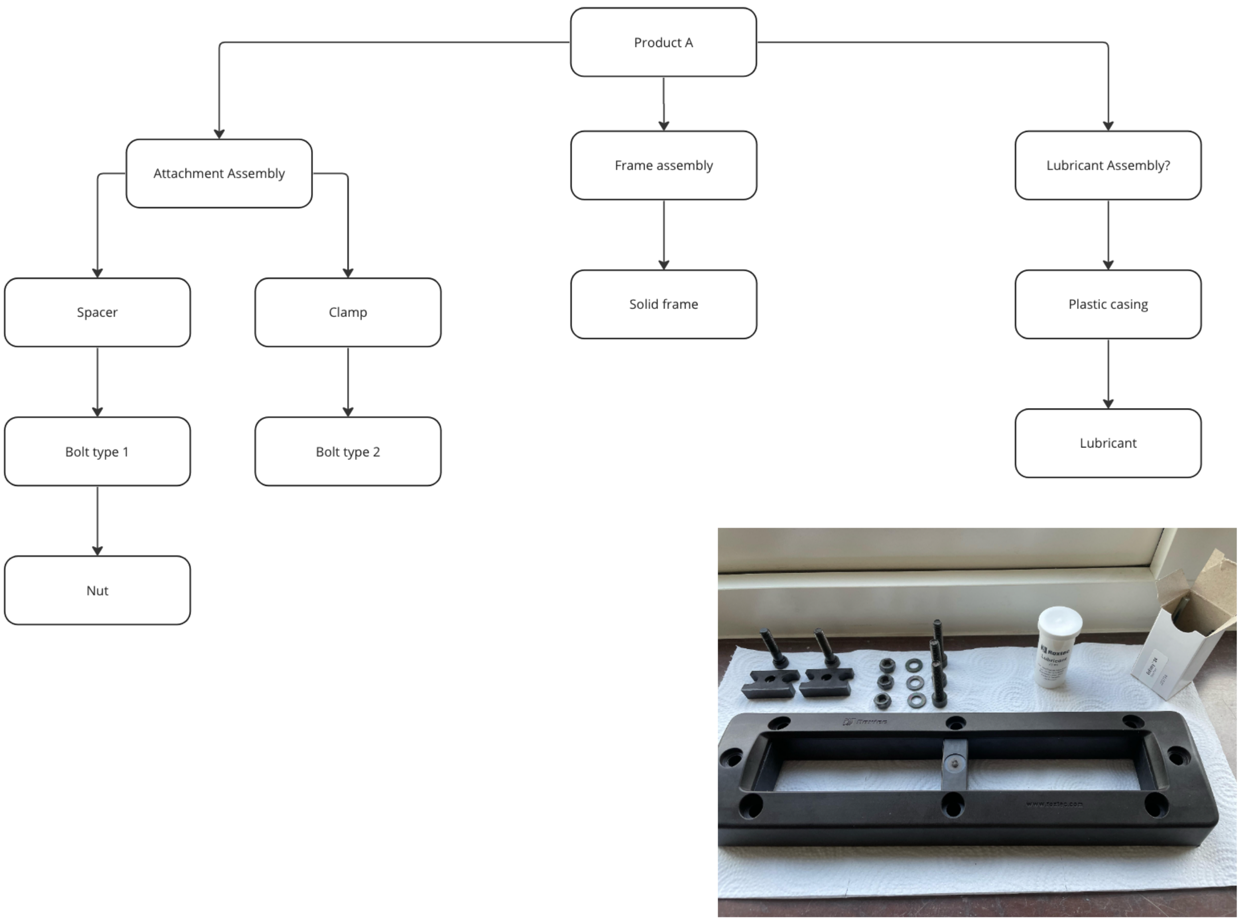
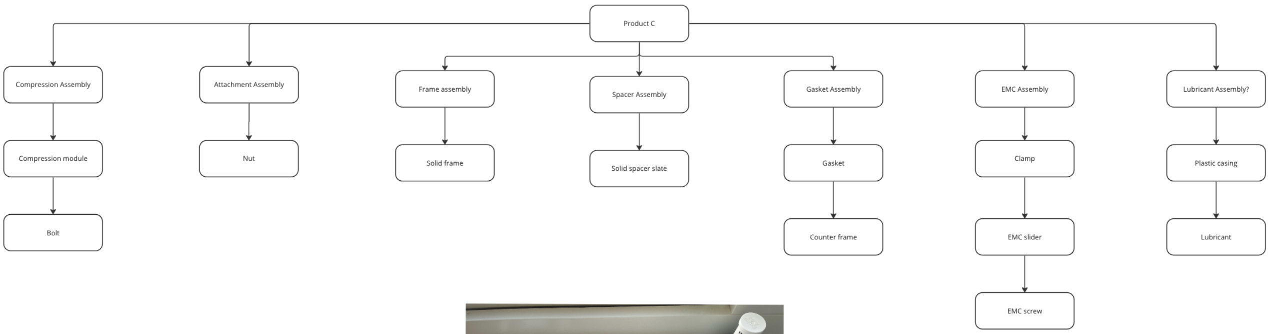


Figure 5.3: Component cluster of Product A



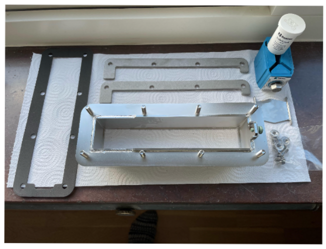


Figure 5.4: Component cluster of Product B

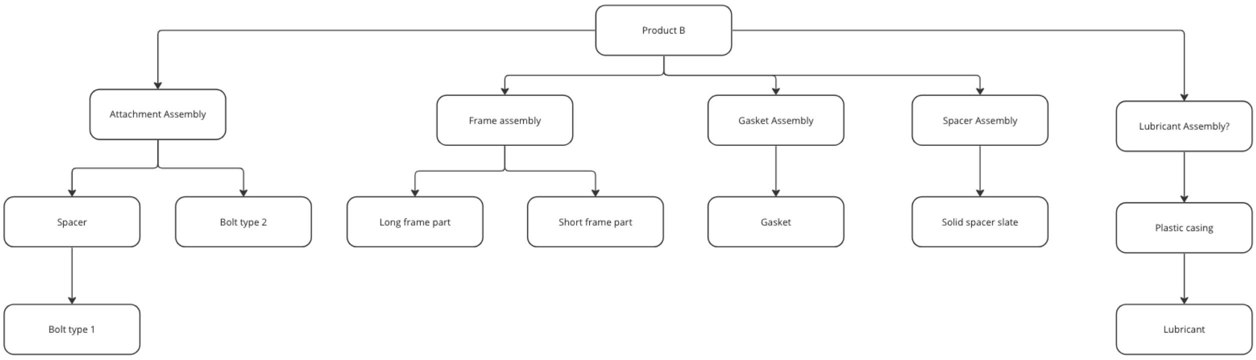


Figure 5.5: Component cluster of Product C

5.4.2 Boundary block diagram

The boundary block diagrams for product A, B and C can be viewed below in figures 5.6, 5.7 and 5.8 respectively. The diagram for product A differ from the other two being that it doesn't have more than one part for constructing the frame. In the diagrams for the product B and C models are blue areas which represent the assembly of the frame that is then mounted with external parts for example screws. Besides physical contact between the parts, two different energy exchanges are happening during the mounting of the frames. Friction and compression are the results of screws being inserted and tightened to mount and pressurize the frame creating a seal. The compression exists in the large opening were the modules and cables are situated, but also affects the gasket that is placed between the frame and wall. Friction is mainly between the threads of the screws. nuts and frames that have drilled and tapped holes.

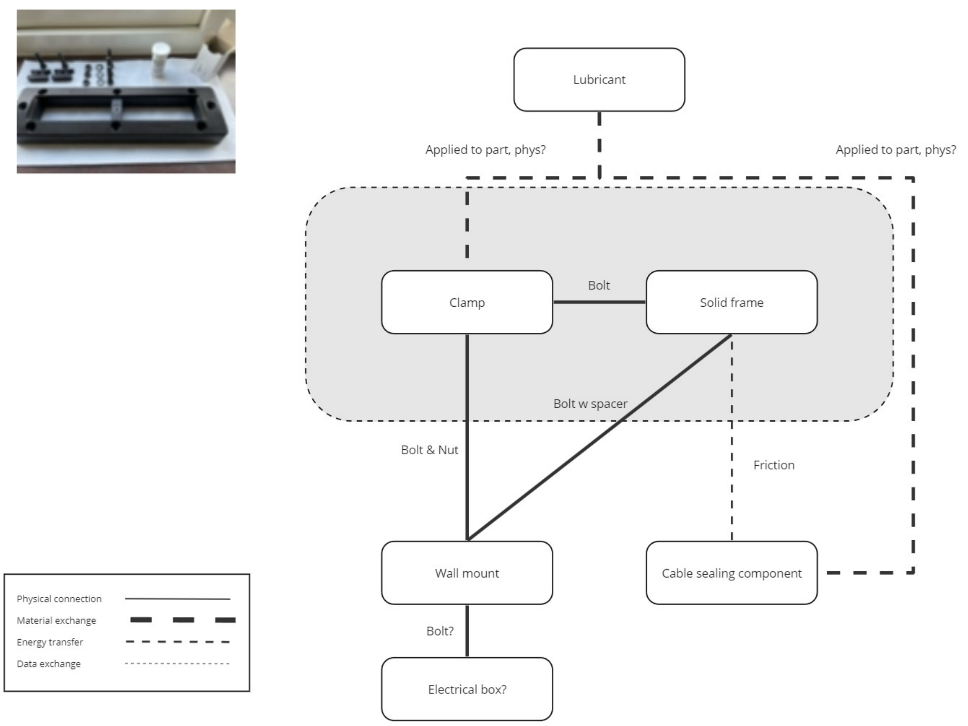


Figure 5.6: Boundary block diagram of Product A

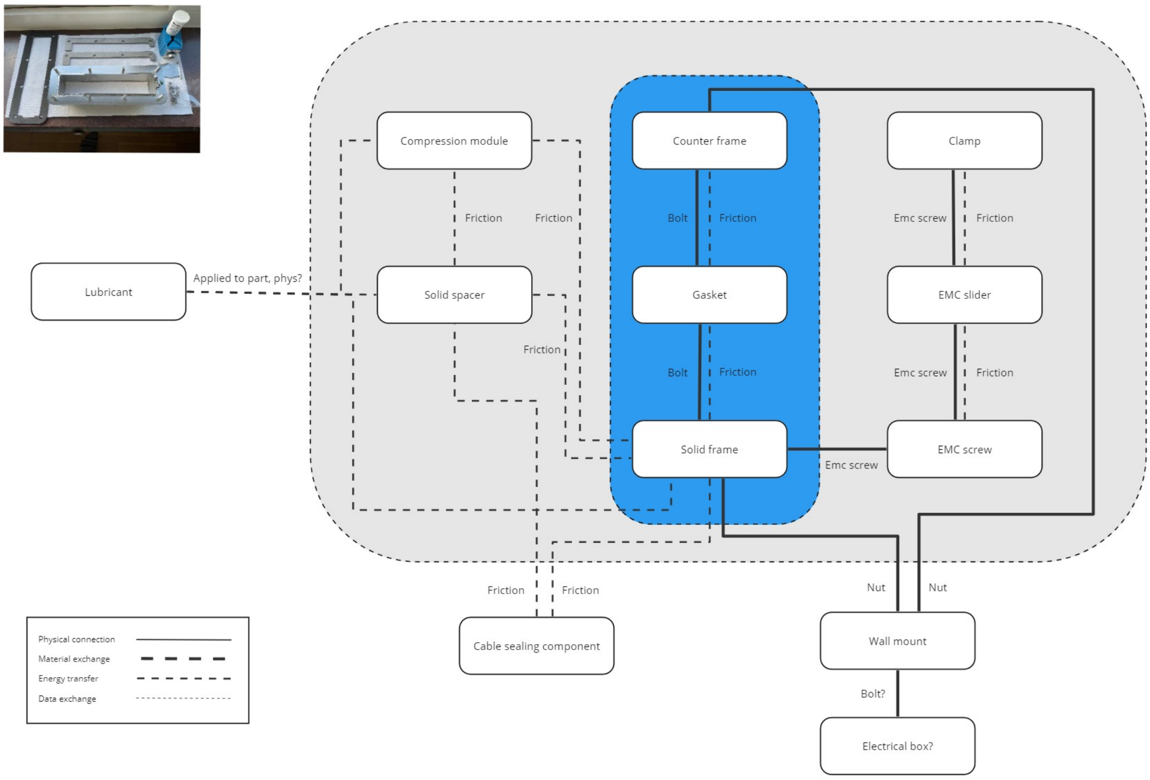


Figure 5.7: Boundary block diagram of Product B

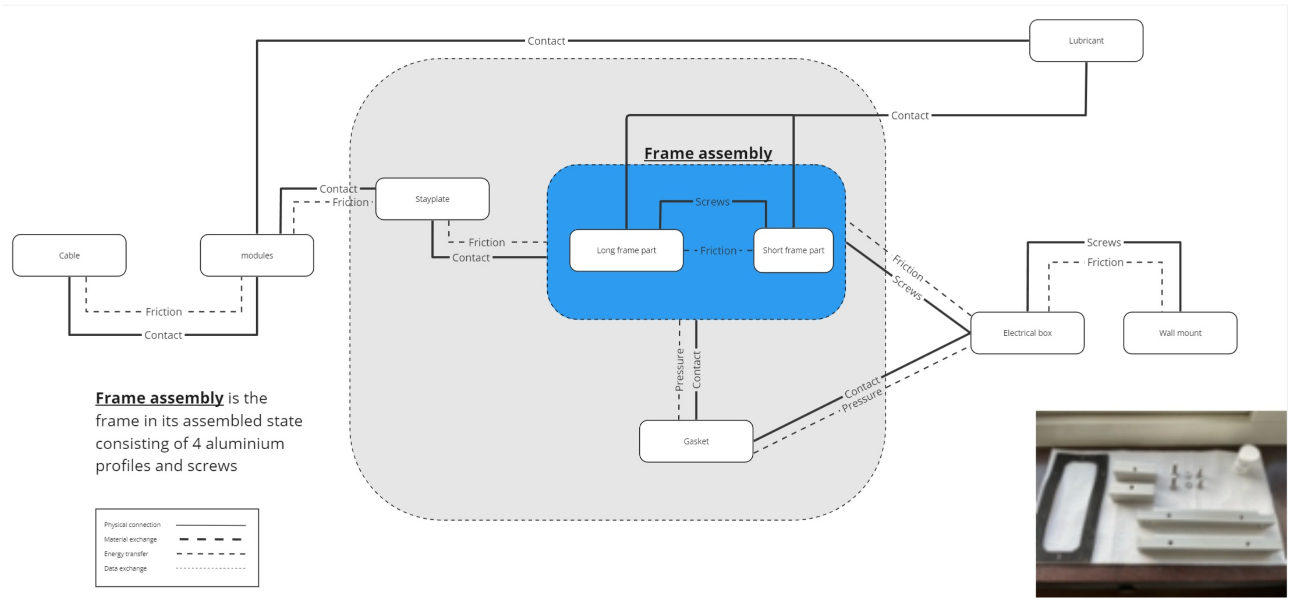


Figure 5.8: Boundary block diagram of Product C

5.4.3 Function flow block diagram

The function flow block diagrams can be viewed below in figures 5.9, 5.10 and 5.11. The frames function flow block diagrams show that the assembly of product A is less complex than for the product B and C models. Being that the products are static while in use, the results of the diagrams describe the process of mounting the frames and how to engage the sealing functions of them. The amounts of parts does also affect their complexity.

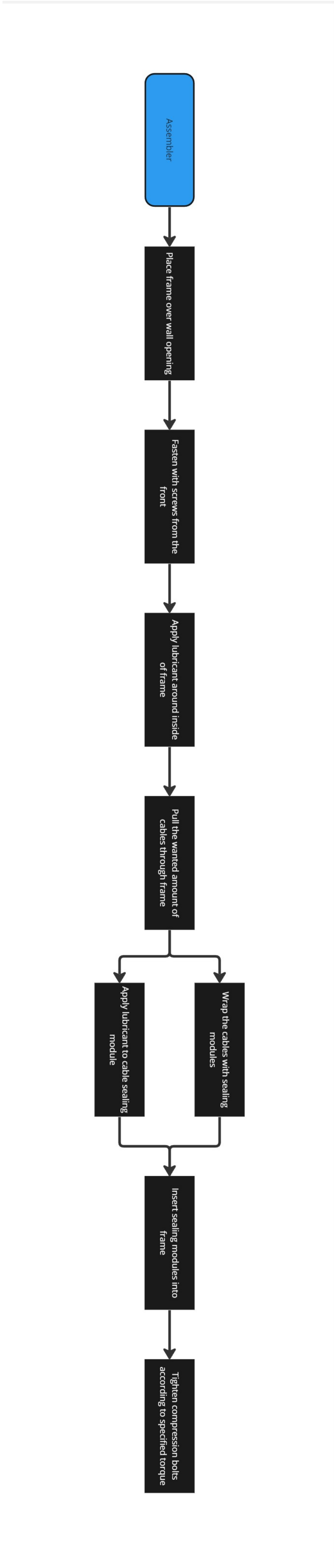


Figure 5.9: Function cluster of Product A

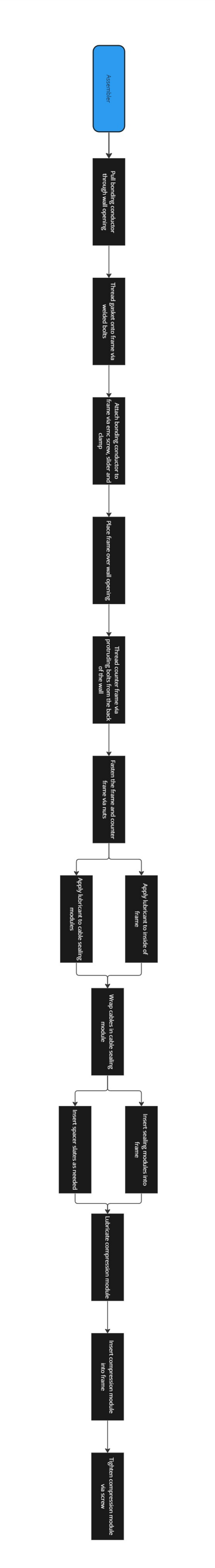


Figure 5.10: Function cluster of Product B

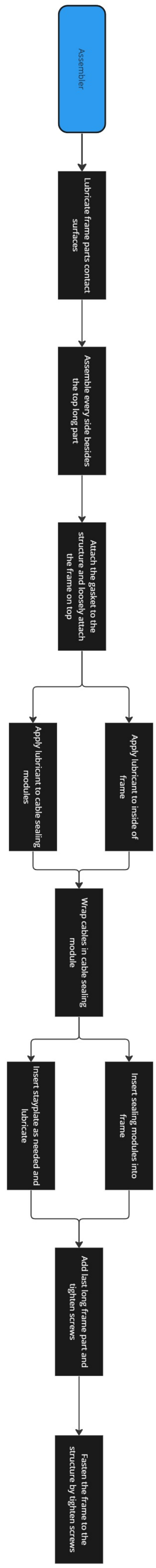


Figure 5.11: Function cluster of Product C

5.5 Brainstorming session 1

The first brainstorming sessions resulted in sixteen different concepts. These are crude ideas that are meant to be presented in front of a focus group during workshops. The ideas range from metallic constructions, closely resembling the products that are in use today, to new ideas that radically change how the products look and how they are set up. Some concept drawings include photos of products from where the inspiration was drawn. A internal selection was made to slim down the amount of concepts that was presented for the focus group and resulted with ten versions.

The image below, figure 5.12, depicts the rubber cable clamp modules that are meant to be housed by the frame. The black rings and cylinder visible in the image represent layers that can be torn of to adapt the rubber module to different cable sizes. The module is not something that is thought to be changed but rather something to be designed around.

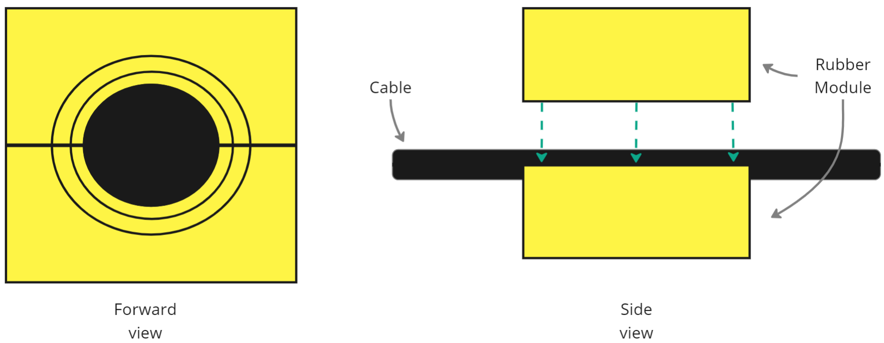


Figure 5.12: Depiction of rubber cable clamp

5.5.1 Concept 1: Telescopic Frame

The first concept consists of a frame that can be lengthened or shortened and can be viewed below in figure 5.13. The frame is made up of two extendable beams. The beams can be extended telescopically like a pair of old binoculars or a fishing rod. To tighten it and make its sturdy, plates are inserted. The plates are manufactured in a set of different sizes to conform to different hole dimensions. When pressurizing the frame, the plates are then also pinched into position holding them in place.

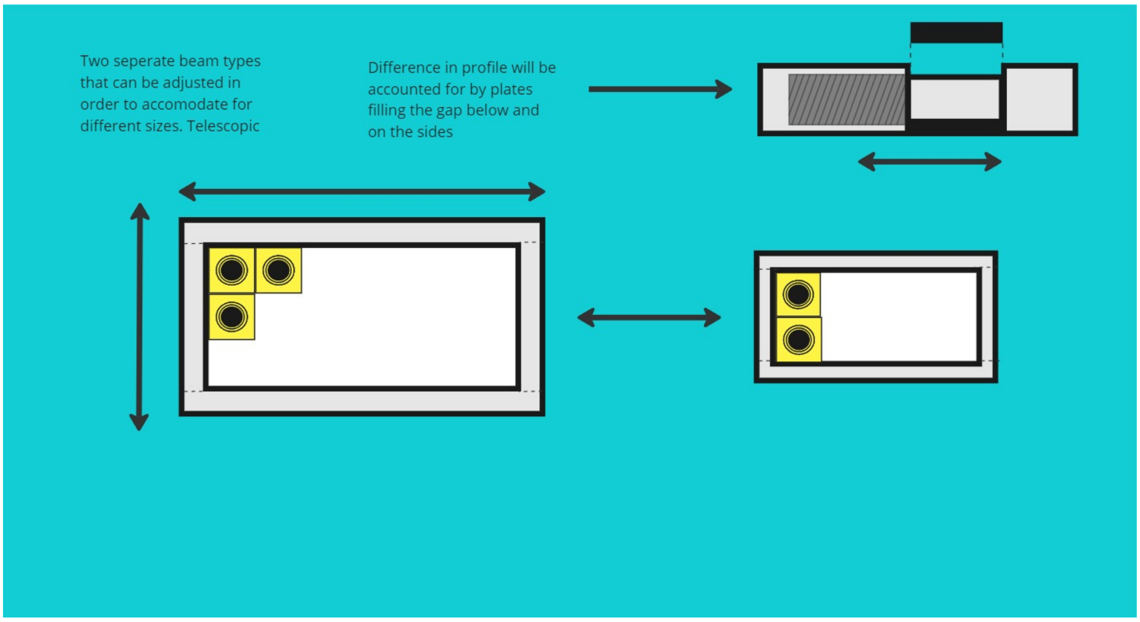


Figure 5.13: Concept 1: Telescopic Frame

5.5.2 Concept 2: Adaptive Anodized Aluminum

The cross frames utilizes solid frames in various sizes with the addition of varying mid section beams an can be viewed below in figure 5.14. The mid sections can be attached to the middle of the frame according to the customers needs. Concept takes strong inspiration from available solutions on the market.

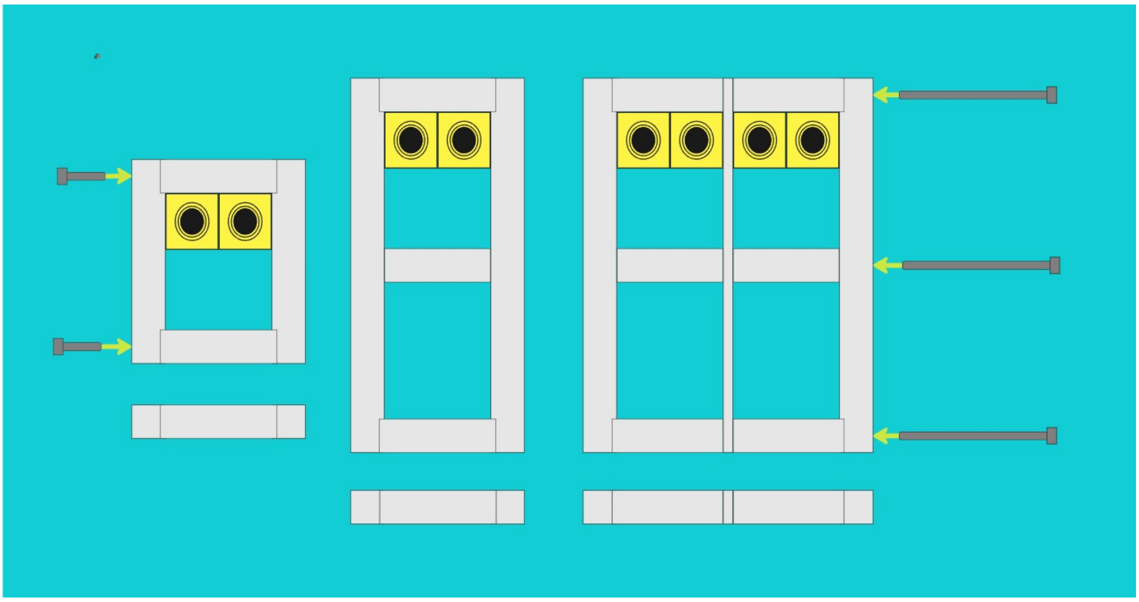


Figure 5.14: Concept 2: Adaptive Anodized Aluminum

5.5.3 Concept 3: L-profile Frame with Corner Fasteners

The L-profile frame is made up of three different parts in total and can be viewed below in figure 5.15. Two different L- profile beams are attached with an L-shaped connector. The beams are thought to come in various sizes which the customer can choose from to meet their specific needs. The design takes inspiration from various products readily available on the market of cable sealers. The main difference is the use of a smaller part that holds the beams together rather than using a screw to bolt the beams to each other. The frame is thought to be made of metal with built-in EMC capabilities. The source of images included in the figure are the following [17], [16] and [7].

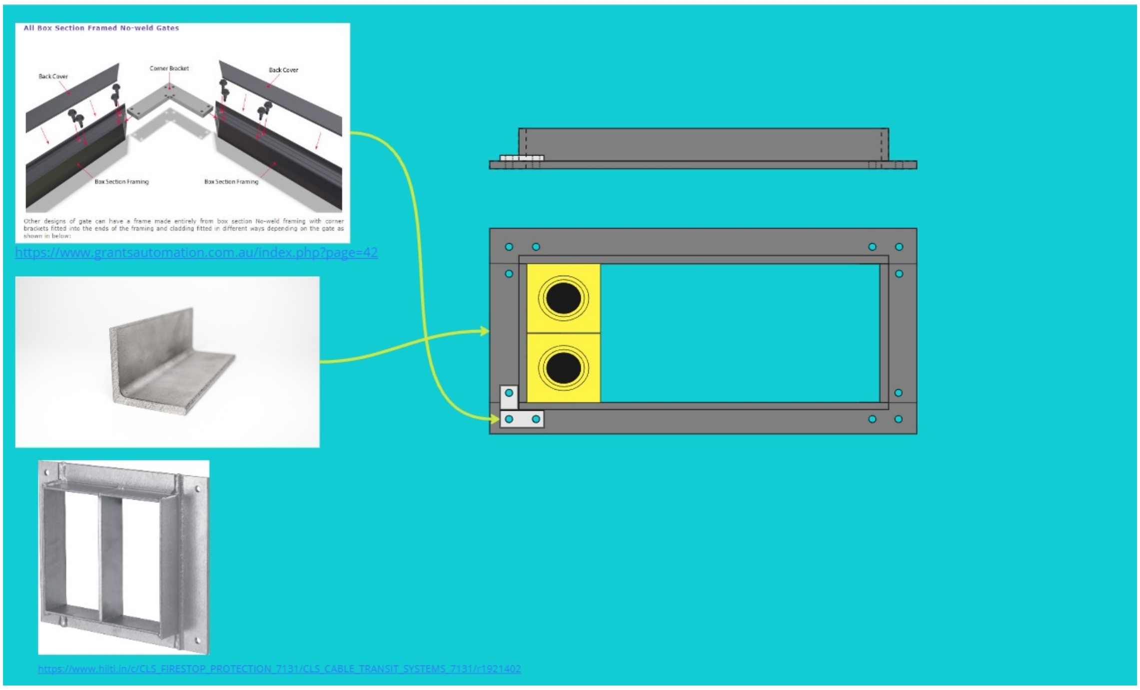


Figure 5.15: Concept 3: L-profile Frame with Corner Fasteners

5.5.4 Concept 4: Rail Frame

The frame is made up of four corner modules, four interchangeable small beams and a number of interchangeable plastic modules. The interchangeable parts refers to the parts supposedly being made in various sizes which allows for customization. The corner modules and beams are made of steel which allows for incorporation of grounding capabilities. The concept can be viewed below in figure 5.16.

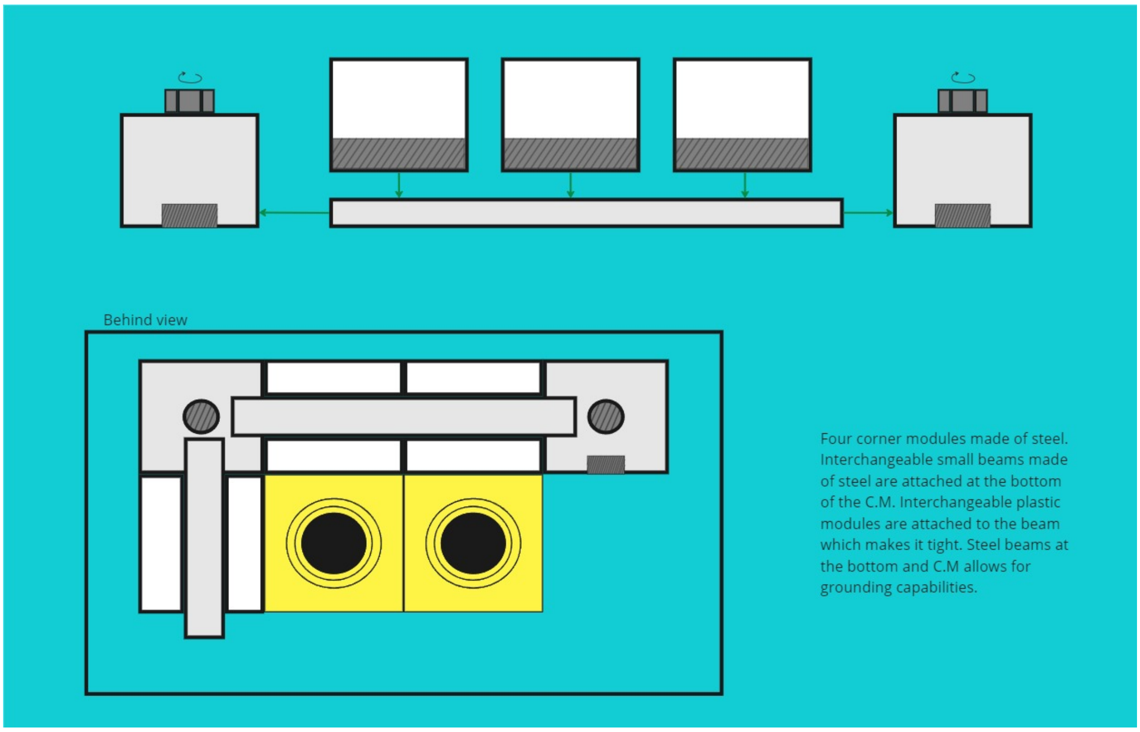


Figure 5.16: Concept 4: Rail Frame

5.5.5 Concept 5: Block Magnet Frame

The frame is made up of two modules, one corner module and a mid section module. The frame is assembled by slotting magnets into the parts and then connecting them. The parts are held in place by bolting the corner modules to the wall. The concept can be viewed below in figure 5.17.

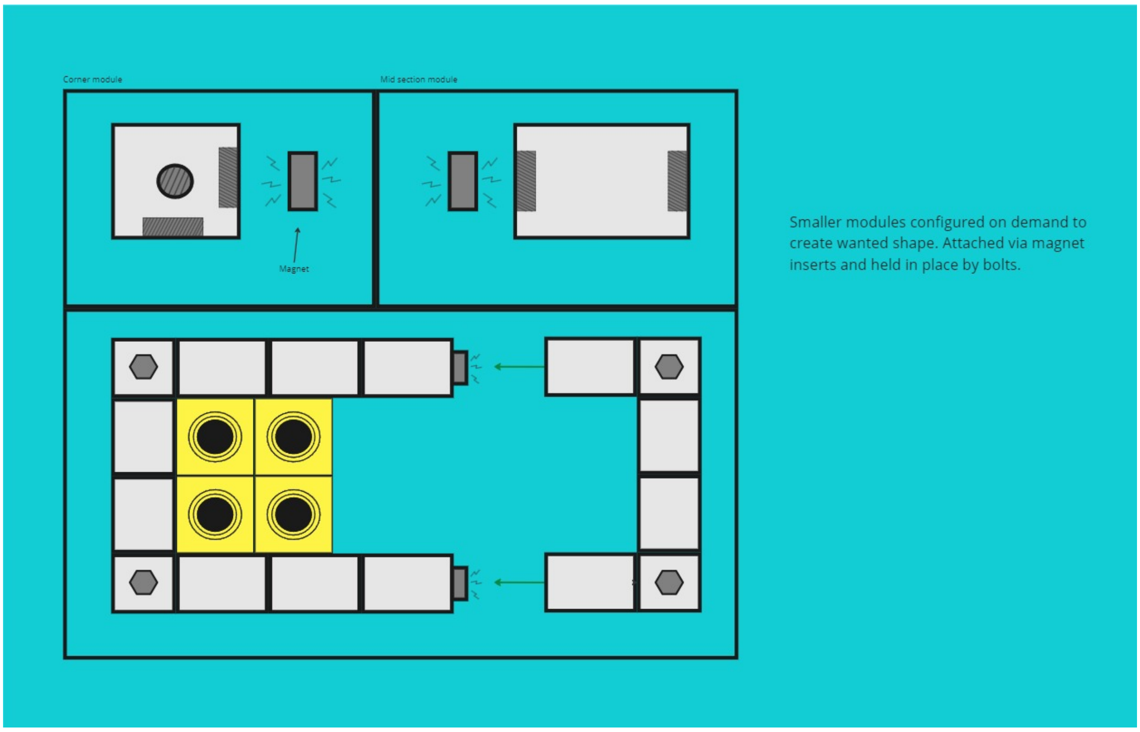


Figure 5.17: Concept 5: Block Magnet Frame

5.5.6 Concept 6: Edge Sleeve Made Out of Conductive Rubber

The frame is made up of a conductive rubber grommet strip that is cut to length and attached around the hole. The strip is made tight through the existing compression unit used in some existing frames. The grommet is situated on the edge of the opening as opposed to on top of it. The use of conductive rubber takes inspiration from an existing cabinet solution that has modules with a rubber mix that acts as a conductor, rather than using a weaved metal strip that has direct contact with the frame. The design overall takes inspiration from the rubber grommets that are available today and is usually used to secure cables from sharp edges. The concept can be viewed below in figure 5.18. The source of images included in the figure are the following [19], [36] and [38].

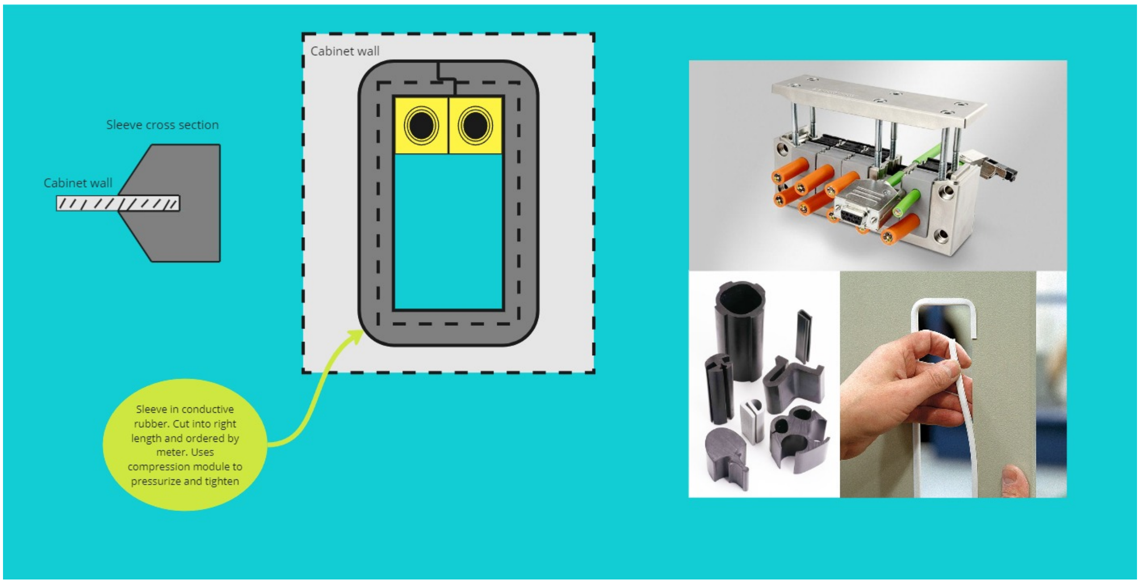


Figure 5.18: Concept 6: Edge Sleeve Made Out of Conductive Rubber

5.5.7 Concept 7: Tool Less Compression Frame

A frame that is made in parts that are directly attached to the wall via groves. The groves are present in the beam parts of the frame. The beams in turn are attached to corner pieces that can expand with the help of a screw making the frame tight. Having the groove holding the parts in place and pressurizing the frame creates the possibility of reducing the amount of tools needed for installation. The corner pieces have a locking geometry helping with keeping the frame parts in place and putting pressure on them rather than other components. The concept can be viewed below in figure 5.19. The source of image included in the figure is [38].

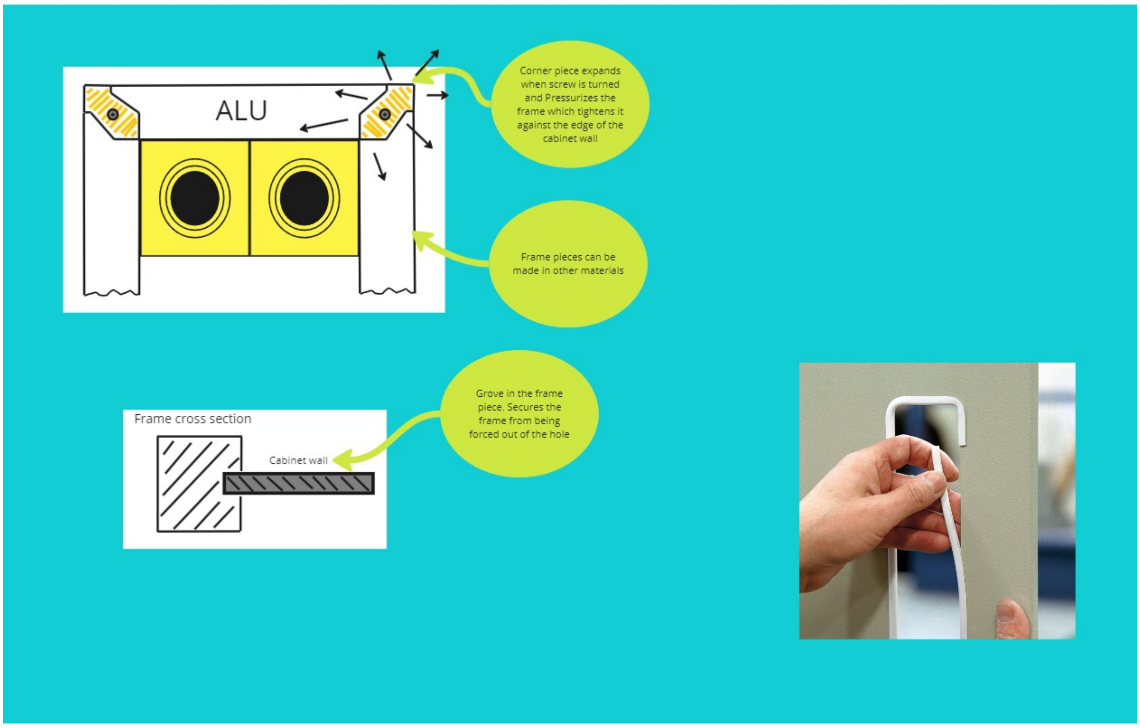


Figure 5.19: Concept 7: Tool Less Compression Frame

5.5.8 Concept 8: Plastic Base Frame with Interchangeable Outer Shell

The frame consists of two sections, one inner frame which is screwed in place, and an outer shell in the form of L-profiles that are placed on top of the plastic frame. For EMC properties the shell is made out of metal and has a longer reach inside the opening for closer connectivity to ground. Manufacturing the parts in L-shapes reduces the amount of different parts needed as the two parts forming the frame are the same one, but one being turned up side down. The concept can be viewed below in figure 5.20.

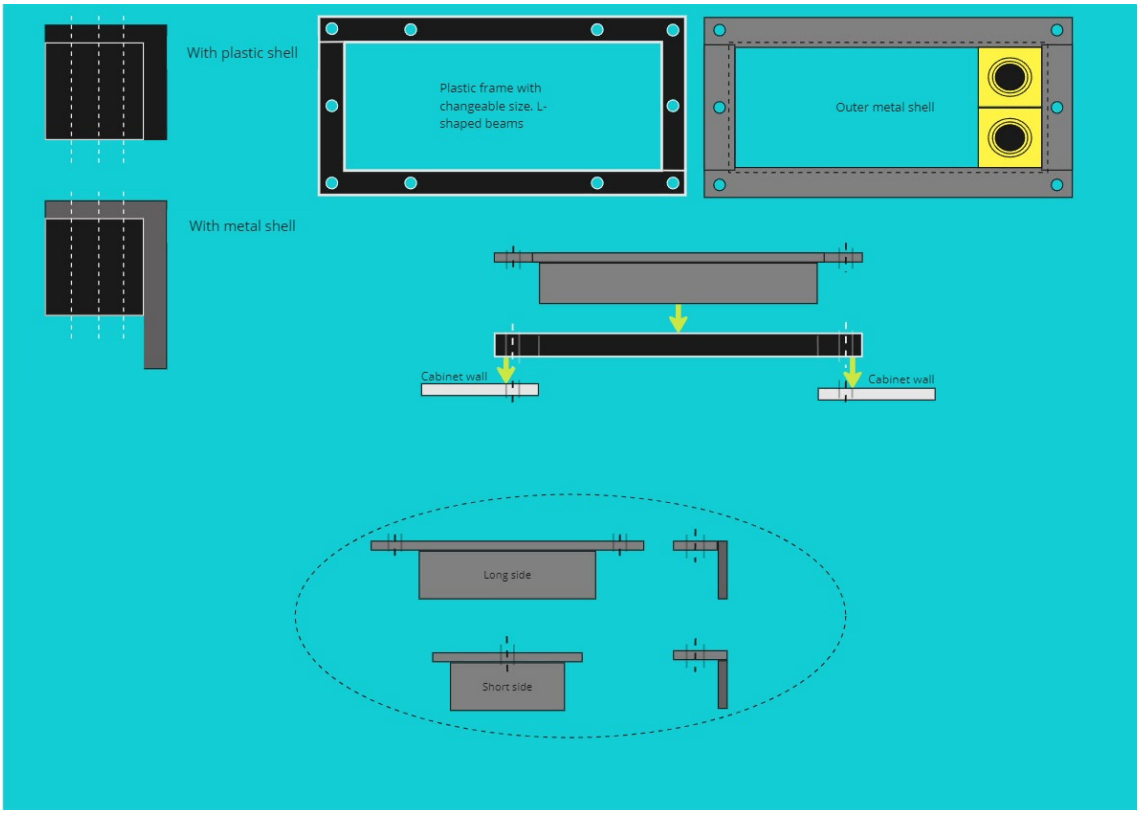


Figure 5.20: Concept 8: Plastic Base Frame with Interchangeable Outer Shell

5.5.9 Concept 9: Modular L-frames

A crude idea of being able to choose material for the frame and keep the changeability in size. With built in EMC and corrosion resistance in the base. The top portion which will make up the majority of the frame and where the modules are situated are interchangeable depending on needs. The base plate will remain the same material and uphold the highest possible certifications which can possibly be determined for a configuration like this. The concept can be viewed below in figure 5.21.

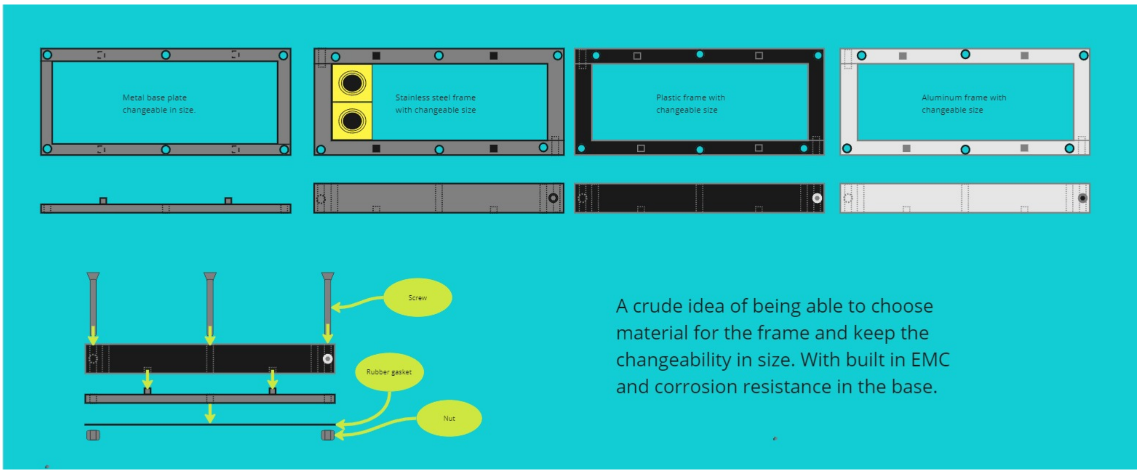


Figure 5.21: Concept 9: Changeable Structure depending on Hole Size

5.5.10 Concept 10: Plastic Frame with Interchangeable Inner Wall

The frame is made from injection molded plastic. The frame is either thought to be one solid piece or be made up of two L-shaped beams. The frames inside (the side that makes direct contact with the rubber modules) are interchangeable walls that can be added or taken away to give different properties to the frame such as grounding capabilities. The concept can be viewed below in figure 5.22.

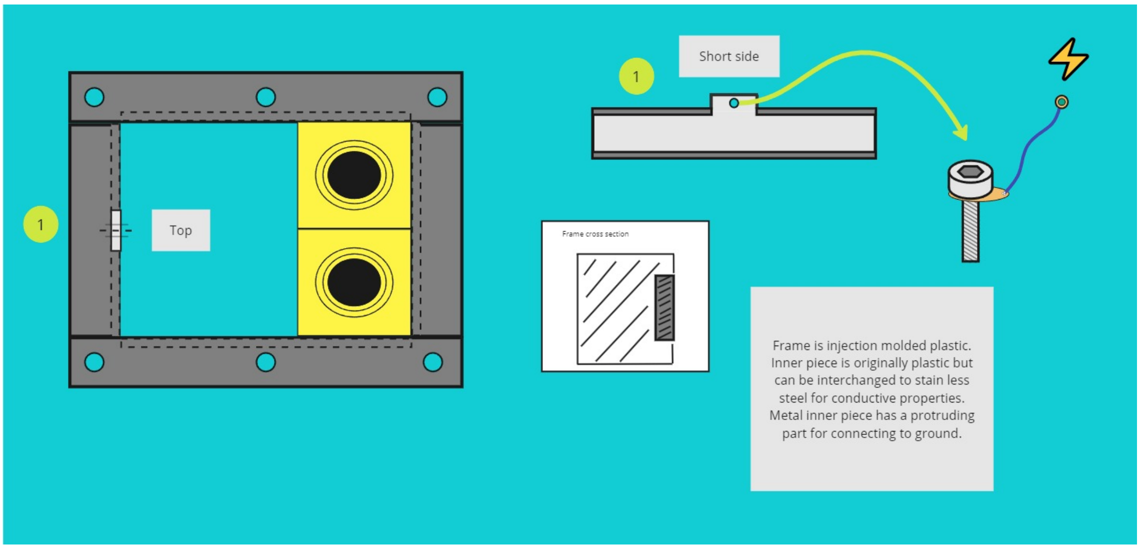


Figure 5.22: Concept 10: Plastic Frame with Interchangeable Inner Wall

5.6 Workshops and concept feedback 1

In order to chose concepts to proceed with it was decided to hold workshops with individuals that were previously interviewed and were involved in the project. The aim of the workshops was to gather feedback on what could be feasible and seem interesting according to the problem owners. Not all concepts were shown due to time constraints. The concepts were chosen internally via mixing concepts that seemed more grounded in the stated needs as well as some concepts that were considered to be outliers in regards to the industry norms.

5.6.1 Workshop 1:1

Due to time constraints and unclear instructions, the first workshop only covered six of the ten concepts. The feedback on the six covered concepts is listed below in 5.3. The format of the feedback were given in pros and cons for each concept were the participant was allowed to write as little or as much as they wanted.

Table 5.3: Pros and cons of from workshop 1:1

	Pros	**Cons**
Concept 1	• Good for retrofit • Looks robust	• Difficult in getting a good seal: – In regards to wall – In regards to the telescopic beam inserts • How will it attach to the wall?
Concept 2	-	• How will the crosses attach to the frame?
Concept 3	-	• Seal in regards to the different parts could be problematic (metal on metal)
Concept 4	-	• Many contact points makes it difficult to get a good seal
Concept 5	-	• Many contact points makes it difficult to get a good seal • Many building elements for customer, hard to assure quality
Concept 6	-	• Potential deflection problems • Rubber not a suitable material

5.6.2 Workshop 1:2

The second workshop covered all ten concepts that were chosen. The feedback given in pros and cons can be viewed below in table 5.4.

Table 5.4: Pros and cons of workshop 1:2

Shown Concepts	Pros	Cons
Telescopic Frame - C1	- Flexible and adaptable - Adaptable after it has been sold to customer	- Accompanying filler pieces, how many? - Waste due to filler pieces? - Hole punching
Adaptive Anodized Aluminum Frame - C2	- Product family in mind - Possibility of creating many combinations with few parts	- Unsure about anodized aluminum - How is this different from CF24?
L-profile Frame with Corner Fasteners - C3	- Seemingly very cost efficient - Very modular since cornerpieces fits many frame sizes	- Joint tightness - High tolerances, might be mediated via cone, incline or guiding - More details?
Rail Frame - C4	- Few articles - Clearly modular	- Many joints/surfaces to seal - Many details - Unclear what counteracts bending - Risk of separation when frame is compressed
Block Magnet Frame - C5	- Intuitive design - Modular - Frameparts has the same size as rubber modules	- Structure stiffness, both in depth (tightness and structure) and width (tightness towards module) - Might need a middle section with additional attachment point
Edge Sleeve Made Out of Conductive Rubber - C6	- Cost efficient - Highly adaptable	- Will most likely need to be extruded, makes it difficult to shape into rectangle with corners - Might require casting - Difficulty in getting a proper seal in joints - Wall thickness might cause problems - Hardness of rubber - Might require rounded corners
Tool Less Compression Frame - C7	- One single corner piece fits all frame variants	- Tightness between aluminum profile and structure, probably puts demands on compression part - Complex assembly, loose deatils?
Plastic Base Frame with Interchangeable Outer Shell - C8	- Easy to switch between EMC and non EMC demands	- Tightness between metal and plastic could be problematic - Tightness in joint of plastic frame
Modular L-frames - C9	- Only two main components - One article	- Bottom plate might make the design counter intuitive - Production method?
Plastic Frame with Interchangeable Inner Wall - C10	- Adjustment or adaptation of product can occur during manufacturing or when it has arrived at the customer - Modular - Easy to switch material depending on customer demands	- Demands on attachment of metal part? - Contact between one another? - What is the point of not always having the metal insert?

With the chosen concepts there were also some comments on possible design changes and functions that could be incorporated to improve them. Concept 10, as seen in figure 5.22, was seen as made out of plastic components where the connecting pieces would use a geometry working with friction for connection, instead of magnets. The term male and female connections was used, as can be seen in a wide variety of other products where two parts or more needs to be joined. An idea of using "screw modules" in the middle of the frame walls to seal it against the mounting medium when the frame is in a larger configuration came to light as well. It was seen as positive to have the wall pieces of the same length as the rubber modules for easy and parametric change in size. The idea is to have a wall piece with a hole in it for the possibility to insert a screw. The interchangeable inserts from concept 10 would be used on the outside of the frame wall on concept 5, as seen in figure 5.17, so that the functionality of making it possible to ground for shortages could be used by simply rotating the walls inwards. For concept 3, as seen in figure 5.15, there was an idea to have some kind of locking geometry for the corner pieces due to the concept as it was presented was seen having trouble pressing the wall pieces together for a leak proof fit. Other than uncertainties in how concept 1, as seen in figure 5.13, would work considering the change in wall dimension when extended, it didn't get as many comments on possible design changes as 3, 5, and 10. It was seen as interesting and something that could be worth exploring, which placed it higher than other concepts that got completely discarded. This resulted in three different concepts and one concept feature that was seen as interesting and worth investigating, 1, 3, 5, and 10. Illustrations of suggested design changes for the combination of concepts 5 and 10 as well as concept 6 can be viewed below in figures 5.23 and 5.24.

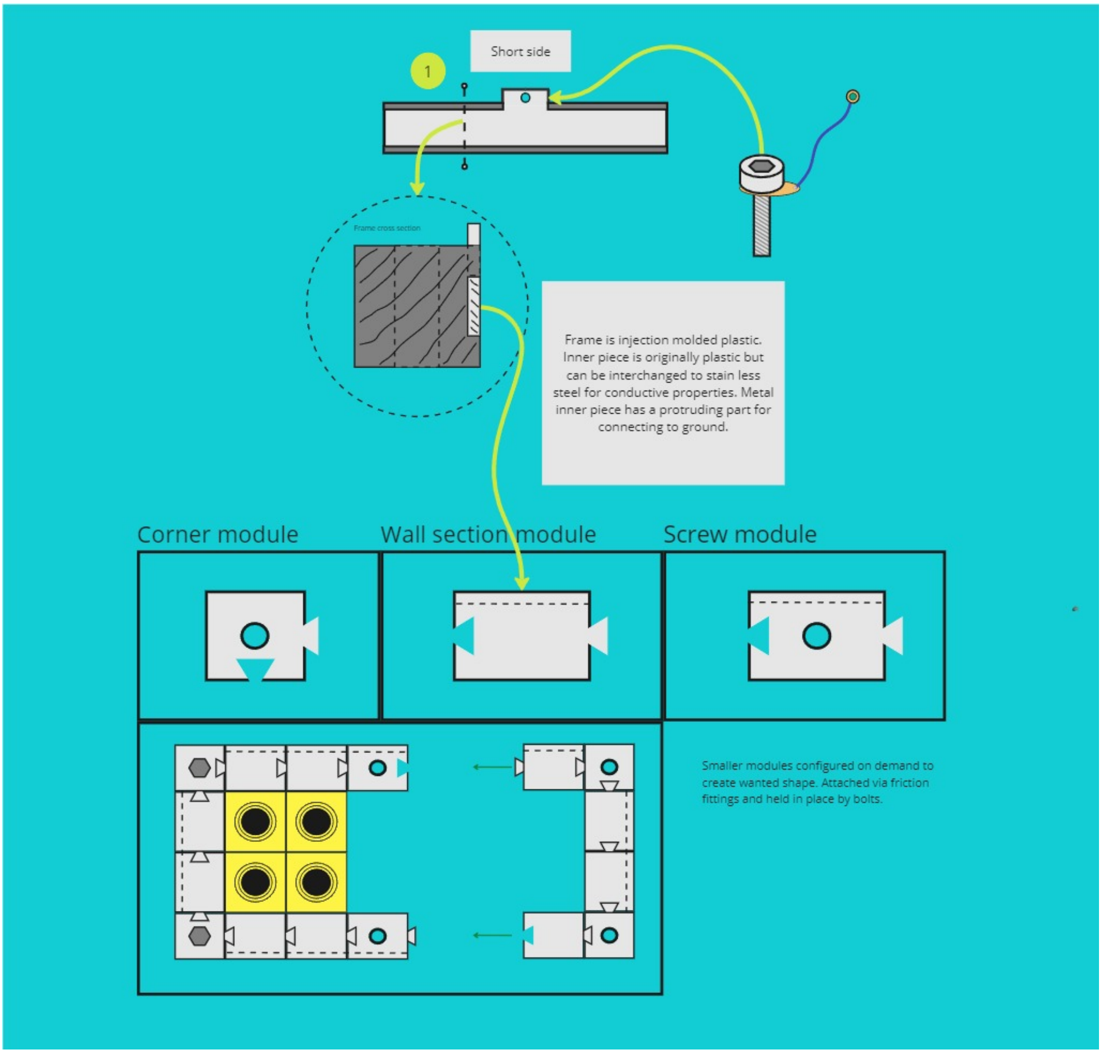


Figure 5.23: Combination of concept 5 and 10 with suggested changes from workshop illustrated

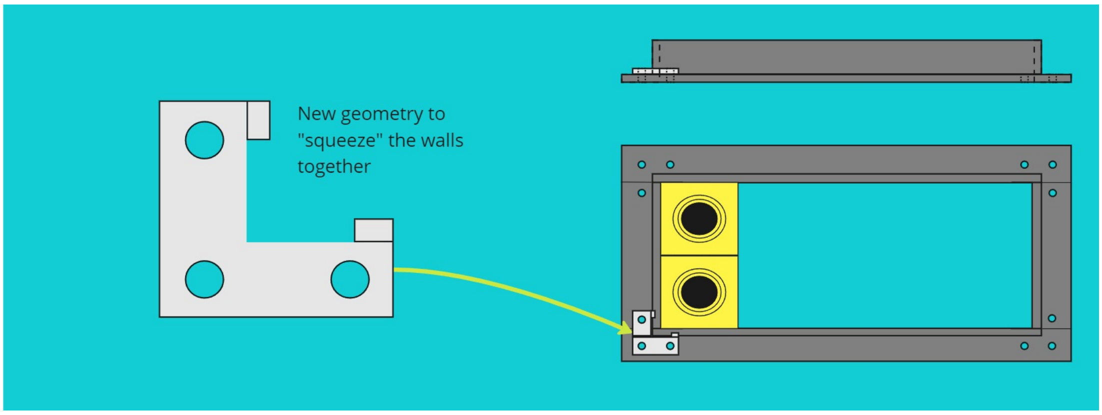


Figure 5.24: Concept 3 with suggested changes from workshop illustrated

5.7 Brainstorming session 2

The consequences of the selection of concepts during the former workshops are three chosen concepts and one feature that was present in a fourth concept, 1, 3, 5 and 10. These four concepts are crude versions that only displays the overall idea on how they will conform to functionalities and needs that was derived from the interviews. The brainstorming session with these and the feedback as the main source of inspiration resulted in fifteen different concepts, five each for concept 1, 3 and 5, that describes their functionalities in greater detail such as fastenings, geometries, and over all finer detailed depictions. Brainstorming is concluded with six different concepts, based on the previous fifteen, which are 3D-modeled. An internal selection of final concepts to present were done to reduce the amount of unnecessary ideas that wont contribute to the end result. The 3D-models may vary from their 2D counterparts.

5.7.1 Concept 1

The first concept consists of a frame that can be lengthened or shortened. The main feature is the functionality of a telescope for easy size adjustment. Both concepts shares the idea of an additional piece that can be placed in the newly extended area to smooth out the differences in diameter that is created. The additional pieces are the same dimensions as commonly used rubber modules for a parametric and consistent change in size of the frame.

5.7.1.1 Concept 1:1

The assembly in this concept relies on an L-shaped profile to attach to two telescopic beams. The adaptability is lowered since motion along one axis is lost, instead the overall robustness of the frame is increased. The revised concept can be viewed below in figure 5.25.

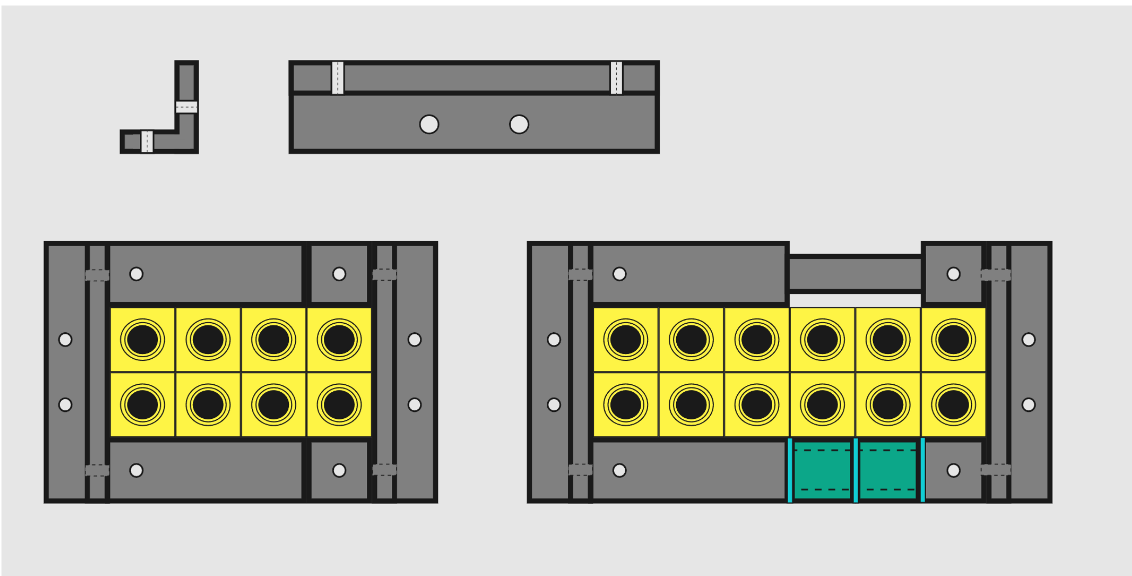


Figure 5.25: Concept 1:1 with new possible design

5.7.1.2 Concept 1:1 CAD-model

The following two images, figure 5.26 and figure 5.27 respectively, shows the frame in its smallest base form and with two additional pieces added per side. This was done to showcase the feature of increasing the concepts size based on the number of wanted rubber modules.

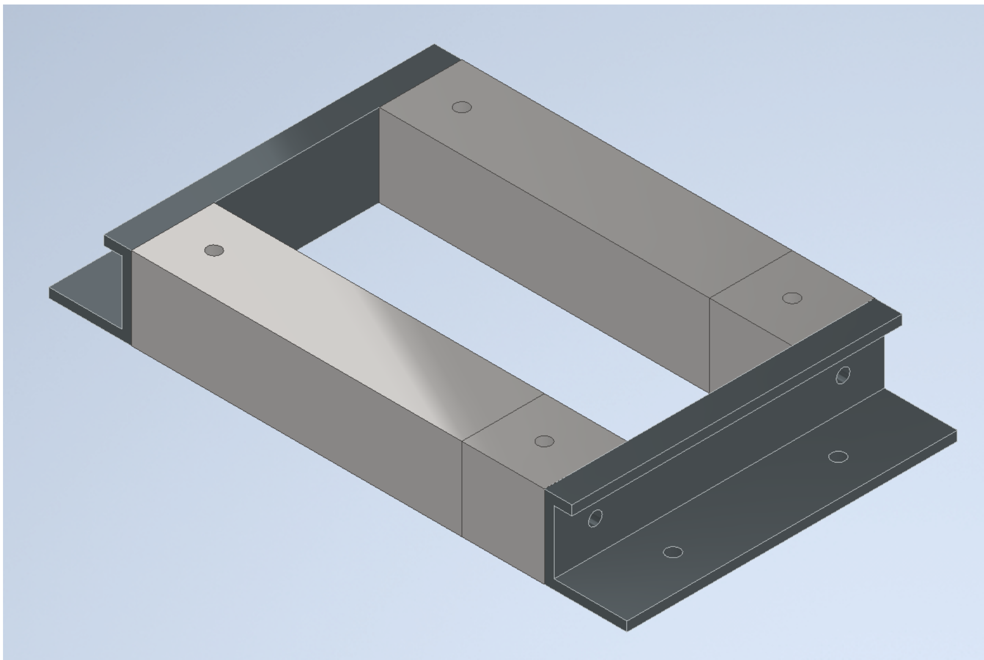


Figure 5.26: Concept 1:1 in its smallest configuration modeled in Autodesk Inventor

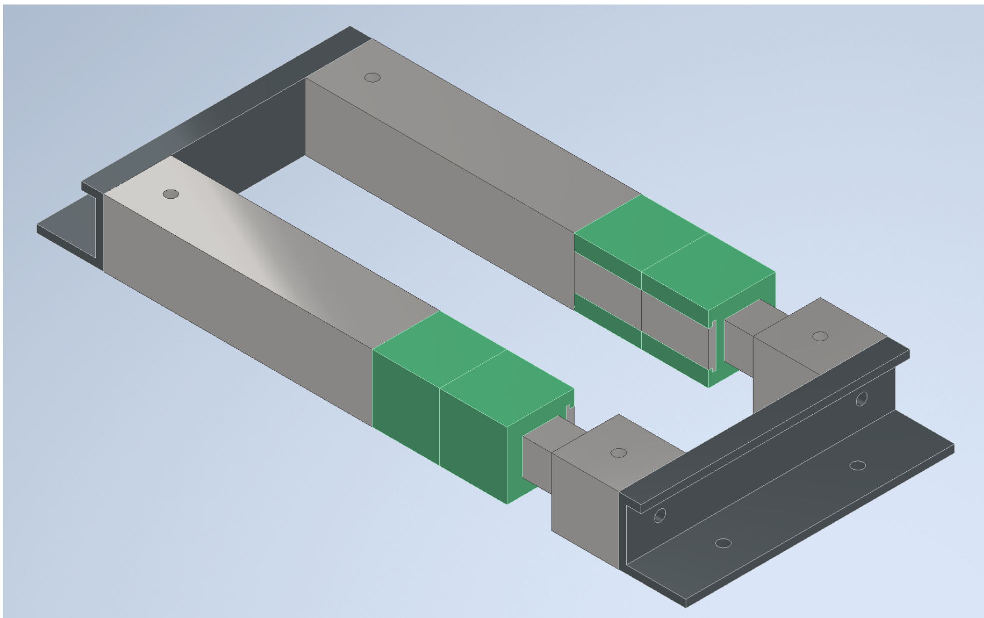


Figure 5.27: Concept 1:1 with a larger configuration modeled in Autodesk Inventor

5.7.1.3 Concept 1:2

Concept 1:2 can be seen below in figure 5.28. The difference with this compared to exiting ideas is reduce the number of parts required to construct a frame. Two housings are fused together in a C-shape. Two "extensions" are also fused into a C-shape. The housing is cut all the way through which allows the shapes to slide in and out of one another. In doing this, the adaptability of the assembly is lowered, but the integrity and robustness is vastly increased. Stoppers can be utilized were the extension exits the housing to tighten the frame further

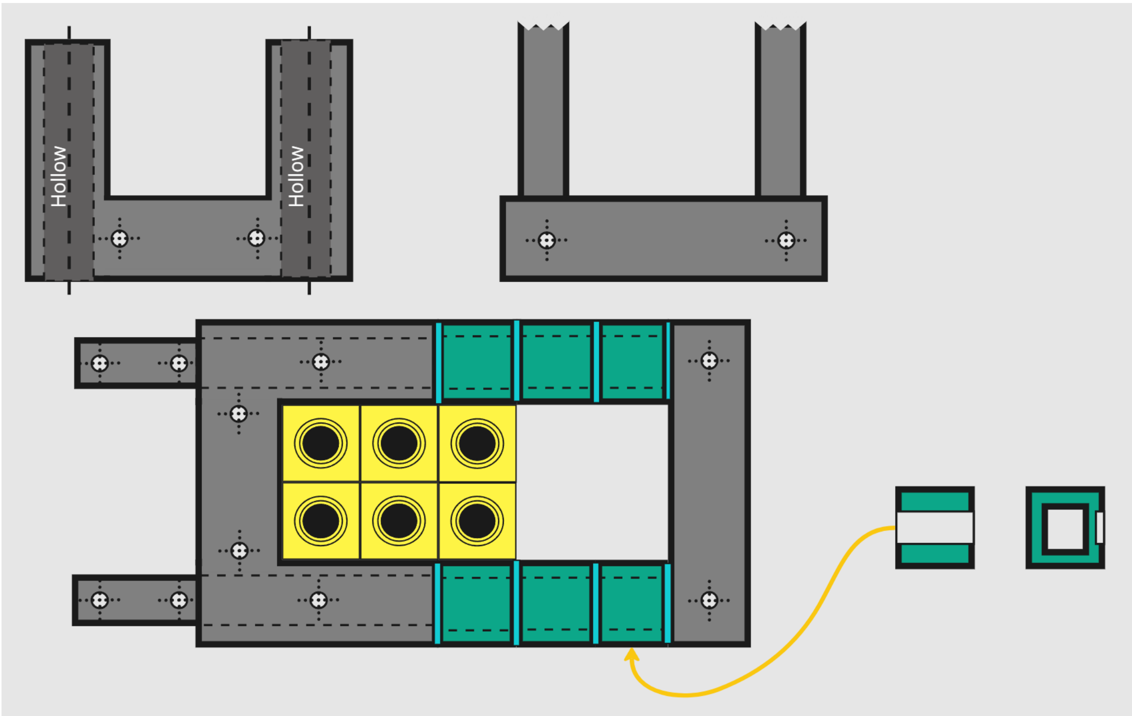


Figure 5.28: Concept 1:2 with new possible design

5.7.1.4 Concept 1:2 CAD-model

The following two images, figure 5.29 and figure 5.30 respectively, shows the frame in its smallest base form and with two additional pieces added per side. This was done to showcase the feature of increasing its size based on the number of wanted rubber modules.

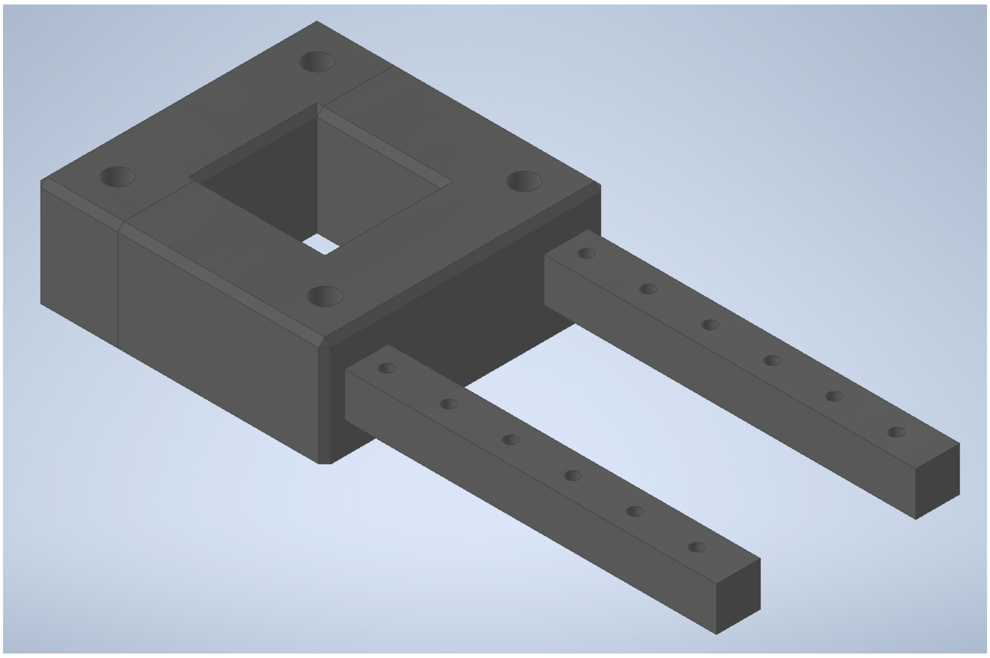


Figure 5.29: Concept 1:2 in its smallest configuration modeled in Autodesk Inventor

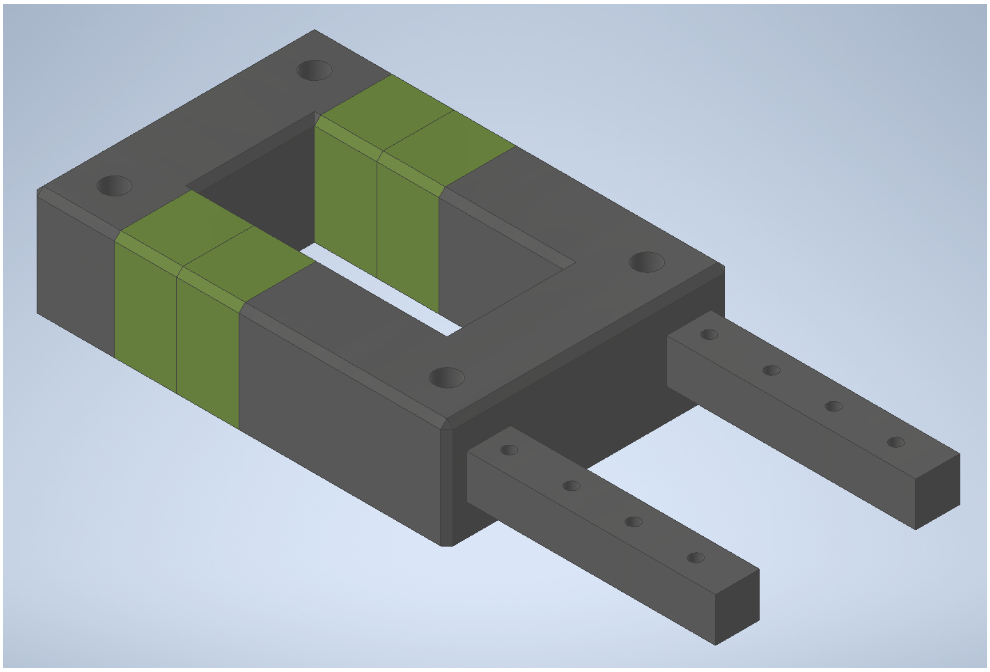


Figure 5.30: Concept 1:2 with a larger configuration modeled in Autodesk Inventor

5.7.2 Concept 3

The frame is made up of three different parts in total. Two different L-profile beams are attached with an L-shaped connector. One of the main issues that was brought up during the workshop was the issue of tightening and leak proofing flat metal surfaces in contact. The first concept uses the idea of having different dimensions for the frames mounting holes and corner fasteners, to squeeze the frame walls together. The second uses some variation of geometries to lock the walls together and supports on the corner fasteners to prevent the sides from bulging when the frame is compressed.

5.7.2.1 Concept 3:1

Concept 3:1 can be seen below in figure 5.31. Using cones on the connectors and counter sinks in the floor of the wall pieces, the connector can be used to press the walls together when screwed in. The cone and counter sink does not have the same dimensions, because if they did the cone might bottom out before the walls are fully pressed against each other. The walls also houses fortifications to reduce bulging in the center of the walls when compression is applied.

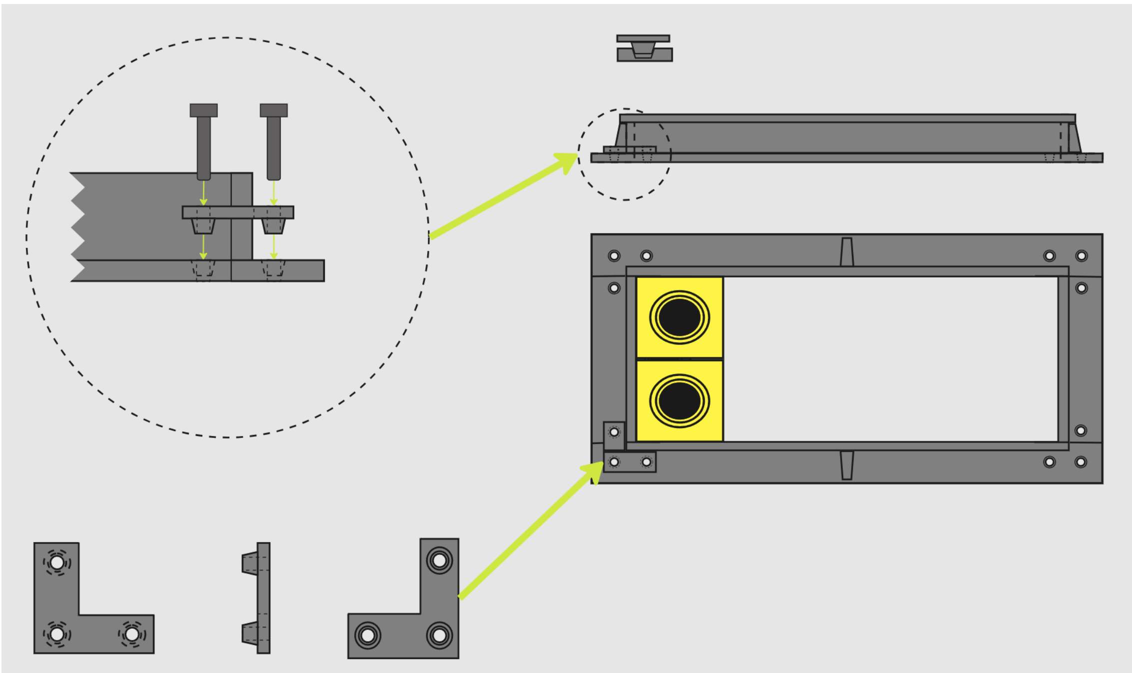


Figure 5.31: Concept 3:1 with new possible design

5.7.2.2 Concept 3:1 CAD-model

Concept 3:1, as seen below in figure 5.32, does not include the rear corner connectors to show the counter sinks that acts together with the cones on the connectors.

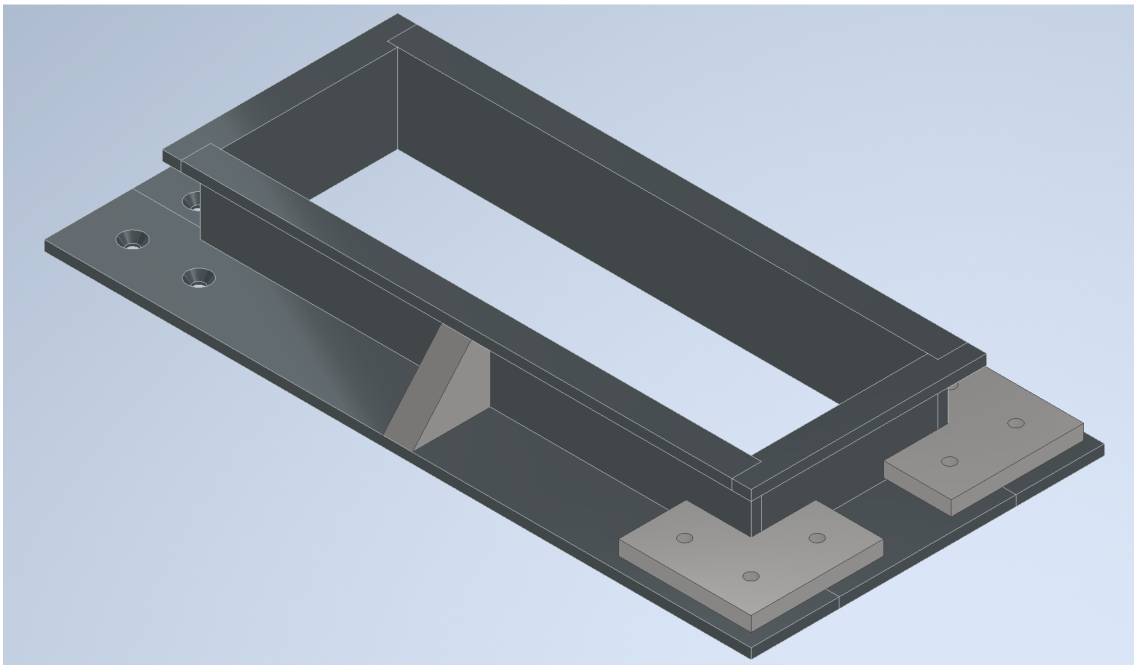


Figure 5.32: Concept 3:1 with a new possible design modeled in Autodesk Inventor

5.7.2.3 Concept 3:2

Concept 3:2, as seen in figure 5.33, utilize flat connector pieces accompanied with locking geometry in the seems of the walls. The locking feature is meant to reduce separation at the seems and hold the pieces together. It lacks the ability to press them together.

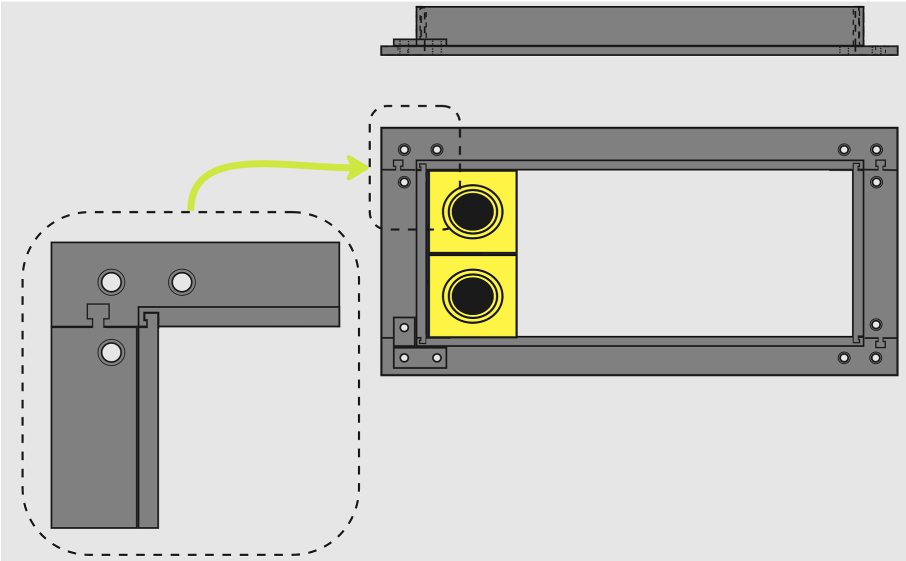


Figure 5.33: Concept 3:2 with new possible design

5.7.2.4 Concept 3:2 CAD-model

Concept 3:2, as seen in figure 5.34, does not include the rear corner connectors to show the counter sinks that acts together with the cones on the connectors.

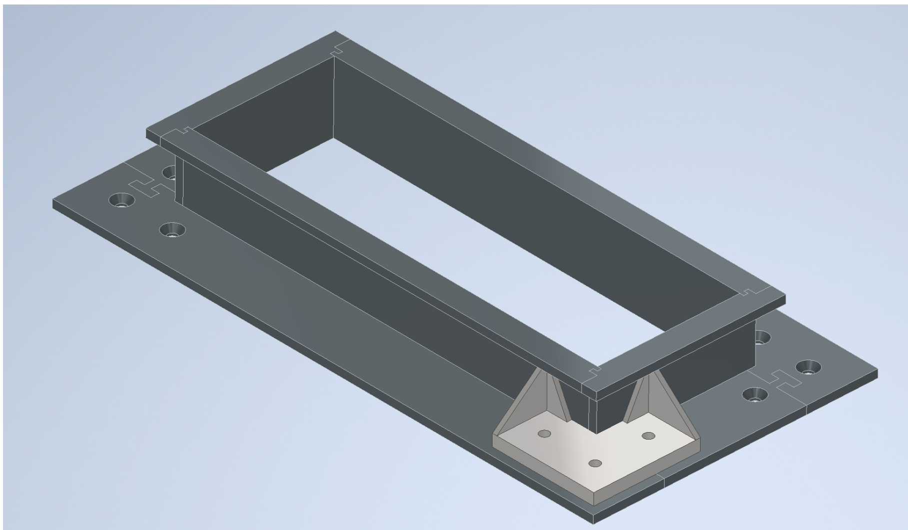


Figure 5.34: Concept 3:2 with a new possible design modeled in Autodesk Inventor

5.7.3 Concept 5

The last concepts are based on concept 5 and 10. Concept 5 in its initial state was meant to be made in metal with magnets used to attached all the blocks with each other. During the workshop the idea of having the blocks made in plastic, using friction based geometry and incorporate the EMC feature of concept 10 was brought up. The following two concepts are based on these ideas and tries to explore different designs in keeping the pieces together. The EMC feature is seen as metal pieces that resides on one side of every block. The blocks can then be turned or moved to the opposite side to have the metal facing the rubber modules.

5.7.3.1 Concept 5:1

Concept 5:1 can be viewed below in figure 5.35. Further iterating on the issue of slippage and breaks, concept 1 uses a singular contact points with a high surface area. This geometry should withstand against breakage and keep the risk of unwanted rotation low. The short sides consists of the same building blocks as the long sides making it possible to change the width while reducing the number of parts needed.

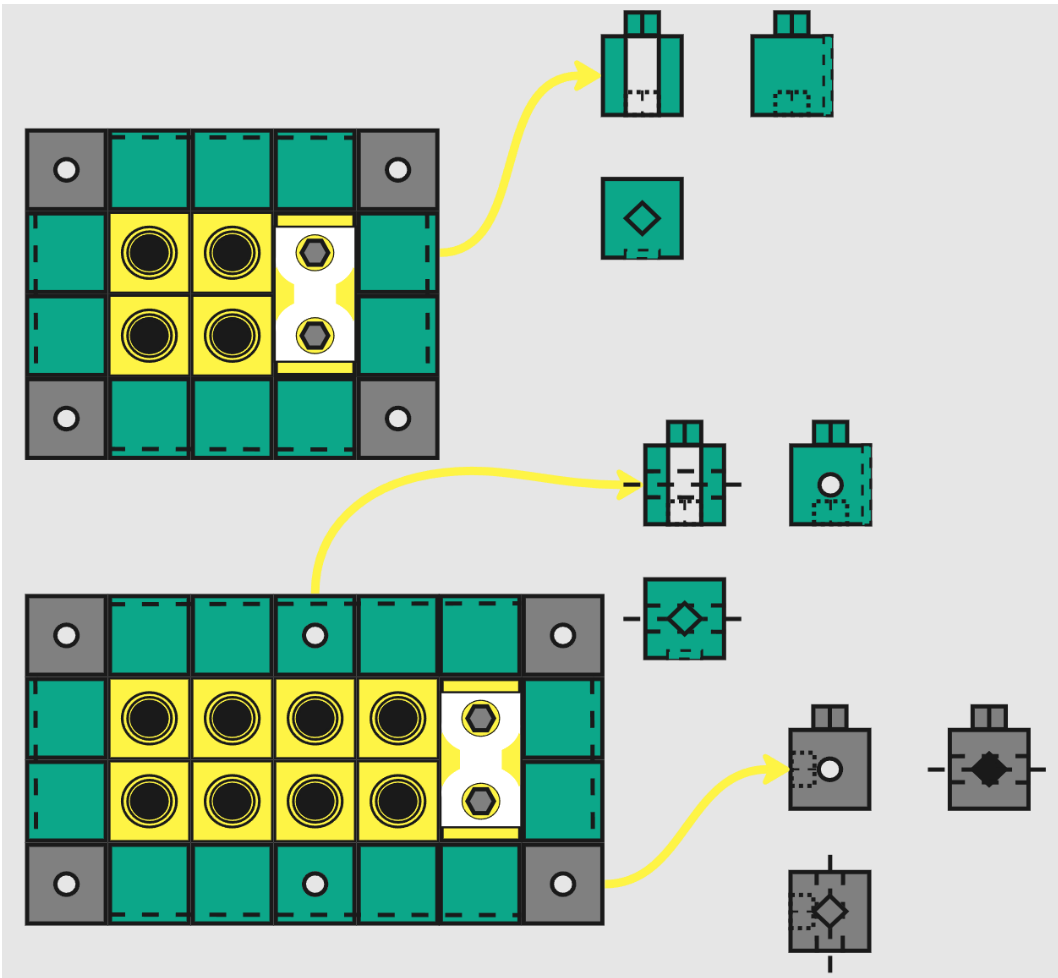


Figure 5.35: Concept 5:1 with new possible design

5.7.3.2 Concept 5:1 CAD-model

Concept 5:1 modeled in CAD can be viewed below in figures 5.36 and 5.37. The first image is shown with the feature of EMC capability not engaged. In the second image the metallic strips is instead turned to face inward which means that the EMC capabilities are engaged.

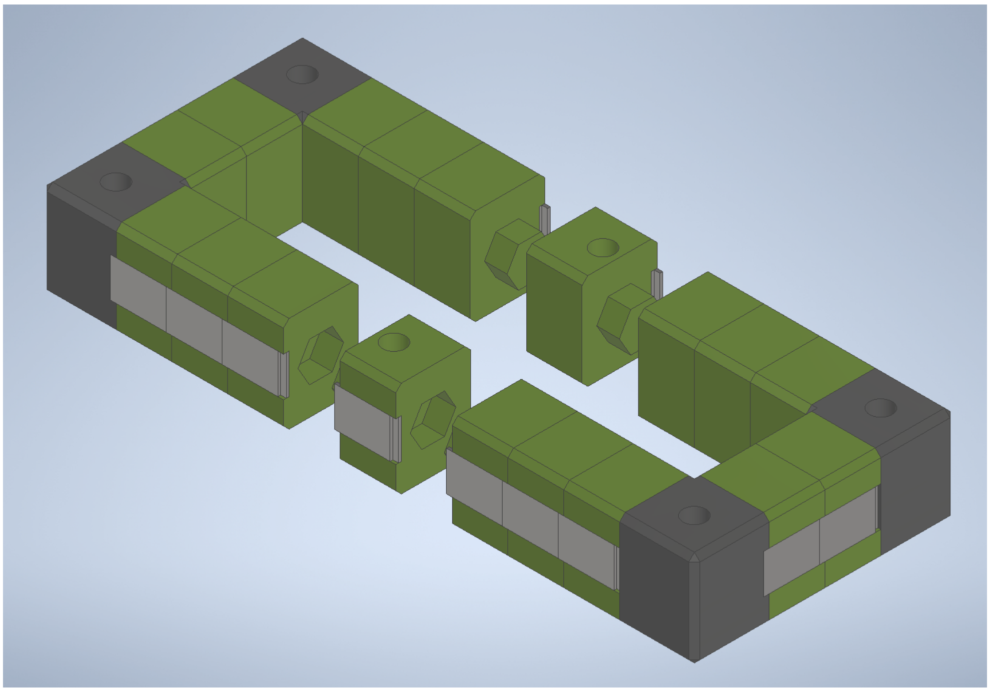


Figure 5.36: Concept 5:1 with the EMC feature not engaged

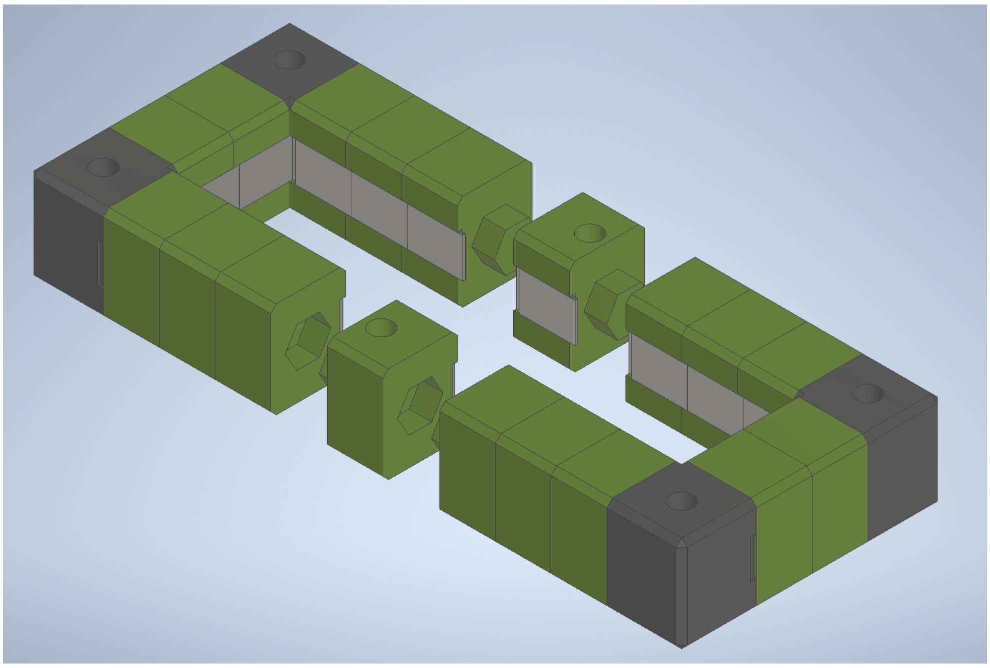


Figure 5.37: Concept 5:1 with the EMC feature engaged

5.7.3.3 Concept 5:2

Concept 5:2 can be viewed below in figure 5.38. The short sides are singular pieces but the connection interface differs from 5:1 and the other scrapped ideas. Instead of the pieces being pressed together they are slid into each other further lowering the risk of them being pulled apart when the frame is compressed.

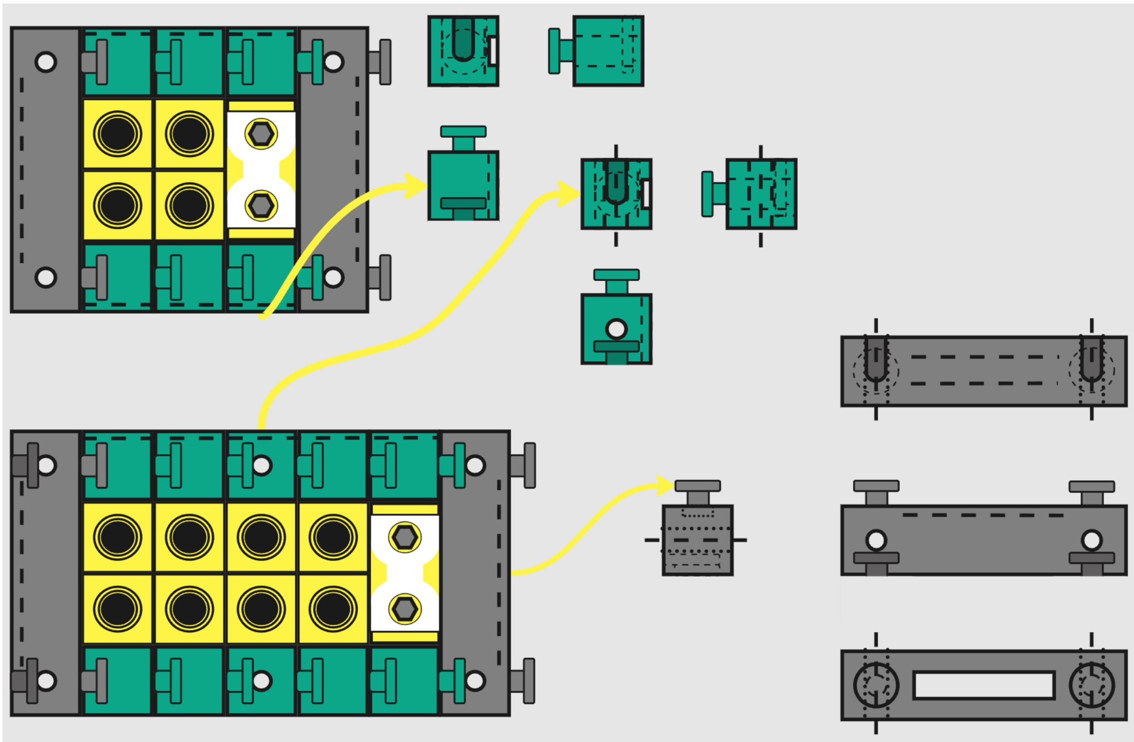


Figure 5.38: Concept 5:2 with new possible design

5.7.3.4 Concept 5:2 CAD-model

Concept 5:2 modeled in CAD can be viewed below in figures 5.39 and 5.40. The first image is shown with the feature of EMC capability not engaged. In the second image the metallic strips is instead turned to face inward which means that the EMC capabilities are engaged.

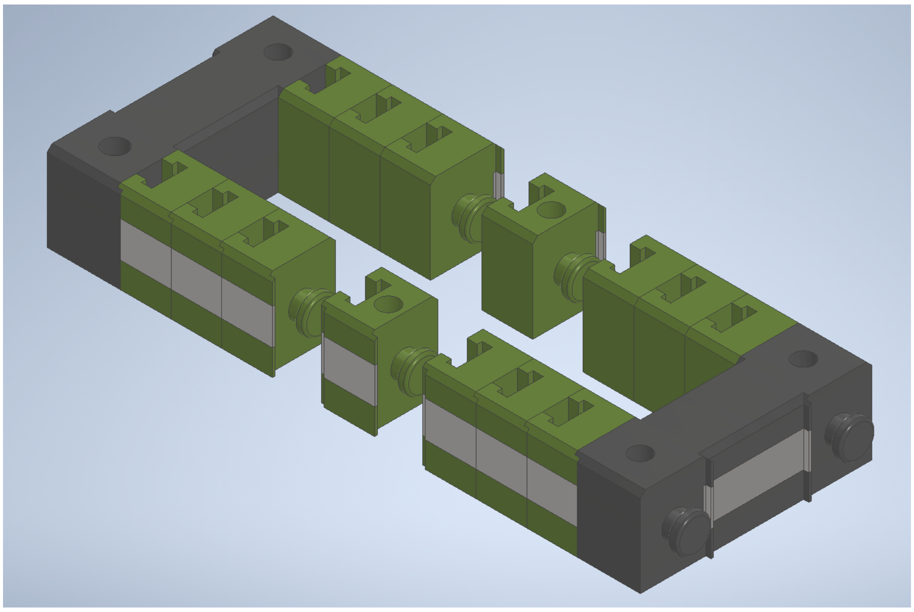


Figure 5.39: Concept 5:2 with the EMC feature not engaged

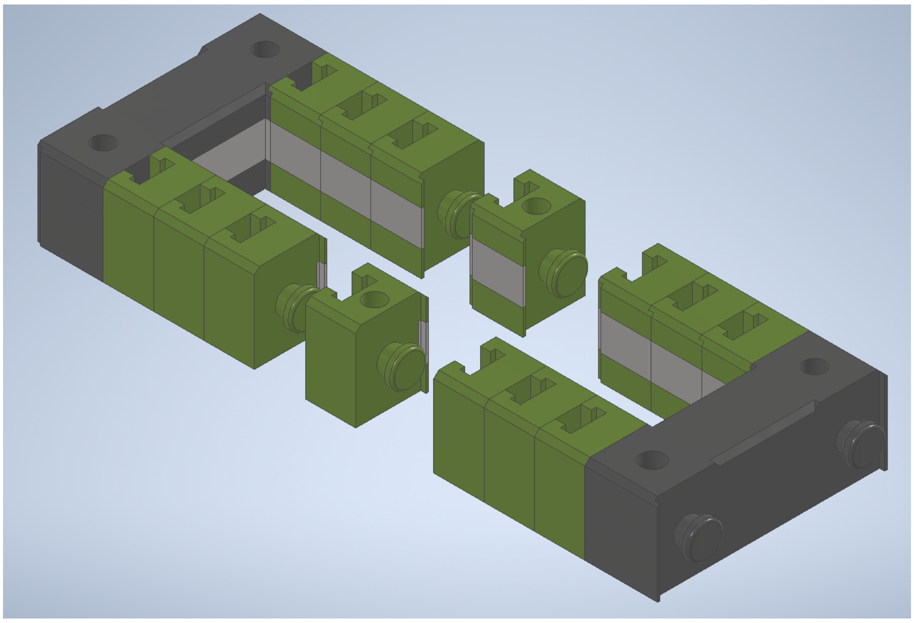


Figure 5.40: Concept 5:2 with the EMC feature engaged

5.8 Workshop and concept feedback 2

The six concepts that were chosen from the second brainstorm were put under evaluation by the same participants as workshop 1:2 and commented. The feedback covered possible issues and positives, but also questions regarding how certain features and functions were supposed to be solved or if some could be added. These are the final concepts that will only later on undergo refinements for improved functionality.

5.8.1 Workshop 2

The feedback was as earlier given in written form and can be viewed below in table 5.5.

Table 5.5: Pros and cons from workshop 2

No.	Comment
Concept 1:1	• Slide-able solution • What is the ration between the maximum and minimum dimension? • Can it slide open in the other axis as well? (Both height and width)
Concept 1:2	• A lot like 5:2 and 5:2 but with internal steering of end parts. Can it like the other suggestions act as compression screw or similar? • How is good contact and tightness between the different parts secured when the screw holes are pointed in another direction? • Possibility for grounding? • Suggestions for material?
Concept 3:1	• Maybe can be further developed for better integration of corner fasteners in the design • How is the support fastened in the middle? • Sealing in the corners is a potential issue. How is the fit and sealing between the long and short sides secured? • Material? Fabrication methods?

Concept 3:2	• Same comments as former concept • Corner fasteners are a substantial amount of material in proportion to the frame itself. Maybe they should be their own separate corner pieces that are complemented with additional building elements • Can the corner fasteners help with sealing the joint between the short and long sides? Can they create force in a direction that helps with sealing the frame when their are mounted in another?
Concept 5:1	• How are the blocks joined? Nothing stops them from being pulled apart when the frame is compressed • Are the pieces rolled over when grounding isn't wanted? • Seal between parts? Rubber surface, grease or self sealing plastic? • How is the frame compressed? If the parts are put together there are no range of motion or moving that can create compression. (If a separate compression module isn't used?) • Guaranteed contact between metal pieces has to be achieved
Concept 5:2	• Interesting idea for locking parts together. An obvious disadvantage of open cavities where water can accumulate. Can the same locking principle be achieved with a smooth top? • With some angles this should be able to be self locking and maybe sealing • Same question as previous concept - How is compression achieved? Could it be done without separate compression module?

5.9 Refinement of concepts 1

The concepts presented during the second workshop are refined or altered based on the feedback and commentary that was given, and tweaked depending on the pain points and possible features. The refinement was concluded with five different versions instead of six which was the amount of concepts that was presented in the last workshop. The reason for this is that concept 3:2 and 5:1 was deemed to difficult to fix or improve and subsequently removed. Concept 5:2 was treated with two different possible solution for the locking interface.

5.9.1 Concept 1

Concept 1 had more than one possible designs that survived the evaluation and by so this section includes two different concepts. The two design stems from different remarks and questions stated during workshops which were about the possibility to lengthen said frame in width and creating force inwards towards the modules and cables.

5.9.1.1 Concept 1:1

Concept 1:1, as seen in figure 5.41, with the possibility to adjust size in width and length.

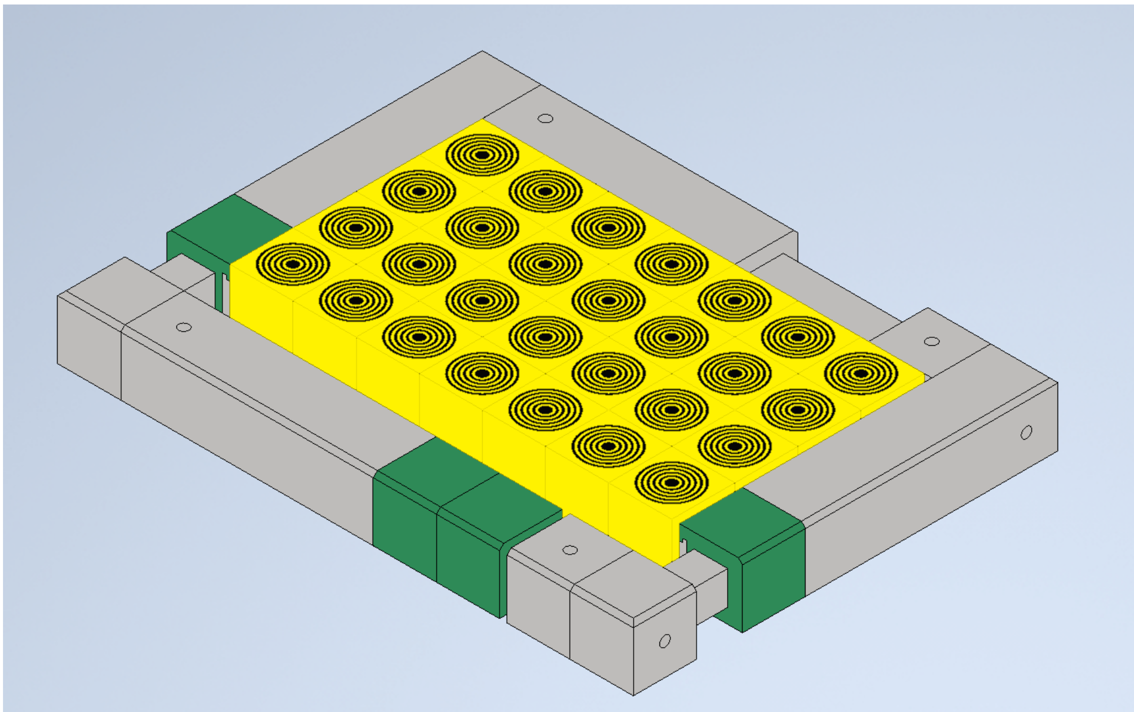


Figure 5.41: Refined concept 1:1

5.9.1.2 Concept 1:2

Concept 1:2, as seen in figure 5.42, with long screws to create force and compression in the frame.

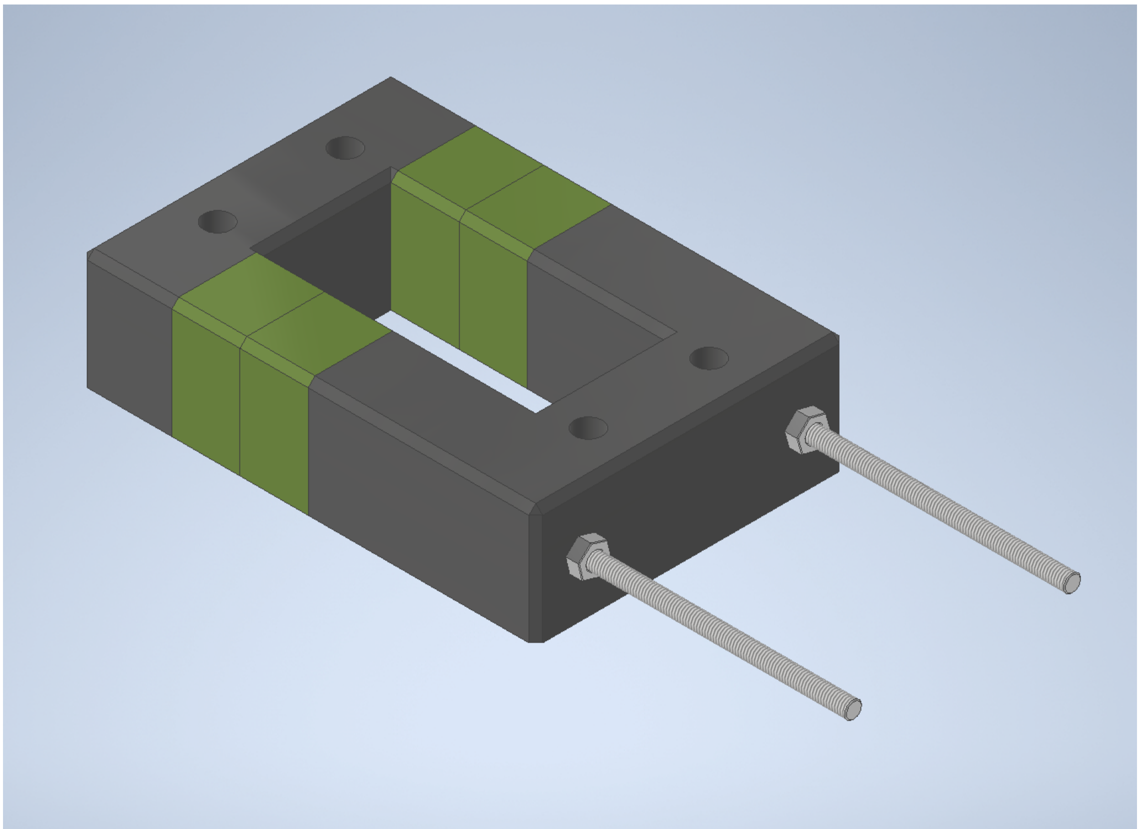


Figure 5.42: Refined concept 1:2

5.9.2 Concept 3:1

Refinement of concept 3:1, which can be seen below in figures 5.43 and 5.44. Corner fasteners are slimmed down and the supports installation is more defined.

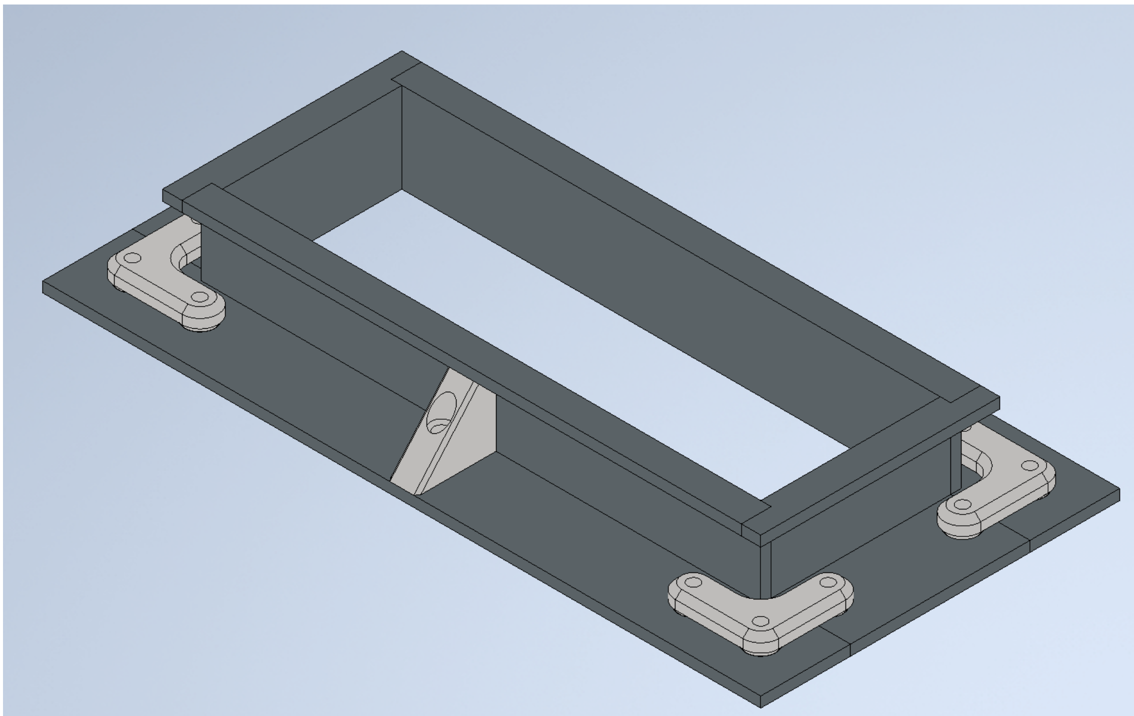


Figure 5.43: Idea of using L-profiles with corner fasteners to tighten and seal joints

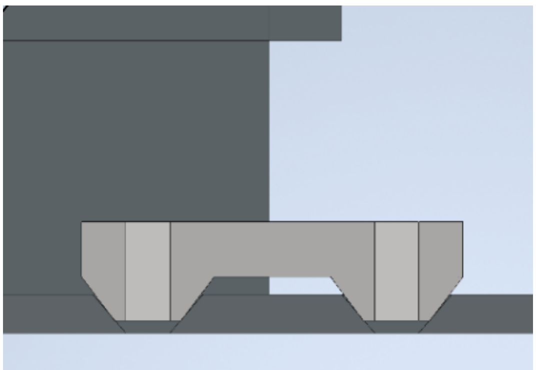


Figure 5.44: Detailed view of the corner fasteners function

5.9.3 Concept 5:2

Refinement of concept 5:2, which can be seen below in figures 5.45 and 5.46. The interfaces uses angles and geometries to lock the parts together, instead of merely friction based contact.

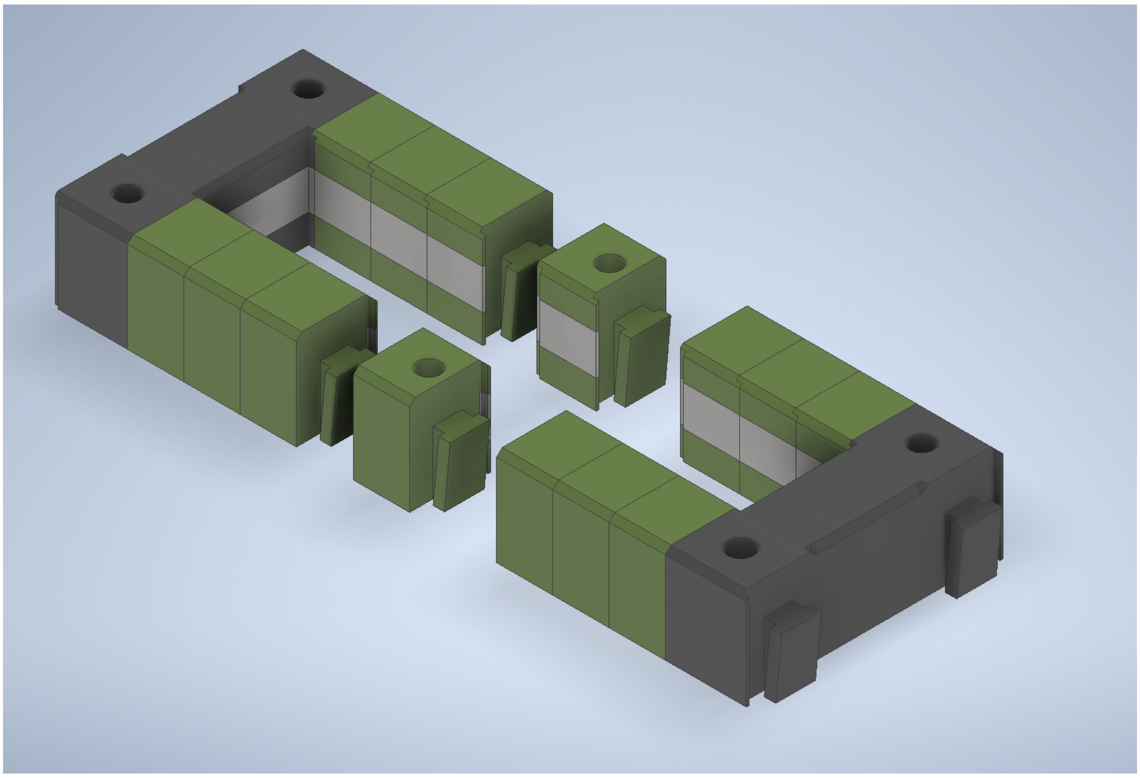


Figure 5.45: Idea of using angles for squeezing parts together

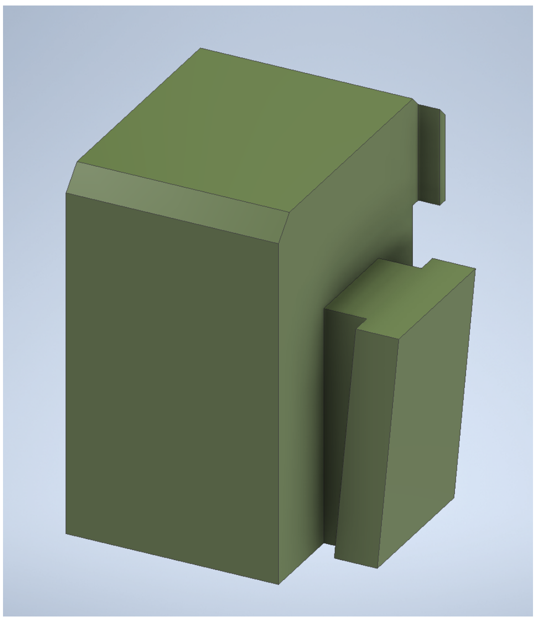


Figure 5.46: Detailed view of the angled solution

Another variant of concept 5:2 can be viewed below in figures 5.47 and 5.48. The interfaces in this variation uses a varying radius as its locking mechanism between the parts.

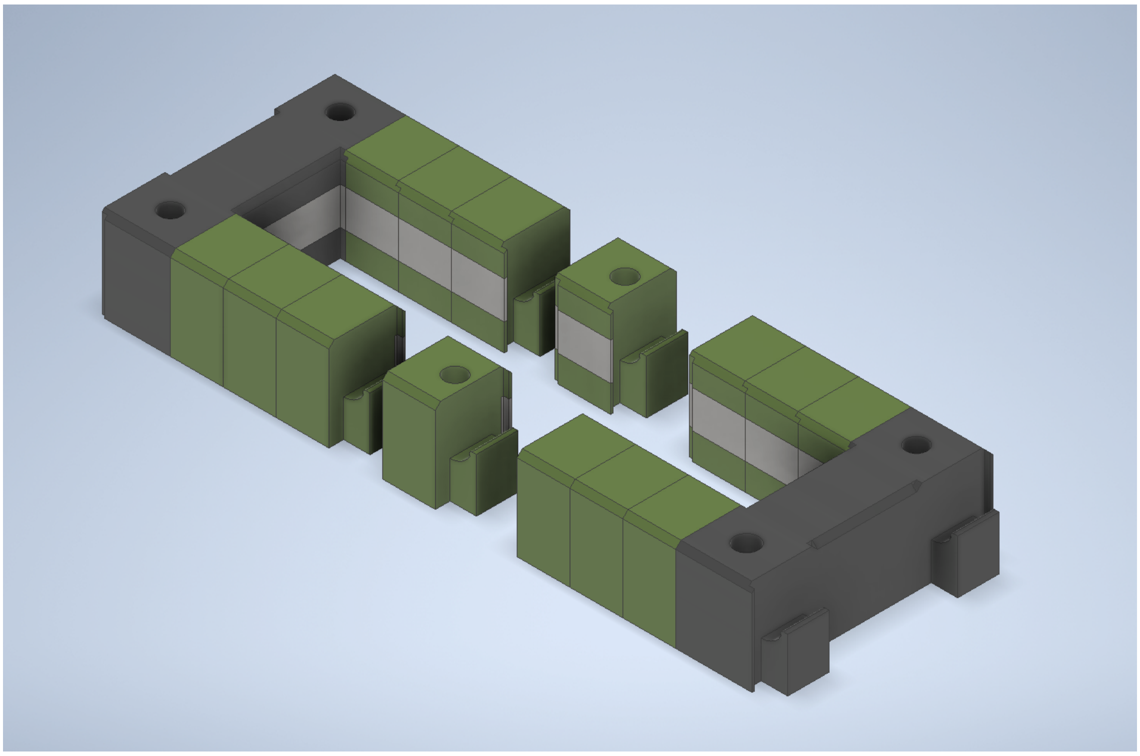


Figure 5.47: Idea of using a radius for providing an interface with haptic feedback and an audible click

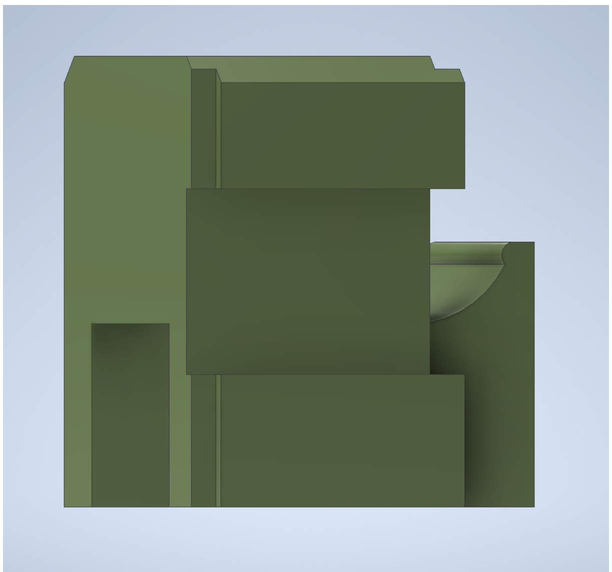


Figure 5.48: Detailed view of the clicking solution

5.10 Workshop and concept feedback 3

The five concepts that were left from the last workshop and refinement were put under evaluation by the the workshops participants, and commented. The given comments can be viewed below in table 5.6. The participants was given the choice to choose the concepts that were most to their liking due to personal preference but mainly what they thought to be the most viable options using their experience and expertise in the field of sealing cables. The selection resulted with three concepts to focus on and further refine which are 1:2, 5:2 and 3:1.

Table 5.6: Written feedback from workshop 3

Concept 1:2	• Why not have a minimum opening measurement of zero? This would require a smaller amount of unique parts • How is the parts steered to unsure a flat bottom?
Concept 3:1	• Potential issues in the corners when the frame is compressed • Bad visualisation of the corner fasteners sealing function • The most suited material choice is heavily controlled by temporary demands or customer needs, which makes the decision hard at this point
Concept 5:2	• There's nothing negative with a locking interface that needs some violence to be closed • The angled solution could be troubled when introducing vibrations • A simple and smooth clicking solution might not ensure a tight and sealing fit • The former comment about "guaranteed contact between metal pieces has to be achieved", does not eliminate the idea

5.11 Refinement and finalization of concepts

The concepts presented during the third workshop are refined or altered based on the feedback and commentary that was given, and tweaked depending on uncertainties that arose. The refinement was concluded with three different versions instead of four due to concept 5:2 being concluded with one locking interface. These will be the final version to be presented and wont have any major future changes. All three concepts were 3D-printed for the last meeting with the problem owner for a last opinion and evaluation. 3:1 is printed in a smaller scale than the CAD-model due to restricted print volumes. 5:2's parts isn't fully engaged to prevent any damages before showcasing the concepts a final time.

5.11.1 Concept 1:2

Refinement of concept 1:2, which can be viewed below in figures 5.49, 5.50 and 5.51. Concept 1:2 provides a possible minimum internal measurement equals zero, lesser amount of unique parts, lengthened side pieces for less points of failure and steering geometry for a guaranteed flat surface.

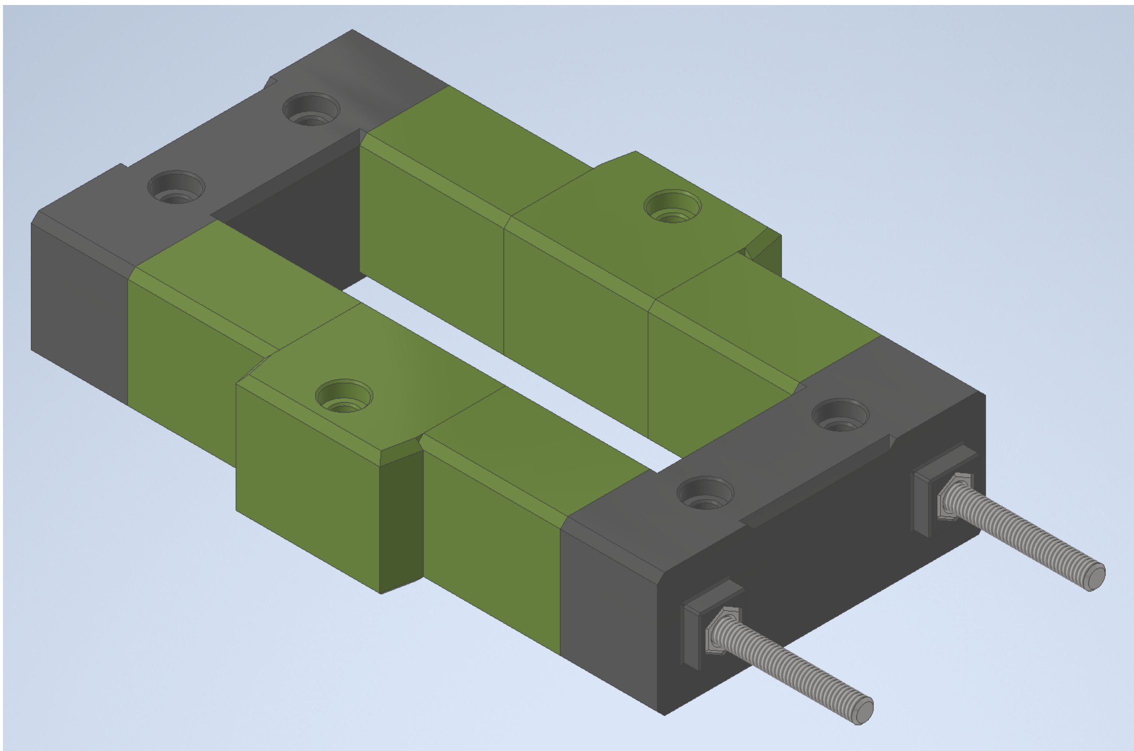


Figure 5.49: Final idea of how 1:2 could look like

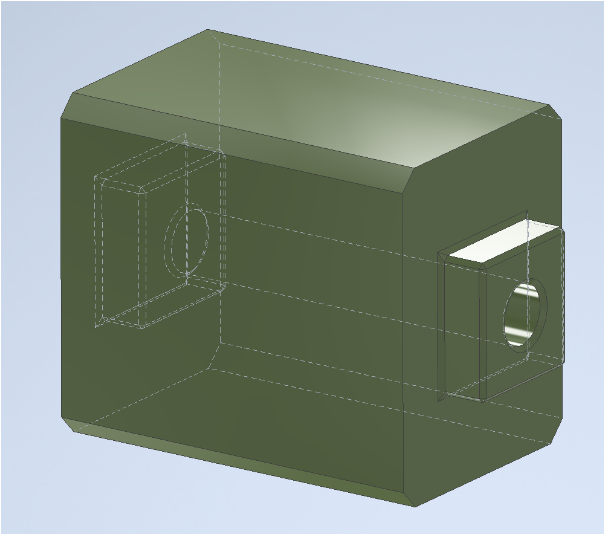


Figure 5.50: Detailed view of the steering geometry

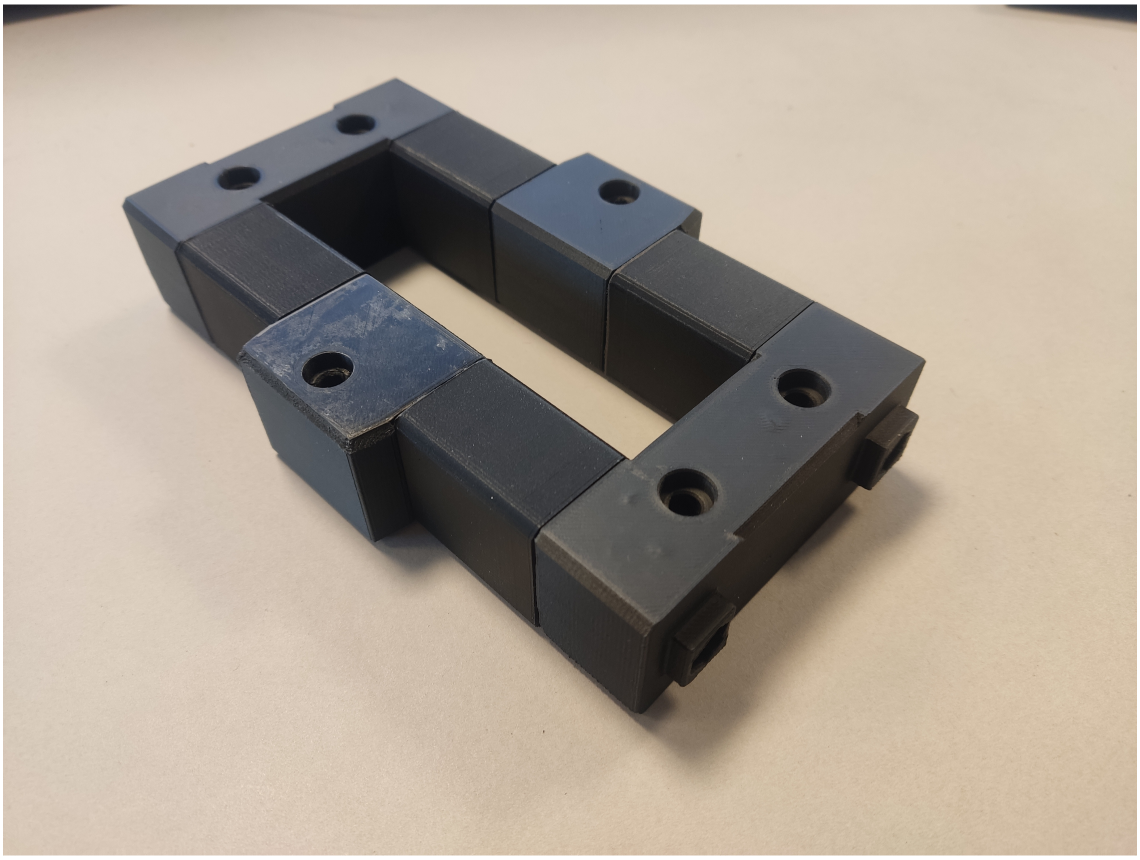


Figure 5.51: 3D-printed 1:2

5.11.2 Concept 3:1

Refinement of concept 3:1, which can be viewed below in figures 5.52, 5.53 and 5.54. The footprint of the L-profiles has been enlarged and walls thickened. The supports have been slimmed down for a better fit in tight spots and the function of the corner fasteners has been tweaked for better visualization.

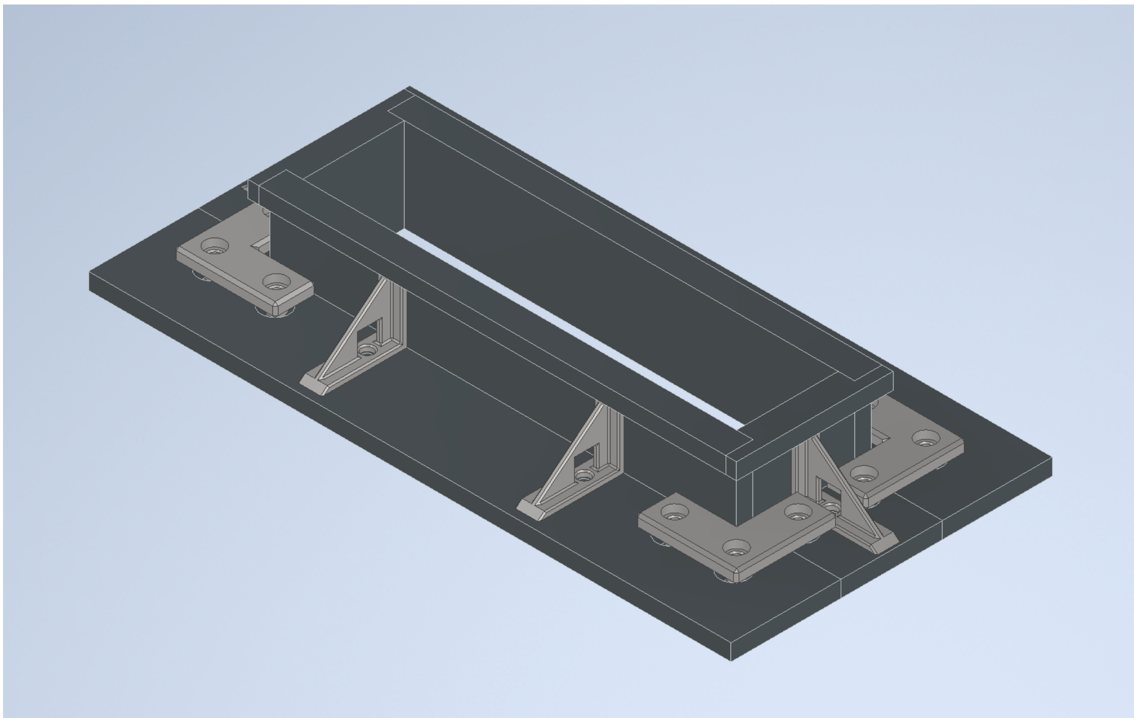


Figure 5.52: Final idea of how 3:1 could look like

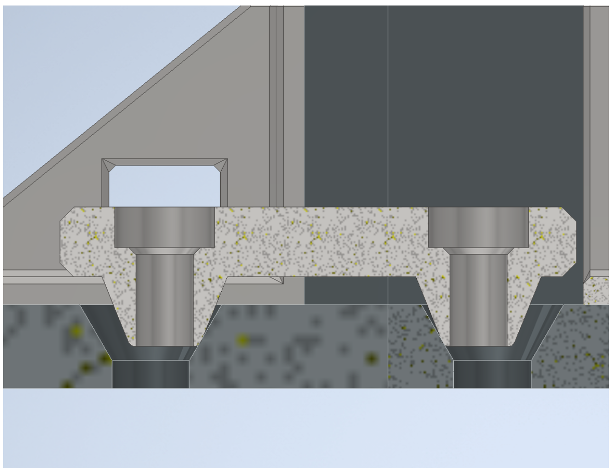


Figure 5.53: Detailed view of corner fasteners

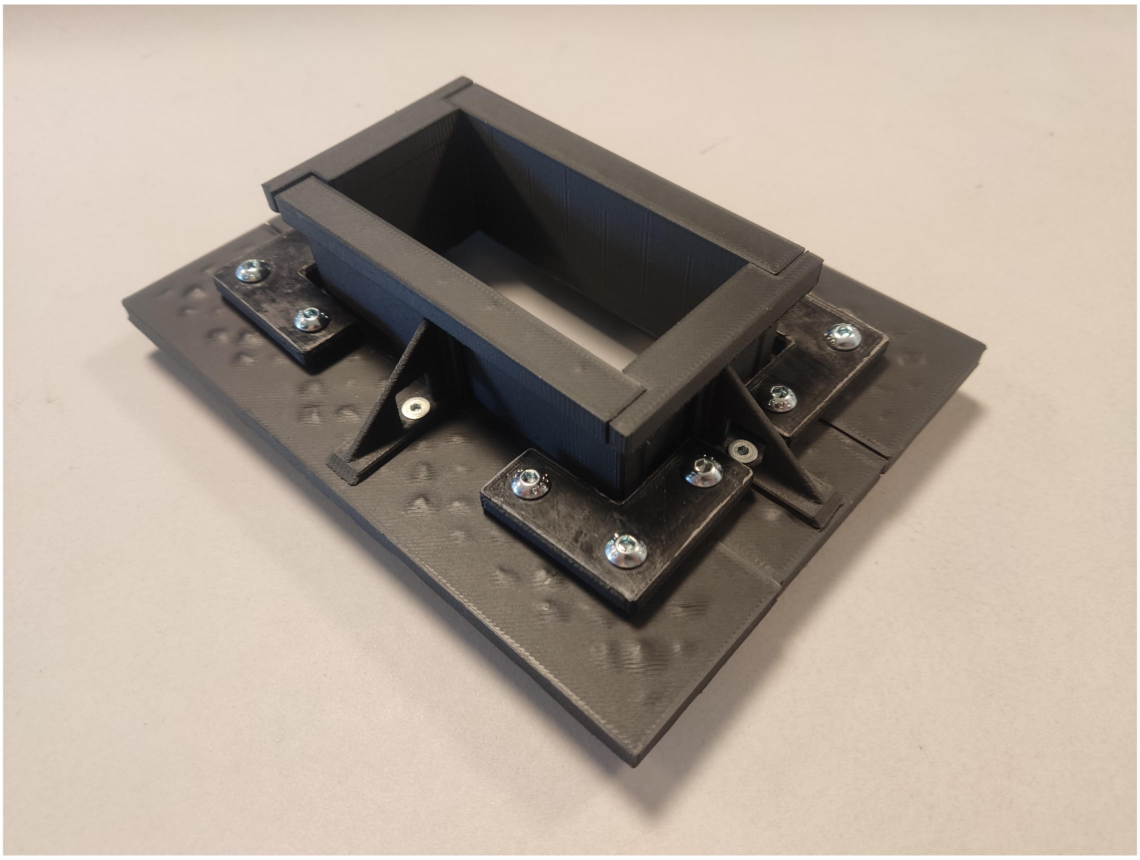


Figure 5.54: 3D-printed 3:1

5.11.3 Concept 5:2

Refinement of concept 5:2 which can be viewed below in figures 5.55, 5.56 and 5.57. The last two ideas of a locking interface has been merged. This is to prevent the parts sliding apart when vibrating and to guarantee a sealing fit. The fitting of the internal metal pieces has been simplified and does not have a defined solution at this point. The parts has also as 1:2 been lengthened for less chance of failure.

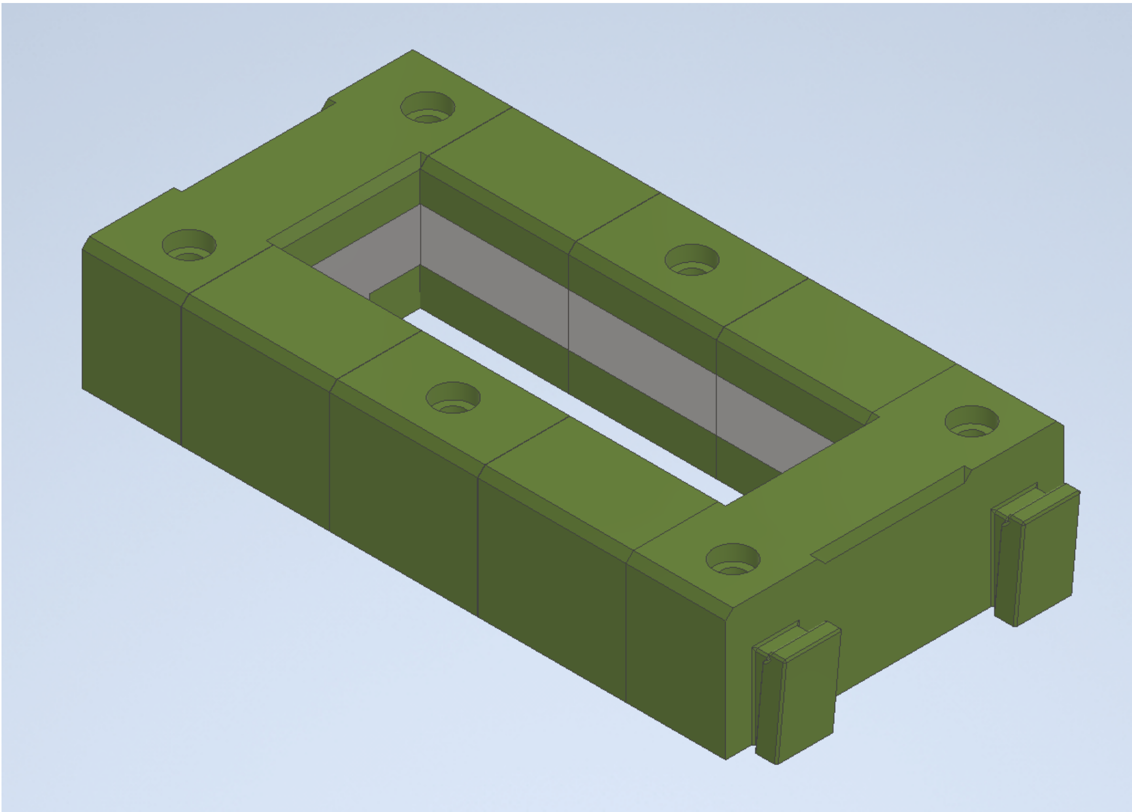


Figure 5.55: Final idea of how 5:2 could look like

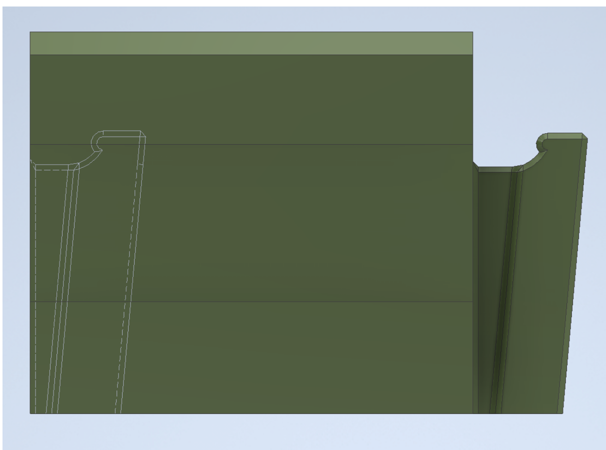


Figure 5.56: Detailed view of the interface

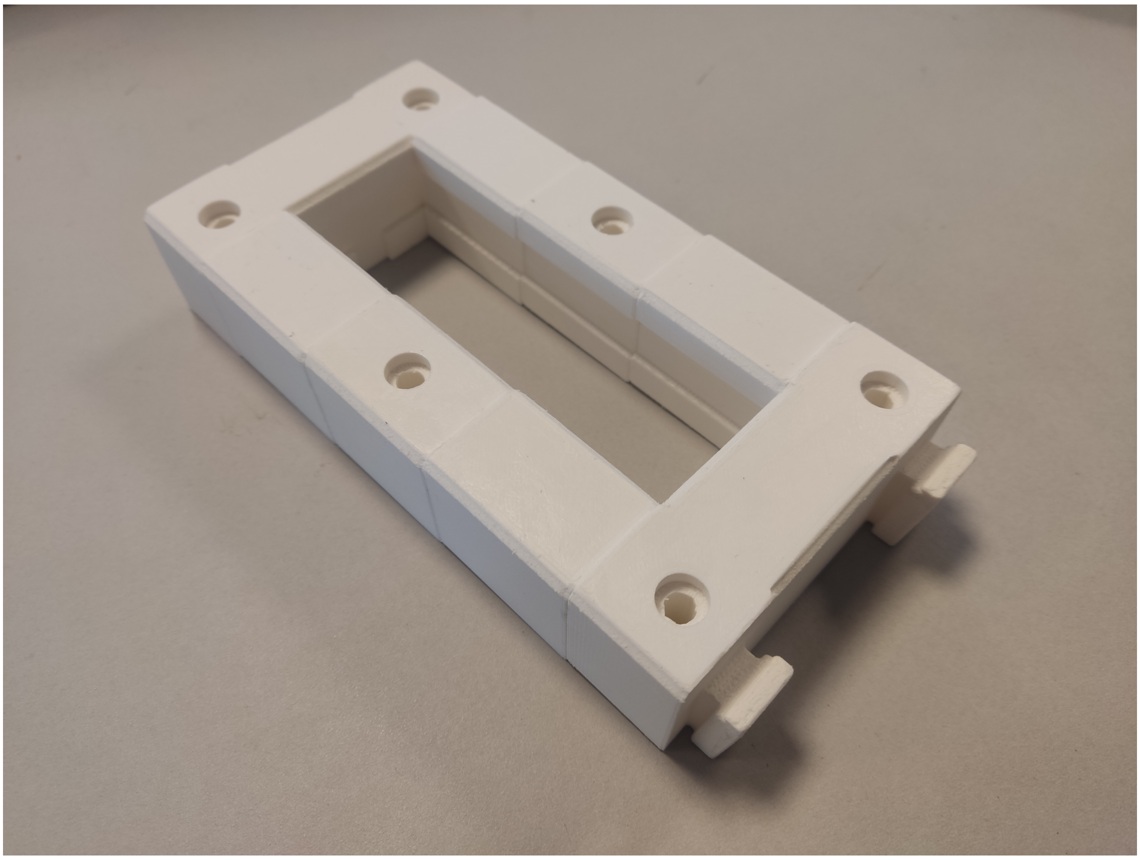


Figure 5.57: 3D-printed 5:2

5.12 Prototypes and IP-testing

1:2 and 5:2 were chosen for testing their ingress protection and are 3D-printed in a more professional environment with tools sufficient enough to produce testable products. The functional prototypes were made in a sturdier material and were given finer tolerances in comparison to the previous 3D-prints. The assembled prototypes 1:2 and 5:2, attached to a testing sheet can be viewed below in figure 5.58. Grease is applied on areas of contact between modules and frame for further leak proofing. The testing environment is on site at the problem owner and conducted by professionals with experience in the field of certifying similar products for a wide range of specifications. Below in figure 5.59 the prototypes can be seen being subjected to direct exposure to a water jet corresponding to a rating of IP-X5. Concept 3:1 was deemed too experimental and in need of further iterations to smooth out any uncertainties that might not be obvious. it is also not as suited to be 3D-printed as the other two concepts as those have a higher chance of achieving their goals when produced in plastic and have been constructed with building blocks in mind, allowing for a wider range of possible manufacturing methods. The resulting ratings with rules and details for the two tested prototypes can be viewed in table 5.7. The testing starts at IP-X4, with the reason being that a frame clearing a high rating is also deemed suited for the lower ratings.

Table 5.7: IP-ratings for concept 1:2 and 5:2.

Concept	**Rate**	**Effective against**	**Details**
1:2	IP-X5	Water projected by a nozzle (6.3 mm (0.25 in)) against enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes. Water volume: 12.5 litres per minute Pressure: 30 kPa (4.4 psi) at distance of 3 meters (9.8 ft)
5:2	IP-X4	Water splashing against the enclosure from any direction shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with no shield. Test a) is conducted for 10 minutes. b) is conducted (without shield) for 5 minutes minimum.	Oscillating tube: Test duration: 10 minutes, or spray nozzle.

The rating for concept 1:2 indicates that the frame with modules are safe to use in environments where directly aimed water jets might occur, while 5:2 has a smaller rating for environments that sees water splashes from a wider range of angles occurring. During the test for IP-X5 frame 5:2 started leaking in the corners inside the frame where the rubber modules has direct contact with the frame. Failing the IP-X5 test within the set time frame, but clearing the first test, IP-X4, puts 5:2 at the rating of IP-X4 as well the remaining ratings that is preceding. Frame 1:2 finished the IP-X5 test during the set time and moved on to be tested for IP-X6. However the modules themselves started leaking before set time was finished, placing 1:2 in IP-X5 and lower ratings.

Figure 5.58: Assembled functional prototypes of concepts 1:2 and 5:2 attached to testing sheet

Figure 5.59: Concepts 1:2 and 5:2 in the testing environment during IP-X5 test

Chapter 6

Discussion

6.1 Methodology

Initially, the planned course of action was to utilize tools and methods that had been created with the main goal of developing modular products. However, these are only functional if the reference products are within the same product family or share enough common parts or elements that can be shared between them. The problem as first stated was to create a modular product that could change its functionality or features depending on the use case of the end user, and that it was being based on the functionality of existing products. The concept of modularity, product development and the presence of existing products directly impacted the way in how information was searched as they would be the main topics. The results of this were the aforementioned tools and methods which later showed to be irrelevant for the real problem description. When investigating the problem more thoroughly it was concluded that the reference products that was going to be used came from three unrelated product families that shared zero commonality besides the main function of sealing cables and some properties regarding certification.

When evaluating the project based on the newly gathered information, a new plan started to be formulated. Instead of mainly relying on existing tools and methods for modular product development, the project steered more towards the use of backwards engineering, needfinding and general product development with brainstorming and quick conceptualization. Something that covers these processes and was readily available were the concept of Agile Product Development and this was deemed a good replacement for the modular product development. Both modular product development and agile product development includes the use of general needfinding and thorough research on the problem and products in question, but they are applied differently due to modular product development mainly being aimed at a certain set of products with common elements, while agile product development theoretically could be used in all cases of product development. Agile product development when created had software and digital products in mind, where as this case is purely physical, showing its versatility.

For proving the inadequacy of the modular product development concept for our selves, design structure matrices was done with all three products. One each individually A.19, A.21, A.20 and one larger matrix with all three products added A.18. This proved our suspicion and worries with clear evidence as can be seen in the large matrix, that none of the products share any elements. But what could be seen as shared between the reference products as aforementioned were built in properties controlled by certifications ordered by costumers. For example, fire resistance, grounding capabilities, rodent resistance, corrosion resistance and so forth. While some properties are stated for all three products there are some hidden capabilities that hasn't been stated for one or two products due to the lack of interest for these properties existing for the products in question. An example could be the tested and confirmed fire resistance for A.17. Even though A.16 isn't tested and by so certified for being resistant against fire, its construction and choice of material is in reality better suited for being used as a fire blockage. With this realisation the modularity that is to be developed shifted it's focus towards the properties and design choice of the products instead of commonly shared physical parts.

6.2 Workshops

The focus group present at the first workshop had a questionnaire shown to them. The questions asked the participants about their thoughts and reactions to the concepts in regards to their functionalities. The functions were based on the high-level requirements that was stated in the beginning of the project and were meant to help the participants to come up with constructive critique and point the open discussion towards the products main functions. However this limited the participants to think freely about the concepts and they instead relied on their experience and what they felt was safe. This was proven in the second workshop were the questionnaire was completely absent to prevent the participants thoughts and ideas being influenced by preconceptions and resulted with a significant higher number positive comments. The participants felt less restrictive and weren't as analytical and negative towards new ideas.

Other issues that came to light during the workshops, especially the first one, is that employees in professional settings has an unmotivated stance towards meetings and workshops that does not really concern their line of work. During the first workshop it was noted that more time needed to be set beforehand as discussions easily went over the initial time frame. Some members had last minute meetings booked during the time for the workshop resulting in participants leaving midway. Some mental notes was derived from this and added as experience for us as authors: **Lower you expectations**. Coordinating participants from different fields of knowledge and departments is troublesome, but good results can still be obtained with fewer participants than anticipated.

6.3 Stakeholders

In this case, the producer can be seen placed higher compared to the Customers. Mainly due to the modular aspect being an internal need and something the producer themselves wants to implement, and not something that has been asked for by clients. Financial loss and the risk of a cold reception by the market is something that the producer or developer has to bear themselves and take full accountability for. It can then be concluded, without any hesitation, that they are the most interested and influential entity closely tied to the project and end goal. The stakeholders that have been interviewed are engineers at the problem-owning company. The subcontractors for the product line and customers that are specifying the certifications that the product must conform to have not been interviewed due to the criteria and certificates being readily available by the engineers. The persons at the company in close contact with the product have asked to not be named in the report. The justification for not expanding the tools for mapping the stakeholders is that the project isn't bound to a plethora of actors and this doesn't demand the use of more sophisticated and refined methods to get a good result.

6.4 Product requirements

The product requirements were formulated by interviewing four individuals with different positions within the company that stated the original problem. An early meeting with the product owner also yielded initial requirements that the products that the company produces needs to fulfill. After analyzing the recordings and notes taken during the interviews an initial set of needs were formulated. The needs were then ranked based on their importance. What is meant by importance in this case depended on how frequent a certain need was brought up during the interviews and, if stated, how important the need was according to the interviewee. The needs were then reformulated into product requirements. The difference between a need and a product requirement is mainly that a product requirement is more clearly defined and in most cases measurable. An example of this is the need for the frame to be openable. The product requirement was formulated into "The modular product shall be able to be retrofitted". Another example could be the need for EMC correcting capabilities. EMC can relate to many things but in this case a grounding capability was the wanted and meant feature of EMC correction. The product requirement was hence formulated into "The modular product shall have grounding capabilities".

Of the needs related to the development of the modular frame that were stated, the ones that ranked the highest mostly related to keeping existing main functionalities such as adequate fire protection, grounding capabilities and having a seal that fulfilled a certain standard. Apart from these the only need that ranked as highly as the ones mentioned was the need for the frame to be openable and allow for retrofitting. This functionality was only present in one of the three reference frames given in the projects beginning. This need is particularly interesting since it is probably the most modular aspect of the products and addresses many of the main problems or needs associated with the existing products. Many of the existing products are installed once and comes in a specific size which is tailored to the size of the hole it covers. An openable frame allows the frame to be opened up after installation where easy rearrangement to cables passing through the frame can be made. Cables can still be arranged within the frames that are not openable through the use of a module that compresses the frame, but being retrofitable allows the frame to be installed around preexisting cables. Another problem associated with having the frame not be openable is that the final size correction of the frame is made early and far away from the point that it reaches the customer. This leads to wasted production time if the dimensions of the hole changes when production of a particular frame has already started and it turns out it does not fit. This makes the need of frames being openable also address the need of size correction closer to the customer.

The interviews utilized to uncover the needs followed a predeveloped template of questions developed by the team working on the project. The questions in the template were based on guesswork for what could be worth probing into and what the underlying problems might be that led to the decision of developing a modular frame. There is a high possibility that potential problems associated with going from an integrally designed frame to a modular frame have been overlooked as a cause of this. To circumvent this as best as possible, the four individuals that were interviewed had different areas of responsibilities and duties in relation to the three example products that were given as reference. This was deemed important since their different positions within the company could give unique insights and views from their respective areas of expertise. Should the views from these differently tasked individuals align in regards to, as an example, a particular functionality or need, it would be considered important.

The interviews utilized a semi-structured format in order to extract the needs of the modular product. The reason for utilizing the semi-structured format specifically, is due to a needed degree of flexibility. The team had, at the point of conducting the interviews, limited knowledge of the general product being developed. This entails that determining relevant and insightful questions proved difficult. What needed to be utilized to discover many of the central needs was the usage of probing. Probing enabled the aforementioned need for flexibility by elaborating on the existing questions, finding new ones and helped in clarifying what was more or less important [2].

The resulting product requirements that were created from the gathered needs were categorized in three different categories. These were function, performance and design requirements. Because of the scope of the project which stretches to the final stages of conceptualization and initial prototyping, only one category is certain to be considered during the design of the modular product. The category that will be considered is the function requirements. The reason for this being the only category being considered is due to a variety of factors. Firstly, the function requirements is the category that, in the stages that this project covers, is something that can be verifiable through planning the design of the product. Secondly, the function requirements all have corresponding needs that have been verified by various stakeholders that they are of actual importance to the modular product. Lastly, the other requirement categories covering performance and design, requires a testable prototype which will not be covered during´the project. This is due to the time constraint and scope of the project. To further elaborate on why the performance requirements are not considered during this project, an example could be the requirement addressing the maximum voltage the modular frame shall be able to handle. This would require an aforementioned testable prototype due to strict standards that have to be met. As for the design requirements, which mostly consist of maximum and minimum dimensions of the modular frame, will most likely not be considered since they are subject to change. The incorporation of the existing functions as well as the new functionality coming from the frame being modular is the prime focus of the project.

One of the requirements was that the products should not deviate from the current product catalogue in regards of chosen materials. The product owner has stated during interviews that environmental sustainability is something that's continuously being discussed and taken in consideration when developing new and old products. This is where the CAS material list comes into play as it is a way for confirm the composition of every material used, and by so being able to stay clear from those that might have a negative impact on the community surrounding the source, production personnel, customers and the nature as a whole. By limiting the possible choices of materials for the concepts, with the current product catalogue, also limits them from having a greater impact on sustainability, both socially and environmentally.

6.5 Resulting concepts

The resulting concepts are directly derived from the needs and problem statements that was unearthed during the interviews and workshops. The final three concepts vary greatly from the initial sketches with only some ideas or design choices surviving the length of the project. With that said, the concepts are far from finalized as some aspects has to go through testing to discern the best course of action. One example is the interface for concept 5:2 5.55 and the way the metal pieces are installed. Another obvious case of trial and error is concept 3:1 5.52 that was deemed to be too experimental for manufacturing it with IP-testing in mind.

As of now its the idea or the method needed for installing said frame, how it behaves and the overall function that is the concept and not a finalized product, meaning that it hopefully will act as a solid foundation for a future market ready product. Out of the preliminary and high-level requirements that was stated for the three reference products in the beginning of the project, having the ability to retrofit the frame around already drawn cables, the abandonment of expensive production methods, using cheap materials and relocation of last product refinement closer to customer, can be clearly seen in the final versions. The ideal concept would have been a solution that achieves all requirements successfully without any trade-offs, but this has shown to be extremely difficult and might be the main reason for ending up with three different concepts that achieves some requirements better than the other, instead of one single perfect product.

Concept 3:1 would be best suited for grounding capabilities as it is based on an idea of using extruded metal profiles for the main frame pieces, concept 1:2 5.49 would be the better option for a cheap frame that can be opened but at the same time more suited for production in metal than 5:2 as it doesn't require complex geometries for compression. Making 1:2 a better option if grounding and versatile dimension altering is a wanted aspect in the future.

5:2 houses the most intricate design of the three which limits the number of possible manufacturing methods and it's independence from a separate compression module, meaning that it could be a strong contender if retro fit and a lower price are the only wanted aspects stated by a customer.

When talking about modularity 3:1 is the weaker one of the three as the only modular part of it is the corner fasteners, it could be said that it is more standardized than modular. 1:2 and 5:2 have the versatility of having an interface and additional pieces with functionality that could be changed later down the line. As of now there's two different side pieces which can be seen in the figures, a normal lengthening piece and one "screw module" which houses additional screw holes for ensuring a sealed fit when the frame is lengthened. For example there could be a future case where a customer only needs to ground a specific number cables in the frame, then a half portion of 1:2 could be metal and the rest plastic. The statement made during workshop 2 5.5 for concept 5:1 about guaranteed contact between metal pieces proves that there's is an issue about having the functionality of grounding and a body that brakes into smaller parts. It could possibly be done but with a lower rated voltage during testing and usage, but having a frame that's modular and openable with functions that requires rigid bodies does not go hand in hand.

6.6 IP-testing of prototypes

The tested prototypes and their results was deemed good for being the first iteration of prototypes which can be called functional. But there was some issues that came to light during the installment and setting the test up. Concept 5:2 had some blocks that slid upwards one or two millimeters away from the testing sheet when tightening the screws. This could be mitigated with some added material and geometry that extends from one part to the other so that the parts don't separate when pressurized against the sheet. It was also noted that the tight tolerances, which are crucial for sealing and keeping the parts together, in the interface of concept 5:2 was not on par with the crude 3D-printed concepts 5.515.545.57. This is due to the geometries and measurements of the CAD-models being adjusted for the print quality and resolution of the 3D-printers that was at hand on campus, while the prototypes used a different printer and material. The design and functions of concept 1:2 allowed it to perform better due to the risk of parts separating being lower. But when comparing both prototypes to the reference products they don't perform as well. This is due to the designs, measurements, tolerances and choice of material not being entirely finalized and/or human error during the installation which could have had an affect on the prototypes integrity. In the case of concept 5:2, it started leaking in one of the corners where the inside of the frame has direct contact with the modules. This could be due to an insufficient amount of grease used during installation, or insufficient compression due to the parts sliding apart. Concept 1:2 started leaking withing the modules which might hint at compression being too low, as the leak didn't occur in areas of direct contact between frame and modules. This could possibly have been solved by tightening the screws a bit more. Compression inside the frame will also increase with real cables installed, as the frames were now tested with modules in their non-hollow base configuration. However, it's due to these kinds of findings and issues that are the motivation for further working on the concepts in the future before being considered ready for production. Future prototype iterations needs to be followed up with more IP-testing to ensure that the frames integrity has not been jeopardised when designs has been altered, or to confirm new wanted ratings.

6.7 Resulting guideline

The project wasn't without any turns or rocky segments. The plan that was sketched up before the project started got quickly scrapped as it was shown that the products presented as references did not meet the requirements needed for the tools and methods regarding modular product development to work. Another approach needed to be found which initially was general product development with needfinding and quick concept generation. Participatory action research came up as a possible candidate to use as a framework for the project, and it worked. Agile product development was also evaluated and seen as a good starting point as well. Regarding the guideline for future possible projects that has the goal of a modular product as output, these could make use of this thesis.

6.8 Reflection and utilization of related works

The use of Modular function deployment was mainly used through making the initial plan for the development and subsequently referred to as the plan changed when needed. This was due to the project, in it's early stages, being slightly undefined in terms of what the end goal would be. The methodology presented in the work provided a framework that was clearly defined and flexible which allowed the end goal to be formulated as development was ongoing. The reason for utilizing this work in particular is due to it being tailored to diverse product catalogues includes highly specific products, which the given reference products consisted of.

The work presented by *Øystein Eggen* addressing modular product architecture was mainly utilized during the formulation of the product requirements. One of the first things mentioned in the presented methodology for this was to set modularity as the first requirement [42]. Why this is relevant is due to the needs that where acquired early on mostly covered functionality that needed to be kept in the new modular product. While important, the end goal was to make a modular product which in turn had to be grounded in needs. With this realization the interviews changed going forward in order to uncover more needs pertaining to modularity for the new product. The cause and effect of this can be viewed in the preliminary list of requirements in comparison to the final product requirements.

Regarding the approach presented by *Baylis et al.*, it was mainly utilized when conducting the reverse engineering portion. The utilization of the presented method was halted when a DSM matrix for the three reference products was constructed A.18. The end goal of making the DSM was to determine a modularity score, which requires that at least some components are shared between the products that are being compared. Whilst setting up the DSM matrix it became clear that none of the components were shared between the reference products. This in turn subverted plans for utilizing a Pareto front to determine strategic modularity based on the reference products. The reason for this is due to the lack of standardized components between them, which to at least some degree is required to utilize a Pareto front. The reasoning as to why the utilization of a Pareto front and this work was considered, was that it seemed to be a suitable approach to modularization in the early stages of the development process. At this point the team was still unfamiliar with the products and the fact that no components were shared between them.

The Brownfield process (BFP) was introduced to the thesis during its later stages. What was utilized from the BFP was mainly what was explained during step 7, which addressed modular architecture. In short, it addresses how to define interfaces between the different components present in the modular product [32]. This was utilized when determining the final concepts 1:2 and 5:2 where constant changes where made to the interfaces between the frames throughout development. For an example, the rectangular steering protrusion came as a result of determining how the interfaces between the different parts would function in practice. This led to incorporating the steering geometry in order to better the interfaces between the different parts in terms of ease of assembly.

Chapter 7

Conclusions and Future Work

Concepts: A modular product can certainly be developed and produced, but not without some trade-offs. The resulting concepts needs to go through more iterations to be properly finalized and considered for manufacturing, which also were shown with the issues that came to light during IP-testing. The choice of most suitable material is heavily regulated by customer needs and temporary requirements, and can't be decided during a conceptual phase unless complexity of geometry is taken into account which can be seen in the case of concept 5:2 5.55. The three resulting concepts will work, with some changes and improvements, but most likely at a cost of the high specifications that the three reference products has.

Implementing modularity: When looking at the possibility of implementing modularity on existing products, it might work to implement the idea on a number of products or product families if they share enough common parts or elements. In this specific case, due to the complete absence of commonality, the results lead to three completely new modular products that were all based on the three existing reference products. Whether these will eventually be a part of product families or if they're acting as standalone products is not yet decided. However, the company has decided to continue development for seeing the potential of the concepts. Depending on how development continues there is a possibility that the three product families will converge into a unique new product family.

Guideline: Using preexisting tools and methods for modular product development are not ideal when dealing with highly specialized products that share low amounts of or no commonality at all. Even though they at first glance seem to be very much alike. An iterative process like agile product development and participatory action research showed to be the most suitable in a case like this were the product has to be continuously evaluated and reworked depending on input, requirements and overall feasibility. The results of this project, if subtracting all activities that did not add to the final product, was generated through the following steps:

1. Evaluate the products and their elements that is to be modularized e.g., reverse engineering tools, information gathering
2. Conduct needfinding research regarding the products by e.g., holding interviews, find openly available information on the internet
3. Evaluate the findings and highlight points of interest

4. Conduct benchmarking and trendwatching for inspiration on possible solutions
5. Generate concepts
6. Evaluate the concepts through workshop
7. Generate/refine the concepts
8. Redo step 6 and 7 until satisfactory results
9. Start prototyping and testing

Future work

- As mentioned in the discussion regarding testing of prototypes, all three concepts needs to go through more iterations and further IP-testing to smooth out issues that has occurred and might occur, as well for more detailed and defined design choices
- Interest from the market needs to be evaluated. The producer might see a value in modular products, but they wont be of value if their not sought after by the market
- Further testing on IP, grounding, fire, etc needs to be done for proper certifications and market placement. New products are compared to old ones when deciding prices and what kind of application should be aimed at

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Appendix A

Supplemental Information

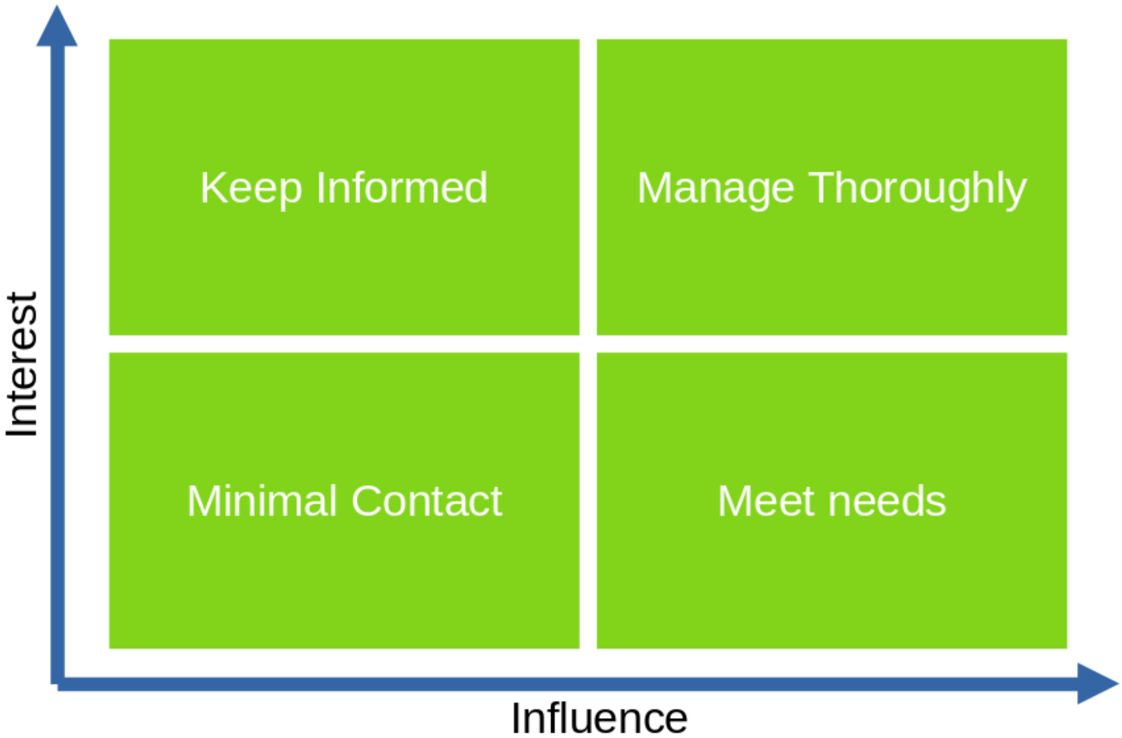

Figure A.1: Stakeholder map

Table A.1: Ranking of groups in stakeholder map example.

Rank	Group	Stakeholder
1	A	
2	B	
3	C	
4	D	

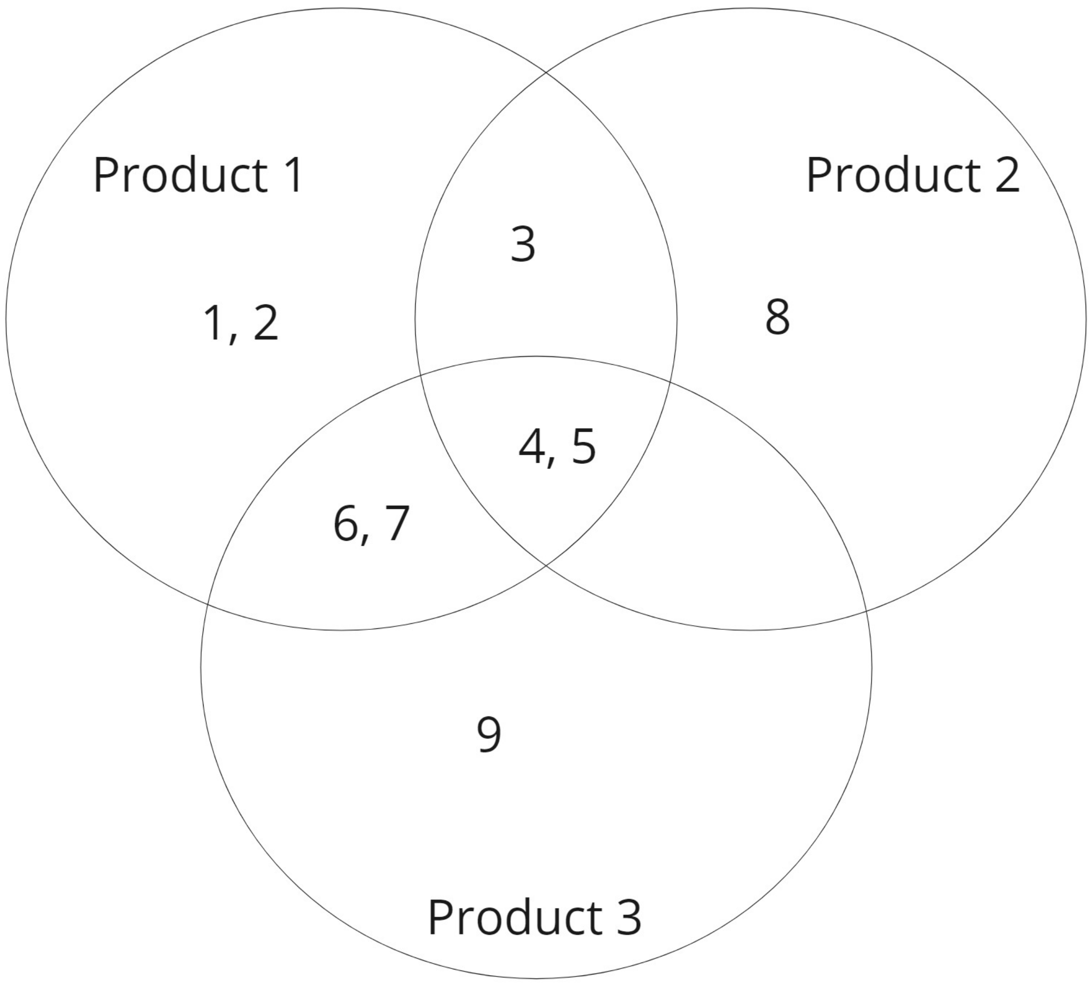

Figure A.2: Example on component cluster Venn diagram

	1	2	3	4	5	6	7
1			X				X
2	X			X		X	
3		X				X	
4		X	X				
5				X		X	
6	X						X
7	X		X		X		

Figure A.3: Example on design structure matrix

No.	name	Product 1	Product 2	Product 3	...
1	A	1	0	0	...
2	B	1	0	0	...
3	C	1	1	0	...
4	D	1	1	1	...
5	E	1	1	1	...
6	F	1	0	1	...
7	G	1	0	1	...
8	H	0	1	0	...
9	I	0	0	1	...
10	J	0	1	1	...
...	...	...	...	...	...

Figure A.4: Example on PCM

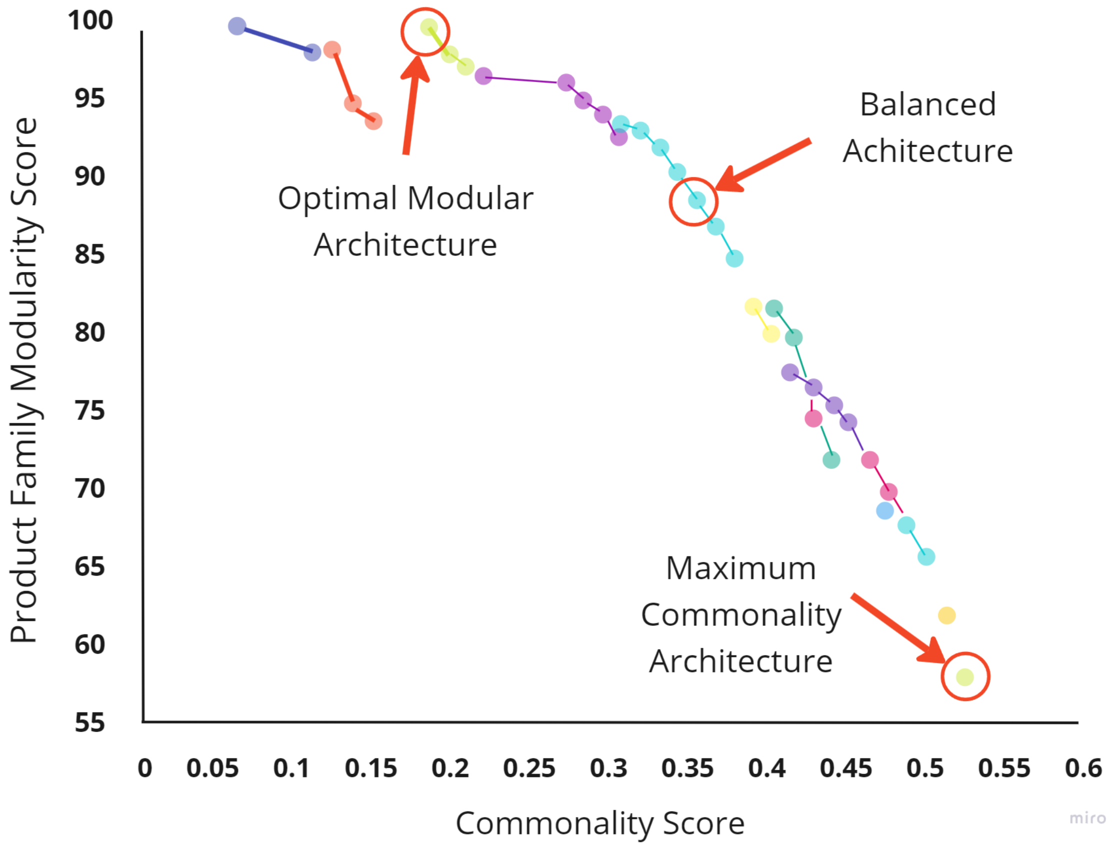

Figure A.5: Example on pareto front with maximum commonality and strategic modularity

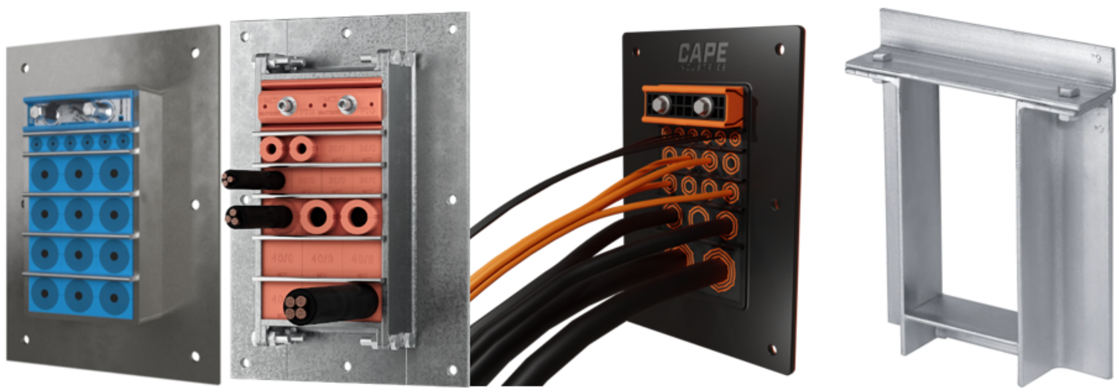

Figure A.6: Larger wall mounted frames from Roxtec, MCT Brattberg, Cape Industries and Hilti

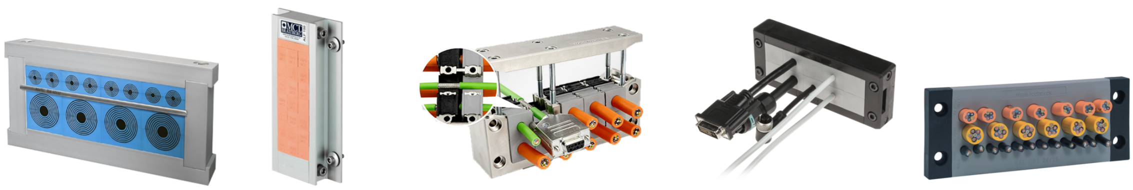

Figure A.7: Smaller wall mounted frames from Roxtec, MCT Brattberg, Icotek, Deltasutra and Icotec

Figure A.8: Large round multi-cable sealers from Roxtec and MCT Brattberg

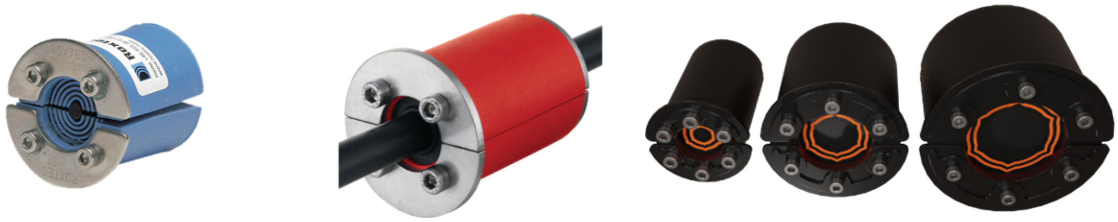

Figure A.9: Small round single cable sealers from Roxtec, Hilti and Cape Industries

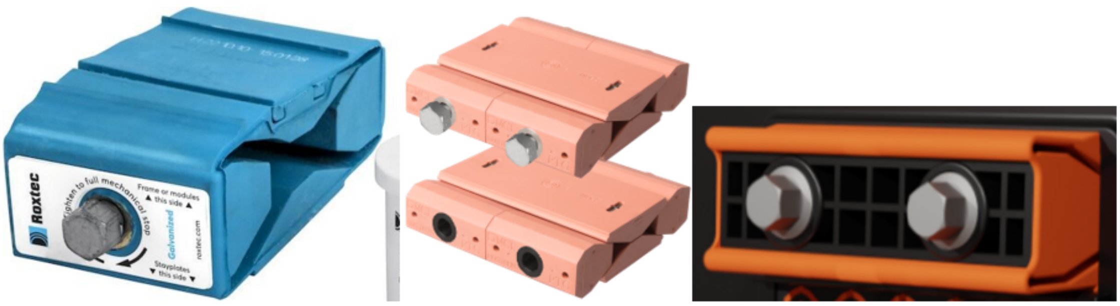

Figure A.10: Compression modules, *Wedges*, from Roxtec, MCT Brattberg and Cape Industries

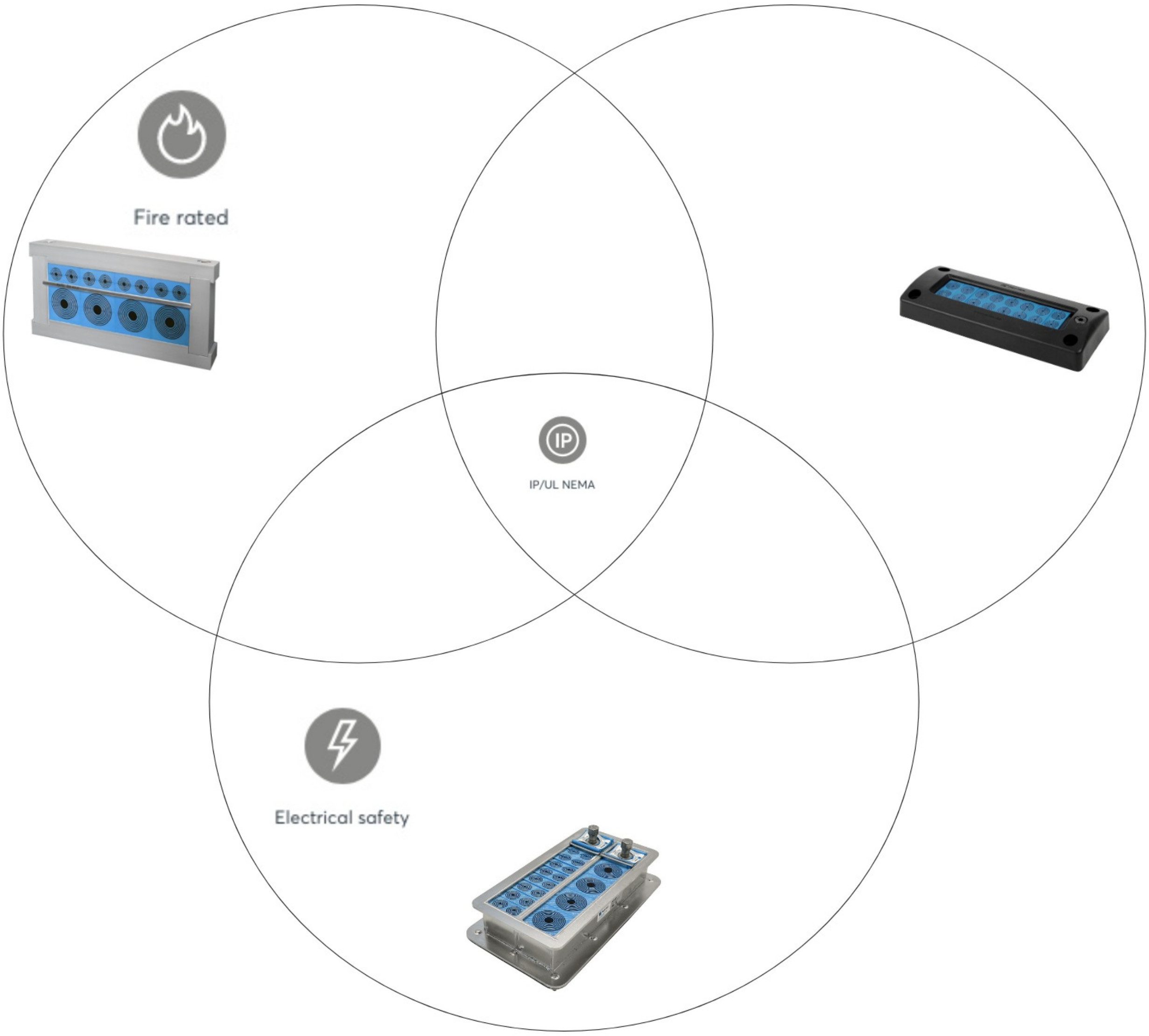

Figure A.11: Example on clustering of functions in relations with each other

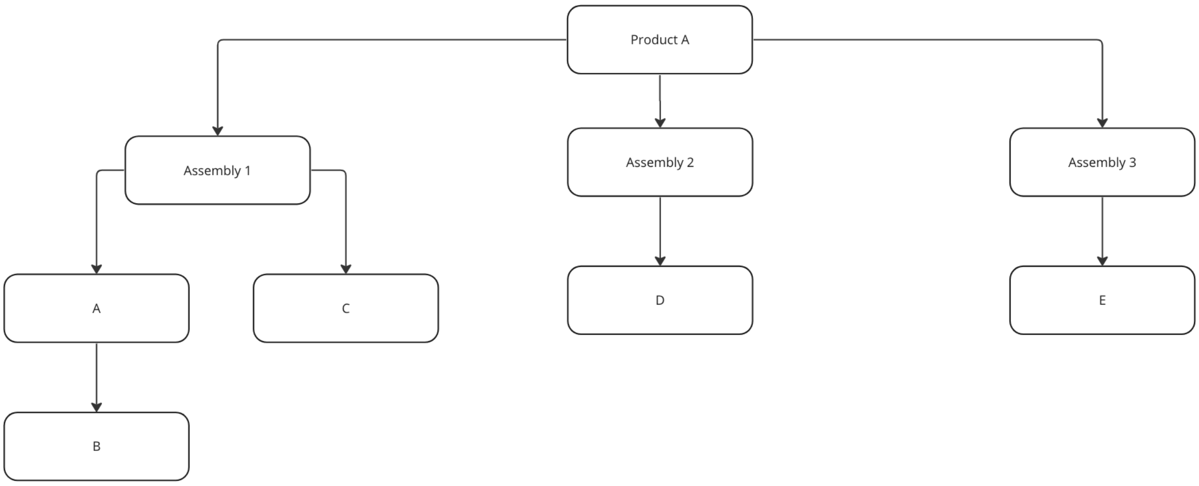

Figure A.12: Example on component clustering with relations mapped out

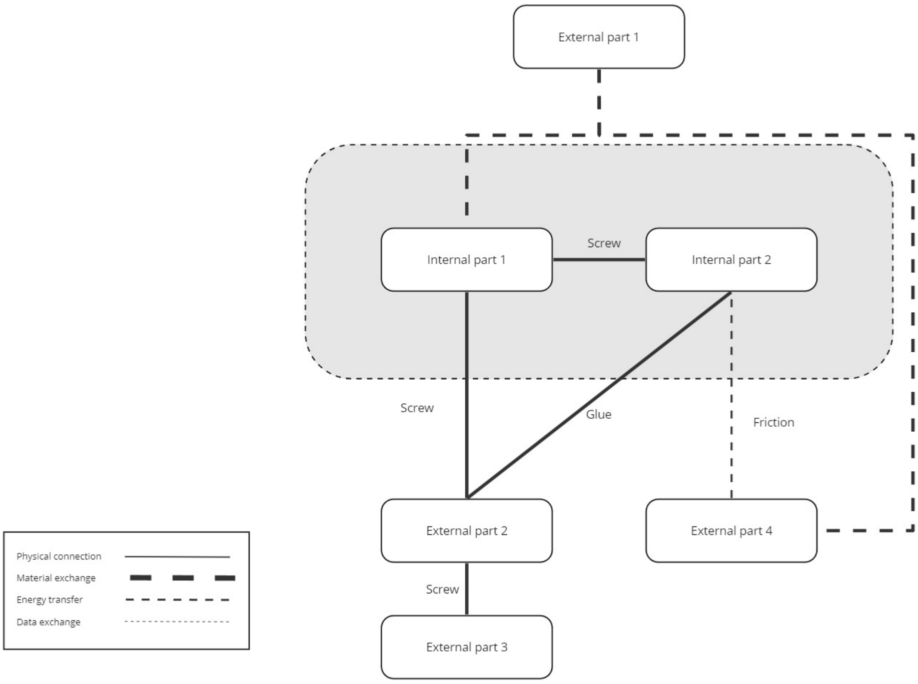

Figure A.13: Example on boundary block diagram

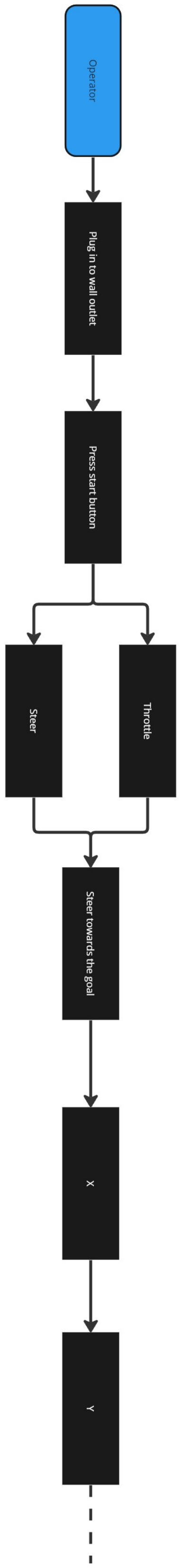

Figure A.14: Example on function flow block diagram

Figure A.15: Product A

Figure A.16: Product B

Figure A.17: Product C

Prod. A | Prod. B | Prod. C

	Solid frame A	Clamp A	Bolt 1 A	Bolt 2 A	Spacer A	Nut A	Frame part 1 B	Frame part 2 B	Bolt 1 B	Bolt 2 B	Spacer B	Gasket B	Stayplate B	Solid frame C	Nut C	Compression module C	Bolt C	Spacer slate C	Gasket C	Counter frame C	EMC Clamp C	EMC Slider C	EMC Screw C
Solid frame A		x	x	x	x	x																	
Clamp A	x																						
Bolt 1 A	x				x	x																	
Bolt 2 A	x																						
Spacer A			x																				
Nut A			x																				
Frame part 1 B								x	x														
Frame part 2 B							x		x	[illegible]													
Bolt 1 B							x	x															
Bolt 2 B							x	x			x												
Spacer B										x													
Gasket B							x	x															
Stayplate B							x	x	x														
Solid frame C															x				x	x	[illegible]	[illegible]	[illegible]
Nut C														x						x			
Compression module C														x			x	[illegible]					
Bolt C																x							
Spacer slate C														x		x							
Gasket C														x									
Counter frame C														x	x								
EMC Clamp C														x								x	x
EMC Slider C																							x
EMC Screw C														x							x	x	

Figure A.18: Group up DSM of all three reference products

No. 1	Solid frame	Clamp	Bolt 1	Bolt 2	Spacer	Nut
Solid frame		X	X	X	x	X
Clamp	x					
Bolt 1	x				X	X
Bolt 2	x					
Spacer			X			
Nut			X			

Figure A.19: DSM of Product A

No. 2	Frame part 1	Frame part 2	Bolt 1	Bolt 2	Spacer	Gasket	Stayeplate
Frame part 1		×	×				
Frame part 2	×		×				
Bolt 1	×	×					
Bolt 2	×	×			×		
Spacer				×			
Gasket	×	×					
Stayplate	×	×	×				

Figure A.20: DSM of Product C

No. 3	Solid frame	Nut	Compression module	Bolt	Spacer slate	Gasket	Counter frame	EMC Clamp	EMC Slider	EMC Screw
Solid frame		X				X	X	-	-	-
Nut	X						X			
Compression module	X			X	-					
Bolt			X							
Spacer slate	X		X							
Gasket	X									
Counter frame	X	X								
EMC Clamp	X								X	X
EMC Slider										X
EMC Screw	X							X	X	

Figure A.21: DSM of Product B

Table A.2: Interview template

Introduction	• Vi är från BTH och gör vårt examensarbete här hos er. • Vi intervjuar för att bygga en förståelse för vad som skulle vara av intresse för att modularisera era produkter. • Vad arbetar du med? • Får vi spela in?
Kick-off	• Har du någonsin byggt ihop en av dessa tre produkter? • Känner du till begreppet modulär/moduläritet? → Dra kamera exemplet
Build rapport	• Vilka funktioner och syften uppfyller dom tre produkterna? T.ex viktigaste funktionen. • Varför ser dom ut som dom gör? T.ex varför skiljer dimensionerna osv • Vad är anledningen till att den inte använder standard öppningen/ vad är en standard öppning? • Vad är det som gör att t.ex. produkt B inte är brandcertifierad? • Kan du beskriva processen för certifiering i.e den "sämsta produkten sätter standarden för alla andra" • Vad är huvudbehoven från kunderna som använder era produkter? • Vilka är huvudproblemen som kunder stöter på i nuläget i relation till era produkter?

Grand tour	• Finns det något/några problem med tillverkningen/designen av produkterna som du märkt av? • Finns det funktioner i produkterna som du tycker saknas? • Vilka problem har uppstått som motiverar en modulär produkt? • Varför blir det dyrt att ändra håldimensioner? Gäller det strikt efterarbete eller är det andra faktorer som påverkar? • Vad händer då kraven på produkten från kunden ändras nära inpå leverans/tillverkningsprocessen? • Finns det något särskilt som kunder har önskat angående ytterligare funktioner och design på era produkter?
Reflection	• Summera lite av vad som sagts. • Är det något du skulle vilja tillägga?

Faculty of Mechanical Engineering, Blekinge Institute of Technology, 371 79 Karlskrona, Sweden