Modularization of Storage Spaces in Cabins with Focus on Cabinets for Multi-brand use Globally

Collaboration between Chalmers, Penn State and Volvo Trucks

Bachelor's thesis in Mechanical Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Executive Summary

This report summarizes the accomplishments of the team tasked with moduarlizing the storage space of truck cabins while working under the the sponsorship of Volvo Trucks. This project is a collaboration between two university's, Chalmers University of Technology and Penn State University with three students from each university.

Volvo trucks is one of the biggest manufacturer of trucks and can be found all over the globe. To many truck drivers, the truck is not just a place for work but also a their home. Preferences and wishes for the modeling of the cabin differs between drivers as well as between markets. Therefor a wish to unite these and create a standardized solution exits. Today, Volvo does not have a modular solution that enable customer adjustment for storage connected to the cabin.

The aim of this bachelor thesis is to create a modular storage solution for the cabin. The goal is to increase benefits for the customer where functionality and individual preferences are in focus. Some created results are a CAD-model, a functioning prototype and an analysis of the results. To enable this, a project plan is developed including milestones and important deadlines. This is followed by concept generation, objective evaluation, tests and discussions. The final concept is developed with the help from an iterative process where early designs are analyzed and reworked with guidance from Volvo employees.

The new solution meets the customer requirements by being transferable between markets, brands and models, by enable customization and improve manufacturing efficiency and by preserving the high safety standard, design and functionality.

Sammanfattning

Denna rapport är en redogörelse över kandidatarbetet ”Modularization of Storage Spaces in Cabins with Focus on Cabinets for Multi Brand Use Globally”. Projektgruppen består av tre ingenjörsstudenter från Pennsylvania State University samt tre från Chalmers tekniska högskola. Projektet är ett internationellt samarbete mellan universiteten samt Volvo Trucks och ämnar utöver att stärka studenternas färdigheter i internationella samarbeten även till att lösa ett verkligt problem för Volvo.

Volvo trucks är den av världens största tillverkare av lastbilar. För många lastbilschaufförer är hytten inte bara en arbetsplats utan även en hemmiljö under långa perioder. Preferenser och önskemål på utformningen av hytten skiljer sig naturligtvis mellan olika förare och marknader. Samtidigt finns det en önskan om att rationalisera tillverkningen och skapa ”enhetlighet” mellan de olika lösningar som erbjuds. I dagsläget har Volvo ingen modulär lösning som möjliggör kundanpassning för förvaringsutrymmet i hytt.

Detta kandidatarbete syftar därför till att möjliggöra modularisering av förvaringsutrymmet i lastbilshytten. Målet är att öka kundnyttan, där både funktionalitet och individuella preferenser uppfylls i hög grad, utan att kompromissa med en effektiv produktion. Några av arbetets resultat är CAD modell, fungerande prototyp, kostnadsberäkning och analys av resultat. För att möjliggöra detta skapades en projektplan innehållande Gantt-schema med milstolpar, enskilda uppgifter samt viktiga datum. Processen för produktutvecklingen inleds med en deviering av problemet där kundens behov identifieras. Detta följs upp av konceptgenerering, objektiv evaluering, tester och diskussion. Det slutliga konceptet är framtaget genom en iterativ process där tidiga designer omarbetats efter vägledning från representanter på Volvo.

Den nya lösningen möter de kundkrav som är ställda genom att vara överförbar till olika marknader, märken och modeller, möjliggöra individanpassning och effektivisering av produktion, utan att kompromissa med säkerhet, design eller funktionalitet.

Acknowledgement

We would like to thank our supervisor Jakob Müller for his expert advice and encouragement throughout this project, as well as our examiner Ola Isaksson, professor in Product Development, for his consultation.

For excellent help with the report and presentation, we would also like to thank the department of Technical language at Chalmers.

We would also like to direct a big thank you to the head of the program in mechanical engineering at Chalmers, professor Mikael Enelund, for his technology assistance during the Tuesday meetings and for his never failing interest in us students. Thank you for your support and guidance.

A special thanks to Volvo Group and Monica Ringvik, Director of Research & Innovation Policy at Volvo Group, Gothenburg, Sweden, for financial support and for making our visit to Penn State possible.

Finally, we would like to direct a big thank you to all the employees at Volvo Trucks who has helped us throughout this project.

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1
Introduction

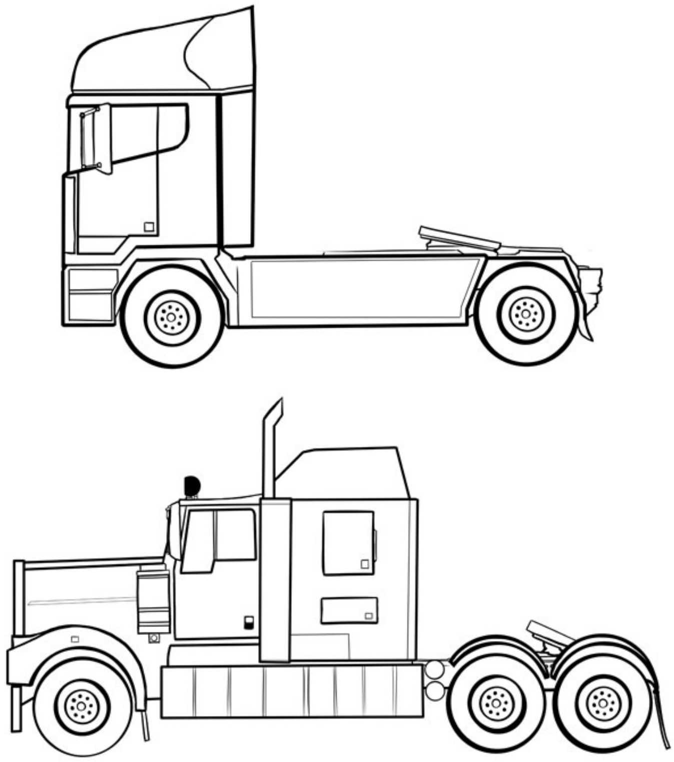
Volvo Truck is one of the largest manufacturers of heavy trucks, creating reliable transport solutions for clients all over the world. The focus of this project is to modularize storage spaces for truck cabins. The cabin provides a mobile workplace and a living environment that the drivers spend a large portion of their time in over the course of the year. Preferences for an ideal truck cabin differ between drivers and between markets across the world. Because of this, commonality in the design of the modular storage space is a critical factor for making the manufacturing process universal and efficient. For this project, it is important that both functionality of the design and individual driver preferences are met without compromising an efficient production.

1.1 Initial Problem Statement

The challenge this project poses is that current Volvo truck models do not have modularized storage spaces in their cabins. Because of this limitation, drivers do not have the ability to customize the storage space to meet their needs and preferences. The main goal of the project is to develop and modularize the storage space in the cabin, basing the design on expected functionality and accounting for production commonality. The solution should be universal and applicable to different trucks that already exist around the world. An example of the differences between trucks are shown in figure 1.1.

The primary problem of not having a modular storage system stems from a lack of customizable options for drivers when they make the initial purchase of a Volvo truck. The sponsor stated that Volvo would like to become the primary source for internal storage customization for their truck lines to satisfy the drivers' desires and needs. This modular, customizable storage system would provide a new selling point for Volvo. After an initial video conversation, the team refined the problem and intended deliverable to focus only on the larger storage spaces behind the driver's seat and in the living space as well as the storage space located above the dashboard.

Figure 1.1: The main difference in European and American trucks [11]



1.2 Objectives

The objective of this project is to modularize the current Volvo cabin storage space and to make it adaptable for multi-brand Volvo trucks. The elements the team is focusing on throughout the design process are the storage areas located above the seats and in the living area behind the seats. The team are not focusing as much of the design on the dashboard area. The new solution is designed with a CAD model and converted into a 3D printed prototypes.

1.2.1 Scope of Work

The scope of work for this project is outlined in table 1.1. It includes deliverables given to the team by the sponsor. A detailed Deliverables Agreement between the sponsor and the team has been written and is included in Appendix A.13. This agreement outlines the specific tasks and major deadlines that the team will adhere to.

Table 1.1: Scope of work

	Deliverable
1	Document drivers' experience and expectations
2	Demonstrations of consideration to safety regulations and existing storage space
3	Technical specifications of the concept
4	CAD models of the solution
5	Evaluate how producible and flexible the solution is
6	Structural data (stiffness, strength, functionality, etc.) of solution
7	Test specification, a verification plan, and a test report of solution
8	Product cost estimate
9	One or more functional prototypes

1.2.2 Limitations

The students from The Pennsylvania State University (PSU) are working on the project between January 9, 2017 to May 2, 2017 and the students from Chalmers University of Technology (CTH) are working from January 17, 2017 to May 26, 2017, meaning the PSU are limited to 15 weeks of time devoted to the project and the CTH students are limited to 17 weeks. This means that projected is limited by both the time frames, and also by different final dates.

The time difference for the two universities of six hours and the, therefore, limited opportunities for communication, are considered to be one of the biggest limitations of this project.

Another limitation of the project is the budget. The project has a strict budget to stay within, which means that too costly activities must be limited. Examples of such activities are comprehensive competitor analysis, manufacturing and functional testing.
The availability of licensed software is a limitation which belongs to the budget.

The project participants' knowledge in product development is also a limitation. As well as the limited knowledge in materials, production and testing. There is also a possibility that our homogeneous background in mechanical engineering causes other knowledge limitations.

This project has a limited design space which limits the range of solutions.

2

Team and Project Mangement

The project group consists of students from Sweden and from the United States of America, three from Chalmers University of Technology and three from Penn State University. All students have a background in Mechanical Engineering and product development. The students are Emma, Hanna, Björn, Garret, Nick and Emily. Besides the supervisors from each university, and an examiner at Chalmers, there is a sponsor from Volvo Group,Timo Kero.

2.1 Preliminary Economic Analyses

This section provides the team's estimates on how the project funds are spent. The PSU students is provided with a budget of $1000. The CTH students is provided a budget of approximately $225.00. The budgets of each university will be tracked by PSU and CTH, respectively. Initial budget information can be found in Appendix A.1. The team is making multiple site visits to various Volvo Truck locations in both the United States and in Europe. Some of the funds for the project is allocated to the travel expenses of these visits. Most of the remaining funds are directed towards making the prototypes of storage and any locking or interlocking mechanisms that is needed for the prototype. Design software is used to create 3D models to be printing and evaluate at 3D printing facilities available at both PSU and CTH campuses. The 3D printing is free of charge for the students at CTH. A small amount of the funds is also directed towards a sign and any other aspects of the Showcase and Final Presentation.

2.2 Project Management

The team's Gantt chart outlines important deadlines and is found in Appendix A.3. The team is using an iterative design process, shown in figure 3.1 in chapter 3; extra time is allocated to gaining feedback from the sponsor and the customers, as well as to iterating the design. Most of the time assigned in the Gantt chart is for CAD modeling and prototyping.
Many important dates are highlighted in the Gantt chart, including the first stage of prototyping completion date of March 21. Meanwhile, the team are being developing the Midterm Report and its corresponding presentation, with the final draft of the report being submitted to the sponsor on April 4. The second phase of prototyping will begin immediately after the first stage and will end on April 21.

The project is culminating with Final Presentations on April 27 at Penn State and May 23 at Chalmers.

2.3 Risk Plan and Safety

A multitude of risk factors may present themselves throughout the project. The primary concerns stem from the global nature of the project. The global collaboration between the two teams produce concerns such as losing or misplacing important data team files, over-constraining the problem, and delays in the schedule. Table 2 organizes these risks and others and presents a prevention plan.

The nature of an international team creates file sharing concerns to ensure the most up to date documents are available to all members at all times. To accommodate the needs of the team, a cloud storage is used to maintain files. Using a single, centralized location for all files is crucial for operational ease of the team. The simultaneous editing capabilities provided by the cloud storage document feature is invaluable to the team coordination on shared work. Loss of data is a mistake that cannot be afforded by the team. For submissions to the sponsor and for grading purposes, Box.com is also been used to ensure sharing across national borders happens smoothly, with easy access for all parties.

Self-imposed constraints may arise due to the size of and varying personality types represented on the team. Remaining open-minded throughout the process is one method to handle these potential self-constraints. During brainstorming of ideas and concept generation, all input will be respected and appreciated to ensure enthusiasm and creativity. Self-imposed constraints may also present issues regarding the direction of the project. Communication amongst all team members is critical to ensuring a cohesive approach by the team to deliver a successful solution. It is imperative that team members speak clearly and understand that translation issues are common. Regular discussion and planning can help to negate the consequences of these miscommunications.

The potential for schedule delays necessitates proper planning and communication between teams to ensure that deadlines are reasonable and that all team members are keeping up with their responsibilities. If the team misses an important deadline, actions must immediately be taken to understand why the delay occurred and what can be done to make sure it does not happen again.

Table 2.1: Risk Plan Evaluation matrix

Risk	**Level**	**Action to Minimize**	**Fall Back Strategy**
Communication issues	Moderate	-Maintain regular contact between teams, sponsors, and instructors -Follow a structured meeting schedule	-Address issues if they become serious
Arguments regarding the project	Moderate	-Clear guidelines of how to solve conflicts -Keeping criticism constructive	-Vote of majority -Use group contract as guidelines
Assembly is over-complicated	Moderate	-Prototype testing -Gather feedback	-Well-worded instructions
Too many self-imposed constraints	High	-Stay open-minded throughout design process	-Seek input from sponsor, professor, or customers
Schedule delays	High	-Clearly establish goals and deadlines -Complete items ahead of schedule -Regular communication among all team members	-Allow excess time in case of unexpected problems -Share responsibilities
Data and information loss	High	-Find reliable storage services -Minimize data stored in alternate locations	-Relying on less current versions of material and data

2.4 Ethics Statement

The team are upholding the integrity and honor of the engineering profession and abide by the ASME Code of Ethics listed in Appendix A.2 at all times (American Society of Mechanical Engineers, 2012). The team are remaining honest through their communication and designs. The team are acting in a professional manner at all times and are respecting the Volvo Group, the sponsor, the instructors, each other, all other persons of communication, and the engineering profession. The team are considering environmental impact and sustainability throughout the project.

2.5 Environmental Statement

The team are striving to reduce the environmental impact of the project from start to finish. Throughout the design process, in the early stages that are being explored, the environmental impact is minimal as most work is conceptual and computer aided design based. The prototyping phases are utilizing 3D printing in campus facilities to minimize wasted materials. Scale models are produced to understand functionality rather than full size models to understand spatial relations. The team is encouraging sustainable material solutions for the implementation of the product and minimize waste that is created throughout the design process.

2.6 Communication and Coordination with Sponsor

The Point of Contact (POC) for each university is maintaining a correspondence with the sponsor, each other, and any other individuals involved in the design process. The primary method of contact with the sponsor is in the form of email from the POC's. Video-conference calls also allow the team to update the sponsor on recent progress and establish clear expectations for both parties. Weekly progress reports are written and uploaded to the team's Box.com folder every Friday. This folder is shared by not just the members from Chalmers and Penn State but also with the sponsor, supervisors and examiners.

3

Method

In the method chapter the tools needed to accomplish the project is defined. The basis for product development can be described in many ways. This project is based essentially on the the Scientific Method. A model of the method is illustrated in figure 3.1. [1]

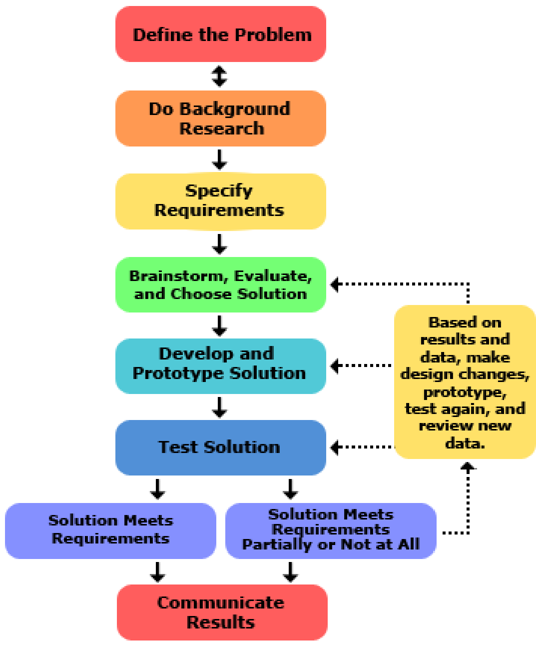


Figure 3.1: The engineering design process [1]

3.1 Define the problem

In the first stage, the project's problem statement is defined. The problem statement needs to answer three questions [1]:

- What is the problem or need?
- Who has the problem or need?
- Why is it important to solve?

3.2 Background search

After clarifying the problem statement the project is continuing with the second step which is background research. This provides a better knowledge in the problem. During this step, the requirements of all parties are identified which leads up to the requirements specification. This gives the understanding necessary to solve the problem.

Three different types of background research are conducted for this project, including a literature study, interviews, and external patent research, these are literature study, interview and patents. An explanation of these are made in chapter 4.

3.3 Specify requirements

Design requirements state the important characteristics that your design must meet in order to be successful. One of the best ways to identify the design requirements is to use the concrete example of a similar, existing product, noting each of its key features.[1]

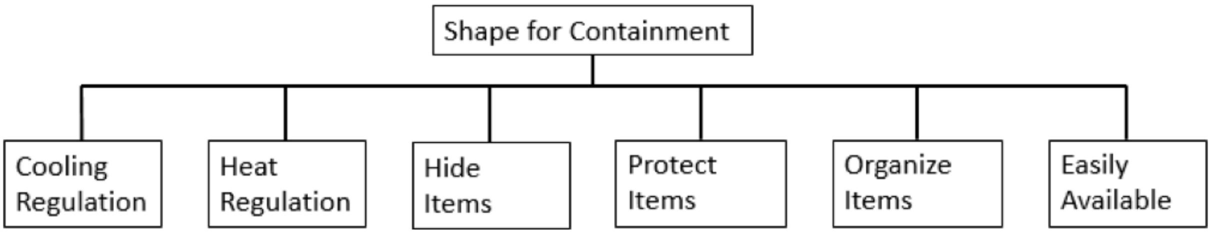
3.3.1 Function analysis

To get a better understanding on how the different needs and requirements correlate with storage compartments in the cabin, a function analysis is made (see Appendix A.7). Since there is a wide variety of uses of the storages, such as storing a coffee maker, microwave and different types of shelving, showcasing the compartment in a visual way is important to get an understanding of what is needed in the cabin. This, along with the problem clarification, makes the concept generation-phase easier. Understanding what is asked for by the customer is fundamental in generating a product that fulfills and exceeds the expectations of the customer. [12]

The function analysis is based on design solutions, function requirements and constraints. The function requirements are the requirements that the customer has on the product. It is solved by the design solution. The constraints are factors that can affect the design solution, such as legal requirements or limitations to the dimensions of the product. [13]

A piece of the functional decomposition diagram, shown in figure 3.2, is created by researching existing storage methods on the Volvo Trucks website and by applying prior knowledge of locking and interlocking mechanisms. The full version of the functional decomposition can be found in Appendix A.7.

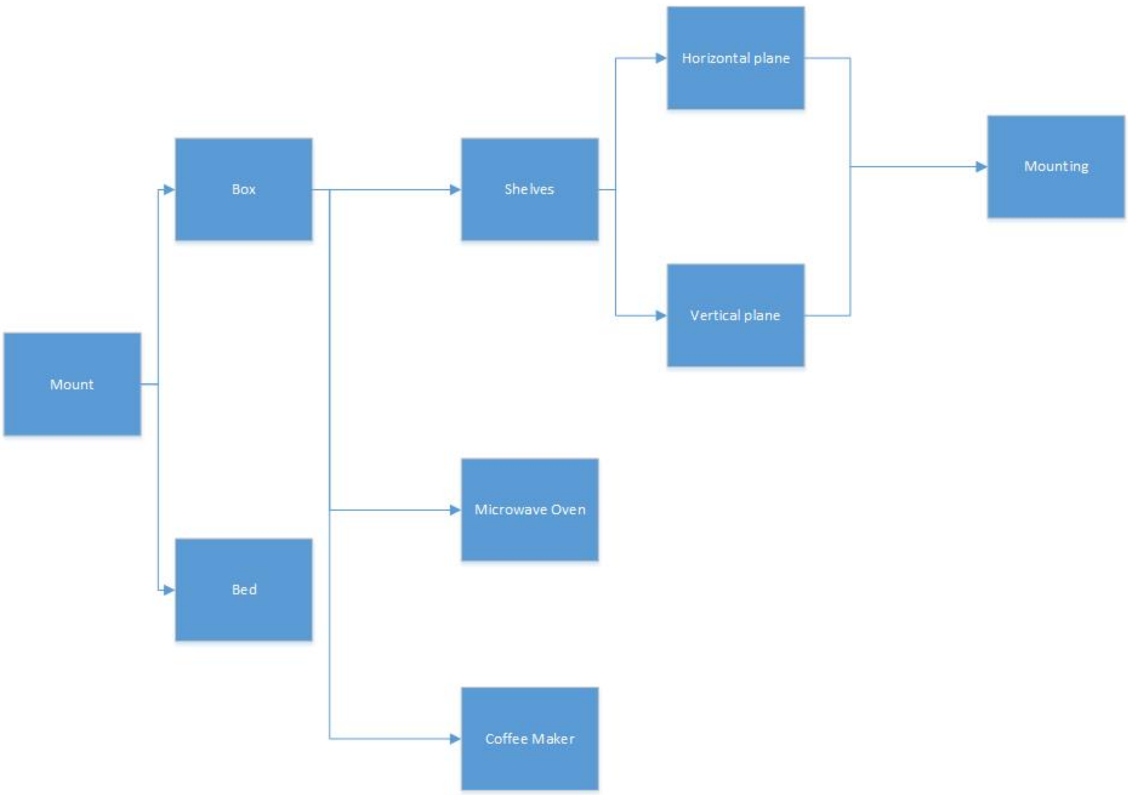
Figure 3.2: A sub set of the functional decomposition to illustrate its purpose.



3.3.2 Product variant master

A product variant master is a tool for modelling and visualizing a product range. The analysis helps to create understanding of content and structure of a product [14]. In figure 3.3 a simplified variant master is shown.

Figure 3.3: Simplified product variant master.



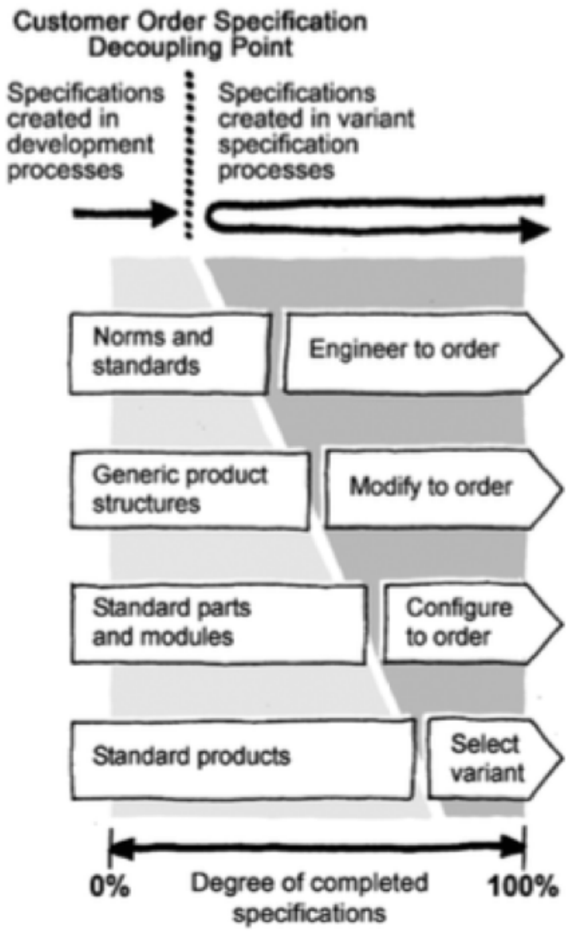
3.3.3 Customer order

The figure 3.4 shows different types of specification processes at diverse positions on the dividing line between specifications worked out on an order-initiated basis and specifications worked out independently of the individual orders.

The process "choice of product variant" means one chooses a standard product, which to the greatest possible extent fulfills the customer's needs. The "Configure to order" process describes a case where the specifications are worked out automatically by using a conjuration system. The process works with standard parts and modules, which can be put together according predefined rules.
The "Modify to order" and the "Engineer to order" process is quite similar and is seen in companies manufacturing customized products.[14]

Volvo trucks are today using The "Configure to order" process but are still manufacturing some customized products in order to satisfy customer needs which is the "Engineering to order" process. The process is more demanding regarding both money and time. There is therefore much to gain by modularization.

Figure 3.4: Customer Order Specification [14].



3.3.4 Modularization

It has become increasingly important to get the most out of available resources because of higher requirements for a lower price for the performance. Therefore,

companies work to increase market share through more varied high-quality product range while reducing their development and production costs per unit produced.
A solution to this is to share resources and devices that are designed to be individually adjusted by various combinations of partial solutions. [15] [16]

Modularity is a design requirements for this product. A modular platform is used to create variants through configuration of existing modules [17]. Some of the benefits of modularization in product development is shown in table 3.1. [10]

Table 3.1: Modularization

Benefits of modularization	
1	Shorter development times
2	Faster product changes
3	Less risk-taking in new development
4	Shorter lead times in production
5	Improved quality of manufacturing
6	Smaller number of part to manage and administer.

We tend to talk about five different categories of modularity, component swapping, component sharing, fabricate-to-fit, bus and sectional modularity. [18]
There are various methods available to modularize. One of them is named the MFD-method (Modular Function Development) contains five steps that are shown in table 3.2. [15] [19]

Table 3.2: The MFD-method

The five steps of the MFD-method	
1	QFD, control of costumer needs and competitive position
2	Generation of technical and modular solutions by processing existent manufacturing criteria.
3	Identification of possible modules using the Module Indications-Matrix (MIM) (Described in section 3.3.4.1)
4	Evaluating modular concepts.
5	Detailed design of the modules using the traditional DFM methods and DFA methods.

To enable modularization, this method has been taken into account. Iterative problem solving, as the method used for this project, is required to balance the need for differentiation with the need for commonality.[16]

3.3.4.1 Module-indications-matrix

The module-indications-matrix, MIM, helps evaluate the different concepts in how modular they are. Identified are the criteria that determine modularity.

The solutions/concepts in the example in table 3.3 are named from A-D. They are graded on every criteria from low to high. The grading is illustrated with colors, light grey for “Some modularity-giver”, darker grey for “Medium modularity-giver” and black for “strong modularity-giver”. The solution with most criteria colored in dark is the most modular [10].

Table 3.3: The module-indications-matrix, MIM [10]

Modularity giver	Solution	A	B	C	D
Development/ Construction	”Carry-over”				
	Technical development				
	Productplan				
Variants	Different specifications				
	Styling				
Production	Shared units				
	Process/Organisation				
	Styling				
Quality	Testable modules				
Purchase	Supplier exists				
After-market	Servicing				
	Upgrading				
	Recycling				

3.4 Concept generation

The process of generating concepts contains brainstorming, evaluation and concept selection.
Brainstorming is a systematic group method used to generate new ideas, concepts and solutions for problems. The method is divided in two phases. Phase one is concept generation where no criticism is allowed. Phase two is selection of the best idea [20]. When the ideas are generated an objective method for evaluation is required. An example of such method is Decision-Matrix Method, invented by Pugh [21]. The basics of the technique is that solutions that do not meet objective requirements are eliminated. Solutions that remain can then, with the help from example Morphological matrix, generate new solutions, which in turn are evaluated.
This is an iterative process. Based on the results of the testing the process may have to be repeated with brainstorming for new solutions. The process is repeated to a final solution is obtained.

4
External Search

To ascertain what products and solutions that already exist, different searches are made, both on patents and current solutions on the market. This includes objects that have been or are used as a storage solution. In this chapter the result of the literature study, interviews, external patent research and existing products are presented.

4.1 Literature study

To get a theoretical framework to base the work on a study of articles and books related to product and concept development is carried out. Article search is made within the field of technology vehicles to provide a strong understanding of the physical problem. Much of the literature are internal articles from product development at Volvo.

4.1.1 Cabin specifications

Specifications of the cabin dimension for both an European and an American model are found i figures 4.1 and 4.2. It can be concluded that the cabin dimension may vary between markets, brands and models.

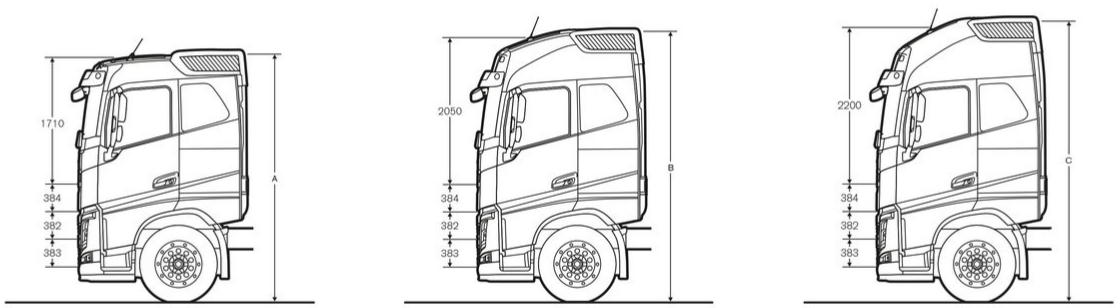


Figure 4.1: Specifications of an European Volvo model.[2]

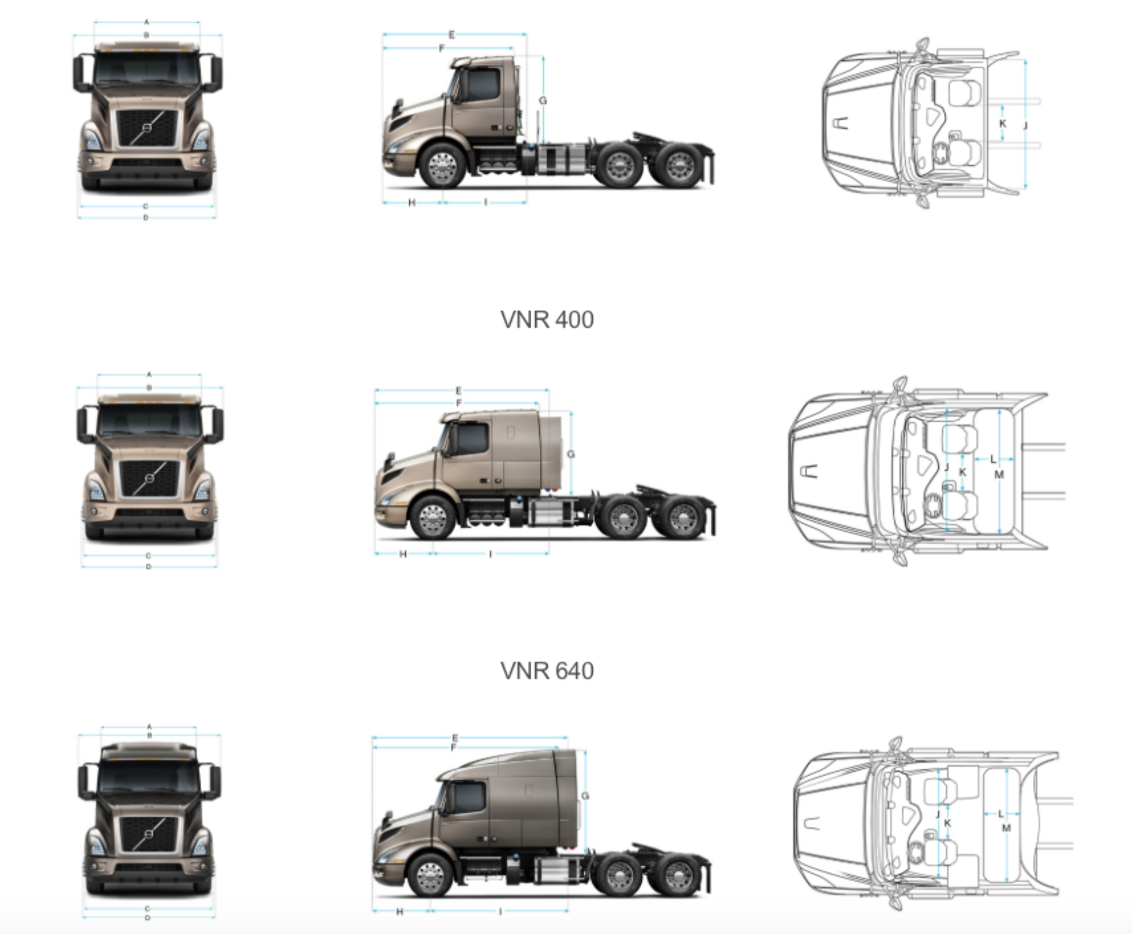


Figure 4.2: Specifications of an American Volvo model.[3]

4.1.2 Current storage solution

The current Volvo design, shown in Figure 4.4 , only provides one storage configuration that cannot be changed throughout a truck's lifespan. This storage space forces the drivers to use the manufacturer's configuration and does not meet individual drivers' needs. It also makes it difficult for the drivers to organize their personal items, especially large items that may not fit into the storage units that come pre-divided. The main goal of the new design solution is to easily allow for regular changes of the configuration of the storage space, such as dividing the shell of the storage into multiple units to organize the driver's personal items or keeping the shell open to allow for larger items such as tools to easily fit in toy the space.

Figure 4.3: Current storage solution above the dashboard in the American model, with no options for customization. [3]

Figure 4.4: Current storage solution behind the driver for the European model. [2]

4.1.3 Safety regulation

Ergonomics

There are many rules and guidelines about ergonomics. This may apply on everyting from to the ability to reach spaces that are placed high up in the cabin, simplicity to open doors and to prevent heavy lifting over the head. Studies in confidential and internal Volvo documents have been made in this subject.

The reachability for different drivers is categorized in typical lengths. A Volvo truck is supposed to function for everyone, from what you call a small woman (F05) 152.5 cm, middle-sized man (M50) 180cm to a big man (M95) 193cm. [22]

Head Injury Criterion

The Head Injury Criterion (HIC) is a measure of the likelihood of head injury arising from an impact. [23] There are legal requirements to consider during the project. FMVSS201 and ECE-R21 are crash safety requirements and in generalI they generate the radius on the interior surfaces to be bigger than 2.5 mm and head injury with HIC: (Free Motion Head) may at most generate HIC(d) on 750. [24]

These are laws are taken into account during product development.

4.2 Interview

An effective method for collecting relevant data to understand the problem is to interview the people concerned. Interviews provide a real insight into the user's everyday life and it provides a tool to capture customer needs. A short interview guide prepared for those occasions where specific concerns and overall goals for the interview described. In theory this method is usually called a semi-structured personal interview. The interviewer's role is to investigate the individuals approach to the problem by deciding the theme for the interview and set open questions. The respondent has the freedom to decide what he/she wants to discuss associated with the set theme and guide the conversation in the direction he/she wants to. [25]

4.3 Patents

Patents protect technical inventions in all fields of technology. Since patent search is a good source of technical information, including detailed drawings and explanations of how the technology works, it is a helpful tool in product development. It provides knowledge of which solutions are protected or which requires a license from the owner to be used. Making a patent search and analyzing solutions can contribute in creating new ideas and solutions to the relevant concepts. [26]
Patents filed in the US are searched using Google patents, which allowed for simple filtering with keywords for the patents. Keywords that are used to search for prior

art are: modular, storage, cab, truck, and vehicle. The criteria listed is used in various combinations to identify a broad range of prior art, regardless of whether it is truck specific. Appendix A.9 contains multiple designs from the Google Patents database. Many of these models have unique locking mechanisms that serves to provide a reference point during multiple stages of the design process. One specific model has a mechanism that looks similar to a puzzle-piece and helps to lock together the corners of a shelf. Another peculiar patent is the conversion of a truck's rear quarter panel into a storage compartment. These products required ingenuity during their creation, but are relatively easy to implement once developed.
To search for European patents, the European patent office and the Google Patents database is used. To narrow down the search results, patents with keywords such as storage, modular and cabin are used. Finding compartment designs specifically made for truck cabins is proving to be hard and a more general search for patents concerning modular storage space and storage space in general is being taken.

4.4 Existing Products

In addition to patents related to modular storage systems, a search of the market's current designs is also useful. By conducting a search it is shown that there is not a large presence of modular storage systems designated specifically to truck cabins, similar to the results of the patent search. However, the products that do exist for broader applications, such as those for home use, do have concepts that relate to the problem. Examples of existing modular storage space that are used as inspiration for this project is Ikea and their modular solutions [5]. Ikea has a wide selection on solutions for modularity and one them is called Billy the Bookcase, this bookshelf is shown in Figure 4.5. More of these existing products are shown in Appendix A.8.

Figure 4.5: Existing solution from Ikea, Billy the Bookcase.

5

Customer Needs Assessment

To make sure that the solution are increasing the customer satisfaction compared to the current solutions, the customer needs are being evaluated. By conducting interviews and later on weighting the need against different categories the desirable information will be gathered.

5.1 Gathering Customer Input

Customer needs is gathered by talking to Volvo employees and truck drivers who have experience spending much of their time in the vehicles. This information provided by the Volvo employees are allowing the team to determine where the storage is located in the cabin, what varying sizes of storage are manufactured, and which aspects of the storage are likely to appear in the proposed solution. From this input, the team decides to focus on the storage space behind the front seats and in the living area and on the storage that can be found above the dashboard.

An interview is conducted with a truck driver with 40 years of experience, which gave the team valuable input concerning current storage problems in the cabin. The driver regularly communicates with other drivers, often including a driving partner, and voiced those opinions to the team. One prevalent need voiced by the respondent is to provide full accessibility to all storage spaces in the trucks. Drivers often find that certain storage areas are too difficult to reach, so they do not regularly use these spaces frequently. Because of this accessibility problem, valuable space in the cabin is often wasted. Another issue with some of the current trucks is that much of the shelving is too narrow or too shallow. This severely limits the ability to store larger items such as a food and drink cooler. In turn, the final product must have the capability to store large items.

Another interview that is performed is with a salesperson, a person who has the experience of transforming the customers wishes and demands into reality. Drivers have a big amount of belongings that they want to bring on their travels, this is a problem due to the fact that the storage space is limited and often not big enough to fit bigger objects. Some of the storage space is user-selectable but this is mostly for objects as coffeemaker and microwave. The conclusion from this interview is that the storage space need to be bigger and preferable adjustable, all of this to fit every customers needs and wishes.

With the help from the interviews, the wishes and demands from those who work closely with the truck becomes clearer. The storage solution must be adjustable to the needs of the driver and their potential passenger. Sometimes there are two drivers in a given truck, therefor the solution must account for the storage needs of two people. Furthermore, the storage space must keep all items safely in place, especially in the event of an accident. There are many objects that behave like projectiles if they were to come out of the storage area, potentially leading to injury and damage to property and humans. All of these customer needs will be taken into consideration for the final solution.

5.2 Weighting of Customer Needs

The team refined the customer needs stated in Section 4 to generalize them for both the customer and the company. These needs are outlined in Table 5.1. The customer needs are weighted using an Analytical Hierarchy Process (AHP).[27] This process uses a weighted comparison chart to determine which main objective categories require the most focus and attention. For this project, the categories Ease of Use and Safety are weighted the most because these categories focus on the direct application to the truck driver and their needs. Safety is paramount for this project in order to protect the drivers. Also, the solution must be easily implemented and potentially reconfigurable for the customer.

Table 5.1: Analytical Hierarchy Process (AHP) Pairwise Comparison Chart to determine weighting for customer needs.

	Safety	**Ease of Use**	**Ease of Mfg.**	**Cost**	**Eff.**	**Dur.**	**Port.**	**Erg.**	**Total**	**Weight**
Safety	1.00	2.50	4.00	4.00	2.00	3.00	2.00	2.00	20.50	0.21
Ease of Use	0.40	1.00	4.00	4.00	2.00	3.00	3.00	3.00	20.40	0.21
Ease of Mfg.	0.25	0.25	1.00	1.00	1.00	0.30	0.50	0.30	4.60	0.05
Cost	0.25	0.25	1.00	1.00	1.00	0.50	0.20	0.20	4.40	0.04
Eff.	0.50	0.50	1.00	1.00	1.00	0.50	0.20	0.20	4.90	0.05
Durabil.	0.33	0.33	3.33	2.00	2.00	1.00	0.80	0.80	10.60	0.11
Port.	0.50	0.33	2.00	5.00	5.00	1.25	1.00	1.00	16.08	0.16
Erg.	0.50	0.33	3.33	5.00	5.00	1.25	1.00	1.00	17.42	0.18
Total	**3.73**	**5.50**	**19.67**	**23.00**	**19.00**	**10.80**	**8.70**	**8.50**	**98.90**	**1.00**

6

Engineering Specifications

To make an objective judgment of a solution there must be quantitative and measurable specifications. These are criteria that the idea must satisfy. In order to be measurable and clear, the specifications must include a measure, target and technical units. Target values is the range of the metric that is acceptable. These specifications relates to the customer needs.

6.1 Establishing Target Specifications

While target specifications can be set for each individual truck brand and each individual cab style and size, it is unnecessary to do so for this project. This is because of the intended solution is to ensure all brands and models can benefit from a form of the solution, not to develop as many solutions as there are brands and models within the Volvo lines. In Table 6.1, the metrics are defined and units provided for how the measurable goals of the project is to be implemented.

Table 6.1: Metric table with defined units to match customer needs

Metric No.	**Metric**	**Measurement**	**Units**
1	Time to Customize	120	Minutes
2	Time to Install	300	Minutes
3	Tolerances generally	0.5	mm
4	Volume	200	Liter
5	Weight	50	Kilogram
6	Accessibility	N/A	N/A
7	Basic User Interface	N/A	N/A
8	Withstood Force	TBD	Newtons
9	User Friendly	N/A	N/A

6.2 Relating Specifications to Customer Needs

The customer needs are related to specifications to understanding how the proposed solutions will meet the needs of the consumer. Metrics are assigned to those needs, allowing for quantitative comparison between solutions. Figure 6.1 addresses the relation between the customer needs and the specific metrics used to quantify them. Some of the customer needs in the table include having a user-friendly solution that is robust, reduces clutter, and allows for customizable spaces. These customer needs are related to the target specifications, including time to customize, time to install, and accessibility.

Figure 6.1: Customer needs shown in relation to the specific metrics they follow.

		Time to Customize	Time to Install	Tolerances	Volume	Weight	Accessibility	Basic User Interface	Withstood Force	User Defined
1	User friendly	X					X	X		
2	Reduces labor		X							
3	Simple to use	X	X				X	X		
4	Easy to store items				X			X		
5	Reduces clutter				X		X			
6	Robust construction			X		X			X	X
7	Customizable spaces	X		X	X			X		
8	Accident Tolerant					X			X	X
9	Aesthetically Pleasing									X

7

Concept

This chapter contains information about developed ideas for this work in product development. In forthcoming sections, sketches of developed concepts and a description of the evaluation of these are presented.

7.1 Concept Generation

During the concept generation, the team are developing concepts with the purpose of meeting identified customer requirements 5. The focus is on solutions to the sub-functions identified in figure 3.2 and the aim is that generated solutions will cover the whole product range from figure 3.3. To achieve this both creative and structured methods, seen in section 3, are required. Generated sub-concepts are sorted by the function that they solve.

7.1.1 Mounting

For the mounting three different solutions are created, the first one is the vertical rails, Figure 7.1, the second is the horizontal rails, Figure 7.3 and the third is the wedge system, Figure 7.4. With the vertical rails it is possible to adjust the height of the storage system and also ad a second bed instead of a storage system if placed where the rear storage space is located. This solution is inspired by the grid system that is found in grocery stores, Figure 7.2. The horizontal rails are fix and not adjustable with height, though it is possible to c switch between a storage space and a bed.

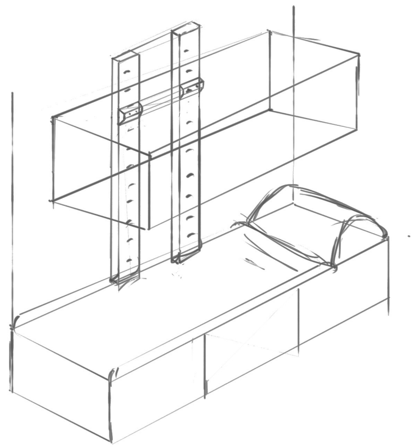


Figure 7.1: The Vertical rails.

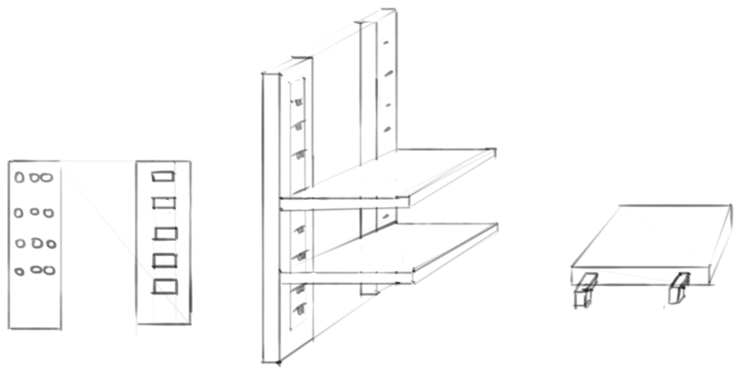


Figure 7.2: The Grid system.

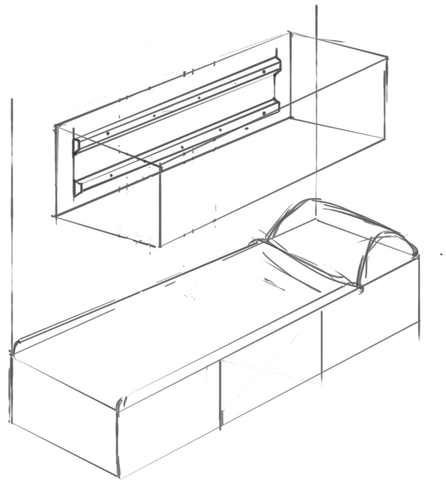


Figure 7.3: The Horizontal rails.

7.1.2 Mounting for shelves

For the mounting of the shelves four different solution are developed. The first one is the Wedge system, Figure 7.4. Wedge support system allows user to easily slide shelving and drawers in and out of the storage space by clicking it in or out. The second one is the Guided tracks, Figure 7.5. These guided tracks helps with sliding the shelves into the right place. The third and fourth ones both helps with guiding the shelves into the right place, the difference between them is how they are slotted. One is called double slotted and has two protruding parts, this is shown in Figure 7.6. The other one is hollowed out for the rails, Figure 7.7.

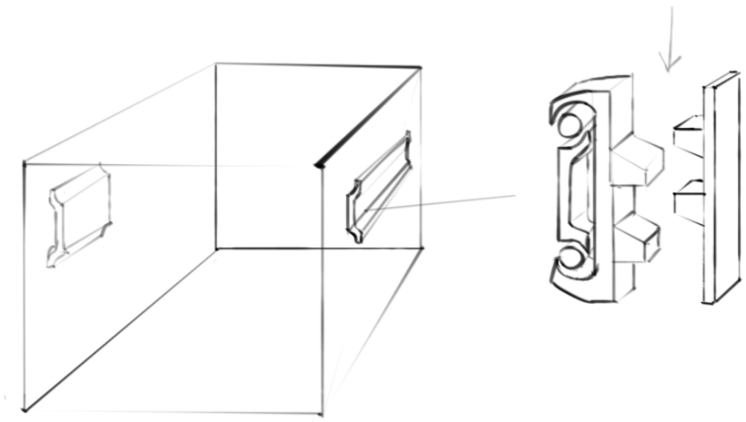


Figure 7.4: Wedge support system.

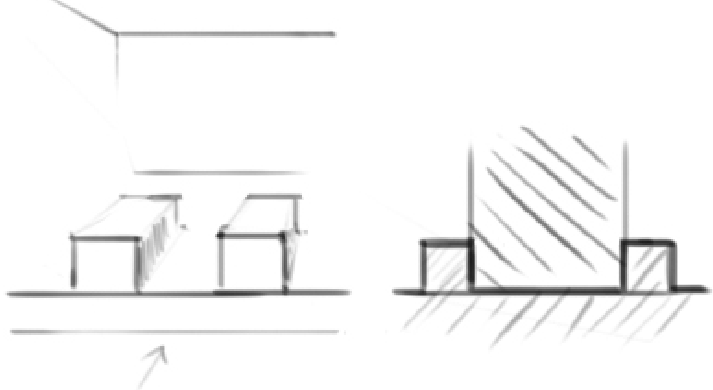


Figure 7.5: Guided tracks.

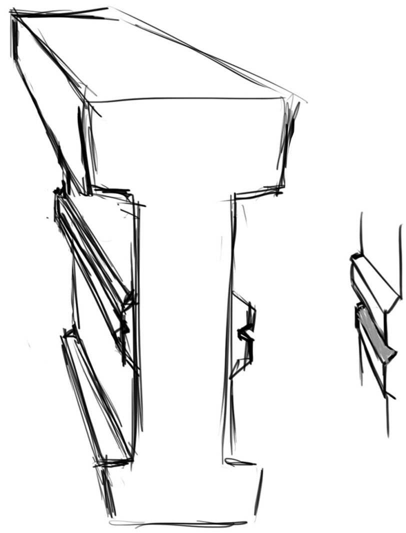


Figure 7.6: Double slotted rails.

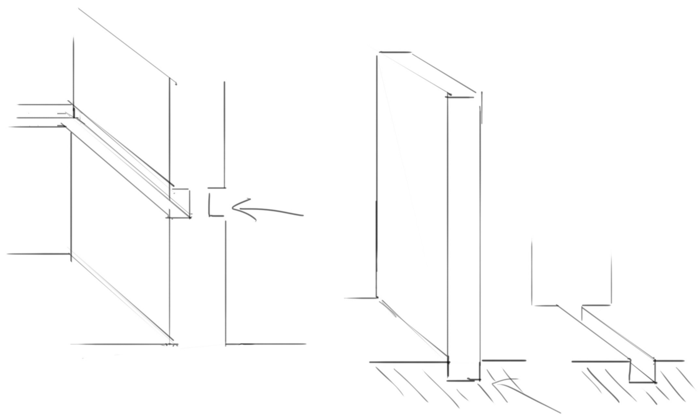


Figure 7.7: Slotted tracks.

7.1.3 Doors

For the door several solutions are drawn, many of them already exists such as the so called airplane solution, Figure 7.8. This door opens upwards. The microwave solution, Figure 7.9, which opens from wright to left or left to wright. The horizontal sliding door, Figure 7.10, which opens by pushing the door from either wright or left, and the vertical sliding door, Figure 7.11. This door opens by pushing the door upwards and closes by pulling it downwards.

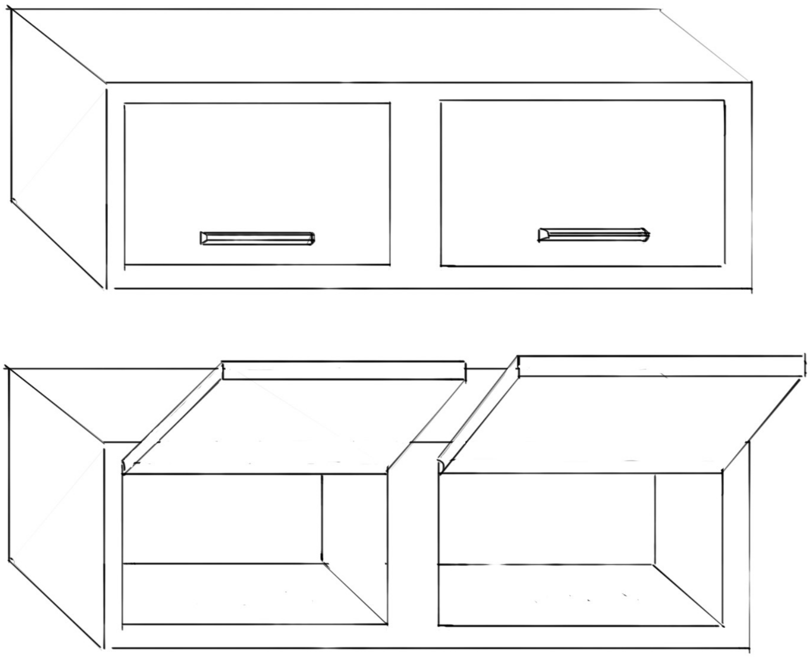


Figure 7.8: The airplane solution.

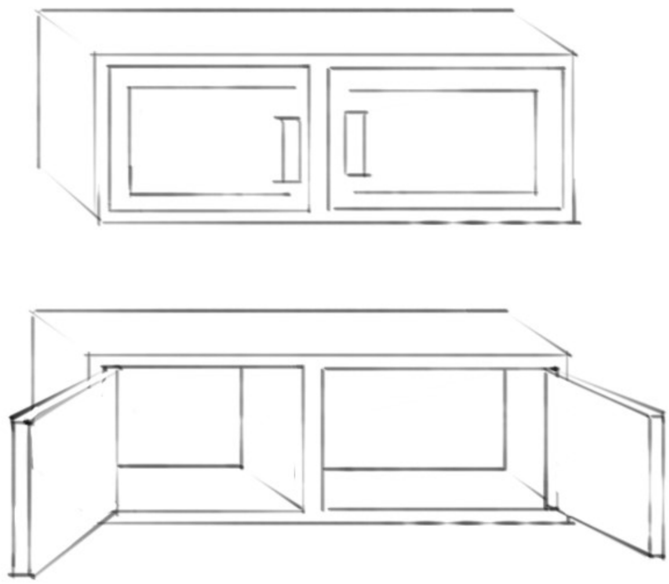


Figure 7.9: The microwave solution.

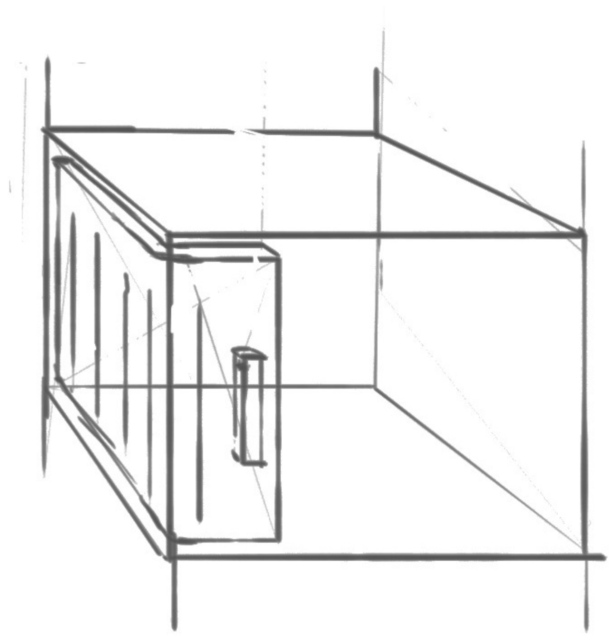


Figure 7.10: The Horizontal sliding door.

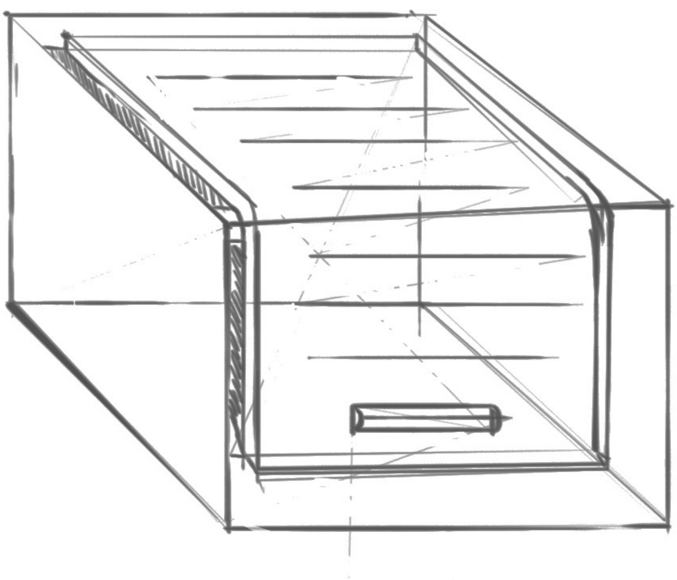


Figure 7.11: The Vertical sliding door.

7.1.4 Main storage

The main storage is the shell of the storage space, also called Box. Two different solution are created, one big and one small. The bigger one becomes a shell that is not changeable, Figure 7.12. The small box can be put together with another small box too create a big enough shell, Figure 7.13.

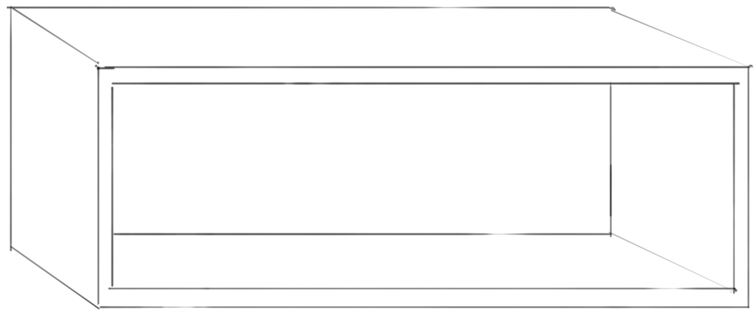


Figure 7.12: The big box.

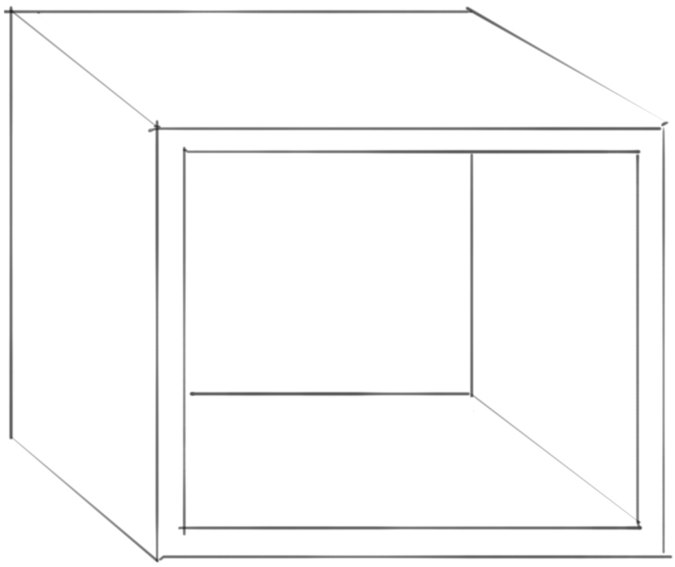


Figure 7.13: The small box.

7.1.5 Installation Solutions

The spring-loaded pin inside the shelves will prevent the shelves from moving, but at the same time make it easily removable for the user, Figure 7.14. The same is for the fan locking mechanism, Figure 7.15. This locking mechanism prevents the shelves from moving by spreading four legs.
The screw-down locks holds the shelves and potentially dividers in place, Figure

7.16. The user will insert the screw into holes in the shelving/divider and twist it to lock it into place. This concept also requires threading in the shelves/dividers.

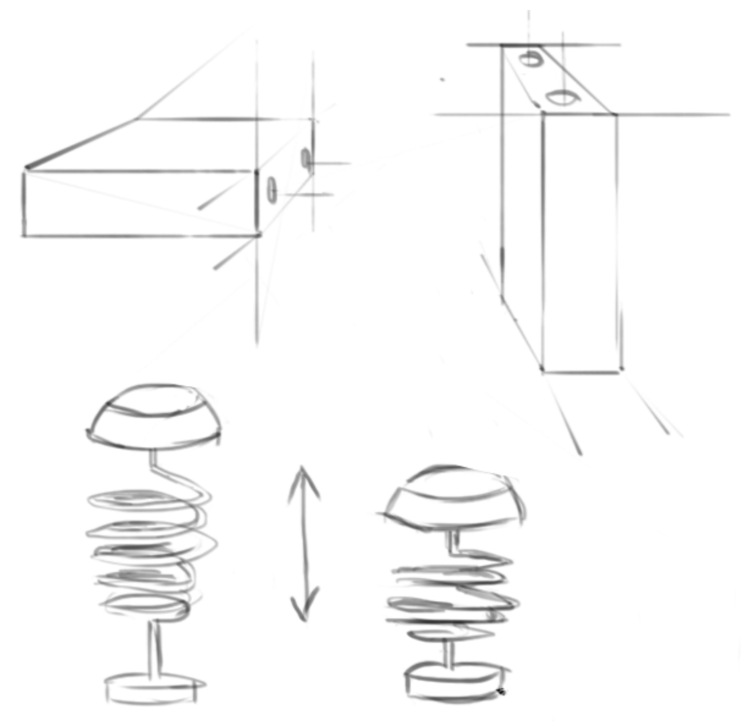


Figure 7.14: Spring-loaded pin.

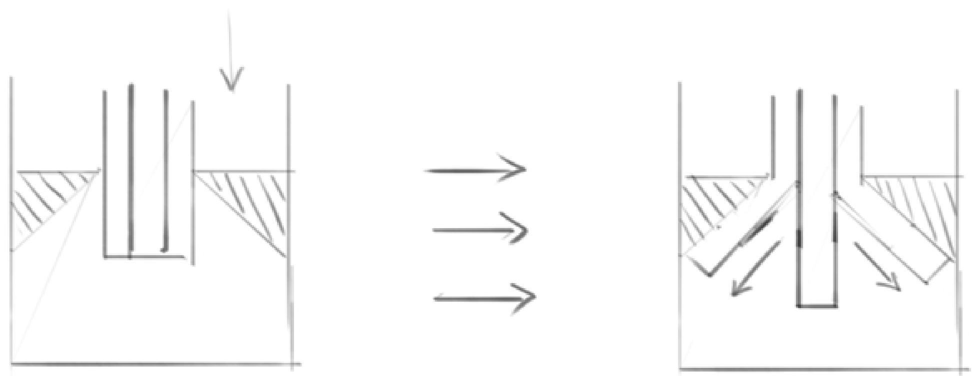


Figure 7.15: Fan locking mechanism.

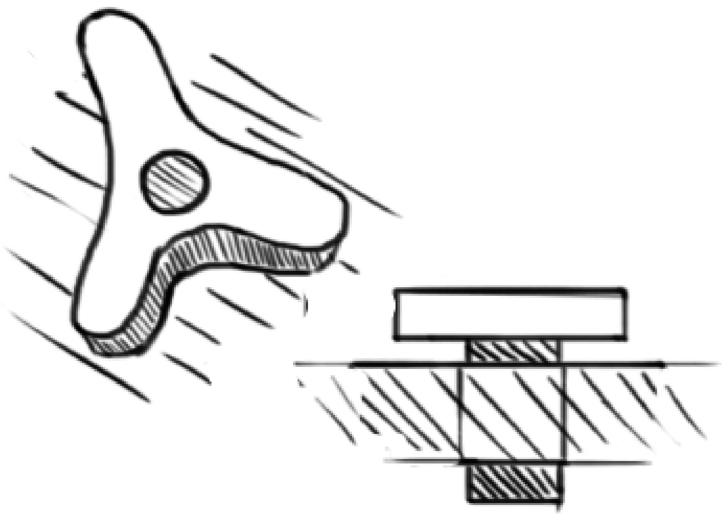
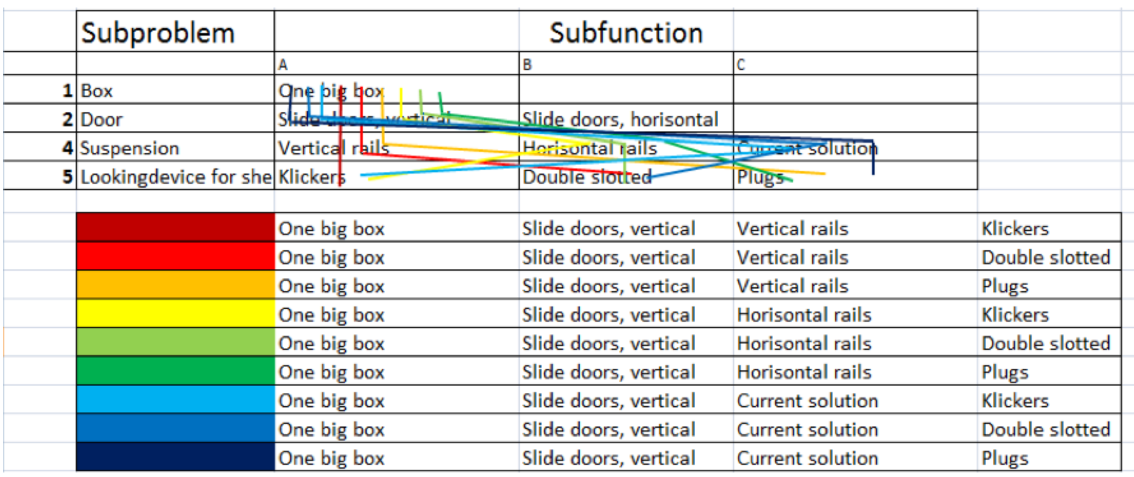


Figure 7.16: Screw-down locks.

7.1.6 Morphological matrix

To combine different sub functions and to generate different concepts a Morphological matrix is used. Due to many different sub functions is created through brainstorming, an elimination is necessary. In this case the total of concepts that could be created is 256, thus to time demanding to evaluate all of them. [28]

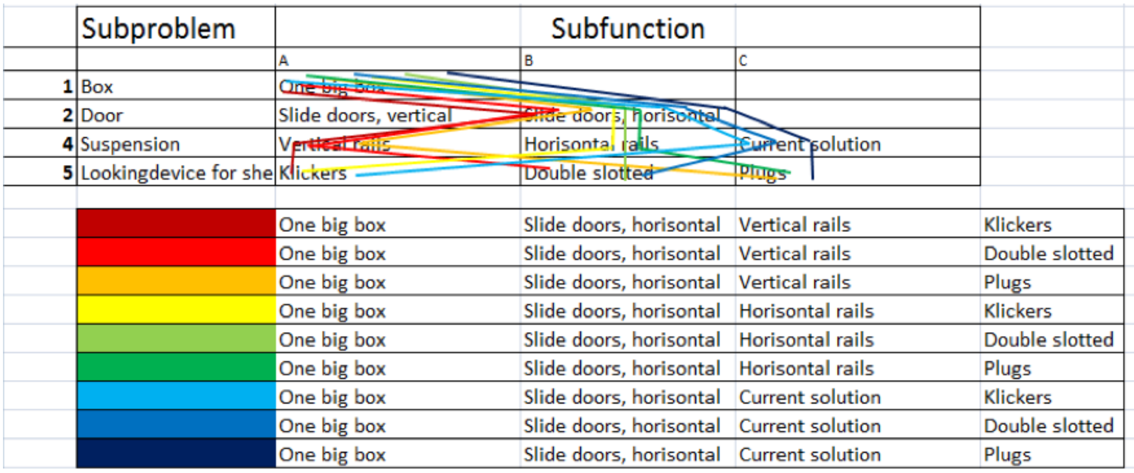
Sub functions that right away are seen as inappropriate, for example due to insufficient geometry or inability to meet customer requirements, is removed. Due to this, the generated total of concepts are 24. In figure 7.17-7.19 the different combinations can be seen.



	Subproblem		Subfunction	
		A	B	C
1	Box	One big box		
2	Door	Slide doors, vertical	Slide doors, horisontal	
4	Suspension	Vertical rails	Horisontal rails	Current solution
5	Lookingdevice for she	Klickers	Double slotted	Plugs

	One big box	Slide doors, vertical	Vertical rails	Klickers
	One big box	Slide doors, vertical	Vertical rails	Double slotted
	One big box	Slide doors, vertical	Vertical rails	Plugs
	One big box	Slide doors, vertical	Horisontal rails	Klickers
	One big box	Slide doors, vertical	Horisontal rails	Double slotted
	One big box	Slide doors, vertical	Horisontal rails	Plugs
	One big box	Slide doors, vertical	Current solution	Klickers
	One big box	Slide doors, vertical	Current solution	Double slotted
	One big box	Slide doors, vertical	Current solution	Plugs

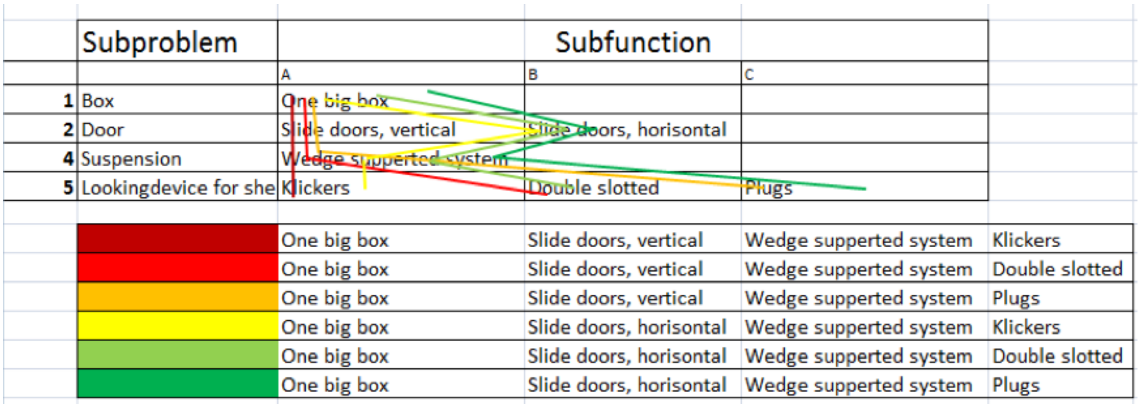
Figure 7.17: Morphological matrix 1.



	Subproblem	Subfunction		
		A	B	C
1	Box	One big box		
2	Door	Slide doors, vertical	Slide doors, horisontal	
4	Suspension	Vertical rails	Horisontal rails	Current solution
5	Lookingdevice for she	Klickers	Double slotted	Plugs

	One big box	Slide doors, horisontal	Vertical rails	Klickers
	One big box	Slide doors, horisontal	Vertical rails	Double slotted
	One big box	Slide doors, horisontal	Vertical rails	Plugs
	One big box	Slide doors, horisontal	Horisontal rails	Klickers
	One big box	Slide doors, horisontal	Horisontal rails	Double slotted
	One big box	Slide doors, horisontal	Horisontal rails	Plugs
	One big box	Slide doors, horisontal	Current solution	Klickers
	One big box	Slide doors, horisontal	Current solution	Double slotted
	One big box	Slide doors, horisontal	Current solution	Plugs

Figure 7.18: Morphological matrix 2.



	Subproblem	Subfunction		
		A	B	C
1	Box	One big box		
2	Door	Slide doors, vertical	Slide doors, horisontal	
4	Suspension	Wedge supperted system		
5	Lookingdevice for she	Klickers	Double slotted	Plugs

	One big box	Slide doors, vertical	Wedge supperted system	Klickers
	One big box	Slide doors, vertical	Wedge supperted system	Double slotted
	One big box	Slide doors, vertical	Wedge supperted system	Plugs
	One big box	Slide doors, horisontal	Wedge supperted system	Klickers
	One big box	Slide doors, horisontal	Wedge supperted system	Double slotted
	One big box	Slide doors, horisontal	Wedge supperted system	Plugs

Figure 7.19: Morphological matrix 3

7.2 Concept Selection

The team are using concept scoring matrices, shown in Tables 7.1, 7.2 and 7.3, to narrow down storage solutions from the concept generation phase. There are two distinct categories for concept selection: sub-unit installation and structural solutions. The sub-unit installation matrix consists of locking or mounting mechanisms that allow divisible units such as shelves to be temporarily attached to the internal storage surfaces. The temporary nature of these solutions allow the user to customize the location or presence of the shelves to their preferences. The structural matrix provides solutions for the body of the storage unit, including shape and divisibility, and may be configured as the customer desires.

Table 7.1: Concept Scoring Matrix 1 for Sub-units Installation Solutions

		Slots		Wedges		Spring Loaded	
Criteria	**Weighting**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**
Safety	0.21	4.5	0.945	4	0.945	4	0.84
Ease of Use	0.21	4	0.84	4	0.84	5	1.05
Ease of Mfg.	0.05	5	0.25	3	0.15	5	0.25
Cast	0.04	4	0.16	4	0.16	4	0.16
Efcy. Instal.	0.05	5	0.25	5	0.25	5	0.25
Durability	0.11	4	0.44	4	0.44	4	0.44
Sze. Adpt-ble	0.16	3	0.48	5	0.8	5	0.8
Ergon-omics	0.18	4	0.72	4	0.72	4	0.72
		Total Score:	**4.305**	**Total Score:**	**3.98**	**Total Score:**	**4.51**
		Rank:	**3**	**Rank:**	**2**	**Rank:**	**1**

Table 7.2: Concept Scoring Matrix 2 for Sub-units Installation Solutions

		Screw Down Locks		Grocery Store Shelving		Spreading fan fins	
Criteria	**Weighting**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**
Safety	0.21	4	0.84	4	0.84	3.5	0.735
Ease of Use	0.21	3.5	0.735	3	0.63	4	0.84
Ease of Mfg.	0.05	4	0.2	0.45	0.225	3.5	0.175
Cost	0.04	4	0.16	4	0.16	3.5	0.14
Efcy. Instal.	0.05	4	0.2	3.5	0.175	4.5	0.225
Durability	0.11	4.5	0.495	4.5	0.495	3	0.33
Sze. Adpt-ble	0.16	3	0.48	4.5	0.72	4	0.64
Ergon-omics	0.18	3.5	0.63	3.5	0.63	4	0.72
		Total Score:	**3.74**	**Total Score:**	**3.875**	**Total Score:**	**3.805**
		Rank:	**6**	**Rank:**	**4**	**Rank:**	**5**

Table 7.3: Concept Scoring Matrix for Main storage Solutions 1

		Tracked Divisible Storage		Unit Divisible Storage	
Criteria	**Weighting**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**
Safety	0.21	4	0.84	4	0.84
Ease of Use	0.21	5	1.05	3.5	0.735
Ease of Mfg.	0.05	4.5	0.225	4.5	0.225
Cost	0.04	4	0.16	4	0.16
Efcy. Instal.	0.05	4.5	0.225	4	0.2
Durability	0.11	5	0.55	5	0.55
Sze. Adptble	0.16	5	0.8	4	0.64
Ergonomics	0.18	4	0.72	5	0.9
		Total Score:	**4.57**	**Total Score:**	**4.25**
		Rank:	**1**	**Rank:**	**2**

Table 7.4: Concept Scoring Matrix for Main storage Solutions 2

		Grid webbing		Retractable shelves	
Criteria	**Weighting**	**Score (1-5)**	**Weighted Score**	**Score (1-5)**	**Weighted Score**
Safety	0.21	3.5	0.735	3.5	0.735
Ease of Use	0.21	4.5	0.945	3.5	0.735
Ease of Mfg.	0.05	3.5	0.175	3.5	0.175
Cast	0.04	3	0.12	3	0.12
Efcy. Instal.	0.05	4	0.2	3.5	0.175
Durability	0.11	4	0.44	3.5	0.385
Sze. Adptble	0.16	5	0.8	4	0.64
Ergonomics	0.18	4.5	0.81	4.5	0.81
		Total Score:	**4.225**	**Total Score:**	**3.775**
		Rank:	**3**	**Rank:**	**4**

The matrices reflect the team's ten best concepts from concept generation. The other minor concepts from concept generation are filtered out through deductive reasoning. Any of the concepts in Tables 7.1, 7.2, 7.3 and 7.4 that have not yet been introduced in the report are explained in further detail in Appendix A.4. An alternative Pugh Decision Matrix is also outlined in Table 7.5.

In Table 7.1 and 7.2, the low-scoring concepts include screw down locks, vertical rails and spreading fan fins. While the screw down locking mechanism is not complex, the repetitive process of screwing them into place would lead to much longer installation times than the higher-ranked solutions, so it received a low score. The vertical rail concept scored poorly because, compared to the other concepts, it would be difficult to install and uninstall. Hooking the shelves onto the rails they attach to can be tedious, and this is something the team seeks to avoid so the customer does not become frustrated with the final product. The spreading fan fins would be too difficult to manufacture due to the complexity of their design and geometry. While the wedges and pins are ranked second and third in the sub-unit installation matrix, the team decides that these ideas are better suited for mounting the solution to the walls, not for securing shelves and dividers in place.

In Table 7.3 and 7.4, the grid webbing, which can be found in Figure 7.2, and retractable shelving, Appendix A.3 concepts received the lowest scores out of the four structural solutions. The grid webbing concept scored particularly low in the categories of *Cost and Ease of Manufacturing.* Since this is a new and unique product designed entirely by the team, it would require a new type of manufacturing process that is complex with many unknown variables. When considering the geometric complexity of this concept, an injection molding process is implemented and it entails high expenses. The retractable shelves scored low in many categories including *Safety*, *Ease of Use*, *Ease of Manufacturing*, *Cost*, *Efficiency of Installation*, and *Durability.* With so many potential hazards and manufacturing problems, this concept received the lowest score in Table 7.3 and 7.4.

Table 7.5: Pugh-Matrix.

Pugh-Matrix						
Criteria	**Weight**	**Existing Solution**	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**
Safety	0.21	3	3	3	3	3
Ease of Use	0.21	3	4	4	5	5
Ease of Manuf.	0.05	3	3	3	3	3
Cost	0.04	3	3	3	3	3
Efficiency	0.05	3	4	4	4	3
Durability	0.11	3	4	2	3	3
Portability	0.16	3	3	3	3	3
Ergonomics	0.18	3	4	4	4	3
	Total score	**3.03**	**3.68**	**3.73**	**3.89**	**3.61**
	Rank		**3**	**2**	**1**	**5**

Explanation of Alternatives

1. Vertical slide doors, big box with ”permanent” brackets, wedge system, upper front panel.
2. Vertical shelves, changeable, either three ”boxes” or two, One big vertical slider, Locking device for vertical shelves, pre-drilled.
3. Big box, slide door vertical, existing solution for mounting, guided tracks, spring loaded.
4. Big box, slide door horizontal, wedge system, slotted, springloaded.

The final solution is chosen with the help from the Pugh-matrix, Table 7.5. The concept “Altenative 3” is ranked number one and is therefor the winning one. The solution had high scores for *Ease of Use*, *Ease of Manufacturing*, *Efficiency of Installation*, and *Size Adaptability.* The idea of having a spring-loaded locking mechanism for securing storage dividers scored the highest in the matrix because it ensures the driver can fully customize their storage spaces. For the structural concepts, the team is using a combination of guided track divisible storage and unit divisible storage, since the two concepts are very similar but would serve as solutions in different locations of the truck cabin. Both solutions allow the placement of vertical dividers or horizontal shelves. The main difference is that the unit divisible storage would be more effective on the back wall of the cabin if the customer had a desire to remove a bunk and replace it with a portable storage area.

7.3 Changes in concept

With the help from feedback from employees at Volvo the guided track solution is shown to be to complicated and therefore it is replaced. The guided track makes it to hard for the drivers to insert the shelves since it can be difficult to place it into the tracks and the raised tracks is considered a to complex geometry for plastic injection molding and would require additional tooling to create them. Instead of the guided tracks the slotted track is chosen, the slotted track is seen in Figure 7.7. This decision is made because slots is ranked as number two in the concept scoring matrix, Table 7.1.

7.4 Concept presentation

The final concept for the front upper storage space is shown in Figure 7.20. This concept has removable vertical dividers as well as removable horizontal shelves. The vertical divider in the middle is fix due to stability and to be able to attach the doors. With this concept the user get the possibility to change the storage space to the users needs.

From the final concept the team could see the big potentials with having removable shelves and a box that is adjustable to different spaces. Therefor a new concept is developed for the space right behind the passenger seat and the driver seat in for the American models. This concept includes the box as a vertical shell and within this box several slotted tracks, Figure 7.7, and horizontal shelves including spring loaded pins, Figure 7.14. This type of storage is useful for separating dissimilar items. For example, allowing for distinct separation for clothing and dirty tools would prevent any grease or dirt from getting onto clean clothing. In this example, the clothing would be stored at the top of the unit and tools would be stored at the bottom of the unit. The new concept is seen in Figure 7.21.

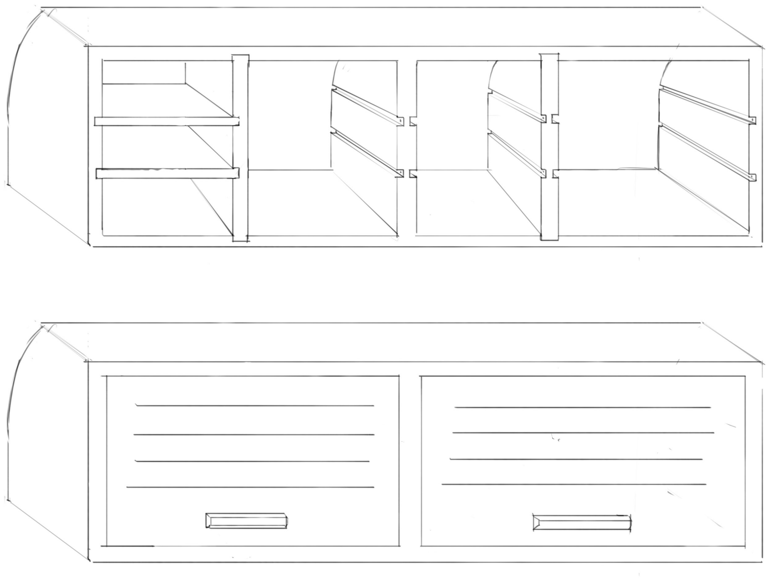


Figure 7.20: The final front concept.

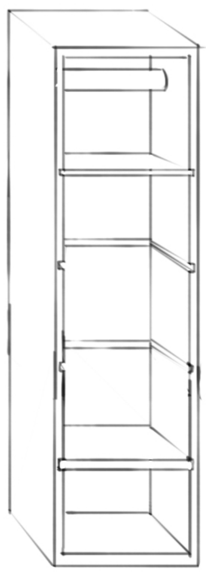


Figure 7.21: The further develop of the final concept also known as the Final Vertical rear concept.

8

System Level Design

In this chapter the concepts are presented by 3D CAD models, technical drawings and prototypes.

8.1 Computer aided design

This section shows figures of 3D CAD models of the final solutions created in SolidWorks [29] and CATIA [30], two programs for computer aided design.

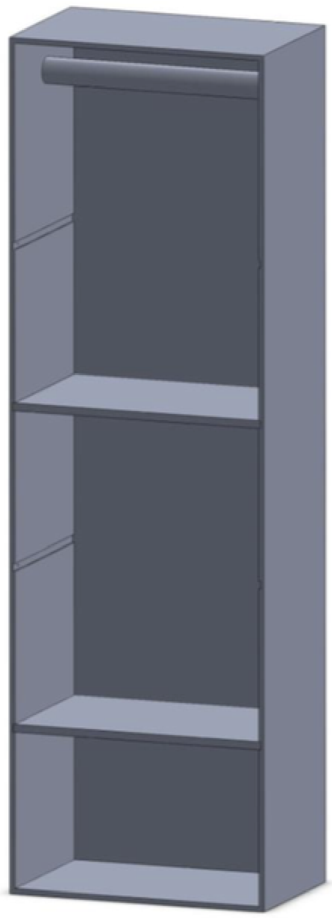


Figure 8.1: Isometric 3D CAD model of storage space located behind the driver and passenger seats.

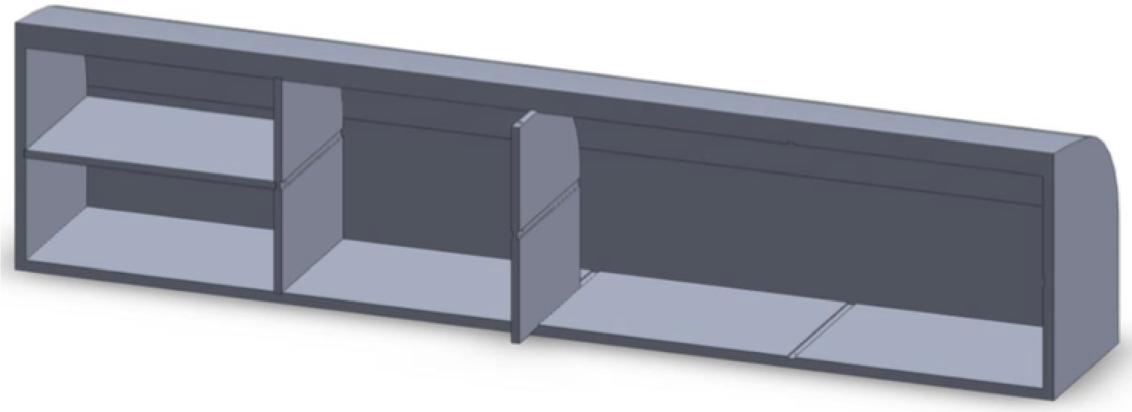


Figure 8.2: 3D CAD model of the front upper storage space.

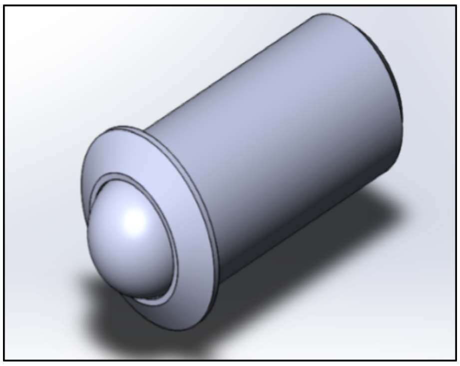


Figure 8.3: 3D CAD model of the spring loaded ball pin.

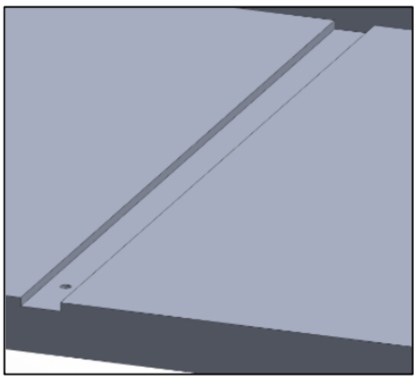


Figure 8.4: 3D CAD close-up of slotted tracks and pinholes.

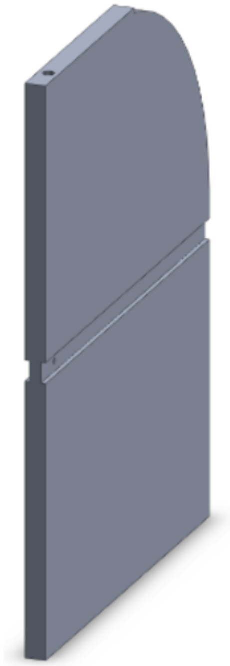


Figure 8.5: 3D CAD close-up of the vertical divider with slotted tracks.

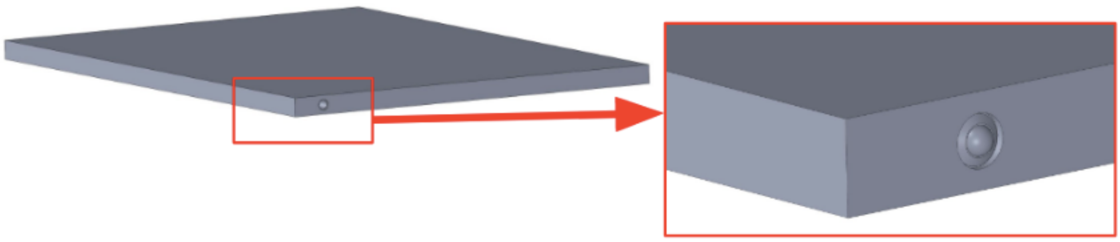


Figure 8.6: 3D CAD close-up of shelf with spring-loaded ball pins.

The final solution are relying on two main parts, the aforementioned spring-loaded pins and dividers. Both the spring-loaded pins and the vertical dividers will be provided to the customer to install if they desire to use them. As the customer slides the dividers into the desired location, the spring-loaded pins, shown in the bottom left of Figure 8.6, are locking into place when the ball comes in contact with the pre-existing holes in the top and bottom of the shell. Using the spring-loaded pins as a locking mechanism is ensuring that the divider does not move when the truck is in motion. There are a multiple of guided tracks in each storage space to allow for customer customization in terms of variable sizing of the storage space. This same notion will be used for horizontally-aligned shelves.

8.2 Technical drawings

In this section the technical drawings are shown. In these drawings the different measurement of the different parts is found as well as isometric views. For more the technical drawings see Appendix A.12.

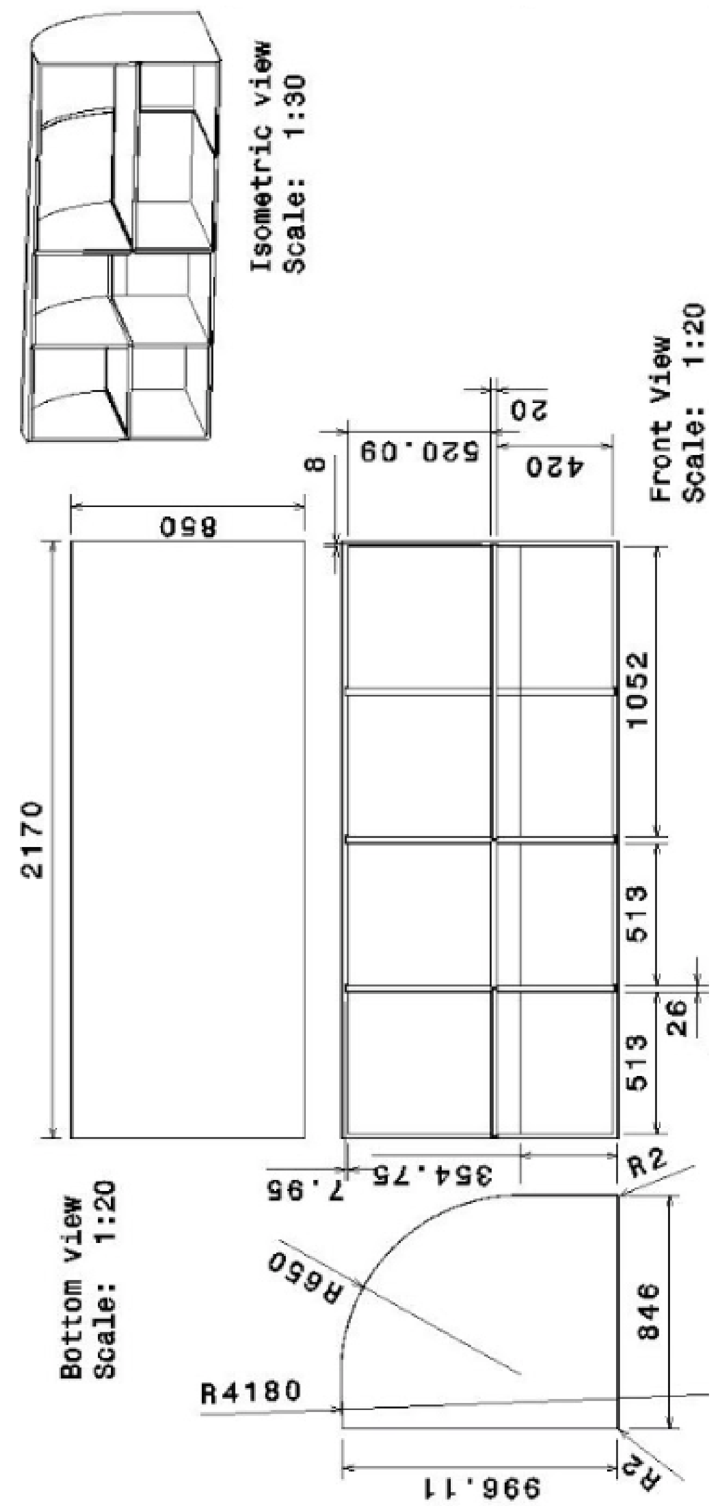


Figure 8.7: Technical drawing of the front upper storage space.

8.3 3D-printed prototype

As an early model of the product to test the concept, 3D-printed prototypes are made. Multiple simplified prototypes are created to provide visual detail of the storage solution and its components.
Due to size constrictions, the 3D-printed model is not full-scale, but is still able to demonstrate the shape and functionality of the different solutions and design.

8.4 Full size prototype

The team are providing a full-scale wooden prototype, shown in figure 8.9 specifically to model the sub-unit installation solution. This prototype is including one full size section of the unit, two vertical dividers, one horizontal shelf, four spring loaded pins, and four weld-in retractable spring plungers.
Saws, drills, and sanders are being sufficient to make the shape of the dividers and shelves. The spring loaded pins are being used in the model to demonstrate how the vertical dividers secure into place inside the shell of the storage unit. Four spring loaded pins are being used to secure each divider. Two pins are being located on the top of the divider to connect to the interior top surface of the shell, and two pins are being located on the bottom of the divider to connect to the interior bottom surface of the shell.
The weld-in retractable spring plungers are being used to demonstrate how the horizontal shelves connect to the vertical dividers and secured into place. Four plungers are being used to secure each shelf. Two plungers are being located on either side of the shelf to secure it into the vertical dividers. The prototype do not include a functioning door.

The full-scale wooden prototype are allowing the team to demonstrate how the customize shelves function. More information about the fabrication of the wooden prototype is to be found in Appendix A.11.

Figure 8.8: The full size wooden prototype without shelves and dividers.

Figure 8.9: The full size wooden prototype with different shelving and divider configurations.

The top picture of Figure 8.9 is a representation of the storage compartment located specifically above the dashboard. It includes a shell of the storage solution conformed to the shape of the truck cabin in that location, vertical dividers that slide in and out of the storage compartment along guided tracks, and spring-loaded pins to secure the vertical dividers into the top and bottom surfaces of the shell.

9

Detailed Design

This chapter consists of detailed information abut the concept including manufacturing, choice of material, CAD-drawings and what tests that are completed.

9.1 Material and Material Selection Process

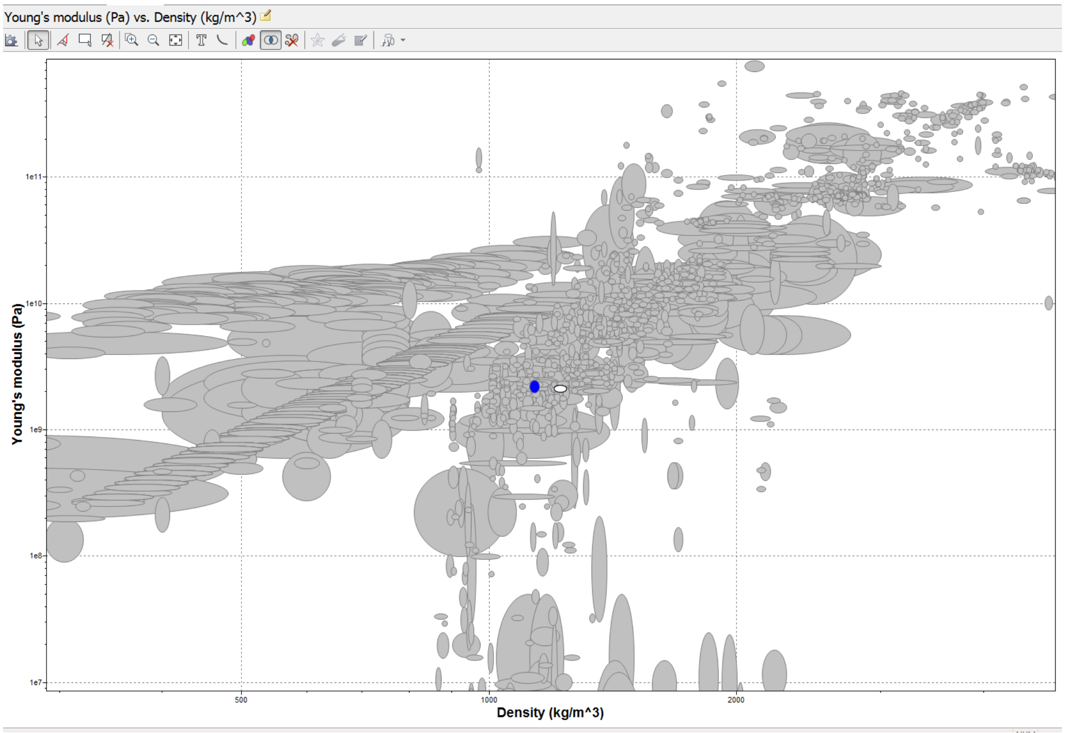
To choose a material for the different components the program CES (The Cambridge Engineering Selector 4.1) is used. This program helps with setting up different limitations and to give a good description of all the materials that exists. The selection went from more than 3900 materials down to less than 20 and the limitations that could be selected are for an example mechanical, thermal, optical, electrical, magnetic and environmental properties. The criteria that are in focus for this concept are durability, the concept is to be as resistant as possible against sun, water and fire, the density, the weight is important both for the user as well as for manufacturing, the Young's modulus, if to elastic the concept will fail as a storage module. All of these criteria connects to safety and is important to consider. The criteria for this selections can be seen in table 9.1.

Table 9.1: Criteria for material selection.

Optical Properties		Opaque
Durability	Water (fresh)	Excellent
	UV Radiation	Fair
	Flammability	Slowburning
Recycling and end of life		Recyclable
Physical Properties	Density	1300 $\frac{kg}{m^3}$
Mechanical Properties	Young's modulus	$2 \cdot 10^9$ Pa

After setting the different criteria the team is left with three candidates of materials. The material that finally is selected is the PC/PET Impact Modified (Polycarbonate and Polyethylene Terephthalate blend). This polymer is common in construction, automotive and transportation et cetera. It has a good Young's module and is recyclable. More details about the PC/PET Impact Modified can be found in figure 9.1

Figure 9.1: Bubble diagram of the selected material.



9.2 Manufacturing Process Plan

Since the geometries of the developed storage solution is rater simple there is not a large need for complex manufacturing in the final product. The dividers and shelves is to be produced with injection molding. The design in uncomplicated and the parts are having various dimensions based on Volvo specifications for each truck and model. Holes for the spring-loaded pins are accounted for before the product is injection molded. Additionally, the spring-loaded pins has a press fit with the plastic dividers and shelving to ensure that they do not move around while the truck is moving. There are being no mandates on the material necessary for the final product given to the team by Volvo, but the team are using a material identification software, the Cambridge Engineering Selector 4.1, to identify that PC/PET (polycarbonate and polyethylene terephthalate blend) plastic are being well-suited to the design needs. The pins and plungers are being purchased from an outside vendor so there is no need for any machining processes to create those. Table A.2 in Appendix A.7 provides an outline of the manufacturing process plan.

9.3 Component and Component Selection Process

Components are being selected for their durability, availability, ergonomics, and cost are shown in Table 9.2. Availability and cost, in the case of components, are closely related. The relation between cost and availability is brought about when considering custom-manufacturing the components, or establishing facilities and equipment to manufacture the components without the need for a vendor. To avoid the cost custom manufacturing, pre-made attachment parts are being used. Discussion is carried out by the team to determine which parts are best for buying pre-manufactured based on complexity and availability of materials. The pre-made parts that are selected are the weld-in retractable spring plunger and the press-fit ball-nose spring plunger. The complexity of the parts drives the need to buy pre-manufactured items for the sake of cost.[31] Dividers and shelves, used for the vertical separation and horizontal separation of spaces respectively, will be custom manufactured for the exact size and shape of the storage solution. The shelves and dividers need to be manufactured specifically for this purpose to ensure the proper fit and full utilization of available space. In Table 9.2 the different way for manufacturing is shown for different components.

Table 9.2: Key components and design solutions.

Component	**Solution**
Horizontal shelving	Custom injection molding
Vertical dividers	Custom injection molding
Vertical dividers lock	Press-fit ball-nose spring plunger
Horizontal shelving lock	Weld-mount retractable spring plungers
Box	Custom injection molding

10
Test Procedure

In order to ensure that the designed solutions meet the requirements set, tests are carried out. This chapter presents finite element analysis and physical test including design for Assembly.

10.1 FEM- Finite element analysis

To make sure that the design is sufficient to carry maximum weight/volume provided by Volvo, a simplified finite element analysis is made on both the designs. This analysis is made with the help of the program ANSYS [32].
The material for the testing is chosen as Polythylene since the material attributes of it resembles the one chosen for the design. Worth noting is that the material attributes are "weaker" than the ones from the real material, which makes the concept less solid in the testing. Assumptions of the material being isotropical is made and therefore the Equivalent Stress is considered the most suitable testing for the stress in the structure [33].
The Equivalent stress on the storage unit can be viewed in Figure 10.1 during maximum load. When comparing the equivalent stress to the yield strength of the material, the conclusion is that the material can withstand the force without permanent deformation.

Figure 10.1: Equivalent Stress for front storage unit.

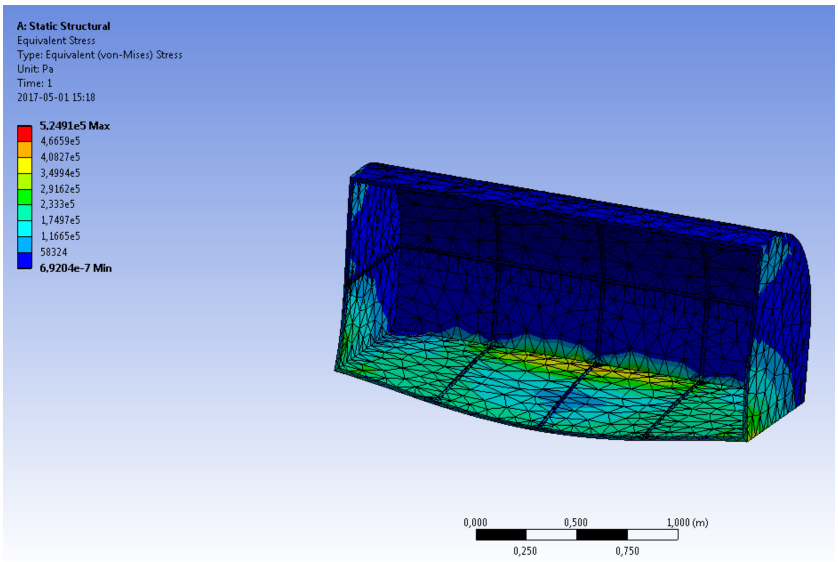
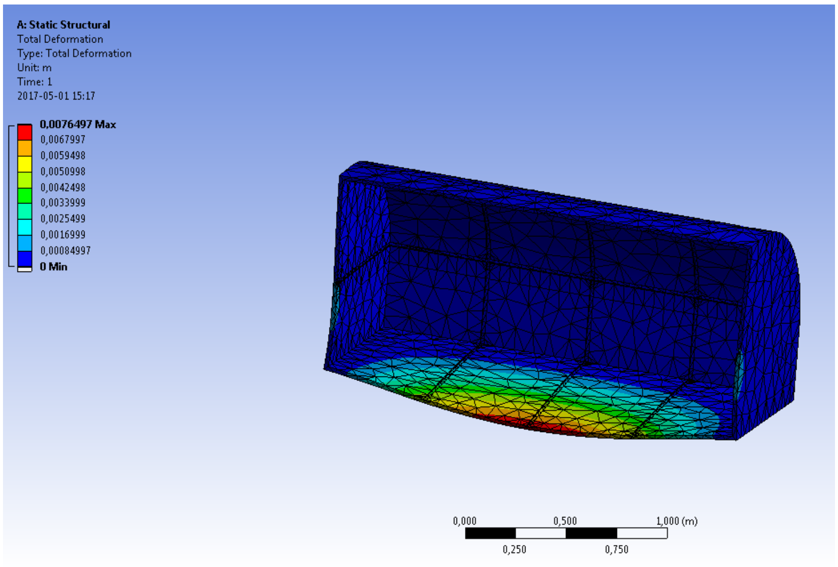


Figure 10.2: Total Deformation for front storage unit.



In Figure 10.2, bending deformation are being in the middle of the storage unit. Since the dividers does not add to the integrity of the design by the load caused by gravity, there could be some complications with the middle divider. When the design is affected by maximum force, the bending deformation is about 7 mm, observed in the Figure 10.2. The fixture to keep the dividers in place are 5 mm, which can cause the dividers to slip out of the fixture. On the other hand, the storage ca be placed on top of the other integrated parts above the dashboard.

10.2 Physical tests

Physical tests are preformed on 3D-printed prototype and the wooden prototype with the goal of testing primarily user-friendliness and ergonomics.

10.2.1 DFA - Design for Assembly

Physical testing of the wooden prototype are showing that the solution works well as a modular storage system. Similar to the 3D-printed prototype, the shelves and dividers stay firmly in place when inserted into the unit. The pins lock into place with ease. The vertical dividers and the horizontal are easy to remove after they have been installed and they are also easy to slide in. This feature allows for quick installation by the drivers, which met the customer needs of "ease of use".

The wooden prototype is demonstrated multiple times over the course of three hours during the Penn State Design Showcase and the pins are functioning without fail each time. This are meting the customer needs of "durability". The wooden prototype allows for visible customization and can be converted from a large space into smaller, compartmentalized spaces, which successfully meets the main customer needs expressed by truck drivers.

10.2.2 Ergonomics

The ergonomic requirement of reachability is tested through functional testing of the full scale wooden prototype.
The test investigate the ease of use for drivers of varying size, described in section 4, and is performed by placing the prototype at different heights. The result for the rear storage space over bed is that the reachability for a small woman (F05) 152.5 cm is extremely limited though it works perfectly for persons who are 175 cm or more.

11
Further Development

This chapter contains further development of the concepts completed on behalf of the Volvo sponsor after the final deadline for the American part of the team. Potential for further development are identified primarily for the the rear storage space over the bed.

This description of the further development includes specifications of areas in need of improvements, conceptual explanations, sketches, CAD-models, technical drawings and simplified conceptual 3D-printed model.

11.1 Areas of improvement

In chapter 10 the results of ergonomic testing is found. The result for the rear storage space over bed is that the reachability for a small woman (F05) 152.5 cm (more closely explained in section Safety regulations in chapter 4) is extremely limited.

For shelf configuration of larger storage spaces there is also a risk that the user, if using these spaces for storing large and heavy objects, will get hurt by the heavy lift. Heavy lifts above the head should be avoided as much as possible. [34]

Because of this, there is a need of improvement regarding the reachability for the storage solution over the bed in the back of the cabin.

11.2 Concept

The further developed solution for the rear storage space is placed in the back of the cabin over the bed, as shown in the Figure 11.1. It is mounted on the wall with the horizontal rails, Figure 7.3. The storage consists of a combination with both one box, Figure 11.3, and two smaller boxes, Figure 11.2 with submersible function. The submersible function can be operated by for example compressed air, suspension or springs. The solution for doors and removable shelves is the same as in the final concept in chapter 7, and they are implemented to complete the solution.

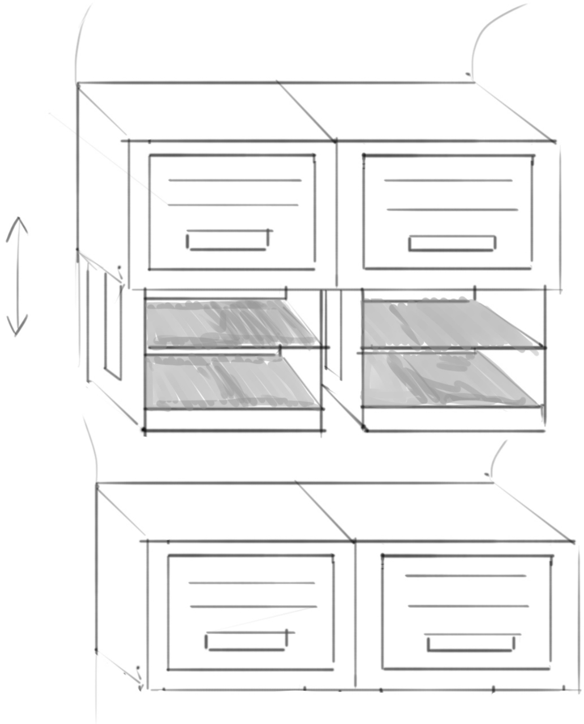


Figure 11.1: Rear storage with submersible function.

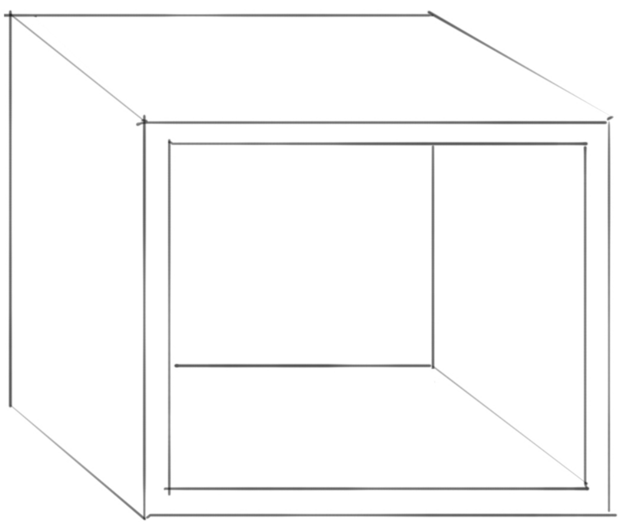


Figure 11.2: Small box with shelves inside the larger box

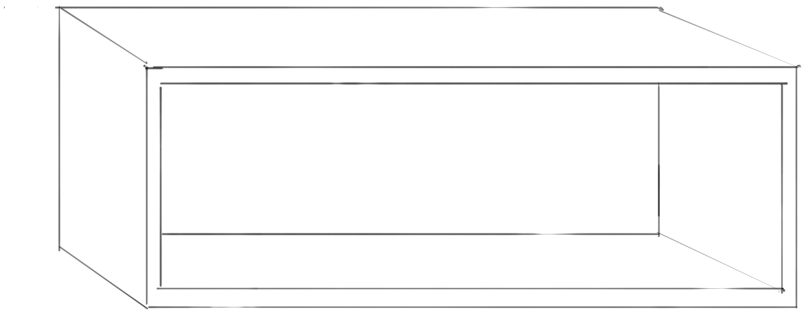


Figure 11.3: Large box that holds two smaller boxes

11.2.1 Computer aided design

This section shows figures of 3D CAD models of the further developed solution in CATIA [30]. In figure 11.4 the CAD-model of rear storage with submersible function is shown. In 11.5 the same storage but with one door is demonstrated.

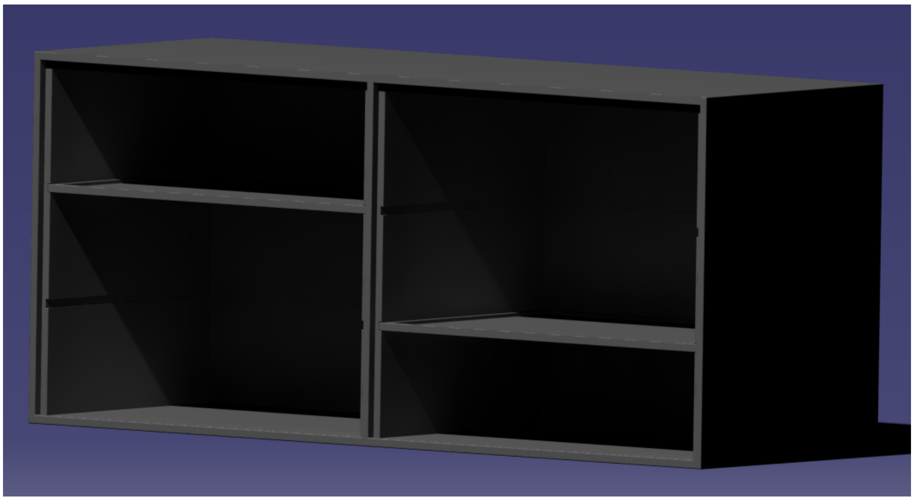


Figure 11.4: CAD-model of rear storage with submersible function.

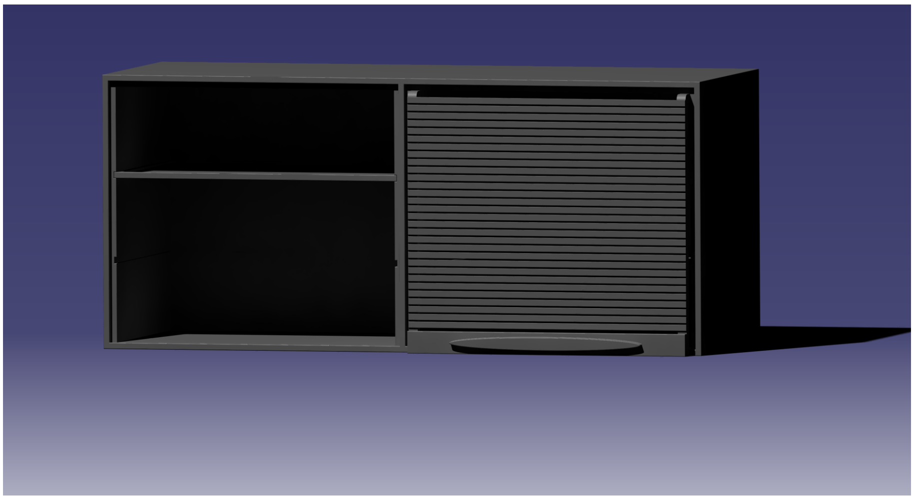


Figure 11.5: CAD-model of rear storage with submersible function icluding one door.

In figure 11.6 the submersible function is shown without the covering door. As seen in the figure the solution consists of two storage boxes attached in a shell. The storage boxes are height adjustable to improve the reachability. Besides lowering the storage boxes the storage space can be accessible from the sliding doors in a elevated position.

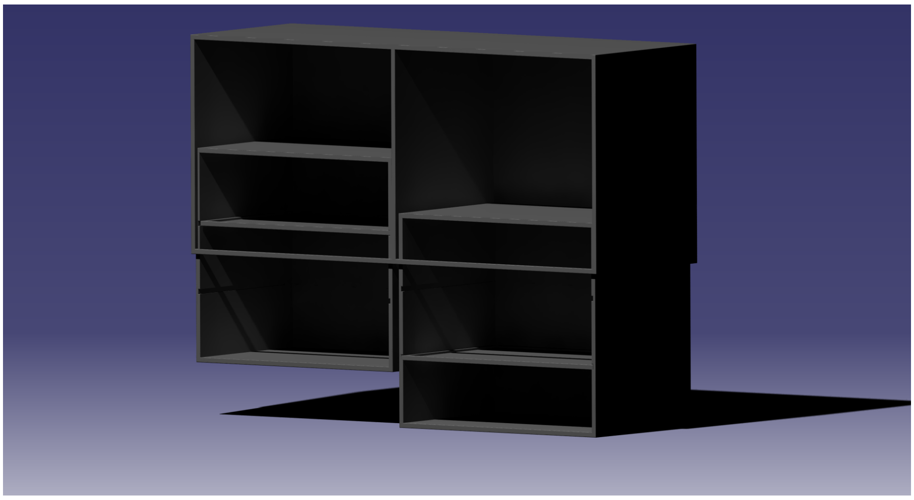


Figure 11.6: CAD-model of rear storage with submersible function.

More CAD-models can be found in Appendix A.16 to A.15

11.2.2 Technical drawing

For more technical drawings see Appendix A.12.

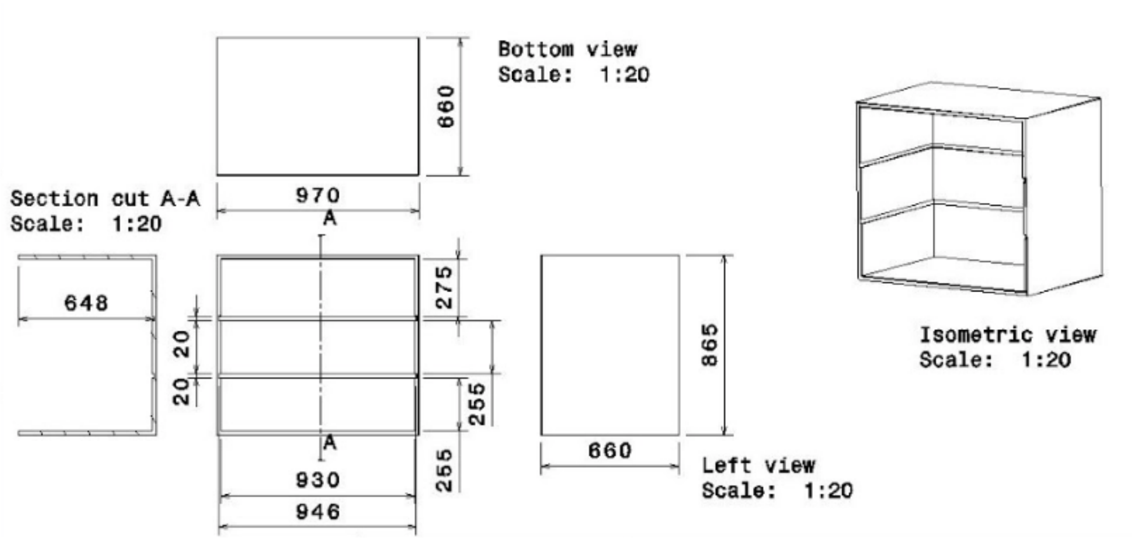


Figure 11.7: Technical drawing of the further developed storage space in the back with submersible function, small box inside the shell.

11.2.3 3D-printed prototype

As a first physical model of the further developed product to test the concept, 3D-printed prototypes are made. Multiple simplified prototypes are created to provide a visual detail of the storage solution and its components.
Due to size constrictions, the 3D-printed model is not full-scale, but is still able to demonstrate the shape and functionality of the different solutions and designs.

11.3 Improvements

This further developed version of the solution for the rear storage space improves the reachability with more than 800 mm.
The submersible function may also prevent drivers from injures by preventing drom doing heavy lifting over the head.

More about the improvements of the total final concepts is found in Chapter 12.

12
Final Discussion

This final discussion includes conclusions that can be made by this project in product development and recommendations for further work as well as improvements between the developed solution and existing solutions.

12.1 Improvements

The main objective of this project was to create a modularized storage system that can be carried out universally to all models of Volvo trucks and across all global markets. This was achieved by creating a vertical storage assembly that housed horizontal shelves as well as a horizontal storage assembly that housed both horizontal shelves and vertical dividers. All shelves and dividers were secured in place with spring-loaded ball pins and divots that extend the length of the storage shell. The CAD models of the horizontal assembly were designed specifically for storage located above the dashboard, but could also be incorporated to other areas in the truck cabin such as below or above the bunk or on the side walls of the cabin if space permits in certain models.

Another important factor of designing this storage solution was to meet all the customer needs given to the team by Volvo employees and truck drivers. One of the most important needs, safety, was successfully met by incorporating the pins to keep the dividers in place, as well as by designing with a sliding door that locks in the middle. Since the truck driver will be the person using the storage units in the future, their needs were taken into consideration and were fulfilled by creating a storage unit that was tailored to their ever-changing preferences.

12.1.1 Modularity evaluation

To evaluate the modularity of the developed concept the module-indications-matrix described in section 3.3.4.1 is used. The concepts, numerated as shown below, are compared with the existing solution on the different indicators of the matrix and is given different colours by how modular it is.

1. Final front concept
2. Final vertical rear concept

3. Further developed rear concept over bed
4. Existing storage solution

Table 12.1: Modularity by the module-indications-matrix, MIM [10]

Modularity giver	Solution	1	2	3	4
Development/ Construction	"Carry-over"				
	Technical development				
	Productplan				
Variants	Different specifications				
	Styling				
Production	Shared units				
	Process/Organisation				
	Styling				
Quality	Testable modules				
Purchase	Supplier exists				
After-market	Servicing				
	Upgrading				
	Recycling				

The result of this evaluation is that all concepts indicates to be more modular than the existing solution. The headings that are most distinctive are specified below:

Carry-over

The meaning of "Carry-over" is that parts and modules can be used in different models and products and that modules can be used in upcoming product generations.

Technical development

The meaning is that parts that will have to be changed due to Technical development should be modular to facilitate the change. Our developed solution improves this by for example the extractable shelves and divider. These allows for a space to be made larger or smaller if the development goes towards, for example, bigger microwaves och coffee makers.

Shared units

All the storage solutions developed in this project consists of shared units. Examples of this is the horizontal rails that can be used in different models for mounting both upper bunk bed and upper rare storage space, or the extractable shelves and divider that can be used in different models and in all the storage solutions developed in this project. Also the usage of the same solution for doors are used for at least two concepts.
This parts are leading towards reduction of the number of parts.

Process/Organization

The new solution uses standardization of parts, replacing numerous similar parts with one common part. This can result in larger part-type buys because the common parts are used in multiple applications. Larger part-type buys enable to benefit from the economies of scale. Using common components can also reduce the organization cost of maintaining technical data and storing, tracking, and distributing multiple parts. Furthermore, the standardization of part simplifies logistics support and enhances substitutability thanks to fewer parts are stocked. [35]

After-market

All the storage solutions developed in this project are easily removable compared to the often site-based existing solution. The removable solutions will ease the recycling.
The extractable shelves and divider will also improve the possibility to proceed upgrading and servicing on parts.Also, it is easier to replace damaged objects, such as shelves for new ones if needed. Place-built shelves cause the whole storage space to be substituted if damaged. When a unit is replaceable it leads to faster product changes. It also leads to less risk-taking when developed new products. This is because a new product launch does not require other changes in the cabin, the module can easily be replaced if it does not reach the standards. This means that the modulized storage system can benefit further development in the interior. [10]

12.2 Discussion

Regarding the complexity of manufacturing, it is not considered to increase. The materials used for all of the storage solutions developed in this project are well-known to the company and something they are currently working with today [22]. However, there is reason to believe that manufacturing would be affected by the implementation of shared units between markets. Even if administration costs and organization should benefit from the change in a long perspective, see section 12.1, the transition can be costly.

By modularizing the solution, parts of the completion of the product is postponed to the customer. This is described in section 3.3.3. In figure 3.4 the costumer order specification is described. The benefits of postponement is that it provides a supply network with the flexibility that requires to customize a product. When the customer makes the final completion it enable a higher level of customization. [36]
To conclude, the developed solution makes Volvo Trucks able to provide the costumer with customized and individualized products without having to use ”engineering to order” process and instead be able to select variants. [14]

With the new solution several of parts are included, these parts includes all the shelves, dividers and an extra bed or storage that can be used if wanted. If not in usage, these parts becomes an extra burden and needs to be stored somewhere. This storage space is up to the user to find. Though this could be a problem the team finds the advantages of having the possibility to arrange the storage space as the user it self pleases to be bigger and cancels out the problem of finding an extra storage unit.

When the team talked to a salesman at Volvo Trucks, described in chapter 4, the salesman expressed that the costumer sometimes are confused by all the different choices that comes with ordering a truck. There is no good tool for the salesperson to visualize the configuration of the truck. The developed storage solution makes the cabin much more customizeable. Without a good tool for the salesperson to visualize the different choices there is a risk that the customer may be even more confused. On the other hand the developed storage solution will be more uniformed and with the right method it will be even simpler to explain the different choices. This is because they have similar designs and will in the future be common for all different types of trucks that are included in Volvo Group.

12.3 Recommendations

It is reasonable to investigate whether the new storage solutions developed in this project is more or less stable than the current solution. Since calculations on the existing solution are not available, the discussion must be based on the fact that the newly generated solution meets the requirements. A recommendation for further development is to compare data of the new and the existing solution.

12.3.1 FEA (Finite Element Analysis)

Recommendations about the robustness of the design of the concepts can be made by taking a look at the results of Finite Element Analysis. Since the forces on the sides of the structure are not causing significant deformation or stress (see picture in appendix A.21), improvements to the design can be made by making the structure less robust that in turn would save money and material. To ensure that the smaller parts of the design, such as the mounting and additional screws and ball-pins, does not deform from the maximum stress they need to be implemented into the CAD-design and tested.

Since a simplified version of the design was used to make the testing possible, ensuring that the design will be sufficient as it gets more complex can not be ensured. With the help of a team with more experience and knowledge about ANSYS and Finite Element Analysis a more detailed and probable testing would be possible. Additionally to the static structural testing, testing in a dynamic environment would resemble driving or during a crash.

12.3.2 RD&T (Robustness Evaluation and Tolerance Analysis)

As a compliment to the Finite Element Analysis a computer analysis of RD&T (Robustness Evaluation and Tolerance Analysis) should be completed. RD&T software will put the CAD assembly into the program and run a simulation of vibration. The weak spots in parts that interfere with other parts will be revealed. The vibration simulation is performed to replicate road surface effects on the internal components of the truck cab.

12.3.3 Life Cycle Analysis

In order to chart how the developed products affect the environment during it´s lifetime, a Life Cycle Analysis, (LCA), should be conducted. In an LCA, the environmental footprint is tracked from raw materials extraction, through manufacturing processes and waste management, including all transports and all energy consumption in the middle line, are followed.[37]
This analysis is resource intensive, which is the reason that it was not implemented in this project. for a simpler analysis, a simplified LCA can be made. This does not provide as extensive information but a good overview.[38]

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A
Appendix

A.1 Budget

Initial Budget	PSU: $1000	CTH: $225
	Actual Expenditures	**Anticipated Expenditures**
PSU Travel	$136.96	$300.00
CTH Travel		
PSU 3D Printing	0.00	50.00
CTH 3D printing		$0
Pre Fabricated Materials	$173.76	$300
Poster	$62.24	$70.00
Raw Materials	149.20	$200
Misc.	0.00	$80.00
Total	$522.16	$1000

Table A.1: Budget

A.2 ASME Code of Ethics of Engineers

The Fundamental Principles
Engineers uphold and advance the integrity, honor and dignity of the engineering profession by:

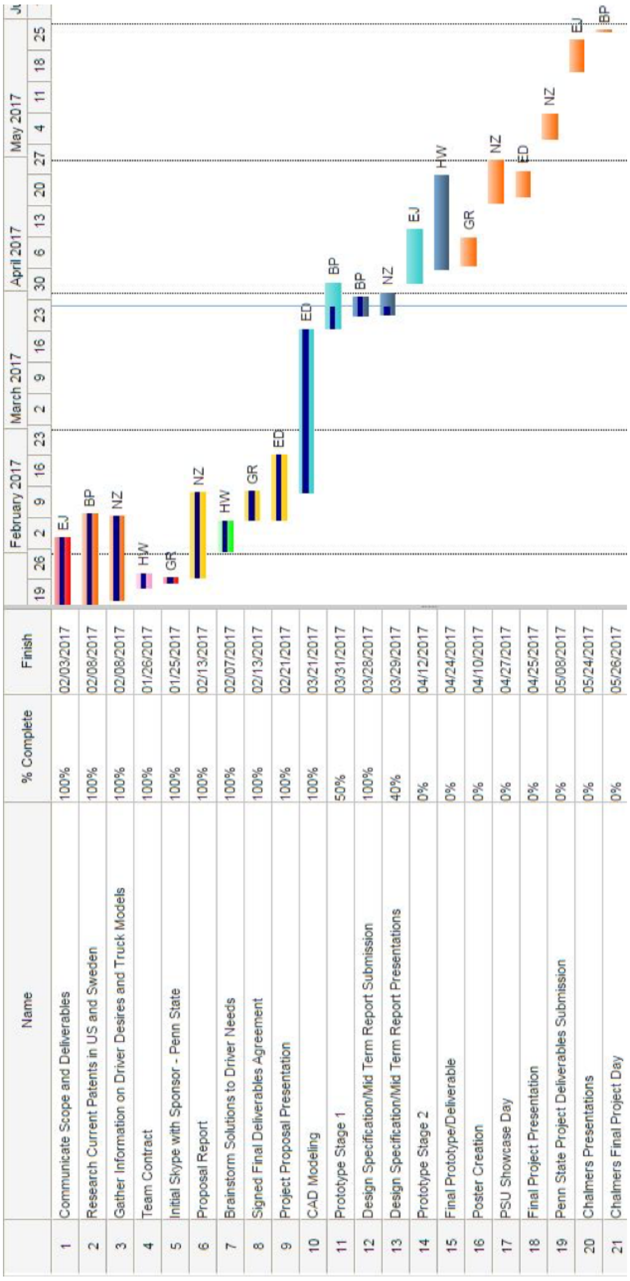
1. using their knowledge and skill for the enhancement of human welfare;
2. being honest and impartial, and serving with fidelity their clients (including their employers) and the public; and
3. striving to increase the competence and prestige of the engineering profession

The Fundamental Canons

1. Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in the areas of their competence; they shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
3. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional and ethical development of those engineers under their supervision.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest or the appearance of conflicts of interest.
5. Engineers shall respect the proprietary information and intellectual property rights of others, including charitable organizations and professional societies in the engineering field.
6. Engineers shall associate only with reputable persons or organizations.
7. Engineers shall issue public statements only in an objective and truthful manner and shall avoid any conduct which brings discredit upon the profession.

8. Engineers shall consider environmental impact and sustainable development in the performance of their professional duties.
9. Engineers shall not seek ethical sanction against another engineer unless there is good reason to do so under the relevant codes, policies and procedures governing that engineer's ethical conduct.
10. Engineers who are members of the Society shall endeavor to abide by the Constitution, By-Laws and Policies of the Society, and they shall disclose knowledge of any matter involving another member's alleged violation of this Code of Ethics or the Society's Conflicts of Interest Policy in a prompt, complete and truthful manner to the chair of the Ethics Committee.

A.3 Gantt Chart for Project Management



A.4 Concept Generation

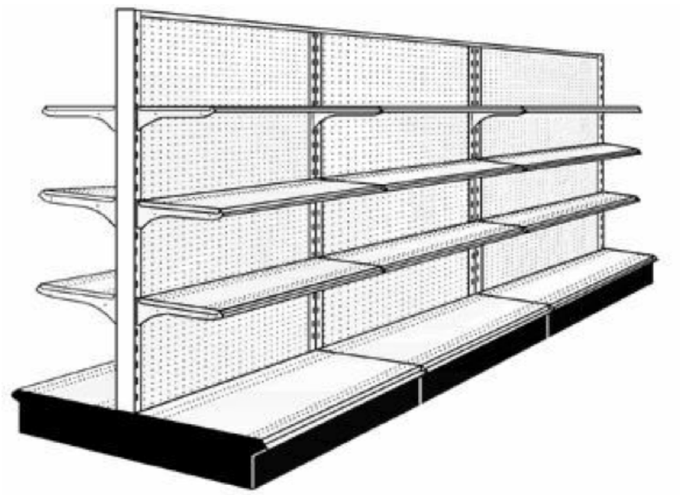


Figure A.1: Grocery store shelving [4]

The grocery store shelving allows the user to place the shelving mounts at any of the given spots on the vertical rails. The mount is tipped slightly upward and pushed downward into the hole on the rail. The user then places screws in the mount to secure it and prevent movement during driving. The user will also screw in the shelves once they are in the proper location.

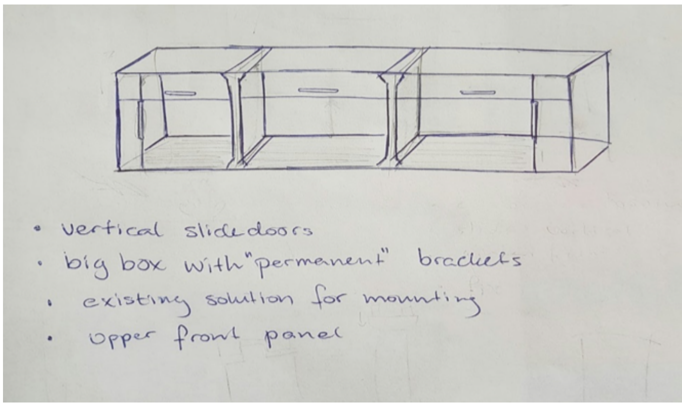


Figure A.2: Unit divisible storage concept

The unit divisible storage concept is shown above. This concept is essentially a box that the user can configure to their needs before mounting it onto the truck. This solution is especially pertinent if there is the potential to replace the upper bunk bed in some truck models.

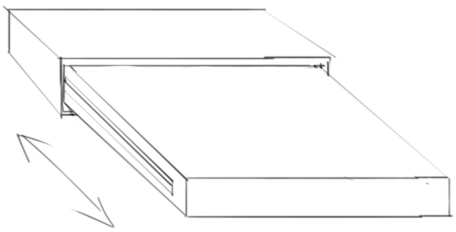


Figure A.3: Retractable shelving concept

This is the retractable shelving concept. Shelves would be placed in the storage space at regular intervals, but would be capable of receding into themselves to allow for the storage of larger items like a guitar or cooler. This would be extremely difficult to manufacture and may not be very durable.

Figure A.4: Pin for locking

These pins would be used to lock the storage solution into place to prevent translation (Pivot Point). This is a temporary solution that is not very secure.

A.5 Sketches

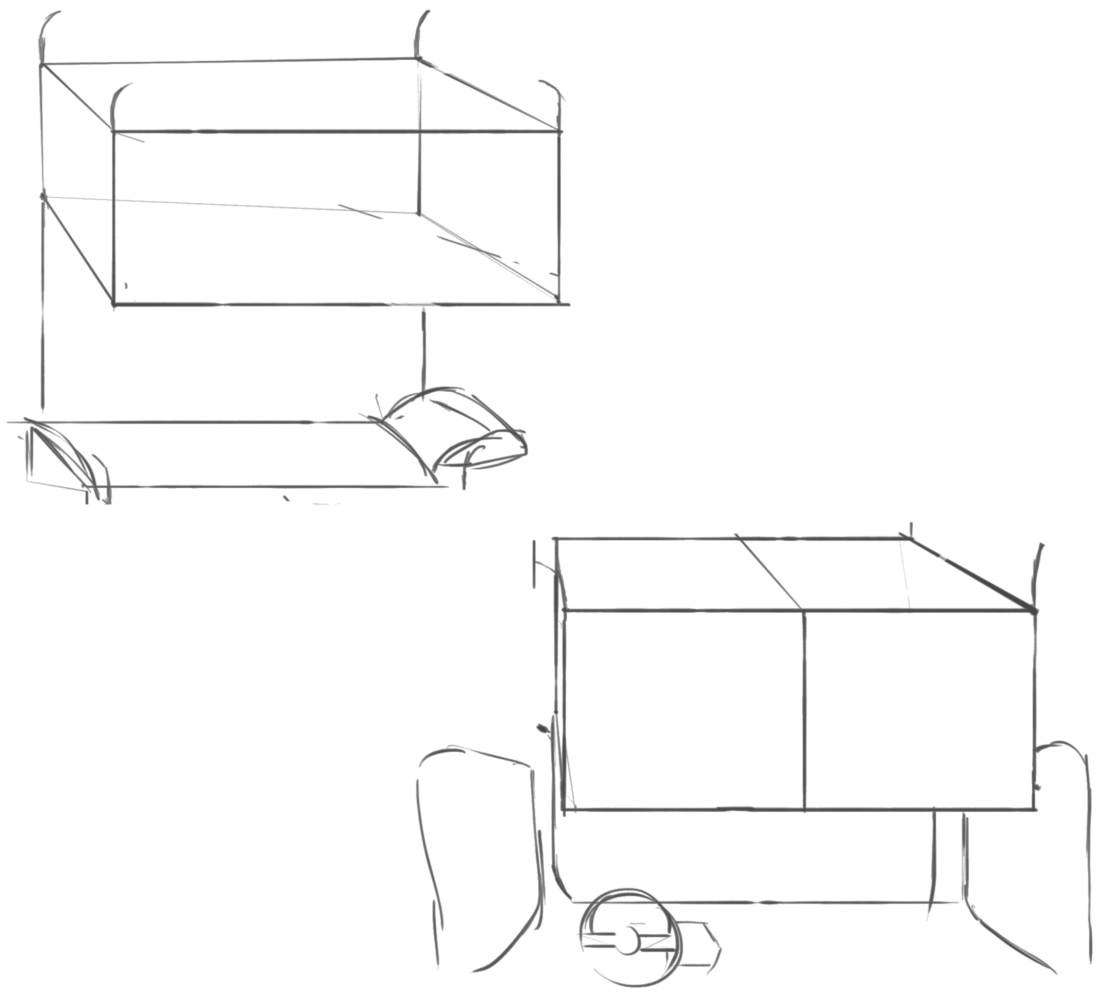


Figure A.5: Back and front storage

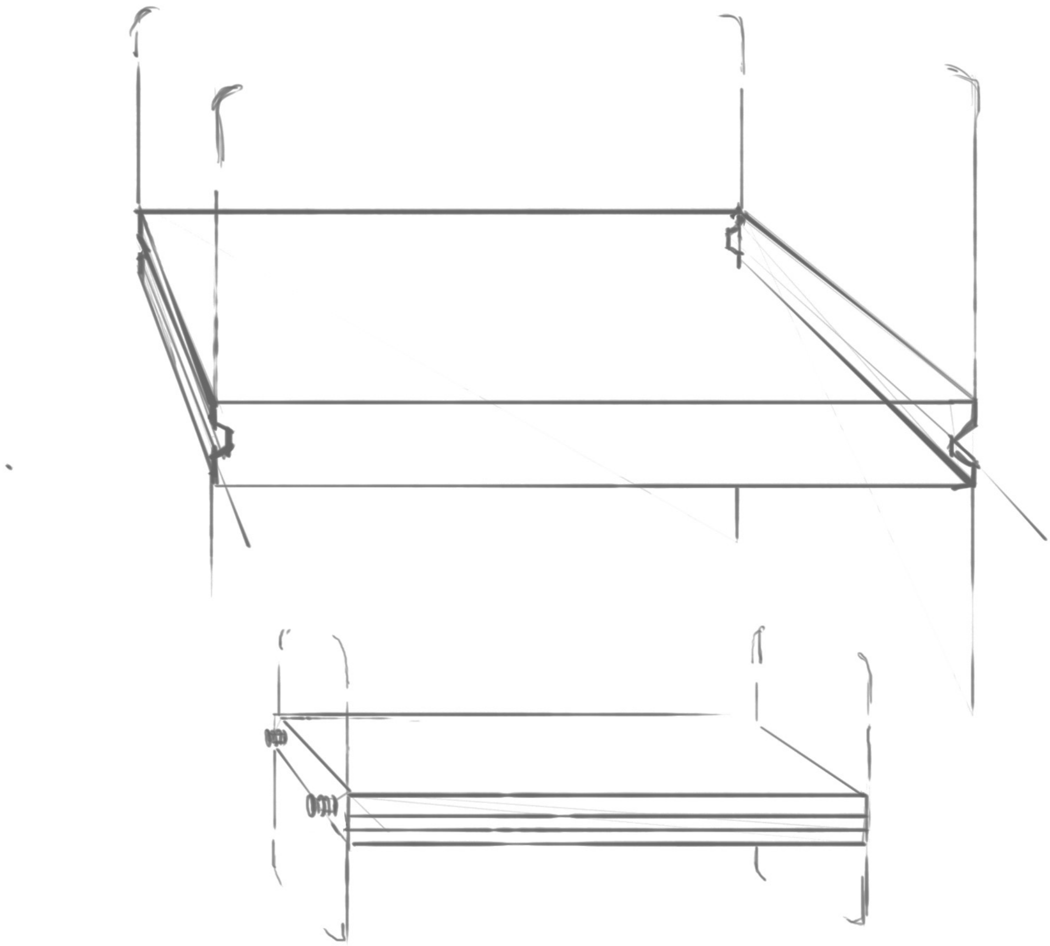
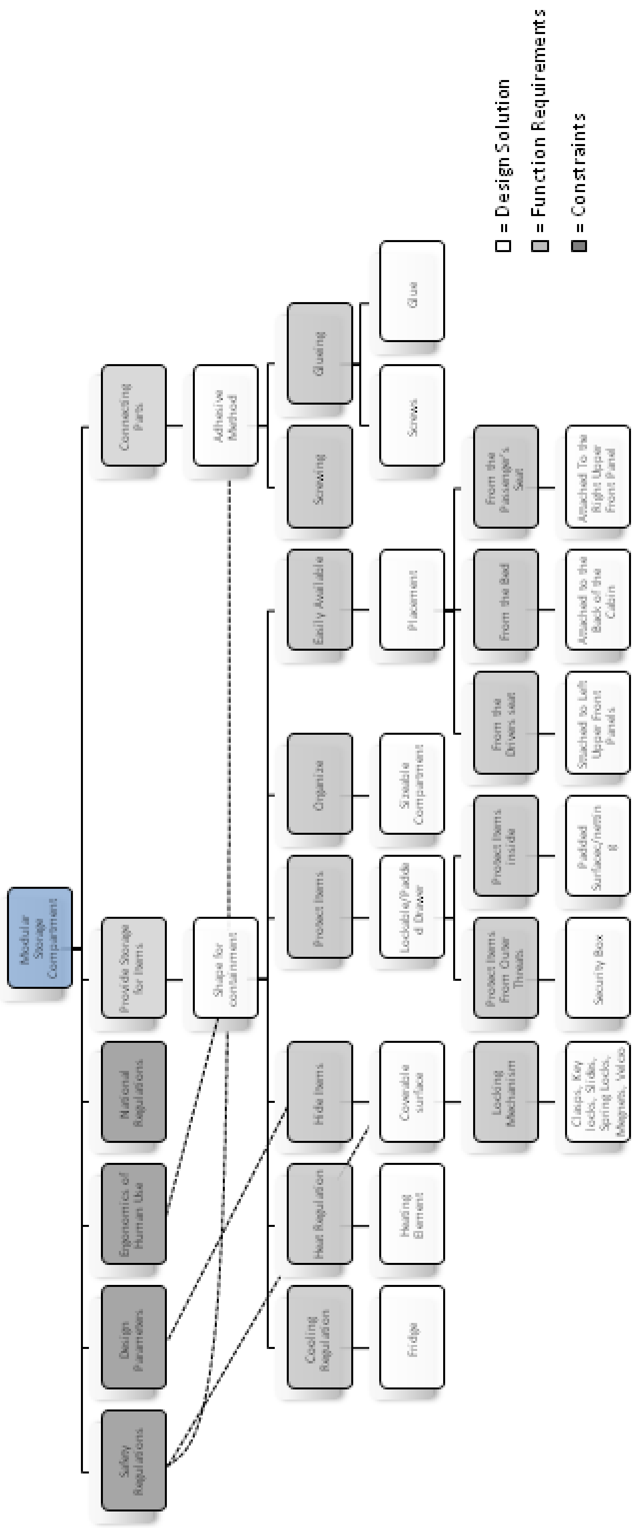


Figure A.6: Shelf design

A.6 Function Analysis

Figure A.7: Function Analysis



A.7 Manufacturing Process

Table A.2: Final Product Manufacturing Process Plan

Assembly Name	**Material Type**	**Raw Stock Size**	**Operations**
• Above dashboard shell with 0.635 cm +/- 0.00508 cm holes on top and bottom surfaces • 0.5 cm x 0.5 cm x 14 cm guided tracks on top surface	PC/PET	• Dimensions dependent on make and model of truck • Hole and guided track spacing dependent on make and model of truck	Plastic injected molded
• Behind seating storage shells with 0.4064 cm +/- 0.002 cm holes on left and right sides • Vertical divider with 0.635 cm +/- 0.00508 cm holes on top and bottom side • 0.4064 cm +/- 0.002 cm holes on left and right sides	PC/PET	• Dimensions dependent on make and model of truck • Hole spacing dependent on make and model of truck	Plastic injected molded
Horizontal shelf with 0.4064 cm +/- 0.002 cm holes on left and right sides	1080 carbon steel	• Dimensions dependent on make and model of truck • Hole spacing dependent on make and model of truck	Plastic injected molded
Spring-loaded pins	Stainless steel	• 0.635 cm diameter • 1.19634 cm body length • 0.79248 cm flange diameter	• Purchased from outside vendor • Press fit into 0.635 cm +/- 0.00508 cm vertical divider holes
Weld-in spring-loaded plungers and Stainless steel	• 0.4064 cm diameter • 0.9652 cm nose length • 2.2225 cm body length	• Purchased from outside vendor • Welding onto underside of horizontal shelf • Press fit into 0.4064 cm +/- 0.002 cm horizontal shelf holes	

A.8 Existing solutions

Figure A.8: Existing solution from Ikea, Bestå [5]

Figure A.9: Existing solution from Containerstore [6]

Figure A.10: Existing solution from Marbodal [7]

A.9 Patents

Figure A.11: Modular storage unit patent [8]

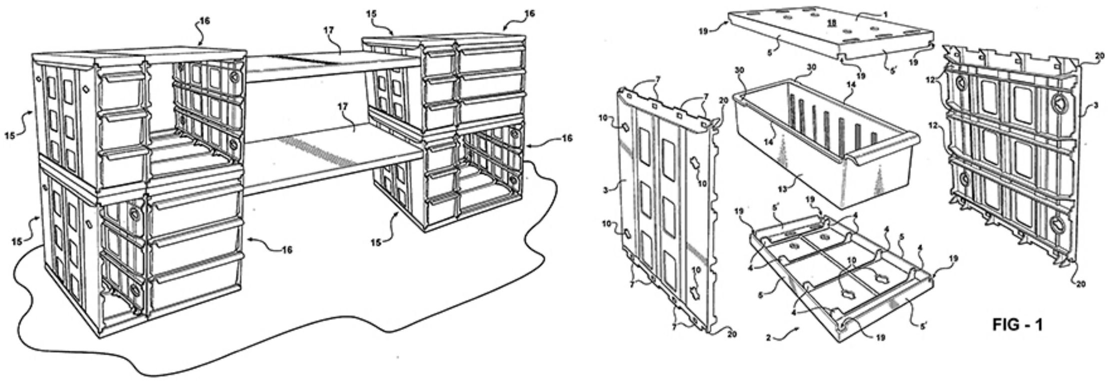


Figure A.12: Modular rack storage system and its method of assembly. [9]

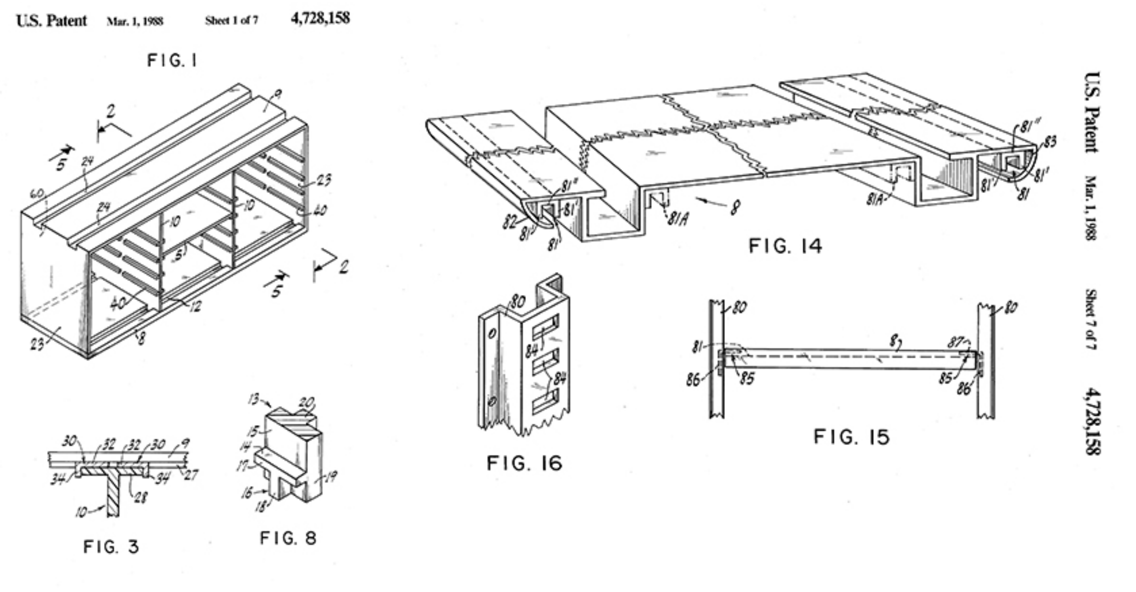


Figure A.13: Snap Together Modular Storage. [9]

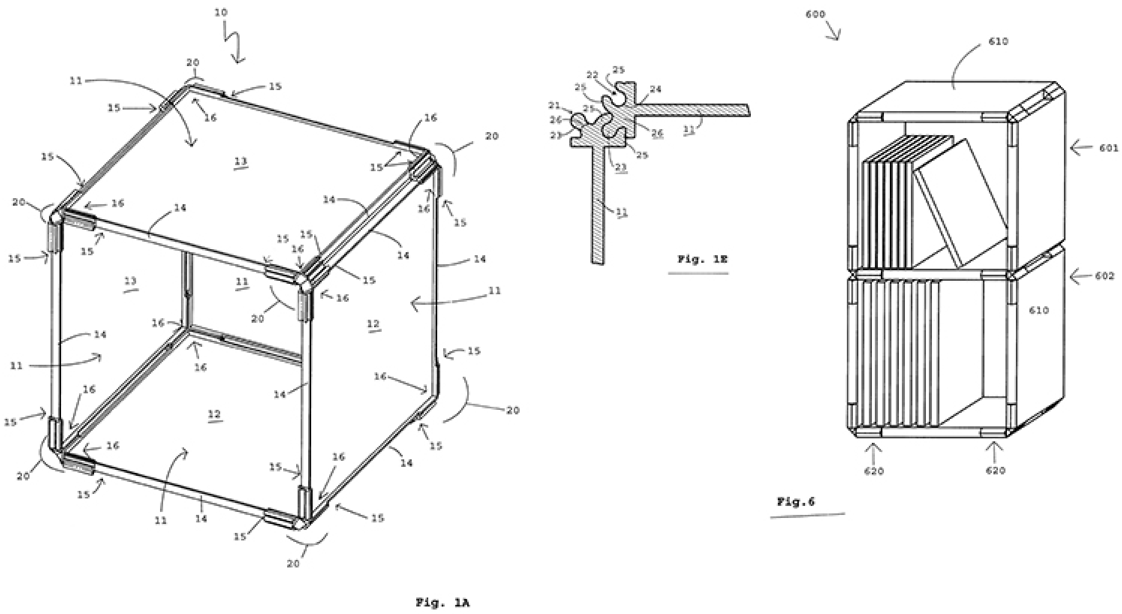
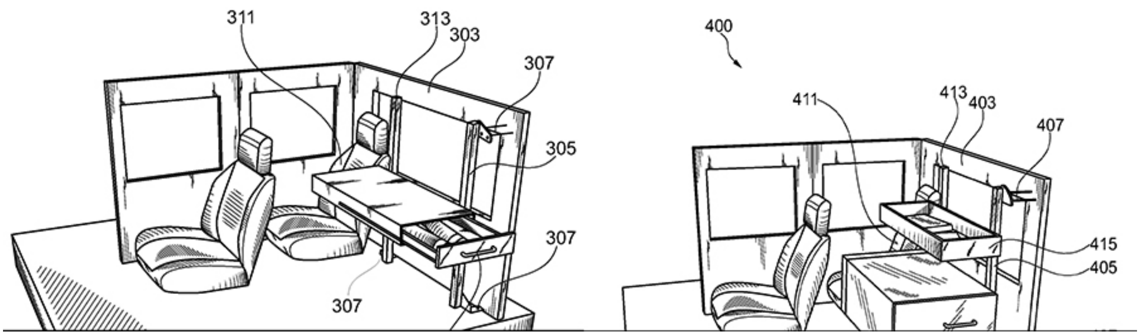


Figure A.14: Modular Storage in Passenger Compartments. [9]



A.10 CAD-models

A.10.1 CAD-models of further developed concept

Figure A.15: CAD-model of rear storage with submersible function.

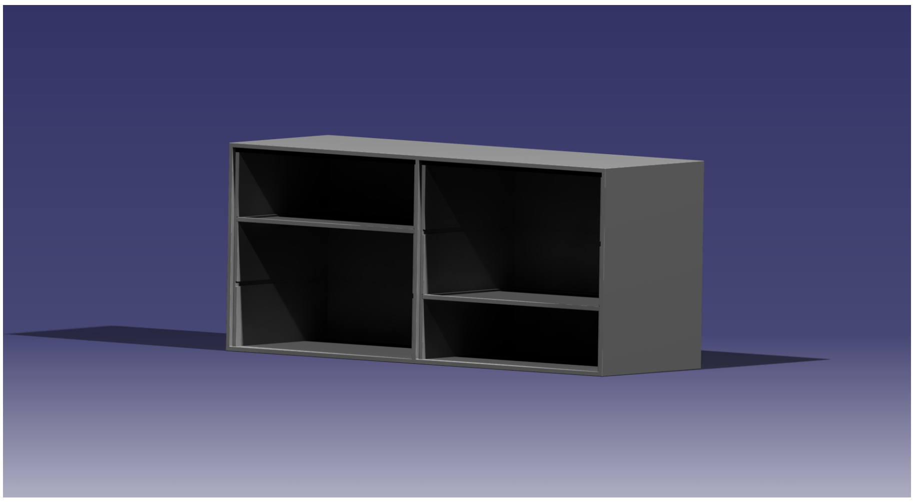


Figure A.16: CAD-model of rear storage with submersible function.

A.10.2 Finite element analysis material and testing

Figure A.17: Equivalent Stress for the minibox with a shelf

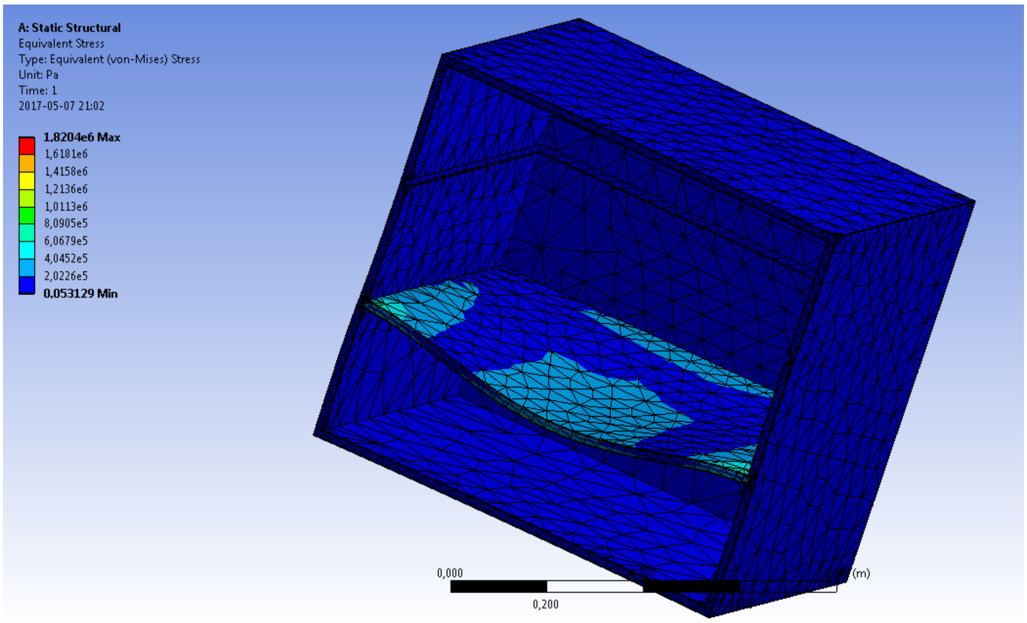


Figure A.18: Total Deformation for the minibox with a shelf

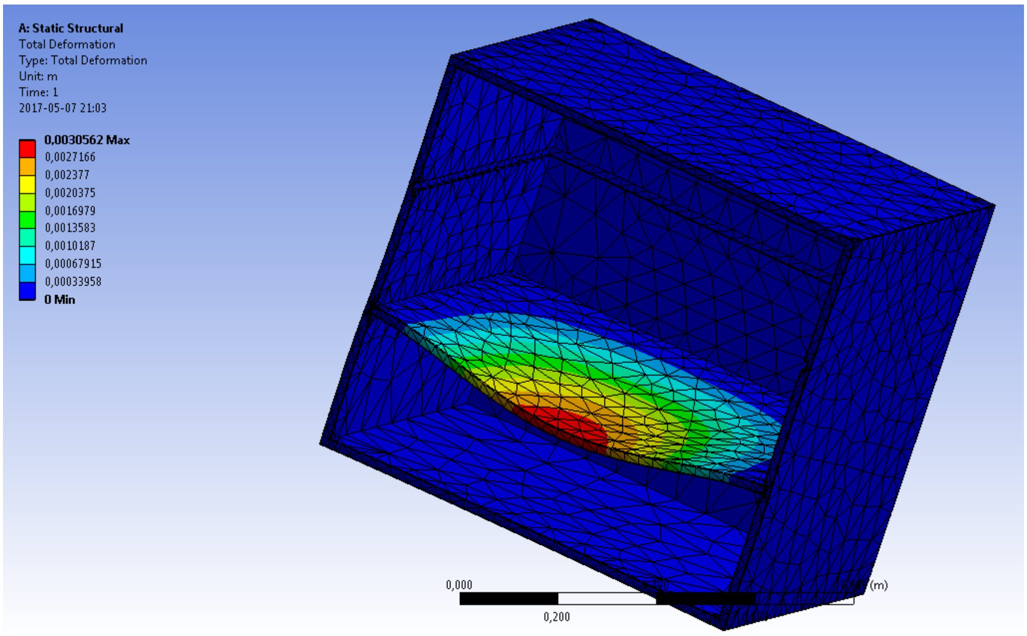


Figure A.19: Total Deformation for the minibox with shelves

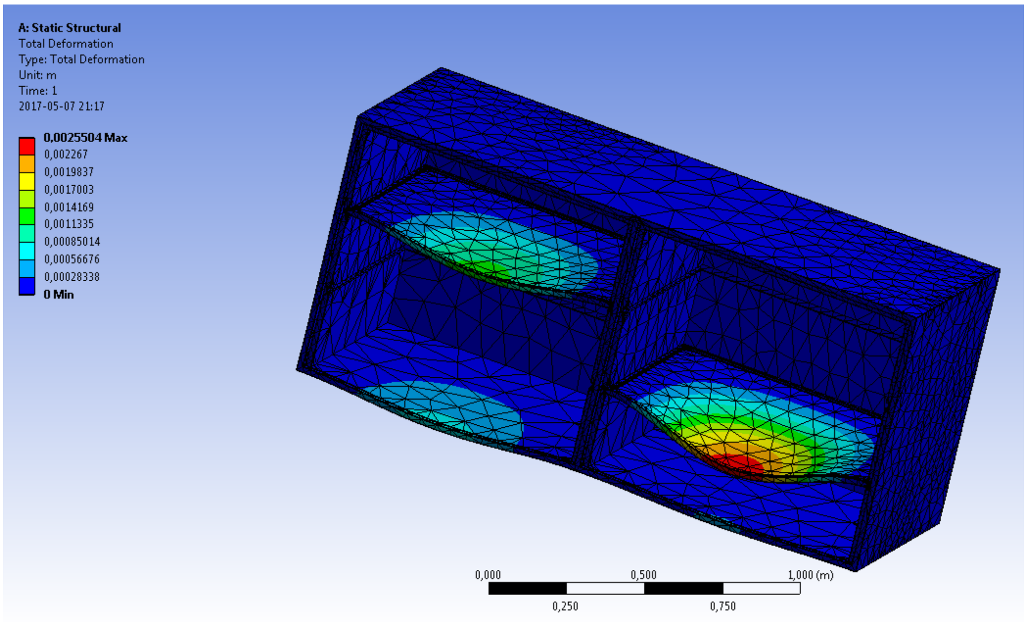


Figure A.20: Total Deformation for the minibox with shelves

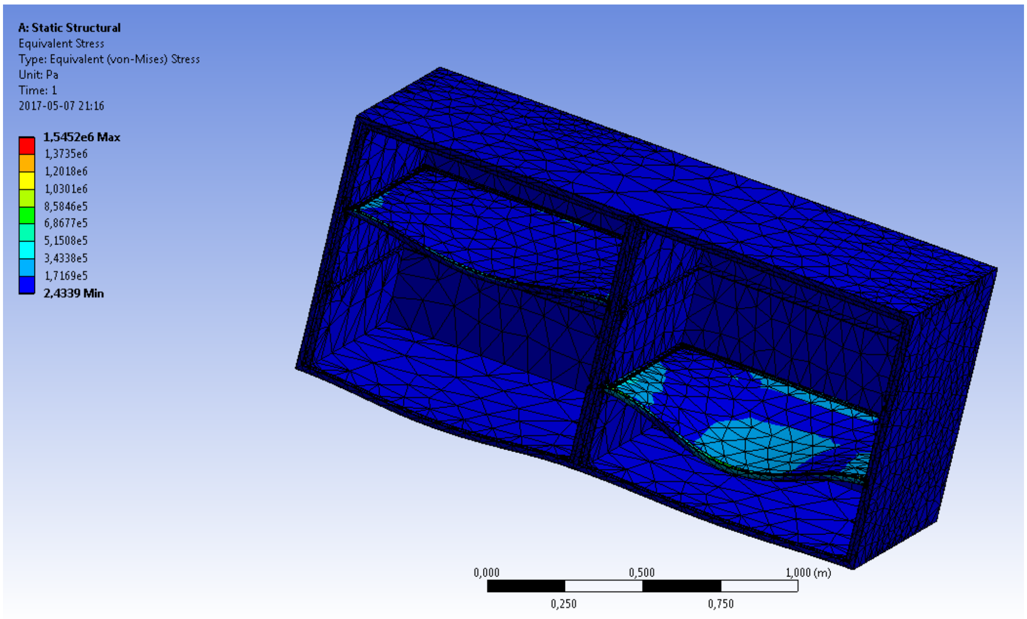


Figure A.21: Total Deformation for the minibox

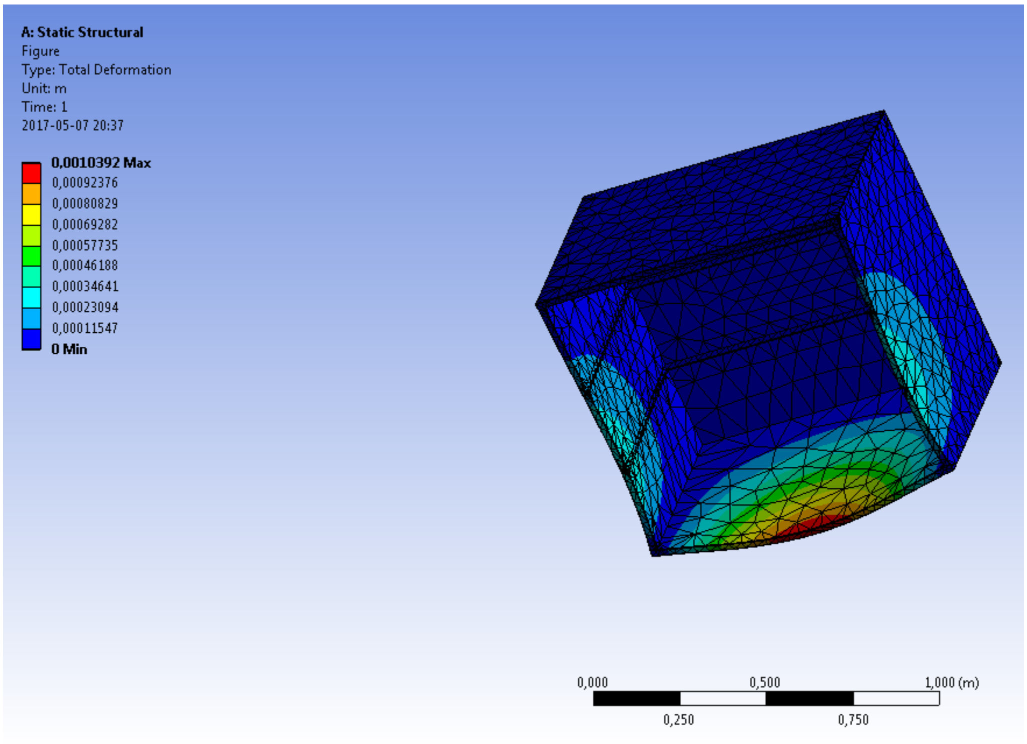
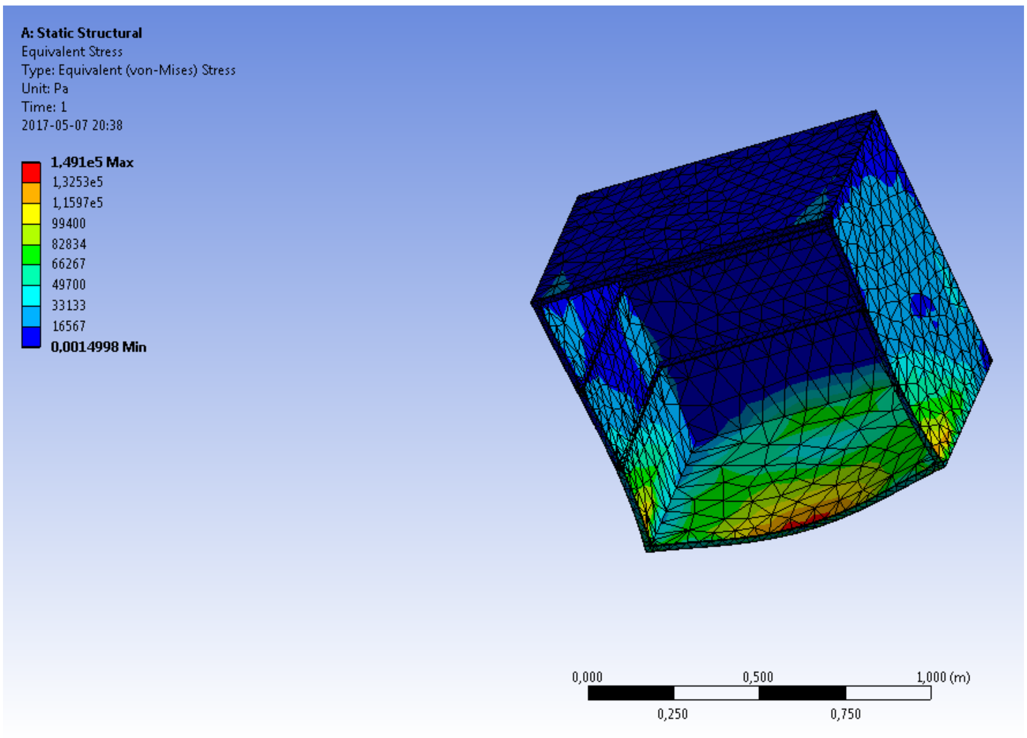


Figure A.22: Equivalent Stress for the minibox

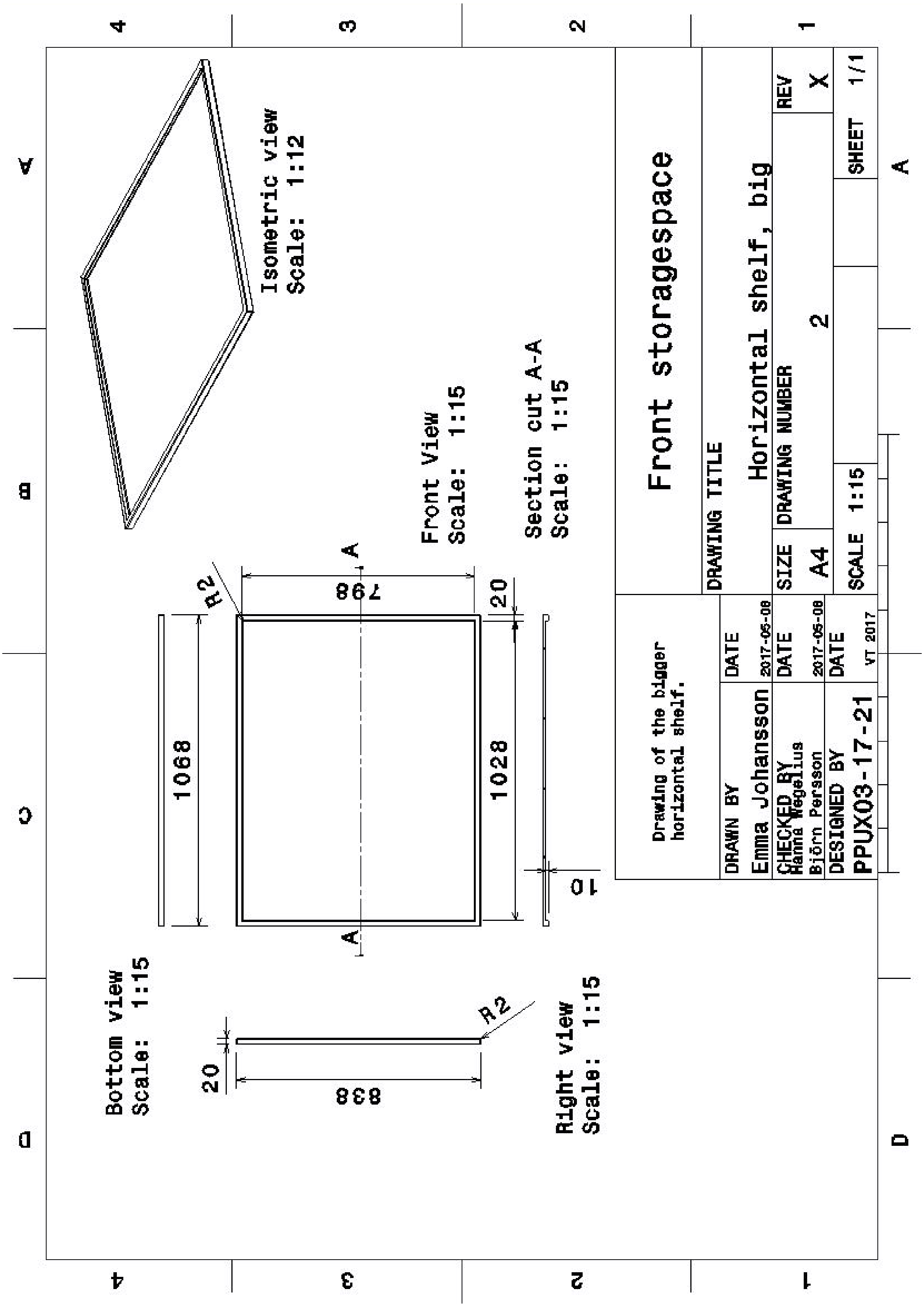


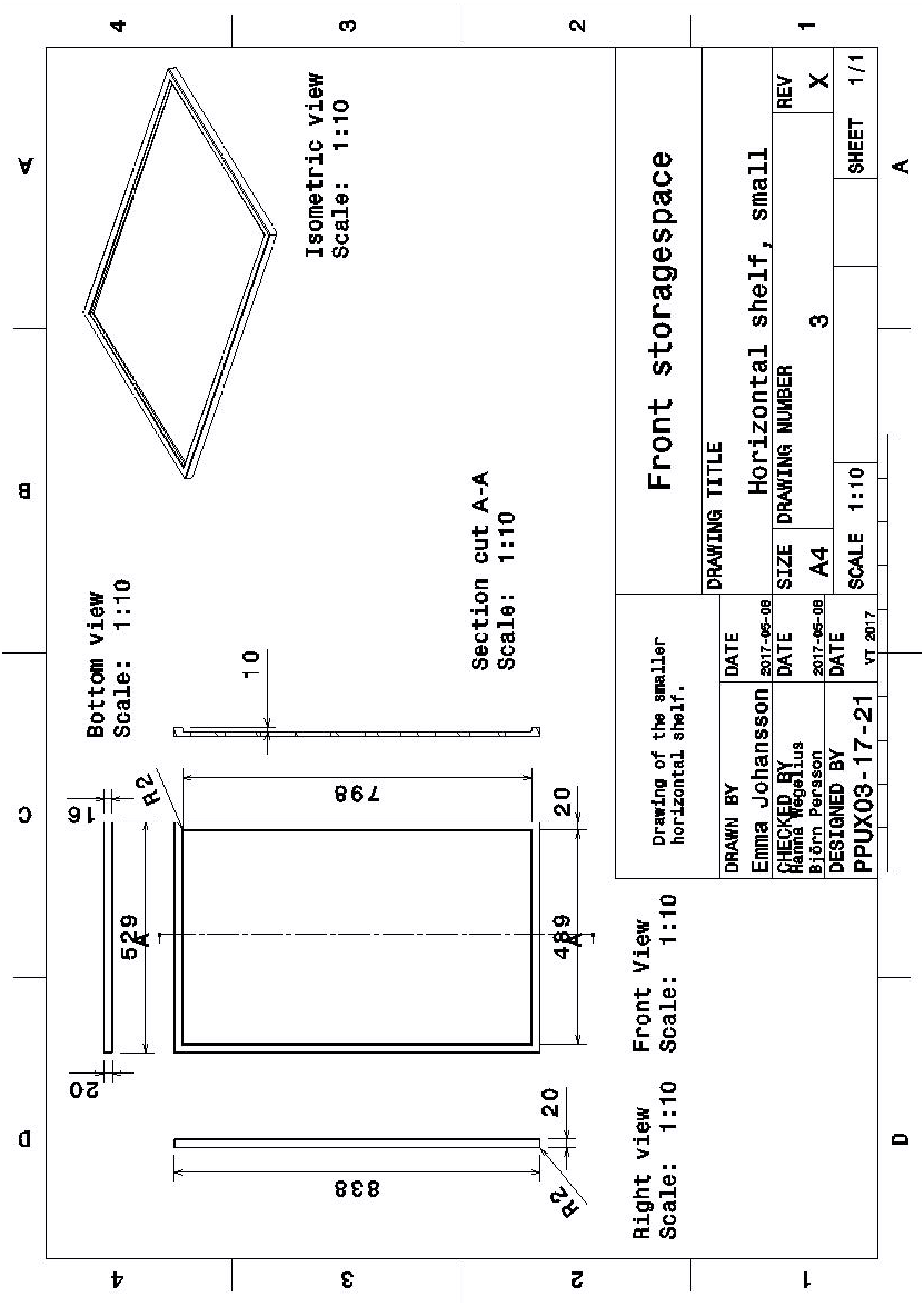
A.11 Fabrication of the wooden prototype

The following bullet points describe the fabrication of the full scale wooden prototype in detail:

- Cut oak (a strong wood with good aesthetic) into multiple pieces
  - 3 x 26.5" pieces that will function as top, back, and bottom of solution (if looking at is as overhead storage)
  - 2 x 9.75" pieces that will also be on outside, left and right sides of solution
  - 1 x 10" to serve as vertical divider
  - 1 x 12.3125" to serve as horizontal divider
- Use palm router to make slots .5" wide by .125' deep in the wood so that dividers can slide in and out. Slots made at the center of the vertical end pieces on the interior of the opening. Slots also made on both sides of the vertical divider at the center, running the full length of the piece from front to back.
- Use palm router to create .125" tall .5" wide ridges on the top and bottom of the vertical divider piece and on the sides of the horizontal divider piece to slide into the channels previously created.
- Drill .25" diameter holes .75 inches deep into the ridges created on the dividers, .75" from what will be the front edge of the divider, the visible edge when complete.
- Drill divots with a .25" bit, just touching the wood to produce a small dent .75" inches from the front edge.
- Use biscuit saw and biscuits with wood glue to attach top to vertical pieces
- Use wood glue and nail gun to attach bottom piece to vertical side pieces.
- Clamp and allow glue to dry
- Use wood glue to attach the back of the unit to the frame.
- Sand smooth
- Apply Danish Oil

A.12 Technical drawings

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Bottom view
Scale: 1:10
Section cut A-A
Scale: 1:10
Front View
Scale: 1:10
Right view
Scale: 1:10
838
798
529
489
10
16
20
20
20
R2
R2
A
A
Front storagespace
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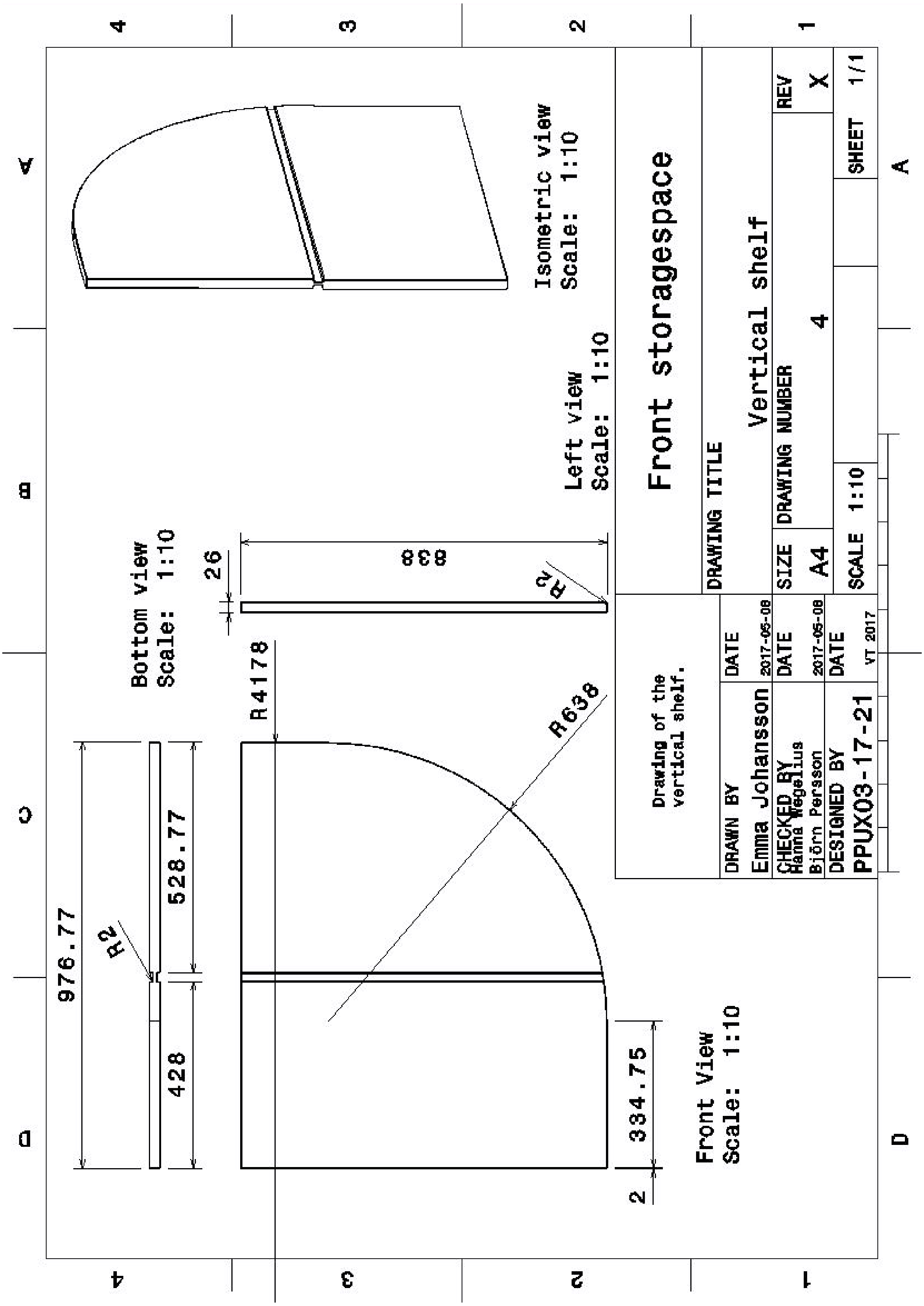
Horizontal shelf, small
Drawing of the smaller
horizontal shelf.
DRAWN BY
Emma Johansson
DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
DATE
2017-05-08
DESIGNED BY
PPUX03-17-21
DATE
VT 2017
SIZE
A4
DRAWING NUMBER
3
REV
X
SCALE 1:10
SHEET 1/1
A
B
C
D
1
2
3
4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Bottom view
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Front View
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528.77
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26
838
R2
R4178
R638
334.75
2
Drawing of the vertical shelf.
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Emma Johansson
DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
DATE
2017-05-08
DESIGNED BY
PPUX03-17-21
DATE
VT 2017
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Vertical shelf
SIZE
A4
DRAWING NUMBER
4
REV
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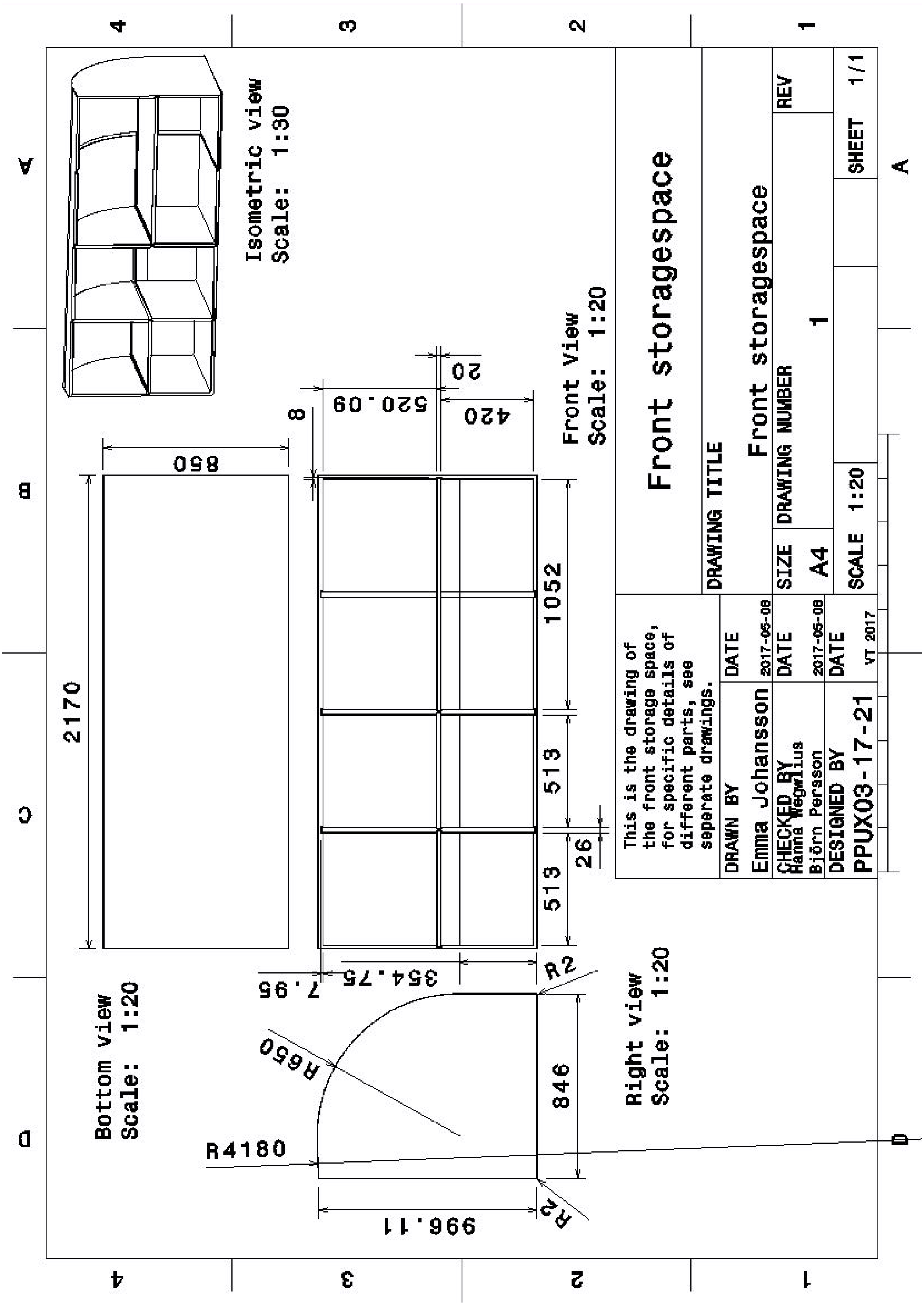
SCALE 1:10
SHEET 1/1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Front View
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Bottom view
Scale: 1:20
Right view
Scale: 1:20
Front storagespace
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DRAWING NUMBER
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SIZE
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SCALE 1:20
SHEET 1/1
REV
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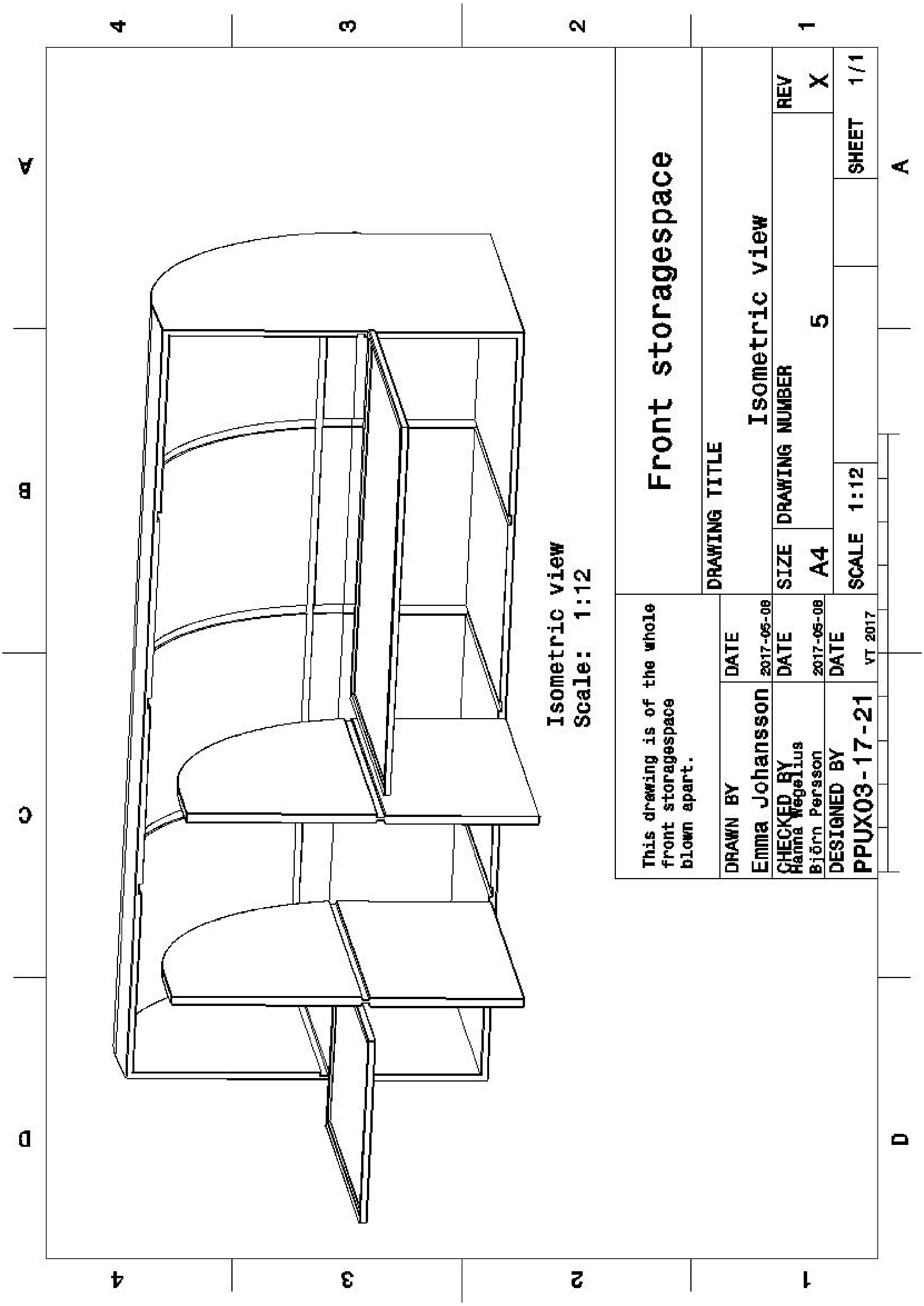
Emma Johansson
DATE
2017-05-08
CHECKED BY
Björn Persson
DESIGNED BY
PPUX03-17-21
VT 2017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Scale: 1:12
This drawing is of the whole front storagespace blown apart.
Front storagespace
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Isometric view
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Emma Johansson
DATE
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Hanna Wegelius
Björn Persson
DATE
2017-05-08
DESIGNED BY
PPUX03-17-21
DATE
VT 2017
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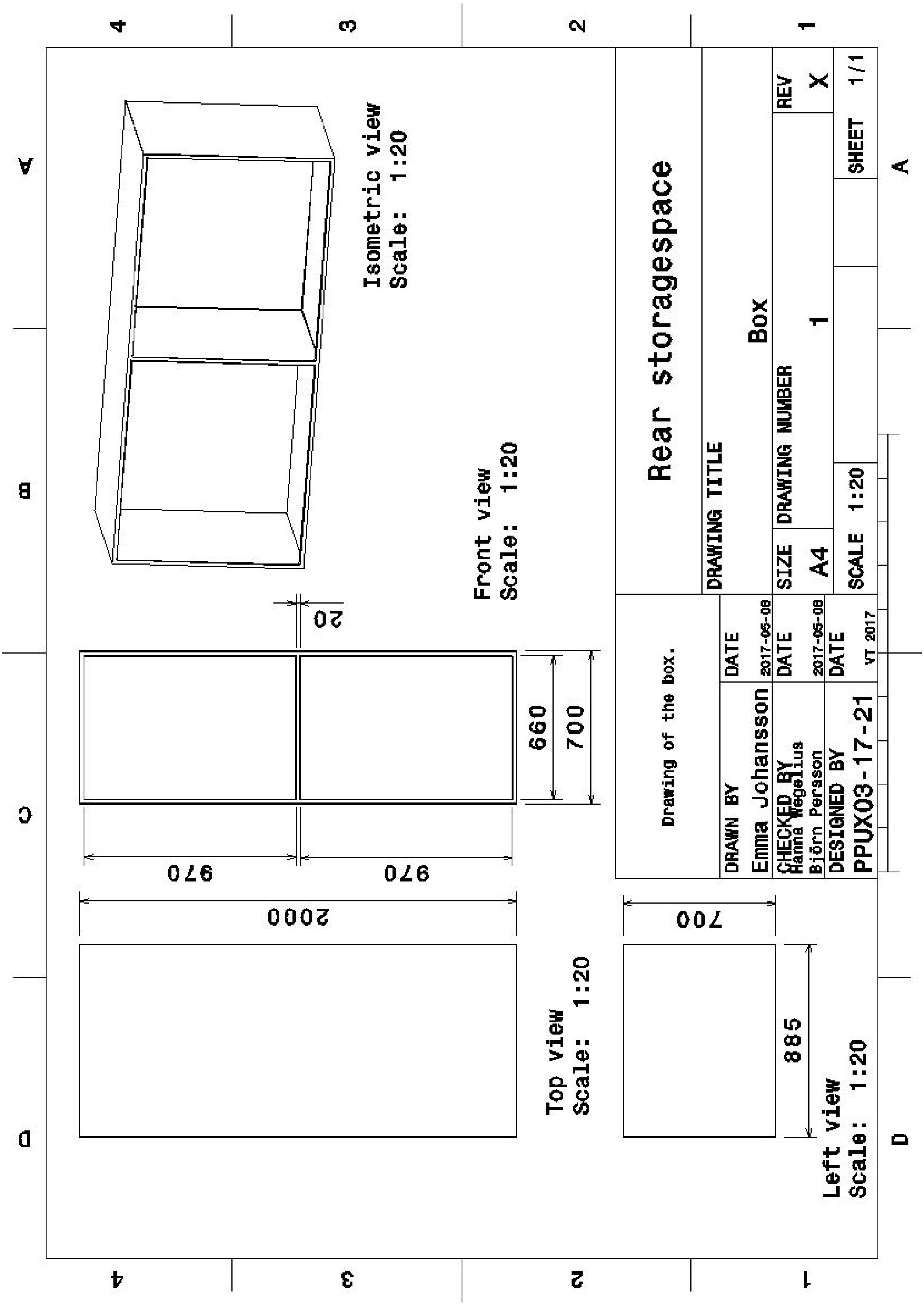
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Top view
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Rear storagespace
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REV
X
SCALE 1:20
SHEET 1/1
Drawing of the box.
DRAWN BY
Emma Johansson
DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
DATE
2017-05-08
DESIGNED BY
PPUX03-17-21
DATE
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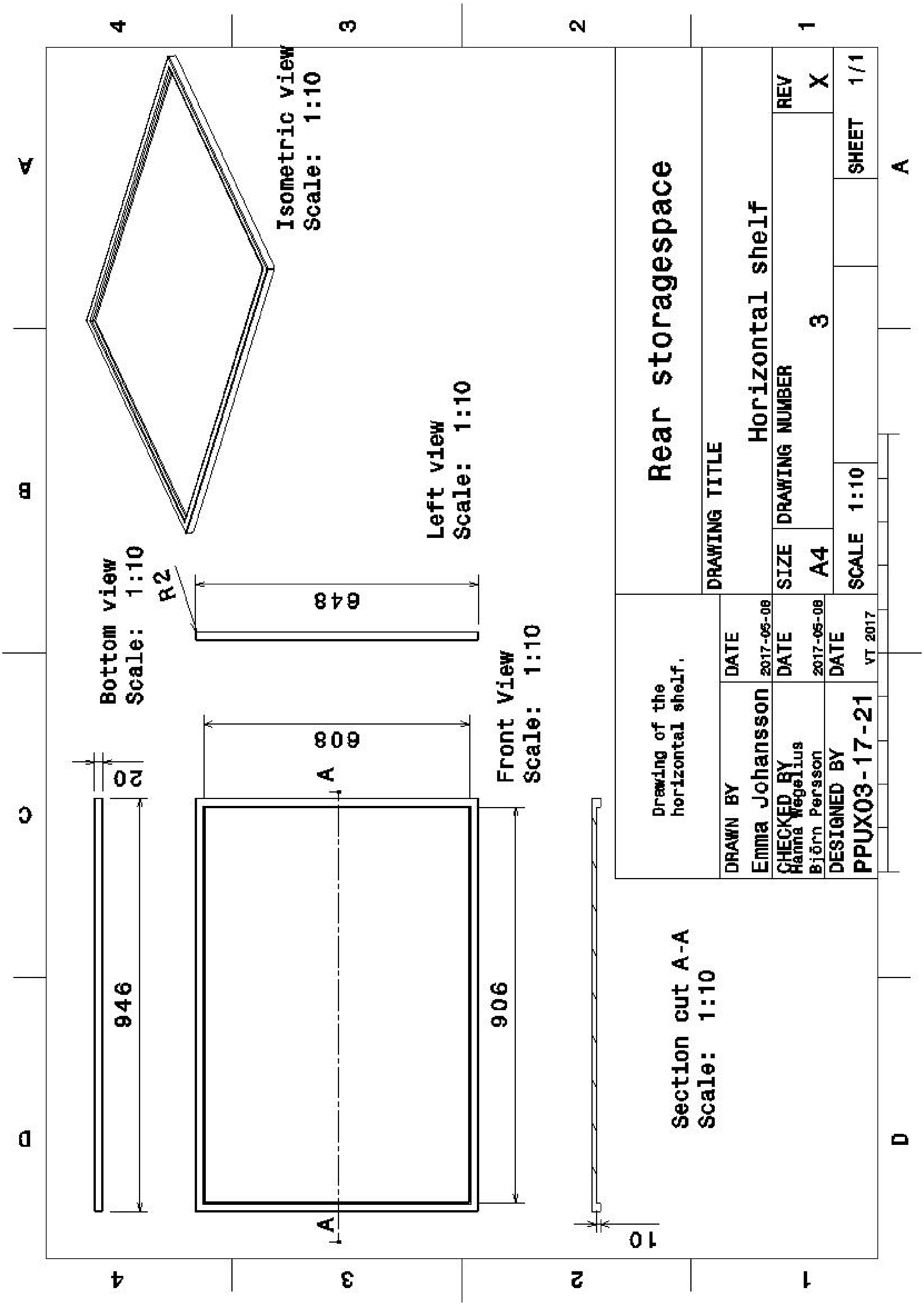
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946
906
Front View
Scale: 1:10
A
10
Section cut A-A
Scale: 1:10
Rear storagespace
DRAWING TITLE
Horizontal shelf
Drawing of the horizontal shelf.
DRAWN BY
Emma Johansson
DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
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2017-05-08
DESIGNED BY
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VT 2017
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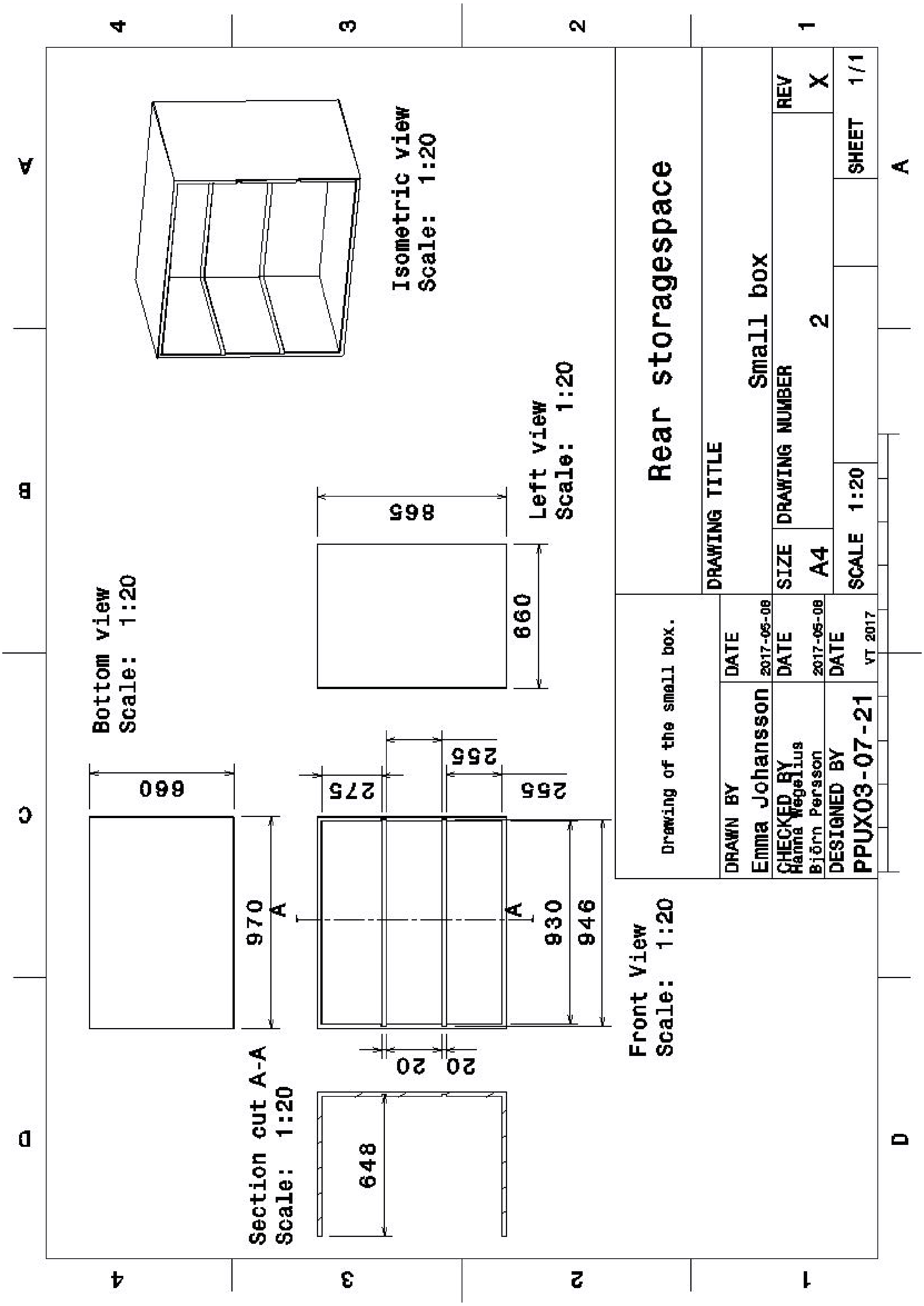
SCALE 1:10
SHEET 1/1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Bottom view
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20
648
Section cut A-A
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Front View
Scale: 1:20
Rear storagespace
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Small box
Drawing of the small box.
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Emma Johansson
DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
DATE
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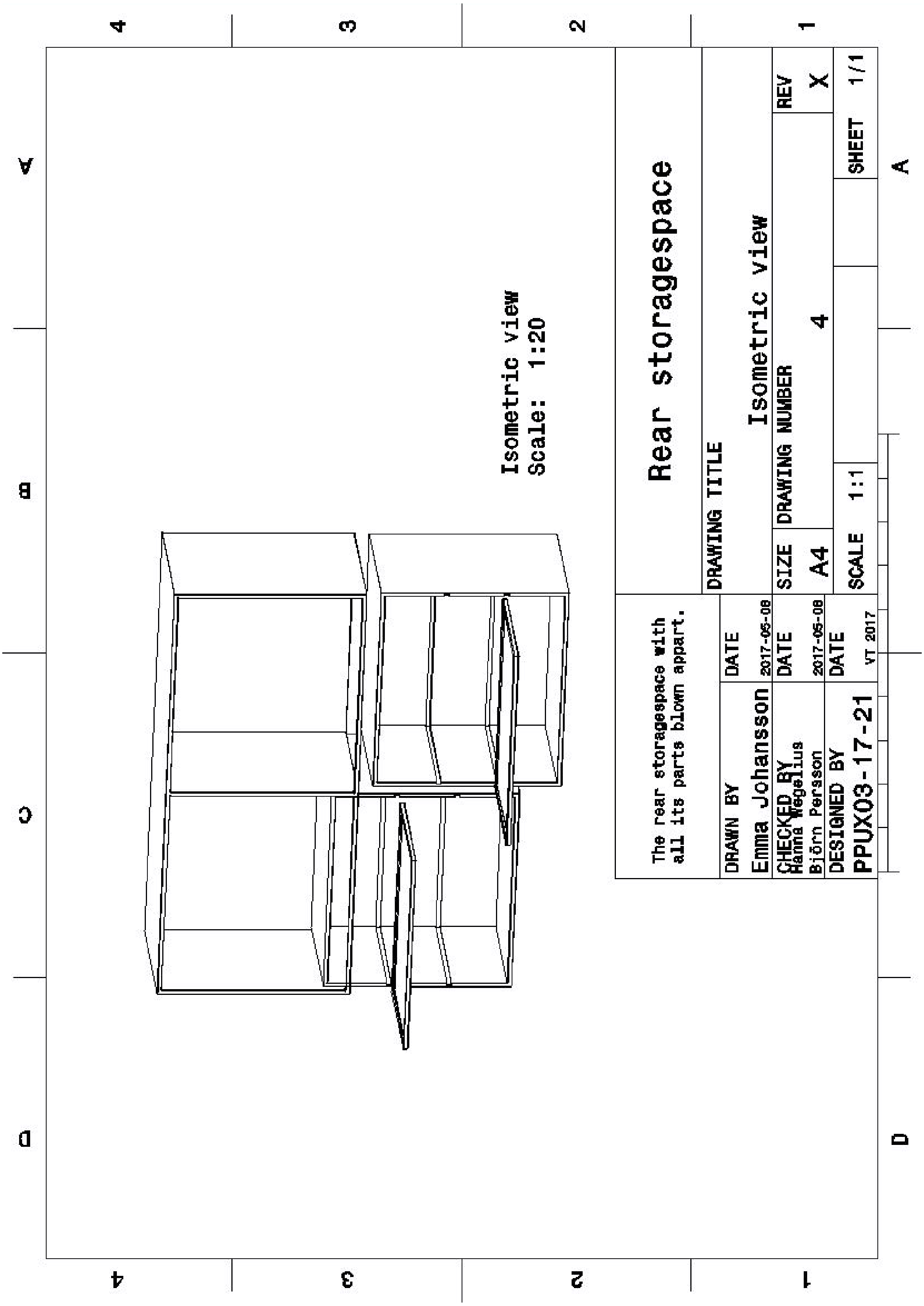
1/1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Rear storagespace
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Isometric view
The rear storagespace with all its parts blown appart.
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DATE
2017-05-08
CHECKED BY
Hanna Wegelius
Björn Persson
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2017-05-08
DESIGNED BY
PPUX03-17-21
DATE
VT 2017
SIZE
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DRAWING NUMBER
4
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X
SCALE
1:1
SHEET
1/1

A.13 Deliverables Agreement

Date 2/15/17

Project Title **Product Development: Modularization of Storage Spaces in Cabins with focus on cabinets for multi brand use globally**

Sponsor Company **Volvo Trucks**

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Problem Statement:
The challenge this project poses is that current Volvo truck models do not have modularized storage spaces in their cabins. The main goal of the project is to develop and modularize the storage space in the cabin, basing the design on expected functionality and accounting for production commonality. The solution should be universal and applicable to different trucks that already exist around the world.

Deliverables:	**Delivery Date**
1) Final Report (copies to sponsor, instructor and Learning Factory)	5/2/17
2) Weekly update memos (status reports); delivery method: Box	Status Reports on Friday evenings
3) Statement of Work (Project Proposal)	2/20/17
4) Detailed Design Specification Report	3/28/17
5) Poster (32 x 40") for Showcase	4/27/17
6) One-Page Project Recap (submit to instructor)	5/2/17
7) First Prototype and CAD Model of Storage Solution	3/21/17
8) First Prototype and CAD Model of Attaching and Locking Mechanism	3/21/17

Check below if this project involves:

☒ Non-Disclosure Agreement (~~attach copy of agreement to this form~~)

☐ Loan of equipment, materials, documents (see next page)

Signatures: We agree to the deliverables listed above:

2/16/17

Project Sponsor date

Faculty Coach: date

Team Members:

2/15/17

date 2/15/17

date 2/15/17

date 2/15/17

date 2/15/17

date 2/15/17