CHALMERS
UNIVERSITY OF TECHNOLOGY

Development of Modul-Cover

A Scalable Storage System for Pickups

Master's Thesis in Product Development

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Cover: Rendering of Modul-Cover installed on a Volkswagen Amarok.

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Abstract

Pickup sales have increased over the last few years, gaining larger and larger market share within the light commercial vehicle segment. Pickup users often equip their cars with a storage solution for the bed. Reasons being mainly to protect stored items from weather and theft, but also to improve the appearance of the pickup. There are many different storage systems on the market, for instance foldable covers, hardcovers and hard tops. However, existing products lack effective storage utilization around the wheelhouses. Modul-System now sees the opportunity to explore the growing pickup market by introducing a storage system, including a hardcover and side compartments, which improves the utilization of the storage space around the wheelhouses. This thesis aims to develop such a storage system for the five best selling pickups in Europe.

3D-scans of pickup beds were used to evaluate different designs for the storage system. Benchmarking, customer need analysis and patent analysis were performed to ensure that desirable functions were included in the product. This resulted in a detailed design of a new storage system called Modul-Cover. Modul-Cover is equipped with four hatches and four side compartments which both provide easy access and improves the utilization of the space around the wheelhouses. Modul-Cover's scalable design, with only a few brand specific parts, enables it to be installed on the different pickup models.

Modul-Cover was evaluated by building a full-scale prototype. The prototype included the major functions and acted as a good representation of the intended design of Modul-Cover. While building the prototype, areas for improvements were discovered. In combination with physical testing and assembling the parts, evaluations of Modul-Cover were performed. The evaluations showed that Modul-Cover fulfills the majority of the requirements. The aim of this thesis is therefore considered fulfilled. It is concluded that Modul-Cover should be seen as a proof of concept and guide Modul-System in their development of products for the pickup truck segment. Therefore further detailed design, optimizations and improvements are necessary before a product launch.

Keywords: Modul-System, Pickup trucks, Hardcover, Storage, Modul-Cover.

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Richard Karlsson, Edvin Martinsson
Gothenburg, June 2019.

List of Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
AM	Additive Manufacturing
CAD	Computer Aided Design
CNC	Computer Numerical Control
LCV	Light Commercial Vehicle
MS	Modul-System
R&D	Research and Development
SLA	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
SWOT	Strengths Weaknesses Opportunities Threats
UV	Ultraviolet

Contents

List of Figures

List of Tables

1
Introduction

In this chapter the reader is provided with the necessary information regarding the master thesis. This includes the background to the initiation of the thesis, description of hardcovers, purpose, aim and delimitations. The chapter concludes with a brief overview of the report outline.

1.1 Background

In recent years, the sales of pickups have increased drastically in Europe. During the first four months of 2018 pickup sales increased by 8,4%. Even though the growth has stalled compared to previous years the market share among light commercial vehicles (LCV) has increased for pickups. During 2018 the total sales for LCVs decreased while the sales of pickups still increased. In total, approximately 180 000 midsized pickups were sold in Europe that year [1]. The increased sales and popularity of pickups in Europe has forced large car manufacturers like Mercedes to develop their own pickup to compete on the still growing market.

Pickups are often bought due to the all-wheel drive, the high towing capacity or the ability to store heavy equipment on the pickup bed. Compared to cargo vans they offer a more distinct, rough and impressive appearance while still offering up to four passenger seats [2]. In most cases, pickup buyers supplement the pickup by purchasing accessories which suits their specific cargo needs, such as hardcovers, foldable covers, hard tops or other solutions which protect the stored items from weather and theft. Depending on the intended usages, some owners equip their pickups with an extendable loading platform or boxes which helps to divide and organize stored items [3].

Modul-System is one of Europe's leading suppliers of storage equipment for light commercial vehicles. Their equipment is usually permanently installed inside vehicles, primarily panel vans. Due to the strong sales numbers for pickups on the European market, Modul-System sees the opportunity to expand their business by developing a storage system for pickups, consisting of a hardcover with side openings combined with storage compartments surrounding the wheelhouses. Parts of the idea comes from an earlier collaboration between Chalmers and Modul-System where a concept for a storage system for pickups was developed. Ideas from the concept combined with existing solutions on the market initiated this thesis.

1.2 General Description of Hardcovers

Due to the usage of pickups in outdoor environments, the bed of the truck is exposed to different sorts of precipitation and dirt as well as theft. Eliminating these problems is

the key to get a large volume where it is possible to store valuable equipment without worrying about them getting destroyed or stolen. A frequently used solution for these problems today is a so called hardcover (see Figure 1.1). The hardcover acts as a flat lid that covers the whole bed, protecting the bed from precipitation and dirt, which is placed on the sidewalls of the pickup. The protection from thieves is accomplished by equipping the hardcover with a locking system.

Figure 1.1: A competitor's hardcover installed on a Nissan Navara.

1.3 Purpose

The purpose of the thesis is to develop a scalable storage system for pickups which provides easy access while at the same time protects the storage compartment from theft and weather. The storage system includes a hardcover and supplementing storage compartments located on the left and right side of the pickup bed. Modul-System can by introducing this product expand their product offering to all light commercial vehicles which enable them to equip a company's entire vehicle fleet.

1.4 Aim

The aim of the thesis is to develop a scalable storage system that fits the five best selling pickups in Europe. Since the system is to be sold on the European market, applicable laws and regulations must be followed. Furthermore, the project aims to test and validate functions by building a full scale prototype mounted on a pickup. The storage system shall consist of a scalable hardcover based on Modul-System's sandwich material. The hardcover has to be weatherproof, theft proof, aesthetically appealing and be able to act as a loading area. The storage compartments surrounding the wheelhouses shall be easily accessed without the need for opening the entire hardcover. The system shall have a premium and robust design, meaning that add-ons such as lighting, electrical locking etc. are to be integrated and that the construction must withstand tough conditions. The system shall also be cost-effective by utilizing as few components and manufacturing processes as possible.

1.5 Delimitations

- The aim of the thesis is to develop a fully functional system, however, the prototype might not include all functionality.

- The major part of the thesis is to develop a hardcover which therefore limits the concept generation, development and benchmark to similar solutions. Thereby excluding other solutions for pickups such as hardtops, foldable covers etc.
- A stated requirement from Modul-System limits the concept development to only focus on a hardcover with side openings.
- The majority of the components in the products must be able to be produced in Modul-System's existing manufacturing facilities or by their suppliers, however, some standardized parts may be purchased from new suppliers.
- Due to the limited time and budget, a comprehensive patent analysis will not be conducted for all components. However, a more holistic patent analysis will be conducted for the whole system.
- The thesis will focus on the mechanical design of the hardcover, thus excluding detailed development of electrical systems, such as central locking, lights and other electrical equipment.

1.6 Report Outline

The report aims to provide an understanding of the different phases that have been carried out through this thesis. The report outline mainly follows the chronological order of a generic product development project. The report's chapters have been divided into three major parts; Background Information, Product Development and Product Assessment. An overview of these parts is presented in Figure 1.2.

BACKGROUND INFORMATION
This part aims to provide the reader with necessary background information needed to fully understand why decisions are taken and why certain methods are used.

Chapters:
2. Modul-System
3. Methods
4. Manufacturing and Material Principles

PRODUCT DEVELOPMENT
This part aims to provide the reader with the most important steps of the development process, starting with a user need identification and ending with detailed design and a protype of Modul-Cover.

Chapters:
5. Prestudy and Market Analysis
6. Concept Development
7. Detailed Design
8. Prototype

PRODUCT ASSESSMENT
This part aims to provide the reader with how well Modul-Cover fulfils the most important requirements and what is recommended to further develop for Modul-system. Ending with a concluding discussion regarding the product and thesis.

Chapters:
9. Evaluation of Modul-Cover
10. Further Development of Modul-Cover
11. Concluding Discussion

Figure 1.2: An overview of the report outline.

2
Modul-System

This chapter aims to provide the reader with an introduction to the company which this project is done in collaboration with. This is done in order to give the reader insight into the company history, organization, current product offerings, market and distribution channels, suppliers and manufacturing capabilities. This provides the reader with information that can be useful in understanding why some decisions were taken.

2.1 History

Modul-System HH AB is a world-leading producer of interior storage solutions for commercial vehicles, founded in 1970 [4]. In the beginning the products consisted of shop-tool racks adapted to fit into service cars. Over the years the focus expanded to include other types of vehicles and usage areas. From the 1970s to the 1990s the products were often customer driven, i.e. made uniquely to meet the customer's demand. Until 1998 the company and its product development efforts remained marginal. However, in 1998 the organization started growing more rapidly and in 1999 large change came through the release of a new product line. With more effort put into product development and more scientific approach to testing, the company became more professional [5]. The development of the company has been largely affected by its owners. Initially owned by three private persons, Modul-System was at the end of 1990 sold to an investment company. In 2002 the current owner, Lifco AB, bought Modul-System and have along with the acquisition expressed a long-term goal for Modul-System. Including, but not limited to, focus on profitability and long term growth. Modul-System should especially focus on innovation, quality, safety and environmental aspects of delivered products [4].

2.2 Organization

Modul-System has a large network of affiliated companies (Modul-System service centers) mostly located outside Sweden with responsibility for distribution, installation, and sales within their respective area. The central core of Modul-System is located in Sweden, where administration, marketing, production, and R&D are done. The majority of Modul-System's products are produced in their factory located in Mullsjö, with the addition of parts of the assortment being outsourced to other producers [4]. As with the production the majority of the R&D is done by Modul-System, with certain tasks being outsourced to partners [5]. The outsourcing enables them to utilize expertise and knowledge that they currently lack.

2.3 Product Offerings

Today the company is offering high-quality interior solutions for storing and organizing tools and equipment for service and delivery vans (see Figure 2.1). Modul-System's products are characterized by their modularity meaning that they offer a wide range of different modules with the possibility to be combined and configured to fit specific customer needs. Modul-System is also offering complete packages for several different models of different vehicle brands. Their products are also sold and used in other applications than vehicles, such as containers and workshops. Complementary products such as electrical systems, flooring, walls, and roof linings are also offered [4]. Modul-System currently strives to deliver high-quality products without need for maintenance, leading to a business model focusing on "one-time sales" [5].

Figure 2.1: Modul-System's products installed in a van [6].

2.4 Markets and Distribution Channels

Modul-System's products are sold in more than 50 countries worldwide, where the majority (95 percent) being sold in Europe. Only ten percent of the sales occur in Sweden meaning that export, logistics, and collaboration with partners are important. The products are provided to the customer through Modul-System service centers, local workshops, and partners where the products are installed. For instance, there is a large organization in the UK, which consists of 40-50 installation personnel and

about ten sellers. Modul-System largest market segment is companies using lightweight commercial vehicles in the utility and service sector [4]. Modul-System ambition is to grow in both new and already established markets, with an effort being made in gaining shares in the pickup truck market [5].

2.5 Suppliers and Manufacturing Capabilities

Modul-System has a broad network of various suppliers of pre-made components as well as raw material for the in-house production. The company has a balance between the outsourced components and in-house component production to enable flexibility and control. Modul-System has partnerships with firms for raw material, semi-finished products and R&D. The partnerships are not exclusively for components and materials and Modul-System has partnered with car dealers across Europe to collaborate in installing their products as per customer needs [4].

Modul-System has a production plant in Mullsjö, outside the city of Jönköping in Sweden. There the in-house production of components and the assembly of the module units are produced and shipped to service centers for final installation [4]. The Mullsjö plant has been divided into different working stations, mainly cutting, welding, punching, bending, painting and assembly. Many of the working stations are automated with partial need of humans. Most of the human effort is used in assembly area which helps to visually inspect the end product before shipment to the service centers. A lot of parts in the in-house production is first punched (see Figure 2.2), bent and then powder-coated to achieve the desired geometry and finish. Another trademark for Modul-System is their customized flooring which is milled in a CNC-router machine (see Figure 2.3) for a precise fit. These combined capabilities, while focusing on their strengths and outsourcing less strong areas, enable great flexibility and capacity for Modul-System to deliver modular and high quality products.

Figure 2.2: Punching machine at Modul-System's plant in Mullsjö.

Figure 2.3: Milling machine at Modul-System's plant in Mullsjö.

3
Methods

Several methods have been used in this thesis to support the development of Modul-Cover. Some methods have been continuously iterated throughout the development of Modul-Cover. This chapter includes a theoretical overview of all relevant methods applied throughout the project.

3.1 Survey

In smaller projects where time and resources are scarce, it might be impossible to perform physical on-site surveys. Instead, web-based surveys act as a great alternative. This allows for faster and less expensive information gathering. A survey performed online also has the advantage to be able to cover a large geographical area. When designing a survey performed online one should consider how the questionnaire is designed. A great effort must be made to ensure that questions are not misunderstood and that there are no uncertainties for the respondent. Who will answer plays an important role in predicting how the questions will be interpreted. After the questionnaire is done it must be distributed to the right target group. Lastly, the data need to be collected and analyzed [7].

3.2 Interviews

A Semi-structured interview consists of a prepared, but quite open, framework of relevant topics. The majority of the questions are improvised and there is often a follow-up question on the answers from the interviewed person. This allows for greater flexibility by digging deeper into desired details. A less strictly structured interview results in a more free conversation, which open up more possibilities to discuss the most relevant topics. A semi-structured interview also allows the interviewed person to express their thought in their own words as well as asking questions to the interviewer. This creates a two-way communication that can enhance the quality of the interview [8].

3.3 Scanning

The 3D-Scanner used in this thesis is the ATOS Triple Scan. The scanner utilizes a blue light technology as the projection unit. This enables the scanner to perform the measuring independently of the surrounding light as well as shorten the measuring time. The scanner projects a fringe pattern on the scanned object's surface while two cameras are recording it. The technique gives an accurate measurement of blank and complex geometries. The data is directly imported to the software GOM Inspect, where the measuring points are visualized. The scanning process runs until the user is satisfied with the created measure points [9].

3.4 Patent

A patent is a document that describes a new way of accomplishing something, which can either be a product or process. The patent provides the owner with an exclusive right to utilize it and to decide whether others can exploit it or not. However, the patent is only valid in the country or region that it has been filed in. It is possible to have a granted patent in more than one region simultaneously. An inventor's exclusive right does not apply forever, the general time is 20 years from the filing date. The exchange for the exclusive right is that all technical information regarding the innovation must be revealed and posted public. This in order to foster technical innovation [10]. Useful information can be found by studying these patents, what they include and how these inventions solve certain problems. Patent analysis can help to find development trends, areas which lacks patents, or be used for analyzing competitors products [11].

3.5 Benchmarking

Benchmarking is a method that aims to identify existing solutions that satisfy the users' needs and evaluates how well they fulfil the chosen criterion. This is done by comparing different competitors' products or processes in the same or other industries. The method's purpose is to explore good solutions and gain inspiration among others problem solving, both within and outside the specific problem area. It is important to have a clear understanding of the problem before the comparison can be performed, in order to not get stuck in the existing solutions [12].

3.6 SWOT Analysis

SWOT is a structured method for evaluating different factors that could affect the outcome of a certain project. The method helps to identify internal and external factors that potentially could affect the result of the project positively or negatively. Internal factors consist of strengths and weaknesses within the company, including factors such as manufacturing capabilities, knowledge, financial strength, selling channels, patents etc. While external factors consist of opportunities and threats, including factors such as market trends, competitors products and position, upcoming regulations, technology advancement etc. [13]. Using the method for evaluating the company's current position and abilities related to the project can therefore further improve the outcome of the project by highlighting areas which are often missed [14].

3.7 Requirements Specification

The requirements specification document acts as a guideline when developing new products. Requirements in the document are the voice of the customer that has been translated into engineering terms which describe what the product is intended to do. The creation of the document starts with establishing target specifications derived from the customer needs in the market study. This is done before the concepts are generated which means that the fulfillment of the requirements depend on which details the development team decides on. This means that the target specification acts more like goals that describe a product which the development team believes is a successful one.

The requirements specification is later updated with a final specification when there is a final concept. Making the final specification includes hard trade-offs concerning desirable characteristics of the product [15].

3.8 Experimental Testing

In the early stages of product development, testing of models or its included parts can act as guidance for the development. This is especially important when there is a high technical risk, meaning that it is uncertain if a key function can be achieved by a part or a system. The generic product development process of testing prototypes late in the development phase is therefore adopted. To deal with the risk, smaller prototypes and tests are conducted earlier in the process to ensure that key functions and performance parameters are met, called experimental testing [15].

3.9 Functional Decomposition

A commonly used method for functional decomposition is the Function Means Tree, which is a hierarchical top-down approach with the product's main function in the top, followed by its underlying sub-functions. Under each function and sub-function there are presented means of how the functions can be achieved. The means are often generic due to lack of knowledge in early stages and to avoid loss of better solutions. The method act as a visual aid to understand the different functions as well as identify unforeseen functions. It also works as a aid to map the product's different requirements to a specific component and to visualize the interactions between the functions [16].

3.10 Brainstorming

Brainstorming is a creative method that inspires and stimulates the thinking process in order to quickly generate different solutions to a problem. It can improve the understanding of various problems and unlock mental barriers. In the process, it is important to avoid negative criticism. The focus should be to get a large range of possible solutions. The brainstorming sessions can either be conducted individually or in groups that preferably should include people with different backgrounds [12].

3.11 Morphological Matrix

A Morphological Matrix is a systematic tool to generate a large amount of concepts in a short time. The columns of the matrix consist of the product's different sub-functions, while the rows consist of respective solutions for each sub-function that have been prior generated. New complete concepts are then generated by combining the different sub-solutions. Because of the large amount of possible combinations it is necessary to only generate concepts that fulfill all requirements and are physically feasible [16].

3.12 Pugh Matrix

The Pugh Matrix is used for deciding, based on a number of criteria, how several different concepts perform compared to a defined reference. The reference could either be an existing product on the market or one of the concepts. In comparison with the reference, the concepts are given a '+', '-' or '0' based on how well they fulfil the criteria. If a concept is considered better than the reference it receives a '+', whereas a '-' is assigned to concepts that are considered worse than the reference. The '0' indicate that there is no distinguishable difference between the evaluated concept and the reference. The final result of the Pugh Matrix is obtained by calculating the sum of all the '+', '-' and '0'. The matrix is iterated several times and the reference concept is changed each iteration. In some cases a weighted matrix is used, which means that the criteria are weighted according to how important they are compared to each other [16].

3.13 Kesselring Matrix

The Kesselring Matrix is a method for making the final evaluation of the remaining concepts. The difference between the Kesselring Matrix and the Pugh Matrix is that the criteria are scored in the Kesselring matrix. The Kesselring support an assessment of how well each concept fulfills a given criterion on a five or ten-degree scale, where a lower score indicates that the concept fulfill the criterion worse than a concept with a higher score. The weighting is then multiplied by the score on how well the criterion is met and then summed up to obtain a final score for each concept. The summed up score can then be compared to other concepts. The concept with the highest score fulfills the criteria in general better than the other. The method can also be used to find improvement areas for the concepts [16].

3.14 Computer-Aided Design

CAD is a software for engineers, architects and designers used to model and simulate concepts and ideas. The concepts can be visualized either in 2D or 3D and with desired materials. CAD-modeling is used instead of hand-drawn drawings to gather data of a concept before it will be manufactured. With CAD-models it is possible to, in a digital environment, simulate how well a concept would perform in reality [17].

3.15 Prototyping

A prototype can be defined as "an approximation of the product along one or more dimensions of interest" and they can either be physical or analytical. Thus, a prototype can either be sketches, simulations, or a full preproduction version of a product. A physical prototype often looks and feel as the developed product and is build to quickly test its functionality or appearance in order to learn and avoid costly iterations. It also serves as a tool to communicate within the company and with suppliers, as well as to investigate if components can be integrated together [15].

4
Manufacturing and Material Principles

This chapter aims to provide the reader with some background theory used throughout the project. The following manufacturing methods and material properties have been considered when designing Modul-Cover. The last three sections regarding additive manufacturing have been considered when adapting the design of certain parts for the prototype build.

4.1 Extruded Aluminium

Extrusion is a manufacturing process for producing rods, tubes or profiles of different cross sections. The desired material is heated to a temperature just below its melting point and then placed in a container. An increased temperature results in decreased deformation resistant and increases the malleability. The heated material is pushed through a matrix, with the desired cross section, into a long string. The extruded part is stretched to get a straight part. Aluminium alloys can be extruded to really small dimensions with tight tolerances from coarse substances [18].

4.2 Die Casting Aluminium

In die casting the desired material is melted and then forced into a permanent mould under high pressure. The mould consists of either two or three components in steel that have been designed to the desired shape. The components are either cooled by water or oil. This enables the molten metal to emit its heat to them, which makes the metal to solidify quite fast. Due to the high injection speed and high pressure it is possible to produce parts with thin sections, down to a few millimeters in thickness. When necessary, metal cores are placed in the mould to create cavities in the model. The method is often utilized to produce components in materials with low melting temperatures, such as zink, magnesium, copper and aluminium [19].

When designing for die casting it is important to consider where the sprue should be placed. The dimension of the sprue's cross section is dependent on the material and component. For aluminium, the dimension should be 1-5 mm and it is desirable to place it near thick walls and on hidden surfaces. It is of high importance to have an even wall thickness on components with thin walls. Die casting allows for thin walls and for different aluminium alloys it is possible to produce components with a thickness of 0,8-3 mm. It is also important to consider the draft angle in the design, to ensure that the component can easily be removed from the mould without complications. It is

recommended to have a draft angle between 0,7-2° for inner surfaces dependent on the core and 0,7-1° for outer surfaces [19].

4.3 Plastic Injection Moulding

One of the most utilized techniques for producing plastic components today is Injection Moulding. The whole process is cyclic and suits mass production well. It starts with the material, often granulated plastic, being fed to a heated cylinder in order to melt. The molten plastic is then injected into a clamped mould. The mould locking unit is closed until enough plastic has melted and a pressure of 50-150 MPa has been built up. There it is cooled until the plastic has solidified and is ready for the mould to be opened. The mould is often divided into two pieces to be able to get the part out [20].

4.4 Sheet Metal Forming

Punching is a cost-effective manufacturing process used to create holes in a workpiece. The hole is created by shearing which occurs when a so-called punch, with the desired shape of the hole, is forced through the workpiece into a punching die. Depending on the shape of the hole, more than one stroke might be needed. The sharp edge of the punch causes first an elastic deformation that turns into plastic deformation. Indication of fractures occur both at the punch as well as the punching die and the punched piece falls out when the two cracks meet. Within sheet metal forming it is common to combine punching with other sorts of sheet metal operations such as deep drawing, embossing and bending [18].

In a bending operation, the workpiece is stretched on one side and compressed on the other. The residual stresses that emerge, results in the sheet metal to slightly spring back towards the position it started at. To compensate for this it is necessary to over-bend the workpiece to create the correct bend [18].

4.5 Corrosion

When corrosion occurs, the anode surface is electrochemically degraded. The anode is the surface where electrons are emitted and oxidation occurs, while the cathode is the surface where electrons are taken up and reduction occurs. When combining different metallic materials, there may be a risk of galvanic corrosion. That type of corrosion can occur during metallic contact between two surfaces where the least noble becomes anode and corrodes. If the cathode surface is larger than the anode surface, the corrosion can occur very fast. Since this type of corrosion depends on the electrical current between metals, the phenomenon can be prevented by using insulation between the materials [21]. Materials with similar nobility have less risk of galvanic corrosion, for instance, acid-proof or galvanized steel screws can be used in aluminium frames to minimize the aluminium's erosion [22]. Atmospheric corrosion is the type of corrosion that occurs on materials in contact with air. Products with poor corrosion protection can suffer from atmospheric corrosion, for example if they are left outdoors and electrolyte in form of rain is added. For passivatable metals, there are also risks of crevice corrosion. If a gap occurs between two metals in which a small volume of liquid penetrates, the oxidant

can be consumed and the passivation in the gap ceases. A small anode surface can then be formed in the gap, while the surrounding passivatable metals' surfaces form a large cathode [21].

One way to prevent or minimize the risk of galvanic corrosion for aluminium when in contact with noble metals is to anodize the aluminium [23]. Anodizing is a electrochemical surface treatment used to increase the thickness of the natural oxide layer that occur on the aluminium surface in contact with oxygen. The process can both be used to get a good protection from wear, corrosion and for aesthetic purposes. Anodizing makes it possible to choose a colour for the component and results in a smooth surface. The aluminium component is lowered in a electrolytically bath where a current runs through the electrolytic liquid. The electrolytic bath creates a oxide layer that penetrates the aluminium. The thickness of the layer affects the possible application for the component and can be adjusted by changing temperature, ampere and time in the bath. Parts that are going to be exposed for hard wear in a corrosive environment, like the developed hardcover, should be anodized with a thickness between 20 µm and 25 µm [24].

4.6 Stereolithography

Stereolithography (SLA) is an Additive Manufacturing (AM) method that utilizes an ultraviolet (UV) laser. The laser hardens a liquid photopolymer resin, placed in a vat, layer by layer to build a 3D model out of the input 3D data. The platform, which the model is placed on, moves downward after each layer is cured. Using this AM method, there is usually no need for any structural support because of the model being built in liquid. However, it is used in special occasions of complex geometries. Stereolithography is the AM method that offers the highest accuracy and the best surface finish [25]. The deviation in the measurement is rarely more than 0.1 mm. When the model is fully cured, it is washed and eventual support is removed. After the post-processing, it is cured in an UV-oven [26].

4.7 Selective Laser Sintering

The AM method Selective Laser Sintering (SLS) utilizes a laser that follows the pattern of the model's cross-section layer by layer. The laser heats up the polymer powder, which is placed on the bed, to just below its melting point. The heated powder is sintered (partially melted) together and one layer is created. After each layer, the bed is lowered and a recoater spreads a new layer of powder on the existing layer. The whole process is repeated until all cross-sections are built. It is not necessary to use support structures due to the model being surrounded by powder. It enables complex geometries like integrated cooling channels [27].

4.8 Selective Laser Melting

Selective Laser Melting (SLM) is an AM method used to create a model layer by layer. The method uses a high-energy laser that fully melts a powder bed. The powder is fused together and creates a layer of the cross-section. New powder is then

evenly distributed on top of the existing layer. The process takes place in a chamber consisting of a controlling atmosphere of inert gas. This is done in order to remove oxygen from the building area. Thus, minimizing contamination of the component and eliminates condensates generated in the melting process. The condensate might reduce the effectiveness of the laser if it is not removed [28].

5
Prestudy and Market Analysis

As a baseline for product development, relevant information must be gathered. In this thesis, it includes sales number, dimensions of pickup trucks and data of Modul-System's sandwich floor. Furthermore, information regarding customer needs, competing products and potential obstacles are required for a successful product development. The gathered information is used to create a specification of requirement. This chapter aims to provide the reader with an insight into the most important information used for forthcoming decisions.

5.1 Sold Pickups on European Market

The aim of the thesis is to develop a storage system that is able to be used for the five best selling pickups on the European market. From January to April 2018 roughly 59 200 pickups were sold in Europe, which is an increase of 8.4% compared to the same time span the year before. This is a decrease in the growth rate, but on the other hand, the pickup market continues to gain more market share in the light commercial vehicles segment [1]. The Swedish market is considered relatively small with only 5.5% of the whole European market [29]. However, the sales on the Swedish market increased with 17%, which makes it one of Europe's most rapidly growing market [1].

To gather information about pickup sales, a detailed sales analysis was performed. In the analysis it could be seen which pickup models that are most popular in Europe (see Table 5.1). The table indicates which models that have the best sales numbers and thereby which five models to take into account when designing the storage system. The five models are Ford Ranger, Toyota Hilux, Nissan Navara, Mitsubishi L200 and Volkswagen Amarok, which together represent 83% of the European market. However, the Fiat Fullback and Mitsubishi L200 are basically identical to each other with slight differences in the front and interior [30]. This means that the products designed for the Mitsubishi L200 also can be sold to the Fiat Fullback without any modifications. This finding applies to the Nissan Navara and Renault Alaskan as well. Thus, these seven pickups represent 87,8% of the European market. Notably is that the Mercedes X-class, Fiat Fullback and Renault Alaskan were launched recently (2016-2017), thus is it hard to foresee how they can compete with the established models in the long run.

Today the majority of the pickup manufacturers are offering different versions of a pickup model. It should thereby be noted that the selling stats above applies to all the different versions. On the European market there are three common versions that can be found, pickups with two doors and two seats, pickups with two doors and five seats, and pickups with four doors and five seats. In addition, the size of the bed varies among the versions. The version with four doors and five seats is often referred to the double cab and is the most popular [3]. Hence, the main focus in this project will be

to develop a storage system that fits the double cab versions for the five best selling pickups. However, it will be investigated if the storage system could be adapted to the other versions and pickup models.

Table 5.1: Pickup sales on the European market between January and April, 2018.

Pickup Sales		
Pickup Model	Europe (Jan-Apr 18)	
	Total: 59 200	Market Share [%]
Ford Ranger	15 392	26
Toyota Hilux	10 064	17
Nissan Navara	9472	16
Mitsubishi L200	7696	13
VW Amarok	6512	11
Isuzu D-max	4440	7,5
Mercedes X-class	2664	4,5
Fiat Fullback	1954	3,3
Renault Alaskan	888	1,5
Others	118	0,2

5.2 Customer and User Needs

To identify customer and user needs regarding the product, one survey and eight semi-structured interviews were analyzed. The survey was published in pickup forums and groups and had 162 respondents. The interviews took place at different pickup user's sites. The study included questions about what pickup users usually store on their pickups as well as what they would like to store. The respondents also had to evaluate the importance of the following attributes; lightweight, security, weatherproof and maintain the original look of the pickup. None of the respondents believes that any of the attributes are unimportant. Furthermore, lightweight had a neutral response while maintain original look was regarded as slightly more important. Both security and weather proof are considered to be attributes of great significance. Finally it was identified that certain accessories and features such as lighting, access to electricity, heating and central locking were desired.

The gathered needs were divided into distinct groups which address similar needs (see Appendix A, Figure A.1 and Figure A.2). The final interpretation of the data is that the majority of the customers want a storage system that allows the user to store various sizes of equipment protected from weather and theft, while having easy and quick access to the storage compartment. This confirm that Modul-System's idea of a storage system with side openings is something that the customers are interested in and are willing to pay for. Another positive finding is that the respondents were positive to have the storage system installed at the reseller, which suits Modul-System's current business with their service centers.

5.3 Dimensions of Pickup Beds

To ease the understanding of the pickup measurements and the following sections in the report, certain terms concerning pickups and its bed are given in Figure 5.1 representing a 3D-scanned Volkswagen Amarok. Similar 3D-scans were used to analyze the five most sold pickups in Europe. In addition a Mercedes X-class, which scan was already available at Modul-System, was analyzed. By doing so it could be investigated if the hardcover could possibly fit eight out of the nine most sold pickups on the market. The software Solidworks 2019 was used to evaluate and measure the 3D-scans. The imported data from the 3D-scan is a large number of points which combined creates a mesh. The mesh is then transformed into a graphic body (see Figure 5.1). The graphical body helps to visualize the model as well as locating suitable measurement points. It can be seen in the figure below that the focus of the scan was on the pickup bed and therefore the majority of the car's front is missing.

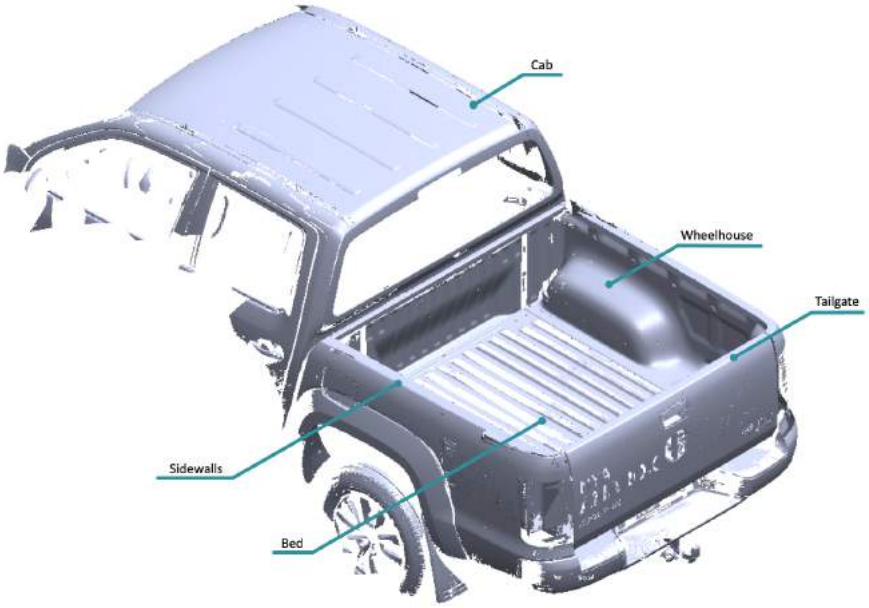


Figure 5.1: 3D-scan of a Volkswagen Amarok in Solidworks.

During the analysis it was realized that a square or rectangular shape with 90 degree corners of the hardcover would not fit very well, this since the distance between the sidewalls decreases as you move back toward the tailgate. This was also identified during the benchmark (see Section 5.4), where it was found out that several competing products have a trapezoid shape. It was also discovered during the benchmarking that almost all hardcovers have rounded corners. Hence, it was decided to measure all 3D-scans with a shape of a trapezoid with rounded corners (see Figure 5.2). One important aspect was that the trapezoid needed to be placed as close to the outer edge of the sidewalls as possible. The reasons being that the hardcover needs an contact area to transfer the load to the sidewalls and that a large overlap makes it easier to seal the cover from water. It was also discovered that different corner radius affected the overlap as well as the dimensions and angle of the trapezoid. To find the best radius and the corresponding dimension a set of radii was tested on all pickups. The radius ranged from 65 mm up to 90 mm with 5 mm intervals, resulting in testing six different corner-radii. All dimensions were then saved for each pickup and radius.

Figure 5.2: 3D-scan of a Volkswagen Amarok with measurements.

The measuring resulted in a large amount of data which needed to be analyzed. One of the first requirement that was taken into consideration was that the hardcover should have as few brand-specific parts as possible. The corners would most likely be moulded and the cost for moulds are relatively high. Brand-specific parts also create more item numbers which result in increased cost and complexity concerning warehousing. Thus it would be beneficial to design a corner which could be used for all brands. Therefore the first dimensions which were analyzed were the corner's radius. It showed that the optimal corner-radius that fit all brands was a radius of 80 mm. In Table 5.2 below the overall difference in dimensions for the measured pickups with a corner radius of 80 mm are shown. It can be seen in the table that the lengths differ as well as the angle. It should be noted that the measurements differ with up to 80 mm, this mean that a "one-size fits all" solution would not be possible. Resulting in that the dimensions of the hardcover must be able to range between the stated values in the table while still utilizing as many common components as possible.

Table 5.2: Min and max measurement for the measured pickups with a corner radius of 80 mm.

Difference in Dimensions		
Measurement	Min	Max
Length	1355 mm	1419 mm
Cab-side width	1400 mm	1480 mm
Tailgate-side width	1360 mm	1420 mm
Angle	88,54°	89,59°

5.4 Benchmark of Competing Products

Useful and critical information for a successful product development project can be found by evaluating competing and existing products. The information can be used to determine what functionality, pricing and performance the product that is to be developed must have. Therefore, the benchmark was conducted to get an in-depth understanding of storage system for pickups, in particular, hardcovers for pickup beds. Furthermore, the benchmark study was helpful to identify promising design solutions, suitable materials, requirements, etc.

The analysis was conducted by searching for storage solutions on the internet. Websites for 15 resellers of hardcovers and seven pickup manufactures were visited. All data, pictures and other relevant information concerning the storage solutions were gathered in a benchmark catalogue. The products in the catalogue were then further analyzed and evaluated against several criteria in a benchmark matrix (see Appendix A, Table A.2). One of the first things that were discovered during the benchmarking was that there is a limited amount of competitors offering hardcovers for pickups in Europe. The six presented competing products comes in different variants depending on the pickup model, as well as some additional optional accessories. Most of the products consist of an aluminum cover with an extruded aluminum frame-structure. The fittings used to install the hardcover on the pickup varies from drilling in the pickup to using clamp systems.

It was found that the price ranges from 14 000 SEK up to around 35 000 SEK as well as the weight varies between 30 to 50 kg. It was also found that almost all products are scalable, meaning that the dimensions of the parts, such as length and width, can be changed to fit different pickup models and brands. However, the shape of the covers is in most cases not a rectangle with 90 degrees corners. The shape follows the sides of the bed which results in a trapezoid shape. The previously mentioned properties among with others identified were then used for creating a specification of requirements and the functional decomposition as well as inspiration and guidance on how to further develop a similar system for Modul-System.

From the benchmarking the development team identified some areas where a product developed for Modul-System could potentially exceed competitors products, so called selling points. One potential selling point would be an integrated lighting system. Some competitors offer lighting but in the form of aftermarket installation which is not integrated into the product. Another selling point would be that Modul-System installs the hardcover and by doing so ensuring that the installation is done correctly. A product from Modul-System would also follow their premium product line and offer a robust and reliable design. Finally, none of the competing products offers a smart utilization of the storage around the wheelhouse. One of the reason might be that the design of the hardcovers is relatively simple. Reasons for this is most likely to keep the price and the weight down. Despite this, due to the discovered customer needs concerning better space utilization, a side compartment surrounding the wheelhouse is motivated, with the possible drawback of a slightly more expensive and heavier storage system.

5.5 Patent Search

A patent search was conducted early in the project to investigate if there are any existing patents that the developed product could possibly infringe on. Patents included in the investigation were mainly whole solutions of hardcovers for pickups. However, it was discovered that many patents had much focus on how to clamp the hardcover to the pickup. The majority of the analyzed patents were filed in the US and had a publication date that ranged between 1966 and 2012. There were no big differences between the found solutions. Most of the hardcovers consisted either of one openable lid (see Figure 5.3) or multiple smaller lids (see Figure 5.4). After the analysis it was concluded that none of the existing solutions had hatches nor complementary side compartments like this thesis intended product. Which could give Modul-System a competitive edge on the market. It should be noted that the conducted patent search was a brief analysis and a more comprehensive analysis is recommended before launching the product.

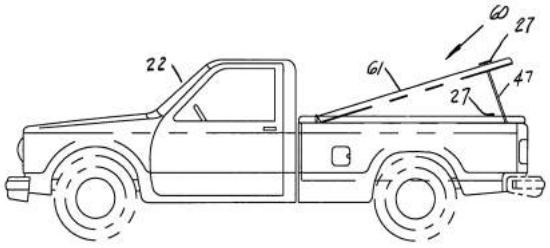


Figure 5.3: Illustration of one openable lid [31].

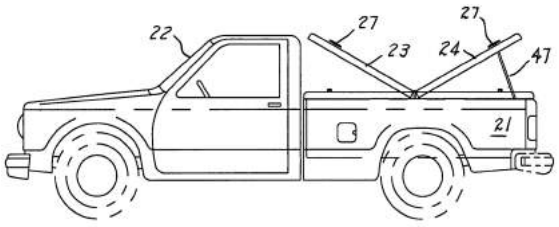


Figure 5.4: Illustration of multiple smaller lids [31].

5.6 SWOT Analysis

A SWOT analysis was conducted to identify factors that could affect the thesis and the hardcover. Some of the aspects were taken into consideration in the detailed design. Weight, for instance, will most likely be even more important over time, due to tougher emission regulations. Thus, keeping the weight down was important when designing the product. Other aspects were used to verify that a product development project concerning storage utilization on pickups is relevant and motivated. It was found that pickup sales have increased several years in a row and that there are companies focusing on only selling hardcovers, thus implying that there are customers interesting in buying hardcovers. Furthermore, it was identified that a large focus must be put to ensure that the product will withstand the outdoor usages and that it would be beneficial to utilize Modul-System's existing sales channels, manufacturing facilities and logistics. The most important results from the SWOT analysis can be found in Figure 5.5.

Figure 5.5: The most important findings from the SWOT analysis.

5.7 Specification of Requirements

The specification of requirements considers all functional aspects of the product. It is organized in several categories with subsequent requirements and desires. These desires are weighted from 1 to 5, where 1 indicates low importance and 5 indicates that the desire is of high importance. The specification was continuously improved during the execution of the project, especially in the early stages of the project. Inputs from Modul-System's internal requirements for their products have been included alongside requirements regulated by traffic laws. Furthermore, inputs from competing products and the performed market research have been incorporated into the specification of requirements. The full specification of requirements can be seen in Appendix A, Table A.1. The four most important requirements are presented in Table 5.3 along with how

they are to be verified. The first two are derived from the most important requirements in the market research while the last two are the most important requirements for Modul-System. The developed system is therefore especially tested against these four requirements (see chapter 9). The four most important requirements are, in combination with other related and important requirements, discussed briefly in the coming two paragraphs.

Table 5.3: The four most important requirements.

The Four Most Important Requirements			
	Performance	**Target Value**	**Verification**
1.1	Weatherproofed storage compartments	No sorts of precipitation or dirt in the storage area	Prototype testing
1.2	Theftproofed storage compartments	Impossbile, without tools, to access	Prototype testing
5.3	Maximum weight for the whole system	< 65 kg	CAD-model
7.3	Common parts accross pickup models	> 65% common parts	CAD-model

The hardcover should support cargo stored on top of it up to a weight of 150 kg. Modul-System´s requires that all products should be designed with a safety factor of three resulting in that the hardcover must be able to withstand loads up to 4500 N in forward and downward directions. This also means that load retention points and cargo accessories mounted on the hardcover should be able to withstand the same load. Two requirements which are highly important for the users is that the hardcover should be weatherproofed and theft protected. This must be accomplished without hinder the user to easily access the storage area inside the pickup bed. Furthermore the weight of the hardcover and the side compartments are limited to 65 kg and it shall enable better utilization of the storage area surrounding the wheelhouses. The weight is especially important due to the new EU test that measures fuel consumption from passenger cars, called Worldwide Harmonized Light Vehicle Test Procedure (WLTP). The test takes into consideration how much optional equipment influence on the fuel consumption [32]. Consequently, Modul-System's assessment is that products installed in a vehicle will affect taxation of the car [33]. Thus, a lower weight of the system will lead to lower taxation as well as lower environmental impact.

Modul-System's products are premium and have high quality compared to competitor's products. It is therefore important that a hardcover for pickups deliver the same quality and premium feel. The hardcover should also be designed to fit the five best selling pickups in Europe. This should be achieved by as few brand specific parts as possible but at the same time offer the customer a solution which both has a good fit to their pickups and has a robust and durable appearance. All this should be delivered to the customer at a competing price below 25 000 SEK.

5.8 Modul-System's Sandwich Floor

Modul-system's product Modul-Floor is a robust and lightweight flooring system that can be cut to fit each customer's specific vehicle (as mentioned in Section 2.5). The floor consists of a thin aluminium sheet at the bottom followed by two layers of fabric and glue that surrounds a honeycomb material and lastly an aluminium treadplate at the top (see Figure 5.6). The installation of the system is done with durable glue, which

means there is no need for drilling holes that can cause corrosion on the vehicle. The system is divided into smaller modules to simplify the installation and to fit an EU-pallet for reducing the shipping cost. To enable the user to fasten their stored items and the interior storage solution there are versions of the floor with integrated t-slots where load retention eyes and fasteners can be installed [34]. The sandwich floor is, compared to other flooring solutions, lightweight which enables the customer to tow a higher load or decreasing their environmental impact.

Figure 5.6: Structure of the Modul-Floor [34].

5.8.1 Experimental Test of the Sandwhich Floor

Due to the fact that the hardcover should utilize Modul-System's sandwich floor acting as a load carrier, it was necessary to perform a experimental test to confirm if it could withstand the required load. All Modul-System's products offered to customers are required to withstand a load of 3 g in downward direction. This means that a fully loaded product needs to support forces up to three times the load while the vehicle is in motion. Since the hardcover should be able to support 150 kg, the floor needs to withstand 4500 N. It was also important to investigate how much load the floor could withstand without breaking. The execution of the test started with cutting a piece of floor into a quadratic shape with the dimensions of 1000 x 1000 mm, this size was the largest dimension which fitted in the test-rig. The floor was later clamped between rectangular steel profiles with 30 mm on each side acting as a support (see Figure 5.7), which represented the most realistic and demanding loading case. The load was gradually applied by a hydraulic press. A wooden piece with the dimension of 200 x 200 mm was placed underneath the hydraulic press to get a more distributed load and thus avoiding a point load.

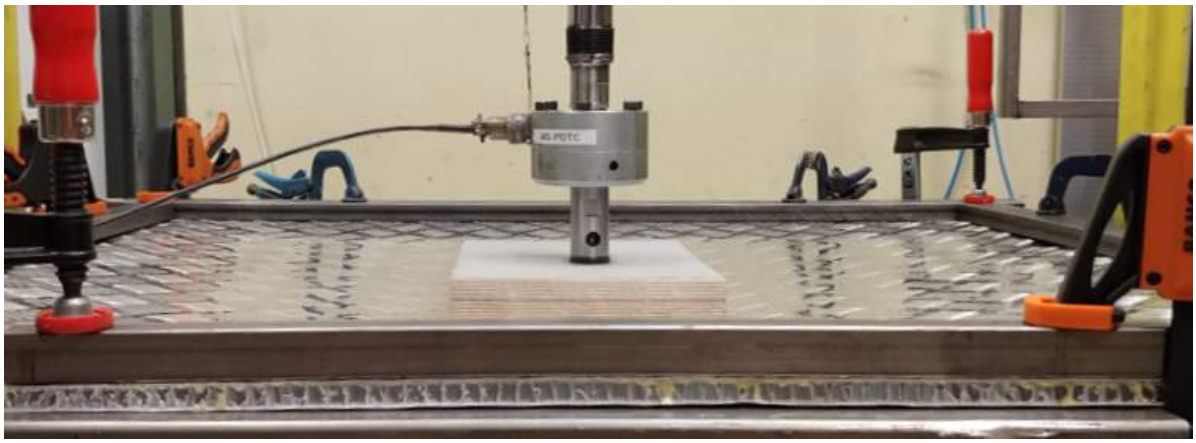


Figure 5.7: Test of Modul-Systems' sandwich floor.

A first test was done to know the equipment better and to get an understanding regarding the elastic deformation of the floor. A load up to 14,58 kN was gradually applied and resulted in a deformation of 43,51 mm (see Appendix A, Figure A.3). However, the floor showed no signs of plastic deformation after the load was diminished. The second test was conducted to explore how much load the floor could withstand without breaking. The floor collapsed at the load 15,94 kN (see Figure 5.8) with a deformation of 45,5 mm. The result for both tests indicates that it is possible to utilize the existing sandwhich floor in the hardcover.

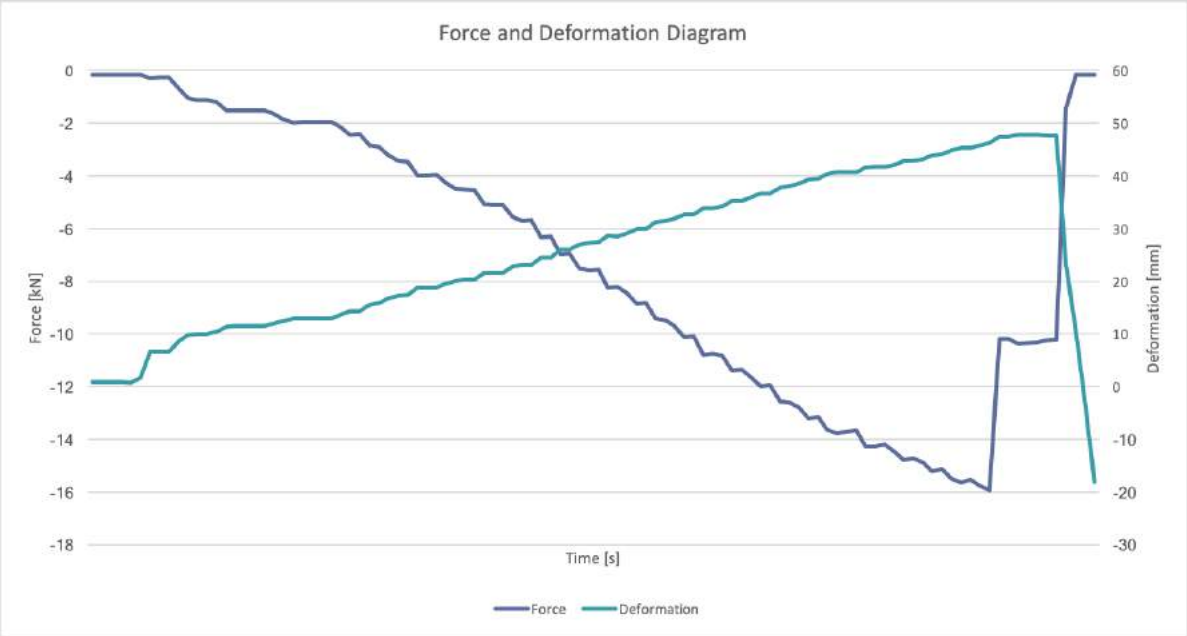


Figure 5.8: Result from the second deformation test.

6
Concept Development

This chapter describes the concept development process included in the master thesis. Inputs from the Prestudy and Market Analysis is used as a basis for the concept development. The chapter ends with deciding on which concept to be detailed designed. A simplified overview of the concept development process is presented in Figure 6.1. It should be noted that the actual development process was done in iterations of several steps and that new information was continuously incorporated into evaluations and design decisions.

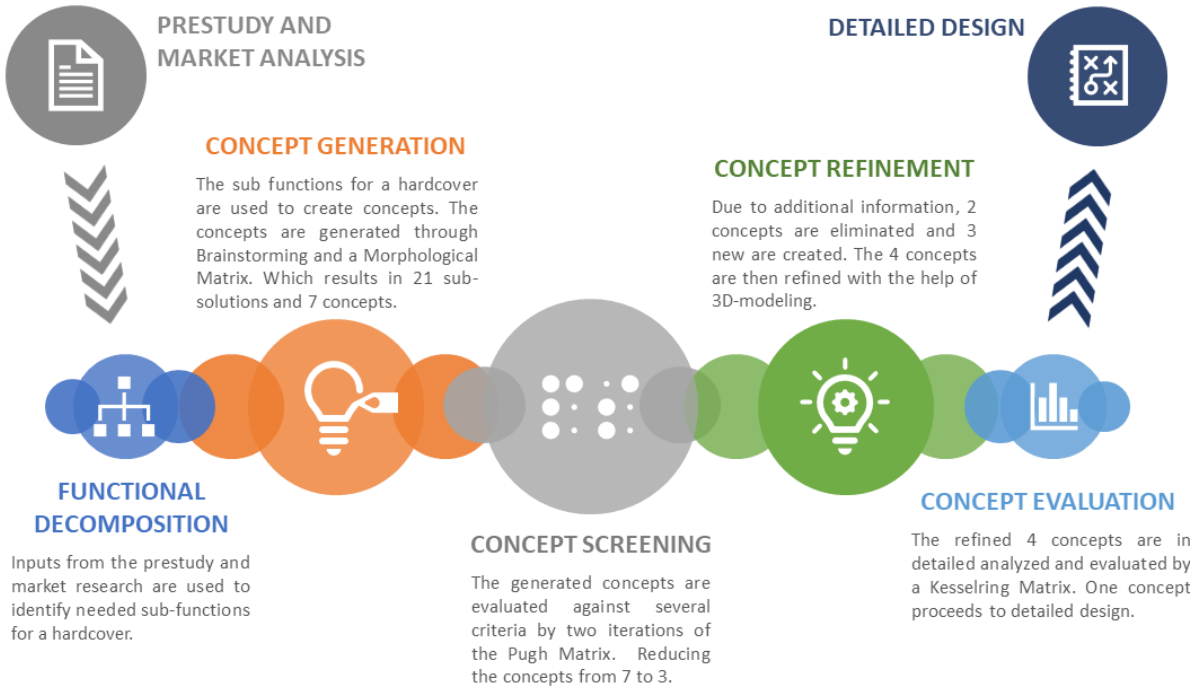


Figure 6.1: Overview of the development process.

6.1 Functional Decomposition

The Functional Decomposition was used to identify needed sub-functions for a hardcover and to support the concept generation (see the full Functional Decomposition in Appendix B, Figure B.1). The main sources of input for deciding the functions have been a culmination of customer needs gathered in the market study and benchmark. The means of the functions have been generated with brainstorming (see Section 6.2). The first level in the tree represents the primary function of the developed product, to protect stored items. The primary function is followed by six different solutions that exist on the market today. However, the thesis is to develop a hardcover. Thus, it was decided to just continue with functions linked to the hardcover. On the hierarchical level below, sub-functions and their respective means have been added. The main sub-functions are

as follows:

- **Create Access:** One of the most common problems when using pickups is accessing items stored on different locations within the bed. Hence, it is crucial to improve accessibility by dividing the storage into different compartments.
- **Theft Protection:** Protecting the stored equipment from thieves is of utmost importance with regard to the system being exposed in outdoor environments. A good locking system instills confidence in the prospective customer to store their equipment on the bed.
- **Weather Protection:** Since the system is exposed to different sorts of precipitation and dirt, it is important to hinder it from reaching the stored equipment.
- **Withstand Load:** The system shall be able to withstand a load of 150 kg on top to allow the user to store larger items there as well as using it like an unloading area.

6.2 Brainstorming

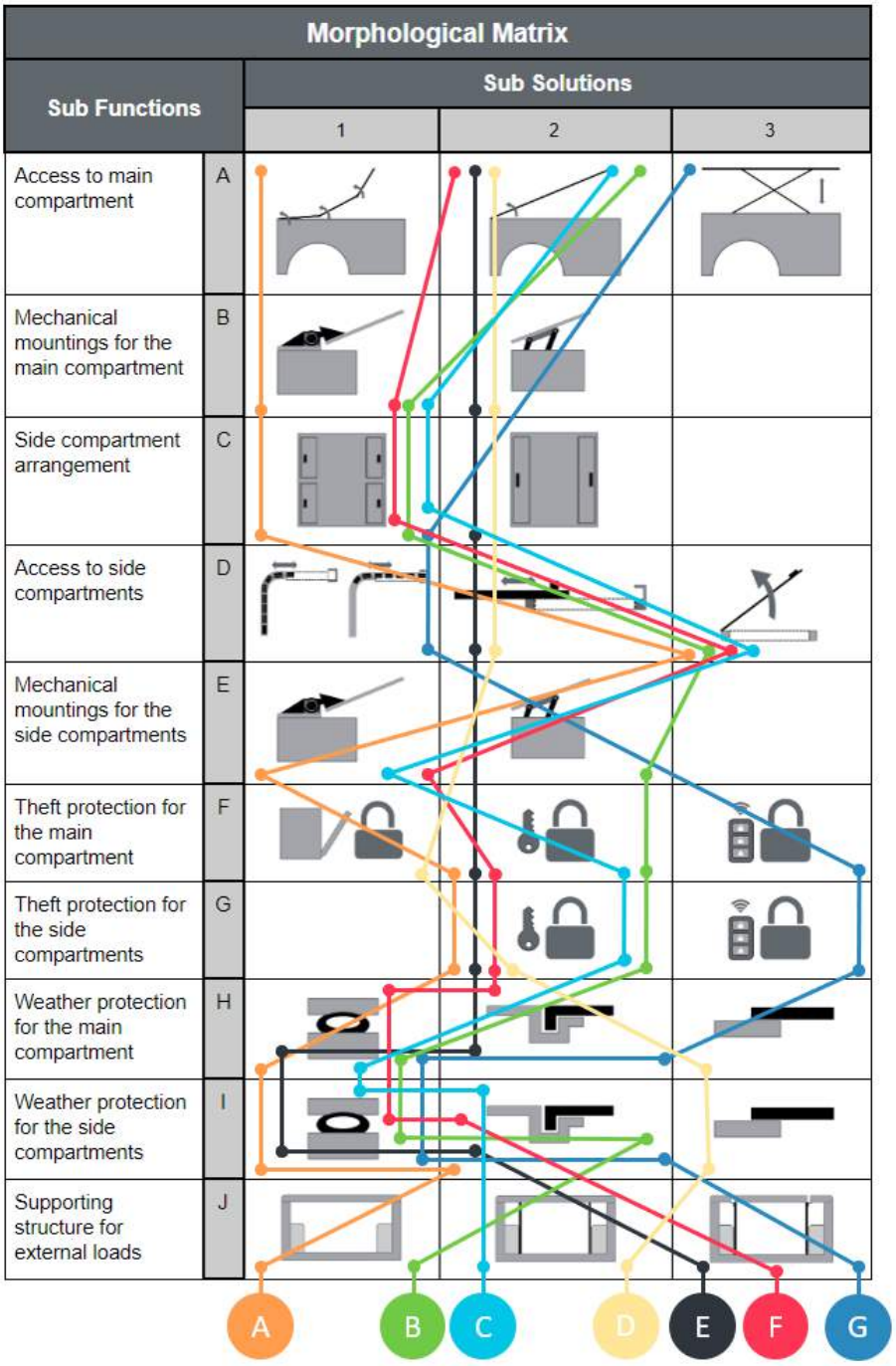
Brainstorming was used to come up with sub-solutions for the main sub-functions identified in the functional decomposition. The session resulted in 26 unique sub-solutions. This meant that detailed design of other functions were left for further development. One of the main reasons for this was that the product consists of more than 100 components making it too time-consuming for detailed development of each function. Furthermore, in the early stages of product development, the uncertainty is high and details are better left for later stages in the development. The generated concepts were visualized with hand-drawn sketches and, if necessary, an explaining description. The sketches were used to discuss different solutions and the sketching helped the creative process of finding new solutions. The generated solutions were then used in the Morphological Matrix to generate concepts (see Section 6.3).

6.3 Morphological Matrix

The Morphological Matrix was used to combine 26 sub-solutions, which were generated during the brainstorming, into seven concepts. All functions and solutions that was included in the early stage of the development are shown in Table 6.1. A total of seven different concepts were generated (A to G), displayed by a colored line and a letter. Each concept consist of a unique combination of sub solutions, and in some cases none or several sub solutions for a single sub function. The matrix indicates with a circle when a solution is used in the concept.

It can be seen that six concepts includes two solutions for function H and I. The reason for this is due to the importance of weather protection which is achieved in these concepts by a combination of two solutions which should improve the weather protection. It can also be seen that concept D, E and G does not include any solution for function E. This is due to a side compartment opening which does not need a hinge solution. After creating seven different concepts it was decided that the majority of the realistic solutions had been created, the concepts where then evaluated with Pugh matrices.

Table 6.1: Morphological Matrix for the lid.



6.4 Pugh Matrix

Two iterations of Pugh Matrix were used to evaluate the seven concepts generated with previously presented concept generation methods. The matrix consists of 15 criteria derived from both desires and requirements from the Specification of Requirements (Appendix A, Table A.1). To ensure that more important criteria had a bigger impact on the decision making, weightings (1-3) on the criteria were implemented. The Pugh

Matrix was conducted in two iterations to validate that the result was reliable.

Concept A acted as the reference in the first iteration (see Table 6.2). In which concept B performed much better compared to the reference. It was also noted that concepts with an internal frame performed worse on criteria such as easy installation, pre-assembly possibility, weight and low cost. This due to the concepts using Modul-System's sandwich floor to support the internal frames. This might result in the need for Modul-System to take care of the whole installation and it can also be hard to persuade the customer to pay for the extra required components. Concepts that require additional Modul-System products could as a result of the higher price lead customers to invest in competing products. It was concluded that further investigation of the internal frames' pros and cons was necessary. Furthermore, it can be seen that either one opening on each side or by introducing central locking to all openings increased the accessibility. By introducing a central locking-system the cost and the complexity would most likely increase. An alternative would be to develop a locking mechanism which unlocks two side compartments simultaneously and as a result reducing the number of unlocking interactions. After an internal discussion with the technical manager at Modul-System it was decided that the product should be fitted with mechanical locks as standard and central locks as an optional add-on.

Table 6.2: Pugh Matrix for the first iteration of the hardcover.

Pugh Matrix - Iteration 1								
Criterion	Weight (1-3)	Concept						
		A	B	C	D	E	F	G
High load capacity	2	Reference	+	+	+	0	0	0
High robustness	3		+	+	+	+	+	-
Weatherproof simplicity	2		+	+	-	-	0	-
No need for additional MS components	1		0	-	-	-	-	-
Protection against theft	3		0	0	0	+	+	+
Theftproof simplicity	2		+	+	+	+	+	+
Easy accessability	2		0	0	0	+	0	+
Low weight	2		+	-	-	-	-	-
Low complexity	2		+	0	-	-	0	-
Low cost	1		+	-	-	-	-	-
High personal safety	1		+	+	+	0	0	-
Good reachability of pickup bed	2		0	0	0	0	0	+
Pre-assembly possibility	2		0	-	-	-	-	-
Easy installation	2		0	-	-	-	-	-
Functional with accessories on top	2		+	+	+	+	+	+
Number of "+"			9	6	5	5	4	5
Number of "0"			6	4	3	3	6	1
Number of "-"			0	5	7	7	5	9
Total with weights			**17**	**4**	**−2**	**0**	**2**	**−5**
Total without weights			9	1	−2	−2	−1	−4
Rank			1	2	5	4	3	6

Concept B was chosen as the the reference in the second iteration of the Pugh Matrix (see Table 6.3). The reason being that it received the highest score in the first iteration and it was thereby interesting to compare the other concepts against it. The second iteration showed, like the first iteration, that concept B outperforms the other concepts,

which can be seen by the negative summation on all the other concepts. It was concluded that concept A, D and G performed worst and they were therefore eliminated. Concept E and F received the same score on all criteria in the second iteration and similar score in the first iteration. Based on this, and due to the similarities in sub-functions compared to concept E, concept F was eliminated. Hence, the concepts that will be further analyzed are concept B, C and E. Further analysis of the Pugh matrix showed that five sub-solutions were eliminated, these being tailgate locking (F1), roll cover hatch (D1), slideable hatch (D2), foldable cover (A1) and scissor lift cover (A3) (see Table 6.1). Reasons being mainly low robustness, high cost and difficulties to weatherproof. It should be noted that the remaining sub-functions had potential and were further investigated for the remaining concepts.

Table 6.3: Pugh matrix for the second iteration of the hardcover.

Pugh Matrix - Iteration 2								
Criterion	Weight (1-3)	Concept						
		B	A	C	D	E	F	G
High load capacity	2	Reference	-	+	+	-	-	-
High robustness	3		-	+	0	0	0	-
Weatherproof simplicity	2		-	0	-	-	-	-
No need for additional MS components	1		0	-	-	-	-	-
Protection against theft	3		-	0	-	+	+	+
Theftproof simplicity	2		-	0	-	0	0	0
Easy accessability	2		0	0	0	-	-	-
Low weight	2		0	-	-	-	-	-
Low complexity	2		-	-	-	-	-	-
Low cost	1		-	-	-	-	-	-
High personal safety	1		-	0	0	-	-	-
Good reachability of pickup bed	2		0	0	0	0	0	+
Pre-assembly possibility	2		0	-	-	-	-	-
Easy installation	2		0	-	-	-	-	-
Functional with accessories on top	2		-	0	0	0	0	-
Number of "+"			0	2	1	1	1	2
Number of "0"			6	7	5	4	4	1
Number of "-"			9	6	9	10	10	12
Total with weights			**-18**	**-5**	**-15**	**-14**	**-14**	**-17**
Total without weights			-9	-4	-8	-9	-9	-10
Rank			5	1	3	2	2	4

6.5 Further Concept Development

Concept B, C and E were further analyzed by a more in-depth design process using a CAD-software. The reason being that by modelling the concepts in 3D, problems and opportunities would be easier to identify. In the early stages while designing concept C it was realized that the design had some problematic layout. For instance, the supporting structure would most likely be unstable when the lid is opened. The reason being that the frame would only be fastened at the bottom meaning that a force applied to the top of it would have a long lever. This means that a moment would act on the fastening point. By that means concept C was eliminated, which resulted in that concept B and E were further developed.

While further designing concept B and E another important aspect was discovered, namely that Modul-System's sandwich floor maximum size is 2500 x 1200 mm. This meant that one piece would not cover the entire hardcover. Therefore concept B was replaced with three new concepts which are based on concepts B. The first is called Wide Profile, the second being called Rail Frame and the third called Single Lid. Concept E was not affected by the new information regarding the sandwich floor, however, the name was changed to ease the communication within the project team, therefore concept E will be called Divided Lid. Single Lid, Wide Profile, Rail Frame and Divided Lid will be further explained in the coming sections.

6.5.1 Single Lid

The Single Lid consists of four smaller hatches, two on each side, an aluminum frame with four aluminum corners (see Figure 6.2). The aluminum frame has t-slots integrated to accommodate optional accessories, such as load retention eyes, roof racks, warning lights etc. The top surface consists of three pieces of Modul-System's sandwich floor. The floor in the middle is separated with two aluminum beams, one on each side, which supports the structure when cargo is stored on top of the lid. The lid is opened from the back with hinges mounted on the cab-side.

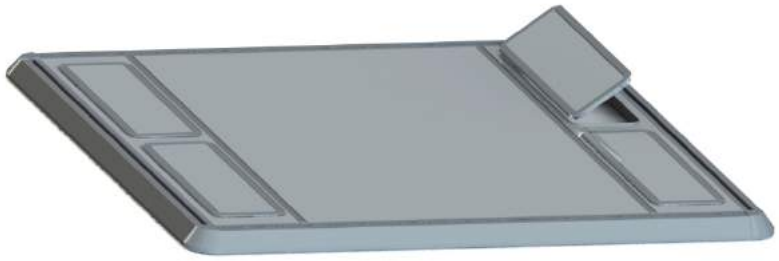


Figure 6.2: Illustration of the Single Lid concept.

6.5.2 Wide Profile

The Wide Profile is based on the Single Lid with the main difference that the top surface only consists of one piece of floor (see Figure 6.3). This is achieved with a wider aluminum frame which results that the width of the floor is less than 1200 mm. This concept might need a radius larger than 80 mm or another corner design, furthermore the aluminium profile would need to be cut so the hatches can be fitted.

Figure 6.3: Illustration of the Wide Profile concept.

6.5.3 Rail Frame

Rail Frame is mostly the same as Single Lid, the only difference is that this concepts has an internal frame which is mounted to the sidewalls (see Figure 6.4). This frame has, similar to the aluminum profiles surrounding the lid, an integrated t-slot. In this concept the internal frame makes it possible for easy fastening of accessories inside the pickup bed and a slightly improved waterproofing.

Figure 6.4: Illustration of the Rail Frame concept.

6.5.4 Divided Lid

Divided Lid has a lot of differences compered to the three previously explained concepts. The most notable difference is that only the middle part of the lid open up, the hatches on each side remains on the sidewalls (see Figure 6.5). The middle part that opens up as well as the hatches are supported by two vertically placed frames. Furthermore, the aluminium profile surrounding the lid is needed to be cut in the back and the waterproofing is assumed to be more difficult compared to the other concepts. This product would also require a larger number of parts, however, due to the internal frames it would most likely be able to withstand heavier items placed on top of it.

Figure 6.5: Illustration of the Divided Lid concept.

6.6 Kesselring Matrix

After designing the four presented concepts in the previous sections, discussing certain problems and important functions with engineers at Modul-System a Kesselring Matrix was performed. This to aid with the final decision concerning which concept to further develop (see Table 6.4). The majority of the criteria were taken from desires in the specification of requirement and weighted accordingly to the specification. Additional criteria were added compared to Pugh matrix, the reason being that the concepts where further designed and more detailed meaning that a more in-depth analysis was possible. New criteria were also identified by a more in-depth knowledge concerning how the actual product would be constructed. Some criteria were kept due to the importance of them, for instance, weight.

Table 6.4: Kesselring Matrix of the four further developed concepts.

Kesselring Matrix									
Criterion	Weight (1-5)	Concept							
		Wide profile		Divided lid		Rail frame		Single lid	
		v	t	v	t	v	t	v	t
Complexity	3	5	15	2	6	3	9	4	12
Number of unique alu profiles	2	5	10	3	6	3	6	4	8
Reuseability of components among models	5	3	15	5	25	4	20	5	25
Low total weight	2	5	10	3	6	4	8	5	10
High loading capacity	1	2	2	5	5	4	4	3	3
Low overhead cost	2	1	2	3	6	3	6	4	8
Low harm on pickup	3	5	15	4	12	5	15	5	15
Ability to integrate add-ons	3	2	6	3	9	4	12	2	6
Pre-assembly possibility	2	5	10	2	4	4	8	5	10
Time to install	3	5	15	4	12	5	15	5	15
Time to deinstall	2	4	8	4	8	5	10	4	8
Aestehtic appealing	4	3	12	4	16	4	16	5	20
Robust	4	3	12	4	16	4	16	3	12
Theft protection of side compartments when main compartment open	2	1	2	5	10	1	2	1	2
Theft protection when main compartment closed	5	4	20	5	25	4	20	4	20
Weather protection of side compartments when main compartment open	3	2	6	5	15	2	6	2	6
Weather protection when main compartment closed	5	4	20	3	15	5	25	4	20
V = sum v		59		64		64		65	
V / Vmax		69%		75,3%		75,3%		76,5%	
T = sum t		**180**		**196**		**198**		**200**	
T / Tmax		**71%**		**76,9%**		**77,6%**		**78,4%**	
Rank		4		3		2		1	

The Kesselring Matrix showed that the concept Wide Profile was the worst one, hence it was decided to focus on the other three concepts. These three concepts all received similar score, where Single Lid scored the highest. Since the score was very close for three of the concepts a more detailed analysis of them was necessary. The only difference in design between Single Lid and Rail frame is an internal aluminum profile which led to a very similar score to each other. Due to the increased cost and weight of the additional internal frame it was decided to eliminate Rail Frame. With the same argument, the concept Divided Lid has an extra weight for the two vertical internal frames, increased amount of parts and higher complexity compared to the Single Lid concept. It was therefore concluded that the Single Lid was the best concept to further develop and build a prototype of.

7
Detailed Design

With help from the Kesselring Matrix and discussions with employees at Modul-System, it was decided to further develop the concept Single Lid. During the detailed design, adaptations and changes had to be made. This was mainly due to new information from suppliers, manufacturers and inputs from Modul-Systems employees. The final product is thereby based on the concept Single Lid but with some modifications and will be called Modul-Cover henceforth. This chapter will begin with a general description of Modul-Cover and thereafter explanations of the major parts of the product.

7.1 Modul-Cover

The Modul-Cover is a hardcover or also called a lid (see Figure 7.1). The majority of the hardcover is made out of aluminium with some details made out of galvanized steel. The design of Modul-Cover is scalable to fit the five best selling pickups in Europe, meaning that only small changes are needed to fit different pickup models. Modul-Cover provides the user with a range of functionality and storage capabilities by its four storage

Figure 7.1: Rendering of Modul-Cover with named parts.

compartments which are located around the wheelhouses, space which usually is hard to utilize. The four Side Compartments enable the user to easier organize and protect smaller items. The larger main storage compartment is accessed from the back and is left free to keep the functionality of the pickup bed. Modul-Cover is fitted with integrated t-slots for easy and fast attachment of load retention eyes. This in combination with the load capacity of 150 kg means that Modul-Cover can be used to transport cargo placed on top of it. Modul-Cover is equipped with mechanical locks as standard but with the possibility to be connected to the central locking system of the pickup as an add-on. Furthermore, the hardcover can be fitted with internal lighting to increase the user's visibility when the bed is accessed in dark environments. The Modul-Cover has a robust and distinct design which ensures that the effect on the pickup appearance is minimized.

Several parts had to be designed specifically for Modul-Cover, this to ensure that all requirements where met. The parts where continuously updated and tested in the CAD-software, test such as FE-analysis and how well the parts would fit together. The parts were also designed for being produced at Modul-System's manufacturing facility or by their suppliers. The parts that have been designed for Modul-Cover are presented in Table 7.1. The presented parts are described in detail in the following sections. In addition to the parts presented in the table, there are about five different simpler brackets which also were designed for Modul-Cover, these are briefly mentioned in the following sections.

Table 7.1: Parts specifically designed for Modul-Cover.

Designed Parts for Modul-Cover	
Outer Profile	Hardcover Hinge
Inner Profile	Cab-side Fastening
Corner	Upper Hatch Frame
Backplate	Bottom Hatch Frame
Side Sheet	Clamp
Side Compartment Shallow	Top sheet
Side Compartment Deep	Pin Bracket
Hardcover Hinge Attachment	Sandwich Floor

7.2 Aluminium Frame

Modul-Cover has an aluminium frame which surrounds the entire hardcover. There are several reasons for the aluminium frame, where the main advantages are the robust, good corrosion resistance and durable construction at a low weight. The aluminium frame also provides a robust and premium feeling to a relatively low price. Furthermore, it was discovered during the benchmark that all hardtops which have a frame is made out of aluminium. It was thereby concluded that an aluminium frame would be beneficial. The frame in Modul-Cover consists of two types of extruded aluminium profiles and four corners in cast aluminium. Together they create a support structure for the Modul-Cover, transferring loads to the pickup's sidewalls. The frame also provides a robust and appealing look while offering t-slots for fastening of attachments points and accessories. The development of the frame has been done continuously as the design of the hardcover has been finalized.

7.2.1 Outer Profile

The first type of aluminium profile surrounds all the four sides of the hardcover and will be referred to as the Outer Profile (see Figure 7.2). The profile is manufactured by extruding aluminum through a die and thereafter anodizing it to the correct color. The Outer Profile has several functions built into it. One of the earlier mentioned function is the integrated t-slot. The t-slot follows Modul-System's standard M8-sized t-slot meaning that existing products from Modul-System can be mounted, for instance, load retention eyes. There is also a t-slot at the bottom of the profile, in this slot a rubber sealing surrounding the entire hardcover is mounted (see Figure 7.6). The design is such that no glue or other fastening methods are needed, the rubber sealing is pressed into the slot and stays there.

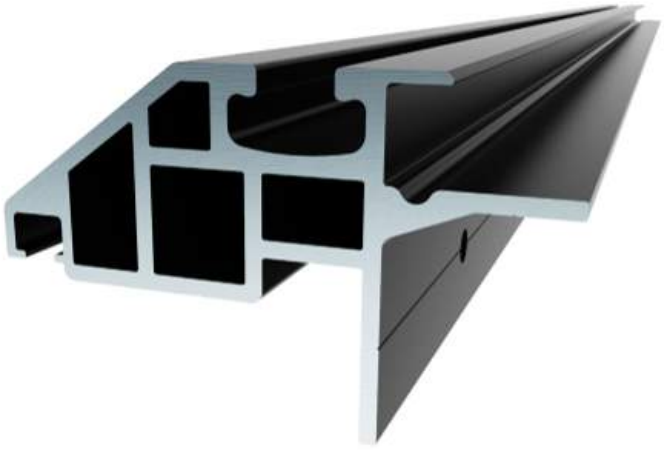


Figure 7.2: The Outer Profile in the Aluminium Frame.

The profile is also extended downwards, this lip is used to mount latches for the locking mechanism as well as fastening-points for the gas springs that support the hardcover in its opened position. The small marking in the middle acts as a guideline and makes it easier to drill the required mounting holes centered on the lip. Along one side of the profile, there are two horizontal lips in which Modul-System's Sandwich Floor or the Side Sheet are mounted in-between with glue (see Figure 7.6). The designed overlap increases the strength of the connection resulting in that glue is the only fastener needed, the glue also makes the connection waterproofed. Finally the overlap guarantees that even if the Sandwich Floor is not cut to perfect size it will not be noticed by the customer, thus reducing the need for tight tolerances. The last function of the Outer Profile is the hollowness which both reduces the weight and is used to mount the corners to the Outer Profile (see Section 7.2.2).

7.2.2 Corners

The four corners of the hardcover are made out of cast aluminium with a number of functions built into the design. Just like the Outer Profile, the corner has a slot for the enclosing rubber sealing (see Figure 7.3). However, since the corner is to be manufactured by die casting, a t-slot is not possible. This is due to the fact that the mould needs to be able to be opened, resulting in a more simple slot for the sealing at

the corners. The corner is fitted with four larger rectangle cup-shaped pins. These pins are inserted into the hollowness of the Outer Profile and act as a fastener between the parts. The pins and the Outer Profiles are permanently mounted with a combination of flat clinching and gluing. Another important attribute is the angled design of the pins. This allows for the Outer Profile to be mounted in angles between 88° to 92°, thus making it possible to accommodate the angle needed for the trapezoid shape of the frame (for more details, see Section 5.3, Figure 5.2). The corner is also designed with a hollowness to reduce the weight and minimize the material used in the production. Similar to the Outer Profile has the corner a lip overlapping the sheet-metal surrounding the hatches. The overlap together with glue creates a tight seal against water. Finally, the corner is anodized in the same color as the profiles.

Figure 7.3: Rendering of the corner.

7.2.3 Inner Profile

To create an appealing and functional connection between the sheets surrounding the hatches and the Sandwich Floor placed in the center of the hardcover, an aluminium profile was designed, called Inner Profile (see Figure 7.4). The Inner Profile is produced and painted by the same methods as the Outer Profile. The Inner Profile has two main functions, transferring loads and to enable fastenings of accessories. After discussions with Modul-System it was decided to integrate the same t-slot as the Outer Profile on the upper side of the profile, thus increasing the fastening possibilities on top of the hardcover for the user. Furthermore, accessed from the inside of the hardcover, two additional t-slots were added. These are Modul-System's standard M6-sized with a small modification. The depth of the t-slot has been increased. This enables the slot to be used as a cable channel for accessories and add-ons such as lighting and central locking. Just like the Outer Profile the extruded aluminium allows for a hollow design thus keeping the weight of the part down.

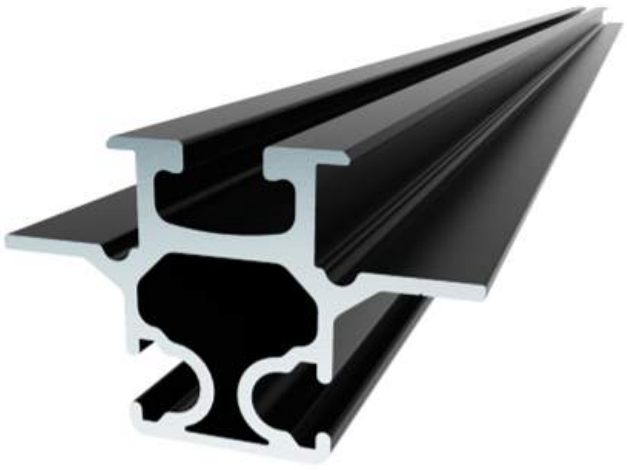


Figure 7.4: The Inner Profile in the Aluminium Frame.

7.3 Sandwich Floor

The Sandwich Floor is a standardized Modul-System product which is cut into the right form for the specified Modul-Cover. The floor is kept in stock at Modul-System's manufacturing facilities where it is cut by an automated CNC-machine. This allows for fast and cost-effective manufacturing of the floor piece thus enabling the floor to be made to order. The Sandwich Floor is placed in the middle of Modul-Cover and is mounted to both Inner Profiles and to two of the Outer Profiles by gluing them into a slot in the profile. A clean appearance and a tight seal can thus be achieved by eliminating other fasteners such as screws and rivets. The floor's load capacity provides a durable and robust area for transport of large and heavy items placed on top of Modul-Cover.

7.4 Side Openings

The main function of the Side Openings is to provide easy access to the storage space alongside the sidewalls. Other important functions are to protect the Storage Compartments (see Section 7.5) from theft and weather. The Side Opening consists of several different parts, both manufactured by Modul-System but also details purchased from suppliers. Parts such as hinges, locks, and slam latches are sourced from external suppliers which already have an established collaboration with Modul-System. There are several reasons for using existing products bought from suppliers. The main reasons are cost effectiveness and development time. Purchasing standard parts are often more cost effective and time-saving. The consequence is that the use of standardized parts can hinder innovative designs of the product. This section will present the parts included in the Side Opening (see Figure 7.5) except the mentioned purchased products.

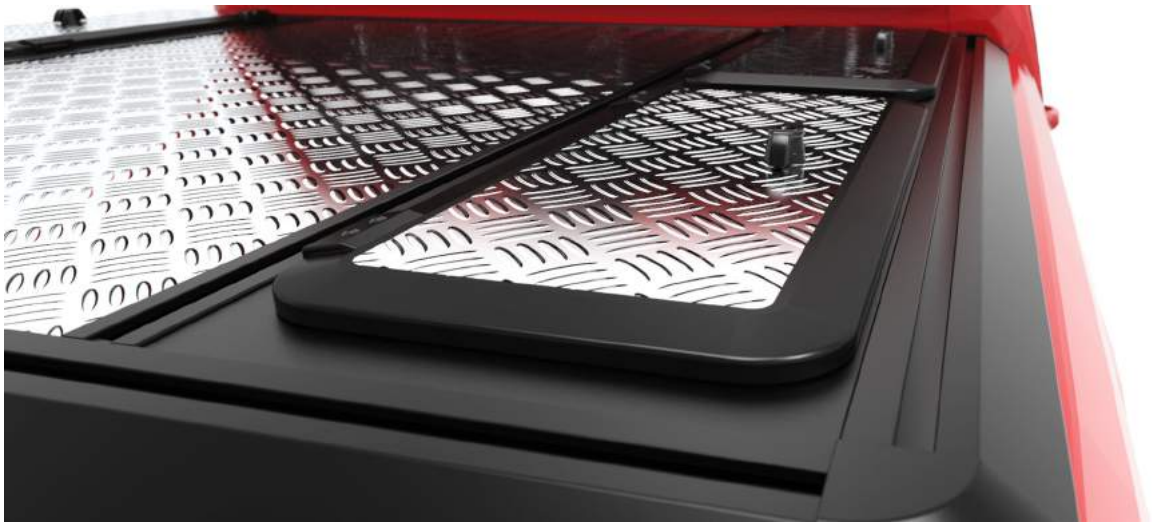


Figure 7.5: Side Opening mounted to the Aluminium Frame.

7.4.1 Side Sheet

The Side Sheet is produced from a 1,5 mm thick aluminium sheet which is punched, bent and painted at Modul-Systems manufacturing plant in Mullsjö. The Side Sheet follows the slightly angled shape of the aluminium frame, meaning that the corners of the sheet are not 90°. To be able to assemble the side sheet together with both the

inner and the Outer Profile all edges are bent in a U-shape. The bends create the same thickness of the part as the Sandwich Floor and thus making it possible to mount the sheet between the lips on the outer and the Inner Profile in a similar way as the floor (see Figure 7.6). The bends provide an increased stiffness of the Side Sheet, which in combination of mounting it between the lips, creates a strong connection with glue as the only fastener.

Figure 7.6: The U-shaped Side Sheet mounted to the Outer Profiles.

7.4.2 Hatch

The Side Opening has two waterproof and lockable hatches. These hatches consist of three major parts, the Upper Hatch Frame, the Bottom Hatch Frame and the Top Sheet (see Figure 7.7). In addition to these, there are purchased products, namely latches and hinges. The size and design of the hatch have been adopted to fit all the required pickup models, thus reducing brand-specific parts. To minimize the weight the Bottom Hatch Frame is manufactured by plastic injection moulding. It fits right into the Side Sheet's punched holes and is assembled by gluing the part to the sheet. The glue ensures a waterproofed and aesthetically appealing appearance. The part is made to hinder water from entering the storage space. This is done in two ways. Firstly, the height of the part hinders water from flowing in along the Side Sheet. Secondly, the upper edge of the bottom frame matches a slot in the upper frame where a sealing gasket is mounted. A locking system (see Section 7.6.3) ensures that the rubber sealing is compressed which makes the hatch waterproofed. The Upper Hatch Frame is made out of fiber reinforced plastic. This ensures a durable but still lightweight part. The Top Sheet is glued to the Upper Hatch Frame that creates a tight seal. The Top Sheet is made of a 2 mm threaded aluminium sheet with a punched hole for the locking mechanism. The hatch is fitted with two friction hinges, mounted to the Upper Hatch Frame and to the Side Sheet. The friction hinges allow the user to open the lid to the desired angle at which the hatch will stay. Similar functionality could have been done with gas springs. However, gas springs would consequently require at least four additional parts per hatch, resulting in a total of 16 parts for all four hatches. The friction hinge therefore out-performs the gas spring since it reduces the number of parts resulting in lower weight, decreased cost and shorter assembly time.

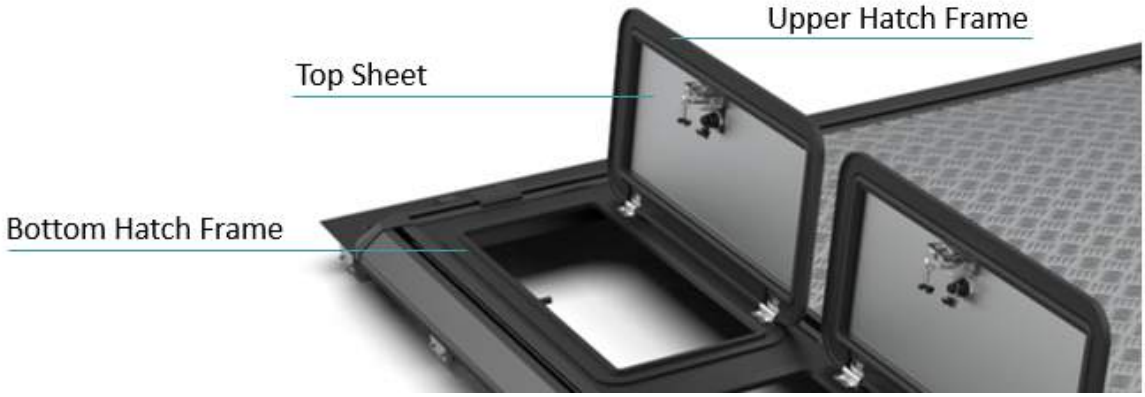


Figure 7.7: Illustration of one hatch with parts named.

7.5 Side Compartments

To accommodate effective storage utilization of the pickup bed, four Side Compartments located along the sidewalls of the pickup have been designed, one placed over the wheelhouse and one close to the tailgate (see Figure 7.8). The compartments are made out of punched, bent, spot welded and painted stainless steel. The Side compartments are mounted to the cab-side fastening (see Section 7.6.2) and the bracket holding the pin in the locking system for the Modul-Cover (see Section 7.6.3.2). The compartments provide the user with two bins with full depth and two more shallow bins placed over the wheelhouses. The Side Compartments are equipped with hole pattern which follows Modul-System's standard for tool boards. By that enabling the user to purchase accessories from Modul-System's large assortment, for instance, tool holders, hooks and dividers to mention a few. The holes also reduce weight while still offering a robust construction.

Figure 7.8: The deep and shallow Side Compartments mounted to the pickup.

7.6 Fastening to the Pickup

The fastening of Modul-Cover to the pickup is important for several reasons. The fastening ensures that Modul-Cover functions as intended and is safe to use. A large effort was made during the earlier discussed benchmark to identify possible solutions for attaching hardcovers to pickups. It was found that a clamping system is the most common. Furthermore, it was realized that existing solutions had some drawbacks. Therefore the clamping system solution was improved to meet the requirements for Modul-Cover. Important requirements related to the fastening are to ensure that Modul-Cover withstands accelerations up to 3 g and that no drilling into the pickup is needed. This section will therefore discuss the important components which securely attach Modul-Cover to the pickup while still being easy to access for the user and at the same time protect the storage space from theft.

7.6.1 Backplate and Hardcover Hinges

The Backplate lays on top of both the sidewalls and the wall closest to the cab. It is made out of bent stainless steel which is painted in a similar color as the aluminium profiles (see Figure 7.9). Between the Backplate and the pickup there is a thin adhesive rubber sealing. This ensures that there is no way for water to enter between the two parts. The rubber sealing slightly separate the Backplate and the pickup thus eliminating both rattling sounds from metal contact as well as eliminating the risk for scratches on the pickup. The Backplate's two major functions are to lead away water that is running of Modul-Cover and to provide attachment points for the Hardcover Hinges. The upward bent fits into a slot in the profile which ensures that even if the pickup is parked in a hill, water can not flow into the storage area. The water is instead lead to the sides of the pickup. The downward bent is placed outside the wall closest to the cab, this helps with water protection and to keep Modul-Cover in place even when aggressive accelerations occur. The Backplate is also bolted with carriage bolts to the Cab-side fastening (see Section 7.6.2), making it impossible to disassemble Modul-Cover when it is locked.

Figure 7.9: Hardcover Hinges mounted to the Backplate.

The Hardcover Hinges are designed to keep Modul-Cover in place, which means they need to transfer loads from Modul-Cover to the Backplate. The hinge consists of three main parts, all three are made out of extruded aluminium and are anodized in the same color as the profiles (see Figure 7.9). The hinge is fastened to the Outer Profile by two large rivets, and by sliding it into the integrated t-slot in the same profile. This creates a sturdy and secure mounting. The two parts that are mounted to the Backplate have threaded holes and are bolted from underneath. This protects the hinge from being dissembled when Modul-Cover is closed, thus improving the theft protection.

7.6.2 Cab-side Fastenings and Clamps

The Cab-side Fastening is placed hanging on the sidewall and against the wall closest to the cab (see Figure 7.10). This provides support in both the forward direction and downward direction. The fastening is, similar to the Backplate, equipped with adhesive rubber sealings at contact surfaces with the pickup. Mounted to the Cab-side Fastening is the earlier mentioned Backplate as well as the gas spring supporting the hardcover in its opened position. The Cab-side Fastening has also been constructed so that the Sidebins, placed over the wheelhouse, can be attached. The fastening is fixed to the edge of the pickup sidewall by two clamps. The clamps have been improved compared to competitors version by increasing the size and amount of screws. The reason being Modul-System's high requirements for handling acceleration. Two screws placed horizontal fix the cab-side fastening toward the inner side of the edge while one vertically placed screw ensure that the fastening can not lift from the sidewall during heavy acceleration in an upward direction. This differs compared to many competitors which only uses one screw for clamping. Since the space is tight under the sidewalls' edge the clamp has been designed with integrated threading. Resulting in that no nuts are needed and therefore there is no need for reaching in with tools under the edge.

Figure 7.10: Illustration of the clamping solution.

7.6.3 Locking

Products from one of Modul-Systems suppliers have been used for locking both the hatches and the entire Modul-Cover. The locking systems consist of rotary latches and wing-locks. This type of latch is used due to its good load capacity and that pushing the Modul-Cover or the hatch down is the only action needed to secure it. This means that the risk of the hatches or the entire lid to open during driving is minimized. Another

benefit of the rotary latch is that it can be operated by mechanical cables. This is leveraged for the latches securing Modul-Cover. Where the Wing-lock that is placed in the center of the rear Outer Profile, operates both latches, one on each side.

7.6.3.1 Locking of the Hatches

To simplify the construction of the hatch and to minimize the number of parts the wing-lock and rotary latch are mounted to the Top sheet. The rotary latch is attached by clamping a bracket with the mounting nut for the Wing-lock (see Figure 7.11). Glue is added at the contact surfaces between the bracket and the Top sheet to ensure a durable fit and to avoid rattle. The close placement of the wing-lock and the latch minimize the parts needed for opening the hatch. The pin, in which the latch locks to, is mounted to the Outer Profile by rivets and bolts.

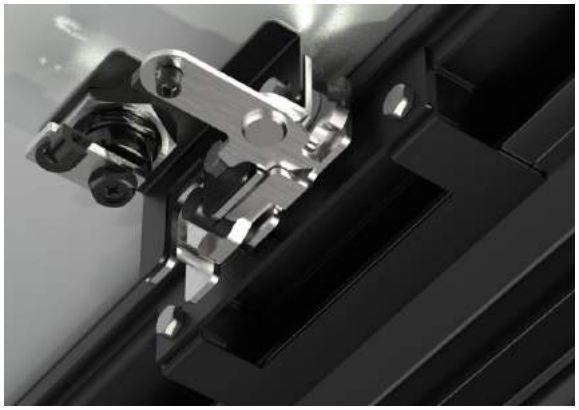


Figure 7.11: The locking system for the hatches.

7.6.3.2 Locking of Modul-Cover

Modul-Cover is kept in place by two heavy duty rotary latches, one on each side, locking to one pin each. The pin is mounted to the pickup sidewall by the Pin Bracket (see Figure 7.12). The Pin Bracket is mounted, in the same way as the Cab-side Fastening, with two clamps. The pin is then mounted by two weld bolts. This design allows for adjustment both in height and length ensuring that Modul-Cover is fixed at the right position and that the surrounding rubber sealing is correctly compressed. The latches are mounted to the Outer Profiles by a steel bracket and bolts. The rotary latches transfers load in the car's driving directions, both forward and backward, as well as upward and downward. Mounted to the bracket and the profile is a distance made of plastic. The distance guides Modul-Cover to the right position and ensure it has support from lateral forces (see Figure 7.13). This in combination with the hardcover hinge, Backplate and Cab-side Fastening creates four fastenings points during driving. Furthermore, the Outer Profiles are placed on top of the sidewalls which provides additional support for downwards vertical loads, related to cargo placed on top of the hardcover.

Figure 7.12: The locking system viewed from inside of the pickup bed.

Figure 7.13: The locking system viewed from the outside of the pickup.

7.7 Customization of Modul-Cover

User customization has been considered throughout the detailed design, this since a wide product offering could potentially result in improved sales and better customer satisfaction. On the other hand, a wide product offering could also result in an increased number of unique parts and thus increased costs. When possible, two approaches have been used to tackle this dilemma, which will be discussed in this section.

Modul-Cover has been designed to accommodate existing products from Modul-System, by that offering customization for the user. Some of the parts have been designed with standardized interfaces, namely t-slots and tool board pattern. The interfaces can, therefore, be used to mount accessories such as lights, load retention eyes, roof racks, tool holders etc (see Figure 7.14 and 7.15). Since already existing products can be mounted to Modul-Cover the costs and the number of unique parts are kept to a minimum. Furthermore, it enables Modul-System to sell these accessories as add-ons which results in an increased profit as well as making it possible for future developed accessories to be integrated with Modul-Cover.

Figure 7.14: Sample of add-ons mounted to the Side Compartment.

Figure 7.15: Illustration of integrated lighting installed.

For further customization there are several options for the customer, options which have a minimal effect on the manufacturing and cost of the product. One option for the customer is to chose how many hatches Modul-Cover should be fitted with. As standard it will be fitted with four hatches, however it could be decreased to two or zero hatches. The only part that needs to be changed is the Side Sheet and the parts related to the missing hatches are skipped. Since the Side Sheet is made to order and punched from sheet metal the costs of the Side Sheet will not be changed. This could also provide an opportunity to sell slightly cheaper versions of Modul-cover since it do not include parts for two or four hatches. An aesthetic option is to choose if the Top Sheet, mounted to the hatches, should be threaded aluminium or the same material as the Side Sheet. This would not result in any major cost increase since the Top sheet is made to order and Modul-System already has both material in stock.

To compete with other hardcovers on the market Modul-Cover could be offered in different colours (see Figure 7.16). For instance, the Sandwich Floor could be powder coated in black. Furthermore, the Aluminium Frame could possibly be anodized in

some other colours than black. This could all be done without changing the design of the parts. However, the cost of this would likely be higher than just offering one colour. Therefore it could be relevant to offer this when Modul-Cover has proved successful and when there are customers willing to pay for the increased cost.

Figure 7.16: Modul-Cover without hatches and with the Sandwich Floor painted grey.

Central locking was found highly desirable in the user need study, this would however increase the cost significantly. Mainly because of additional and expensive electrical parts. A central locking system could therefore be offered to the customer at a certain price point. Even though this would result in a more expensive product it is presumed that the option would be quite popular.

8
Prototype

After the detailed design was conducted, a physical prototype was built in order to evaluate if Modul-Cover fulfills all the requirement established throughout the thesis. This method also acted as an evaluation of how well the design facilitate manufacturing and assembly. The prototype was installed on a Volkswagen Amarok that was available at Modul-System. During the prototype building, adaptations concerning production methods had to be made. The main reason for this was due to the limited time and budget in the thesis. Some components have high initial investment cost, hence it was more beneficial to choose other manufacture processes for the prototype. However, the adaptations were carefully considered to not affect the evaluation of important functions. This chapter will cover the manufacturing and building of the prototype as well as the adjustments that had to be made.

8.1 Manufacturing of Parts by Suppliers

Several suppliers were involved in producing parts for the prototype, this was due to limitations in Modul-System's manufacturing capabilities and cost aspects. The developed parts are designed to be produced by a specific manufacturing method, however, some methods are not economically feasible for a prototype, thus certain design and manufacturing changes were necessary. This section will present the reasoning regarding choices of manufacturing processes, modifications in the design, and the result of it. An overview of the intended manufacturing methods and the methods used for the parts included in the prototype along with references to drawings are presented in Table 8.1. Parts missing drawings were produced by utilizing 3D CAD-models.

Table 8.1: Overview of the manufactured parts by suppliers.

Part	Intended Manufacturing	Prototype Manufacturing	Drawing
Inner Profile	Aluminium extrusion, anodizing	Aluminium extrusion	Appendix C, Figure C.1
Outer Profile	Aluminium extrusion, anodizing	Aluminium extrusion	Appendix C, Figure C.2
Corner	Die Casting Aluminium, anodizing	3D-printed plastic (SLS)	Not required*
Hardcover Hinge	Aluminium extrusion, anodizing	3D-printed aluminium (SLM)	Not required*
Hinge Attachment	Aluminium extrusion, anodizing	3D-printed aluminium (SLM)	Not required*
Upper Hatch Frame	Plastic injection moulding	3D-printed plastic (SLA)	Not required*
Bottom Hatch Frame	Plastic injection moulding	3D-printed plastic (SLS)	Not required*

** The supplier did not require drawings, the parts were manufactured by utilizing 3D CAD-models.*

8.1.1 Hatches

As mentioned in Section 7.4.2, the Upper Hatch Frame and Bottom Hatch Frame are to be manufactured by plastic injection moulding. However, considering the high investment cost for two moulds it was not a viable solution for the prototype. The two parts were instead outsourced to the company GTP, who makes prototypes using

additive manufacturing (AM). The AM method used for the Upper Hatch Frame was stereolithography (SLA) even if it is more expensive than the other available methods. The used material was a polymer called Visijet Tough, which has a high impact strength and gives the impression of a injection moulded component. The reasoning behind choosing SLA was partly due to the risk for the part being skew using another AM method, which can cause problems on parts exposed for rough use. The prototype of the Upper Hatch Frame was also intended to demonstrate the appearance in addition to its main function. Hence, the part was post-processed and coated in black to match the surrounding sheet and aluminium profiles.

The Bottom Hatch Frame was produced in the polymer Polyamid PA2200 with the AM method Selective Laser Sintering (SLS). This part was also in the risk zone of being skew using SLS, due to the part's geometry and the method utilizing added heat. However, this part is not exposed to the same rough usage and is not visible when the hatch is closed. It was thereby not worth paying three times as much to produce it with SLA. For the same reason, it was decided to not add any supplementary post-processes. In order to reduce the risk of skewing, GTP divided the part into several pieces which they later merged together before shipping.

8.1.2 Aluminium Frame

As mentioned in Section 7.2, the Aluminium Frame consists of the Outer Profiles, Inner Profiles and Corners. The manufacturing of both the Outer Profile and Inner Profile was outsourced to one of Modul-System's current suppliers of extruded aluminium, located in China. Due to the long lead time, the profiles had to be ordered early in the thesis. The early order made it difficult to decide a suitable colour. Thus, it was decided to skip the anodization and instead coat them later at Modul-System, to avoid a mismatch with other components. The profiles were delivered in pieces of two meters, which required them to be cut into the right length and angle in Mullsjö. The Outer Profile with the wing lock had to be milled in a CNC-machine to fit all the locking mechanism. Lastly, the mounting holes for diverse fastenings were drilled manually.

The Aluminium frame's corners are to be manufactured in cast aluminium (see Section 7.2.2). Due to the high investment cost for the moulds, it was decided to outsource the prototypes of them to GTP as well. The design of the Corner resulted in a lower risk of skewing, therefore the cheaper SLS method was used. GTP only offers SLS models in plastic, which resulted in some modifications of the geometry. The parts had to be slightly thicker to ensure that they could withstand the forces. The used material was the polymer Polyamid PA2200. The corners were post-processed and coated in the same black color as the Upper Hatch Frame.

8.1.3 Hardcover Hinges

As mentioned in Section 7.6.1, the components in the hinge are to be made out of extruded aluminium. To avoid investing in two new expensive dies before the design was approved, RISE IVF was contacted. RISE IVF is a research institute that supports innovation and development of different kinds of materials and processes, including powder for AM [35]. Modul-System and RISE are both partners in the competence center of CAM^2. The competence center offers close collaboration between the involved

organizations within AM. Consequently, RISE offered to manufacture the components in the aluminium alloy AlSi10Mg using the AM method Selective Laser Melting (SLM). The parts were later post-processed at Modul-System by removing the support structure with a drill and thread the holes where the hinges are attached to the backplate. The last step was to coat them black to match the other components.

8.2 Manufacturing of Parts by Modul-System

All the parts produced in Modul-System's facility in Mullsjö only utilized their existing manufacturing processes. Adaptations in some part's design had to be made iteratively throughout the detailed design to facilitate the manufacturing. These adaptations were used to update the design of the affected parts and thereby ensuring that the parts can be manufactured by Modul-System for a potential release of the product. Therefore the parts produced for the prototype are identical with the designed parts presented in Chapter 7. An overview of the produced parts by Modul-System, manufacturing methods and drawings are presented in Table 8.2.

Table 8.2: Overview of the manufactured parts by Modul-System

Part	Intended Manufacturing	Prototype Manufacturing	Drawing
Sandwich Floor	CNC-machining	CNC-machining	Appendix C , Figure C.3
Side Sheet	Punching, bending	Punching, bending	Appendix C, Figure C.4 & C.5
Shallow Side Compartment	Punching, bending, welding	Punching, bending, welding	Appendix C, Figure C.6, C.7 & C.8
Deep Side Compartment	Punching, bending, welding	Punching, bending, welding	Appendix C, Figure C.9, C.10 & C.11
Backplate	Punching, bending	Punching, bending	Appendix C, Figure C.12 & C.13
Cab-side Fastening	Punching, bending	Punching, bending	Appendix C, Figure C.14 & C.15
Top Sheet	Punching	Punching	Appendix C, Figure C.16
Pin Bracket	Punching	Punching	Appendix C, Figure C.17

8.3 Prototype Build of Modul-Cover

The project team built the prototype of Modul-Cover in one of Modul-System's service centers located in Mölndal. The prototype was adapted to fit a Volkswagen Amarok that Modul-System uses for fairs and customer visits. Hence, the dimensions of the components used in the prototype were determined by assembling Modul-Cover on the 3D-scanned Amarok. The Outer Profiles, Inner Profiles and the Sandwich Floor were cut into the right length in Modul-System's production facility Mullsjö.

The majority of the produced components were painted by the project team in the workshop, this was done in order to test how to match the different components' colour (see Figure 8.1 and 8.2). The coating process began with cleaning the components with a liquid to remove residues from the manufacturing process. After cleaning the components they were placed in a paint booth where they were powder coated with a black and smooth color. Finally the components were left to cure in an 180°C hot oven for about 20 min.

Figure 8.1: Powder coating of smaller components.

Figure 8.2: Powder coating of the Outer and Inner Profiles.

After the powder coating, the Bottom Hatch Frames were attached to the Side Sheets and the Top Sheets were attached to the Upper Hatch Frames, both by utilizing a strong glue with a curing time of 24 hours (see figure 8.3 and 8.4). Latches, wing locks and rubber sealings were then attached before the hatches were installed to the Side Sheets with bolts and nuts.

Figure 8.3: Bottom Hatch Frame glued to Sidesheets.

Figure 8.4: Top Plate glued to Upper Hatch Frame.

All the parts were then spread out on the floor and cleaned as a preparation for gluing Modul-Cover together (see Figure 8.5). Due to the overlap on the Outer Profile and Inner Profile the gluing process had to be begin with assembling one side of the Outer

Figure 8.5: Preperation before gluing.

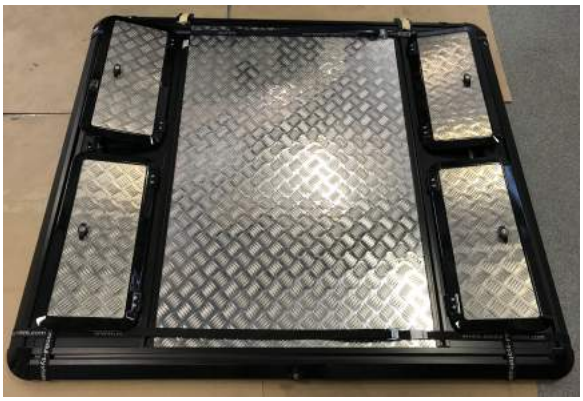


Figure 8.6: Strapped after gluing.

Profile with its corresponding corners and nearby profiles. The rest of the parts then had to slide in from the side. The whole hardcover was then strapped with four straps

placed at the corners to push the parts together and to ensure that they remain there under the 24 hour long curing process (see Figure 8.6).

The last step in the building of the prototype was to mount the hardcover, brackets, locking pins, Backplate and the Side Compartments on the pickup (see Figure 8.7). The brackets were clamped to the side of the pickup by utilizing existing clamps from a competitor's product. The whole hardcover was installed to the pickup by attaching it to the Hardcover Hinges that are screwed to the Backplate. Additional Modul-System products such as load retention eyes, Mobil-box, spray can holders, lighting and straps were attached to showcase all possibilities with Modul-Cover. The final prototype is a good representation of how Modul-Cover should look and function. However, some adjustments on the parts had to be made during the building of the prototype, which needs to be taken into consideration in the further development.

Figure 8.7: The final prototype of Modul-Cover.

8.3.1 Prototype Adjustments

Modul-Cover's design is based on 3D-scans of the five best selling pickups in Europe. The scans helped the development by enabling fast testing of design choices in a CAD environment. However, these scans did lack some details which meant that estimations had to be done. To counteract this two approaches were used. Firstly mounting holes where made into mounting slots, which enabled adjustments when mounting the hardcover. The second approach was to modify the manufactured parts by either drilling larger mounting holes or cutting parts which were to big.

The scan of the Volkswagen Amarok, which the prototype of Modul-Cover was built for, lacked details close to the cab. This resulted in that the Backplate and the Cab-side fastenings needed some small modifications to fit the pickup. This was done by cutting and drilling larger mounting holes to accommodate the difference from the CAD-model and the actual pickup. From this, it is noticed that even with 3D-scans it can be hard to account for all aspects of the pickup. Furthermore, it was noticed that suitable tolerances must be incorporated into the design before a product launch. Finally, the value of having the profiles overlap the Sandwich Floor and the Side Sheets were realized. This made it possible to hide misalignments, and to cut the Sandwich Floor into slightly smaller dimensions, by doing this ease the assembly of Modul-Cover.

When Modul-Cover is fully opened the user can access all storage compartments, both the large space in the middle of the pickup bed as well as the four Side Compartments. In its opened position Modul-Cover is supported by two gas springs, one on each side of the pickup (see Figure 8.8). When mounting the gas springs it was noticed that their initial position needed some adjustment. Therefore new mounting holes were drilled in the Outer Profile and the gas springs were re-attached. It was thereafter found that the gas springs were too weak to lift Modul-Cover from its closed position. Therefore it is recommended for a further product to use stronger gas springs than 400N.

Figure 8.8: Modul-Cover in its opened position supported by gas springs.

In the prototype it was decided to assemble the Side Compartments on one side (see Figure 8.9). This was due to installed brackets on the left side of the pickup bed. They could not be removed due to them being mounted with rivets and the pickup had to be returned in the same shape as it was received. Another adjustment that had to be made was regarding the lighting system (see Figure 8.9). It was intended to be connected to Modul-Systems own control system, Modul-Connect. However, due to time limits it could not be done and the lighting were instead directly connected to the car.

Figure 8.9: Integrated lighting in the prototype.

9
Evaluation of Modul-Cover

In this chapter, the evaluation of Modul-Cover will be discussed. Both the physical prototype and the 3D-modeled prototype will be analyzed. The evaluation will be based on the most important requirements from the specification of requirements. The result from the evaluation, both met requirements and missed ones will be further addressed to in chapter 10.

9.1 Weather Protection

Modul-Cover was designed to improve weather protection compared to competing products. This was to be achieved by increasing the amount of rubber sealing and an overall better fit to the pickup. The idea when designing Modul-Cover was to use a large rubber sealing surrounding the entire hardcover. However, due to time and issues of sourcing a suitable rubber sealing a smaller sized one was used in the prototype. This resulted in small gaps around Modul-Cover and the pickup, which meant that water could enter the pickup bed. Furthermore, the included parts which were glued together did in some joint leak small amounts of water. This was mainly due to poorly placed glue strings. It was also discovered during the prototype building that the hatches got warped on the sides due to the hatches' locks being placed in the middle. This created smaller gaps between the Upper Hatch Frames and the Lower Hatch Frames which mean that the rubber sealing is not compressed.

9.2 Access and Theft Protection

Modul-Cover is equipped with locks for all compartments, both the Side Compartments and the large compartment in the middle. This gives the user the possibility to choose which compartments that can be kept unlocked and which to be locked. By having a separate lock on each hatch enables the user to lock, for instance, two compartments which they store expensive equipment while having two compartments unlocked. In the unlocked compartments can items which are often used and brought from the pickup be stored. This allows for easy and fast access to the Side Compartments located on the driver's side of the pickup. Modul-Cover is when locked theft protected, however, it is not theft proof. The construction and the locks protect the cargo from being stolen by someone without tools. But with the right tools and time, it is possible to break into the compartments. For example, with a disc cutter the side sheet or the Sandwich floor be cut open in just a minute. The goal was therefore not to make Modul-Cover theft proofed, instead it was decided with Modul-System that Modul-Cover should be theft protected, thus minimizing the risk for theft compared to a product without locks. Finally, it is noticed that a central locking system would ease the access of the Side Compartments which therefore is recommended to further investigate and develop.

9.3 Weight

Weight is an important requirement for Modul-Cover, therefore two requirements were set. These are; the weight of Modul-Cover, excluding the Side Compartments, must be below 50 kg and that the total weight of Modul-Cover, including the Side Compartments, must be below 65 kg. In addition, there is a highly rated desire for the total weight to be below 60 kg. Some changes were made to the prototype compared to the detailed design, thus it was not possible to weigh the prototype. Instead, correct materials were applied to all parts in the CAD-model and the weights were calculated by the CAD-software. The result can be found in Table 9.1. It should be noted that the total weight is calculated with two of each Side Compartment.

Table 9.1: Weight of Modul-Cover and Side Compartments.

Weight of Modul-Cover	
Modul-Cover	42,8 kg
Side Compartment Deep	5,5 kg
Side Compartment Shallow	4,1 kg
Total	**62 kg**

The result showed that Modul-Cover fulfills the requirements related to the weight. During the benchmark (section 5.4) it was found that competitors hardcovers range between 30 and 50 kg, this can be compared to the weight of Modul-Cover excluding Side Compartments with a weight of 42,8 kg. The total weight is hard to compare since the existing products lack the utilization of the space around the wheelhouses. Furthermore, the desire for the total weight to be lower than 60 kg is not met. Here the project team noticed that the Side Compartments weight is relatively high compared to the total weight, which will be further discussed in chapter 10.

9.4 Common Parts Across Pickup Models

One important requirement in the thesis was to keep costs down by having a scalable product, a product that fits a range of different pickup models without an extensive need for brand-specific parts. This has been considered throughout the project, affecting the evaluations and the design of certain parts. An example in the earlier stages of the project was to find a suitable corner radius by measuring the 3D-scans. The requirement has also forced the team to revisit the 3D-scans throughout the entire design phase, ensuring that the design of certain components would fit all the required pickup models. Resulting in, after several time-consuming assessments, Modul-Cover with the majority of the parts being shared across all required pickup models.

Modul-Cover has a total of 106 parts, excluding screws and nuts. 90 out of these parts are common across all models while 16 parts need to be sized differently depending on pickup brand, called scalable parts. In addition there is one extra part needed for the Mitsubishi L200 which the other models do not require. Thereby 85% of the components used are exactly the same for all models. By that reducing the costs of warehousing, manufacturing and purchasing. Each scalable component is produced from the same

raw material and the customization for a specific pickup model can be done late in the process at Modul-Systems factory. The most important scalable components are the Side sheet, Backplate, Sandwich floor and the aluminium profiles. The Backplate and the Side sheet are made out of sheet metal which can easily be punched and bent at Modul-Systems factory to fit a specific pickup model. Sheet metal is kept in stock for other products which in combination with the automated bending machine enables short lead times and thereby justifies the parts to be made to order. The Sandwich floor is kept in stock and can be cut to order in Modul-System's large CNC-machine. Lastly, the Aluminium profiles can be ordered in large quantities from their suppliers and be cut to the correct length at Modul-System's factory when needed.

9.5 Overall Impression

The overall impression of Modul-Cover is that it has a good fit on a real pickup truck, which indicates that the proof of concept works as intended. The whole system has an appearance and functions that differs from the existing hardcovers on the market. Thus, giving Modul-System an opportunity to enter the market with a product with improved functionality. Furthermore, the appearance of the powder coated parts met the expectations and the color should thereby be matched when anodizing the components in the future. Even if the prototype has some flaws it is a fair representation of Modul-Cover that succeeds in reflecting robustness, premium feeling, main functions etc. and could thereby be used to get inputs from prospective customers.

10
Further Development of Modul-Cover

Further development of Modul-cover is recommended before launching the product. During the thesis several aspects upon which needs improvements have been found, both aspects which have been considered but also aspects which this project has not covered. This chapter lists areas in which further investigation and development is recommended before the product is produced and sold to the customers.

- **Weight Reduction:** Modul-Cover fulfills the requirements regarding weight, however, it is recommended to further analyzing the parts included in the product. Due to limited time, detailed studies of the structural strengths of the parts has not been carried out, thus the project team believes that parts can be better weight optimized. By reducing the total weight the product will most likely become more popular, especially with the new WLTP regulation affecting the taxation of vehicles. Based on the robustness of the prototype the team believes that the dimensions and the wall thickness of the aluminium profiles can be reduced. A wall thickness reduction of 30% for the Outer profile and 20% for the Inner profile would result in 5kg decreased weight in total.
- **Patent Analysis:** The conducted patent search in this thesis was just a brief analysis of patents regarding full solutions of hardcovers. Thus it did not cover patents on single components. Hence it is recommended for Modul-System to outsource a more comprehensive patent analysis before they potentially launch the product. That analysis should focus on both the full solution as well as the individual components. This in order to investigate if any individual component has infringed on patents not discovered by the project team.
- **Hatches** In the prototype, it was evident that the Hatches had some areas that could be improved before launching Modul-Cover. One recommendation being to investigate the possibility to design a new locking system that locks the hatch on both sides instead of just in the middle. This will probably prevent the hatch to be warped on the sides which results in better weather protection. An alternative is to re-design the hatch with a slightly parabolic shape instead of a flat shape. This shape will cover the gap that is created by the lock being in the middle. Furthermore, it was discovered that the hatches built up a bit on the height, which makes it problematic when loading items from the side. Modul-System should, therefore, investigate if it is possible to lower the hatches to the same level as the Sandwich Floor, without increasing the complexity and the number of components.
- **Side Compartments:** The developed Side Compartments are made out of bent sheet metal, the main reason being that possibility to scale the compartments

depending on the pickup model. Thus achieving a low cost for the product. However, it was discovered that this solution has some limitations and drawbacks. Firstly the weight of the Side Compartments are relatively high, secondly, the shape is limited due to the bend operation. It is therefore recommended to investigate if plastic could be an alternative. This would enable a more complex form with integrated functionality and a better fit to the pickup while reducing the weight.

- **Weather Protection:** The test of the prototype showed that Modul-Cover needs a larger rubber sealing then one used in the prototype. This was mainly due to the fact that the pickup is not perfectly flat along the edge. As well as that Modul-Cover itself might have some imperfection and thus slightly bent, especially when loaded on top. It is therefore highly recommended to either source or design a larger and better rubber sealing. With a larger sealing a more evenly compressed sealing between the hardcover and pickup can be achieved. This will increase the weather protection and it could also, if designed correctly, enhance the appearance of Modul-Cover. To ensure that the joints between the parts in Modul-Cover are watertight it is recommended to apply the glue strings with a robot. By doing so it possible to ensure that the right amount of glue is placed in the right place. If this change still would not create a tight seal it is recommended to modify the aluminium profile and integrate an additional t-slot where a rubber sealing can be placed. This rubber sealing would be placed where it would be compressed between the sandwich floor and the aluminium profiles.

- **Additional Prototypes:** 3D-scans of pickups were used to investigate if Modul-Cover can fit the five most sold pickups in Europe. It was concluded that a hardcover with a trapezoid shape and rounded corners with a radius of 80 mm would fit eight of the nine most sold models. However, it is hard to detect all deviations between the models in a 3D environment. Furthermore, during the building of the prototype it was also discovered that it is not possible to only rely on the scanned models for exact dimensions. Thus it is recommended to build a physical prototype for each model to ensure that all dimensions are correct and all functions act as intended.

- **Electrical Systems:** The work in this thesis focus on the mechanical design and construction of the hardcover, however, it was noticed that electrical add-ons such as central locking and lighting were highly desired by the users. Modul-System is therefore recommended to further develop and integrate these electrical systems for Modul-Cover. The project team believes that lighting and central locking and other potential electrical system could be integrated into Modul-System's existing system for electronics called Modul-Connect.

- **Crash and Load Testing:** The developed hardcover is mounted to the pickup by eight clamps, these clamps and the mounting brackets must be able to withstand forces from both driving but also a potential car accident. The suggested design is assumed to improve the fastening to the pickup compared to competing hardcovers which relies on clamps (see Section 7.6.2). Though, it is highly recommended to perform crash tests to ensure that Modul-Cover fulfills requirements for crash safety. It is also recommended to test the maximum load capacity for Modul-Cover.

11
Concluding Discussion

During this thesis, a functional design and prototype have been developed and tested. This has been done by evaluating pickups on the market, analyzing competing products and creating several different concepts. Furthermore, user needs have been incorporated during the development while, at the same time, requirements and limitations set by Modul-System have been considered. The used development process by collecting data has guided the team throughout the project. Decisions have been based on information and knowledge which the team has gained during the thesis. The project team is therefore confident that Modul-Cover fulfills the most important customer requirements and that it fits Modul-Systems product portfolio. Modul-Cover even opens up the possibility for Modul-System to equip a company's entire vehicle fleet, which can attract new customers. However, further investigations are highly recommended before a product launch. The team believes, for instance, that there are inputs which can be collected by showing the prototype for potential users and customers.

One of the most challenging requirements in this thesis was that the product should be able to fit the five best selling pickups on the European market. The analysis and discussions on how to best solve this problem have been time consuming by having to revisit and re-analyze the pickups along with the concept development. The lack of actual pickups to test and measure has also increased the complexity of ensuring that Modul-Cover can fit the reacquired pickups. However, based on that 3D-scanned pickups are representative the team believes that only small changes would be needed to fit these pickups. Thereby, there is a great potential of leveraging economy of scale with the proposed design. Mainly because Modul-Cover shares the majority of the parts across pickup models while more expensive parts are scalable. It is therefore concluded that Modul-Cover provides an economical beneficial design.

The aim of this thesis was to develop a scalable storage system for the five best selling pickups in Europe. It was also required that the developed product should have Side Compartments located around the wheelhouses and that the storage system should be water and theft protected. With Modul-Cover the project team has developed a hardcover with Side Compartments which fulfills the aim. The developed product should be seen as a proof of concept and function as a stepping stone for Modul-System's future products aimed for the pickup truck segment. The developed product, Modul-Cover, has compared to competitors the advantages of offering smart and space effective utilization of the storage space around the wheelhouses. Modul-Cover has therefore potential of fulfilling the majority of the requirements that were set by analyzing and improving areas which was identified as problematic. The team believes that, even though the prototype did not fulfill all requirements, the learnings from building and testing the prototype will aid Modul-System when further developing a hardcover solution for pickups. These learnings and improvements are discussed in the two previous chapters. Finally, Modul-System expectations on the project have been fulfilled. The management

discussed if the design of Modul-Cover should be patented, however, due to several technicalities, it was decided that an application for industrial design right should be filled. The team therefore concludes that the project has delivered a product proposal in which Modul-System sees great potential in.

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A

Prestudy and Market Analysis

The storage system is easily accessible.
The storage system is easy to access.
The storage system provides easy access to tools.
The storage system ease identification of what is stored.
The storage system is accessed without climbing on the pickup bed.
The storage system provides quick access to items.

The storage system is intuitive and undemanding to use.
The storage system is easy to install.
The storage system is easy to open.
The storage system helps to lift and place heavy items.
The storage system provides visibility when dark.
The storage system provides light that turns on automatically.

The storage system needs low and easy maintenance.
The storage system needs low maintenance.
The storage system is maintained less than twice a year.
The storage system is possible to have installed at the reseller.
The storage system is easy to wash and clean.
The storage system is easily kept clean.

The storage system is capable of storing various sizes of items.
The storage system provides space to store smaller items.
The storage system provides space to store bulky items.
The storage system provides space to store long items.
The storage system provides space to store heavy items.
The storage system provides space to store middle sized items.
The storage system provides space to store tall items.
The storage system provides space to store straps.
The storage system provides space to store screws.
The storage system provides space to store hearing protection.
The storage system provides space to store a shovel.
The storage system provides space to store long and delicate items.
The storage system provides space to store a crowbar.
The storage system provides space to store petrol cans.
The storage system provides space to store tool boxes.
The storage system provides space to store a ladder.
The storage system provides space to store a broom.
The storage system provides space to store weapons.
The storage system can accommodate standard sizes of building material.

The system provides secure storage
The storage system provides fastening opportunities for items.
The storage system can fasten and transport long objects.
The storage system fasten tools easily.
The storage system can fasten heavy equipment.
The storage system provides secure storage.
The storage system provides simple fastening.
The storage system provides interchangeable fastening system.
The storage system has contained storage compartments.

The system provides safe storage.
The storage system informs the user when locked.
The storage system is theft proof.
The storage system is optional to lock.
The storage system conceals what is stored inside.
The storage system is lockable.
The storage system's mounting points are protected.
The storage system reduces redundancy in locking.

The storage system provides warm and dry storage.
The storage system provides warm storage areas for tools.
The storage system provides warm storage areas for clothing.
The storage system provides warm storage areas for batteries.
The storage system dries wet items.
The storage system has a dry storage area.
The storage system removes odur.

The storage system enables the user with a workplace.
The storage system enables a space to work and put down items.
The storage system provides a workbench.
The storage system enables a stable placement for a vice.
The storage system enables work from on top of the system.

The storage system has miscellaneous value add-ons.
The storage system provides compressed air.
The storage system provides storage of fuel and delivery system.
The storage system provides power outlets.
The storage system provides a sound system.

Figure A.1: User needs from the market study (part one).

The storage system has minimal impact from external factors.
The storage system has similar performance when loaded.
The storage system is robust.
The storage system has durable opening and closing functions.
The storage system is resistant to corrosion.
The storage system functions in dirty conditions.
The storage system is durable.
The storage system is weather protected.
The storage system has waterproof storage
The storage system stops water from accumilating

The storage system keeps the desired functionality of the pickup.
The storage system keeps the rear view mirror visibility.
The storage system keeps the functionality of the tailgate.
The storage system allow use of the towbar.

The storage system has a attractive design.
The storage system has a durable design.
The storage system maintains original design.
The storage system has a clean and industrial look.

The storage system provides good space utilization.
The storage system provides good space utilization.
The storage system utilizes the space around the wheelhouses.
The storage system is customized to the pickup.

The storage system provides adaptability to fit the changing user needs.
The storage system has interchangeable compartments/dividers.
The storage system helps organizing items.
The storage system has interchangeable modules/customizable modules.
The storage system provides subcompartments for organizing smaller items.
The storage system provides various storage solutions.
The storage system is detachable from the pickup.
The storage system can be customized at purchase.

Figure A.2: User needs from the market study (part two.

Table A.1: Requirements Specification for Modul-Cover.

Requirements Specification for Modul-Cover						
	Critierion	Target value	R/D	Weight	Evaluation / Verification	Justification
1	**Performance**					
1.1	Weatherproofed storage compartments	No sorts of precipitation or dirt in the storage area	R		Prototype testing	Market competition
1.2	Theftproofed storage compartments	Impossbile, without tools, to access the storage	R		Prototype testing	Market competition
1.3	Storage area on top of the hardcover	Flat surface	R		CAD-model	Market competition
1.4	Fastening options on top of the hardcover	> 4 fastening points	R		Prototype testing	Related to 1.2
1.5	Load capacity on top of the hardcover	> 4500 N in downward direction	R		Crash testing	Modul-System acceleration standard
1.6	Load capacity on top of the hardcover	> 4500 N in forward direction	R		Crash testing	Modul-System acceleration standard
1.7	Load capacity on top of the hardcover	> 1500 N in lateral direction	R		Crash testing	Modul-System acceleration standard
1.8	Load capacity on top of the hardcover	> 1500 N in backward direction	R		Crash testing	Modul-System acceleration standard
1.9	Load capacity on top of the hardcover	> 1500 N in upward direction	R		Crash testing	Modul-System acceleration standard
1.10	Selfopenable hardcover	Carry weight of the hardcover + 5 kg of equipments	R		Prototype testing	Market competion and usability
1.11	Selfopenable hardcover	Carry weight of the hardcover + 15 kg of equipments	D	3	Prototype testing	Market competion and usability
1.12	Minimum sound	No metallic rattle	R		Physical testing	Premium feeling
1.13	Access to side compartments	Seperately access/ Accessable with hardcover closed	R		CAD-model	Usability
1.14	Hatches stays in desired position	Hatches stays in desired position	R		Prototype testing	Usability
1.15	Ability to utilize Modul-Systems's existing products	Integrate Modul-System's sandwich floor	R		CAD-model	High load capacity, predefined Modul-System requirement
1.16	Ability to utilize Modul-Systems's existing products	Integrate > 4 of Modul-System's t-slots	R		CAD-model	Customizability for the user, additional accessories sales
1.17	Ability to utilize Modul-Systems's existing products	Integrate > 2 of Modul-System's 27 mm interface	D	4	CAD-model	Customizability for the user, additional accessories sales
1.18	Facilitate visibility inside storage area	100 Lux	R		Prototype testing	User ergonomics
1.19	Facilitate visibility inside storage area	50 Lux	D	5	Prototype testing	User ergonomics
2	**Retail Price**					
2.1	Retail price	< 25 000 SEK	R		Cost estimation	Market competition
2.2	Retail price	< 20 000 SEK	D	5	Cost estimation	Market competition
3	**Legislation**					
3.1	Handle deceleration in forward direction	1.0 g	R		Crash testing	Transportstyrelsen
3.2	Handle deceleration in forward direction	3.0 g	R		Crash testing	Modul-System standard
3.3	Handle acceleration in backward direction	0.5 g	R		Crash testing	Transportstyrelsen
3.4	Handle acceleration in a lateral direction	0.5 g	R		Crash testing	Transportstyrelsen
3.5	Handle acceleration in a lateral direction	1.0 g	R		Crash testing	Traffic safety
3.6	Not cover lights/indicators on car while driving	0% coverage	R		CAD-model	Transportstyrelsen
4	**Shipping**					
4.1	Effective packaging	Packageable in one flat package	R		Test packaging	Minimize shipping costs
4.2	Effective packaging	Fits on one standard EUR-pallet	D	1	CAD-model	Minimize shipping costs
4.3	Logistics	Compliant with Modul-Systems current solution	D	3	Test packaging	Minimize shipping costs
4.4	Height on pallet	< 2500 mm	D	3	Test packaging	Transport-efficiency
5	**Weight**					
5.1	Maximum weight for the hardcover	< 50 kg	R		CAD-model	Market competition, WLTP
5.2	Maximum weight for the hardcover	< 45 kg	D	4	CAD-model	Market competition, WLTP
5.3	Maximum weight for the whole system	< 65 kg	R		CAD-model	Market competition, WLTP
5.4	Maximum weight for the whole system	< 60 kg	D	4	CAD-model	Market competition, WLTP
6	**Material**					
6.1	Corrosion resistant	No corrosion within warranty period	R		Salt spray test	Premium feeling, Modul-Standard
6.2	UV-resistant	Low visible colour fading during warranty period	R		UV-testing	Premium feeling, Modul-Standard
6.3	Functionable and resistant temperature variations	-30°C to 60°C	R		Temperature testing	Functional in all climates
6.4	Resistance againt common used chemicals	Gasoline, oils, degreaser, washing fluids, diesel, etc.	R		Chemical testing	Market competition
7	**Scalability**					
7.1	Adaptable Fit different pickup models	The five most popular models on the EU market	R		CAD-model	The five best selling models represent 83% of the market
7.2	Adaptable Fit different pickup models	The seven most popular models on the EU market	D	3	CAD-model	The seven best selling models represent 88% of the market
7.3	Common parts accross pickup models	> 65% common parts	R		CAD-model	Scale of economy
7.4	Common parts accross pickup models	> 80% common parts	D	5	CAD-model	Scale of economy
7.5	Scalable parts across pickup models	< 25% scalable parts	R		CAD-model	Scale of economy
7.6	Scalable parts across pickup models	< 15% scalable parts	D	5	CAD-model	Scale of economy
7.7	Unique parts across pickup models	>10% unique parts	R		CAD-model	Scale of economy
7.8	Unique parts across pickup models	> 5% unique parts	D	5	CAD-model	Scale of economy
8	**Assembly and Installation**					
8.1	Pre-assembled at Modul-Systems factory	Delivered to service centers fully assembled	R		Test assembly	Modul-System standard
8.2	Time to assemble	< 2 h	R		Test assembly	Cost effieciency
8.3	Time to assemble	< 1 h	D	3	Test assembly	Cost effieciency
8.4	Easy to assemble	Two persons with standard tools	R		Test assembly	Cost effieciency
8.5	Easy to assemble	One person with standard tools	D	5	Test assembly	Cost effieciency
8.6	Time to install on pickup	< 1.5 h	R		Test installation	Cost effieciency
8.7	Time to install on pickup	< 1 h	D	5	Test installation	Cost effieciency
8.8	Minimum impact on the pickup	No drilled holes on the pickup	R		CAD-model	Aftermarket for pickups, rust protection of the pickup
8.9	Minimum impact on the pickup	No gluing on the pickup	D	3	Protoype testing	Aftermarket for pickups, no harm to the car paint

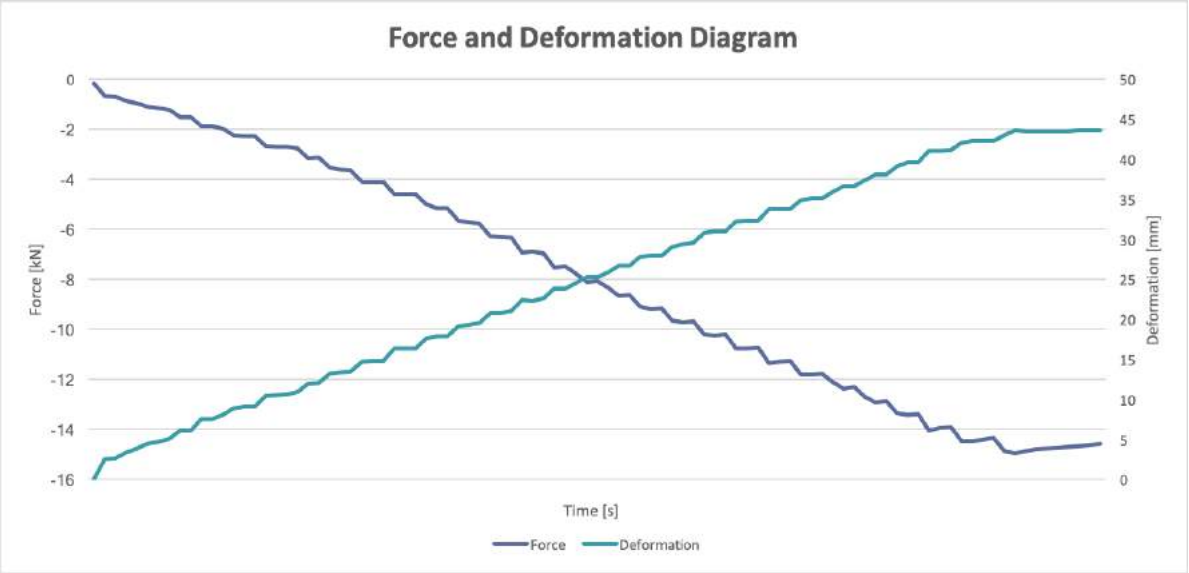

Figure A.3: Result from the first deformation test.

Table A.2: Benchmark Matrix of competing products.

Benchmark Matrix						
Name	Mountain Top Style HD+	EVO400 Upstone	Almecolock	UnderCover Ridgelander	Aluminium tonneau cover	Black diamondback 270
Price	16 000 SEK	19 000 SEK	23 000 SEK	14 000 SEK	14 000 SEK	17 000 SEK
Accessability	Opened from the back tilting the lid upward toward the CAB. Gas springs makes it harder to acces items close the the cab	Opened from the back tilting the lid upward toward the CAB. Gas springs and the advanced hinges makes it harder to acces items close the the cab	Opened from the back tilting the lid upward toward the CAB. Gas springs and cover close to the cab makes it hard to acces items close the the cab. Possible to fold the cover in different positions	Opened from the back tilting the lid upward toward the CAB. The advanced hinges makes it harder to acces items close the the cab. The gas springs are installed clos to the tailgate so it makes even harder to reach items from the sides.	Opened from back tilting 2/3 of the whole lid upward toward the CAB. Gas springs makes it harder to acces items	Open one lid from the back and two from the side next to the cab
Complexity	Simple solutions, few part that are needed. Back flip hinges	Medium complexity, few parts needed. "Window fittings". Uses a longer rail mounted on the inside of the sidewalls	Medium/High complexity, several back flip hinges are needed and serveral areas which needs to be sealed.	Medium complexity, few parts needed. "Window fittings". Uses a longer rail mounted on the inside of the sidewalls	Simple solutions, few part that are needed. Back flip hinges	Simple solution. No need for rails on side walls. Several back flip hinges
Installation	Four clamps under the edge of the pickup sides. No drilling needed. One piece close to tha cab is needed which the hinges are mounted to	One rail is mounted on each sidewall and cab side. The"window fitting" is then mounted to the rail as well a the locking pins	Mounted close to the cab. Unclear if drilling needed. Rail mounted on the inside of the sidewalls	One rail is mounted on each sidewall and cab side. The "window fitting" is then mounted to the rail as well a the locking pins. 60 min according to the manufacturer	Hard to see exactly how it is installed	One part is clamped to the side wall in middle of the bed. The lids are later installed on the middle part. 75 min according to the manufacturer
Sealing	Rubber sealing fasten on the lid which is pressed against the sidewalls	Rubber sealing fasten on the lid which is pressed against the sidewalls	Rubber sealing fasten on the lid which is pressed against the sidewalls. The lid is sealed to it self when closed by pressing rubber sealings together	Rubber sealing fasten on the lid which is pressed against the sidewalls	Rubber sealing fasten on the lid which is pressed against the sidewalls	Compression gasket around the lid. There is drainage channels between lids.
Theft protection	Mechnical locking which are locking the lid at both sidewalls of the pickup. Locking mechanism connects around a pin on each side	Mechnical locking which are locking the lid at both sidewalls of the pickup. Locking mechanism connects around a pin on each side	Mechnical locking which are locking the lid at both sidewalls of the pickup. Two rods are located under the pickup's sidewalls when rotating the handle. Can be connected to the central locking system of the car	Mechnical locking lock which are locking the lid at the side walls. There are wires from the key lock to the locking mechanism on each side.	Mechnical locking which are locking the lid at both sidewalls of the pickup. Two rods are located under the pickup's sidewalls when rotating the handle.	Mechanical locking system for each lid. Using rods to lock the lids
Adadaptability	All part can be used on different models as long as its is possible to use clamps. The lenght and width of the frame, the length of the drip cover close to the cab and loading platform must be cut to right dimensions	All part can be used on different models as long as its is possible to use clamps. The lenght and width of the frame, the length of the drip cover close to the cab and loading platform must be cut to right dimensions	All part can be used on different models as long as its is possible to use clamps. The lenght and width of the frame, the length of the drip cover close to the cab and loading platform must be cut to the lenght of the pickup	All part can be used on different models as long as its is possible to use clamps. The lenght and width of the rails and loading platform must be cut to the lenght of the pickup	Seems to only exist for Volkswagen Amarok	All part can be used on different models as long as its is possible to use clamps. The lenght and width of the frame and lids must be cut to theright dimensions
Loading capacity	150 kg	80 kg	150 kg	115 kg	N/A	180 kg
Integrated add-ons	Integrated accessory fitting channel in side profiles, which enables side bars or roof racking	Integrated accessory fitting channel in side profiles, which enables roof racking	Possible to mount roof racking. Central locking system	Possible to mount roof racking, inside fitting channel	Bike carriers, roof racking and other systems to mount items on top	Possible to buy accessories such as side bins, side boxes, ramps, boxes reaching side to side etc.
Material	Aluminium cover with an aluminium frame	Aluminium cover with an aluminium frame	Aluminium cover	Aluminum cover with an aluminium frame	Aluminium cover	Aluminum cover, stainless steel hinges and die-cast zink handles
Available in Europe	Yes	Yes	Yes	No. Fits none of the popular models in Europe	Seems to be just for Amarok	Only for Ford Ranger on the European market
Weight	29-40 kg	35 kg	40-50 kg	40-50 kg	N/A	41 kg

B
Concept development

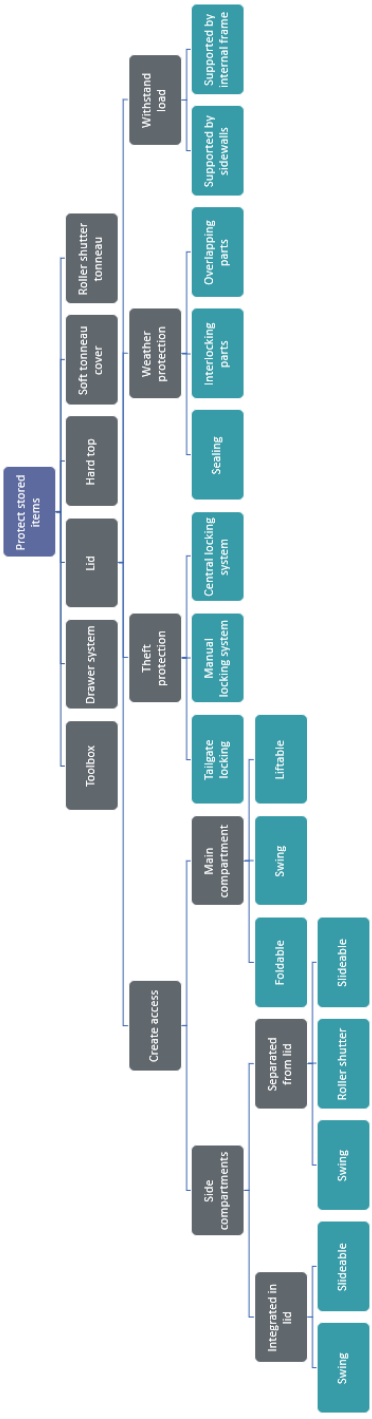

Figure B.1: Functional tree for the hardcover.

C
Prototype

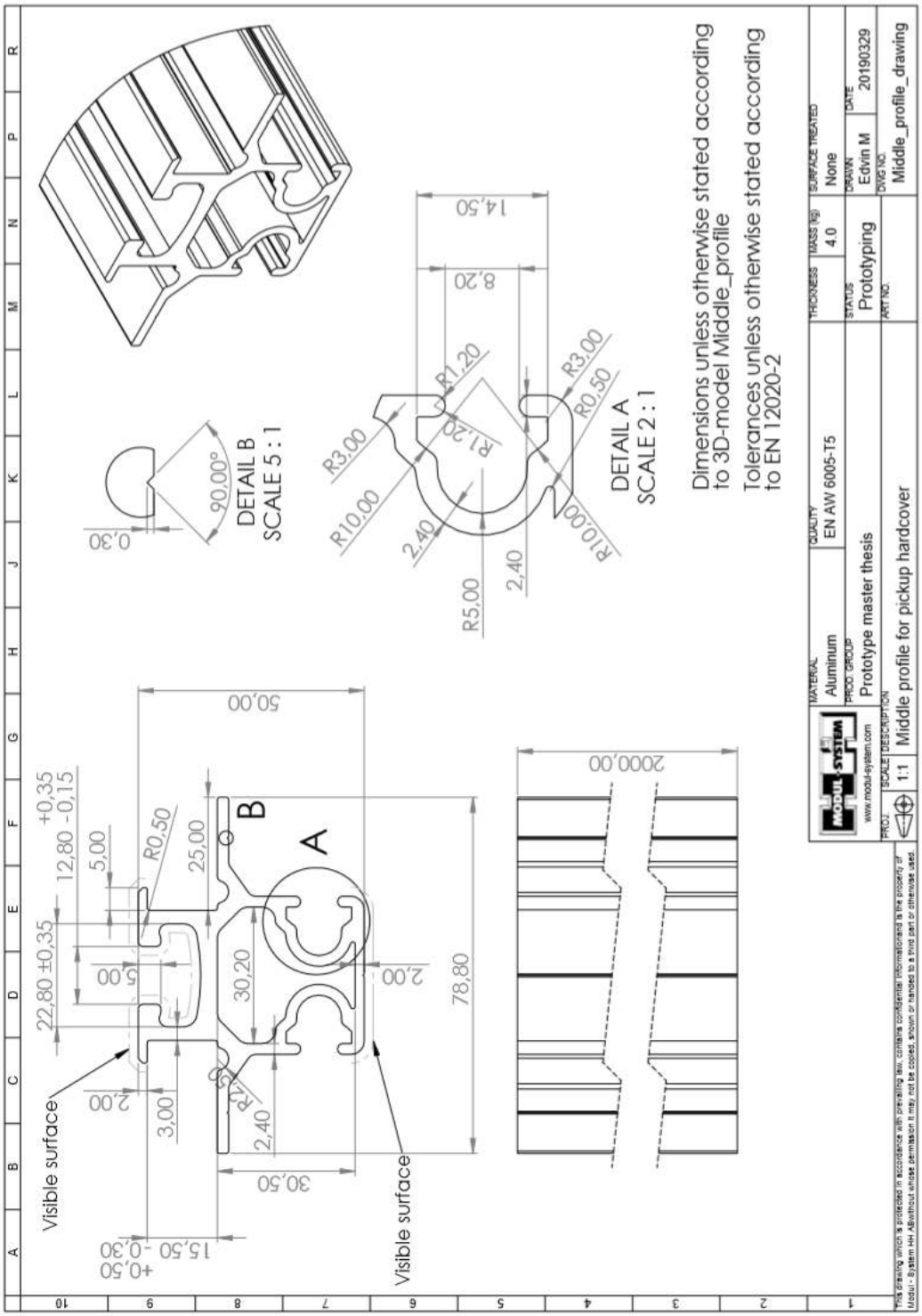

Figure C.1: Drawing of the Inner Profile.

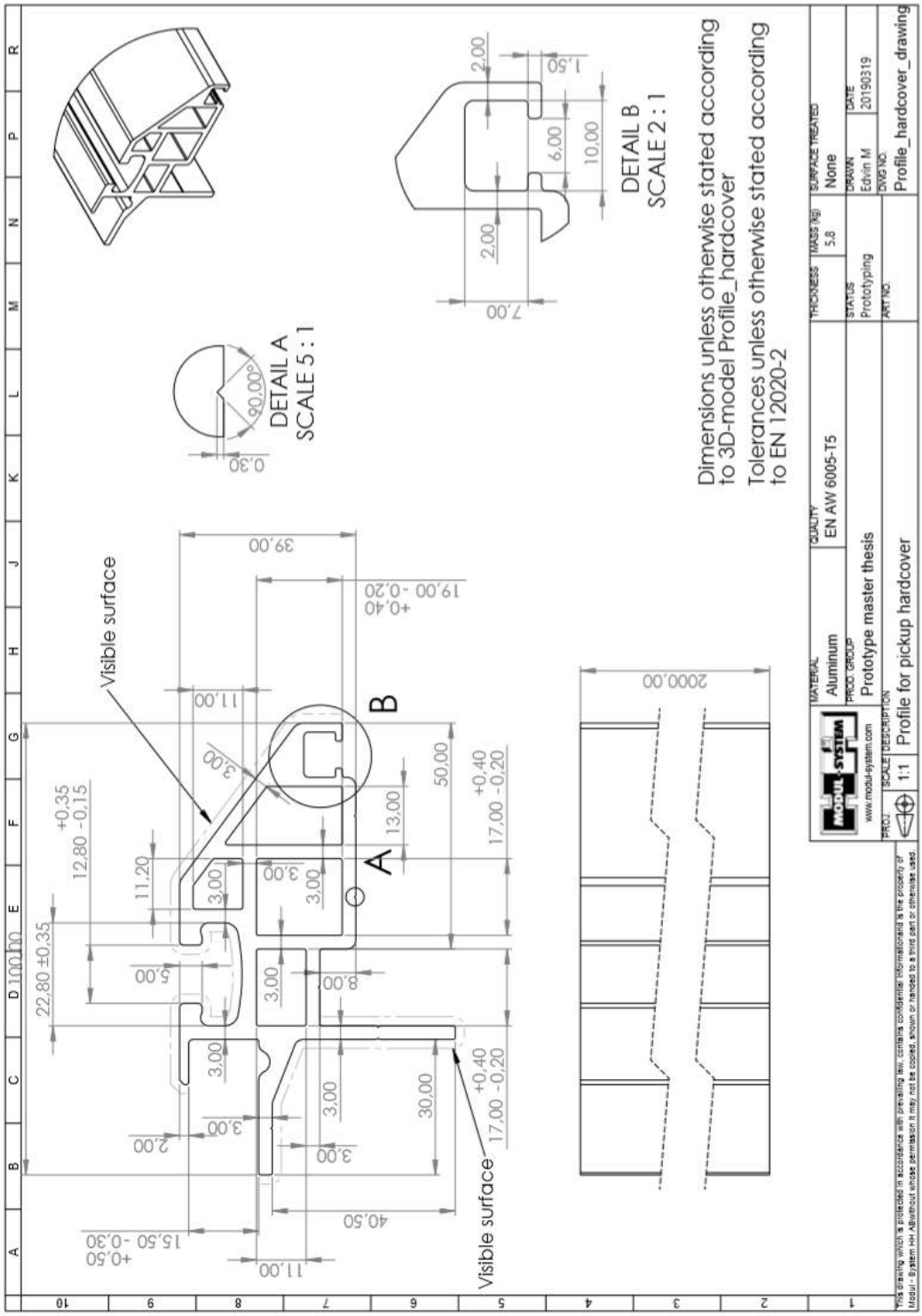

Figure C.2: Drawing of the Outer Profile.

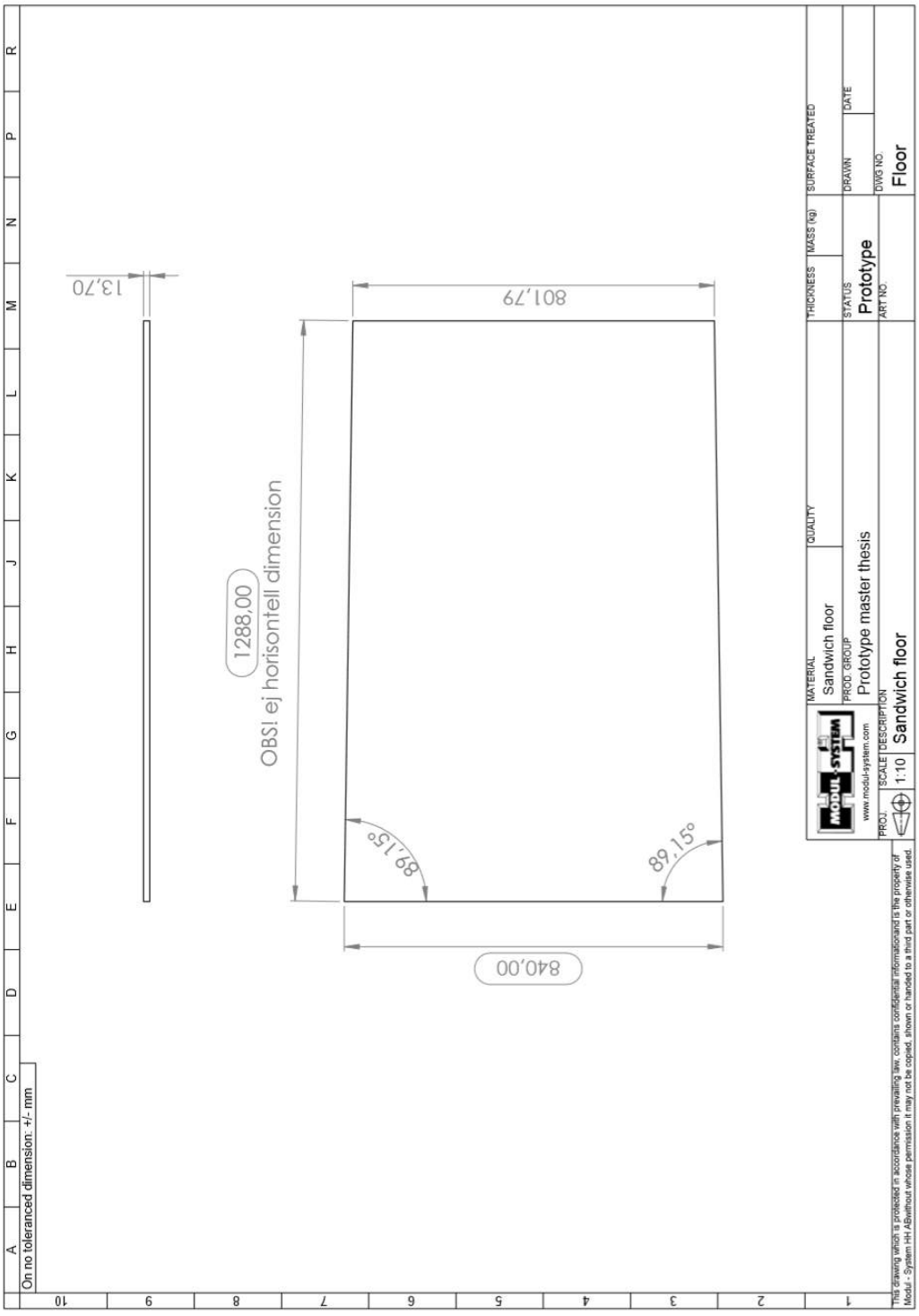

Figure C.3: Drawing of the Sandwich floor.

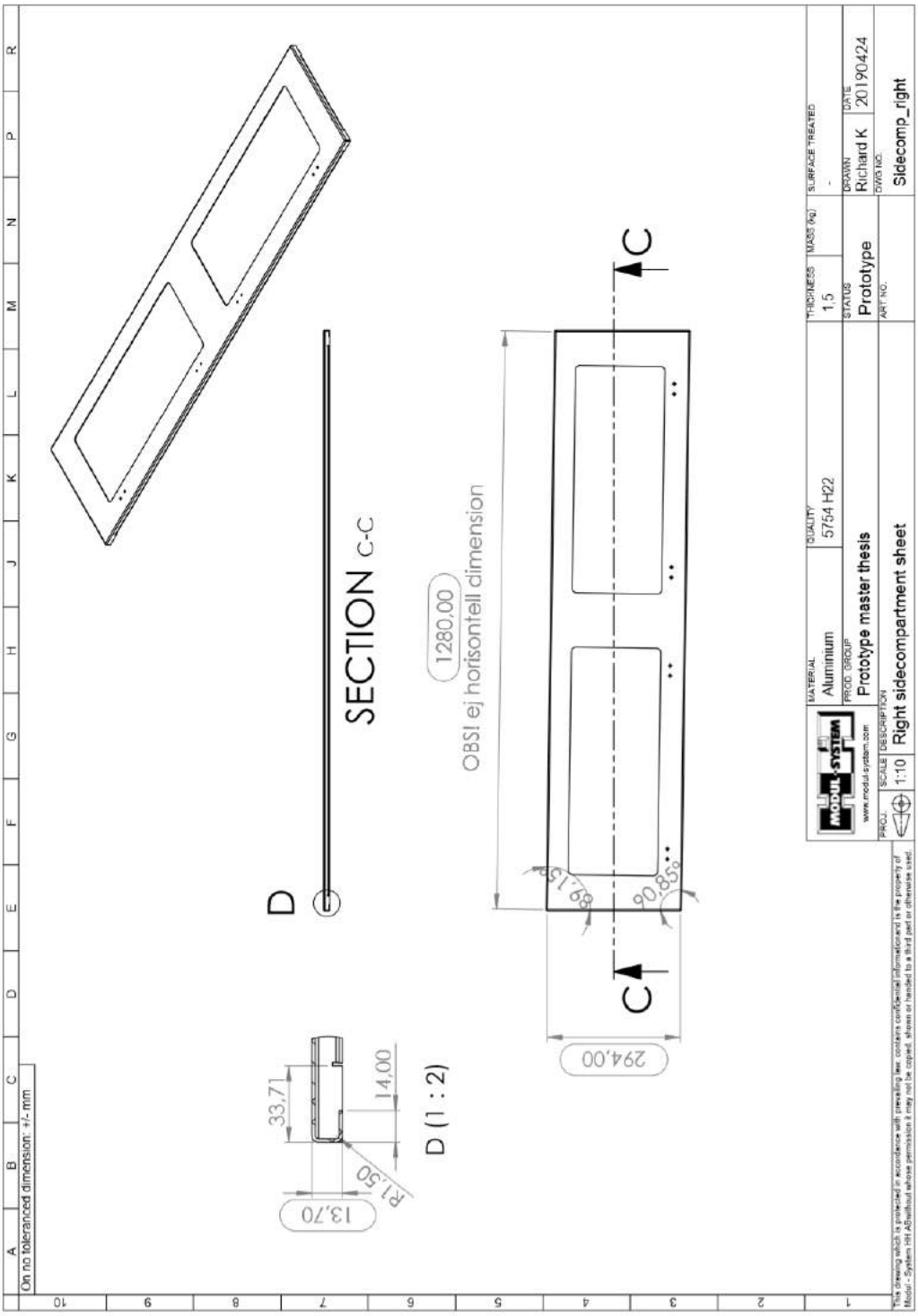

Figure C.4: Bend drawing of the right side sheet.

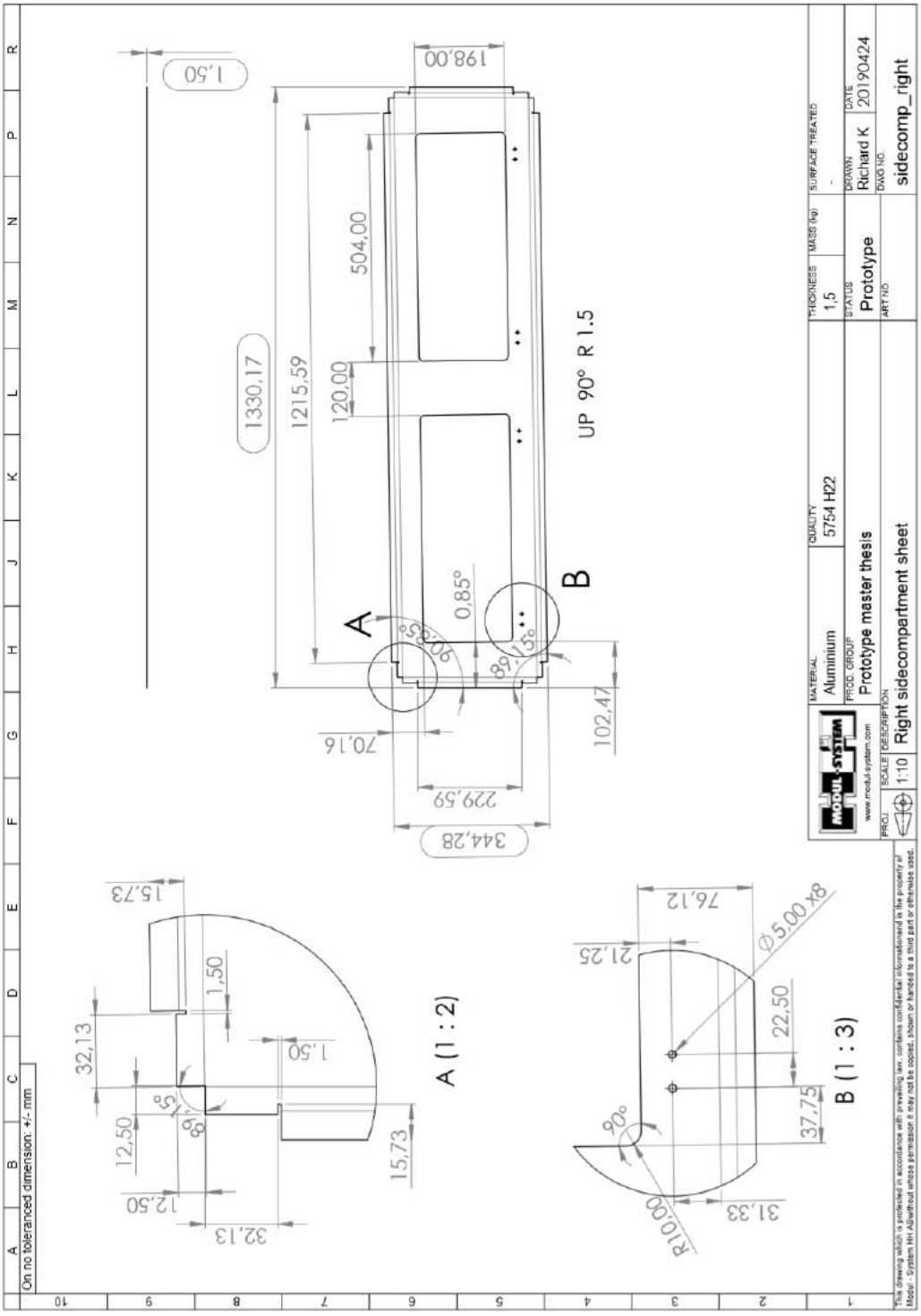

Figure C.5: Flat drawing of the right side sheet.

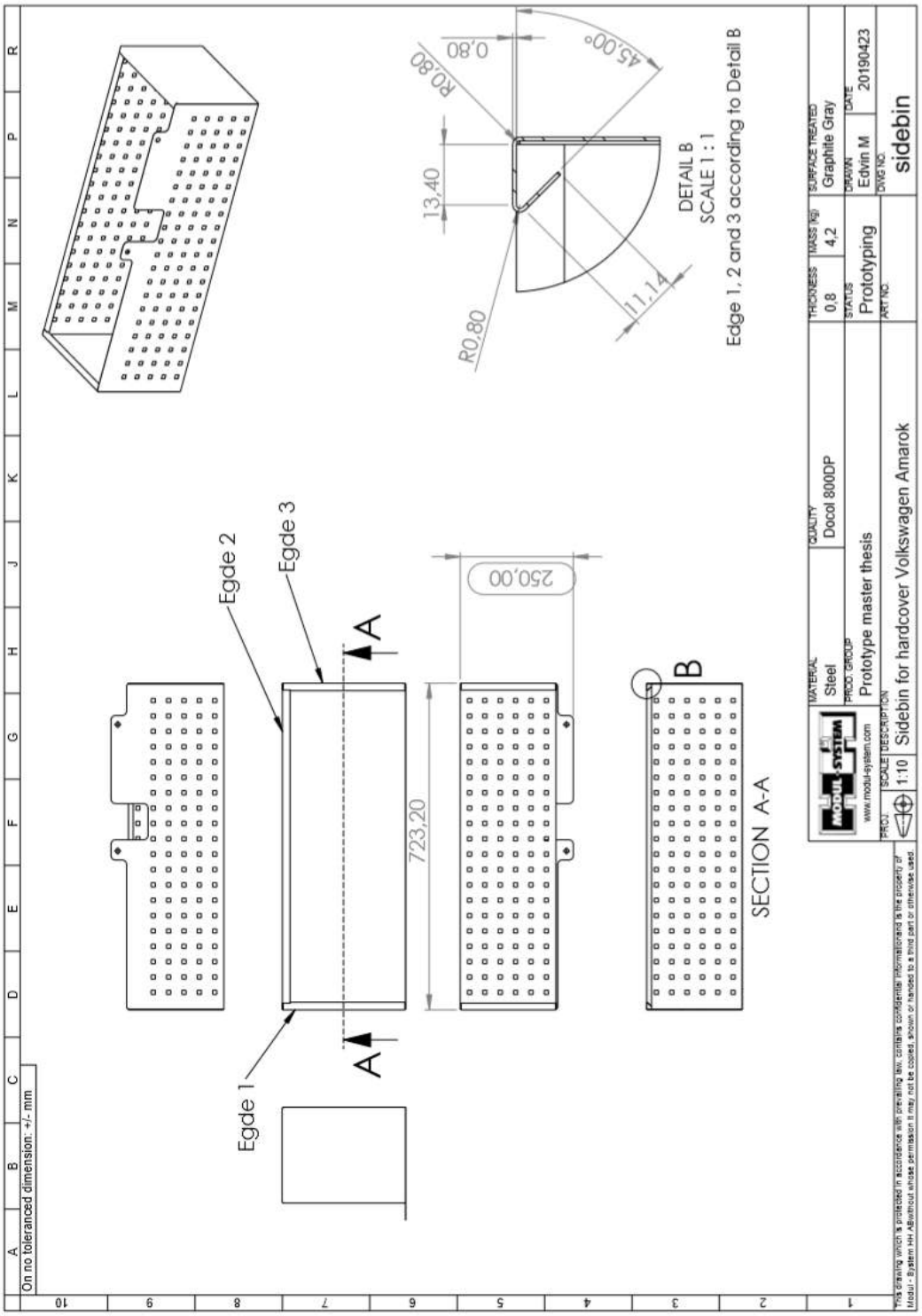

Figure C.6: Bend drawing of the shallow Storage Compartment.

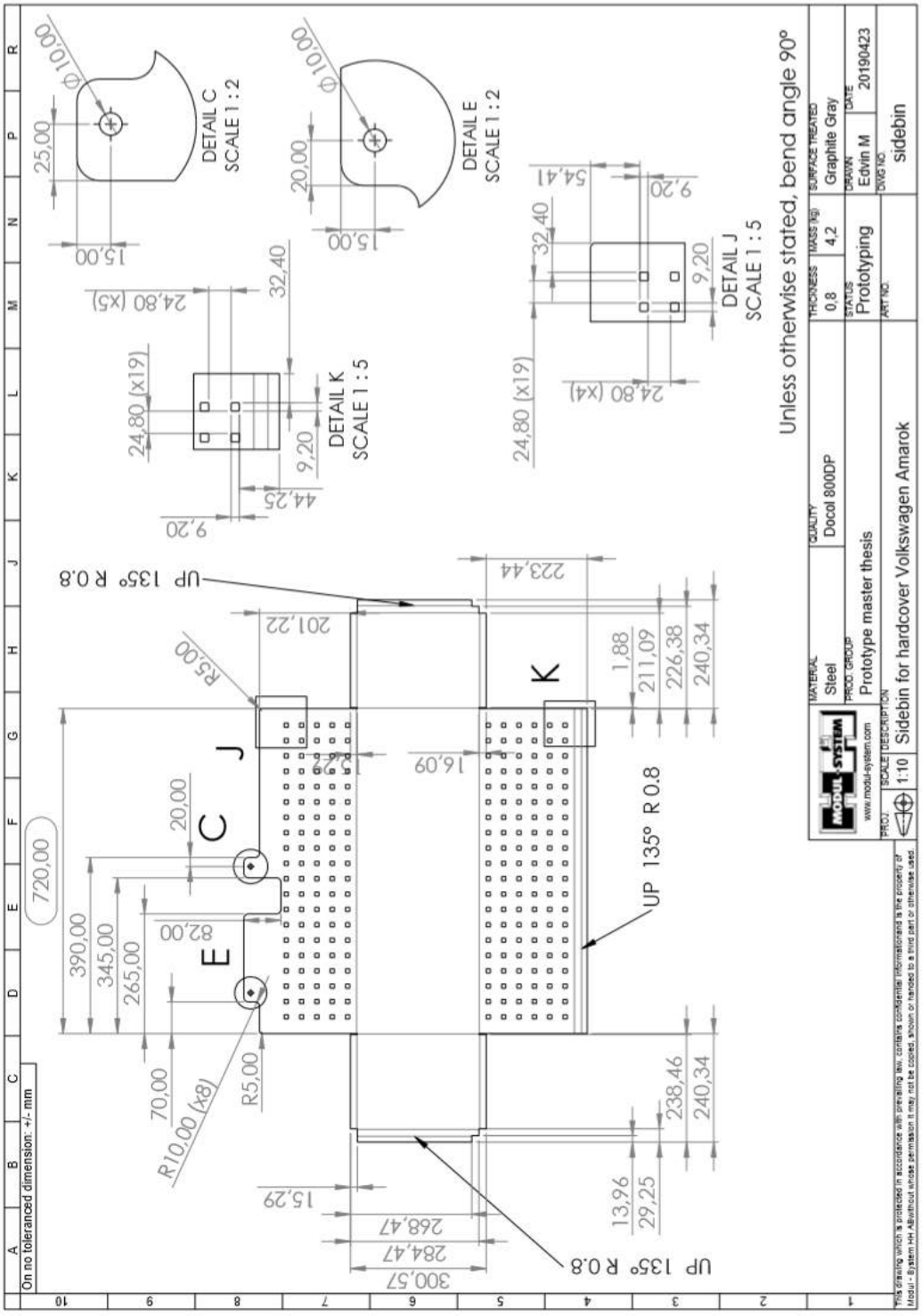

Figure C.7: Flat drawing of the shallow Storage Compartment.

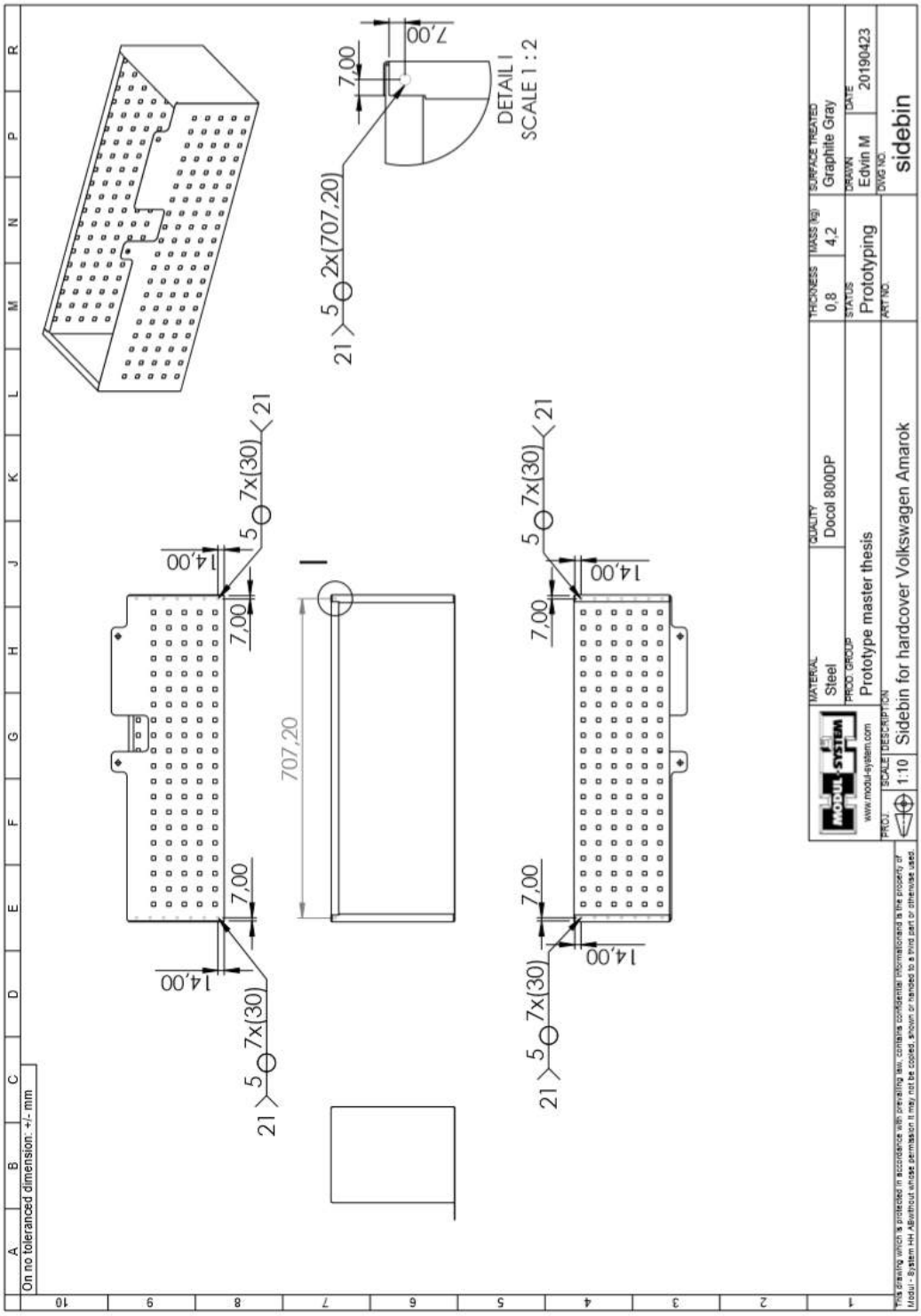

Figure C.8: Weld drawing of the shallow Storage Compartment.

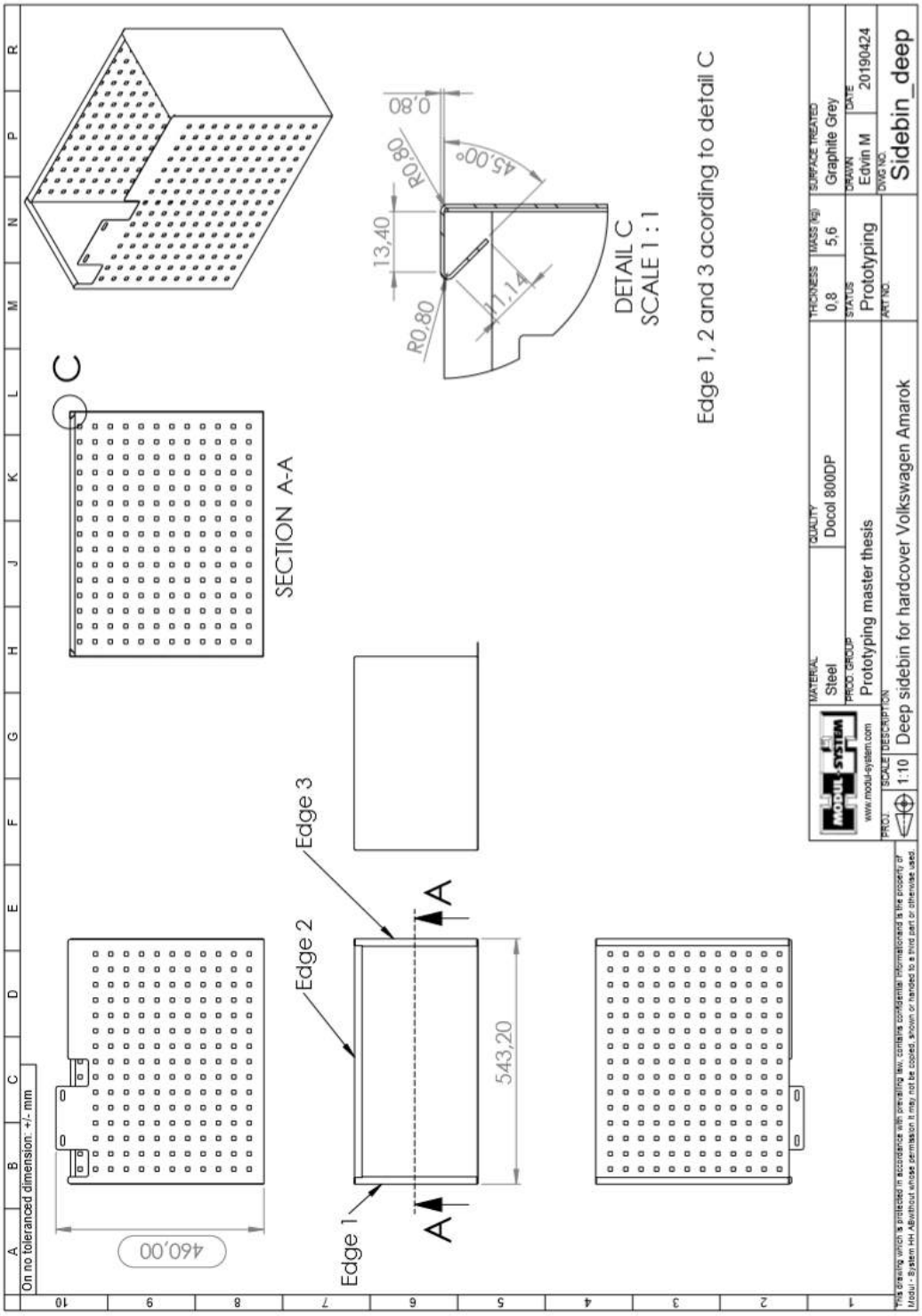

Figure C.9: Bend drawing of the deep Storage Compartment.

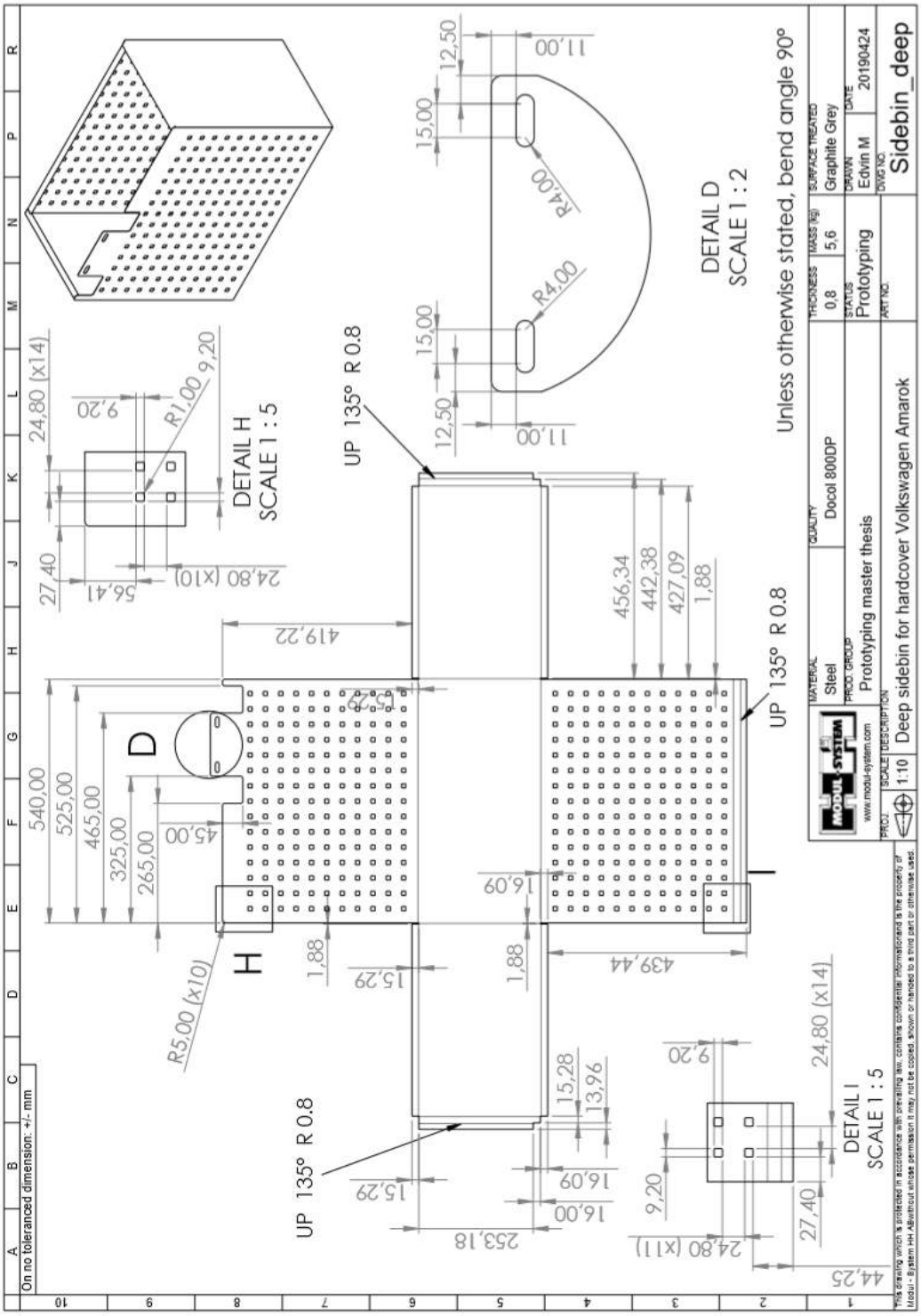

Figure C.10: Flat drawing of the deep Storage Compartment.

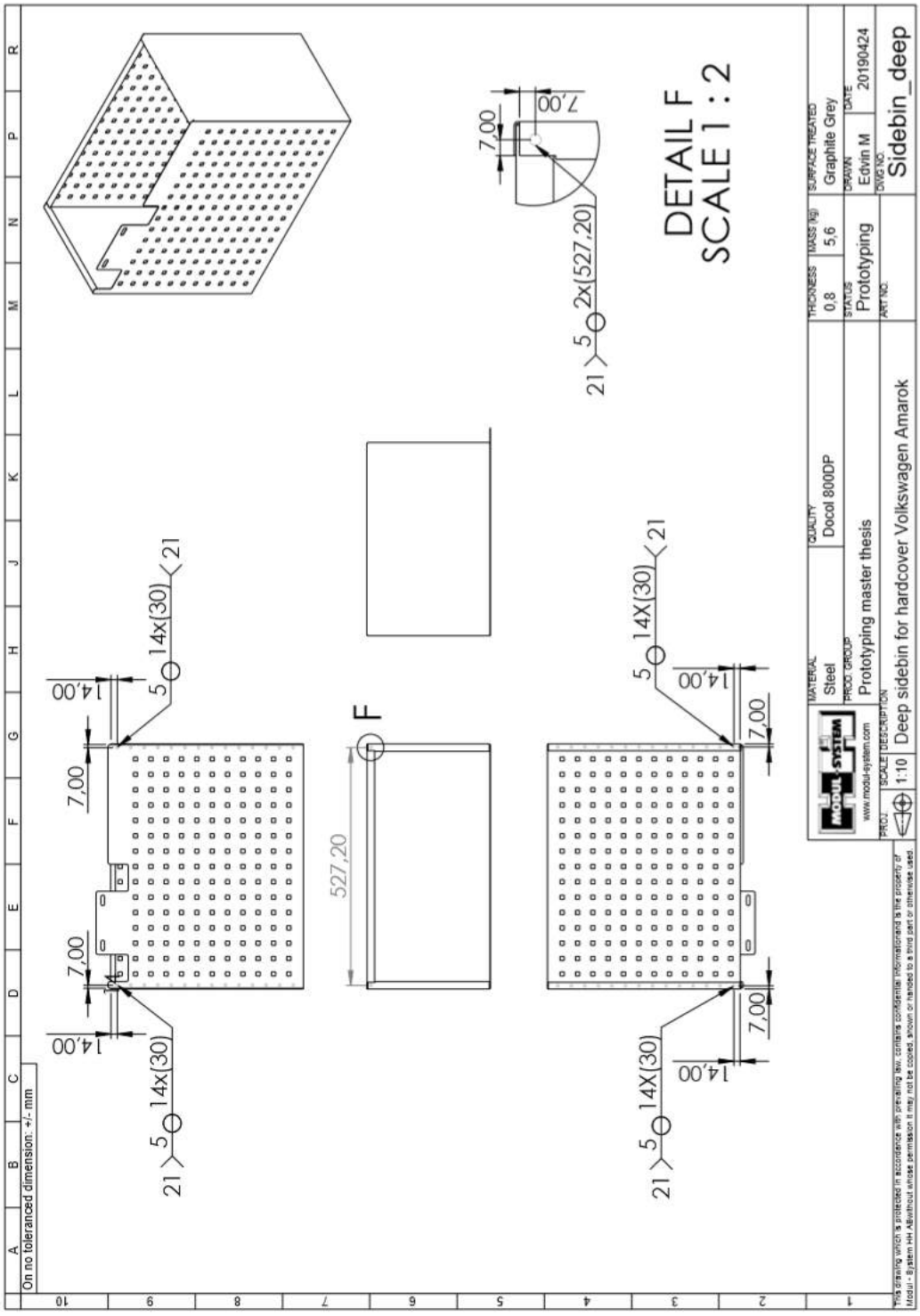

Figure C.11: Weld drawing of the deep Storage Compartment.

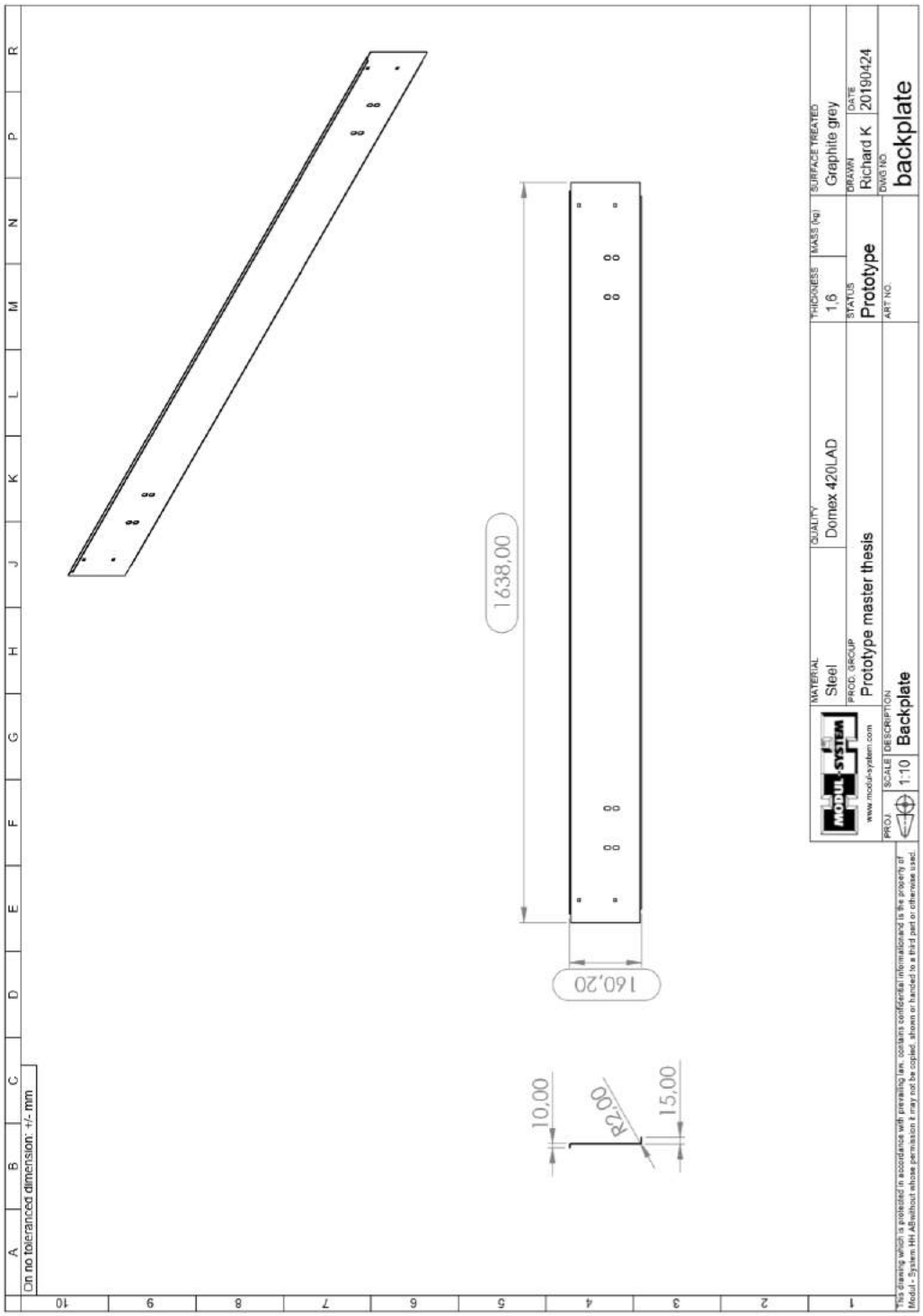

Figure C.12: Bend drawing of the Backplate.

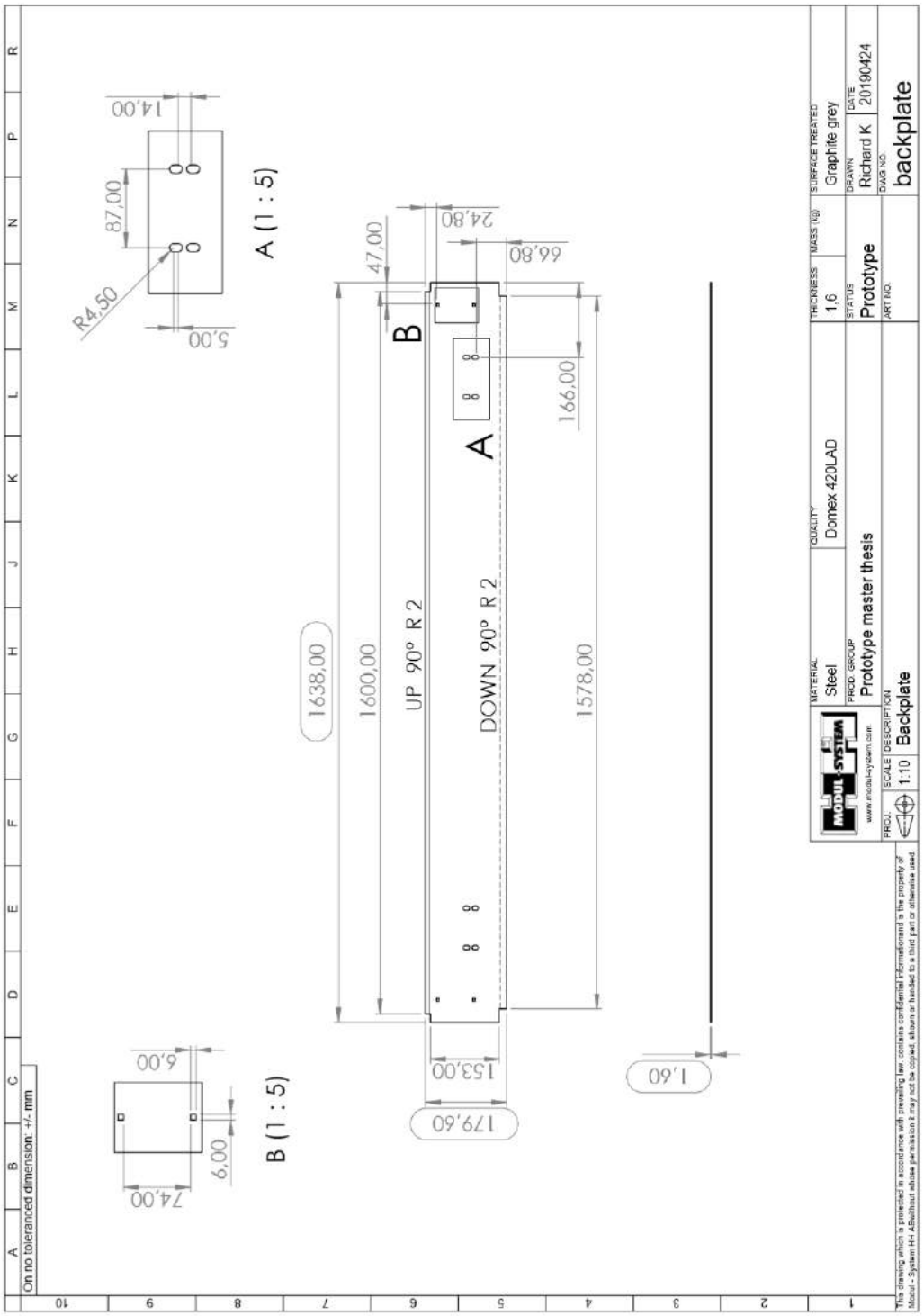

Figure C.13: Flat drawing of the Backplate.

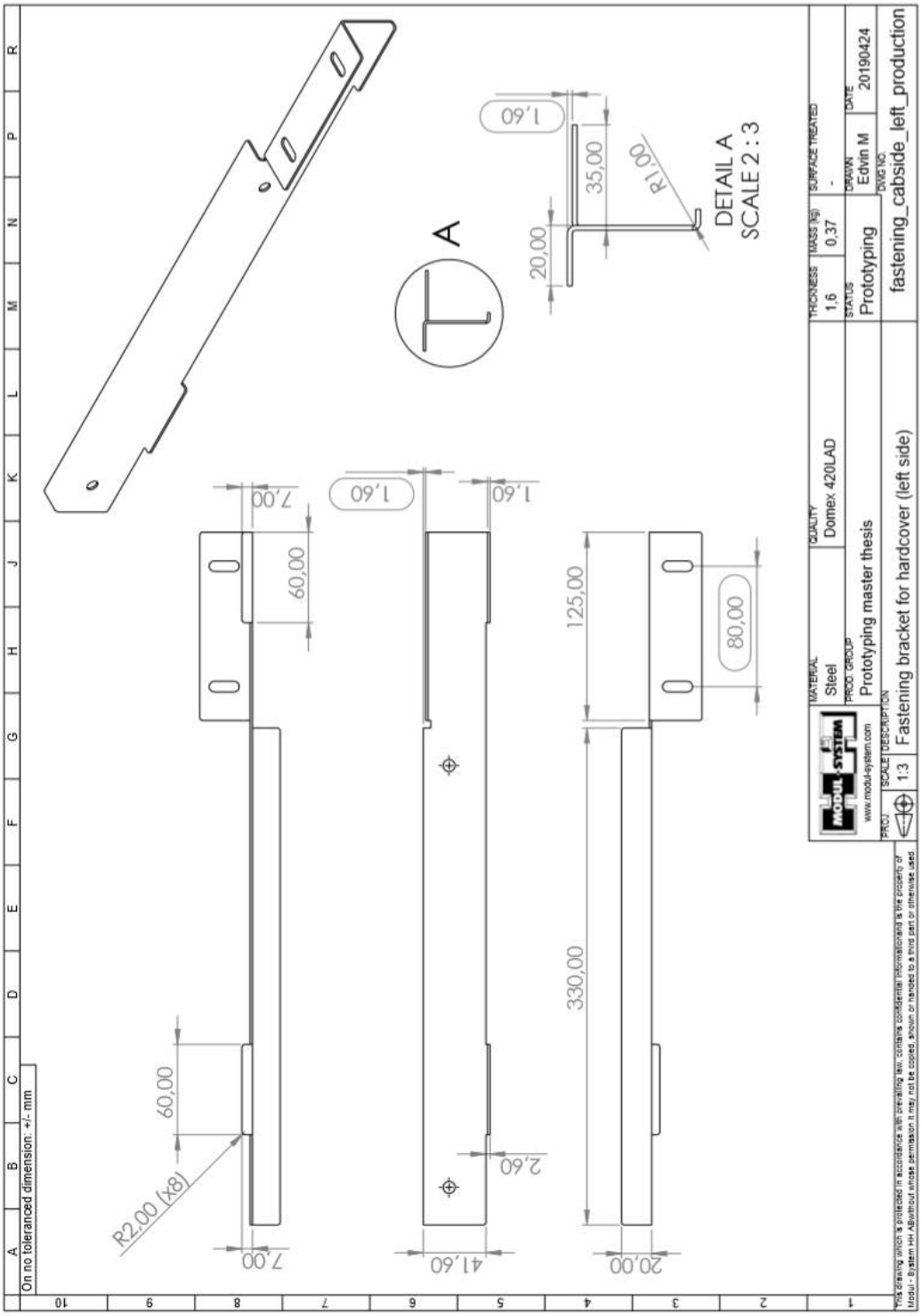

Figure C.14: Bend drawing of the Cab-side Fastening.

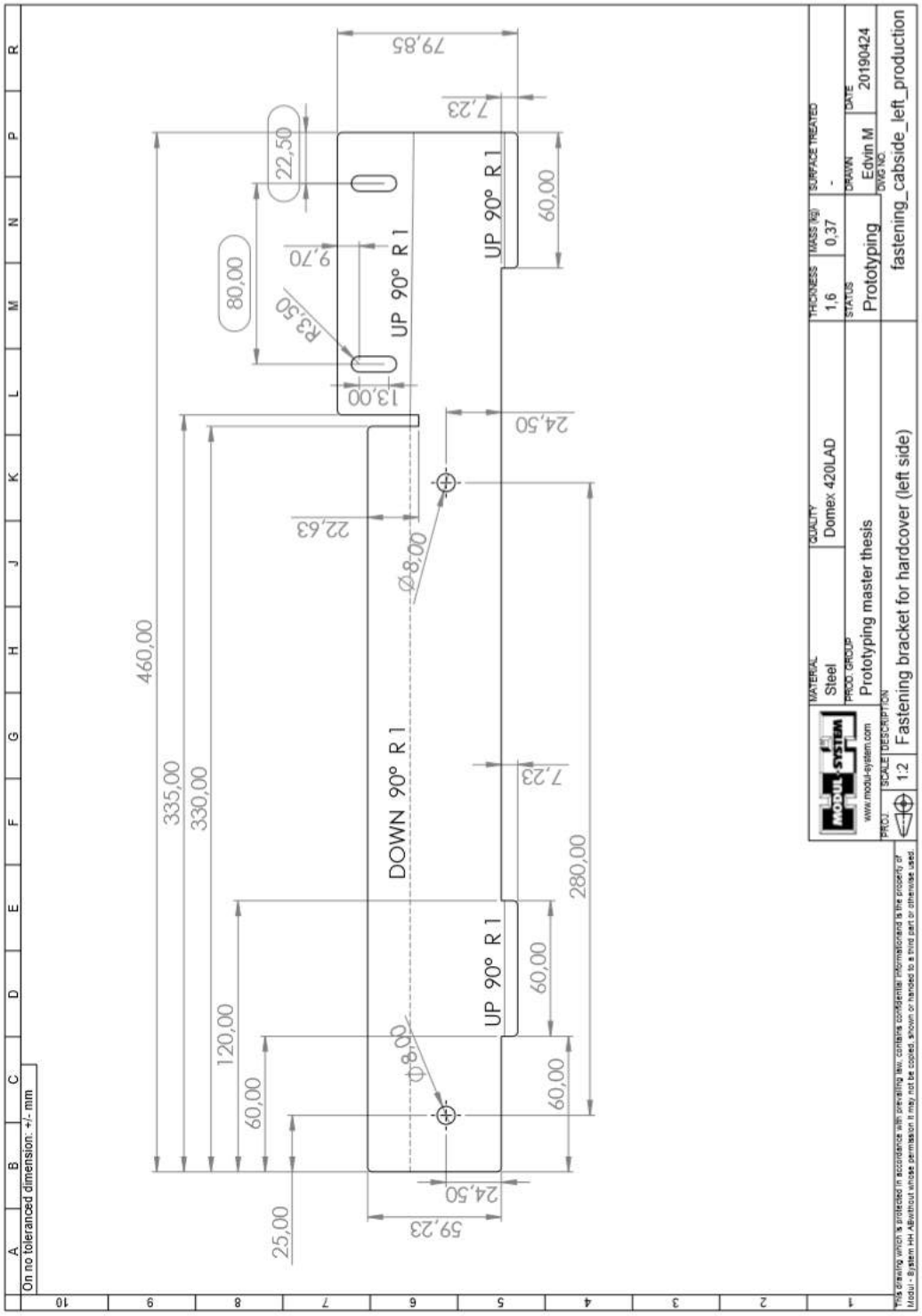

Figure C.15: Flat drawing of the Cab-side Fastening.

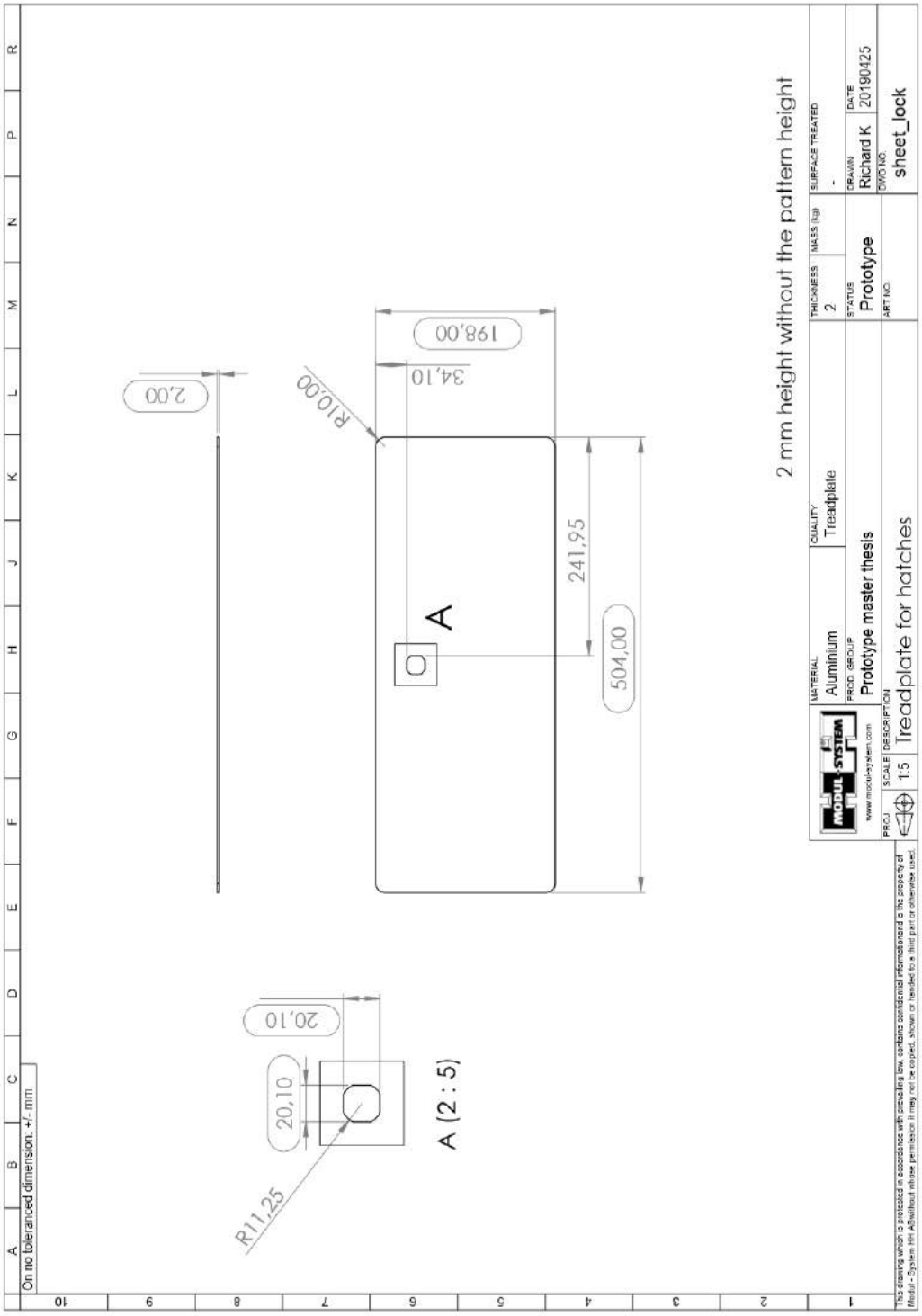

Figure C.16: Drawing of the Top Sheet in treadplate.

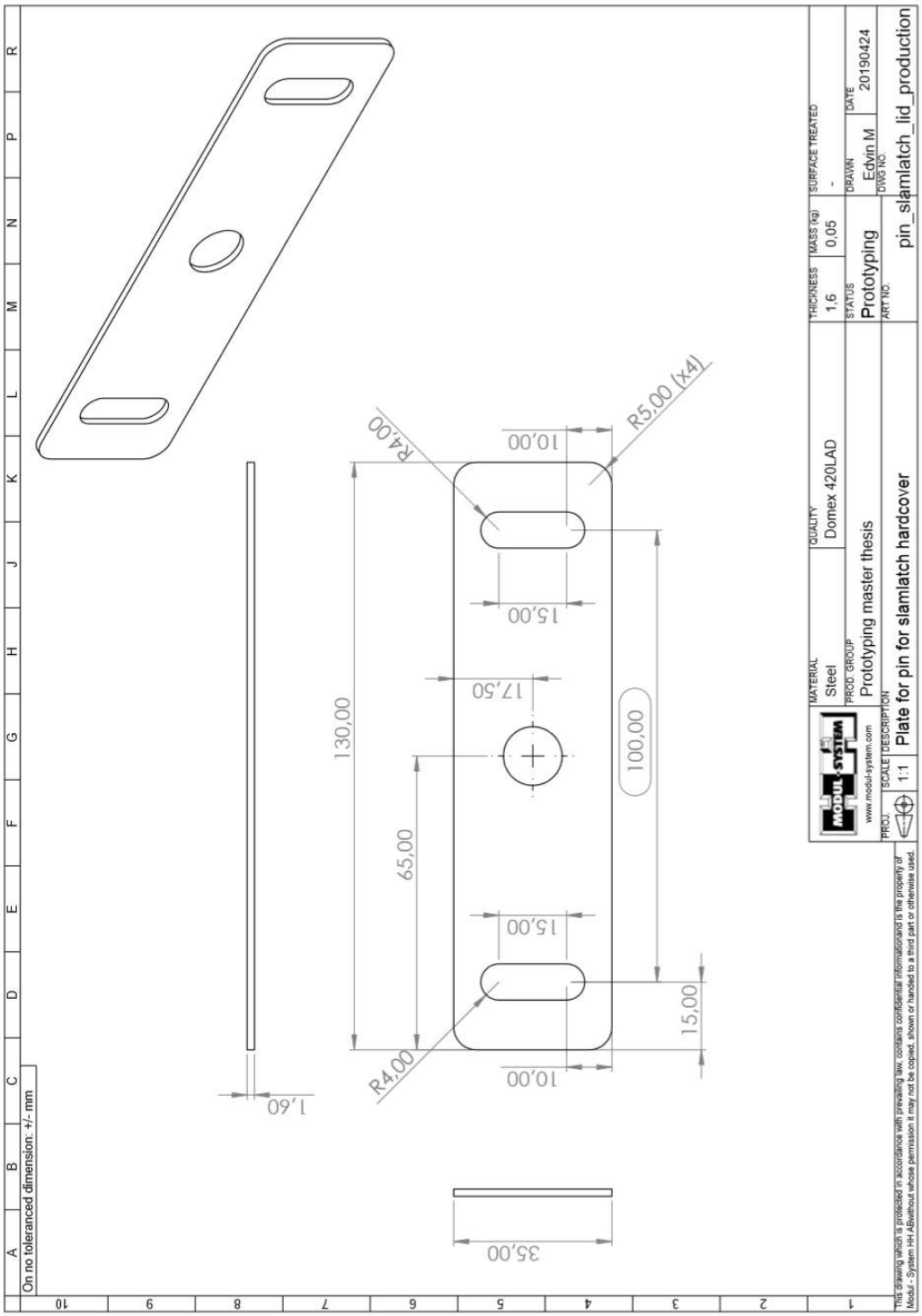

Figure C.17: Drawing of the Slamlatch pin.