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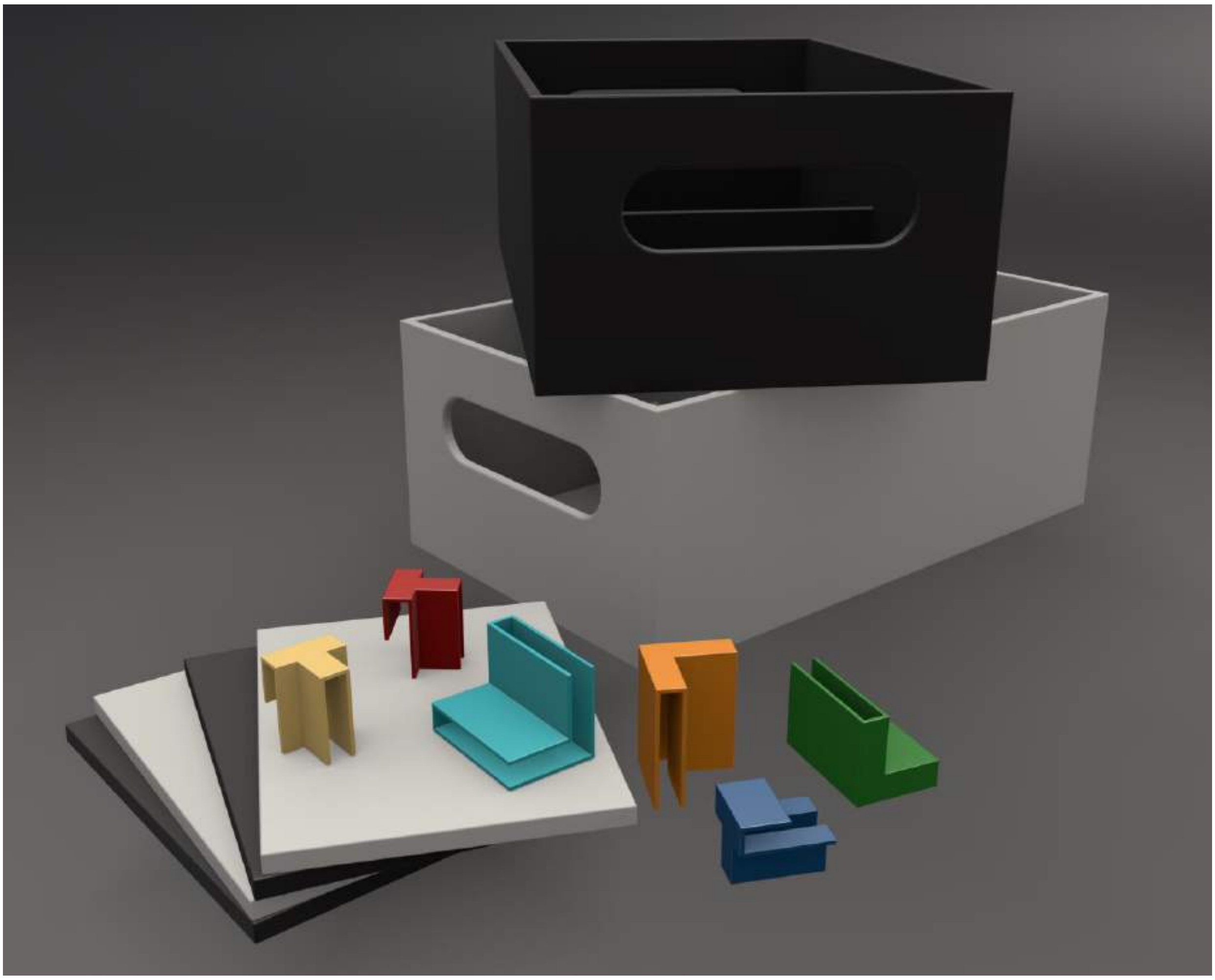

Construction Guidelines for Customized Kitting Solutions

Assembly and Material Selection

Master's thesis in Product Development

OLIVER BOLIN & SAMUEL JOHANSSON

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
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Master Thesis

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Oliver Bolin
Samuel Johansson

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Oliver Bolin
Samuel Johansson

Supervisor and Examiner: Dr. Lars Almefelt
Industrial and Materials Science

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Abstract

Virtual Manufacturing Sweden AB (Virtual Manufacturing) is a company that offers products and services within industrial management, production flows, automation and lean manufacturing products. More specifically, this includes everything from project management and technology implementation to work flow simulations, intern logistics and material handling. This project addresses kitting solutions, which are part of their lean manufacturing products. Kitting solutions can be defined as a variety of component handling solutions, and range from basic and stationary containers to mobile trolleys with more complex structures, depending on the situation.

The purpose of this project is to provide Virtual Manufacturing with construction guidelines that should help in making competent and cost-efficient material and manufacturing selections towards their customers of kitting solutions. This also involves researching their current use of materials and manufacturing methods, to see how this can be improved and developed. As designers at the company receive orders from their customers, often with short notice, a need to rapidly select suitable materials and manufacturing methods depending on the usage situation has emerged. It is therefore important that the guidelines provide the designer with useful information that is easy to understand and act upon.

The methods that have been used during the project follows a traditional product development framework, but has been adjusted to fit the situation accurately. This includes research, material search, concept development and developing final concepts and prototypes. Specific methods have been selected and used to fit the project, creating a valuable and usable result.

The result is a comprehensive compendium consisting of guidelines that helps the designer in making decisions regarding the construction of the kitting solution, from initial order to final product. The guidelines aim to cover a wide spectrum of different kitting solutions, and should be used as a complement to the designers own expertise and perception of what is needed in different situations. The guidelines present three different types of kitting solutions which includes materials and assembling methods, and the information is based on the knowledge that was gained during the project. Consequently, it can be concluded that the process has led to an outcome that fulfills the objectives and needs that were stated in the beginning of the project.

Preface

This is a report that summarizes the master thesis project that was conducted by the students Oliver Bolin and Samuel Johansson. The project was the final course of the master program Product Development which is a mechanical engineering master at Chalmers University of Technology in Gothenburg, Sweden. The master thesis project was conducted for the institution of Industrial and Materials Science and for the company Virtual Manufacturing Sweden AB. The students met the company at a master thesis exhibition at Chalmers University of Technology and the corporation started after the students were offered an interesting product development project that suited their education in a satisfying way.

We will start to thank Virtual Manufacturing Sweden AB that they provided us with this master thesis project. Also, special thanks to our supervisor and examiner, Dr. Lars Almefelt for your support throughout the project and Professor Antal Boldizar for your support through the material search.

We would also like to thank persons that have been particularly helpful during the project, including Mohammed Abo Daya at Vink Essåplast Group AB, Markus Godtman at Kärnsund Wood Link AB and Peter Piltorp at Piltorps Varmluft AB. Finally, we would like to thank all other companies or persons that have been helpful throughout the project, such as suppliers and employees at Chalmers University of Technology.

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1 Introduction

This is an introduction to the master thesis project that provides guidelines of how to construct kitting solutions for the company Virtual Manufacturing. The master thesis was conducted by two product development students at Chalmers University of Technology in Gothenburg. The introduction chapter includes the background to this project, the purpose, a problem definition and other parts that are useful to know about before continuing reading the following chapters.

1.1 Background

In the background, the involved company, Virtual Manufacturing is presented. Basic information about Virtual Manufacturing and their kitting solutions is also introduced together with pictures of some of the kitting solutions that the company has designed and produced.

1.1.1 About Virtual Manufacturing

Virtual Manufacturing is a company that offers overall solutions for factories, such as assembly and production flows, consultancy and lean manufacturing products. The company was founded in 2006 and has approximately 70 employees, mainly in Sweden and Denmark. The company's logotype and slogan is presented in Figure 1.1. All founders are still active within the company. Virtual Manufacturing's vision is to be a natural and innovative company within production development, where competence, quality and sustainable commitments are key factors [1].

(a) Virtual Manufacturing's logotype

(b) Virtual Manufacturing's slogan

Figure 1.1: Virtual Manufacturing's logotype and slogan.

Their core values are:

- Innovation - Long term improvement and new approaches.
- Customers - Satisfy customers by showing real profits and building knowledge.
- Change - Create opportunities for a natural change process.
- Employees - Take responsibility for our employee's development, competence and creativity potential.

- The Virtual way - Global thinking with local power to act - we shall be an example of how to create results with small resources.

Virtual Manufacturing offers products and services within five areas, including Industrial Management, Assembly & Production Flow, Robotics & Automation, Virtual Manufacturing Labs and Lean Manufacturing Products. Kitting solutions include all solutions between a small kitting box to a big kitting trolley, and are located in the Lean Manufacturing Products.

1.1.2 Virtual Manufacturing's Kitting Solutions

The manufacturing companies today, for example in the automobile industry, have a lot of different models and product configurations that make the material handling more complex. A kitting solution is therefore an important tool in many assembly lines. The kitting solutions are used for transporting and structuring the right amount of material and components from the warehouse or one part of the production facility to the assembly line. The kitting solutions are therefore making the assembly process more effective since the assemblers receive the input components in a structured way and in time. The kitting solution can have a more general layout or be tailor-made for its application [2]. Most kitting trolleys have a shelving or standing box system where the components are placed. Virtual Manufacturing also produces individual kitting boxes that are not attached to a kitting trolley. Components in a box are placed and brought up from above while components in a shelving system are available from the side. This project both includes shelving systems and boxes since Virtual Manufacturing offers both types of solutions.

Customers have different requirements depending on how the kitting solutions are used and what they contain, such as sensitivity, durability and electrostatic discharge (ESD) protection. Today Virtual Manufacturing mainly uses four different materials in their kitting solutions; Aicelwood, polyvinyl chloride foam (PVC-foam), corrugated plastic (Wellplast) and tarpaulin. Wellplast and tarpaulin have only been used in a few applications. They design around 200 specific kitting solutions each year. Three examples of the company's kitting trolleys and boxes are visualized in Figures 1.2 and 1.3. When Virtual Manufacturing creates customized production solutions for their customers, a variety of different components can be used in their kitting solutions. This includes different kinds of bins, boxes, sheets, pipes, fasteners and holders.

(a) A kitting box that is made in wellplast.

(b) A kitting trolley with a box system that is made in Aicelwood.

Figure 1.2: Two different kitting solutions from Virtual Manufacturing.

Figure 1.3: A kitting trolley with a shelving system that is made in PVC-foam.

1.2 Purpose of the Project

This master thesis has aimed to develop guidelines about how to design and manufacture kitting solutions that are more configurable and easy to construct and produce. This have included appropriate material selection, manufacturing strategy and final assembly of the kitting solutions. The customer has different requirements depending on how the kitting solution is used and what it contains, such as sensitivity, durability and ESD-protection. The new solutions should preferably be cheaper since Virtual Manufacturing's customers have accepted the price level that exists today and Virtual Manufacturing wants to make more profit for each kitting solution.

1.3 Problem Definition

The problem for Virtual Manufacturing has been that they are limited regarding material alternatives and production methods when it comes to kitting solutions. Because of this, the company may come up with solutions that are not the best possible ones for their customers, for the best possible price. As a result, they want to extend their material library in order to create solutions that better fit their customers' needs, while at the same time reducing unnecessary material and production costs.

1.4 Specific Questions to be Answered

This part presents a number of relevant questions for the project. The expected outcomes that the project should deliver should also answer the questions which are listed hereafter.

- What are the needs for the users of kitting solutions?
- What kind of information is needed for the constructors of kitting solutions?
- How are the manufacturing processes conducted today?
- What factors contribute to the manufacturing/assembly cost of kitting solutions?
- What kind of requirements will depend on the specific application?
- What materials and their respective manufacturing and assembly procedures are best suited for these situations?
- How should the kitting solutions be designed in order to get a high degree of configurability?

1.5 Objectives

The project's objectives are presented during this section. The objectives are important since they describe what this project should deliver, and have been taken under careful consideration during the whole project. When the final outcome of the project is presented in the end of this report, a reconnection to the objectives is made in order to secure that the project's outcomes have been fulfilled, see Section 9.6. The project's objectives are described hereafter.

- Investigate materials, components and manufacturing strategies that can be applied to the design process of kitting solutions.

- Provide guidelines for how the construction and production departments at Virtual Manufacturing should manage their kitting solutions in relation to their customers.
- To come up with a cheaper solution.
- To develop a more versatile solution.

1.6 Limitations

This master thesis provides guidelines for material selection and manufacturing strategies, and recommendations regarding construction details. The design of the steel frame to which the kitting shelf system is attached to (if the kitting solution is a kitting trolley) is not included in the project. This project will neither design a specific kitting solution configuration for a specific customer application or specific dimensions of boxes.

1.7 Stakeholders for the Project

The stakeholders that have been identified for this project are the following:

- Virtual Manufacturing's product developers - designs the kitting solutions and box components.
- Virtual Manufacturing's production and assembly employees - produces and assembles the kitting solutions.
- Suppliers - supplies Virtual Manufacturing with materials and components.
- Industry workers - fitters, production personnel and other users that are in direct contact with the kitting solutions.
- Industry companies - purchases the kitting solutions and use them in their production lines.
- Chalmers University of Technology - has supervised, supported and graded the project.
- Master thesis students - has accomplished this project.

1.8 Expected Outcome

The expected outcome from this project has been to provide Virtual Manufacturing with guidelines about how to construct and produce kitting solutions in the most efficient way, by using appropriate materials and assembly strategies. The final outcome also consists of prototypes that demonstrate the developed way of producing, choosing materials or assembling the kitting trolleys or boxes. The expected outcome for Virtual Manufacturing is that they can deliver better products, decrease their development time and cost of kitting solutions and therefore get more profit from each sold product. It is important to emphasize that this should not compromise customers' satisfaction.

1.9 Reading Guidelines

Including the introduction, this report consists of ten chapters. First is the methodology presented, which describes the general development approach and how different methods have been used to generate the final outcome. This includes how the research was conducted, including benchmarking, user studies and concluding requirement specifications. These specifications worked as a foundation for the following material search and concept development phase. The section describes how different methods have been used to investigate currently used materials and manufacturing methods, as well as how new materials and concepts have been researched and developed. After this, it is specified how these materials and concepts were screened, selected and combined and how they were further developed and investigated. To conclude the methodology chapter, methods that have been used for the final development and determination of concepts and materials, prototype building and testing and for the final outcome are presented.

The methodology is followed by nine chapters that describe the results for the different phases and follows the same structure as the methodology chapter to make the report more comprehensible. More specifically, this is the result of the research, material search and concept development, material and concept selections, investigation and determination of materials, final development of concepts, prototype building and testing and the final outcome of the project. The report is concluded with a discussion chapter that concerns the work during the entire process, as well as a conclusion chapter that summarizes the project and presents recommendations for further work.

2 Methodology

In this chapter, approaches for the different parts of the project work are described in order to provide an overview of why certain methods were used and how they were executed. The methodology is also described which includes the working process. The methodology chapter is divided into nine main areas, the first one is about the methodology or the process that has been followed through the project. The following seven parts are about the methods that have been used during the main parts of the project. The seven parts are market and user needs research, material search and concept development, material and concept selections, further investigation and determination of materials, final development of concepts, prototype building and testing and finally, the final outcome. The last part of this chapter is a concluding on the methodology which summarizes the methodology chapter.

2.1 The General Development Approach

The methodology that has been selected for the project mainly follows the methodology that is described in the book Product Design and Development by Ullrich and Eppinger [3]. Since this project focus more on material search and selection compared to many other product development projects, the methodology has been customized after the projects specific needs in order to come up with the best possible solution. The process that has been followed during the project is summarized in Figure 2.1. The process contains a research of the kitting solution market which includes benchmarking and user studies with different stakeholders. The research part ends up in two requirement specifications, one for the kitting solutions and one for the guidelines which state the requirements and desires that the different stakeholders have on the final outcome. The research together with the requirement specifications ensure that the right information has been collected which is an important part in the further work of finding suitable solutions for the stated problems.

The process continues with material search and concept development. This part differ from the normal way of processing product development since the material part normally is a minor part, and located during the concept decision. This project will have a larger focus on material selection since the material has a major role for a kitting solution today. The decision was therefore to make an accurate material investigation in order to find the best suitable material on the market. Simultaneously, the concept generation phase was conducted so that the best concepts can be combined with the best materials in an early stage in order to find the best combination. It is important that a promising concept has a suitable material and that a promising material has a suitable concept, otherwise it can be difficult to use the promising concept or material. This methodology enables early decisions in that area which hopefully leads to a more effective product development process.

The next step in the product development process was material and concept screening which partly works like a normal concept development screening process. One difference is that the materials are screened in the same way as the concepts. The screening process consists of different steps where the concepts and materials are exposed to more difficult gates that they need to pass if they should be further considered. The material screening however differs from the normal way of screening concepts since one of the methods that were used was to test the material in reality with a structured testing process. That broadened the perspective since the information that is available for a material can be difficult to interpret. Continuously iteration was an important part of the screening stage.

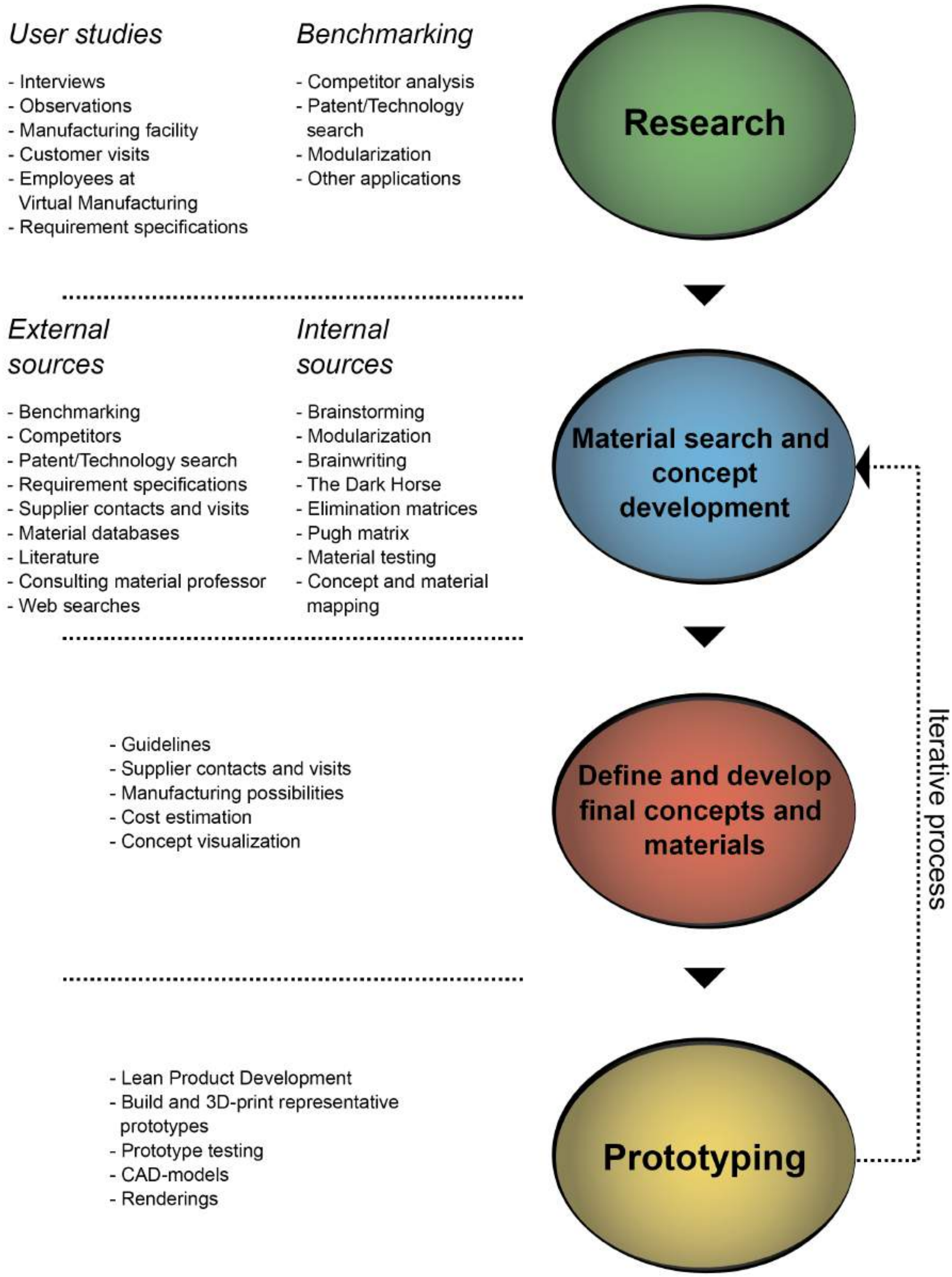


Figure 2.1: The project's process is divided into four parts and the used methods are listed.

After initial screenings of the materials and concepts, only the best materials and concepts were still available. In order to improve the concepts' level of detail, they were combined with the materials. With this fusion of materials and concepts, there was an early decision if the concept or material was possible to use or not. It was also advantageous that the material decision had been made when the detailed design was started since the focus then could be to find suitable suppliers of the material and to find the best variant of the specific material. There are a lot of different variants of a material that have different properties so a further investigation in the selected materials was needed. This way of combining concepts and materials in an early stage in other words saved a lot of time in the process. The first mapping between materials and concepts was only preliminary since new knowledge was added and changed the final combination of materials and concepts continuously.

After the concepts had been mapped with materials, the next step in the project was started which included further investigations and development of materials and concepts. This part was divided into two different chapters, one for materials and one for concepts. The reason why is that before the materials were ready to be used, a deeper investigation of which specific sort of a certain material that was to be recommended needed to be conducted. This also included determination of suppliers or producers. In the same way, before a concept could be used in combination with a material, the concept needed to be further developed and investigated. These two chapters ended up with defined materials and concepts on a more detailed level so that they could be used in order to build prototypes and to be included in the guidelines that this project resulted in.

When the materials and concepts had been determined on a higher level of detail, prototypes were made in order to visualize the concepts and materials. The prototypes were tested in different ways in order to get a first view of how the concepts and materials would work in reality. The feedback from the building process and the tests resulted in information that was useful to optimize the material and concept choices or be used as a further recommendation to Virtual Manufacturing. There was also a time limit that resulted in that not all concepts or materials could be visualized into prototypes. Additionally, some of the materials or concepts were not used for prototypes since they would not provide new information or show anything special.

The next stage presents the project's outcome which mainly is the construction guidelines that will be used by Virtual Manufacturing when they are constructing and building customized kitting solutions. All parts of the project that have been conducted have been a part of the goal of making the perfect construction guidelines. The guidelines are designed after the requirements that different stakeholders have which optimizes the chances that the guidelines are useful for the users. The stage about the projects outcome will also present a concept that has been developed completely from scratch during the project and that also can be seen as a outcome of the project since it has been created as a result of the work. The last part of the chapter reconnects the objectives and requirement specifications to the actual outcome of the project. The mapping of the requirements to the project's results increases the chances that the stakeholders will be satisfied and if some parts are not fulfilled, they are be presented so that no negative surprises arise later on.

2.2 Methods Used During Market and User Needs Research

In this section, the methods that were used during the market and user needs research are described and motivated, including benchmarking and user studies. It was considered as a necessary step to start the project with an investigation about the market and how customers and other stakeholders interact with the kitting solutions. To be properly inserted in the kitting solution environment will probably affect the end result in a positive way.

2.2.1 Benchmarking

The research study was initiated with a benchmark of what kind of products that Virtual Manufacturing's competitors offer in comparison. Benchmarking is an important first part in a development project since it creates valuable knowledge that is used further on during the project. The primary focus of this project was Virtual Manufacturing and their kitting solutions so therefore, investigation of the area was necessary. A description of these two areas is presented in Chapter 1.1. Competitors or potential competitors were found by asking the company who they considered to be their main competitors, and through searching the web for different providers of kitting solutions or material handling products in production environments. A patent search did also contribute to the benchmarking. Apart from Virtual Manufacturing's lean manufacturing products, different solutions, such as pipe-connecting components and other similar fitting solutions were investigated. These were saved for future work as they may prove to be useful when generating useful solutions in the concept development phase of the project.

In the benchmarking section, a description of the concept of modularization is also presented and how this can be implemented when constructing kitting solutions. As kitting solutions may need to be reconfigured during their lifetime to fit a new situation or environment, modularity is central as it enables a design to have many configurations without having to replace or redesign components, which ultimately can save time and financial resources.

In the last benchmarking section, other applications of kitting solutions are briefly overviewed to see how widely the product is used in a number of different contexts. Furthermore, different components of kitting solutions, such as pipes, boxes and bins, are described with respect to how they can be used in a production environment.

2.2.2 User Studies

The first part of the user study was conducted with two employees at Virtual Manufacturing who are modelling the kitting solutions according to customers' specifications. These persons represent the starting point in the kitting solution development process as this is where requests from customers are received. The interviews were conducted in a semi-structured way, where the focus was to understand and learn about their current situation and workflow, management of incoming orders and perceived problems. Several general questions were asked initially, while more specific questions became relevant as the interview went on and the situation became more comprehensive [4]. The approach of having semi-structured interviews with broad questions in the beginning and more specific ones later on was considered to be suitable since it enabled the interviewees to talk freely about their workflow, as well as it gave room for additional relevant questions to learn more in certain areas. A more strict and structured interview would be better suited when there already is knowledge about the process and workflow, and more specific matters need to be investigated.

A visit of Virtual Manufacturing's manufacturing and assembly facilities in Linköping was conducted in order to get an overview and understanding of their workflow and how this is related to the designers in Gothenburg. This involved investigating what materials they purchase and work with, how they process it, what kind of equipment and components they use, and how they use these tools to create kitting solutions that are ready to be sent to the end customer. The study was initiated with an observation, where one of the employees working at the production site did a walk-through of the facilities. Spontaneous questions were asked along the way to get an initial understanding of what their process looks like, from purchasing raw material to finished kitting solution. After this, a more structured interview was conducted in their office in order to complement and clarify what was learned during the walk-through and to answer other questions that were relevant for the project. Having a walk-through with a complementing interview was considered to be the most suitable approach since it provided information about their way of working, which made it easier to formulate and direct relevant questions later on.

The first customer visit was at Volvo Trucks, which is a Swedish company that manufactures trucks. Since the company uses Virtual Manufacturing's kitting solutions in their production line, the company was visited in order to get an understanding of how their solutions are used and handled by the employees there. This study first involved a walk-through of the production line, in which the core production process of trucks were shown. This enabled the possibility to observe what kind of components that were stored in different kinds of bins, boxes, kitting trolleys and stands. Furthermore, this clarified and supplemented learnings from the previous interview with the employee at Virtual Manufacturing and studies of their order inputs. The observation was followed by a short interview to assess and clarify how they use their kitting solutions and what they require from them. Similarly to the manufacturing visit in Linköping, it was considered to be useful to observe and learn about the process during a walk-through of the production line, before complementing with relevant questions afterwards.

The second customer visit was conducted at Adient which is a company that produces car seats. As Adient is oriented towards a different area than assembly of entire vehicles, it was considered useful to see how they are using different kitting solutions in a different production context. It was also important to get another view and perspective of how kitting solutions are used generally, in addition to the other customer visits. The visit was conducted through a guided tour in the factory and was followed by a semi-structured interview where a consultant from Virtual Manufacturing that works with the production flow was interviewed. The interview followed a structure that was similar to the one used during the first customer visit.

Volvo Cars was the third customer visit during the user study. This company develops and manufactures cars and have numerous ways of containing and handling components in their production line. The company was looking to implement kitting boxes from Virtual Manufacturing into their production line as they saw problems with their current situation. The visit involved a brief walk-through of the factory before specific areas were visited in order to get an understanding of the problem with the kitting boxes used today. A complementing interview was held afterwards, with a similar structure used at the other customer visits, to assess what particular requirements they had. This customer also worked as a test reference in this project, as prototypes and models from this project were built and tested in their production line.

2.2.3 Function Analysis

A function analysis was created with the method function-means modelling, which is a way of visualizing the functions and the means/components that a kitting solution have. The functions are connected to their means so that the connections can be viewed easily. The method is used in order to analyze a kitting solution and see which functions that are important parts to the project. The method is useful when creating a requirement specification list of materials and concepts where the stakeholders needs are listed. It is also important to give a detailed description of the functions that the kitting solutions have [5].

2.2.4 Requirement Specifications

The research chapter ends with two requirement specification lists, one regarding materials and concepts and one that handles construction guidelines. These lists requirements and desires that are needed in order to achieve the desired outcome. The requirement specification of materials and concepts also explains the target values, importance, how it will be controlled etcetera. The requirement specifications contain essential information that the concepts, materials and guidelines need to fulfill [6]. The method is mainly used to create an overview and summary of the research chapter, and as a reference to make sure that the final outcome fulfills the objectives of the project. The requirement specifications have been updated during the project when new information and knowledge changed or added requirements or desires.

The lists were created by identifying the stakeholders' needs which were mainly found during the user studies. The benchmarking also contributed to the requirement specifications. Regarding the specification for materials and concepts, the components that will be transported and stored in the kitting solutions were identified and categorized into four different categories that have different requirements and needs. The requirements and desires that were identified were then placed in the list and the component categories that were affected by specific requirements or desires were also identified. The desires were also categorized in a scale between one to five where one is not so important and five is really important to fulfill. A goal value was also decided, for example which temperature the kitting solution needs to manage for a temperature requirement. The last thing that was decided was how the requirement or desire can be checked and by whom.

The second requirement list concerns the construction guidelines and consists of demands that need to be fulfilled. The purpose of the demands is to ensure that the guidelines will aid the designers at Virtual Manufacturing in their daily work. This was done by providing them with information that helps them make more conscious and cost-effective decisions, such as price of materials and available suppliers.

2.3 Methods Used During Material Search and Concept Development

This part mainly comprises methods that were used for material searches, as well as different approaches for generating assembly concepts of boxes and shelves with or without internal dividers. The section begins with a short description of currently used materials and their respective properties, as well as currently used tools and equipment for assembling boxes and shelves for kitting trolleys or independent boxes. The section thereafter continues to describe the used methods during the material and concept development phases.

2.3.1 Currently Used Materials and Manufacturing Methods

This section describes what materials and manufacturing methods Virtual Manufacturing currently use to construct boxes and shelves for their kitting solutions. Information about this subject was gathered from the conducted interviews with employees and observations of manufacturing facilities. This was done in order to get a clear picture of how and under what conditions employees work today, and to create a reference for future concepts to be evaluated against.

2.3.2 Material Search

The search for appropriate materials comprises different sources of information. To start with, the software Cambridge Engineering Selector (CES) was used several times in order to find interesting materials. The software has a huge material library and to search after usable materials, a lot of constraints were set, like use temperature, price requirements and mechanical constraints. The different materials that passed the sorting were then visualized in a 2D coordinate system with properties at each axis like density, price per kilogram and fracture toughness. In the coordinate system, the materials that had the best properties were shown and further information about the material was analyzed before the material was decided to be further investigated during the project or not [7]. CES was also used in order to find inspiration that was further used with internet search or the other way around, that more information was conducted from CES when an interesting material was found on the internet.

Searching online was also an important way of finding usable materials. Different approaches were used for the material search online like finding suppliers of plastic materials or other building elements or interesting materials. If an interesting material was found at a supplier website, it would probably not be a problem to buy the specific material in the future if it becomes necessary. Another way of finding materials was to search for a specific material category like construction plastics or lightweight materials which enables a wider search than just to see which material a specific supplier has. Several interesting materials were found during the search but it was simultaneously important that there existed available suppliers of the specific material. Other applications and products that were interesting and found during the benchmarking were also used here in order to find inspiration for the material choice. If an interesting material was found but there was a lack of information, additional book sources were used in order to gain the needed knowledge.

Simple and straightforward thinking about possible suitable materials was also conducted and by using the web to find inspiration, several interesting materials or ways of using materials were found. Additionally, material literature was studied to complement the knowledge gained from the software and web searches. One additional source that was used to find potentially suitable materials was Material Connexions "Materials Database", which contains over 8000 materials. The search constraints include, for example, country of origin, material category, physical properties, processability, sustainability and availability. Different constraints were used for different searches and resulted in a list of materials that could be useful as building material for boxes and shelves. This list was generated by analyzing pictures of the material and the description of its properties, to decide if it was worth to investigate further or not [8].

During the material search on the web, a number of different retailers and producer of material were found. For example, a meeting with one seller from an interesting company was therefore held in their facilities. The purpose of the meeting was to get inspiration and to know which materials that the seller thinks are suitable for building kitting solutions with. Other companies were also contacted in order to find out if they had interesting materials that would be suitable for kitting solutions. A meeting with a material professor at Chalmers University of Technology was also conducted in order to discuss and suggest potentially useful materials. During the meeting, a semi-structured interview was held where interesting materials were discussed.

During the material search, multiple hardware stores were visited in order to gain more knowledge. No new materials were found but the already existing materials in the material search could therefore be quickly investigated so that a better understanding of the specific materials was achieved. Some materials were also bought so that even more knowledge was gained. To feel the material instead of just reading about the material or look at pictures broadens the perspective and creates a deeper understanding so therefore, this part of the material search was important.

2.3.3 Concept Development

In this section, different methods and tools were used to generate a number of concepts of how boxes and shelves with dividers can be assembled. The kitting solutions as systems were also taken under consideration. The concept generation was held in different creativity levels like how to transport and store components which opens for a lot of creativity, to how to assemble boxes which is a more focused way of creating concepts. Both internal and external methods were used. The internal ones are the concept generating methods that takes advantage of the internal knowledge and creativity by using methods like brainstorming, brainwriting and the dark horse. The external sources are the other concept generation sources that utilizes the external knowledge that was provided from the research part of the project or by web sources, to name a few.

The main methods that were used during the concept generation was the internal concept generation methods. The first used method was brainstorming which is an internal search method that uses the internal knowledge that the project team has. It is important during brainstorming that there is a lot of creativity, negative judgment is therefore not allowed. The brainstorming was held with different themes or aspects that were taken under consideration. The focus was to come up with many solutions or concepts, where quantity is more important than quality. The brainstorming was held both with collaboration in the group and independently [3]. Another similar method that was used in order to create concepts was brainwriting. The method works the same way as brainstorming with the difference that instead of discussing, the concepts are directly visualized by drawing figures of them. This method was used both in group and independently. When using brainwriting as a group activity, one group member sketched a concept and sent it to the other group member that continued with the specific idea or came up with a similar solution in the same theme [9].

The dark horse is another internal method that was used during the concept development stage. The method is about to completely think outside the box and have no limitations about what is possible or not. The created concept that the dark horse generates can be the most revolutionizing ones that can have a big potential [9]. It is important to use different idea generation methods with different approaches since it improves the overall quality and span over the generated concepts. Some of the created ideas were not big or good enough to create an own concept. These ideas were rearranged and further analyzed which led to that some of the ideas were made to concepts instead.

The other concept generation sources that were used consisted of external concept generation. During the benchmarking and user studies, a lot of information about how Virtual Manufacturing and other companies work today have been used in order to create usable concepts. Other products and applications have also been used as inspiration to come up with concepts. The external concept generation sources also include internet and literature searches, for example in order to find other suitable assembling methods. Both using internal and external idea generating methods broadens the perspective and the possibilities to come up with new and usable ways of constructing and building kitting solutions.

2.4 Methods Used During Material and Concept Selections

After potentially useful materials were gathered and concepts were generated, these were evaluated and screened in order to reduce the number of materials and concepts to a few ones that were further developed and investigated. The initial screening of both materials and concepts was made through an elimination matrix. An elimination matrix is a matrix where the different materials or concepts are checked against the basic requirements from the requirement specification list of materials and concepts. Some requirements were rearranged or combined with other ones in order to get a productive screening process. If a material or a concept did not fulfill a certain requirement it was eliminated. The elimination matrix was therefore eliminating all solutions that did not fulfill the basic requirements since that is essential for all materials or concepts that will be taken under further consideration. An elimination matrix was used for both materials and concepts since it ensures that all concepts and materials fulfill the basic requirements from the requirement specification.

The remaining materials and concepts were then further evaluated in different ways which is described during the next sections. The concepts and materials were also mapped together in order to determine which materials that would work with a certain concept.

2.4.1 Initial Material Selections

During the material elimination matrix the decision if a material does fulfill a requirement or not was mainly based on the first found information source about the material which also was used for and refereed in each material description. In some cases, additional information was needed to confirm that a specific material was suitable or not. Some materials were also bought or ordered in this early stage in order to get a feeling and better perception about the material. The gathered information was interpreted in the best possible way. The decision can therefore not be seen as the absolute truth but was a guidance in the decision making. If a material was eliminated, a motivation was provided.

The next step in the material screening process was to test the remaining materials. The reason why a material testing was the best way of continuing the screening process is that it is important to get a feeling for the materials and to know which possibilities each material will have further on. It can also be difficult to find information about the material properties so making a physical test gives a lot of data that is useful further on. The material tests were arranged to examine the most of the material properties that are listed in the requirement specification of materials and concepts. For the material testing, suppliers were found which will be useful further on for Virtual Manufacturing when new materials need to ordered. Some material properties were not tested like how the materials' properties change in high temperature or if the materials are suitable for ESD-classified components since it was too difficult to accomplish. The material test is not the absolute truth but was seen as guidance for future decisions. The test was conducted in a small scale environment during a short time which means that longer exposure is needed in some cases to determine if a material tolerates certain using conditions. Hereafter follows the test steps and how they were performed.

1. Control if the material is dimension stable by stretching and bending the material.

2. Test if the material is suitable for sensitive components by trying it against two sensitive components, one glossy plastic component and one lacquered metal component.
3. Check the materials impact resistance by hitting the material with a hammer.
4. Test the scratch impact of the materials by scratching the material with a sharp tool.
5. Test if it is possible to screw with a screw driver in the materials and if the specific material requires predrilling.
6. Control if it is possible to saw or cut in the materials by using a saw or a utility knife.
7. Check the possibility to glue two parts of the specific material together by using an allround glue.
8. Try to clean the materials from dirt by soiling the material before cleaning it.
9. Control if the material tolerates water by pouring water on the specific material.
10. Control if the material tolerates oil by applying oil to its surface.

The test results for each material were then compared to each other relative to the specific materials density and cost. The decision if a material would pass the test or not was therefore based on how the material performed compared to its price and density and how similar materials performed.

2.4.2 Initial Concept Selections

The first concept screening matrix that was used in order to select concepts was an elimination matrix. The decisions here if a concept was eliminated or not was based on a estimation if the concept would fulfill the requirements or not. After the elimination matrix, an iteration process was conducted which resulted in a few new concepts. The iteration was based from the collected knowledge which included new thoughts and combinations and iterations of the already existing concepts.

After the iteration, a new screening process was made with a Pugh matrix. The Pugh matrix compares the concepts with a reference concept which makes it possible to compare the concepts to each other. The criteria that the concepts were compared with are desires from the requirement specification of materials and concepts. A Pugh matrix is a suitable way to screen the remaining concepts since the concepts were compared with each other which makes the decision making more reasonable. The Pugh matrix resulted in a ranking of all the concepts but it was not only the concepts with the worst ranking that were eliminated. The result from the Pugh matrix was investigated and discussed in order to make a reasonable decision for each concept. Some concepts were needed to be used later even if they got a bad result in the Pugh matrix since specific customers or applications will require that kind of solution. A motivation of each concept decision was therefore made and is presented after the Pugh matrix.

2.4.3 Final Concepts Combined With Materials

In order to summarize the chapter about concept and material selections, a mapping of the concepts and materials was made. The mapping showed which materials that can be usable for each concept which was useful later in the project. It is important to know in which kind of interactions a concept and a material will create when further investigation and development of materials and concepts is made. In order to determine which concept that works with a certain material, the specific needs for a concept was analyzed and mapped with the materials' properties. A motivation of which materials that can be combined with a specific concept is also presented. The mapping was only preliminary since new information was continuously gathered which led to some changes of the possible combinations which will be presented later in the report.

2.5 Methods for Further Investigation and Determination of Materials

Some of the materials that were found during the material search were just types of materials and other found materials were specific sorts of a trademark. The demand of further investigations for the materials therefore differed but a general investigation was made for each material. This included web searches for different variants of a material sort. Suppliers and producers were identified and in some cases contacted if their products seemed to be interesting. The investigation of the materials also included mail and phone correspondence with suppliers and producers. Physical meetings with some suppliers were also conducted and a deeper understanding of their variety of materials was therefore gained.

Through information from documents available on internet or by seller at the companies, price, weight and other relevant estimations were obtained. In the cases where multiple producers or suppliers were found they were compared against each other and the best one or ones were further considered. Some of the materials are available by many companies so all of these companies have in some cases not been investigated due to lack of time. In some cases, the different sorts of a specific material were ordered in order to compare the material sorts physically. When the investigation of a specific material had been made, a determination of suitable suppliers and material variants was made in order to provide all information that was needed for the guidelines that this project will end up with. In some cases, the companies did not respond despite several tries to contact them by phone and mail which made the process more difficult, especially when a specific material just had one supplier or producer. There was therefore a lack of interesting information in some cases which also affected the final construction guidelines.

2.6 Methods Used During Final Development of Concepts

Several methods were used during the final development of concepts but the most useful one is an important part from the methodology of lean product development, which is early testing. Making tests in an early phase was fast, cheap and created a lot of knowledge that could be used further on. It was also important that the tests leads to failures since otherwise no new information would be gained [10]. The early testing of the concepts made that the process of further developing the concepts is based on fact instead of just predictions. The gained knowledge from the testings was used further on when prototypes were built since the tests already have shown prof of concept.

Beyond early testing, further brainstorming about the final concepts was made in order to construct the concept in the best possible way. The concepts that consisted more of a method that already exists, further investigations was made in order to find suppliers that can supply Virtual Manufacturing with the required knowledge and technique. At least one supplier of the method that can produce the physical concept was found through further searches and investigations. This was important since the final guidelines recommend different assembly methods for different cases. In a few cases, suppliers or resellers of a specific assembly method were visited in order to gain more knowledge of the technique so that correct assumptions and recommendations could be made to Virtual Manufacturing.

One of the concepts that has been further developed and that does not exists on the market today in the required shape needed more time consuming development. Besides brainstorming that of what the concept will look like, the computer aided design (CAD) program Catia V5 was used, which is one of the biggest CAD-programs available [11]. The program was used in order to make a virtual prototype that enables a first physical prototype made with 3D-printing. A brief investigation of how the concept can be manufactured and approximately how much it would cost was also made so that it will be easier for Virtual Manufacturing to decide whether or not they will start to use the concept. For calculating the manufacturing cost, the software CES was used in combination with a manufacturer.

During the further concept development, continuous iterations were made in order to combine existing concepts and materials in new ways. To use iterations in a product development process, new value can be created continuously since combinations of several materials or concepts can solve problems that the individual material and concepts can not do by themselves. The iterations therefore increased the probability that the outcome of the process would be the best possible from the current circumstances.

2.7 Methods for Prototype Building and Testing

The prototype building and testing started with that some prototypes were made of some of the materials or concepts. The most interesting ones were selected since the lack of time made it impossible to make prototypes of all variants. Two of the prototypes were made of the same material but with some differences in assembly methods. They were built in Virtual Manufacturing's production facility in Linköping with advise from the production personnel. The reason why is that it was important to see if it was possible to build the prototypes with the available equipment at the company's production facility. The two prototypes were then taken into Volvo Cars production line in order to determine if the selected material and assembly methods (concepts) would be good enough to be used as a kitting solution. The responsible employees for the kitting station at Volvo Cars were continuously informing how the prototypes were performing during the testing. The possibility of testing the prototypes in Volvo Cars production was a good way of gaining knowledge of the solutions which was useful for the whole project.

Some other smaller prototypes were made so that the concepts or materials could be shown in principle even if no further testing was conducted. The prototypes that have been made throughout the project have been made in order to gain information so some of the prototypes will open new possibilities for Virtual Manufacturing for both selection of materials and assembly methods. All materials that will be useful continuously for Virtual Manufacturing will at least be available since they have been collected throughout the project.

2.8 Methods used for Final Outcome

The final outcome of the project was created in order to summarize the result of the project. The main part of the chapter is about the construction guidelines that are constructed after the requirement specification of construction guidelines that was developed during the research part of the project. It is important that the guidelines are easy to understand and interpret so therefore, a lot of time was spent on making it user friendly completely regarding to the earlier stated requirements. The construction guidelines were created in near contact with the end users which are the two product developers at Virtual Manufacturing. They gave input continuously and when a first layout was made, they were responding to the structure in order to corporate and thereby creating useful construction guidelines.

The second part of the presentation of the final outcome shows what one of the final concepts looks like and more useful information about the specific concept. The reason why is that the concept has been completely developed during the concept development phase since there was no similar solution existing at the market. The other concepts that are part of the final solution are already existing so no further development has been needed more than smaller testing. The concept that is presented during the final outcome of the project is a result of the project and it is therefore obvious that it needs to be presented as an outcome of the project. The third and last part of the final outcome reconnects the objectives and the two requirement specifications to the final outcome in order to secure that all requirements have been fulfilled in the best possible way. If there are any requirements that has not been met, it is important that it is presented as well so therefore will it be natural to sum up the projects process with a mapping between the requirements and the projects' outcome.

2.9 Concluding on Methodology

The general development approach and the different methods that has been presented during this chapter aims to create the best possible conditions in order to deliver the best possible outcome of the project. The general development approach was selected to be followed early in the project with some additional adjustment further on. The approach was important when selecting methods in order to follow the process in a satisfying way since it would have been more difficult to select methods of how to conduct the work if no general approach was defined. The methods have in some cases been adjusted so that the best possible conditions have been created in order to deliver the expected outcome of the project.

3 Results of Market and User Needs Research

The chapter consists of five parts, first will the conducted benchmarking be presented, which includes interesting solutions and products that will be usable during a later part of the project. The user studies will thereafter be presented which includes both observations and interviews with different stakeholders. Then a function analysis was made for a kitting trolley, which is the most complex kitting solution. The last two parts of the chapter presents and describes two requirement specifications, one for materials and concepts and one for the construction guidelines.

3.1 Benchmarking

The benchmarking sub-chapter will present the conducted benchmarking. This include an overview of Virtual Manufacturing's competitors and their solutions but also information about technical solutions and other applications that can be of interest for the project.

3.1.1 Competitors

The market for different material handling systems is wide since all assembly lines needs to handle the material flow in some way. There are only a few big global actors since many small companies sell material handling solutions in their own region. Many companies that sell material handling solutions have standardized products that can be configured in different ways depending on the required needs. The market for customized kitting solutions is a minor niche market since each kitting solution design will be produced in small quantities [2]. Virtual Manufacturing is an actor in Sweden which makes the company a small and local actor in the global kitting solution market. The most interesting competitors for Virtual Manufacturing are therefore local actors that sell their solutions in the Swedish market which will be the main focus during the competitor analysis.

One identified competitor to Virtual Manufacturing is Flexqube which is a Swedish company that develops and sells flexible structures for material handling. Their products consist of a few different components that can be arranged in many ways that suits different material handling situations. The company's products can be reconfigured if the material handling needs changes [12] which is an advantage compared to Virtual Manufacturing's kitting solutions. Flexqube's kitting cart system is not welded together as many competitors solutions, instead the system is bolted together. The flexible system consists of standardized building blocks that can be mounted in many different ways, see Figure 3.1. The company has a lot of different kitting carts in their product portfolio but they also design carts on demand. This means that the carts will be tailor-made according to the customers assembly line principals [13] just as Virtual Manufacturing's kitting solutions. The main difference between Flexqube's and Virtual Manufacturing's kitting solutions is that Flexqube's can be rearranged in an easy way for other purposes. The material handling solutions are mainly produced with large steel frames which probably make them more robust and durable compared to Virtual Manufacturing's solutions that have a more narrow structure.

Figure 3.1: The figure shows one of Flexqube's flexible kitting carts [14].

Flexqube has a patent that protects their way of locking tubes to each other and to locking other components to the tubes. The patented solution consists of lock plates and lock housings that together creates a flexible way of joining tubes and other components, see Figure 3.2. The patented solution enables that the trolley's layout can be changed if the needs change [15]. This patent will limit the possible ways of joining the boxes and containers to each other and to the steel frame so it is important to take this patent in consideration during the later part of the project.

Multitube is a Dutch company that provides modular pipe constructions for workplace designs, material storage and internal logistics. Multitube sells products that support lean manufacturing and offers both standardized kitting carts solutions but also tailor-made solutions for the customers' specific needs. The carts construction is like Flexqube's system modular and can be rearranged if needed [16]. Virtual Manufacturing's kitting solutions are less flexible and robust due to other material usages and production processes.

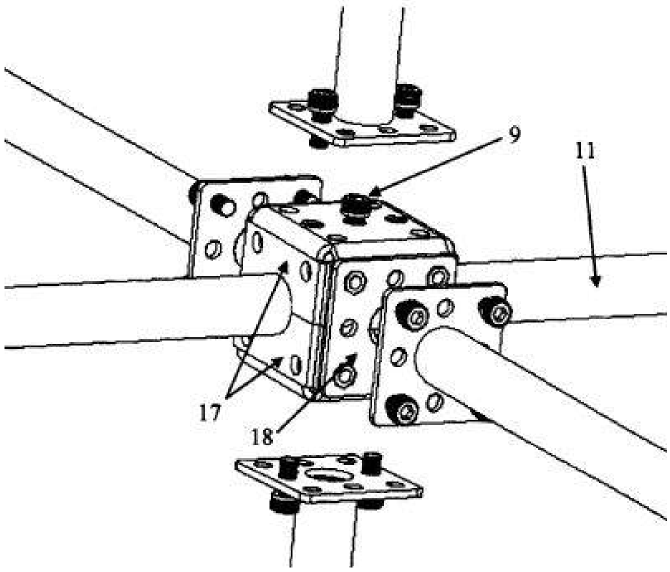


Figure 3.2: Flexqube's patented lock housing [15].

Indeva is an over 130 year old company that was founded in Italy that has a site in Sweden as well. The company is a total supplier of lean production solutions which includes kitting solutions and special constructed trolleys. The trolleys consist of metal pipes that are connected through a connection system. The trolleys also consists of additional boxes that can be fixed or movable, see Figure 3.3. The company has a wide product portfolio within material handling solutions and the kitting solutions can be customized after the customers' specific needs. Indeva's products are supposed to be safe and ergonomic to use [17]. Indeva's solutions seems to be similar to Virtual Manufacturing's solutions since they also consist of pipe frames and boxes in different combinations.

Figure 3.3: A kitting trolley from Indeva. [18].

Trilogiq is a material handling solutions company from France that has a site in Sweden. The company sells all kinds of material handling solutions, including kitting solutions. The trolleys consist of metal tubes that are connected through a connection system and a number of boxes in different configurations. Trilogiq builds kitting solutions tailor-made for the customers demands [19]. Li-Hu is a Swedish company that also is a competitor. The company sells different material handling solutions to the industry. They also customize kitting solutions after the customers' demands. Li-Hu's systems also consist of metal tubes with boxes in different configurations [20]. Both Trilogiq and Li-Hu are competitors that are selling approximately the same type of kitting solutions as Virtual Manufacturing does.

One common construction method for different types of kitting trolleys is to weld the components together. The welding process creates robust constructions that has a long life time but it is not possible to change the trolleys layout afterwards. Nailing and gluing are assembly methods that are used, mainly for the tailor-made kitting solutions. Bolting is another common used way of constructing kitting solutions which can enable rearrangement of the kitting solution systems [2].

3.1.2 Modularization

There are different ways of building kitting solution systems, the most flexible way is to use a modular design and construction method. Flexqube's kitting solution system is one way of using modularization with different construction elements. This sub-chapter will describe the theory of modularization and give examples when it is used.

Modularity is a design property of the product architecture which includes common interfaces (one to one mapping). The components or modules can be assembled in many different combinations due to the common interface [21]. Modularization means that the product architecture is built with independent components within modules. This means that a change in one module does not create a major affect for the whole product. The modularization creates the opportunity to combine modules in many different ways since they have standardized interfaces. One module can also be developed or changed independently from the other ones since they always have a common interface so that they can be combined anyway. Modularization will make it possible to with just a few standardized parts build a product in many different ways. The need of a warehouse with a lot of components of different kinds will be reduced since the same components can be used in many different ways. A modular product can in many cases also provide the opportunity to rearrange the product if the specific needs change [22].

The automotive industry is a sector where the modularization strategy has been an important part for several decades. Vehicles are complex and expensive products with many parts. The customers can also in many cases customize their cars for example by selecting engine size, colour and different types of optional packages. Since the automotive industry has a platform and modularization approach, the vehicles can be tailor-made without any major changes in the product architecture [22]. The automotive manufacturers can also have the same parts and modules in different models or between other brands. For example, Volkswagen, Audi, Skoda and Seat have a lot of common components and modules in their cars. In Figure 3.4, four different models from the four car manufacturers are shown that have the same platform. The modularization leads to that the unique number of parts that needs to be developed, manufactured and stored will be reduced significantly which furthermore leads to a lower overall cost [23].

Figure 3.4: Four cars from different brands that have the same platform. [24].

The modularization architecture that has been presented in this chapter can be useful in this project. If a modular solution can be found, relatively few components can be used in order to build tailor-made kitting solutions after the customers' requests. The overall time for construction and production of the kitting solutions will probably decrease and there will then be a economical benefit for Virtual Manufacturing.

3.1.3 Other Applications of Kitting Solutions and Their Components

Kitting solutions and other similar products have a lot of usages apart from being material handling and storing equipment on production lines. At grocery stores, they are used to assist and aid employees when they transport different food items between the stock and the store. For companies in the logistics industry they are instead used to transport packages, among other items, between different facilities or vehicles. Trolleys can also be used for sanitation and cleaning purposes as cleaners need to carry their equipment with them during the day in order to work efficiently. Other possible usage areas for trolleys or boxes are in warehouses where employees use them for collecting and transporting items from their respective storage place, or for people in vehicle workshops with different tools they need to store and move during their workday.

Components that are used or could be used in kitting solutions are different kinds of storing products. This could be pipes, plastic boxes or bins, steel baskets, tool holders, fasteners for boxes or stands. Pipes can be used to numerous things, to transport fluids, construction equipment or as storage for cables, smaller pipes or other thin and long items that fit. Plastic boxes or bins can, depending on their size, be used in different ways. Smaller boxes are useful when it comes to smaller bulk items such as screws, nuts, O-rings, bolts, electronics or other small details that are to be assembled on the production line. Larger boxes can be used in a similar way, either to simply contain a higher quantity of smaller items or bigger and heavier items in general to fit the needs of a specific part of the production line. Tool holders and fasteners are typically used to fasten boxes and tools to workstations or trolleys. These enable the operator to place items, such as storage boxes, screwdrivers, hammers and other tools where they are needed which allows them to work more efficiently and organized. Fasteners can also be used to enable flexible and strong frame constructions.

3.2 User Studies

This part of the research chapter regards the results of conducted user studies. First, result from interviews with employees at Virtual Manufacturing is presented, followed by the outcome of interviews and observations of the production and assembly process of kitting solutions and customer visits.

3.2.1 Designers at Virtual Manufacturing

The two interviews with the designers at Virtual Manufacturing lasted about one and a half hour respectively, and were mainly focused on getting an understanding of what their current workflow looks like, how they interact with their customers, what materials that are used and how they want the solution to aid them in their everyday work. The entire interviews, including questions and answers, are presented in Appendix A.1.1.

Virtual Manufacturing designs on average around 200 different kitting solutions annually. Designers at the company usually get a request by mail with complementing drawings, dimensions and material specifications for the boxes, and sometimes pictures or CAD files of components that the box will contain or what the boxes should look like. Different examples of input data from customers and what the components that the trolleys will handle can look like can be seen in Figures 3.5, 3.6, 3.7, 3.8 and 3.9. An order is usually for one or two kitting solutions, but it happens that as much as 50-100 kitting solutions are ordered. The level of detail of the specifications often depends on how ambitious the customer is or how much time they have to define what they want. Additionally, ESD-certification (which is further explained in Section 3.4), scratch resistance, shockproof, oil resistance and color are important requirements to consider when making a material choice. After this, the designer uses this information when they build a 3D-model, which takes about two hours.

Virtual Manufacturing does not charge their customers for the time spent building the model, unless the modelling time exceeds a certain limit, usually two hours. When this happens, Virtual Manufacturing contacts their customer and resolves the issue from that point. The 3D-model is then sent back to the customer for verification. When the design is approved, Virtual Manufacturing sends an offer to the customer which not seldom ends up in negotiations before a price is agreed upon. New customers usually send drawings and specifications to more than one company to get leverage in negotiations, and therefore to see who they can get the best deal from. When the offer is accepted, the designer creates manufacturing specifications that are sent forward to production and assembly personnel within Virtual Manufacturing. As a result, the entire design process takes about three hours, which includes designing the box or container, creating manufacturing specifications, calculating costs and moving various files. The company aims to only manufacture parts that can not be bought from subcontractors. This makes it easier to show the customers what they will get when they order. When customers require more complex products that the company can not manufacture with their current methods and materials, an external company is contacted to supply them with this. It also happens that one of the designers travels from Gothenburg to Linköping to help constructing these more complex products when it is necessary.

Figure 3.5: One example of input data of components that will be transported and stored in a kitting solution.

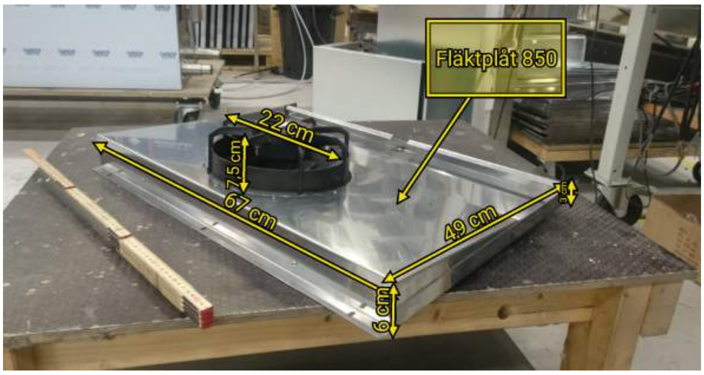


Figure 3.6: One example of input data of components that will be transported and stored in a kitting solution.

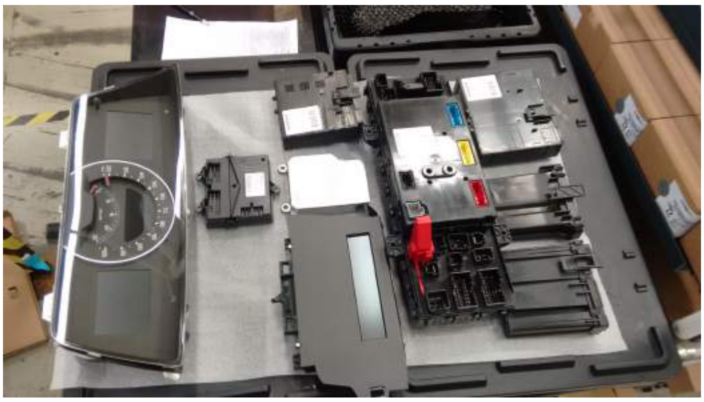


Figure 3.7: One example of input data of components that will be transported and stored in a kitting solution.

Figure 3.8: One example of input data of components that will be transported and stored in a kitting solution.

Figure 3.9: One example of input data of how the kitting solution should look like.

The materials that are used currently are Aicelwood, PVC-foam, Wellplast and tarpaulin. Aicelwood, or Durawood, is based on the plastic material polyethylene (PE) and has properties that makes it suitable for kitting solutions. It is tough, impact and scratch resistant and is processed in a similar way as wood. Its surface is also very smooth which makes it suitable for sensitive or fragile components. The material is delivered in yellow sheets in various thicknesses and is available as an ESD-material as well. It is also easy to put in screws and it does not splinter when you process it. The surface needs to be napped for glue to stick to it properly.

The second material that is used is called PVC-foam, or Forex Color. Sheets of PVC-foam can be coated with felt by using double-sided tape. The material is more brittle than Aicelwood and can be broken more easily if hit with enough force but around 95% of the produced kitting solutions are made with PVC-foam. Sheets of PVC-foam are often connected with screws or rivets. The material is available in two colors, black and white. The third material is Wellplast. Wellplast is a corrugated material that reminds of cardboard, and is folded into boxes. The surface can be coated with fabrics and the box can be stretched slightly to fit more components. In terms of purchasing price, Aicelwood is the most expensive one, while PVC-foam and Wellplast are on second and third place respectively. The last material Virtual Manufacturing is using today is tarpaulin which normally is used for boat covers. Tarpaulin is a fabric which often is used to construct kitting solutions that contain lighter and more sensitive components, such as headrests for car seats.

The properties of contained components can affect the choice of materials for boxes. It is therefore common to have boxes in different materials, such as Aicelwood and PVC-foam, in the same trolley to fit the needs of specific components. For example, components that are visible in the end product need to be handled more carefully than other things. Inserted shadowboards are therefore also common if it is important to fix components inside the boxes. The size of the components can vary between a few centimeters up to entire truck doors. Boxes of the described materials are most often hemmed within the frame of the kitting trolleys or connected with screws. These materials and their properties will be described more in depth in Section 4.1. The kitting solutions are primarily used by operators, fitters and other production personnel. The main reasons to why trolleys or boxes are worn out is that they get hit by trucks, screws loosen up, heavy objects are dropped on them, or that they are handled too violently. Consequently, if they are well maintained, they last longer. One of Virtual Manufacturing's product developers is assigned to service and repair their products at customers sites. The tools that are used during service visits are screwdrivers, drilling machines, cutters and carpet knifes.

The biggest reason to why they want a more extensive material library and guidelines is that they want to keep track of the market in a better way. This allows them to acquire materials that may be cheaper and better suited for the application. The most important factors to include in the guidelines would be purchasing price, providers, delivery time and matching of materials versus the components that are to be contained. A simple and better assembly process of the kitting solutions is also desirable.

3.2.2 Kitting Solution Manufacturing Visit

The user study in the factory was conducted both through observation and interview and lasted for about four hours. The main purpose was to gain knowledge about how the kitting solutions are manufactured and what kind of requirements and desires that the manufacturing employees have. The entire interview is presented in the Appendix A.1.2.

The manufacturing facilities were equipped with common tools and machines like screwdrivers, fixtures and different kinds of saws. Figure 3.10 shows some parts of the workshop. Aicelwood and PVC-foam is delivered by the suppliers in big sheets that can be difficult to handle. If multiple kitting solutions are to be produced, the material can be delivered in the right dimensions which saves a lot of time. PVC-foam is the most used material for kitting solutions, Aicelwood is used sometimes and Wellplast is used more seldom. Tarpaulin has only been used once. Both Aicelwood and PVC-foam are easy to cut with a saw. Aicelwood is a durable and smooth material and is not required to be deburred, compared to PVC-foam boards. PVC-foam is a static material and is therefore not usable for ESD-components. PVC-foam has a smooth surface and the sawdust from cut PVC-foam is sticky and hard to clean up. PVC-foam sheets are assembled with screws, tacks or rivets (see Figure 3.11) and there is no need for predrilling.

(a) The factory floor.

(b) A sawing station.

(c) An auxiliary tool is used to assemble the steel frame.

Figure 3.10: Three pictures from Virtual Manufacturing's production facilities.

(a) A material transport trolley.

(b) The boxes are assembled with screws.

Figure 3.11: A material transport trolley under construction.

Aicelwood sheets are mostly assembled with screws, and require predrilling. The fastening method for all materials varies by the size of the boxes that are supposed to be constructed. It is difficult to glue both Aicelwood and PVC-foam. Therefore, there is a demand to find a glue that can be used with these materials. The eventually new materials that this project will find are not allowed to have worse properties than the existing materials. It is also important to have suppliers that can deliver the material fast and to a low price.

The communication between the construction department in Gothenburg and the manufacturing facilities in Linköping could be better, the geographical distance complicates the collaboration as most conversations are through phone or e-mail. The designers have visited the factory multiple times in order to gain knowledge about how to make assembly friendly solutions. Sometimes the manufacturing employees need to make creative solutions since the supposed way of manufacturing is difficult to realize or that the end result will be better with another construction. The CAD-program's dimensions are sometimes incorrect which creates problem in the manufacturing process. The manufacturing employees also thinks that they sometimes need more knowledge about how the products that they produce are used by the customers, so some type of study visit would be desirable.

It happens that the production personnel have better ways of constructing a kitting solutions than the way the customer requests. For instance, some customers have asked for boxes in 3mm Aicelwood but it is almost impossible to assemble sheets with that thickness. Instead, a PVC-foam box can be covered with Aicelwood. Sometimes, the bottom frame of a kitting trolley can be constructed with cubic steel pipes, see Figure 3.12, for example if the trolley should be forklift compatible. Otherwise, the frame construction is constructed with circular steel pipes.

Figure 3.12: A bottom frame construction.

It is favourably to have a lot of materials in storage but it simultaneously ties capital and requires space so that is something that needs to be balanced. Virtual Manufacturing's suppliers of material are Beewatec for Aicelwood, Glasfiber & Plastprodukter AB for PVC-foam and Wellplast AB for Wellplast. Beewatec is a German supplier so the freight costs a lot but if Virtual Manufacturing orders for more than 100.000 SEK, they get a 10 % discount. Aicelwood costs around 150.000 SEK/m^3, and with ESD-protection, approximately 270.000 SEK/m^3. PVC-foam costs about 15.000 SEK/m^3. Obviously, Aicelwood is much more expensive than PVC-foam (around 10 times) and Aicelwood with ESD-protection is almost twice as expensive than regular Aicelwood. The material purchasing is the biggest cost in the manufacturing and assembly process.

The production facilities has been located in Linköping for almost three years, and there are some plans to automate some parts of the factory, for example with a collaborative robot. The manufacturing employees describe that they often are behind the schedule and that they get short deadlines, around one to three weeks on average. The finalized products are transported to the customers by truck and 95 % of the products are transported assembled.

3.2.3 Customer Visit Volvo Group

The visit in one of Volvo Group's truck factories was conducted through observation with simultaneous information and spontaneous questions. After the observation, a more structured interview was conducted. The observation and interview will be summarized here but all collected information is presented in Appendix A.1.3.

Volvo Group is a company that manufactures trucks, marine engines and construction equipment. The visit was conducted in one of the company's truck factories. Volvo has around 20.000 unique variants of what the truck could look like which require a complex material handling system. Some special truck models are produced more seldom like only 20 trucks a year. There are special assemblers that are rotating in the production lines and assembles special variants. Every station in the assembly line has assembling information about each truck so that they know what components that need to be assembled and where. It is important that the components that the assemblers get from the kitting solutions are located in an ergonomic way.

If a component for some reason is missing, the whole truck is taken out of the assembly line until the problem is solved, which costs about 50.000 SEK. This happens very rarely, about 1 % of all trucks. To make the assembly line more effective and economic, a low amount of different components is desirable. The forklift and tugger train drivers are responsible for the supply of screws, bolts and other parts. The material and components usually comes in pallets from the suppliers. Trilogiq and Indeva is two other companies that Volvo are using as suppliers for material handling solutions besides Virtual Manufacturing. The factory has a pilot assembly line where new components, tools and material handling solutions etcetera are tested. When new components will be used in the trucks, new kitting solutions are required, so they are arranged after the component's needs. It takes around half a year for a new idea to reach its implementation in the factory. There are a few employees that work with rebuilding and optimizing kitting solutions in order to improve the working conditions for the assemblers. The reason why some kitting solutions are destroyed is that they get hit by forklifts or other vehicles in the production. Many kitting trolleys in the production have bad wheels since they are noisy and creates dust as they get worn out. Overall, functionality is prioritized over aesthetics, but it does not hurt if it looks good on the production line.

The components that are stored in the kitting solutions are many different things like control units, pipes, cables and interior parts etcetera. Smaller components, like bolts and nuts, are contained in cardboard or plastic boxes that are placed in the flow racks. Larger and heavier components are often placed in wooden pallet stands. Heavier shafts are commonly contained in "spice racks" made of halved PVC pipes, dressed with a flocked carpet. Relatively large and sensitive parts are placed in trolleys dressed with coated tarpaulin. It is possible to roughly categorize the components in four different groups, insensitive, sensitive, ESD and oily components. It is important that the kitting solutions are cheap and ergonomic. Today a kitting trolley costs around 15.000-20.000 SEK which can make it difficult to motivate a purchase. The flexibility that many kitting solutions has today is another high ranked property. The kitting solutions' durability is good today since there is a correlation between price and durability, meaning that when they are expensive they are normally durable as well. New truck versions are coming continuously which can require new kitting solutions so a long life time is not always required but 10 years is desirable. Because of the flexibility of the pipe frame, it is not uncommon to rebuild the trolley after new needs. The kitting solutions made by Wellplast AB are less durable. It is important that the material in the kitting solutions does not sliver or create dust.

It can be difficult to standardize the boxes in a kitting solution since the size of the components differ a lot and it would probably be a too big change in between standardized sizes. PVC-foam is one material that is used today, which is easy to cut and process. The biggest problem is that PVC-foam looks ugly after a while when it gets dirty. The kitting solutions are only exposed to neutral pH values and are not stored or transported outside so water and UV resistance is therefore not prioritized. There is no routine in cleaning the kitting solutions.

3.2.4 Customer Visit Adient

The visit in one of Adient's factories was conducted through a guided tour and with a structured interview afterwards. The observation and interview will be summarized here but all collected information is presented in Appendix A.1.4.

The Adient factory that was visited is located in Gothenburg and produces car seats for all cars of Volvo Cars that are produced in their assembly line in Gothenburg. The factory mainly uses kitting trolleys that has tarpaulin sheets attached to the frame. The reason why is that they mainly have sensitive components that need extra protection or to be handled with more care. Two of the kitting trolleys that are used in the factory are shown in Figure 3.13.

The components that are stored in the kitting trolleys are upholstery, foam and various metal, plastic and electronic parts. There is only one component that needs ESD-protection which is the airbag. Otherwise, most components are sensitive in some way but there are also components that are not in need of special protection.

The kitting trolleys durability is relatively poor as they wear quickly and tear apart. A kitting trolley last for maximum five years but many of them need to be discarded prematurely after they have been hit by forklifts. One important property for the kitting trolleys is that they have a low weight since they sometimes are moved manually. It is also important that the components are protected so that they are not damaged. There are small opportunities to standardize the dimensions of the kitting trolleys since there are a lot of components in different sizes and it is important that a kitting trolley holds as many components as possible. The kitting trolleys today can not be rearranged and they are therefore replaced every time when a new car model is introduced.

The materials that is used in the kitting trolleys is mainly tarpaulin and other similar materials and works well since it protects the components. Putting components in stands with a soft fabric to contain them means they will not risk being scratched, which could be the case if they were stored in shelves or boxes with solid boards. Sometimes, there are sharp edges that can damage the components. The newest kitting trolleys are ordered from Flexqube and works well. The


(a) A kitting trolley for sensitive components.


(b) A kitting trolley for sensitive components

Figure 3.13: Two kitting trolleys in the Adient factory that are made by tarpaulin or other types of textiles or similar material.

tarpaulin material is white and there is no specific strategy when the colour is determined. The kitting trolleys are only exposed to neutral pH values but can sometimes be stored outside so water and UV resistance can therefore be of interest. There is no routine in cleaning the kitting trolleys.

3.2.5 Customer Visit Volvo Cars

The visit was conducted in Volvo Cars factory in Torslanda, Gothenburg, through a guided tour and with a structured interview afterwards. The observation and interview will be summarized here but all collected information is presented in Appendix A.1.5.

Volvo Cars factory in Gothenburg produces Volvo cars and uses Virtual Manufacturing's flow racks solutions. They also use kitting boxes in Wellplast from the company Wellplast AB. The kitting boxes in Wellplast has a low life length, from only a few weeks to a year which they are dissatisfied with. They have therefore ordered a kitting box from Virtual Manufacturing, made of Aicelwood. This kitting box was six times more expensive than Wellplast's solution and lasted for only three weeks. The kitting boxes will be used in the assembly line and will be brought into the car during the assembly. The kitting boxes will also be automatically transferred from one flow rack to another through a shooter function. This means that when one flow rack is attached to another one, a barrier will open and the kitting boxes will automatically roll over the the empty flow rack. It is important that the kitting boxes manage this transfer. The boxes in Wellplast does not retain their original shape which creates malfunction in the shooter function in the flow racks.

The kitting boxes that Volvo Cars use today contains all sorts of components, small and big parts in both plastic and metal. The components can be divided into three categories, insensitive, sensitive and ESD-components. Each kitting box solution consists of two boxes, one bigger and one smaller that are placed inside the bigger box. Figure 3.14 shows a few kitting boxes with components. The kitting boxes in Wellplast have a low weight (less than one kilogram) which is important. The boxes should have a weight below two kilogram, preferably not more than one and a half kilogram. Figure 3.15 shows what the boxes looks like after they have been used in the assembly line. The boxes are not allowed to harm the cars or the employees which means no sharp edges and protruding screws etcetera. The wall thickness of the boxes should not be thicker than one centimeter and the box material is not allowed to sliver or dust.

Figure 3.14: Kitting boxes that are filled with components and stored in flow racks.

Figure 3.15: Empty kitting boxes that are stored in flow racks.

It is desirable that the kitting boxes are rearrangeable, the boxes that are used today does not have that ability. It is important that the boxes are customized after the components they will store since it is important that the flow racks fit as many kitting boxes as possible. The boxes are not exposed to liquids, UV-light, oil or other types of harmful circumstances. The kitting boxes that Volvo Cars use today in Wellplast cost around 500-600 SEK and the test box in Aicelwood costs around 3000-3500 SEK.

3.3 Function Analysis

The kitting solutions that Virtual Manufacturing produces and sells have been further investigated through the user study. In order to summarize a typical kitting solution where the functions and components are included, function-means modelling was used. The type of kitting solution that was investigated was a kitting trolley since that is the most complicated type of kitting solution. The modelling describes which functions the kitting trolley have and which parts of the kitting trolley that provide the certain function. The function-mean modelling will be used later in the project as a support for the stakeholders' needs. The function analysis can be seen in Figure 3.16.

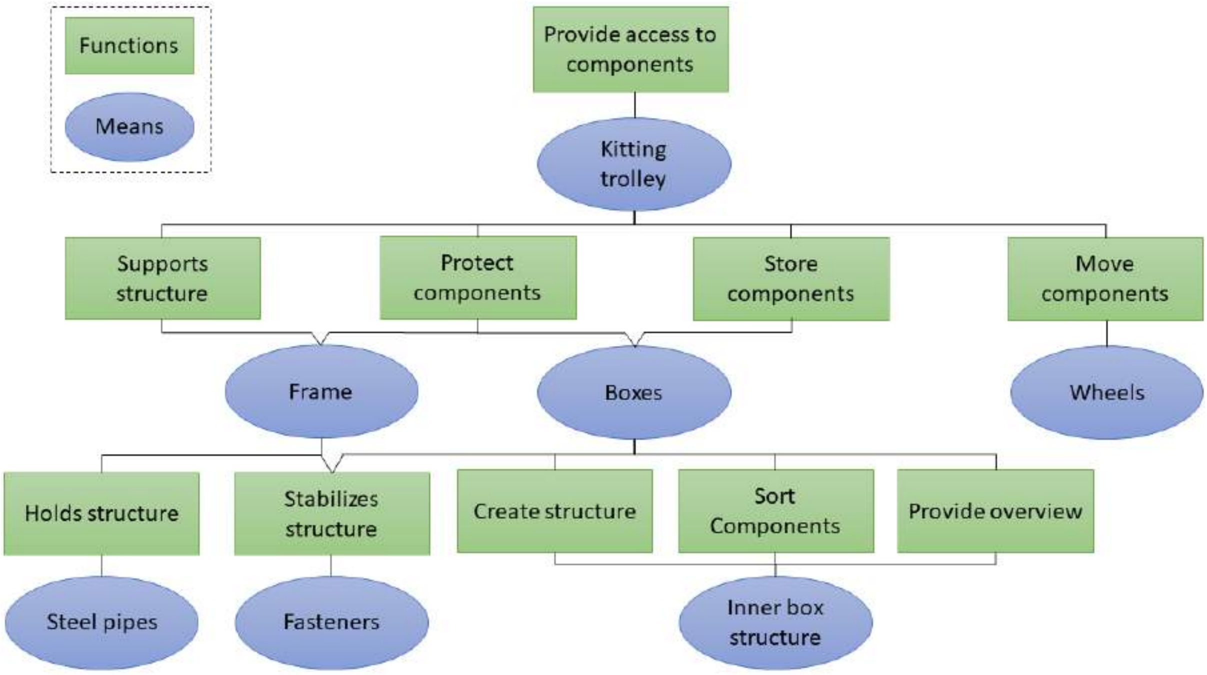


Figure 3.16: Function-means modelling.

The function means modelling contains all parts and functions that the kitting trolley have. Some of the parts and functions will not be investigated and developed in the project. The wheels and the frame will not be taken under consideration since it is the functions and means that are related to the boxes and shelves that are in focus.

3.4 Requirement Specification of Materials and Concepts

During the user study, information about the components that will be transported and stored in the kitting solutions has been collected. Different components have various characteristics and will therefore have different requirements on the kitting solution. The requirement specification lists requirements and desires and will in some cases only be valid for some types of components. The components that will be placed in the trolleys will therefore be divided into four different categories as follow:

1. **Insensitive components** - This includes parts that are not sensitive to scratching or are easily destroyed, and do not need to be handled in a special way.
2. **Sensitive components** - The components need to be handled carefully due to expensiveness or easiness to damage etcetera.
3. **Oily components** - Components that are greasy or have some kind of lubricant. The oily components can be both sensitive or insensitive.
4. **ESD-components** - Mainly electrical parts that need ESD-protection. Can also be both sensitive or insensitive.

ESD stands for electrostatic discharge and means that some type of components like electrical components are sensitive for this phenomena which could damage the components. Electrostatic discharge occurs through contact, friction and separation of materials. Static electricity exists everywhere and employees that will handle the ESD-components need ESD-protection as well, like special shoes and clothes. The ESD-components therefore need to be handled with care and be transported or contained by ESD-materials. A good ESD-material is a good conductor of electricity. Metals are therefore the best material category for ESD-protection and plastics are typical the least suitable material category. Except metals, ESD-materials can be divided into three categories which are ranked with the best category first, conductive materials, dissipative materials and anti-static materials [25].

The requirement specification will mention every requirement or desire that the constructors and manufacturers of the kitting solutions have. The customers, in this case the companies and their employees, will also contribute to the requirement specification. The benchmarking of the kitting solution market will affect the requirement specification in some cases as well. The requirement specification list will be used during the material and manufacturing studies but also during the concept development phase. The list will mainly have requirements for the material properties and their ability to be processed and assembled but will also cover the overall system solution which will be developed during the concept development phase. The specification includes costs, durability, manufacturability and other limitations that will affect the end result. During the whole project, the list has been continuously updated when new information has changed or added requirements or desires. The requirement specification is presented in Figure 3.17.

Requirement Specification List for Materials and Concepts					Created: 5/2-18		
Construction Guidelines for Customized Kitting Solutions					Modified: 16/4-18		
	Criteria	Component Class	Target	Requirement or Desire	Importance	Verification	Reference
1.	Cost						
	1.1 Manufacturing/assembling cost per kitting trolley	Insensitive components	Lower than today	Desire	5	Virtual Manufacturing	Construction department
	1.2 Manufacturing/assembling cost per kitting trolley	Sensitive components	Lower than today	Desire	5	Virtual Manufacturing	Construction department
	1.3 Manufacturing/assembling cost per kitting trolley	Oily components	Lower than today	Desire	5	Virtual Manufacturing	Construction department
	1.4 Manufacturing/assembling cost per kitting trolley	ESD-components	Lower than today	Desire	5	Virtual Manufacturing	Construction department
	1.5 Material cost	Insensitive components	Lower than today	Desire	5	Material manufacturer	Construction department
	1.6 Material cost	Sensitive components	Lower than today	Desire	5	Material manufacturer	Construction department
	1.7 Material cost	Oily components	Lower than today	Desire	5	Material manufacturer	Construction department
	1.8 Material cost	ESD-components	Lower than today	Desire	5	Material manufacturer	Construction department
2.	Service of the kitting solution						
	2.1 Able to replace damaged parts by customer	All	Yes	Desire	3	Detailed design	Customer
	2.2 Able to be repaired by customer	All	Yes	Desire	5	Detailed design	Customer
3.	Durability of the kitting solution						
	3.1 Designed durability	All	5 years	Requirement		Customer testing	Customer
	3.2 Designed durability	All	10 years	Desire	4	Customer testing	Customer
4.	Manufacturing						
	4.1 Possible to glue the material	Insensitive components	Yes	Desire	5	Test	The students
	4.2 Possible to glue the material	All exept insensitive components	Yes	Desire	4	Test	The students
	4.3 Possible to saw or cut the material	All	Yes	Requirement		Test	The students
	4.4 Possible to screw in the material	All	Yes	Requirement		Test	The students
	4.5 No need of predrilling	All		Desire	5	Test	The students
	4.6 Possible to screw in the same hole multiple times	All	Yes	Desire	3	Test	The students
	4.7 Harmless to work with the material	All	Yes	Requirement		Investigation	Material data
	4.8 Possible to only use the existing tools in the manufacturing facilities	All	Yes	Desire	4	Test	Factory
	4.9 Possible to weld parts togehter	All	Yes	Desire	2	Test	Factory
	4.10 Modularity (standardization of components)	All	Yes	Desire	5	Detailed design	The students
5.	Recycling						
	5.1 Recyclable	All	Yes	Desire	3	Investigation	Material data
	5.2 Possibility to reassemble	All	Yes	Desire	3	Investigation	Material data
6.	Material specifications						
	6.1 Minimum use temperature	All	- 20°C	Requirement		Investigation	Material data
	6.2 Maximum use temperature	All	50°C	Requirement		Investigation	Material data
	6.3 Tolerates water	All	Yes	Requirement		Investigation	Material data
	6.4 Resistence to weak acids	All	Yes	Desire	2	Investigation	Material data
	6.5 Resistence to weak bases	All	Yes	Desire	2	Investigation	Material data
	6.6 Oil resistance	Only oily components	Yes	Requirement		Investigation	Material data
	6.7 Does not scratch the components	All exept insensitive components	Yes	Requirement		Investigation	Material data
	6.8 ESD protected	Only ESD-components	Yes	Requirement		Investigation	Material data
	6.9 Possible to determine colour	All	Yes	Desire	3	Investigation	Suppliers
	6.10 Impact resistance	All	Yes	Requirement		Test	The students
	6.11 Does not sliver	All	Yes	Requirement		Test	The students
7.	Use of the kitting solution						
	7.1 Ergonomic	All	Yes	Requirement		Customer testing	Customer
	7.2 Not harmful to use for the operator or surroundings (no particles, no sharp edges etcetera)	All	Yes	Requirement		Customer testing	Customer
	7.3 The components are protected	All	Yes	Requriement		Customer testing	Customer
	7.4 Creates structure	All	Yes	Desire	4	Customer testing	Customer
	7.5 Sort components	All	Yes	Desire	4	Customer testing	Customer
	7.6 Provide overview	All	Yes	Desire	4	Customer testing	Customer
	7.7 Can be used in a flow rack	All	Yes	Desire	5	Customer testing	Customer
	7.8 Provide easy acess to components	All	Yes	Desire	4	Customer testing	Customer
8.	Availability						
	8.1 The used material can be easily bought from a supplier	All	Yes	Requirement		Investigation	Suppliers
	8.2 The supplier has the material in stock	All	Yes	Desire	5	Investigation	Suppliers

Figure 3.17: The requirement specification of materials and concepts.

3.5 Requirement Specification of Construction Guidelines

Information about materials and manufacturing methods needs to be assessed and visualized in a clear and understandable way in order to work as guidelines for the designers at Virtual Manufacturing. A requirement specification for the construction guidelines has therefore been created in order to ensure that correct and useful information is shown. This will be presented in a way that helps Virtual Manufacturing make correct decisions regarding the construction of their kitting solutions, which ultimately should benefit both them and their end customers. The requirement specification was developed in collaboration with the designers, utilizing the information gathered from interviews and internal discussions with the employees, and has been refined during the project. The requirement specification of the construction guidelines is presented in the following list.

- Help user to make correct and cost efficient decisions
- Easy to overview
- Show available thicknesses of material sheets
- Show price of material
- Show approximate delivery time
- Pictures that visualize the materials
- Present assembly methods for each material
- Provide name of supplier/suppliers

4 Results of Material Search and Concept Development

This section will present the results from the conducted material search and concept development. Concepts includes different ways of assembling or designing a kitting solution. First, materials and manufacturing methods that are currently used by Virtual Manufacturing will be described to show how the company works with their materials and manufacturing facilities. The next part will be about the search of materials that, given the found needs and requirements in the research study, will yield new and potentially useful materials that can broaden Virtual Manufacturing's material library. As information will be gathered from multiple sources, this part will be divided into a number of subsections. These are Cambridge engineering selector search, internet search, literature search, Material Connexion database search, consulting material retailers or producers and consulting material expert. Simultaneously as the material search was conducted, concepts were generated during the concept development phase. The concepts will therefore be presented in this chapter as well after the material search section. The concept generation phase consists of both internal and external idea generating methods like brainstorming and brainwriting that led to different concepts. The concepts will be presented continuously during the section for each method. Throughout this chapter, a large amount of materials and concepts have been presented and later screened during the next chapter.

4.1 Currently Used Materials and Manufacturing Methods

As it was briefly described in the interview with the designers at Virtual Manufacturing, in Section 3.2.1, the company mainly uses four different materials when constructing the containers for kitting solutions. These were Aicelwood, PVC-foam, Wellplast and tarpaulin.

Aicelwood is a plastic material, based on the plastic material PE, that has a number of properties that makes it suitable for several applications [26] [27]. It costs around 1500 SEK per square meter with a thickness of 10 mm, and has a density around 520 kg/m^3 [27]. Aicelwood with ESD-protection costs almost twice as much. Aicelwood can also be processed in several different ways, which adds to the flexibility when constructing with the material. This includes machining, drilling, milling, screwing and gluing among other processing methods. It can be recycled and is light, durable and has a smooth surface, which is why it today is used for sensitive components. It is also resistant to water and oil and is impact and wear resistant. The material has been used for packaging and transporting components for more than 30 years by various companies, such as Toyota, Honda and other automotive manufacturers.

The second material, PVC-foam, is also plastic, but has different properties than Aicelwood. It costs around 150 SEK per square meter with a thickness of 10 mm, and has a density around 550 kg/m^3 [28]. It can be processed similarly to Aicelwood as it is excellent for drilling, milling and gluing. It is more stiff and has a harder surface than Aicelwood, but has good impact resistant and a similar density [28]. The third most used material, Wellplast, is the trademark for a corrugated material, consisting of mostly chalk and polypropylene (PP) plastic [29]. The Wellplast sheet consists of three layers of this material, and weighs around 0,43 kg/m^2 with a thickness of 3,5 mm. The middle one is corrugated, and joint together with two flat layers by welding the material. The material exists in several different versions and has slightly different properties depending on the intended use. Wellplast materials are waterproof, chemically resistant, have good insulation properties, are safe for food contact, recyclable, clean in the sense that they do not emit fibres or dust, and strong in relation to its weight [30]. The fourth material, tarpaulin, is a polyester based plastic sheet, often coated with a layer of PVC, that is suitable for sensitive components [31]. It is mostly used as a material for shelves as it can be customized to steel frames, allowing it to carry and contain components that are too impact or scratch sensitive to be placed on a solid material. This was especially evident from the visit at Adient where many trim components were stored in these kinds of shelves. Tarpaulin and other similar materials are strong, durable, smooth and easy to clean. In total, Virtual Manufacturing purchases material for around 250 000 - 300 000 SEK every year.

During the visit of Virtual Manufacturing's manufacturing facilities in Linköping, the tools and machines used for producing and building the kitting solutions were observed and documented. This was done in order to see what kind of equipment that is used currently, which also is mentioned in Section 3.2.2. Additionally, employees at Virtual Manufacturing in Gothenburg use a number of tools when service of customers' existing kitting solutions is needed. These tools need to be in consideration when materials are investigated as it could save resources if the current equipment can be used to process new materials.

The tools and equipment most commonly used for processing material and assembling boxes and shelves for the kitting solutions were:

- Cross-cut saws, jig saws and manual saws
- Fixtures
- Electric and manual screwdrivers
- Torque wrenches
- Screws, rivets, tacks and glue for assembling boards

4.2 Material Search

The material search was made through different information sources. The material search section is therefore divided into the currently used materials, Cambridge engineering selector search, internet search, literature search, material Connexion Database search, consulting material retailers or producers and consulting material expert. Each part will produce different usable materials which will be screened during the next chapter. The materials will be numbered continuously which means that each material that will be taken under consideration will have a specific number. A lot of materials were investigated during the material search and only the materials that seemed to have potential were taken into consideration and listed in this chapter.

PVC-foam is used for around 95% of all kitting solutions that Virtual Manufacturing produces today so the biggest effort in the search was to find a cheaper material or a material that has better properties than PVC-foam. It is also important to find materials that are oil resistant, does not damage sensitive components and fulfill the ESD-requirements. It would be suitable to find materials that can be used to more than one component class, preferably for all four categories, see Section 3.4.

4.2.1 The Currently Used Materials

The currently used materials have been presented in Section 4.1. The materials listed here will be compared to the new materials that have been found during the material search. The materials and to which applications that they can be used for is presented hereafter.

1. **PVC-foam** - Many of the kitting solutions that Virtual Manufacturing are producing today are made from PVC-foam sheets. The material is mainly used as insulation and flotation and is usable to construct boxes with and tolerates oil but is not suitable to protect or store sensitive components.
2. **Wellplast** - This material is used by Virtual Manufacturing in their kitting solutions today. The material has potential to be used for all component classes which includes insensitive, sensitive, oily and ESD-classified components.
3. **Aicelwood** - The material is used today by Virtual Manufacturing in order to construct kitting solutions. The material can be used to build boxes with, to protect sensitive components and as an ESD-protection material.
4. **Tarpaulin** - One of the currently used materials for Virtual Manufacturing's kitting trolleys is Tarpaulin which typically is made by polyester and then coated with PVC. The material is mainly used as protection material and will be suitable to construct shelving systems with and protect sensitive components. Tarpaulin can also handle oily components.

4.2.2 Cambridge Engineering Selector Search

Cambridge engineering selector (CES) is a material database that enables the possibility to screen materials through different parameters [32]. The first screening that was made in CES was to find suitable materials that were cheaper or had the same price compared to PVC-foam. Some basic criteria were used during the screening like that the price was not allowed to exceed the price of PVC-foam and the temperatures that the material needs to tolerate. During the first screening, the tensile strength was taken into relation to the material price per cubic meter. The first screening is illustrated in Figure 4.1. Other screenings were conducted further on in a similar manner, for example with price per kilogram and shear modulus as parameters.

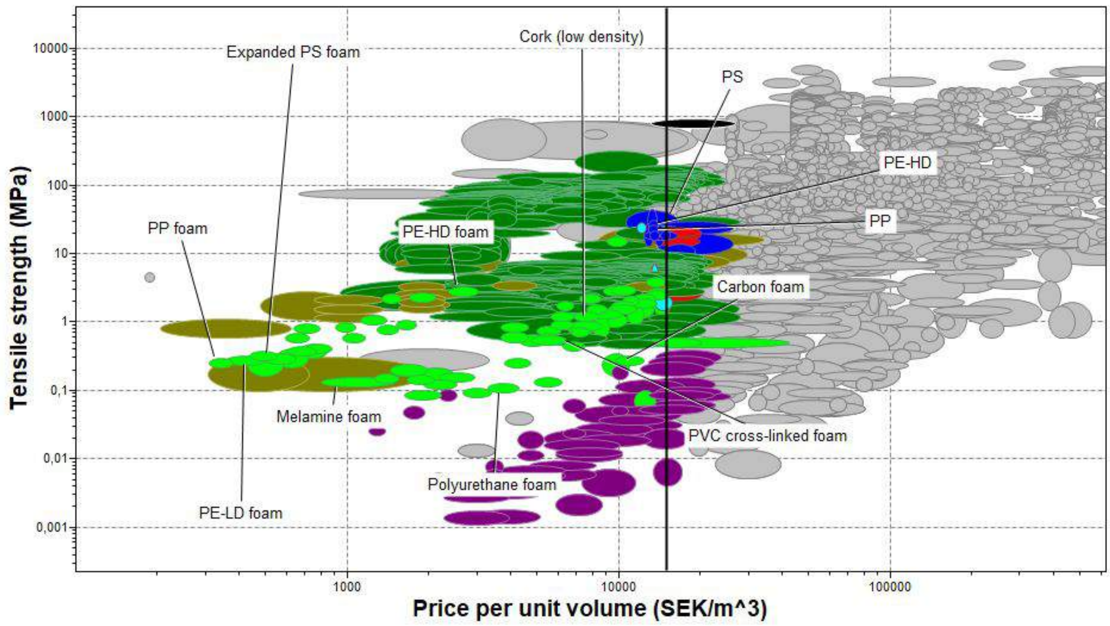


Figure 4.1: The first material screening in CES.

From the different screenings, the following materials has been analyzed as promising:

5. **PP-foam** - This is a cheap plastic material compared to PVC-foam and is widely used in the automotive industry as bumper cores, door panels etcetera but also to electrical packaging and other applications. The material can therefore be a suitable material for sensitive components [7]. The material seems to be unsuitable to build boxes with but could be used as coverage within a box of a different material.
6. **PE-foam** - The polyethylene (PE) foam could be in high or low density version and is also a cheap plastic material that is mainly used for packaging and in the automotive industry [7]. The foam will be most suitable as protection for sensitive components but can also be an alternative to oily components.
7. **Expanded PS-foam** - The polystyrene (PS) material is mainly used for packaging, for example electronics and food [7]. Expanded PS-foam is therefore probably most suitable for sensitive components.
8. **Melamine foam** - This material is for example used for sound absorption and thermal isolation. Melamine foam is soft and is therefore not dimensional stable [7] but could be used as protection for sensitive components.
9. **Polyurethane foam** - The foam is mainly used for seats in vehicles and for door panels. This material is soft [7] and could probably not be used to build boxes with but can be used as protection for sensitive components.
10. **Cork** - This material is mainly used for bungs for bottles and for vibration dampening etcetera. Cork is a brittle material and it could be problematic to use in order to build boxes [33]. The material is suitable for oily components and will protect sensitive components due to its softness. Cork has better ESD-properties than plastics since it is an anti-static material which means that cork is an ESD-material [7].
11. **Carbon foam** - This is another type of foam that is more expensive than the other foams mentioned before. The material is mainly used for insulation and noise absorption etcetera. Carbon foam's most interesting property is that it is a conductive material [7] which means that it is perfect to use as an ESD-material. The foam seems to be too soft to use in order to build boxes but can be suitable to use for protection of sensitive components.
12. **PS** - The material is used for example in household appliances and electronic housings [7]. PS will be suitable in order to build boxes with and thereby store insensitive components.
13. **PE** - The material is available as low or high density variants and is used for tanks, bowls, containers, pipes and much more [7]. PE is one of the most used plastics and will be an alternative for insensitive components.
14. **PP** - The material is a widely used plastic, for example to automotive interior, coatings and food packaging [7]. The material will be suitable for insensitive components.
15. **Foamglas** - This material is used for floors, walls and tanks etcetera. The material has a relative low density compared to its stiffness [7]. The material has potential to be used to build boxes or shelves for kitting solutions.
16. **Steel sheets** - This metal is mainly used for construction like buildings and cars. The material has a high density but is dimension stable, the material will be suitable for building boxes, tolerates oil and has excellent ESD-properties [7].

17. **Carbon fiber** - The material has excellent mechanical properties compared to its weight but is also very expensive. The material can be used to build light weight boxes and is also a conductive material which makes it suitable to use as an ESD-material [7].
18. **Plywood** - This is a material made from wood and is a stable material compared to its price and is used for example in automotive industry and in construction purposes. Plywood could be a functional material in order to build boxes or shelves but it also tends to sliver during use and wear [7].
19. **Aluminum sheets** - This metal is mainly used for construction like buildings and cars. The material has a high density but is dimension stable, the material will be suitable for building boxes or shelf structures, tolerates oil and has excellent ESD-properties [7].
20. **Rubber** - The material is for example used in tiers and for electrical isolation. The material will be an alternative for protecting sensitive components [7].

4.2.3 Internet Search

The internet search were made by searching for different construction materials etcetera. The different materials that were found during the search are listed hereafter.

21. **Plexiglas** - This is a material that is transparent and is therefore used instead of real glass. The material is impact resistant and is easy to process. The material can be used to construct boxes or shelves with and is also oil resistant [34].
22. **Rubber cork** - Is a soft material that mainly is used for example in floors and seals. The material has less tendency to sliver compared to cork and can probably be used to both construct general kitting solutions (for insensitive components) and to protect sensitive components. Rubber cork is also oil resistant [35].
23. **Wood-plastic composite** - This material consists of a mix of wood fibres, polymers and additives that integrates the two base materials and adds functional properties, such as strength or smoother processing. The material is most commonly used when building balconies, porches and fences [36]. The material is mainly suitable to construct general kitting solutions for insensitive components.
24. **Polyurethane** - The material is impact resistant and can be made in different hardness levels. The material could be used in order to construct general kitting solutions and is also oil resistant. The material is mainly used for industrial applications [34].
25. **WPE S** - This is solid boards made from PP and is mainly used as packaging material. The board is durable, clean and resistant against chemicals. [37]. The material is interesting for building general kitting solutions and could probably be used as protection for sensitive components.
26. **Teflon coated PAN** - The material is polyacrylonitrile (PAN) coated with teflon and is durable and repellent to both water and oil. Another name for this material is awning cloth. It is often used as sunshade and table cloth, and could in this project be an alternative for sensitive components in stands where the material is supported by a frame. This way, the material works as a cushion for the components. It can also be used as a coating material for oily components or for insensitive components in solid boxes or shelves. [38].

27. **Cotton impregnated with a fluorocarbon-based chemical** - Water and dirt resistant. Commonly used as tent cloth. It is light, durable and mostly used for tents [39]. In this project, it would have similar application possibilities as teflon coated PAN (number 26) but the material is not oil resistant.

28. **Cotton and nylon fabric** - Is durable and water repellent and typically used for working clothes or overalls [40] and is also called beaver nylon. In this project, it would have similar application possibilities as teflon coated PAN (number 26) but the material is not oil resistant.

29. **Nylon net** - Used in many applications such as fishing and sports, because of its low weight and high durability. In this project, it would have similar application possibilities as teflon coated PAN (number 26) but the material is not oil resistant [41].

30. **Global ESD** - This is a textile material that consists of wool and metal fiber which makes it a suitable textile material for chairs and clothes that are used in ESD-classified areas [42]. The textile will be a suitable material for ESD-components but can also be used for insensitive and sensitive components.

31. **Glass fiber sandwich with a core of PS** - This material is mainly used in construction of houses and truck-containers. The material is interesting since the glass fiber reinforces the PS and makes it stable and robust which will make it suitable to build general kitting solutions with [43].

32. **PE-coated paperboard** - The material is mainly used in food storage applications like milk bottles and ice cream cups. PE-coated paperboard could be used as an inner structure in a box which makes it possible to use for insensitive and sensitive components [44].

33. **APET** - This plastic is known as Amorphous polyethylene terephthalate (APET) and is mainly used for food package and other types of packages. The material will be suitable to build general kitting solutions with since it has high stiffness and good impact resistance [45].

34. **PETG** - This material is known as Polyethylene terephthalate glycol-modified (PETG) and has even better impact resistance than APET. The material will be an alternative to use in order to build general kitting solutions [46].

35. **Balsa** - This is a lightweight wood material that mainly is used for lightweight applications like sandwich panels [47]. The material will be suitable to use in order to transport and store insensitive components.

4.2.4 Literature Search

During the literature search, books about different materials were studied and complemented the search. The new interesting materials that was found will be presented in the list hereafter.

36. **PC** - The material is also known as Polycarbonate (PC) and is used as a more durable material than glass. The material will be usable in order to build general kitting solutions since it has high impact resistance [34].

37. **PF** - The plastic is also known as phenol formaldehyde (PF) and is mainly used in housings binders and other industry applications. The material will be suitable to build general kitting solutions with [34].

38. **ABS** - This is a plastic material that is also known as acrylonitrile butadiene styrene (ABS) and is for example used for industry applications and for roof boxes. The material will be suitable for building general kitting solutions with since it has a high impact resistance [34].

4.2.5 Material Connexion Database Search

The material search in Material Connexion's database comprised two separate searches with different constraints. The criteria for the first one was "Polymer", "Stiff", "Matte" and "Opaque", which resulted in 408 different materials. By analyzing pictures and descriptions of potentially useful materials, two were investigated further to see if samples could be ordered. The second search only had the constraint "Sweden", as it was found difficult to find suppliers within reasonable distances for the found materials after the first search was conducted. The search resulted in 144 materials and two of these were perceived to be applicable for this project. All four materials are presented hereafter.

Two interesting materials from the first search are based on PVC-foam, like the one used currently by Virtual Manufacturing. They are therefore not included in the list of material since they already will suit under the PVC-foam category but can be usable during later parts of the project if they prove to have better properties than the current one. The first material is Corelite Board which is a cost-competitive material made of PVC-foam. The panels have high flexural strength and stiffness, and is highly resistant to chemicals and temperature changes. Its density is also low, as it spans between 400 and $480/m^2$ [8]. The second material is Intefoam and is a rigid, abrasion-, chemical- and fire-resistant material made of a PVC-foam board with a homogeneous core, available in many different colors in a matte finish. It serves as an alternative to wood and is often used for displays and exhibits as graphics can be printed on the material [8].

39. **Noraplan** - Rubber material that is easy to apply without any adhesives. It is suitable in environments that are exposed to grease and oil, and can be cleaned and maintained by using regular water and cleaning pads. The thickness of the material is two millimeters and is most commonly used for office flooring and other similar applications [8]. It is also available in ESD and is suitable as coating material for oily components or for sensitive components in solid boxes or shelves.

40. **Durapulp** - A material made of wood fibres and bio-polymers from renewable, non-fossil based materials. The material can be made very strong, rigid and dimensionally stable with low water absorption, much similar to the properties of plastics. Durapulp is biodegradable and is currently used for furniture and consumer products [8]. The material would be used to build general kitting solutions with.

4.2.6 Consulting Material Retailers and Producers

During the internet search, different retailers and producers of materials were found. One of the biggest retailers of semi-finished plastic products, Vink Essåplast Group AB was therefore visited and the company had some interesting alternative materials that can be suitable to use in order to construct kitting solutions. Other consultations with companies were also made like the companies Diab Group AB, Sundolitt AB and Christian Berner AB. The materials that emerged during the consultations are presented hereafter.

41. **Stadur** - Stadur is a sandwich material with a core of foamed PS and outer layer of PVC. The material is mainly used for advertising applications and is around 60 % lighter than PVC-foam [48]. Stadur can be a possible material to be used as a construction material for insensitive components.

42. **Reynobound** - This is a material that consists of a sandwich structure with outer layers of coil coated aluminum sheets and a core of PE. The material is mainly used for advertising applications. The material is lighter and thinner than a corresponding PVC-foam sheet with similar durability properties [49]. Reynobound will be an alternative for insensitive and oily components.

43. **Divinycell** - This is a strong material compared to its weight and is made of lightweight PVC-foam and will advantageously be fronted with some thin film of some other material in order to create a sandwich structure. Divinycell is used for different lightweight constructions, for example in the aviation and marine industries [50]. The material will primary be suitable to use to construct boxes and shelf system with in order to transport and store insensitive components.

44. **PA** - This is the plastic material polyamide (PA) and is mainly used in the industry for different components as gears and bearings [34]. The material will be suitable to be used as a construction material in order to store insensitive components.

4.2.7 Consulting Material Expert

To discuss some of the materials that have been named so far during the material search and to hear if there are some other interesting materials, a meeting with Antal Boldizar was conducted. Antal Boldizar is a professor in environmentally adopted polymeric materials at Chalmers University of Technology. The information and advises from the consulting will be used later on when the founded materials will be screened.

It is difficult to find a material that is cheaper than PVC-foam but PE-foam will meet the requirements in a better way since it is a tougher material. Foamed plastics are overall advantageous if they are produced in the right way since they have a lower density, gets a higher toughness and better fracture properties. One way of solving the problem today with too brittle PVC-foam is to add a softener in the foam which will make the properties imitate the PE-foam properties to an extent. PP-foam is also an alternative plastic which is more form stable than PE-foam but can only be used to -10° Celsius which is less than PE-foam that has its properties remained to -100° Celsius. Aicelwood, which is a type of PE, is one of the materials that Virtual Manufacturing is using today. Aicelwood is compact foamed and is therefore harder than other foamed PE variants. PE-foam can be produced in a wide range of compactness which affect the material's density and form stability. Since PE is the most used plastic material, it will be easy to find suppliers that can handle a PE-foam material with the right properties to a reasonable price. Other more rare plastic variants will therefore probably not be interesting for the project.

PE seems to absorb more oil than PVC which can be a negative factor but plastics in general does not withstand oil. Polyurethane which is another material that has been brought up during the material studies is not a good alternative since it has unpleasant properties, for example if it catches fire, an old variant of chemical warfare agents is created. PET och PC are two another materials that are common but PET is too brittle and PC costs around three times as much compared to PE. PA is an interesting plastic with interesting properties but it is uncertain if it is possible to get PA in a foamed variant. Wood composites have been found during the material search but will not bring any new properties that makes it more interesting to use, compared to purely plastic materials. The material has acceptable price levels in other countries, but is not enough used in Sweden to reach the same desirable price to use it in a larger extent in product development [51].

All kind of plastics will more or less absorb dirt which will make the material less aesthetically pleasing after a while but by using a dark color of the material, the dirt will be less visible. A material in another category that can be usable is steel. Plastics and steel have approximately the same stiffness in relation to density which makes steel sheets to an alternative. The main recommendation was to find PE-foam with the right level of compactness or PVC-foam with an added softener.

4.3 Concept Development

During the concept development, different methods for generating usable concept were used. The concepts concerns how to transport and store components in the industry but also about how to assemble boxes or shelves that can be used in a kitting solution. The concept development can be divided into two parts, internal and external sources. The internal methods that have been used for the concept development are brainstorming, brainwriting and the dark horse, these methods were used to come up with new and unique ideas. There was always a focus of creating concepts with a modularization approach. The external methods that were used to come up with interesting concepts were knowledge from the market and user needs research, where other products and manufacturing methods were investigated. The internal methods will be presented hereafter followed by the external methods. Some concepts are more manufacturing related and some concepts are more about how to assemble and rearrange the kitting solution structure. These different types of concepts can in some cases be combined in order to have a complete solution.

4.3.1 Internal Concept Generation

The main part of the concept generation was made through different internal concept generation sources. The first internal method that was used was brainstorming. Around ten brainstorming sessions were made with different goals and topics. The topics that the idea generation was about were the following ones:

- How to transport and store components
- Rearrange the box interior
- Shelving systems
- Modularization
- How to assemble a box
- Processing kitting solutions
- How to disassemble a box
- How to place the components

The second internal concept generation method that was used was brainwriting. Brainwriting sessions were held a few times and the topics were modularization, how to build a box and create a rearrangeable kitting solution. The dark horse is another method that was used in order to come up with concepts. The method was used to create more revolutionizing and unexpected ideas.

Some smaller ideas and sub-solutions were also created which were used later on in order to combine different concepts or used in other ways in the project. All concepts can be used both as an independent box structure or used in a kitting trolley system if nothing else is specified. All concepts that were generated during the internal concept generation are presented hereafter. The sketches of each concept can be found in Figures 4.2 and 4.3.

1. **Battleship** - The bottom sheets will have holes in a grid system with standardized distances between each hole. The walls will be produced in long strips with plugs (that have the same dimensions as the holes in the bottom sheets) that will be located in the bottom of the walls which make it possible to easily assemble the walls with the bottom sheet. The walls can also be easily sawed in the right dimensions. The walls will also have holes in the top which make it possible to assemble another wall above which can be required if the walls need to have a certain height. The holes that are not used can easily be plugged if it is required, for example if a sensitive component will be stored and transported in the box. The assemble structure will be like Lego's assembling structure which means that the walls can be rearranged and moved if the needs change but will require some force to be disassembled. The outer walls or other walls that needs to be fixed can easily be attached by adding glue.

2. **Sliding Tracks** - The inner wall structure will be changeable since the walls will have a rail in the bottom that will slide into the bottom plates track. The tracks in the bottom sheet will be in a grid structure that enables the possibility to create a customized box structure. The outer walls will be mounted as today with screws which makes it possible to rearrange the box if it is needed by disassembling two outer walls of the box.

3. **Magnetic Walls** - This concept works almost in the same way as the first described concept Battleship. The difference is that the walls will be attached to the bottom by magnets instead of the Lego attachment. The magnetic force will be high enough so that the walls can not move easily but if the user wants to rearrange the structure, it is possible. The magnets will be positioned with standardized distances.

4. **Comb-Walls** - The walls are shaped as combs which enables the possibility to assemble perpendicular walls together by attaching the walls to each other. This structure can easily be used in an existing box with fixed outer walls.

5. **The Telescope Walls** - The concept consist of standardized walls that all have the same feature but the walls' length can be adjusted after the specific requirements.

6. **Textile Hooks** - This concept will have a textile material that will be attached to the steel frame with hooks. This concept works primarily with components that are not too heavy but depending on the textiles properties, it can be possible to transport and store the most types of components with this solution.

7. **The Node Gear** - This concept is based on a gear-like node. The walls can be attached to each other by placing them between the cogs of the gear. The gear itself can be anchored to the floor or to walls in the box by screwing, gluing, or using some kind of joint.

8. **The Wall Hook** - The concept can be described as a hook that will be placed over a wall and will form a track where another wall can be attached. The attachment method will be a simple way of attaching the inner walls to the outer walls and inner walls to each other.

9. **The Turning Fork** - This solution is almost formed as a turning fork and will be used in the same way as the first presented solution, Battleship. The Turning Fork will be attached to the walls and then snapped into the holes in the bottom plate. By pressing the fork structure, the walls can be disassembled if needed.
10. **The Cotter** - In this concept, both the wall and the bottom sheet has a hole where a cylinder of some kind is mounted through, the cylinder is then locked by cotters in the ends. The box structure can then be easily rearranged if needed. If the cylinders are in metal, the cylinders can be attached in the top and bottom of the kitting trolleys and in that way totally replace the existing steel frame system.
11. **The Chain** - This is a concept where the walls are standardized with tracks where other walls can be attached. The system can therefore create a grid structure. The concept would mainly be used for creating the inner walls structure.
12. **The Brush** - The concept consists of a carpet with a brush structure that stand up from the carpet. The components can then be placed on the carpet and will then be almost fixed due to the brush and the friction. There is therefore no needs of walls.
13. **The Piano** - This is a concept that consists of a plate and looks like a keyboard since there are a lot of tiles on the plate. When a component is placed on the plate, the tiles that are directly under the component will be pressed into the plate just like a keyboard does when it is used for playing. The component can then not move horizontally due to the other tiles that are not pressed. This solution will therefore not require any traditional walls.
14. **The Ball Node** - This concept will be used as a node that joins sheets from different directions together in one node. The node has the shape of a ball since it will take less space and it will simultaneously miss sharp edges that could damage the components that would be stored and transported.
15. **Modelling Clay** - The concept is about to fasten the walls and the bottom together with modeling clay. After attaching the parts together, some kind of heating process will be made so that the structure will be stable. The concept will not make it possible to rearrange the box-structure if needed.
16. **Velcro Straps** - The concept is about to glue Velcro straps on the walls and bottom and then easily fasten the walls in the requested way. The structure can be easily rearranged further on if the needs changes.
17. **Box in a Box** - This concept is about to have a stable outer structure of a box and then make the inner structure of other smaller boxes, for example in welded paper which will be less stable but since the outer walls is in a dimension stable material, the inner structure may not have the same requirements. The box structure can also be rearranged easily since the boxes of the inner structure are movable.
18. **The Strap** - The concept consists of a bottom sheet with straps or elastic bands that makes it possible to fix the components without having any walls.

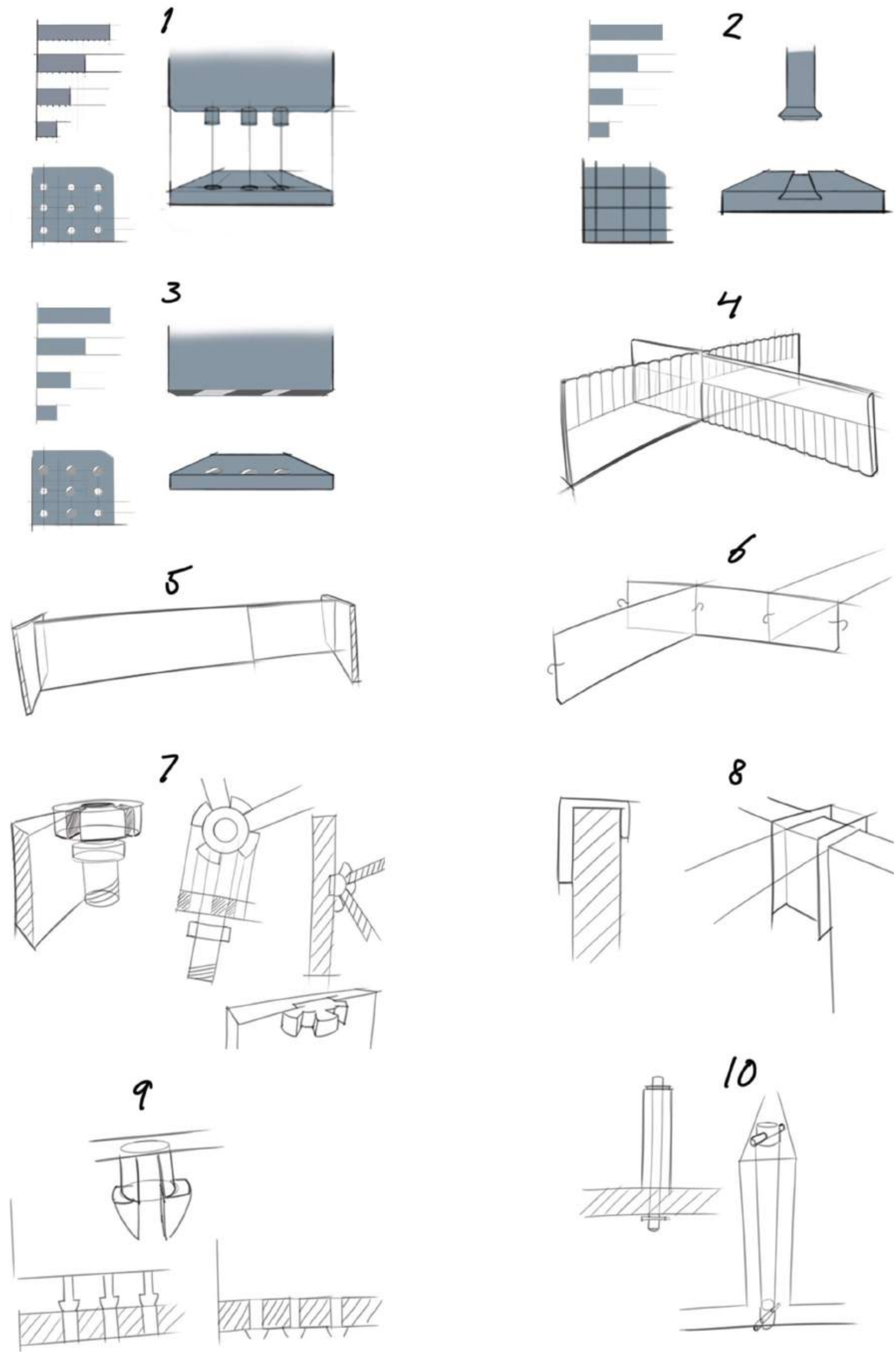


Figure 4.2: Sketches of some of the concepts from the internal concept generation.

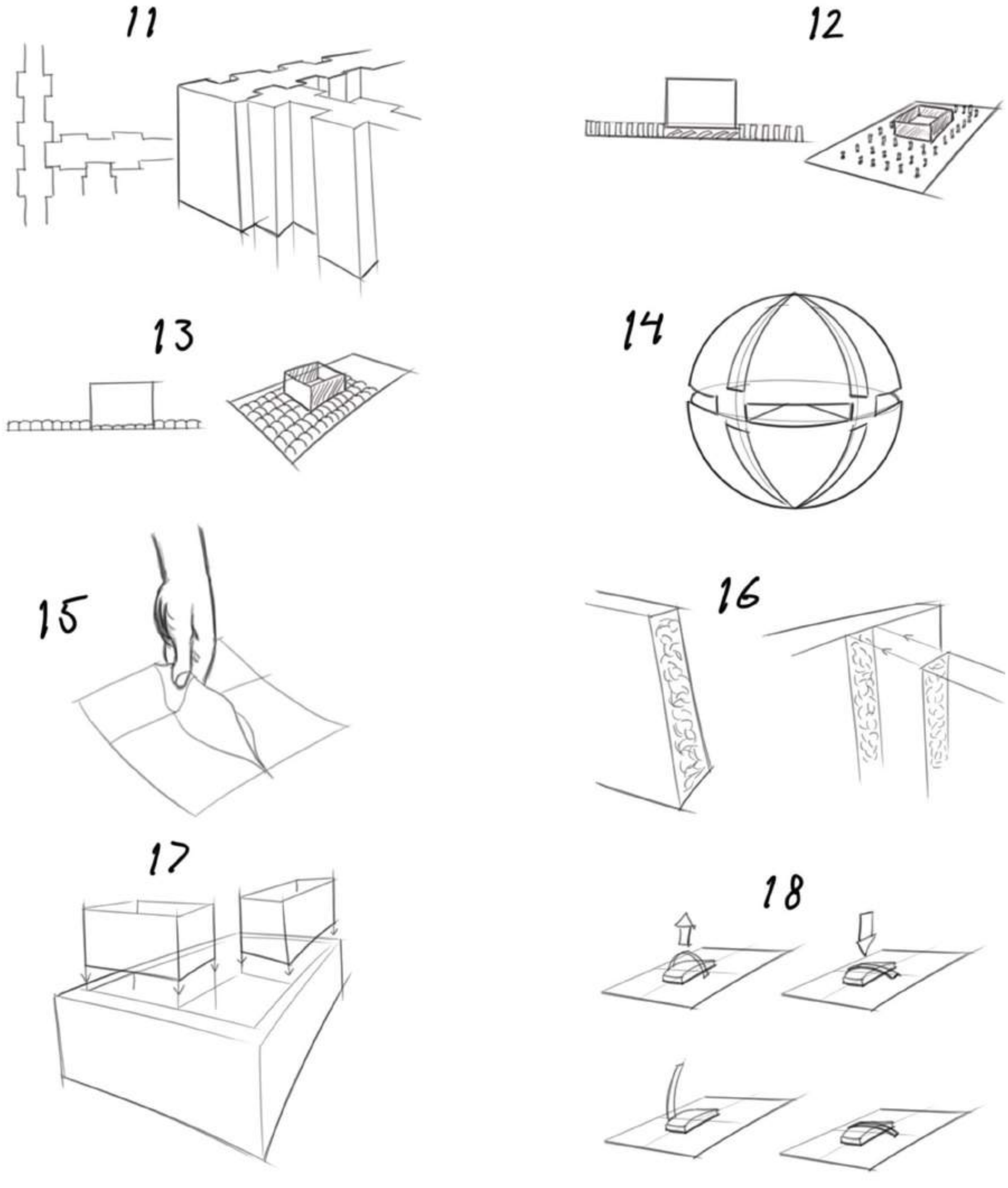


Figure 4.3: Sketches of some of the concepts from the internal concept generation.

4.3.2 External Concept Generation

Several external sources were used in order to find usable concepts of how to build and assemble kitting solutions in the best possible way. During the market and user needs research (Chapter 3), knowledge about other products and how it is possible to assemble boxes was acquired. The user studies also contributed with inspiration and together with that knowledge and internet and literature searches about manufacturing methods and competitors, some interesting concepts were found that will be presented hereafter. Sketches of the concepts are presented in Figure 4.4.

19. **Plastic Welding** - This concept is based on assembling plastic box structures by welding the parts together. There exist different kinds of methods and tools for welding plastics together which depends on the application [52].
20. **Textile Tracks** - The solution is almost a copy of the textile kitting trolleys that Virtual Manufacturing produces today. The textile will be sewed so that the textile can slide into the steel frame. The concept suits mainly lighter components but the textile properties can broaden the potential.
21. **Business as Usual** - This concept means that the currently used methods will be used further on as well. Screws, glue, tacks and rivets are functioning and proven methods that could be used in the future as well if the materials allow.
22. **3D-Printing** - This concept it about producing boxes in a small scale. 3D-printing is an additive manufacturing method where a machine prints an object layer by layer according to a data file [53]. Virtual Manufacturing is making their kitting solutions in CAD today before manufacturing so the change to starting 3D-print boxes would not cause a dramatic change to the current work flow for the designers.
23. **Vacuum Forming** - This concept is about to manufacture separate boxes. Vacuum forming is a method where a plastic sheet is heated and formed by vacuum into a desirable shape. The manufacturing method suits small or medium scale productions [54].
24. **Plastic Bin Structure** - The concept is based on buying plastic bins in different sizes and hanging them on a wall structure that is attached to the bottom structure of the kitting trolley or by making a kitting box structure of them. The bins would be available in many different sizes so there always would be at least one bin that suits a component in a satisfying way.
25. **Folding** - This is a way of assembling boxes or shelf systems. The material will be folded together, like the way a paper box can be folded together. This is how boxes made of the material Wellplast are produced.
26. **Shadowboard** - This concept is about to have customized pockets for the components. The component will then perfectly fit into the pocket and will therefore be fixed and protected during transportation. The shadowboard can for example be made in a plastic foam which is soft and protects the material if the box or container is exposed to movements.

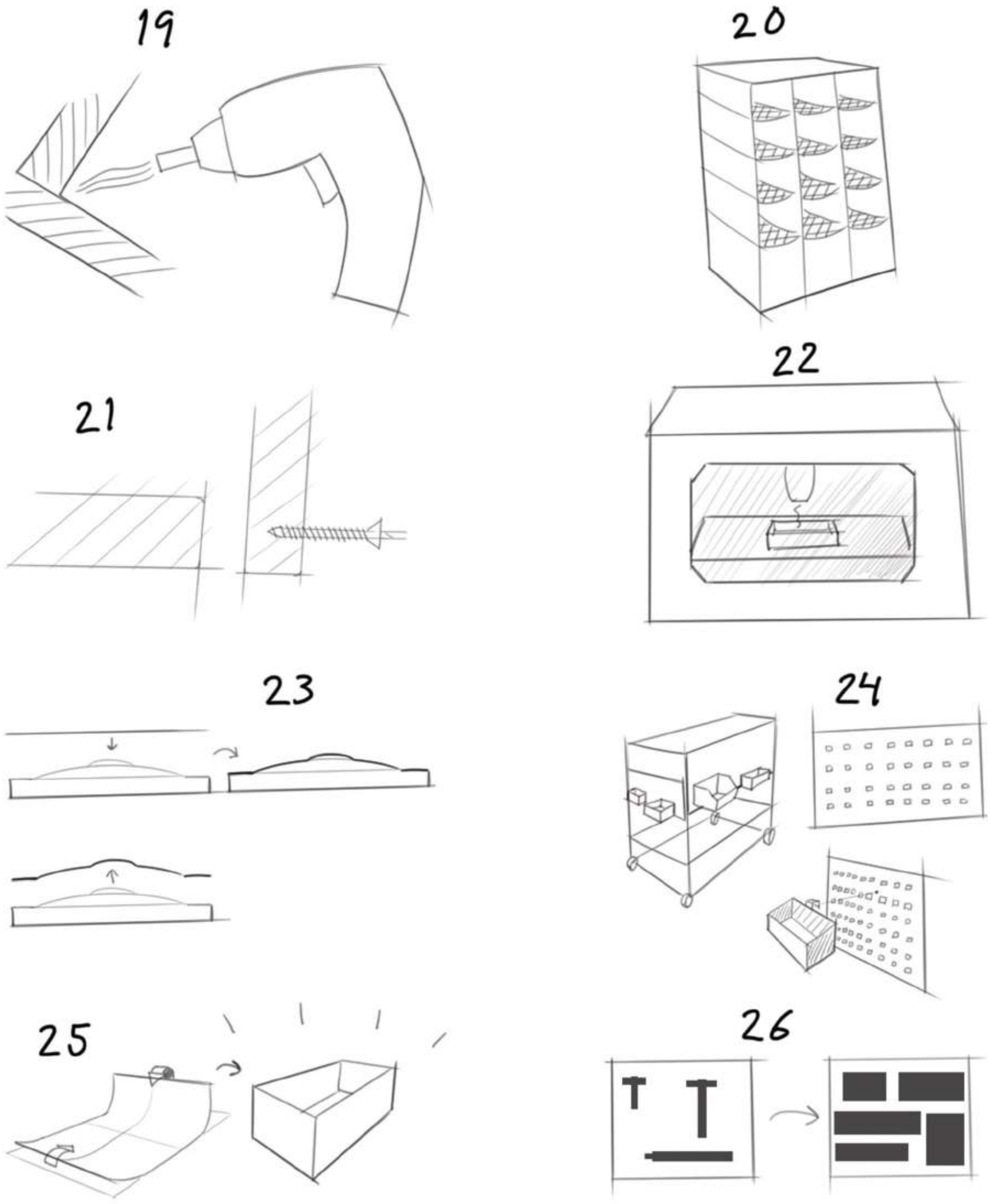


Figure 4.4: Sketches of the concepts from the external concept generation.

5 Results of Material and Concept Selections

During this chapter, both the found materials and the created concepts will be screened in order to determine the most promising variants. The screening will be made through different structured methods and between the different screenings, iterations will be made in order to improve concepts or material choices. After an initial material and concept screening where the number of materials and concepts were reduced dramatically, the concepts were combined with the materials. This means that complete concepts were created which include concept and material selections. The mapping between materials and concepts is preliminary but will be a guidance for the further work with the materials and concepts.

5.1 Initial Material Selections

The material screening process consists of two screening steps with continuous iterations. To start eliminating materials that does not fulfill the basic requirements from the requirement specification, an elimination matrix was used. After an iteration, a test of the remaining materials was conducted in order to eliminate the materials that did not perform well during the material test.

5.1.1 Elimination Matrix

To make a first screening of all found materials, an elimination matrix was used. If a material does not fulfill all the basic requirements from the requirement specification of materials and concepts, the material was eliminated. The elimination matrix ensures that the materials that pass the matrix will have potential to be used in Virtual Manufacturing's future kitting solutions. In the elimination matrix, there are three different claims, the first claim is that the material fulfills the requirement (green box with a plus sign). The second claim is that it is uncertain if the requirement is fulfilled (yellow box with a question mark). The last claim will be used if the material does not fulfill the requirement (red box with a minus sign). A red box will automatically result in elimination of the specific material. The elimination matrix will be presented hereafter in Figure 5.1 and a comment why a certain material is eliminated will be presented afterwards.

Material	Component class	Has a resonable cost to its application	Can be processed and used to a competitive price	Will last for five years	Can be manu-facturerd with common methods	Harmless	Impact resistant	Tolerates normal using conditions	Can be easily bought from a supplier	Decision
1. PVC-foam	1,3	+	+	+	+	+	+	+	+	+
2. Wellplast	1,2,3,4	+	+	?	?	+	+	+	+	+
3. Aicelwood	1,2,4	?	+	+	+	+	+	+	+	+
4. Tarpaulin	1,2,3	+	+	+	?	+	+	+	+	+
5. PP-foam	2	+	+	+	?	+	-	-	?	-
6. PE-foam	2,3	+	+	+	+	+	+	+	?	+
7. Expanded PS-foam	2	+	+	+	+	+	-	+	+	-
8. Melamine foam	2	+	+	+	+	+	-	+	+	-
9. Polyurethane foam	2	+	+	+	+	-	-	+	+	-
10. Cork	2,3,4	+	+	?	+	+	-	-	+	-
11. Carbon foam	2,4	-	+	+	+	+	+	+	+	-
12. PS	1	+	+	+	+	+	-	-	+	-
13. PE	1,3	+	+	+	+	+	+	+	+	+
14. PP	1	+	+	+	+	+	+	+	+	+
15. Foamglas	1	?	+	+	+	+	+	?	-	-
16. Steel sheets	1,3,4	+	+	+	?	+	+	+	+	+
17. Carbon fiber	1,4	-	?	+	?	-	+	+	+	-
18. Plywood	1	+	+	+	+	+	+	?	+	+
19. Aluminium sheets	1,3,4	-	+	+	?	+	+	+	+	-
20. Rubber	2	+	+	+	+	+	+	+	+	+
21. Plexiglas	1,3	+	?	+	-	+	+	+	+	-
22. Rubber cork	1,2,3	+	+	+	+	+	-	+	+	-
23. Wood-plastic composite	1	-	+	+	+	+	+	+	-	-
24. Polyurethane	1,3	+	+	+	+	-	+	+	+	-
25. WPE S	1,2	+	+	?	+	+	-	-	+	-
26. Teflon coated PAN	1,2,3	+	+	+	?	+	+	+	+	+
27. Cotton impregnated with a flourocarbon-based chemical	1,2	+	+	+	?	+	+	+	+	+
28. Cotton and nylon fabric	1,2	+	+	+	?	+	+	+	+	+
29. Nylon net	1,2	+	+	?	?	+	+	-	+	-
30. Global ESD	1,2,4	+	+	+	?	+	+	+	+	+
31. Glas fiber sandwich with a core of PS	1	-	+	+	+	+	+	+	?	-
32. PE-coated paperboard	1,2	+	+	?	+	+	?	+	+	+
33. APET	1	+	?	+	-	+	+	+	+	-
34. PETG	1	+	?	+	?	+	+	+	+	+
35. Balsa	1	+	+	+	+	+	?	?	+	+
36. PC	1	-	+	+	+	+	+	+	+	-
37. PF	1	+	+	+	+	+	+	+	-	-
38. ABS	1	+	+	+	+	+	+	+	-	-
39. Noraplan	2,3,4	?	+	+	+	+	+	+	+	+
40. Durapulp	1	?	+	?	+	+	+	-	-	-
41. Stadur	1	+	+	?	+	+	?	?	+	+
42. Reynobound	1,3	+	+	+	?	+	+	+	+	+
43. Divinycell	1	?	?	+	+	+	+	+	+	+
44. PA	1	-	+	+	+	+	+	+	+	-

Figure 5.1: The material elimination matrix.

The following materials was eliminated and the motivations are as follow:

5. **PP-foam** - This material was eliminated since it seems to be too brittle and will therefore not be suitable. It was also hard to find a supplier.

7. **Expanded PS-foam** - The material is mainly used as packaging material and is stiff but brittle [55] [34]. The brittleness of expanded PS-foam makes it unsuitable to use the material to protect sensitive components in an industry application.

8. **Melamine foam** - This material is an unstable and not durable material since it is very soft and has poor mechanical properties [7]. Melamine foam will therefore be unsuitable

to use for kitting solutions.

9. **Polyurethane foam** - The material is inappropriate to use in industry due to its dangerous fire characteristics, see Section 4.2.7. The material is also brittle and will therefore risk to break apart [7], the material is therefore not suitable to this application.
10. **Cork** - The properties that this material has is interesting but cork has one big negative aspect. The reason why the material is eliminated is the brittleness of the material which means that the material easily starts to crumble. Materials that are used in the industry are not allowed to create dust so therefore is cork eliminated.
11. **Carbon foam** - The material will be eliminated since the cost of the foam is too high [7] and to have a ESD-protected box, the whole construction needs to be in ESD-material so to use the foam as an ESD-material will be difficult.
12. **PS** - This material is too brittle and will therefore be unsuitable in order to construct kitting solutions [56] [34].
15. **Foamglas** - This material is mainly used for constructing buildings, and there are suppliers that sell foamglas but not in the right dimensions and the material has some other doubts that leads to the elimination of the material, including cleanliness issues as dust easily emits when the material is handled or processed [57].
17. **Carbon fiber** - The material is expensive and also harmful if it is catching fire or if it breaks apart [58] so the material is therefore not suitable in the industry.
19. **Aluminum sheets** - The material has good mechanical properties but is more expensive than steel which also has many properties that are better. Steel will therefore be a better alternative since it is more affordable [7] and therefore, aluminum is eliminated.
21. **Plexiglas** - This material is eliminated since it is difficult to process it. Drilling and screwing in the material is not possible with current equipment.
22. **Rubber cork** - Initially, this material was thought to fit multiple component classes but minor tests proved it was too sensitive as the material started to sliver when another material was rubbed against the surface.
23. **Wood-plastic composite** - The reason why this material is eliminated is that it has no additional properties compared to traditional plastics that motivates a considerably higher price tag, see Section 4.2.7.
24. **Polyurethane** - This material is eliminated since it creates toxic gases if it is catching fire. The material is therefore not appropriate in the industry [34].
25. **WPE S** - The material is eliminated since it will not be able to withstand the normal using conditions that are existing in the industry today since the material is too brittle [37].
29. **Nylon net** - This material is strong but can get stuck into components or other things since it has a net structure. The material will therefore not be suitable for a kitting solution and is therefore eliminated.
31. **Glas fiber sandwich with a core of PS** - The material has good mechanical properties but is too expensive as there are other appropriate plastic materials that are more cost competitive. The material is therefore eliminated [43].

33. **APET** - This material is eliminated since it is difficult to process it by drilling and screwing in the material.
36. **PC** - This material costs around four times more than similar plastics like PE so the higher cost is not motivated [34].
37. **PF** - The material will be eliminated since no supplier was found.
38. **ABS** - The ABS plastic was eliminated since no supplier of the material in the right dimensions was found.
40. **Durapulp** - The material was eliminated since it seems to not tolerate normal using conditions. A supplier that could provide the material in suitable dimensions was not found either.
44. **PA** - This material will not be further investigated since the cost of the material is around three to four times higher than similar materials like PE [34].

5.1.2 Material Testing

All the materials that passed the elimination matrix were tested through a test that consists of the following steps:

1. Control if the material is possible to make dimension stable as a construction material for building boxes and shelves. This also includes textile materials that can be used for shelves if they are hanging with a steel construction. This test is essential for a material in material class one which is insensitive components.
2. Test if the material is suitable for sensitive components. This test is essential for material class two, sensitive components.
3. Check the materials impact resistance.
4. Test the scratch impact.
5. Test if it is possible to screw in the materials and if the specific material requires predrilling.
6. Control if it is possible to saw or cut in the materials.
7. Check the possibility to glue two parts of the specific material together.
8. Try to clean the materials from dirt.
9. Control if the materials tolerates water.
10. Control if the materials tolerates oil. This test is essential for material class three, oily components.

The ESD-protection capability will not be tested since that will be difficult to do in a correct way. Many plastic and other materials can be produced in an ESD-format so the ESD-requirement will not be taken under consideration during the material testing. ESD-protection confirmation will therefore be confirmed through material specifications provided by the supplier. A material that got a good test result in a category will be marked with a plus sign, a test result with an okay result but with some problems will be marked with a zero. If a material got a bad result for a test category, it will be marked with a minus sign. Depending on which material categories that the material will be used for, some of the tested properties of the material will not be important.

One example is if the material only will be used as protection layer for sensitive components on another material, it is not important if the material is dimension stable or tolerates oil but it is positive if it do so. Some of the testing steps will be compulsory for a material to fulfill. The materials need to pass certain tests depending on which component class/classes that they will be used for, otherwise the material will not be allowed to be used for that specific component class. There are three cases which are described hereafter.

- The materials that will be used for component class one, insensitive components are not allowed to fail the first material testing step which is about the possibility to construct boxes or shelves with the material.
- The materials that are supposed to be used for material class two, sensitive components needs to not have a dissatisfying result for the test step two which is the test for sensitive components.
- In the same way, the materials that are in material class three, oily components needs to pass test ten which is the test for oily components.

After all tests were accomplished, the result for each material was compared to the cost and density of the different materials with the same properties and possibilities. If a material is more expensive than a material with the same properties, the material that is more expensive was eliminated, the same reasoning was used for a heavier material. The materials that pass the material testing need to have good material properties compared to its price and weight in order to motivate a continuation for the material. During the testing there were some problems to test the possibility to glue parts together of a specific material (step number seven) due to the used allround glue not working properly for each material. The decision was then to skip the glue test and make a further investigation of which glue type that can be an alternative for each of the material that passes the material and concept screening later in the project. The test result for each material is presented in a material testing matrix and can be seen in Figure 5.2. A picture from the material testing can be seen in Figure 5.3. A brief explanation for each material that was removed after the material testing is presented after the material testing.

Material	Dimensional stable	Protects sensitive components	Impact resistant	Scratch impact	Possible to screw	Possible to saw or cut	Possible to clean	Tolerates water	Tolerates oil	Cost competitive-ness	Weight competitive-ness	Decision
1. PVC-foam	+	0	0	0	+	+	+	+	+	+	0	+
2. Wellplast	-	+	-	0	-	+	+	+	+	+	+	+
3. Aicelwood	+	+	0	0	+	+	+	0	0	-	0	-
4. Tarpaulin	+	+	+	+	-	+	+	+	0	+	+	+
6. PE-foam	-	+	0	-	-	+	0	0	-	+	+	+
13. PE	+	0	+	0	0	+	+	+	+	0	-	-
14. PP	+	+	+	-	0	-	+	+	+	-	-	-
16. Steel sheets	+	0	0	0	-	0	+	+	+	0	-	-
18. Plywood	+	-	+	-	+	+	+	0	-	+	-	+
20. Rubber	-	-	+	-	-	+	0	+	+	0	0	-
26. Teflon coated PAN	+	+	+	+	-	+	0	+	-	0	+	-
27. Cotton impregnated with a flourocarbon-based chemical	+	+	+	0	-	+	0	+	-	0	+	-
28. Cotton and nylon fabric	+	+	+	0	-	+	0	+	-	0	+	-
30. Global ESD	+	+	+	0	-	+	0	+	-	-	+	+
32. PE-coated paperboard	-	+	-	-	-	+	+	0	-	+	+	-
34. PETG	0	-	+	-	-	+	+	+	+	-	-	-
35. Balsa	-	0	-	-	+	+	-	0	-	0	+	-
39. Noraplan	-	+	+	-	-	+	+	+	+	-	-	-
41. Stadur	+	0	-	-	0	+	+	+	+	+	+	+
42. Reynobound	+	-	0	-	0	+	+	+	+	+	+	-
43. Divinycell	0	0	0	0	0	+	0	-	-	+	+	+

Figure 5.2: The test result from the material testing.

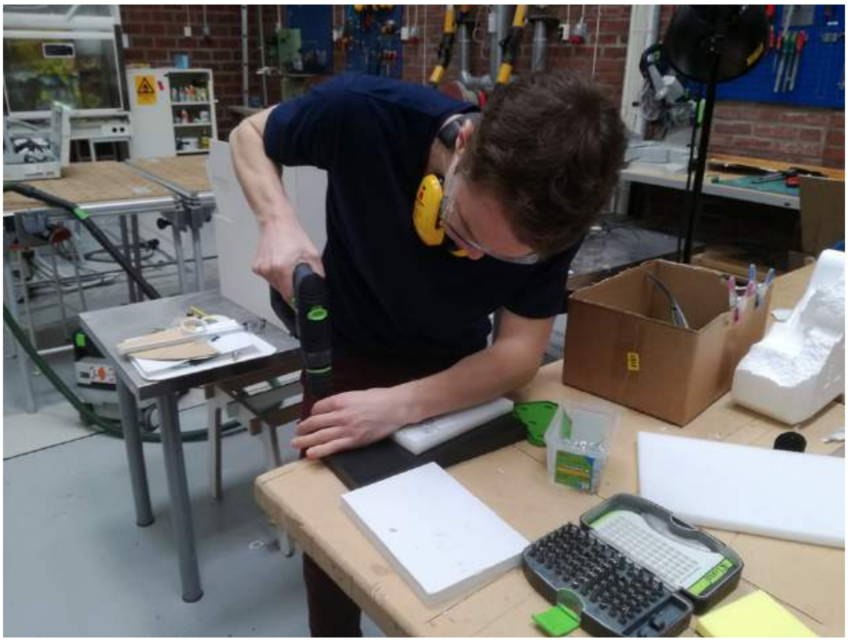


Figure 5.3: A picture from the material testing.

The motivations why a certain material did not pass the material test are presented hereafter.

3. **Aicelwood** - The gathered information about Aicelwood, presented in Section 4.1, states that the material is suitable for sensitive components and has a long durability. During the material testing, Aicelwood did not show anything that could prove the high durability and that the material does not scratch sensitive components, compared to several other materials. Aicelwood had approximately the same properties as PVC-foam but has a cost that is 10 times higher. Aicelwood is therefore eliminated since the higher cost can not be motivated.

13. **PE** - This material will not be further investigated since the material has a high weight compared to its properties. For example, the PVC-foam has similar characteristics but the density is half of PE [34]. The material is still interesting for ESD-applications since the material is available in ESD-format for a cost of around 450 SEK/m^2 with a thickness of 10 mm. This is a competitive price compared to Aicelwood in ESD-format which Virtual Manufacturing uses for ESD-applications today. The same thickness of 10 mm Aicelwood costs 2640 SEK/m^2. Aicelwood has a weight that is about the half compared to PE so if the weight is really important in a specific application for ESD-components, Aicelwood could still be an alternative. Since a specific version of PE with ESD-properties has been found and has interesting requisites, this will be taken further into consideration and the new name of the material will therefore be ESD-PE.

14. **PP** - The material is more expensive and has a higher density compared to many other materials that has been investigated [34]. It was also difficult to saw material and the scratch impact resistance was poor so the material will therefore not be taken under further consideration.

16. **Steel sheets** - This material has good properties overall but the weight will probably be problematic compared to other alternatives and new assembling methods are required. It can also be dangerous for operators to handle thin steel sheets. The material is therefore not an alternative further on.

20. **Rubber** - The material did not correspond to the expectations to be a coating material in order to protect sensitive components as it was slivering. Rubber is eliminated since it was important that the material did not scratch or discolor sensitive components, which it did during the material testing.
26. **Teflon coated PAN** - The material did not pass the material testing since it is more expensive and has inferior material properties compared to tarpaulin (material number 4), which is a similar material.
27. **Cotton impregnated with a fluorocarbon-based chemical** - The material was eliminated since it is more expensive compared to the similar material tarpaulin (material number 4). Additionally, the material does not tolerate oil as good as tarpaulin.
28. **Cotton and nylon fabric** - This material is more expensive and has inferior material properties compared to tarpaulin (material number 4) which is a similar material. Cotton and nylon fabric do therefore not pass the material testing.
32. **PE-coated paperboard** - This is a cheap and lightweight material but has bad properties concerning the context it will be used in. The material is not dimension stable or impact resistance and starts to sliver when a sharp object is drawn along the surface. The material does therefore not pass the material testing.
34. **PETG** - This material is relatively expensive and has a high density. It was also impossible to screw in the material, even if the impact resistance was good. The material is therefore eliminated.
35. **Balsa** - The material is not so dimension stable since it was heavily bent when a force was applied. Balsa is neither impact resistant or scratch resistant so the material will therefore not be usable even if it has an advantageous weight.
39. **Noraplan** - The material will be a good alternative for sensitive components but PE-foam is both cheaper and lighter which makes the foam to an overall better alternative for sensitive components. The material is also oil resistant and could be delivered in ESD-format but the weight and price of the material is too high to make it competitive compared to other alternatives [8].
42. **Reynobound** - This material is an excellent alternative to PVC-foam since Reynobound is thinner and lighter compared to PVC-foam, with the same material properties. The material does still not pass the material testing since it is too thin to be assembled properly. Reynobound is also only 3 mm thick which creates sharp edges that could harm users and components.

5.2 Initial Concept Selections

The concept screening process consists of two screening steps with continuous iterations. To start to eliminate concepts that do not fulfill the basic requirements from the requirement specification of materials and concepts, an elimination matrix was used. After the elimination matrix, the concepts that passed were compared to each other in a Pugh matrix. The concepts that passed this matrix were then further developed which includes material selections. Continuous iteration was performed during the whole elimination process in order to come up with new concepts, for example by combining existing ones.

5.2.1 Elimination Matrix

To make a first screening of all generated concepts, an elimination matrix was used. If a concept did not fulfill all the basic requirements from the requirement specification of materials and concepts, the concept was eliminated. The elimination matrix ensured that the concepts that passed the matrix have potential to be used in Virtual Manufacturing's future kitting solutions. In the elimination matrix, there are three different claims. The first claim is that the concept fulfills the requirement (green box with a plus sign). The second claim is that it is uncertain if the requirement is fulfilled (yellow box with a question mark). The last claim was used if the concept did not fulfill the requirement (red box with a minus sign). A red box automatically resulted in elimination of the specific concept. The elimination matrix is presented hereafter in Figure 5.4 and a comment why a certain concept was eliminated is presented afterwards.

Concept	Can be processed/ assembled and used to a competitive price	Will last for five years	Can be manu-facturerd with common methods or bought to a competitive price	Harmless	Ergonomic	Protects the components	Impact resistant	Tolerates normal using conditions	Decision
1. Battleship	+	+	?	+	+	+	+	?	+
2. Sliding Tracks	-	+	-	+	+	+	+	+	-
3. Magnetic Walls	-	+	-	+	+	+	+	+	-
4. Comb-Walls	+	+	+	+	+	+	-	-	-
5. The Telescope Walls	-	+	-	+	+	+	+	+	-
6. Textile Hooks	-	+	+	+	+	+	-	-	-
7. The Node Gear	-	+	-	+	+	+	+	+	-
8. The Wall Hook	+	+	+	+	+	+	+	+	+
9. The Turning Fork	+	?	?	+	+	+	-	-	-
10. The Cotter	?	+	?	-	+	+	+	-	-
11. The Chain	?	+	?	-	-	+	+	+	-
12. The Brush	+	+	+	+	+	?	+	?	+
13. The Piano	?	+	?	+	+	?	+	?	+
14. The Ball Node	+	+	-	+	+	+	+	+	-
15. Modelling Clay	?	?	-	+	+	+	?	+	-
16. Velcro Straps	?	-	?	?	+	?	-	?	-
17. Box in a Box	+	?	?	+	+	+	?	+	+
18. The Strap	+	?	?	+	?	+	+	+	+
19. Plastic Welding	+	+	?	?	+	+	+	+	+
20. Textile Tracks	?	+	?	+	+	+	+	+	+
21. Bussiness as Usual	+	?	+	?	+	+	+	+	+
22. 3D-Printning	-	+	-	+	+	+	+	+	-
23. vacuum Forming	+	+	?	+	+	+	+	+	+
24. Plastic Bin Structure	+	+	-	+	+	+	+	?	-
25. Folding	+	?	?	+	+	+	?	?	+
26. Shadowboard	+	+	?	+	+	+	?	?	+

Figure 5.4: The concept elimination matrix.

There were 12 concepts that passed the elimination matrix and 14 that were eliminated. The motivation for why a certain concept was eliminated is presented hereafter.

2. **Sliding Tracks** - This concept was eliminated since the tracks probably will be difficult and expensive to manufacture, and they will probably be needed to be manufactured with a milling machine which does not exist today in the factory. The walls that should be placed in the tracks would also have a complicated and expensive manufacturing method.

3. **Magnetic Walls** - This solution is difficult to produce since a lot of holes will be needed in all parts that should be attached to each other which is a complicated process that takes a lot of time. The magnets will also be an extra cost that will make the concept expensive

to produce. The concept was therefore eliminated.

4. **Comb-Walls** - This concept was eliminated since the walls are expected to be sensitive and quite easily be destroyed since they need to be thin where the intersections between two walls can be made. It is important that a solution is durable under normal using conditions and this concept does probably not fulfill that criterion.

5. **The Telescope Walls** - The concept has an unnecessary amount of material since the telescope solution is not using its maximum length all the time. The mechanism is also difficult and expensive to manufacture so therefore has this concept been eliminated.

6. **Textile Hooks** - To use textile in some way can be useful sometimes but this textile solution will probably not be durable enough since the textile will be tensioned which will weaken the textiles. The other textile concept, Textile Tracks is more suitable so therefore was this concept, Textile Hooks, eliminated.

7. **The Node Gear** - The concept makes it possible to attach plates in different directions but the solution is too complicated and will be too expensive to manufacture so the concept was therefore eliminated.

9. **The Turning Fork** - The concept was eliminated due to the sensitiveness of the concept. During normal using conditions, there is a significant risk of that the function will be damaged due to the thin forks that is included in the concept.

10. **The Cotter** - This concept has a high risk of being harmful to the surroundings since it contains sharp edges. The Cotter will therefore not tolerate normal using conditions either and was therefore eliminated.

11. **The Chain** - This concept was eliminated due to the sharp edges that the concept contains which is not ergonomic and can harm the surroundings.

14. **The Ball Node** - This concept can attach many plates to each other in order to create a box or shelve system but the cost and complexity of the concept is too high so therefore was this concept eliminated.

15. **Modelling Clay** - The concept was eliminated since it will be complicated and expensive to manufacture this type of solution.

16. **Velcro Straps** - This concept was eliminated due to the durability of Velcro Straps which probably will be difficult to use quite fast and the walls will be unstable and therefore not impact resistant.

22. **3D-Printing** - This solution was investigated further by visiting two different companies websites that provide 3D-printing, 3D Hubs [59] and Wematter AB [60]. The kitting solution that Volvo Cars is using in their production (see Figures 3.14 and 3.15) was used as a sample to see if it was possible to print it, how much it would cost and how fast it could be delivered.

    Volvo Cars kitting solution consists of one bigger box and one smaller that is placed in the bigger one. The bigger box is not printable as it is too big to be printed. The smaller box is small enough and can be printed in several materials. Using PETG would cost around 3000 SEK, while ABS would cost around 4000 SEK, with a delivery time of around one week [59]. As the bigger box was not printable, it is hard to estimate the cost. Considering the relative size, it would probably cost around twice as much. Regardless, it is safe to say that it would not be to a competitive price, considering the market situation during this project. 3D-printing is mostly used for building prototypes and testing ideas in the early stages of product development, and is for many applications not a cost-efficient alternative for mass production today but the prices are continuously dropping [61]. That is the case for this project, which is why it is eliminated from further development, at least when it comes to entire kitting solutions. Worth to mention though is that it might be an alternative in the future, when the market could be in a different state.

24. **Plastic Bin Structure** - The concept of using plastic bins will be too expensive since a lot of different sizes will be required which will lead to a too high price. The concept was therefore eliminated.

5.2.2 Concept Iteration Process

During the concept screening, iterations were made in order to combine or develop existing concepts or to include new ideas that appeared. This part presents the result from the iteration process of concepts and a few new concept were created and will be introduced here. The concepts that are presented here fulfills the basic requirements from the requirement specification of materials and concepts if nothing else is mentioned and it is therefore ensured that the new concepts can be compared to the old ones that passed the elimination matrix. The new concepts are presented hereafter and sketches of the new concepts can be seen in Figure 5.5.

27. **Pin walls** - This concept is based on pins or sectional walls that are placed on a bottom sheet according to the components that should be placed in the box. Only parts that are contributing to the fixation of components will be included, which reduces the total weight as much material can be excluded. This requires the walls to be placed in a more specific way to make sure components are fixed during use.

28. **Circle node** - The Circle node is an iteration of The Wall Hook and is supposed to be placed on the bottom sheet of the box instead of the walls. The node encloses inner walls of the box to make sure they are fixed, and can be designed in different versions depending on how many walls they should be able to enclose.

29. **Suction walls or pins** - This idea is based on suction walls or pins on one end of the walls, that are fastened to the bottom sheet by using suction force to support the construction. The idea will not be further developed since it will not fulfill the basic requirements from the requirement specification, like durability and tolerating normal using conditions.

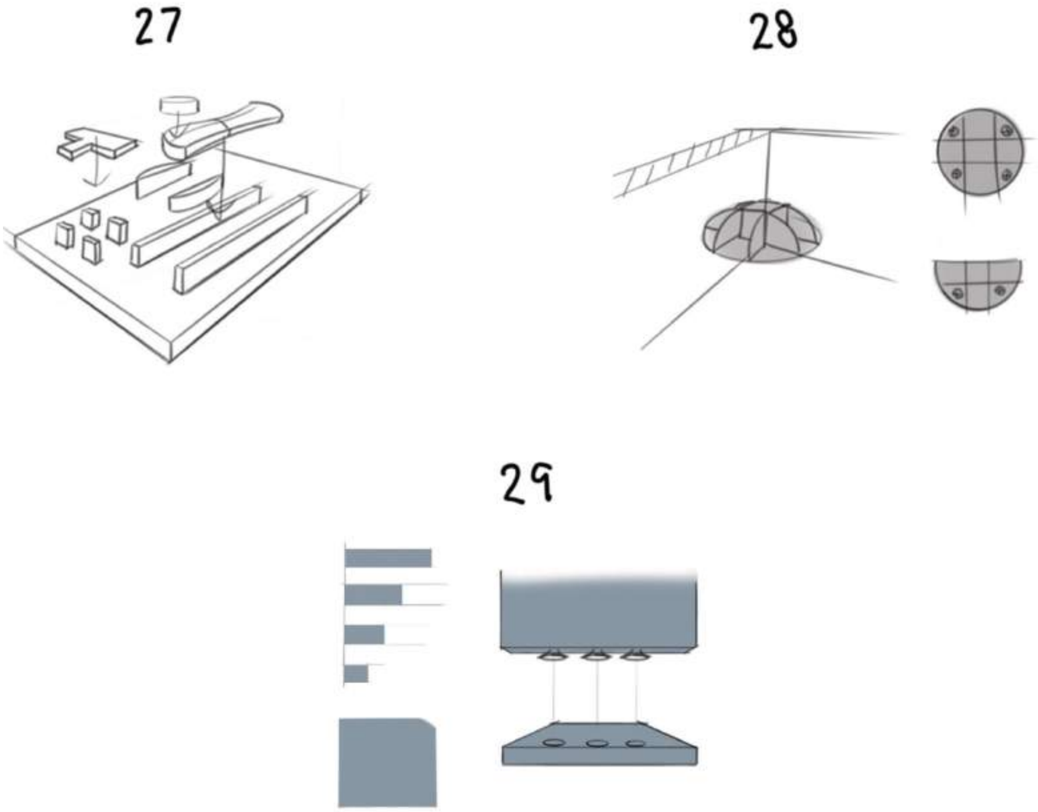


Figure 5.5: Sketches of the concepts from the concept iteration.

5.2.3 Pugh Matrix

The concepts that have not been eliminated so far were screened one more time in a Pugh matrix. A Pugh matrix has a reference concept that all other concepts were compared with. If a concept had better properties for a criterion than the reference concept, the concept was marked with a plus sign. If the concept had similar properties for a specific criterion than the reference concept, this was be marked with a zero. If the concept had inferior properties for a criterion than the reference concept, this was marked with a minus sign. The number of plus signs, zeroes and minus signs were then summarized. A plus sign was worth one point, a zero sign was worth zero points and a minus sign was worth minus one point. The total score for each concepts was then calculated and the concepts were then ranked. The concepts that was decided to not be further developed are marked with red colour in the Pugh matrix. The decisions were made through discussions and the results from the Pugh matrix. Worth mentioning is that the result from the matrix works only as a guidance for the decision making. The criteria are collected from the requirement specification of materials and concepts, see Section 3.4, and contain all desires that are listed in that requirement specification. All concepts fulfill the requirements from the requirement specification since they passed the elimination matrix. Therefore, only desires are included in the Pugh matrix, which can be seen in Figure 5.6. The decision for each concept will be motivated after the Pugh matrix.

Criteria	Reference: 21. Business as Usual	1. Battleship	8. The Wall Hook	12. The Brush	13. The Piano	17. Box in a Box	18. The Strap	19. Plastic Welding	20. Textile tracks	23. Vacuum Forming	25. Folding	26. Shadow-board	27. Pinwalls	28. Circlenode
Manufaturing /assembling cost		-	0	-	-	0	-	+	0	-	0	0	0	-
Possibility to repair		0	0	-	-	0	0	0	0	-	0	-	0	0
Possibility to replace damage parts		0	0	0	0	0	0	-	0	-	0	-	0	0
Durability		0	0	-	-	-	-	0	0	0	-	0	0	0
Modularity		+	+	+	+	+	0	-	-	-	-	0	+	0
Possible to reassemble	D	+	0	0	0	+	0	-	0	-	0	-	0	0
Creates structure	A	0	0	-	0	0	0	0	0	0	0	+	0	0
Sort components	T	0	0	-	0	0	+	0	0	0	0	+	0	0
Provide overview	U	0	0	+	+	0	+	0	0	0	0	+	+	0
Can be used in a flow rack	M	0	0	-	-	0	0	0	-	0	-	0	0	0
Easy acess to components		0	0	+	+	0	-	0	0	0	0	+	+	0
Sum +		2	1	3	3	2	2	1	0	0	0	4	3	0
Sum 0		8	10	2	4	8	6	7	9	6	8	4	8	10
Sum -		1	0	6	4	1	3	3	2	5	3	3	0	1
Net value	0	1	1	-3	-1	1	-1	-2	-2	-5	-3	1	3	-1
Ranking	6	2	2	12	7	2	7	10	10	14	12	2	1	7

Figure 5.6: The Pugh matrix, the concepts that are eliminated are marked in red colour.

The decision for each concept will be motivated hereafter.

1. **Battleship** - This concept was perceived to have very good potential when it comes to modularity and reassembly of the kitting solution, but it was doubtful if this would be appreciated and utilized enough to make it worth developing further. Therefore, this concept was eliminated.

8. **The Wall Hook** - The concept is useful and possible to use in most situations when sheets or boards need to be assembled to boxes. It enables modularity and assembly of kitting boxes, especially inner walls, in a more convenient and ergonomic way than for example screws and glue. The concept itself also works as a supporting fixture and makes the final product more robust, and will be further developed.

13. **The Brush** - The concept is useful when it comes to modularity and improved overview of components, but is questionable when it comes to complexity, durability and structuring or sorting of components. Therefore, this concept was eliminated.

14. **The Piano** - This concept is a variant of The Brush, and is slightly better at creating structure and sorting components since they become more clearly enclosed by the "piano keys". However, the concept is even more complex and hard to implement so the concept was eliminated and not further developed.

18. **Box in a Box** - This concept scored fairly high in the Pugh matrix, but it was hard to justify further development due to the concept's low durability with a light, thin and easily foldable material. Loose boxes could also be an issue if the kitting box is handled in various ways. Therefore, this concept was eliminated.

19. **The Strap** - Using straps or rubber bands to fasten components could be a viable solution when components need to be fastened, but would mean increased manufacturing complexity and handling time for operators to fix or collect components from the box. It is therefore hard to justify the usability of the concept, and was therefore eliminated.

20. **Plastic Welding** - This concept lacks when it comes to repairability, modularity and possibility to reassemble since parts are welded together, but could be a useful and efficient assembly method if these properties are not desirable. Therefore, this alternative will be investigated further.

21. **Textile tracks** - This concept is used today and is most commonly used for stands for sensitive components, but can not be rearranged or translated to a solution that can fit into

flow racks. The concept will not be developed beyond its current stage, but will be further described and included in following chapters as a kitting solution to certain situations.

22. **Business as usual** - This concept is used as a reference for other concepts and includes assembly of the boxes through screwing, gluing, rivets or tacks, which are the methods used today. Apart from being a reference, this concept will be investigated in more detail with respect to what glue that is best fitted to the materials that have been evaluated, since this has been a strong wish from Virtual Manufacturing.
24. **Vacuum Forming** - This manufacturing method does not provide modularity since the solution is made in essentially one piece, but could provide a more robust construction with more narrow walls, which results in a lower total weight. It is only a viable option for larger production volumes since the initial cost for tools and molds is high. This was investigated and confirmed by a manufacturer that was contacted during the project. This concept was not further developed or investigated.
26. **Folding** - This concept is used today at Volvo Cars, and is a possible solution when low weight is important and no modularity is needed. However, folding does not provide a robust enough construction, which was seen at Volvo Cars during the research. The concept will not be developed beyond its current stage, but will be further described and included in following chapters as a kitting solution to certain situations.
27. **Shadowboard** - Using a shadowboard to store components is a possible solution that can be useful when components need to be fixed and there is no need to reassemble or repair the kitting solution. Shadowboards are manufactured through water cutting and this method could provide a solution that is better customized for the components, which can lead to a better structure and overview for the user. This concept will be investigated further.
28. **Pinwalls** - This concept would provide better overview and decrease the weight since excess material is excluded, but it is only applicable in certain situations. The Pinwalls need to be shaped and placed in a very specific way to fit a certain usage situation, and would therefore make the assembly process of the kitting box more complex. Therefore, this concept was eliminated.
29. **Circle node** - This concept is an iteration of The Wall Hook and would in the same way enable modularity and an easier assembly process, but requires several versions depending on how many walls it should contain, which could vary between one and four. This would make the assembly process more costly and complex, which is the main reason to why this iteration is eliminated.

5.3 Final Concepts Combined with Materials

The final concepts that are further developed and investigated during the next chapters were here combined with suitable materials. The suitable materials are the materials that have been selected through the material screening process and that can be used for a specific concept. A matrix that shows which concepts that are combined with which materials is presented in Figure 5.7. A motivation why a certain material and concept will be suitable together is presented in the following subsections. This is only a preliminary assumption of how the concepts and materials can be combined so the combinations can be changed further on during the project. The final combinations of materials and concepts are presented in Section 7.7.

8. The Wall Hook	19. Plastic Welding	20. Textile Tracks	21. Business as Usual	25. Folding	26. Shadowboard
PVC-foam	PVC-foam	Tarpaulin	PVC-foam	Wellplast	PE-foam
ESD-PE	ESD-PE	Global ESD	PE-foam		
Plywood			ESD-PE		
Stadur			Plywood		
Divinycell			Stadur		
			Divinycell		

Figure 5.7: This matrix shows how the concepts and materials can be combined.

- **The Wall Hook** - This concept will make it possible to assembly a box or a shelf structure in a fast and simple way due to that the hook positions the plates. It is important that the material that will be used together with this concept will have a stiff surface so that the hook really can position the material in a good way. Softer materials will therefore not be an alternative for the concept. The materials that will be stiff enough that makes them possible to use together with The Wall Hook are PVC-foam, ESD-PE, plywood, Stadur and Divinycell.
- **Plastic Welding** - First of all, in order to use plastic welding, the material needs to be a thermoplastic. The material also needs to tolerate the process of heating and or adding of material. It is therefore important that the material is not a sandwich material since that can cause problems when the material is melting. The materials that further are alternatives for plastic welding are PVC-foam and ESD-PE.
- **Textile Tracks** - For this concept, it is important that the material will protect the components and can hang in a frame. It is also advantageous if it is possible to sew the material to the correct format and if the material is flexible. The only materials that has passed the screening process and that could be used for this concept are tarpaulin and Global ESD.
- **Business as Usual** - This concept is the most used solution today by Virtual Manufacturing in order to assemble boxes and shelf systems. Almost any material can be assembled with glue, tacks, rivets and screws, but for textile materials, it will be more usable to use the previous concept, Textile Tracks. Wellplast can not be used together with this concept but glue can be usable sometimes. All the other remaining materials from the material screening will be usable for this concept. The materials that can be used in this case are therefore PVC-foam, PE-foam, ESD-PE, plywood, Stadur and Divinycell.
- **Folding** - This concept needs a material that is bendable so that it is possible to fold the material into a correct position. It is also important that the material stays in the folded position which leads to that there only is one material that fulfills the requirements for this concept which is Wellplast.
- **Shadowboard** - The concept needs a light, soft but still robust material that protects and encloses the components. The material therefore needs to be soft and easy to shape in the right dimensions. The only material option that fulfill the mentioned requirements is PE-foam which is the material that will be used for this concept.

6 Results of Investigation and Determination of Materials

During this chapter, all materials that passed the material screening process were further investigated. At least one suitable supplier or manufacturer of each material was found, price estimations and delivery times are also presented if that kind of information is available. Some of the found materials have own trademarks which means that it is a certain material from a specific provider. The material will not be further investigated if a specific appropriate supplier of a desired variant of the material has been found. In other cases, several suppliers of similar materials were found and a brief comparison was made to determine the most suitable ones for Virtual Manufacturing. It is desirable that the supplier or manufacturer can deliver the material quickly due to the tight time schedules that Virtual Manufacturing often have towards their customers, and to a competitive price. For some materials there will be a need of additional material in order to create the most suitable solution for a specific application and that will be investigated and presented as well for the specific materials that have those kinds of needs. During the next chapter, development of final concepts, the more detailed information of each material will be usable in order to understand why a specific concept and material have been combined. Pictures of the recommended materials are presented in Chapter 9.

6.1 PVC-foam

PVC-foam is used for most kitting solutions by Virtual Manufacturing today. The material can be used for insensitive components, oily components and in some cases also for sensitive components if a protection layer of PE-foam is applied which is described in Section 6.4. This will create a better protection for sensitive components. PVC-foam has a relative long durability during normal using conditions. The specific sort that is used is called Forex Color and costs around 150 SEK/m^2 with a thickness of 10 mm. Forex Color has a density of 500-580 kg/m^3 [28] and the supplier is Glasfiber & Plastprodukter AB (GOP) which is a Swedish supplier of different plastic products for industry, construction and advertising applications. GOP has multiple dimensions of Forex Color in stock between 3-19 mm, and is available in black or white sheets.

GOP also sells another type of PVC-foam, Forex Print which has over 20 % lower density compared to the currently used material Forex Color. Forex print costs around 150 SEK/m^2 and has a density of approximately 400-450 kg/m^3. The material is available in thicknesses between 2-10 mm [28]. Furthermore, Forex Color and Forex Print seems to have identical physical properties, which makes Forex Print the best choice if a low weight for the kitting solution is desirable. During the prototype building and testing in Chapter 8, a prototype was built in Forex Print in order to investigate the possibility to create lighter solutions with PVC-foam.

Another supplier of plastic materials that has been contacted during the project is Vink Essåplast Group AB. The company have two other types of PVC-foam which have similar properties compared to Forex Color and Forex Print and they are called Foamalux L-light and Foamalux S-light [62]. There is a difference in price since both Foamalux variants cost around 125 SEK/m^2 which means that the material is around 17 % cheaper than the PVC-foam that Virtual Manufacturing uses today. Vink Essåplast Group AB has also a lot of additional services, like several different possibilities of processing the materials.

6.2 Wellplast

Wellplast AB is a company that offers several different versions of their trademark material, including Wellplast Soft, Wellplast Flexi Soft and Wellplast Foam among others. Each of these suits different applications depending on the specific need. This includes materials sorts that can handle all four component classes that have been identified during the project which are sensitive, insensitive, oily and ESD-classified components. The material is made of the plastic material PP combined with chalk, and the material is mainly made in thicknesses around 3,5 mm but can be produced in other thicknesses as well, ranging from two to ten millimeters, and weighs 250-3000 g/m^2. Wellplast AB delivers complete solutions which means that they are folding and gluing boxes together. The price varies between different Wellplast versions, but a generic box that is made of 0,4 m^2 material and ready to use costs 355 SEK. The kitting box that Volvo Cars uses today costs around 500 SEK and consists of approximately 0.8 m^2 Wellplast material. If ESD-classified Wellplast is used, the material will be more expensive. Wellplast AB can besides from delivering complete solutions also supply raw material sheets as well. The minimum order limit of the raw material is 500 kg. More information of how Wellplast can be used in this project is described in Section 7.4, where the concept folding is described. The material has a relative bad durability compared to other materials but the delivery time is relatively short.

6.3 Tarpaulin

Tarpaulin, or different version of it, is today mostly used for stands where more sensitive components are stored. Tarpaulin can be used for all of the four identified component classes. The material has a competitive weight and cost since it is a common material. There are numerous suppliers of tarpaulin, and it can be bought in ordinary hardware stores. If a large amount of material will be ordered, other companies like producers or industrial suppliers can be used. Tarpaulin will only be used together with the concept Textile Tracks so more information of how the material can be used will be presented during the further development of Textile Tracks which is presented in Section 7.3. Tarpaulin is a material that Virtual Manufacturing has used only a few times so the need of a solution where tarpaulin is used is probably limited. A few companies that can deliver custom made tarpaulin that does not need any further preparation will be presented during the presentation of Textile Tracks in the next chapter.

6.4 PE-foam

This material will be used in combination with two different concepts which are Business as Usual and Shadowboard. PE-foam will be suitable for insensitive, sensitive and ESD components, since ESD-classified PE-foam also is available. Worth mentioning is that the material requires to be placed upon another material preferably with glue since the material itself is not dimension stable. The material has a bad durability but will be more durable when it is placed on another material. Depending on which of the concepts that the PE-foam is used for, the supplier of the material can differ. If the foam will be used as protection for sensitive components and be placed as a thin surface over another material, the company NMC Cellfoam AB can be a good supplier. The company produces and sells a lot of different plastic foams with various densities and thicknesses from 3 mm. NMC Cellfoam AB is a global company that has a factory located in western Sweden which is advantageous for delivery times and freight costs [63]. There are two different sorts of the PE-foam, one with ESD-classification and one without.

Plastazote LD30SD is the one with ESD-protection, the weight is 30 kg/m^3 and costs around 85 SEK/m^2 with a thickness of three millimeters. Plastazote LD15 is the material sort that does not have ESD-classification, the material weights 15 kg/m^3 and costs around 30 SEK/m^2 with a thickness of three millimeters. For the concept Shadowboard, another PE-foam supplier can be advantageous to use since they also make the shadowboards in their factory. This is further described in Section 7.5 which describes the further development of the Shadowboard-concept.

6.5 ESD-PE

PE that is ESD-classified can be used as an alternative to Aicelwood with ESD protection, which is used today. The material weighs around 950 kg/m^3 which is almost twice as much compared to Aicelwood, but has similar physical properties and costs significantly less. The specific name of the material is PE EL 500, and can be provided by Vink Essåplast Group AB. Sheets of this material are available in thicknesses between 6-150 mm and costs around 450 SEK/m^2 with a thickness of 10 mm, which can be compared to Aicelwood with ESD protection which costs about 2500-3000 SEK, with the same thickness. The material can be stocked and delivered to Virtual Manufacturing in low and high volumes and with short delivery times, which can be important as kitting solutions that requires ESD-protection are made more seldom. ESD-PE can also be used for insensitive and oily components, and with a thin layer of PE-foam, sensitive components with or without need of ESD-protection can also be stored with ESD-PE. Worth mentioning is that there are more cost efficient materials to use if there is no need for ESD-protection.

6.6 Plywood

The spectra of different plywood variants or similar wood materials is enormous and different sorts will be suitable for specific applications. A meeting was therefore conducted with the company Kärnsund Wood Link AB which is a Swedish supplier of wood materials [64]. There are a number of materials that could be interesting for this project, such as lightweight blockboard, which mainly is made of albasia which is a lightweight sort of wood. This kind of blockboard has a density around 350 kg/m^3 and has a reasonable cost compared to other alternatives. This alternative could be more suitable than PVC-foam and other materials for many customers if the specific company allows wood materials in their production facilities. The problem with the blockboard from Kärnsund Wood Link AB is that the producers are located in China and a minimum order is a full container which is a too big quantity for Virtual Manufacturing nowadays.

From the meeting with Kärnsund Wood Link AB, three other interesting materials that are easier to purchase in smaller quantities were discussed. The first one is regular plywood which can be used for insensitive components. With a protection layer of PE-foam, the material can also be used for sensitive components, see Section 6.4 and can be bought to a cheap price in a regular hardware store. This is advantageous since an order to Kärnsund needs to be at least one package of plywood which contains around 100 m^2, which is a large amount of material in the context of this project. Since a normal hardware store sells plywood, even a small order for a kitting solution from a customer can be made of plywood without the need of a large amount of material in stock. Plywood will be an excellent alternative if the weight is not prioritized and the customer allows wood products in their production. Plywood will probably be the cheapest alternative of construction material in many cases and it is simultaneously a dimension stable material which is easy to process and assemble. Pine plywood also has a relative long durability.

If a smaller quantity is bought, Bauhaus is one of the hardware stores that sell plywood. For example, 10 mm of pine plywood costs around 110 SEK/m^2, with a weight of 870 kg/m^3. The available thicknesses will be 4-21 mm [65]. If a bigger amount of plywood is used, it will be better to order the material from a business to business supplier like Kärnsund Wood Link AB.

The second material that was discussed during the meeting with Kärnsund Wood Link AB and that will be an alternative for Virtual Manufacturing to use was a plywood coated with PP which creates a extremely robust and durable material. The PP surface makes it possible to use the material for oily components besides insensitive components. With a protection layer of PE-foam, the material can also be suitable for sensitive components, see Section 6.4. Since the surface is covered by PP, the material can be used in industries where wood-products are not allowed. Depending on which kind of wood that the plywood is made of, different densities are available. A material with a density around 500 kg/m^3 can be achieved if a lighter plywood is used as the core material. The price for the material will be somewhere around 230 SEK/m^2 with a total thickness of 9 mm. This makes the material competitive compared to PVC-foam since it most likely is more durable and around 10 % lighter than Forex Color PVC-foam. The delivery time is about three to four weeks.

The third and last wood material that could be an alternative for Virtual Manufacturing to use in the future is B-PLEX Light balsa plywood which is available in thicknesses between 12 mm to 40 mm and has a density around 210 kg/m^3. The supplier is Kärnsund Wood Link AB and they have a delivery time about three to four weeks. Balsa is a soft kind of wood, with a hard outer layer of beech. The material is quite durable and dimension stable, and the material will therefore be suitable for insensitive components but also for sensitive components if a protection layer of PE-foam is applied, see Section 6.4. This means that B-PLEX Light can be used in order to create lightweight solutions if the company that orders a kitting solution can accept this kind of wood-based material in their production facilities. The material costs 464 SEK/m^2 with a thickness of 12 mm. B-PLEX light is around 60 % lighter than PVC-foam [66].

6.7 Global ESD

This is a textile material that will be an alternative for sensitive components that need ESD-protection but can be used for insensitive and sensitive components as well. Global ESD can be used together with the concept Textile Tracks. How it can be used more in detail will be described in the next chapter during the Section 7.3. Global ESD is made of wool and metal fibers, the material is manufactured and provided by the Swedish company Bogesunds which is a textile supplier. The material costs around 290 SEK/m^2, weighs approximately 0,4 kg/m^2 and is available in seven different colours [42]. This material is not presented as a option in the construction guidelines since the situations where it will be useful are extremely rare.

6.8 Stadur

Stadur is a trademark and a material that is a sandwich material with a core of PS and thin outer layers of PVC. The material is available in thicknesses between 5 and 19 mm. Two different variants of the material has been found at two different plastic retailers. The first material is Viscom goBoard and is a specific version of Stadur that costs around 140 SEK/m^2, with a thickness of 10 mm, and weighs 2.1 kg/m^2 with the same thickness [67]. The material can be supplied by Glasfiber & Plastprodukter AB which is one of Virtual Manufacturing's current suppliers, with a short delivery time. An identical material, instead called Stadur Viscom Sign

SF, is the original Stadur material. Stadur Viscom Sign SF is supplied through Vink Essåplast Group AB [68] and has a similar cost and delivery time as Glasfiber & Plastprodukter AB offers. The cost is around 140 SEK/m^2 for a 10 mm thick sheet. Stadur will be possible to use for insensitive and oily components but also for insensitive components if a protection layer of PE-foam is applied, see Section 6.4. The material has a relative bad durability compared to other materials and will therefore require to be handled with more care.

6.9 Divinycell

Divinycell is a group of different materials that is a plastic mix that has been foamed and is supplied by the Swedish company DIAB. Divinycell will need some sort of thin outer layers in order to protect the Divinycell which will work as a core material in a sandwich construction. The material itself is brittle so the outer layers will protect the material and create torsional stability that Divinycell is missing. The material is available in many thicknesses from a few millimeters up to a several centimeters. The different sorts of Divinycell have different prices, but a suitable material in this case is Divinycell PN200 which is made of PET plastic. It has a density of 200 kg/m^3 and costs around 170 SEK/m^2 for a thickness of 10 millimeters. DIAB is the producer of the material and can supply customized dimensions orders for the sheets and with a delivery time at a few weeks but they are only producing the core material [50]. This means that another company is needed for supplying the thin outer layers, for example a laminating company that laminates the core material with a thin outer protection layer at each side of the core material. Another alternative is that Virtual Manufacturing assembles the outer layers by themselves. The problem with using Divinycell is that the material is not ready to be used when it is bought since an additional process of constructing the outer protection layers will be needed. Divinycell is therefore not recommended to be used.

There are other alternatives for using similar sandwich-materials which will create the same utility as Divinycell. The problem more generally is that sandwich-materials are overall expensive due to its complexity. Stadur, which is a sandwich-material that was presented during Section 6.8, is the cheapest sandwich-material that has been found for a Swedish supplier. There are a few Swedish suppliers of sandwich materials that can be useful in this project. There are a lot of suppliers in China that sells different sandwich-materials which will lower the price but a bigger amount of sheets needs to be ordered and the delivery time will be at least one month. A Swedish supplier that the seller at DIAB recommended to use is Kenpo AB which can supply finished sandwich-sheets that are ready to use. Kenpo AB is a Swedish company that produces sandwich-materials to different sectors like the construction, industry and marine sectors [69]. The company did unfortunately not present any specific material due to lack of time from their side so no new sandwich material will be presented here.

7 Results of the Final Development of Concepts

The concepts that remain after the concept selections will be further developed and determined during this chapter. The development of each concept depends on if the concept is existing and will be bought from another company or if the concept does not exist and will be developed on a detailed level. The concepts will be usable in different situations, which is the reason to why all six concepts remain from the previous step of the process. As Virtual Manufacturing's customers will use their kitting solutions in different contexts, these concepts will cover a wide area of applications with different usage situations and requirements.

7.1 The Wall Hook

The Wall Hook is an entirely new concept that was developed during the concept generation process. Therefore, there are no similar solution that exists at the market today that are used in a similar application so the concept needs to be developed on a higher level of detail. A variant of The Wall Hook that is used for another application was found in IKEA's assortment, see Figure 7.1.

Figure 7.1: IKEA's solution that reminds about The Wall Hook.

The original idea of the concept was to enable a more convenient way to assemble and reconfigure the interior of a kitting solution. A more detailed sketch of the concept is shown in Figure 7.2. An initial design of The Wall Hook was modelled in the CAD program Catia V5. Dimensions and proportions of the concept were discussed with consideration to how well the hook needs to be attached to the outer wall and how much area that is required to keep the inner wall firmly in place. It was also important to make sure that it is not bulky or subject components or users to any risk of being harmed when handling the kitting box. An early test of the concept was conducted through 3D-printing which enabled an early confirmation that the material has potential to work as a wall connector. One of the early prototypes is shown in Figure 7.3. The test was also made to determine which width the hooks needs to have so that the sheets that will be attached by the hooks fits in a suitable way. The testing showed that The Wall Hook concept worked and that there needs to be around 0,2 mm extra space in the hook so that the walls can be attached correctly.

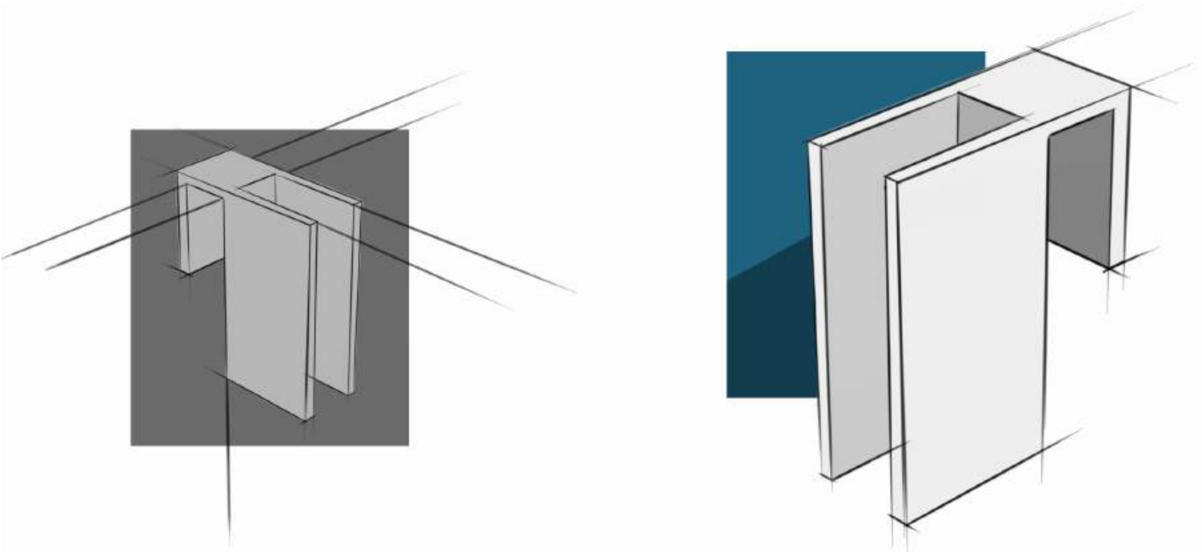


Figure 7.2: A sketch of The Wall Hook.

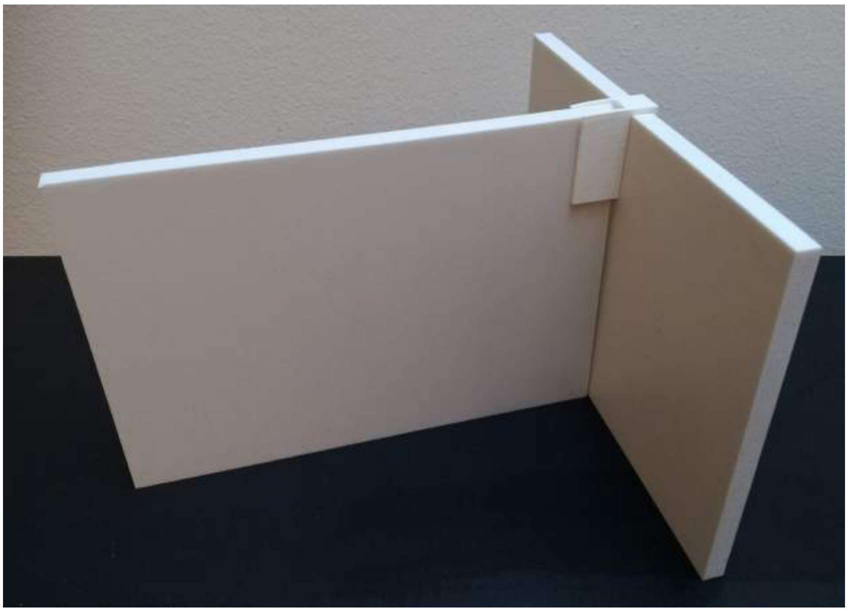


Figure 7.3: The first test of The Wall Hook.

When the early test showed that the concepts principle is working, further development of how the concept can be used in similar situations was made. Through the further development, an additional variant of The Wall Hook, called The Corner Hook was developed in order to enable assembly of the four outer walls of the box, a sketch of the idea is shown in Figure 7.4. Since the original concept The Wall Hook now consists of two concepts, The Wall Hook and The Corner Hook, they can both be summarized as The Wall and Corner Hooks later on during the report. The Corner Hook extends the possibility to make the assembly process even more convenient and efficient. Dimensions and proportions of the concept were discussed with consideration to that the outer walls are more exposed. Its main purpose is also to hold outer walls together, not enable flexible placement of inner walls which is the case for The Wall Hook. An early testing was conducted as well for The Corner Hook to test if the principle is working which it did. The

3D-printed test object of The Corner Hook can be seen in Figure 7.5.

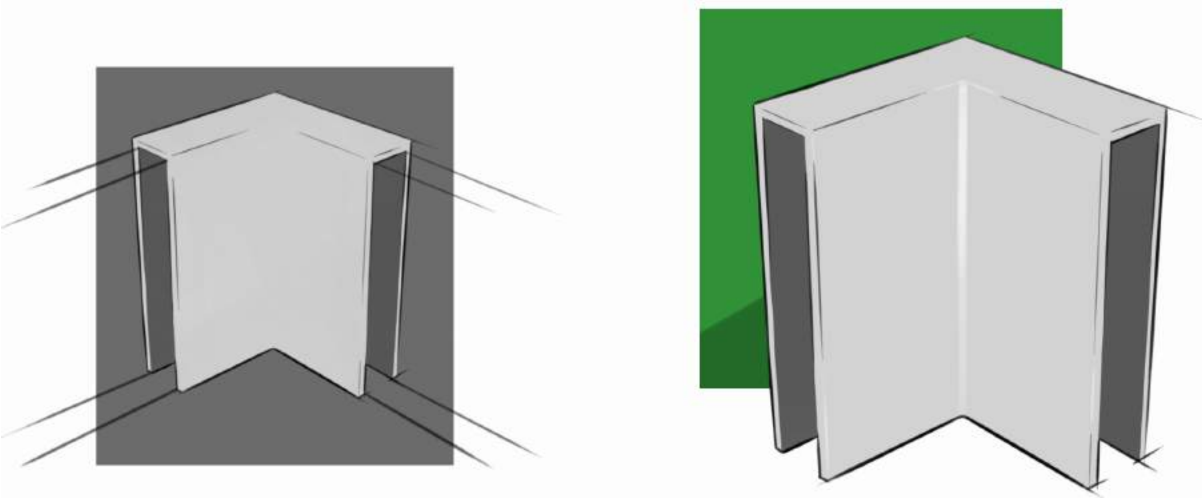


Figure 7.4: A sketch of the concept The Corner Hook.

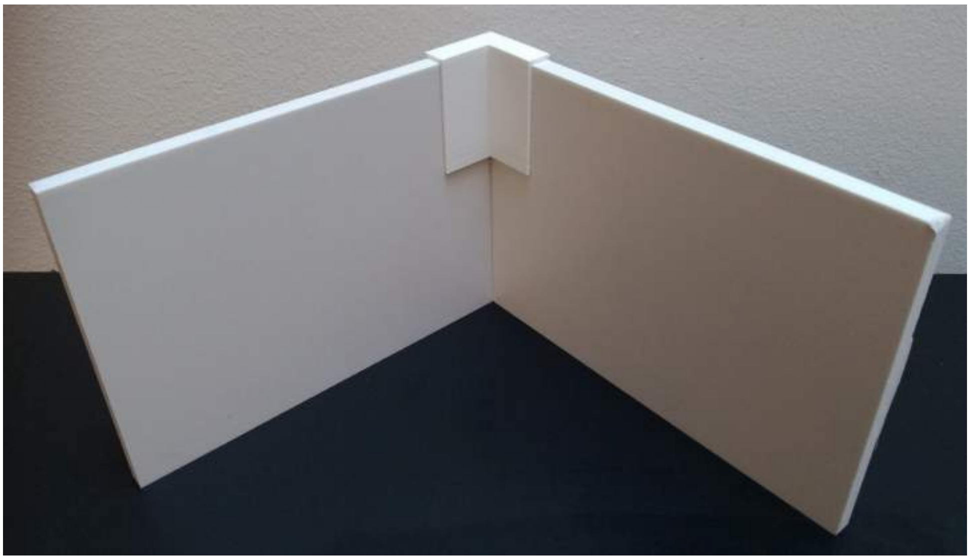


Figure 7.5: The first test of The Corner Hook.

After the CAD-models were printed and tested, further discussions about how they could be improved were held. The Wall Hook was redesigned so that the gap created between the inner and outer box wall was removed. Two flanges were added on the sides to make the concept more durable if the inner walls of the box is exposed to bending or other similar forces. Additionally, larger fillets were used on edges and corners that are facing outwards to make sure components are less susceptible to scratches from it. The Corner Hook also received larger fillets for this reason. Otherwise, the design of The Corner Hook remained. The new design of The Wall Hook can be seen if Figure 7.6. The new version of The Wall Hook will be 3D-printed again during Chapter 8 which is about prototyping and testing.

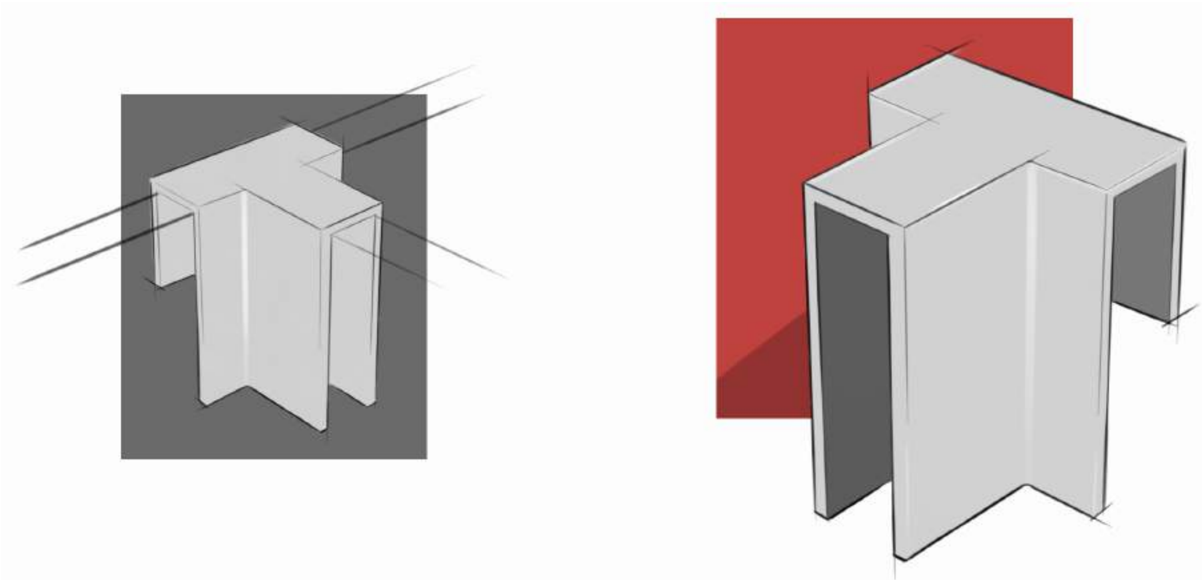


Figure 7.6: The new design of The Wall Hook.

A more radical approach was to combine The Wall Hook and The Corner Hook into one single concept, which can be seen in Figure 7.7. The idea is to make a frame-like structure that is placed on all the exterior walls, while The Wall Hook is implemented where the interior walls are supposed to be. The concept could be useful for a number of applications, but was not developed further due to the limited possibility to create a prototype to verify the functionality of the concept. The particular designs of The Wall Hook and The Corner Hook are made to fit a normal box with straight edges but if the geometry needs to be different of some reason, the design can be customized.

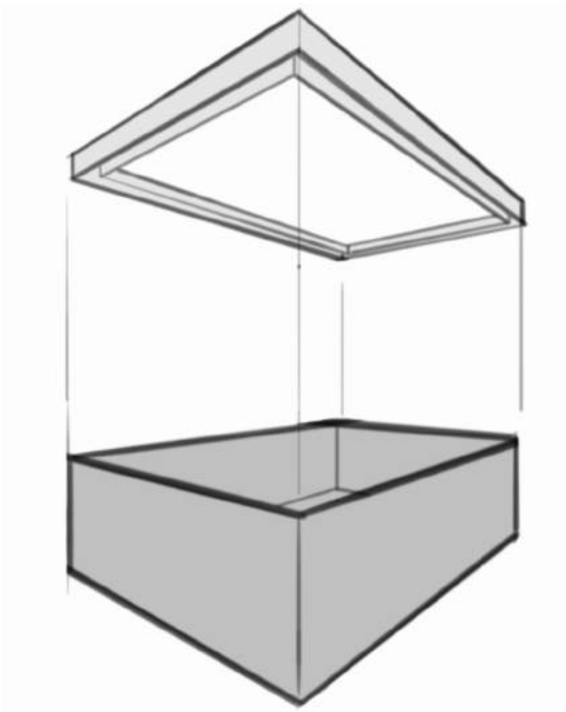


Figure 7.7: A sketch of the combination of The Wall and Corner Hooks.

The Wall Hook and The Corner Hook can for example be manufactured by 3D printing or with injection molding which seems to be two of the most suitable manufacturing methods. 3D-printing would cost around 25 SEK per part for The Wall Hook and 60 SEK per part for The Corner Hook, if 100 or more of each are manufactured. The material for 3D-printing would be ABS plastic, which has good mechanical properties and excellent impact strength. The price for the parts does not decrease substantially if more than 100 are produced [59].

Injection molding is one of the major manufacturing methods for plastics. The plastic will be molten and placed into a shape-specific mold cavity which creates the desired shape of the plastic product. The plastic will then solidify and the plastic product will after that leave the machine. This is a repetitive process [70]. The cost of injection molding strongly depends on the number of ordered parts since the cavity has a high cost. If hundred units are ordered of both The Corner and Wall Hooks, just like the cost-estimation for 3D-printing, The Wall and Corner Hooks will approximately both have the same cost which is around 2000 SEK each in the plastic material ABS. The ordered number needs to exceed around 5000 parts of each sort before injection molding will be cost-efficient [7]. Therefore, 3D-printing is probably the best alternative since Virtual Manufacturing produce low quantities of kitting solutions. The weight of The Wall Hook will be about 8 grams and 20 grams for The Corner Hook if the plastic material ABS is used.

7.2 Plastic Welding

This concept or assembly method was further investigated and several companies that provides plastic welding systems were found. There are also several kinds of plastic welding techniques that could be suitable for different situations. One company that provides plastic welding equipment is Piltorps Varmluft AB which is located in Gothenburg. A visit of the company was conducted in order to test if it is possible to use plastic welding for kitting solutions. Two materials has earlier been identified as possible materials to be used in combination with plastic welding, which are PVC-foam and ESD-PE. The test was therefore primarily conducted with PVC-foam since that material is used more often than ESD-PE by Virtual Manufacturing. Nevertheless, both were tested for feasibility, see Figure 7.8.

Regarding the use of the tool itself, there are different types of plastic welding guns, and the one that was used can cost around 3000-5000 SEK and can be seen in Figure 7.9. Different nozzles can be used to get a desired finish of the joint, and it is important that the user has enough workspace to apply the joint properly. The parts that are to be joined together first need to be aligned and fixated correctly, preferably by using clamps. Then, they should be pre-joined by slightly heating the material, see Figure 7.10. After this, the sealant is inserted into the nozzle and the user applies the joint by putting out a steady stream of sealant while applying some pressure with the gun. The sealant should be of the same material as the kitting solution, since both materials are melted in the process. Therefore, the temperature of the welding gun needs to be set according to the material. The tools require some training and skills in order to create a good looking finish.

Figure 7.8: The test of plastic welding with PVC-foam.

Figure 7.9: The plastic welding machine that was used.

Figure 7.10: The process of pre-jointing the materials.

The feasibility test was successful for both materials, which means that plastic welding could be an alternative way of assembling kitting solutions in the future. Further testing of plastic welding will be performed and presented during the prototype chapter which is Chapter 8.

7.3 Textile Tracks

The concept of textile tracks includes that a shelf system made of some sort of textile is attached to the steel frame system, most likely a tarpaulin like material. Since the steel frame is not in focus during this project, no further development of this concept was made. The solution is held together preferably with stitches or glue. This kind of concept has been used by Virtual Manufacturing a few times and it is only in few cases that this kind of solution will be an alternative when all components are particularly sensitive. A Textile Tracks solution will have relatively good durability and the weight of the solution will be relatively low. As this concept only will be recommended for a few applications, it may be better to buy customized solutions from a supplier instead of purchasing expensive machines and educating the production personnel in the factory in Linköping. Three companies have been identified that can supply Virtual Manufacturing with solutions that will ease the possibility to offer this kind of customized product. The companies will be described hereafter.

The first company is conTeyor which is a global supplier of shelf systems and other transport solutions for mostly sensitive components and products. Their systems are made of tarpaulin or similar materials. The company's solutions can also be flexible which means that they easily can be assembled and disassembled in order to save space when the carrier is empty. The company can provide solutions that can contain all four different component classes that has been identified in this project. This means that besides insensitive and sensitive components, also oily and ESD-clasified components can be stored and transported in conTeyor's kitting solutions. ConTeyor delivers complete solutions which means that the steel frame is included in the products that they are selling. A typical conTeyor solution can be seen in Figure 7.11. The company does not have any minimum order limit but the design and consulting cost will be high if a small quantity is ordered since the cost will be divided into only a few units. The lead-time is about 10-12 weeks for their products, but the contacted seller for the company was not willing to share any price estimations of how much their products cost in an early stage. Virtual Manufacturing can use conTeyor when a bigger amount of complete customized solutions need to be in a textile material in order to give the best protection for the components that the kitting solution will contain. It is also advantageous to use a partner that has more knowledge about different textile transport solutions.

Figure 7.11: A typical solution from conTeyor.

If a smaller quantity is needed of customized kitting solutions that are made in a textile material, a company that provides tailor-made textile solutions will be a better alternative to use. It will probably be more cost effective to use local suppliers with shorter lead-times when smaller quantities are to be produced. Two different companies that can be used in this type of situation are Lindevalls Industri AB [71] or Hansson-Kapell AB [72], which are two of Sweden's biggest companies within industrial sewing. Both can provide a complete solution in tarpaulin or other textile materials that will be suitable for the specific application [71]. Virtual Manufacturing has to construct the steel frame and then assembly the finished textile solution to the construction.

7.4 Folding

This concept was first considered to only be used together with the material Wellplast since that is the only material that has been selected that can be folded and then maintain the geometry that it has been folded to. The company Wellplast AB sells customized box or shelve systems that has been produced in the material Wellplast. This concept together with the material Wellplast will create a lightweight solution but is not particularly dimension stable. This concept will be usable in the case when low weight is prioritized over durability. Since the company Wellplast AB both produces the material and constructs boxes or shelves it could be more suitable to buy complete solutions from them instead of buying unfolded material.

Through an iteration of the concepts, the idea of using the material Stadur (see Section 6.8) combined with the concepts Folding and The Corner Hook (see Section 7.1) arose further on during the project. Stadur has a thin layer of PVC at each side and a core of PS. This makes it possible to mill out a V-shape track that removes the PVC-layer at one side and the polystyrene-core. The track will then make it possible to fold the Stadur-sheet 90 degrees which creates a bottom and a wall structure. In the same way, a bottom sheet can be combined with four walls, one on each side which will be folded to a complete box. The walls need to be fastened in the right position and that is the reason why The Corner Hook will be used. The Corner Hook will be fastened in each corner to ensure that the walls will stay in the supposed position. An early testing in order to ensure that this concept works was made where an example from the supplier Vink Essåplast Group AB was used. Two walls were folded together with the bottom plate and then The Corner Hook was used to lock the structure. The test can be seen in Figure 7.12.

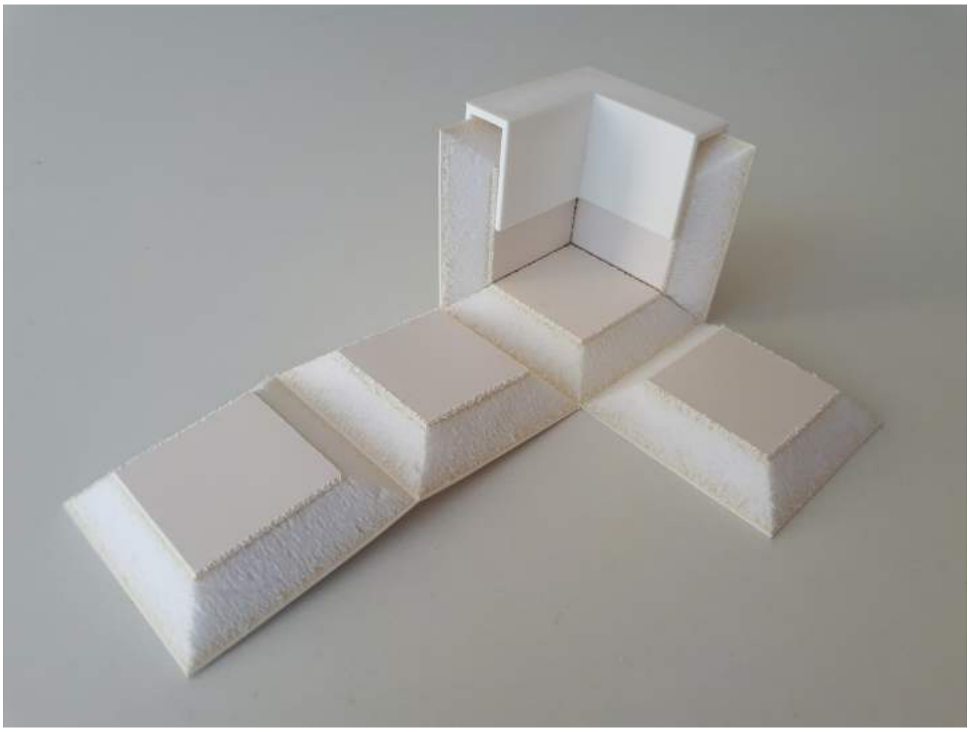


Figure 7.12: Early test of the combination of Folding and The Corner Hook together with the material Stadur.

The test shows that the principle works and can solve the problem that screws need to be used for a sandwich-material like Stadur, since screws entails the risk of damaging the surroundings. The newly found combination of Stadur and the two concepts will be further constructed and tested during the next chapter. There could be a need of using glue inside The Corner Hook since that will ensure that the locking mechanisms will work in a proper way.

7.5 Shadowboard

This concept contains a thick sheet of a foam, for example PE-foam there holes have been milled or cut out so that the components that the Shadowboard will contain fits into the Shadowboard's cavities. The concepts will probably be more expensive than most of the other alternatives of constructing a kitting solution but is a good alternative for sensitive and small components or if the components need to be well structured. Virtual Manufacturing used this kind of solution for the first time to a customer during the spring 2018 so this concept did not exist at Virtual Manufacturing in the beginning of this project. It is advantageous that Virtual Manufacturing uses this concept simultaneously as the concept is developed here since that will ease the process of verifying that the concept works in a satisfying way. A price estimation for this kind of solution will also be easier to present. The company that Virtual Manufacturing has used for shadowboards is Kongsbergs Emballasje which is a Norwegian supplier of packaging solutions. They can produce shadowboards in different foam materials, for example in PE-foam. The supplier also offers foam in ESD-format which means that ESD-components also can be stored in a shadowboard solution [73]. Kongsbergs Emballasje seems to be an appropriate supplier of shadowboards since no Swedish supplier was found. The delivery time will probably be relatively long due to that the supplier is not located in Sweden and that the shadowboard needs to be manufactured by milling out cavities. A typical shadowboard is shown in Figure 7.13.

Figure 7.13: A shadowboard.

Two price examples from Kongsbergs Emballasje are a shadowboard with the dimensions 1200 times 800 mm that can contain 30 components, which costs 3500 SEK. The second example is a shadowboard with the dimensions 400 times 300 mm that costs 400 SEK. The price depends for example of the size, how many components that the solution will contain and material sort. The shadowboard's weight depends on the specific material that is used but somewhere around 30 kg/m^3 is a reasonable assumption, considering it is some kind of PE foam. The shadowboard can in many cases need a bottom plate or another type of support structure since the shadowboard itself can have too low dimension stability. Since the material is soft, careful use is needed so that the construction not is damaged by a sharp object etcetera. The durability will probably be worse than many other types of kitting solutions but if the shadowboard is handled with care, it can be quite durable.

7.6 Business as Usual

This concept means that the assembly methods that Virtual Manufacturing use today remain and are used in a similar way as before. In order to have assembly methods that also suits all the materials that have been found during the material search, complementary investigations about screws and glues have been conducted. This included consulting employees at hardware stores and testing of different screws and glues. Rivets and tacks have been used a few times by Virtual Manufacturing but since these two assembling methods seems to not be usable for sandwich materials, they will not be further investigated even if they can be used in some applications as they are today. The screw and glue investigation will be divided into two separate parts and they are presented hereafter.

7.6.1 Screws

Screws are commonly used today and will be a good alternative if customers allow that screw heads are visible and exposed. Today, Virtual Manufacturing is using normal wood screws, which most often works well when two parts of wood or plastic materials are joined together. Virtual Manufacturing can continue to use these for example when merging two PVC-foam boards together. For other materials, such as sandwich composites like Stadur or other light materials that are not as dimension stable as wood or PVC-foam, these screws do not work in a satisfying way. The thread of the screw needs to be as wide as possible in order to make sure that it attaches well and, when subjected to force, does not unfasten and crushes a more light and porous material. A screw with a wider thread is therefore needed, but not too wide since the screw then will be wider than the material itself. A type of screw that has a wider thread is gypsum screws. A small test was conducted in order to investigate if gypsum screws are more suitable than regular tree screws in order to merge two lightweight solid materials, in this case Stadur. The test resulted in that the gypsum screws were found to be more suitable since the thread is wider and creates more contact between the screw and the material. Gypsum screws can be bought in a regular store that sells construction materials, for example at the store Ahlsell, and has different formats. The screw that was tested had a length of 41 millimeters and a width of 3,9 millimeters. The screw is made of steel and costs 120 SEK for 500 pieces [74].

7.6.2 Glues

Virtual Manufacturing's factory that manufacturers the kitting solutions has tested the glue Epoxy snabblim ESK-50 from the company Würth. This is a two components epoxy glue which means that two different substances need to be mixed before applying the glue to a certain surface. This is time demanding and the glue hardens rapidly which makes the assembling process intensive and difficult to accomplish. If the material that should be glued is made of wood, a normal wood glue can be used. To glue plastic materials, a more specific glue is required. During the investigation, three different glues that are suitable for plastic materials were found. The first glue is Scotch Weld, Industrial Plastic Adhesive and is made by 3M. The glue can be bought from the Swedish internet store Paintpro. One package of the glue contains almost one liter and costs around 250 SEK. The glue can be used for most plastic materials and is both water and weather resistant. It is a one component glue that has a longer hardening time which will ease the assembly process [75].

The second glue that was identified as an alternative was Maxi Bond Xtrem which is a glue made by the company Bostik AB. The glue can for example be bought at the store Bauhaus and costs around 140 SEK for 300 milliliters. Maxi Bond Xtrem is a one component glue, has a relative fast core time and can be used for most materials like plastic and wood [76]. The third and last tested glue was PL200 construction glue which is a flexible hybrid one component glue. PL200 can be used for most materials, including wood, metals and some plastic materials. The producer of the glue is Illbruck and the product can be bought at most hardware stores like Bauhaus for a cost of 56 SEK for 300 ml [77].

The three newly found glues will be easier and faster to use than the glue that Virtual Manufacturing uses today since they are one component glues, which removes the need of mixing different glue components together. In order to check if the glues really were suitable for plastic materials, a small test was performed. The adhesives were used to merge two parts of the same plastic material. The materials that were investigated were PVC-foam and Stadur. Aicelwood was also tested even if the material has been eliminated from the project since there is a possibility that Virtual Manufacturing will continue to use the material further on despite the project's result. Figure 7.14 shows how parts were merged with the glue.

Figure 7.14: Part of the testing of three different glues together with three different plastic materials.

The result of the glue test was that it is difficult to glue Stadur and probably other sandwich materials with a lightweight core since the core is brittle, which means that the material can be torn apart. It was easier to glue PVC-foam and Aicelwood since these materials have consistent material properties. The best glue of the tested ones is PL200 which also is the cheapest one (price/liter). The glue joint with PL200 was the strongest and most stable one since it required a large force to tear the joints apart. The other two glues that were tested had worse results, even if they managed to create a somewhat stable joint. A picture of the best glue, PL200 is shown in Figure 7.15.

Figure 7.15: The winning glue.

7.7 Final Conclusion of Concepts

During this chapter, six different concepts and some sub-concepts have been investigated and developed. Some of the concepts are more independent and others are just a way of assembling a kitting solution. The different concepts will therefore be divided into three types to better represent how to create a kitting solution. The first type is a regular box or shelf structure which will be created through a material that is assembled through one or a few of the assembly methods that are included. The methods that will be usable for a regular box or shelf structure are screws, glue, tacks, rivets, The Wall and Corner Hooks, plastic welding and folding. This type of kitting solution is most often the cheapest alternative and is the best alternative for insensitive components but can also be suitable in some situations for other component categories. The following list shows which materials that are included in the category of regular box or shelf structure and which of the assembly methods (concepts) that are suitable for respective material.

- **PVC-foam** - Can be assembled by The wall and Corner Hooks, Screws, glue, tacks, rivets and plastic welding.
- **PE-foam** - Can be assembled by glue.
- **ESD-PE** - Can be assembled by The Wall and Corner Hooks, screws, glue, tacks, rivets and plastic welding.
- **Pine Plywood** - Can be assembled by The Wall and Corner Hooks, screws and glue.
- **Plywood coated with PP** - Can be assembled by The Wall and Corner Hooks, screws and glue.

- **Balsa Plywood** - Can be assembled by The Wall and Corner Hooks, screws and glue.
- **Stadur** - Can be assembled by The Wall and Corner Hooks, screws, glue and folding.
- **Wellplast** - Can be assembled by glue and Folding.

The second type of kitting solution is the Shadowboard-concept which will create a solution where the components are placed in a structured way with extra protection. The material used for this type of solution is PE-foam. The third and last type of kitting solution option is Textile Tracks which creates a lighter and more protective kitting solution than the regular box and shelve structure. The material that will be used to construct a Textile Tracks solution will be tarpaulin. For all customer orders, there will always at least be one alternative way of constructing the kitting solution, which the three different kitting solution types that has been presented will represent.

8 Results of Prototype Building and Testing

This chapter reflects on the process of building and testing prototypes. The prototypes were made in different levels, two of them were tested in Volvo Cars production and some other prototypes were only made in order to visualize concepts or materials. Depending on if the prototypes were to be used or not, the functionality, accuracy and time spent on each prototype differ. First, the prototypes that were built to be tested in Volvo Cars assembly line are presented and further on, the remaining prototypes are presented. Some concepts and materials were not considered during the prototype building and testing so the most important concepts and materials were selected. It was important that the prototypes led to new knowledge so that Virtual Manufacturing would get usable information.

8.1 Volvo Prototypes

Stadur is a lightweight material that is further described in Section 6.8 and was used in order to build two prototypes of the kitting box type that Volvo Cars was using in their assembly line at that time, see Figures 3.14 and 3.15. Each prototype consists of two boxes, one big and one small that can be placed inside the big one. The material was ordered by Virtual Manufacturing's current supplier Glasifber & Plastprodukter AB and the prototypes were made in Virtual Manufacturing's production facility in Linköping. Figure 8.1 shows the process of building two prototype kitting boxes. The boxes were completely made by the equipment that was available in the factory which enables the possibility to produce similar solutions without any investments in equipment.

Figure 8.1: A jigsaw was used to create handles and other contours.

One of the kitting boxes was assembled with screws and glue while the other one was assembled only with screws. The testing of different glues in the previous chapter (Section 7.6.2) showed that it is difficult to join parts in Stadur by glue only but by testing to use glue in one of the two prototypes, information if gluing will make any difference was gained. The glues and screws that were used were the ones that are presented as the best alternatives during the testing in Section 7.6. Both prototype kitting boxes weighed around 1,6 kg each which is below the maximum limit of 2 kg but slightly over the desired weight that was below or equal to 1,5 kg that Volvo Cars expressed during the initial meeting. Weight was an especially important factor to consider since operators are carrying the boxes around during the assembly process. One of the two almost identical prototype kitting boxes is shown in Figure 8.2.

Figure 8.2: One of two prototypes made in Stadur.

The Prototypes were tested in Volvo Cars assembly line to see how well they endured regular use. This mainly consists of loading the boxes with various metal and plastic components, carrying them around inside or outside the car, and placing them in different flowracks. The testing of the prototypes was conducted in less than a week in the production before the prototypes got into a bad condition. The production personnel thought that the prototypes had a low weight but the material which was Stadur was not durable enough as it was too brittle. Figure 8.3 shows how the prototypes looked like when they were leaving the production. The prototype that was assembled with both glue and screws managed the production environment slightly better than the prototype assembled only with screws.

During the project, a lot of materials have been evaluated and it seems to be difficult to find a material that can be used to build kitting boxes to Volvo Cars production that is dimension stable, durable and has a low weight without costing too much. The solution in Wellplast that Volvo Cars is using today has a excellent low weight and acceptable price but has a doubtful durability and is not dimension stable. There has been three other companies including Virtual Manufacturing that have tried to make a kitting solution that responds to Volvo Cars requirements but none have succeeded.

(a) One of the handles.

(b) One of the corners.

Figure 8.3: Two pictures that show how the prototypes looked like after being used in Volvo Cars production.

Due to the lack of time, no further testing has been made. However, using thinner PVC-foam sheets in combination with plastic welding could be an alternative for future development. Using PVC-foam with a thickness of 5 mm instead of 10 mm would decrease the weight by 50 %, resulting in a solution that weighs around 1,7 kg. This is an acceptable weight, and would provide a much more durable solution than the current boxes in Wellplast. Another possibility is to use the concepts Folding and The Corner Hook together with the material Stadur which was made as an prototype in Section 8.4. The construction will then be more durable thanks to The Corner Hook and to the way the solution is assembled.

8.2 Welding Plastic Materials

The visit at Piltorps Varmluft AB showed that it was possible to use plastic welding in order to merge two parts of PVC-foam or ESD-PE together, see Section 7.2. Since it was possible to use plastic welding, a box in PVC-foam was assembled with the method in order to show a physical prototype of a plastic welded product. The PVC-foam was the sort Forex Print. The prototype is visualized in Figure 8.4, and the welding thread that was used was gray so that the welding is visible but other colours are possible to use. The prototype was stable and the walls are joined to the bottom plate in a good way which means that it is very difficult to tear apart the box. Plastic welding is therefore a better alternative than glue since the testing of glue in Section 7.6 showed that it is possible to tear apart a joint made by glue in many cases. To use plastic welding will be an excellent alternative when the customer does not accept screws or other fasteners that can damage the components or the surroundings.

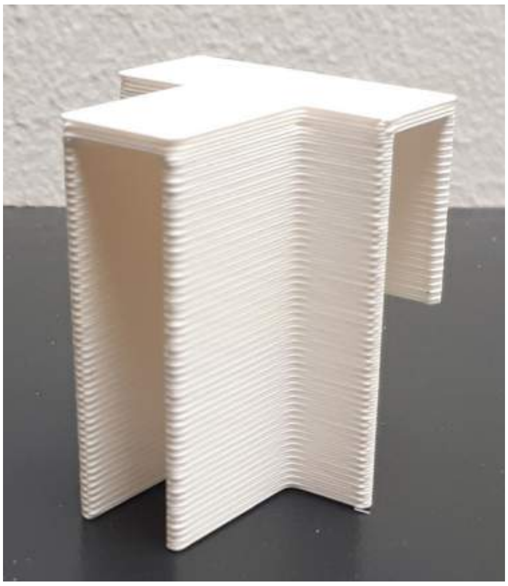
(a) The welded box.

(b) The weld joint.

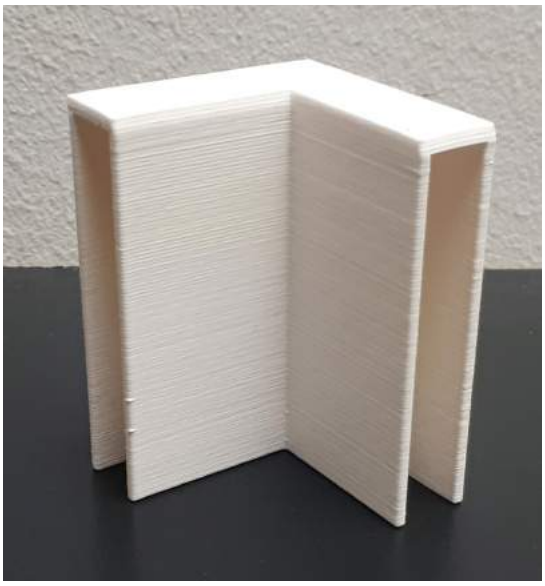
Figure 8.4: The prototype box in PVC-foam assembled with plastic welding.

8.3 The Wall and Corner Hooks

The final prototypes of The Wall Hook and The Corner Hook can be seen in Figure 8.5, and is a result of the iterative development of the two concepts, see Section 7.1. Both can be used independently of each other, and can be used together depending on the situation. The Wall Hook is used to fixate and enable flexible placement of internal walls in the kitting solution, while The Corner Hook is used to connect or strengthen the external walls, or both.



(a) A prototype of The Wall Hook.



(b) A prototype of The Corner Hook.

Figure 8.5: Prototypes of The Wall and Corner Hooks.

8.4 Folding Combined with The Corner Hook

Another prototype was made to demonstrate how the concept Folding and The Corner Hook can be combined to a kitting solution. The material, in this case Stadur, was milled in a certain way in order to be able to fold the material, see section 7.4. The external walls were then folded and joined together with four Corner Hooks, which can be seen in Figure 8.6. To strengthen the construction additionally, glue can be added in the joints of the external walls and on the contact surfaces between the Hooks and the walls.

The prototype showed that the principle is working but it was difficult to make the pattern in the material by hand with a knife which affected the functionality and finish. One of the mentioned suppliers of Stadur, Vink Essåplast Group AB has the possibility to mill out the correct pattern in the material which makes it possible to fold the box together and fixate it with The Wall Hook. When a milling machine is used, the accuracy will be much better which creates a more durable solution. Vink Essåplast Group AB was asked to make a estimation of how much the Volvo prototype box that was presented in Section 8.1 would cost to produce if 100 units were ordered. The cost would be 378 SEK per kitting solution which is excluding the cost of The Corner Hooks. There is a high probability that this kind of solution made of Stadur, assembled by folding and The Corner Hook, will be more durable than the prototypes that was tested in Volvo Cars production.

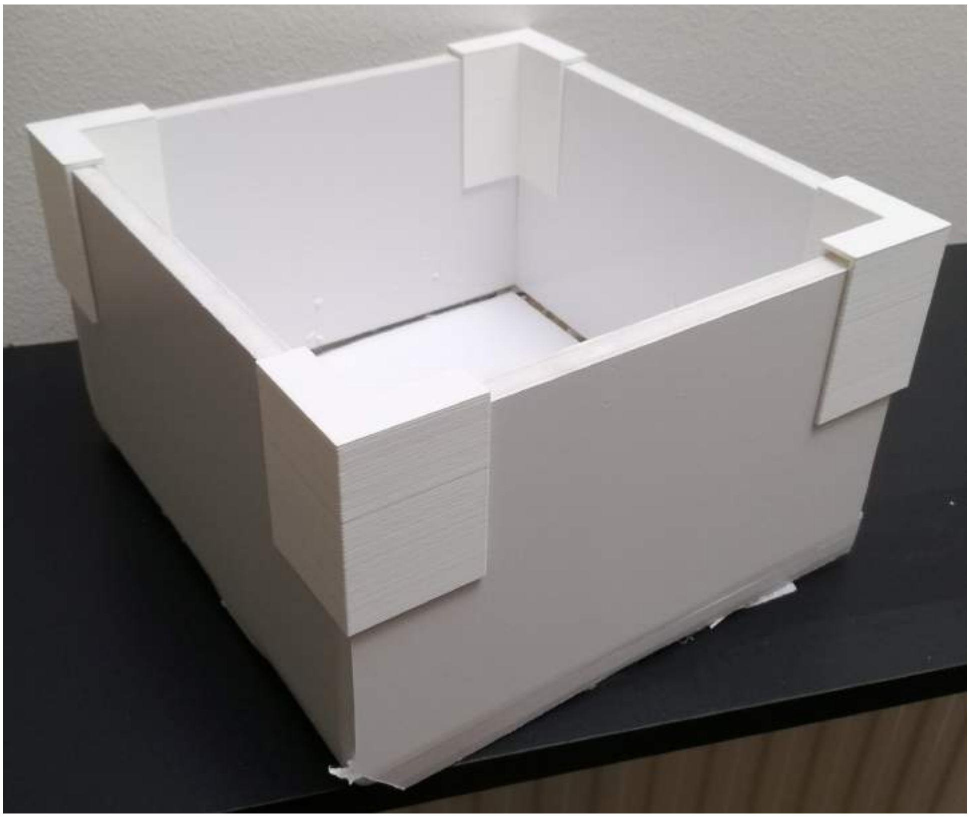


Figure 8.6: The concepts Folding and The Corner Hook combined with the material Stadur.

9 Final Outcome of the Project

This chapter aims to be a description that presents the project's final outcome. The four first sections work as the construction guidelines for Virtual Manufacturing when they choose the kitting solution type, including material and assembly method. The first section is an introducing paragraph to the guidelines and the three following sections are about the three different types of kitting solutions that has been found to be the best way to structure a kitting solution depending on the customer requirements and desires. The fifth section will be about the concept The Wall and Corner Hooks which has been developed during the project. If more information is required or a deeper understanding of how a specific part in the guidelines has been constructed, the information is available in Chapters 6 and 7. The last part of this chapter will reconnect to the project objectives and the two requirement specifications in order to assess how the project results corresponds to the final outcome of the project.

9.1 Construction Guidelines for Material and Assembly Selection

The construction guidelines should be used by first deciding if a regular box or shelf structure is suitable for the specific kitting solution that should be constructed or if the Shadowboard or Textile Tracks are more suitable solutions. The regular box or shelf structure contains several usable materials and assembly alternatives, that mostly will be manufactured by Virtual Manufacturing and are therefore not a separate concept combined with a single material. Shadowboard and Textile Tracks, which has fewer material alternatives within their solutions, will be bought partly or completely from other suppliers.

The first step in the guidelines will therefore be to decide which of the three different kitting solution alternatives that suits the specific situation in the best possible way by reading the information about each solution. When the decision has been made and one of the three alternatives has been selected, more information about the next step in the process will be found under respective alternative. The regular box and shelf structure is presented in Section 9.2, the Shadowboard solution is presented in Section 9.3 and the solution Textile Tracks is presented in Section 9.4.

The whole process of selecting and designing a specific kitting solution which also contains the whole outcome of the project is summarized in Figure 9.1. Some parts that are mentioned in the figure has required more work than other parts but every part together summarizes the project. Figure 9.1 first shows the three different types of kitting solutions which are regular box or shelf structure, Shadowboard and Textile Tracks. The first step of using the construction guideline is therefore to decide which of the three possible kitting solution types that is most suitable. The next step in the chart is to decide one or a few of the nine materials if a regular box or shelf structure is selected. If the kitting solution is a Shadowboard or a Textile Tracks solution, the material will most often be predetermined. The third and last step in the figure before a finalized kitting solution can be presented, specific assembly methods need to be selected, which also can include that the production is outsourced. There are seven different alternatives in total in this step, and the previous choice of solution type and material affects which of these seven that are available.

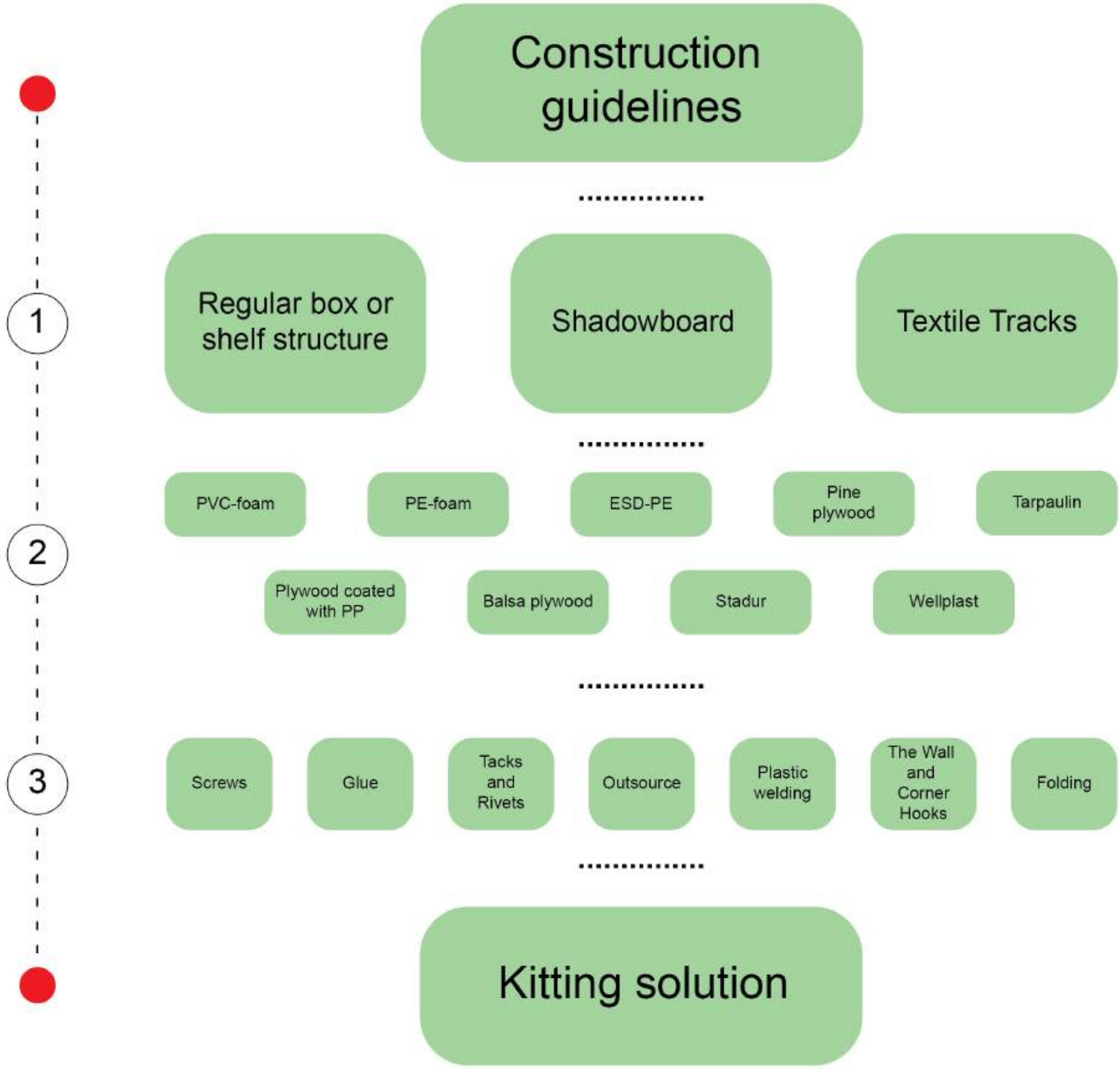


Figure 9.1: A summary of the final outcome and the steps that are required to construct a kitting solution.

9.2 Regular Box or Shelf Structure

This is the most used type of solution by Virtual Manufacturing today and will likely be the most suitable solution to use for most kitting solutions in the near future as well. Regular box or shelf structure means that sheets of one or a few materials are used and assembled together into a box or shelf structure. The box or shelf structure should be more or less dimension stable and is held together without any support from a frame structure. Using a regular box or shelf structure is in many cases the cheapest way of constructing a kitting solution and is definitely the best alternative for insensitive components. If it is important that the components that are stored and transported in the kitting solution need extra protection, be structured in a specific way or needs ESD-protection, Shadowboard or Textile Tracks concepts can be better alternatives. If the solution will be carried around by hand, a regular box or shelf structure will be the best alternative since the other two alternative are not dimension stable or movable in that sense.

If the decision has been made that a regular box or shelf structure suits the specific application better than the other two alternatives, it is time to make the material selection. All materials that can be suitable for this kind of application are shortly presented in Figures 9.2 and 9.3. The figures gives a brief introduction to the materials that are suitable for a regular box or shelf structure. This includes which component classes that the material can be used for which are shown as a colored circle. If a circle is half filled, it means that the material needs an extra layer of another material in order to fulfill that component category, which will be explained further on. An approximation of cost, weight and durability is also shown in the figures which will make it easier to compare the different material alternatives.

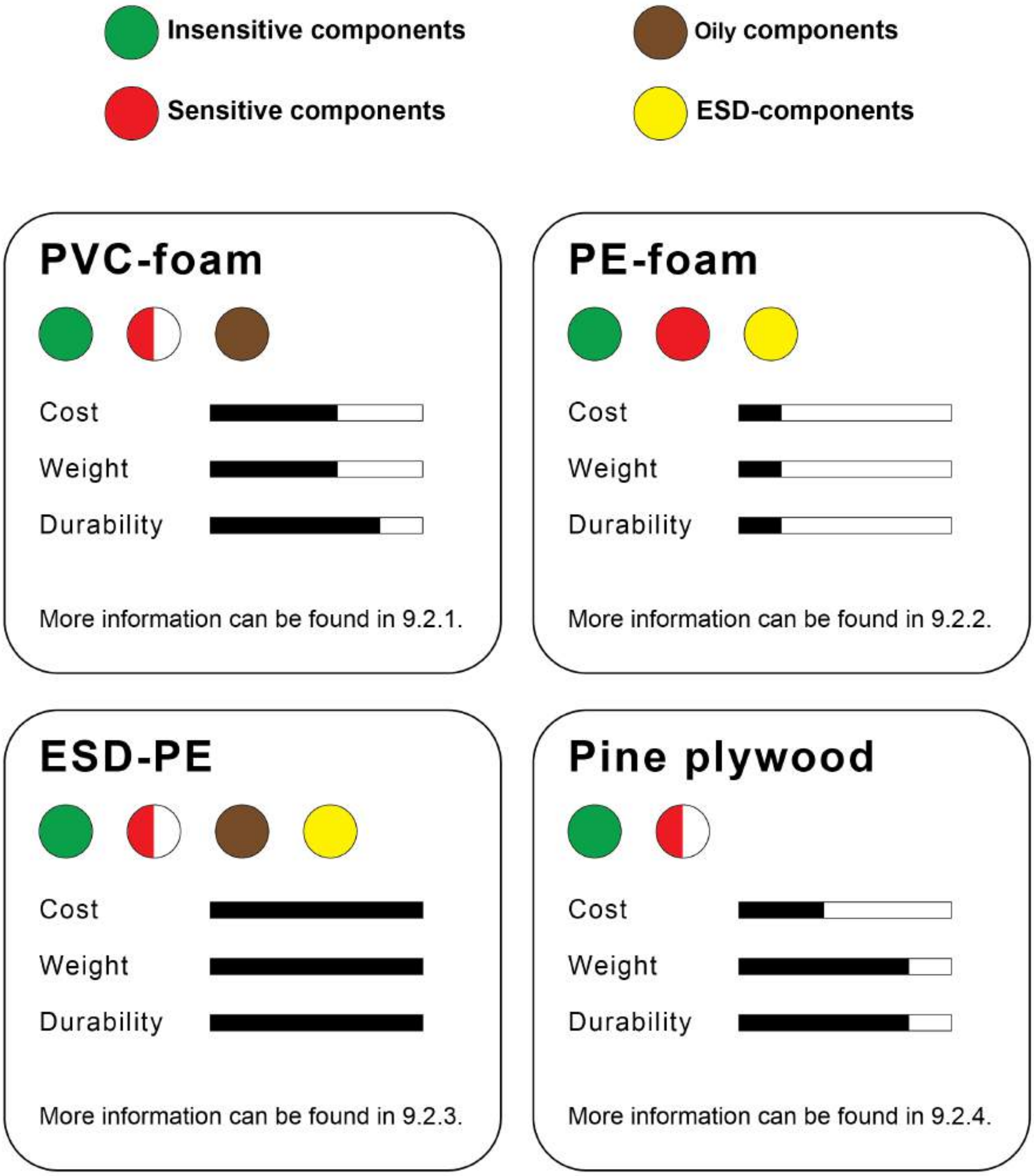


Figure 9.2: A summary of four materials that are suitable for a regular box or shelf structure.

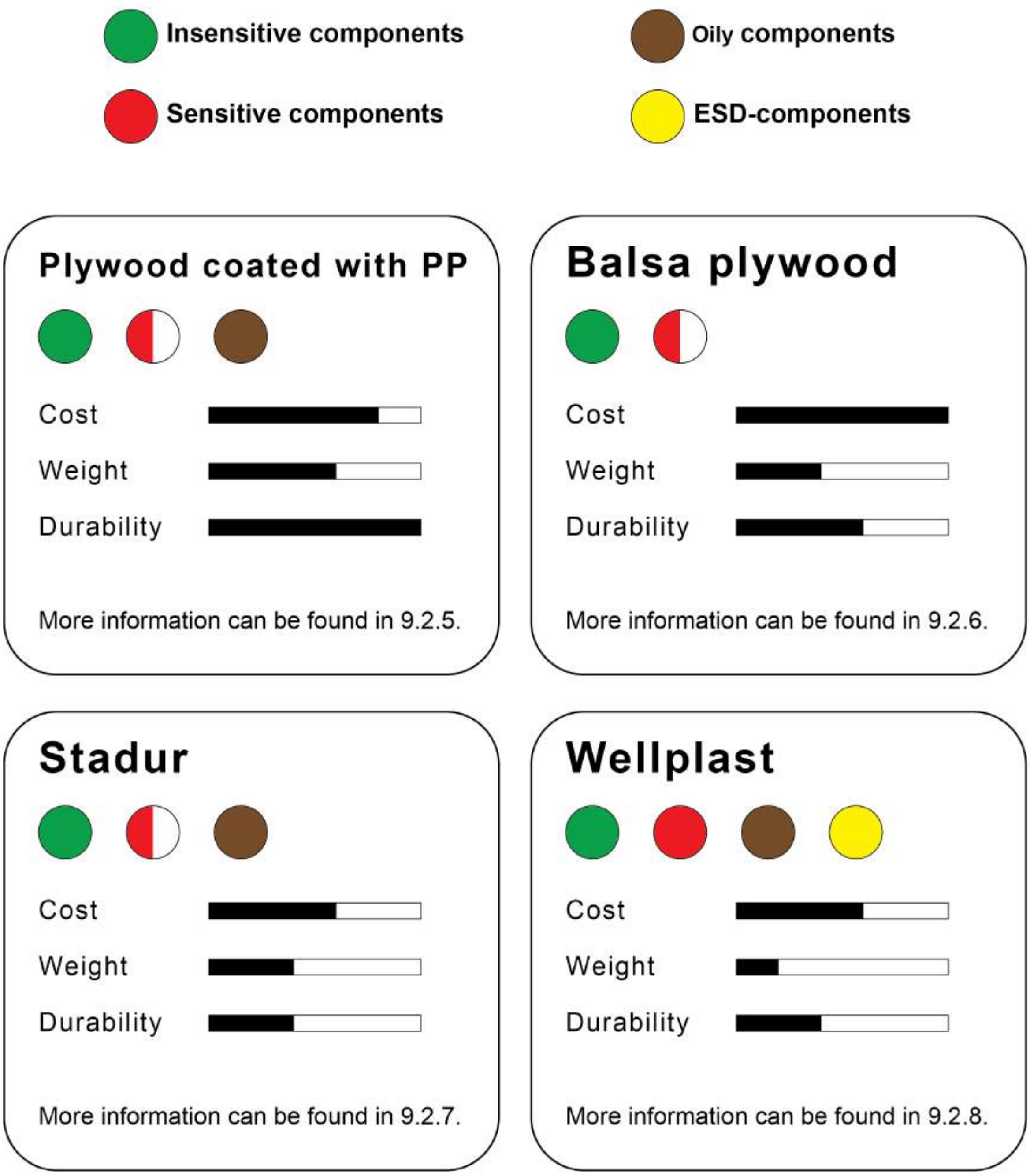


Figure 9.3: A summary of four materials that are suitable for a regular box or shelf structure.

More information about each material including appropriate assembly methods will be presented further on. For more detailed information about the suitable assembly methods that are presented for each material, see Chapter 7. Furthermore, it can be advantageous to combine multiple materials, for example in order to create extra protection or reducing the total weight by combining materials.

9.2.1 PVC-foam

The following list presents the most important information about PVC-foam of the specific sort named Forex PVC-foam. For additional information, see Section 6.1.

- Can be used for insensitive and oily components but also for sensitive components if a thin layer of PE-foam is applied on the surface, see Section 9.2.2.
- Relatively long durability.
- Is available in two variants, Forex Color and Forex Print.
- Costs around 150 SEK/m^2 for a thickness of 10 mm.
- Forex Color has a density around 550 kg/m^3.
- Forex Print has a density around 425 kg/m^3.
- The supplier is Glasfiber & Plastprodukter AB and has a short delivery time [28].
- Forex Color is available in sheets with a thickness between 3-19 mm.
- Forex Print is available in sheets with a thickness between 2-10 mm, see Figure 9.4.
- Can be assembled by The Wall and Corner Hooks, screws, glue, tacks, rivets and plastic welding.
- Another supplier that offers similar materials to a lower price is Vink Esssåplast Group AB [62].

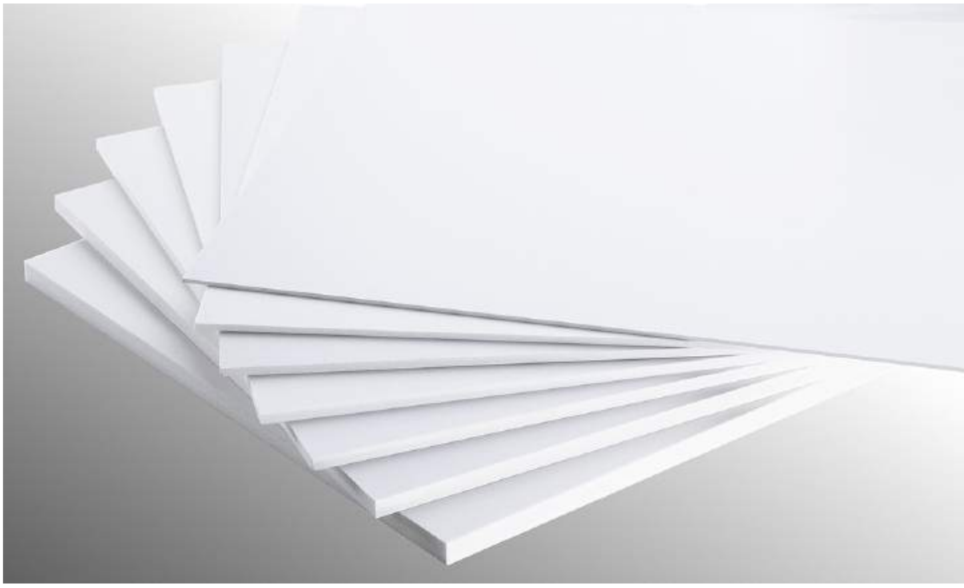


Figure 9.4: Seven sheets of Forex Print in different thicknesses.

9.2.2 PE-foam

The following list presents the most important information about PE-foam. For additional information, see Section 6.4.

- To be used as a protective layer for sensitive components including sensitive ESD-components. Should be placed on top of a harder material since it is a soft material.
- Available in two variants, one that is ESD-classified and one without. The one with ESD-protection is called Plastazote LD30SD and and the one without is called Plastazote LD15.
- Lowest available thickness is 3 mm.
- Plastazote LD30SD has a density around 30 kg/m^3.
- Plastazote LD15 has a density around 15 kg/m^3 and can be viewed in Figure 9.5.
- Plastazote LD30SD costs around 85 SEK/m^2 with a thickness of three millimeters.
- Plastazote LD15 costs around 30 SEK/m^2 with a thickness of three millimeters.
- The supplier is NMC Cellfoam AB and has a short delivery time [63].
- Should be fixated by using glue.

Figure 9.5: A roll with Plastazote LD15.

9.2.3 ESD-PE

The following list presents the most important information about the ESD-PE material which name is PE 500 EL. For additional information, see Section 6.5.

- Primarily meant to be used for ESD-classed components. Works as a cheaper but heavier alternative to Aicelwood with ESD-protection. Additionally, it can be used for insensitive components, oily components or for sensitive components with or without ESD-classification if a protection layer of PE-foam is applied, see Section 9.2.2.
- Has a relatively long durability.

- Costs 453 SEK/m^2 for a thickness of 10 mm when 60 m^2 or more is ordered.
- PE 500 EL has a density around 950 kg/m^3.
- The supplier is Vink Essåplast AB and has a short delivery time [62].
- PE 500 EL is available in sheets with a thickness between 6-150 mm.
- The material is shown in Figure 9.6.
- Can be assembled by The Wall and Corner Hooks, screws, glue, tacks, rivets and plastic welding.

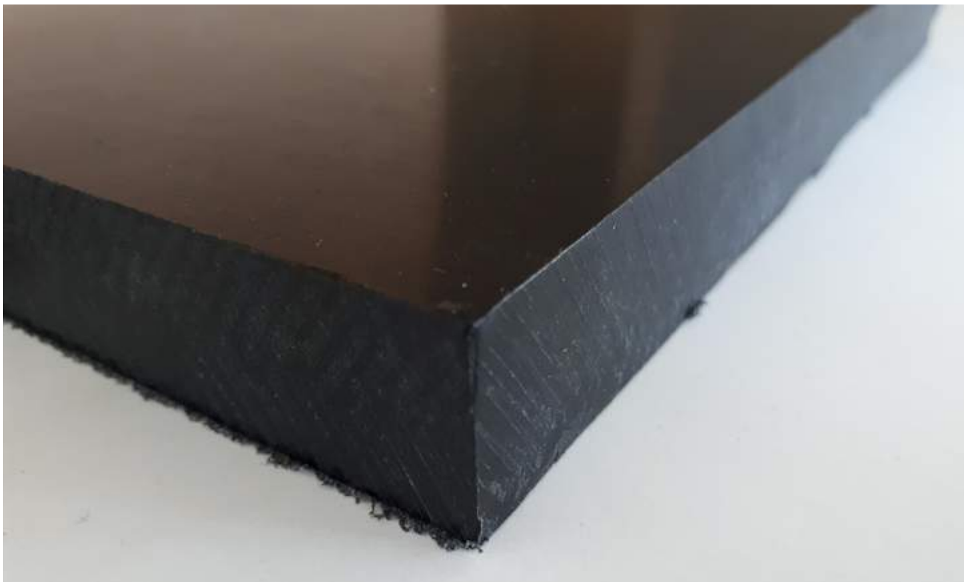


Figure 9.6: A piece of the PE 500 EL which is an ESD-classified material.

9.2.4 Pine Plywood

The following list presents the most important information about pine plywood. For additional information, see Section 6.6.

- This is the cheapest dimension stable material that can be used for kitting solutions.
- Can be used alone for insensitive components. Can also be used for sensitive components if PE-foam is mounted on the surface, see Section 9.2.2.
- Requires that the customer accepts wood materials in their production.
- Pine plywood has a relative long durability.
- Has a density around 870 kg/m^3.
- Costs around 110 SEK/m^2 with a thickness of 10 mm, other thicknesses are available, approximately between 4 to 21 mm.
- Can be bought at most hardware stores, an example of the material from the hardware store Bauhaus [65] is shown in Figure 9.7.
- Can be assembled by The Wall and Corner Hooks, screws and glue.

Figure 9.7: An example of a pine plywood with a thickness of 10 mm.

9.2.5 Plywood Coated with PP

The following list presents the most important information about plywood coated with PP. For additional information, see Section 6.6.

- Can be used for insensitive and oily components. Can also be used for sensitive components if PE-foam is mounted on the surface, see Section 9.2.2.
- Does not require that the customer accepts wood materials in their production since the plywood is coated with PP.
- The material has an excellent durability.
- Has a density around 500 kg/m^3 depending on which type of wood that the plywood is made of.
- Costs 230 SEK/m^2 with a thickness of 9 mm, the material can be seen in Figure 9.8.
- Can be bought from the supplier Kärnsund Wood Link AB with a delivery time around three to four weeks. [64].
- Can be assembled by The Wall and Corner Hooks, screws and glue.

Figure 9.8: The plywood covered with PP with a total thickness of 9 mm.

9.2.6 Balsa Plywood

The following list presents the most important information about balsa plywood which is of the specific sort B-PLEX Light. For additional information, see Section 6.6.

- Consists of a core of balsa with a protective outer layer of beech.
- Can be used for insensitive components, can also be used for sensitive components if PE-foam is mounted on the surface, see Section 9.2.2.
- Requires that the customer accepts wood materials in their production.
- The material has quite good durability.
- Has a density of 210 kg/m^3.
- Costs 464 SEK/m^2 with a thickness of 19 mm, the material can be seen in Figure 9.9.
- B-PLEX Light is available in thicknesses between 12-40 mm.
- Can be bought from the supplier Kärnsund Wood Link AB with a delivery time around three to four weeks. [64].
- Can be assembled by The Wall and Corner Hooks, screws and glue.

Figure 9.9: A picture of B-PLEX Light balsa plwyood.

9.2.7 Stadur

The following list presents the most important information about Stadur. For additional information, see Section 6.8.

- The material has a core of PS and outer layers of PVC.
- Can be used for insensitive and oily components but also for sensitive components if PE-foam is mounted on the surface, see Section 9.2.2.
- The material's durability is relatively bad compared to other materials, such as PVC-foam or plywood, and can not be exposed to rough handling.
- Costs around 140 SEK/m^2 with a thickness of 10 mm.

- Stadur has a density around 210 kg/m^3.
- The supplier can for example be Glasfiber & Plastprodukter AB, who has a short delivery time. [67].
- The material is available in sheets with a thickness between 5-19 mm.
- Two sheets of Stadur is shown in Figure 9.10.
- Can be assembled by The Wall and Corner Hooks, screws, glue and folding.
- Another supplier that offer a similar material to a similar price is Vink Esssåplast Group AB [62].

Figure 9.10: A picture of the material Stadur.

9.2.8 Wellplast

The following list presents the most important information about Wellplast. For additional information, see Section 6.2.

- The material has a core of PP and chalk.
- Wellplast is available in different versions which makes it possible to use the material for insensitive, sensitive, oily and ESD-classified components.
- The material's durability is relatively bad compared to other materials, and can not be exposed for rough handling during long time.
- Complete box or shelf structures need to be bought, a typical box made of 0,4 m^2 material costs around 355 SEK. The material will be more expensive in ESD-format.
- Wellplast weighs around 0,43 kg/m^2 with a thickness of 3,5 mm.
- The supplier is Wellplast AB and has a relative short delivery time [37].

- The material is mainly made in thicknesses around 3,5 mm, but can be produced in other thicknesses as well.
- A sheet of Wellplast is shown in Figure 9.11.
- Can be assembled by glue and folding.

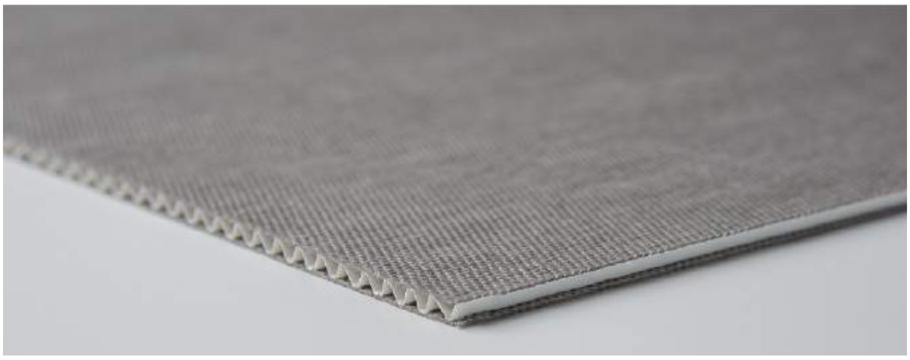


Figure 9.11: A picture of the material Wellplast.

9.3 Shadowboard

This is a solution that is suitable to use for components that are sensitive and needs extra protection, need to be clearly structured or that are small and easy to loose. Shadowboards can also be made with ESD-protection. A shadowboard is more expensive than many of the regular box or shelf system solutions. The price differ for example due to size, number of components that will be stored in the solution and how many shadowboards that are ordered. For example, a shadowboard that has the dimensions 800 times 1200 mm and has space for 30 components costs around 3500 SEK. A smaller shadowboard with the dimensions of 400 times 300 mm costs around 400 SEK. The most used material for shadowboard is various kinds of PE-foam. A possible supplier of shadowboards is Kongsberg Emballasje, located in Norway [73]. A typical shadowboard that the company can provide is shown in Figure 9.12. The delivery time for this kind of solution will probably be relatively long since the supplier first needs to mill or cut the holes for the components and then send the shadowboards to Sweden. On the other hand, the required work from Virtual Manufacturing will be lower since another company produces the solution.

A shadowboard is a lightweight solution since the foam that is used has a low weight, approximately somewhere around 30 kg/m^3. In some cases, additional materials could be needed, like a bottom plate, since a shadowboard is not dimensional stable in itself. The shadowboard is available in many different thicknesses. The durability of a shadowboard can be inadequate if it not is handled with care since the foam is soft and can be damaged, especially by sharp objects. If the shadowboard is handled with care, it will probably have enough durability but in many cases, a regular box or shelf structure will create a more durable solution with most of the materials.

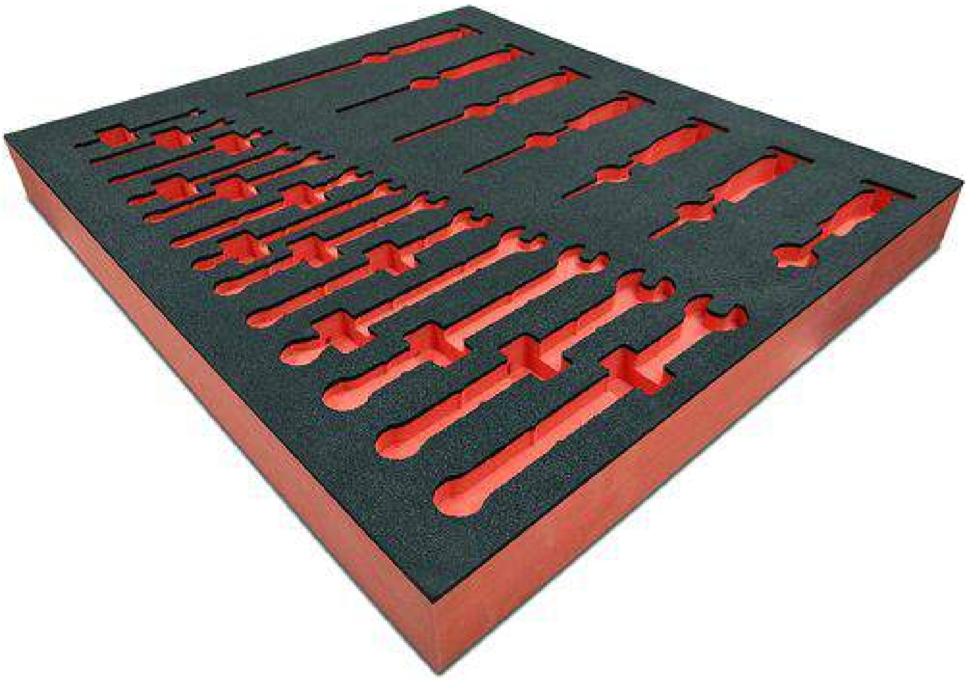


Figure 9.12: A shadowboard like the ones that Kongsberg Emballasje provides.

9.4 Textile Tracks

This solution is suitable for components that are sensitive or for various reasons need to be sorted in a shelf system, but the solution can fit every of the four component classes. conTeyor is a supplier that can provide a wide range of different tarpaulin and textile solutions for this situation and is the best alternative if large volumes are needed [78]. One example of conTeyor's customized kitting solutions in tarpaulin is shown in Figure 9.13. The seller at conTeyor refused to give a cost estimation of this type of solution, so that is not available. ConTeyor can provide Textile Tracks solutions that can contain insensitive, sensitive, oily and ESD-classified components. When the order volume is smaller, Lindevalls Industri AB [71] or Hansson-Kapell AB [72] are examples of more suitable suppliers. These local suppliers can provide and customize tarpaulin or other textile materials for Virtual Manufacturing's kitting solutions.

A Textile Tracks solution has a relatively good durability depending on the tarpaulin's properties and how it is used. The weight of this kind of solution will be remarkably lower than if it is a regular box or shelf structure. The delivery time is long for this kind of solution, conTeyor has for example a delivery time around 10-12 weeks. The solution will be assembled through stitches or glue. Depending on the supplier of The Textile Tracks, the solution can be delivered completely finished. Otherwise, some processing work will be needed. Nevertheless, most work will be done by the suppliers which will reduce the amount of time that Virtual Manufacturing needs to work in order to create this kitting solution.

Figure 9.13: A picture of a Textile Tracks solution from conTeyor.

9.5 The Wall and Corner Hooks

The two concepts have been developed from scratch throughout the project. These two concepts can be used in different situations, either separately or together. The Wall Hook should be used when it is desirable to rearrange the interior of the kitting solution during its lifetime. It can also work as a replacement for screws when fastening the inner walls. A rendering of The Wall Hook is shown in Figure 9.14. The Corner Hook can for example be used when kitting solutions are folded together and for less dimension stable materials, since it provides structural support and a more convenient assembly approach. A rendering of The Corner Hook is shown in Figure 9.15. Both concepts build on the same modular principle and can easily be redesigned to fit different situations. The cost per part for 3D-printing these in ABS plastic is 25 SEK for The Wall Hook and 60 SEK for The Corner Hook. If the order volume exceeds approximately 5000 pieces of one of the sorts, injection molding will be a cheaper manufacturing method of The Wall and Corner Hooks. The weight of The Corner Hook will be about 20 grams and 8 grams for The Wall Hook. For more information, see Chapters 7 and 8.

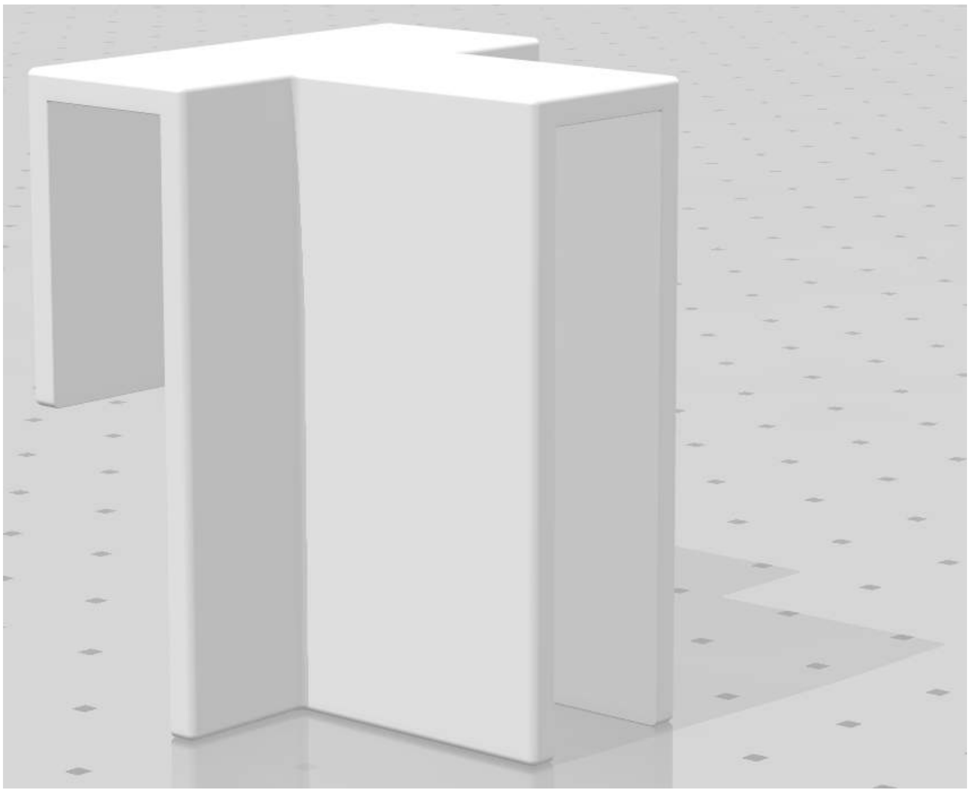


Figure 9.14: A rendering of The Wall Hook.

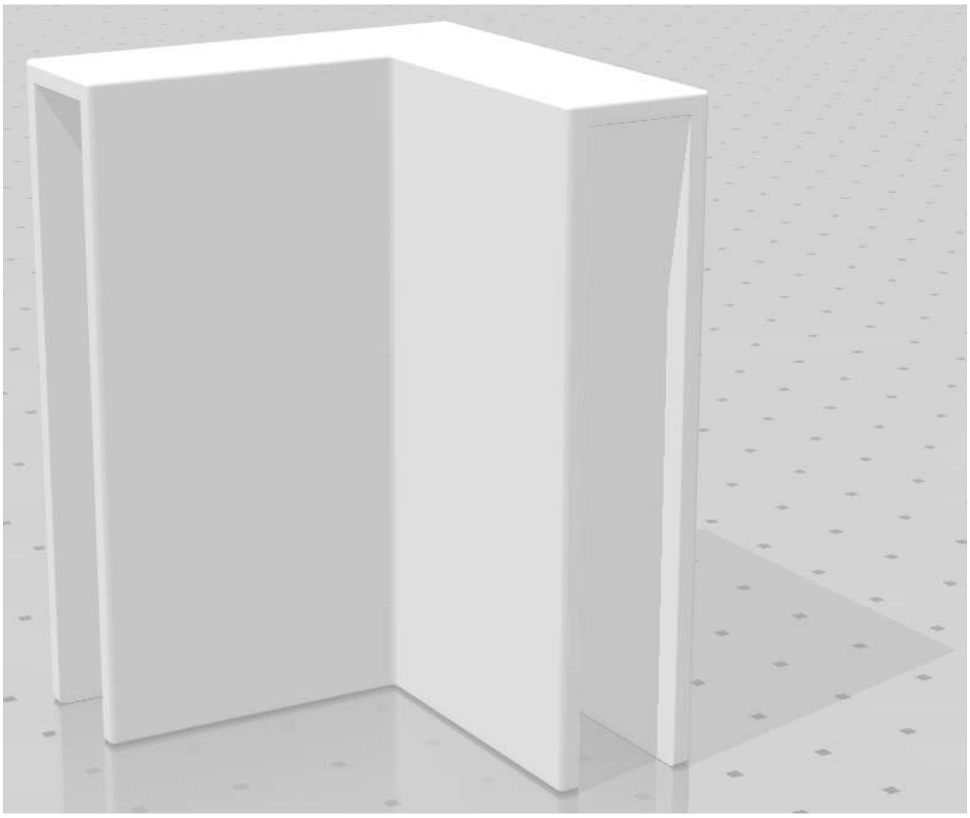


Figure 9.15: A rendering of The Corner Hook.

9.6 Fulfillment of Project Objectives

This section aims to reconnect to the objectives stated in the beginning of this report, and how the development approach has led to the results that fulfill these. The objectives are listed below and can also be found in the first chapter of this report, see Section 1.5.

- Investigate materials, components and manufacturing strategies that can be applied to the design process of kitting solutions
- Provide guidelines for how the construction and production departments at Virtual Manufacturing should manage their kitting solutions in relation to their customers
- To come up with a cheaper solution
- To develop a more versatile solution

A thorough investigation of potentially useful materials and concepts has been conducted in order to see if this can result in beneficial changes in the design process of kitting solutions for Virtual Manufacturing. This has been done through a research of the situation, including relevant users and a benchmarking study, which resulted in two requirement specifications. These worked as guiding frameworks throughout the entire material search and concept development phases. The most successful materials and concepts has been evaluated and furthermore assessed in a clear and comprehensive way to provide Virtual Manufacturing with guidelines. These guidelines should support the company in making faster and more accurate decisions, while being cost-efficient and able to provide versatile solutions that bring more value to their customers. Thus, the objectives are therefore fulfilled.

In order to reach the objectives, the two requirement specifications have been important tools that have been updated and used throughout the project so that no important stakeholder opinion was missed to be processed. The requirement specification of construction guidelines has been taken under consideration during the creation of the construction guidelines and the requirements have been fulfilled in the best possible way. There was a lack of information in some few cases that led to that a small amount of information is missing. It is difficult to determine if the requirement specification of materials and concepts is fulfilled since a wide range of testing during a long time needs to be conducted to confirm this, but there will at least be one material and concept that fulfills a specific point in the specification. It will therefore probably not be any problem to provide a kitting solution that fits each specific customer and their requirements.

10 Discussion

During this chapter, the overall development process as well as more specific parts of the project will be discussed. Challenges and problems that have emerged during the project are discussed and also parts that have been successful during the project. The discussion will first handle the general approach of the project and then the different parts of the project will be discussed separately.

10.1 The Project's Process

The process that was decided to be followed early in the project was a rather traditional product development process. Some changes were made so that the process would fit the wider development and search of both concepts and materials. The way of structuring the work process was the first major challenge in the project and it occurred during the first weeks. In most product development processes, a specific product or concept will be developed with one or a few final concepts that will be developed in detail. This project's outcome should instead consist of several concepts and materials which required a more holistic process that enables a wider final result. Much of the project's time was therefore assigned to investigating and testing a wide range of different materials, which was a relatively new experience. This holistic way of working was hard to condense into a comprehensible and clear result, and a more specific and defined objective would probably have been beneficial for the project. Previous knowledge from various product development projects was important in order to decide how the projects process should be structured, but it was hard to tell if it was the most optimal approach. Nevertheless, the decision to make a wide concept generation and material search simultaneously seems to have been beneficial as it yielded results that corresponded well to the stated objectives of the project.

Virtual Manufacturing had not finalized their expectations when the project started so the general project approach needed to be adjusted slightly throughout the project. This was a challenging experience but a useful one since it probably usually happens in the industry. The time plan of the project was created with the previous experience from other product development projects that have been a part of the education. The time plan was successful since it was followed without any major problems and led to that the project was finalized when it was planned. However, some ongoing work with prototypes and established supplier contacts had to be transferred over to Virtual Manufacturing, so that this can be continued with in the future. The planning that was made in the beginning of the project, including the time plan, was important so that there always was something to relate to. Simultaneously, useful changes were made continuously in order to optimize the project's outcome. The planning phase was not a new experience but once again, it was easy to realize the importance of planning since the plan has always been a support throughout the project, even if it not has been the absolute truth all the time.

10.2 Market and User Needs Research

The information available about users of kitting solutions was limited due to the fact that it is not a consumer product, which makes it more difficult to get in contact with certain stakeholders, such as Virtual Manufacturing's customers. A kitting solution in itself is a wide concept that can differ a lot in sizes, shapes and materials which makes it even more difficult since there is no standardization at all at the market. Nevertheless, benchmarking other companies and areas that deliver kitting solutions gave an overall understanding of the current market situation and how product offerings differ between competitors. It was also useful to investigate similar solutions that are used in other contexts since that gave inspiration for the concept development. The investigation and literature search of modularization also gave useful knowledge that was used during the concept development since a modular type of solution would be beneficial in many ways.

The user study was divided into three parts, the designers at Virtual Manufacturing, kitting solution manufacturing visit and three customer visits. The interviews with the designers at Virtual Manufacturing resulted in a lot of knowledge of how they work and what they expect from this project. This was fundamental information that was important in order to create useful guidelines for them. Regarding employees at Virtual Manufacturing, information from them was more accessible as the project was conducted in their facilities, which was a great asset during the project. Nevertheless, the final outcome would probably have benefited from more regular and frequent commitment from the company itself. The visit of Virtual Manufacturing's manufacturing facility in Linköping gave knowledge about how their work can be eased but also which limitations that the facility had which was needed to be taken under consideration throughout the project. The customer visits at customers gave a lot of useful insight of how the kitting solutions will be used further on. One problem that emerged during the customer visits was that the operators and other employees that were using the kitting solutions were assigned to their shifts during most visits, so interviews had to be held with contact persons to Virtual Manufacturing, which may not have been optimal in every case. The project would probably have benefited if the customers were better prepared and informed in general about our project and what the purpose of it was, so that they could see the value of contributing to it.

10.3 Material Search and Concept Development

The biggest challenge that occurred during the material search and the investigation and determination of materials was lack of information due to poor responsiveness or disinterest from suppliers and producers. When the contact was made to suppliers and producers of materials that were interesting, they were in many cases not interested to speak with students since that does not directly lead to profit from the company's point of view. It was mentioned that Virtual Manufacturing wants to find new materials to their applications but the possible future order quantities are relatively low and therefore, other customers could be more prioritized for suppliers. This unwillingness of corporation from many companies has unfortunately affected the project in a negative way since most information that has been of interest has been difficult to get. Nevertheless, several good relationships between suppliers and producers of materials and assembly methods have been created throughout the project which has been helpful. This can be built upon in the future with continuous commitment from Virtual Manufacturing.

The lack of information of materials was difficult to manage as it sometimes could be misleading. For example, if a material is used for another application, such as house building situations, it is not sure that the specific material also will be a suitable alternative for kitting solutions. The process of ordering material tests and then making physical testing of the materials against the requirement specification gave a lot of knowledge, which has been really useful throughout the project. To have the opportunity to physically feel the material gives a better understanding than just reading about the material properties.

Several sources of information were used for the material search, which included literature studies, consulting a material professor and suppliers and two extensive searches in material databases, which was complemented with more open web searches. Considering the nature of the project, it was useful to have as many possible sources of information as possible to learn about potentially useful materials and to make connections with suppliers. The concept generation was made through several methods during approximately a month which was important in order to come up with as many useful concepts as possible. A major problem was that it is a simple kind of product that has been developed and investigated, which made it hard to come up with useful and creative concepts that are not too complicated for the application.

10.4 Material and Concept Selections

The screening process was important since a lot of materials and concepts have been found or developed during the material search and concept development. It was therefore important to make a first screening of the materials and concepts, and the elimination matrices that were used ensured that all requirements in the requirement specification of materials and concepts were fulfilled for the materials and concepts that passed the matrices. The concepts were then further screened through a Pugh matrix which ranked the concepts which made the further screening easier. Multiple Pugh matrices could have been made so that the concepts would have been compared to different reference concepts but since the Pugh matrix that was used only was a guidance rather than the absolutely truth, only one Pugh matrix was made. Instead, the concepts were analyzed and the decision if a concept would pass the gate or not was made in combination of the analysis and the result from the Pugh matrix. This felt like a reasonable way to move forward since the result of screening matrices depend on the discussions and interpretations of the input, not the number of matrices used.

The material was tested through a physical test that tried to test most of the requirements and desires from the requirement specification of materials and concept. The learning from the testing was that it is useful to make physical testings if possible since a deeper knowledge is gained that otherwise is difficult to get. However, this is dependant on being able to get samples of each material, which has been difficult. The mapping between concepts and materials that ended the concept and material selections chapter was useful to make since it eased the further investigation and development of materials and concepts. The mapping demarcated the possible material and concept combinations which made it easier to spend the time in a more efficient way, as the results until that point had been quite general.

10.5 Investigation and Determination of Materials

The materials were further investigated and determined since there in many cases existed a lot of different sorts of the specific material which includes a wide range of suppliers and producers. Since this project did not aim to find a specific supplier that has the cheapest prices, best delivery time, best services etcetera, the investigation was made concise. This means that the suppliers or the producers that the report is presenting for a specific material not necessarily needs to be the most suitable for Virtual Manufacturing. All suppliers or producers that have been found fulfill the requirement specification of concepts and materials but there could have been more suitable suppliers or producers if a deeper investigation was made. The unwillingness from many suppliers and producers made this part of the project more difficult as previously mentioned, although some good relations to some companies resulted in a lot of useful information for Virtual Manufacturing. There were a few cases where more information would be advantageous to have, but when interesting companies were contacted several times through different methods without any response, it was hard to argue for any other alternative than leaving out some information that could have be useful.

10.6 Final Development of Concepts

Some concepts needed more development than others since they where more or less finished. The concepts The Wall and Corner Hooks needed a lot of development since they were new assembly methods that had not be used for this kind of application before. It was challenging but fun to develop concepts from scratch since this project otherwise almost only consists of existing materials and concepts. It will be easier for Virtual Manufacturing to use existing things but it is important to show that there can be other types of solutions in the future as well that can be advantageous. Especially if the cost of 3D-printing will drop since it will be easier to make customized solutions in a smaller scale to a competitive price. It feels great to present solutions that both are easy to implement and use but also solutions that may be more difficult and take longer time to realize but has a bigger potential. Since there were many concepts and materials that have been taken under consideration through this part of the project, a deeper investigation or development would be desirable in some cases but the width of the project made it difficult to perform. Instead, the resources have been carefully divided so that the project result will be as useful as possible for Virtual Manufacturing.

10.7 Prototype Building and Testing

It is always interesting to build and test prototypes but the lack of time for several test iterations is a common problem in most projects in product development, and so was the case for this project. The kitting solutions should have a durability of at least five years, which is mentioned in the requirement specification of concepts and materials. This is hard to confirm or control within the scope of one particular project, which makes durability tests reliant on individual estimations and evaluations from short test periods. Similar problems also occurs with other requirements. The testings conducted at Volvo Cars at least gave an idea if it is reasonable that the kitting solution is durable or not since the testing was conducted in a real industrial environment. Making prototypes is also a good way of visualizing concepts or materials for the projects stakeholders, which makes the step to implementation later on easier. The early testing that was made with the lean product development philosophy gave a lot of knowledge that was usable in order to determine if a concept or material were suitable for a certain application. Some early prototyping was therefore presented while it was happening during other chapters than the prototype building and testing.

10.8 Final Outcome of the Project

The final outcome is a direct effect of the support from different suppliers and producers of materials and assembly equipment. If more companies that were contacted during the project had responded, it is very likely that the project result would benefit from this. This means that more potentially useful materials could have been found. The final outcome of this project will regardless have a wide range of alternatives for Virtual Manufacturing which leads to that a customized kitting solution can be constructed for customers of Virtual Manufacturing.

The project has sometimes suffered from the lack of support from Virtual Manufacturing which resulted in that the projects outcome may not deliver some of the expected outcome. The company had problem to explain what kind of information that they want since different employees at the company have asked for separate things but all opinions have been taken under consideration in order to deliver a useful result for every part. The project has been conducted in the best possible way with the prevailing conditions but another result would have been possible if Virtual Manufacturing had specified the project more clearly. This means that the company could maybe suffer from that the project result does not match their expectations in some specific parts.

The guidelines have been developed with help from the information that has been available and will make a difference for Virtual Manufacturing to meet each customer's requirements and desires. It has been important throughout the project that there always will be at least one concept and material that fits a certain customer's requirements. It has therefore been important to divide the components that the kitting solutions will contain into four different categories since that has eased the process of having an alternative concept and material for each customer. The problem related to this is that there are a lot of concepts and materials that needs to be taken under consideration for Virtual Manufacturing which will require a large amount of tied capital in stock or long delivery times for the end customer. Regardless, it has been important for Virtual Manufacturing that there will be a solution for every customer so a lot of alternatives are a direct effect of customized products to customers that has a wide range of needs.

The chapter about the final outcome of the project has also mapped how the project's objective and the requirement specifications are related to the outcome of the project. This is an important comparison since it is useful that Virtual Manufacturing knows if some parts are missing so that they can spend time in order to fulfill the gap or that they at least are aware of it. It is gratifying that the objectives are fulfilled and that the requirement specifications also are fulfilled in the best possible way with the current conditions. Things can always be performed in a better way by taking a second look, but the general perception is that the project has met the objectives and fulfilled the expectations in a satisfying way.

11 Conclusion

This chapter consists of two parts, first a conclusion of the project that contains a summary of the project's most important findings. This includes recommendations that can be implemented immediately, and are direct results of this project. The second and last part of the chapter concerns further work, which includes recommendations for areas that have not been fully covered within the scope of this particular project, but should be taken under future consideration by Virtual Manufacturing. The most important findings are summarized as a recommendation after the specific paragraph.

11.1 Conclusion of the Project

The major part of this project was to find new materials that are better than the materials that Virtual Manufacturing use today. The absolutely most used material was PVC-foam which turned out to be a really competitive material for kitting solutions. It was therefore a difficult task to find better materials but through a wide search and investigation about materials, several alternatives were found that have better properties in at least one category, which for example can be cost or weight. No material that was found had better characteristics than PVC-foam for every property. Consequently, Virtual Manufacturing had found the useful and competitive material PVC-foam before this project was started, which is a good thing regarding their current material library. Another material that Virtual Manufacturing has used a lot is Aicelwood which has a cost of approximately 10 times more than PVC-foam which is not motivated. Aicelwood protects sensitive components in a good way but does not have a much better durability compared to PVC-foam. There are instead cheaper and better alternatives than Aicelwood like the concepts Shadowboard and Textile Tracks or a kitting solution in Wellplast. To cover a material with PE-foam is another way of creating a cheaper solutions for sensitive components than Aicelwood so there are several alternatives that can completely replace the material.

Recommendation: *Continue to use PVC-foam but stop using Aicelwood.*

The prototypes that were tested at Volvo Cars, made of the material Stadur, were too brittle and did not survive in the tough industrial environment that Volvo Cars has. More testing could have been made, which probably would have given a better result but the lack of time made it impossible to fit in. In fact, solving the company's problem with their kitting solutions could have been a separate master thesis. Three other companies including Virtual Manufacturing have tried to make a useful kitting solution for Volvo Cars but none of them has succeeded so far. The project's investigation of materials shows that there has been a problem in finding a material combined with an assembly method that is enough dimension stable, durable, lightweight and provided to a low cost so that Volvo Cars all requirements are fulfilled. Throughout the project, several other suggestions of how to solve Volvo Cars problem have been made. They are presented in Section 8.1 and are built upon the construction guidelines. Other kinds of solutions can probably be developed as well with support from the construction guidelines.

Recommendation: *Use the suggestions and construction guidelines in order to solve Volvo Cars problems with their kitting boxes.*

It is important that the designers at Virtual Manufacturing use the construction guidelines in the report continuously for every situation when a customer orders a kitting solution. The reason why is that the company otherwise risk to come up with the old kind of solutions that in some cases not are the optimal ones. The guidelines have not been created to be used only when the designers are unsure of how to design a kitting solution. There is of course room for interpretations and in some cases, the designers' experiences are also important to make an optimal kitting solution for a customer, but the guidelines should always be a basic part of the construction process. It is also important that more exchange is needed between the designers and the manufacturing employees since they all seem to suffer from the other part since, due to lack of knowledge in some cases. The designers at Virtual Manufacturing should therefore spend more time in the company's manufacturing facilities and the manufacturing employees should more often visit companies that use the kitting solutions that they produce. This exchange will probably lead to a gain of useful knowledge.

Recommendation: *The designers at Virtual Manufacturing need to use the construction guidelines continuously and the exchange between the designers and the production employees needs to be increased.*

One important thing that Virtual Manufacturing needs to do is to contact Vink Essåplast Group AB since they offer the same kind of materials but to a lower price than the current supplier to Virtual Manufacturing does. Vink Essåplast Group AB prices are around 17 % lower than the currently used supplier Glasfiber & Plastprodukter AB and they also offer more processing alternatives for the materials. Since Virtual Manufacturing buys PVC-foam for about 250 000 SEK to 300 000 SEK each year, the yearly savings would be around 50 000 SEK if they change supplier which is a strong advise. If Virtual Manufacturing notifies the current supplier that another company offers the same products to a considerably lower price, they could probably decrease their prices in order to keep Virtual Manufacturing as a customer. The project has tried to find all relevant plastic suppliers in Sweden so the probability that there is another plastic supplier that offers even lower prices are low but can not be rejected.

Recommendation: *Start to use Vink Essåplast Group AB as a supplier for plastic materials.*

It will be beneficial for Virtual Manufacturing to buy a plastic welding machine which will make it possible to weld some of the plastic materials together, for example PVC-foam which is the most currently used material. The plastic welding creates a stable construction that does not contain any sharp fasteners which is the case if for example screws are used. The initial cost for buying a plastic welding machine is about 4000 SEK which is a relatively small investment. Screws and other fasteners will continuously need to be used in some situations when it is difficult to get access with the plastic welding machine, for example in narrow spaces. The plastic welding method will also need some initial practise in order to understand how to use the tool in the best way. The production personnel in Virtual Manufacturing's production specifically asked for a plastic welding machine and since this project concluded that plastic welding will be possible in many situations, Virtual Manufacturing should buy a plastic welding machine.

Recommendation: *Invest in a plastic welding machine and thereby use plastic welding as an assembly method.*

An assembling or production method that Virtual Manufacturing needs to continuously investigate is 3D-printing. The project has concluded that the cost of 3D-printing kitting solutions, which often are big and have relatively simple shapes, is too expensive today. The price of 3D-printing is continuously dropping and the technique is more and more developed which probably will open for possibilities in the future to use the method. Since the kitting solutions that Virtual Manufacturing in many cases are producing are customized and produced in a small scale, the possibilities to use 3D-printing increases since the method mainly fits prototype building or small scale production.

Recommendation: *Be continuously updated about 3D-printing.*

11.2 Further Work

The Wall and Corner Hooks are assembly methods that have been developed during the project so that they can assemble walls by themselves or together with the method folding to completely create a box structure with a wall thickness of 10 mm. If other thicknesses are used, The Wall and Corner Hooks needs to be slightly redesigned so that the concepts can be used with respect to the wall thicknesses. Two different manufacturing methods of the concept are presented in the project, which are injection molding and 3D-printing, but further work will be needed to start to produce the concept. The concept is more like a principle of how to assemble a structure so there will be cases when The Wall and Corner Hook need to be more redesigned to work for different applications. The combination of folding the material Stadur and use The Wall and Corner Hooks to fixate the solution will also need some further development which could be a usable way of producing box structures. It is recommended to continue this development together with Vink Esssåplast Group AB since they can help in providing this type of solution.

Recommendation: *Continue the development of The Wall and Corner Hooks.*

The project investigated different types of sandwich materials which makes it possible to have a durable material that still is light and dimension stable. Unfortunately, it was difficult to find suppliers or producers of these kind of materials but sandwich materials can be a good alternatives for lightweight constructions, at least when the customer is willing to pay a relative high price. Sandwich materials are therefore something that would be beneficial to further investigate. Volvo Cars had problems with their kitting solutions as earlier mentioned and their problems could maybe be solved with some kind of sandwich material as well. Further analysis and development of a solution for Volvo Cars kitting solutions will also be appropriate but the solving of Volvo Cars problem could, as stated before, be a separate master thesis.

Recommendation: *Further investigate appropriate materials, such as sandwich materials.*

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A Appendix

A.1 User Studies

A.1.1 Designers at Virtual Manufacturing

The interviews were conducted in Swedish so the notes from the interviews are therefore in Swedish. A summary of the interviews are presented in chapter 3.2.

The first interview was with Anna Andersson which is one of the two product developers at Virtual Manufacturing.

Hur ser arbetsflödet ut generellt, från order till avslutat projekt eller lösning?
En kittingvagn, får måtten på hur stora lådorna är, kan få fyrkanter i en ritning. Använder det som underlag för att rita upp det i Catia. Kunden får sen en ritning på hur vagnen ser ut, och när de godkänt den, då bestämmer kunden om de vill ha den eller inte. Nya kunder har ofta skickat ut ritningar till många företag, sen bestämmer dom sig utifrån vem man får bäst "deal" med. Vissa beställer alltid oavsett hur offerten blir, arbetet är lika noggrant oavsett om Virtual Manufacturing vet att kunden vill ha det eller ej. Max 2 timmar, annars flaggas det till säljaren att det tar längre tid, kunden kan få börja betala för den extra konstruktionstiden om de köper kitvagnen sen. Ibland finns fasta mått för vagnen, typ för materialtåg, ibland får det bli så stort som det krävs. Om det ska skäras så ska det vara en part för varje del (enskilda delar kan t.ex fräsas, och då behöver man "produktionsbereda" delarna), annars inte. Man får förfrågan, kunden godkänner, kunden får en offert, kunden beställer. Finns val i material, kostar olika mycket, så kunden bestämmer. Gäller att inte vara dumsnål när kunden väljer vagn så att de blir hållbara. Efter ordern görs tillverkningsunderlagen.

Hur ser ordrarna från kunderna ut?
Det är olika, ibland får vi en ritning i en sketch och ibland får vi reda på vilka delar som ska transporteras i vagnen. Det är olika med hur ambitiösa kunderna är och hur mycket tid de har.

Varierar det mellan olika kunder hur orderspecifikationen ser ut?
Ja, ibland får man bara beskrivet i ett mail vad dom vill ha. Annars får man 2D bilder/ritningar och förklaringar för hur de vill ha det.

Hur påverkar kunders olika "approacher" ditt arbetsflöde?
Det är tiden, ju mindre info desto svårare är det. Kan få stepfiler på det som ska ligga i lådan och då lägger jag i det för att se hur stora lådorna behöver vara. Det ska vara tydligt synligt.

Vilken information avgör hur lådan ska konstrueras och vilket material som ska användas till kitlösningarna?
ESD (electrostatic discharge), om det ska vara reptåligt, inte repa detaljen i lådan, oljiga detaljer i lådorna, färg (svarta detaljer, inte svart låda). Kunden kan få bestämma priskategori.

Vilka material används idag?

- Aicelwood, kan slå på det med hammare, repas inte, kan inte gå sönder, används mest för fixturer istället för POM. Materialet kan bearbetas som trä och finns i ESD-format. Aicelwood är gjort av PE plast och Kommer i plattor. Materialet är det dyraste som Virtual Manufacturing använder.
- Skummad PVC, kan kläs med filt med dubbelhäftande tejp på baksidan, billigare men inte lika bra på alla punkter. Kan slås sönder, om man slår emot med en hård axel.

- Wellplast, vikta lådor, utvidgas. Ganska billigt material. Kan slutpris men inte tillverkningskostnad. Ungefär 1500 kr för en större låda med fackindelning.
- Båtkapell, segel, tyg, till fack, lätta produkter typ nackstöd.

Använder mest skummad PVC (cirka 95% av alla kitlösningar). Aicelwood, skummad PVC och Wellplast (dyrt-billigt). Lätt att bearbeta PVC, kan dock spricka om man tappar något tungt i lådan/kitvagnen. Mycket sprödare än Aicelwood. Aicelwood "formas" bara, mkt mjukare/segare än skummad PVC. Ska gå att bygga om och det flisar inte. Får inte gå sönder framme vid operatören. När man skruvat i skummad PVC några gånger så fäster inte skruven längre (blir så till slut). De skruvar och limmar främst den skummade PVC, Aicelwood skruvas, måste rugga upp ytan för att limma så att det sätter sig i materialet. Nitar ofta också genom den skummade PVC.

Kitlådan trycks in och skruvas fast. En till två millimeters spel på varje sida behövs. Svart och vitt (gult Aicelwood) är färgerna. Enkelt för kunderna att bestämma sig om man begränsar valfrihet.

Virtual Manufacturing vill ha ett större materialbibliotek, bättre koll på marknaden. Bättre monteringsprocess hade varit önskvärt. Wellplast levererar färdiga lådor som är ihopvikta från ett ark.

Verifierar kunderna kitvagnens design innan produktionen börjar?
Ja, via ritning, kostar den 30000 kronor så kan det bli i VR (hos Virtual Manufacturing).

Hur påverkar deadlines ditt/ert sätt att jobba?
Ibland påverkar deadline konstruktionen, kunden kollar inte hur stora delar som ska vara i lådorna. Lättare att det blir fel.

Vad vill du ska vara med i guidelines? Vilka faktorer är viktiga för dig/er? Hur ska den assistera dig i ditt dagliga arbete?
Priset är en viktig faktor, inköpspris. Har leverantören det på hyllan, hur snabbt kan vi få det? Har rabatt hos vissa kunder om man köper mycket material. Vilket material ska det vara för olika komponenter. Leverantören bör finnas med. Tar mycket tid att leta material. Kostar mer i början innan man har köpt mycket.

Arbetar ni två produktutvecklare tillsammans på något sätt? Hjälper ni varandra?
Båda är produktutvecklare, Fredrik har 25% service, han gör mer komplicerade grejer. Anna har mer kundkontakt, gör mer lådor och vagnar. Alla ordrar kommer till Anna, är "teamleader".

Har Virtual Manufacturing kunder utanför Sverige också?
Mest Sverige, får inte sälja så mycket till andra länder pga avtal. Håller delvis på med Volvo USA.

Vem jobbar med kitlösningarna? Enbart operatörer?
Operatörer, montörer, produktionspersonal. De roterar. All personal som är i fabriken.

Pris på komponenter som ska ligga i vagnen, påverkar det vad ni får välja för material?
Kan påverka om det inte får gå sönder, de är villiga att betala mer då. Shadowboards etc. kan vara viktiga för att fixera delarna i vagnen. Får oftast inte reda på om sakerna som ska ligga i. Saker som är synliga i slutprodukten är mer känsliga. Händer att man blandar materialen, oftast skummad PVC och sen gör man ett inlägg med Aicelwood.

Vad kostar dagens material?
Vet inte exakt. Kan inte svara på den frågan.

Hur görs prissättningen?
Aicelwood 1500 kr för en låda. Kvadratmeterpris. Prisexcellista, lägger in antal rör, skivor etc så räknas det ut. Finns standardtider för tillverkning av rör, skivor etc. Erfarenhet säger hur mycket tid det tar att montera ihop.

Hur många timmar tar designprocessen?
Är alltid olika, två timmar för designen, en timme för beredningen, excellista, kopiera över filerna etc. Kan ta längre tid om det är komplicerade grejer.

Hur många lösningar konstruerar ni på ett år?
870 konstruerade totalt, cirka 200 om året.

Hur många produkter är genomsnittsordern på?
Ibland bara en, två kanske. Volvo Cars lägger 70 i taget. Oftast få men ibland många.

Vad slits ut först på vagnarna/lådorna?
Oftast blir de påkörda av truckar. Det utförs service, de ska få rör och kopplingar så att de kan byta själva när dom går sönder. Hjulen kan slitas. Tänk hjul på rullresväskor. Med rätt underhåll så håller de kanske i tio år. Klagomål att skruvarna lossnat etc.

Tillverkar Virtual Manufacturing endast det som inte går att köpa in från andra?
Ja, försöker ha så många underleverantörer som möjligt så att kunden får veta vad de ska få.

Vad har ni gjort i er verksamhet fram tills nu? Vad började ni göra 2006?
Industrial management började vi med. Sen har de andra avdelningarna kommit allteftersom. Lean manufacturing products är cirka 4 år gammalt.

Vad för slags komponenter transporteras i lösningarna?
Storlek på innehållet i lådorna/kitvagnarna är all från usb till sidodörr till lastbil. För tyngre detaljer: Mest stål, Volvo Köping vill ha aluminium (om ramen behöver vara lättare).

The second interview was held with Fredrik Nilsson, product developer at Virtual Manufacturing AB with complementary questions.

Hur ser ditt arbetsflöde ut jämfört med Annas?
Anna har hand om början med ordrar och sånt som kommer in från kunder. Jag tar hand om det fysiska och servicebiten, åker ut mycket till kunderna och byter ut eller lagar produkter som kommer från oss. Lagar bland annat rörsystem (de som Virtual Manufacturing använder) när det behövs.

Jobbar du och Anna mycket ihop?
Till viss del.

Anna sa att du gör mer komplicerade saker, vad innebär det?
När vi inte bygger produkterna själva uppe i Linköping sköter jag kontakten och utvecklingen av produkten i samarbete med externa legotillverkare som gör produkterna åt oss. Kan vara att ett material som vi köper in som behöver användas. Sen när det är något som är komplicerat att konstruera åker jag ibland upp till Linköping och hjälper produktionen med tillverkningen.

Anna sa att du jobbar 25% med service, vad innebär det? Vad reparerar/underhåller du? Vad är det vanligaste felet på lösningarna?
Fabrikspersonalen tappar grejer på vagnarna/ställningarna, kör på dem med truck etcetera. Ibland tror jag att folk tar ut aggression på ställen och vagnarna, kanske sätter in något för

våldsamt och så vidare. Lådorna i Wellplast är det inte vi som gör så de håller jag inte på med. Händer att masonitskivor välts på PVC-skivorna så att de går sönder vilket gör att jag får åka ut och fixa det. Lösningarna blir påkörda, kläms och så vidare av truckar, hjulen på vagnarna kan då också gå sönder. När delar på vagnarna behöver bytas ut beställer jag nya delar från Linköping så skickar de ner det som behövs. Jag jobbar absolut mest med Volvo Cars, någon enstaka gång på Adient.

Vad använder du för verktyg?
Främst skruvdragare, borrmaskin och rörkapare. Mattkniv för att dela PVC-skivor. Det är inte så noggrant hur rakt/rätt de blir skurna, beror lite på var de ska användas någonstans.

Vad får du för information från kunder angående fel och skador?
Kunderna hör av sig, nästan uteslutande Volvo Cars.

Vad kostar servicedelen för kunderna?
Det finns en kundgaranti som innebär att vi lagar eller omarbetar garantiärenden gratis. Övrig service betalar kunden per timme.

Något speciellt som du tycker vi bör tänka på?
Det är viktigt att lösningarna är så lättkonstruerade som möjligt för produktionen.

A.1.2 Kitting Solution Manufacturing Visit

This observation and interview was conducted in Swedish so the notes from the interview is therefore in Swedish. A summary of the interview is presented in chapter 3.2.2.

Hur levereras era produkter till kund?
95% av alla vagnar och rullställ levereras ihopmonterade. De färdiga produkterna fraktas ut med lastbil till kund.

Hur levereras materialet till er?
PVC och Aicelwood köps in i stora plattor som kan vara svåra att hantera. Vi får ofta åka iväg till ett lokalt snickeri som hjälper till med att bearbeta materialet, till exempel när man behöver göra spår i skivorna. Ibland vid större beställningar av lösningar så kan materialet köpas in färdigkapat vilket sparar mycket tid.

Vilka material används mest?
PVC används klart mest, Aicelwood används allt mer men fortfarande i mindre skala. Wellplast är mer sällsynt. Händer ibland att lådor kläs med filt för att skydda komponenterna. Vi köper in material för ungefär 250-300 tkr per år.

Hur upplever ni de olika materialen?
Aicelwood är smidig att kapa, man behöver inte grada kanterna. Aicelwood är dock lite hårig men väldigt slitstarkt. PVC i sin tur är statiskt, är inte heller bra i ESD sammanhang. Lätt att bearbeta, spånet som blir vid kapning är dock svårt att hantera, klibbigt. PVC är genomfärgad och har en bra yta.

PVC och Aicelwood gör inga avfällningar och dammar inte vilket är krav att materialen inte får göra i många industrier, annars hade plywood varit bättre att använda då det är stabilare och tål mer.

Vilka sammanfogningsmetoder används?
PVC sätts ihop med hjälp av skruvar eller stift, materialet är så mjukt att det inte behöver

försänkas. Aicelwood kan också skruvas ihop men behöver förborras. Ihopsättningsmetoden kan variera för lådor beroende på storlek. När lådor stiftas så kan stiften skjutas in snett ibland, då måste stiften plockas ut igen vilket är bökigt och tar tid. Aicelwood och PVC går inte att limma, iallafall inte med de lim som används i produktionen idag.

När det är lådor som ska monteras så skruvas eller nitas de ihop. Det finns dock önskemål att hitta ett enkomponentslim som också kan fungera. Problem uppstår ibland med passformen för lådorna som ska monteras på vagnar då de har varit för små. Distanser har därför behövts.

Vilka problem kan uppstå när man monterar?
Att hålla saker på plats. Därför använder vi fixturer eller gör enkla versioner själva.

Är kommunikationen mellan konstruktionsavdelningen och produktionen bra?
Kommunikationen mellan konstruktionsavdelningen i Göteborg och produktionen i Linköping kunde varit bättre. Kan vara problematiskt med ett så stort geografiskt avstånd mellan avdelningarna. Ibland kan det vara svårt att få en färdig lösning från konstruktionsavdelningen då det inte alltid blir som planerat, då får produktionen improvisera och hitta på kreativa lösningar. Oftast går det snabbare än att skicka fram och tillbaka konstruktionsunderlaget. CAD-programmet kan ibland visa ett mått men sen så stämmer det inte sen i verkligheten när lösningarna ska monteras ihop.

Konstruktörerna i Göteborg har vid flertalet tillfällen varit med i produktionen i Linköping så att de ska få bättre underlag och information vid konstruktionsfasen.

Behöver ni bättre koll på hur produkterna sedan används?
Vi tycker att mer erfarenhet om hur produkterna som de tillverkar används av kunderna vore bra. Studiebesök eller liknande vore därför önskvärt.

Händer det att ni tycker att det finns bättre sätt att konstruera en vagn på?
När en kund kommer med ett önskemål så kan vi ha bättre förslag på hur konstruktionen ska lösas då vi har erfarenhet att bygga materiallösningar.

Ibland får vi förfrågan på lådor med 3 mm Aicelwood, finns dock inget bra sätt att fästa in så tunna väggar. Ofta kläs dock PVC-lådor med 3 mm Aicelwood.

Hur ser ni på att ha många material i lager?
Det är en balansgång, bra att ha lager med material så att man kan tillverka alla beställningar, men det är inte bra att ha för stora lager som tar stor plats och binder kapital.

Vilka typer av stålramar för vagnarna används?
Ibland används fyrkantsbotten, främst om vagnen ska kunna lyftas med truck etcetera men annars används alltid runda stålrör.

Vad tar mest tid när ni bygger en kitvagn?
Förbereda materialet så att man får rätt mått på skivorna. Monteringen tar inte så mycket tid jämfört med det.

Hur långt tid tar det att tillverka en hel vagn?
Beror på vad det är för vagn, men ungefär fem timmar.

Hur ser transporten ut mellan fabriken och kund?
Vi har ett fraktbolag som kör produkterna åt oss mellan Linköping och Göteborg.

Är det problematiskt att tillverka ESD-produkter?
ESD-material är dyrt, finns inget bra alternativ idag, alltså ingen standard för hur man ska lösa ESD-konstruktioner.

Vilka leverantörer har ni idag för material?
Beewatec levererar Aicelwood. Beewatec är ett tyskt företag så frakten är väldigt dyr, om vi beställer för mer än 100.000 kr så får de dock 10 % rabatt så vi försöker alltid komma upp i den summan vid beställning. Frakt är dock väldigt dyrt över lag. Priset baseras på flakmeter, vikt och hur lång frakten är. Glasfiber och plast levererar PVC medan Wellplast levererar Wellplast. Hos Glasfiber & Plastprodukter AB har vi 53% rabatt.

Vad är ert inköpspris för materialet?
Materialpris:

- Skummad PVC 10 mm (3050x1560 mm) kostar 676 kr/ark
- Skummad PVC 19 mm (1525x1560 mm) kostar 734 kr/ark
- Aicelwood 3 mm (440x2000 mm) kostar 492 kr/ark
- Aicelwood 5 mm (440x2000 mm) kostar 762 kr/ark
- Aicelwood 7 mm (440x2000 mm) kostar 1080 kr/ark
- Aicelwood 10 mm (440x2000 mm) kostar 1320 kr/ark
- Aicelwood 15 mm (440x2000 mm) kostar 1940 kr/ark
- Aicelwood ESD 5 mm (250x2000 mm) kostar 673 kr/ark
- Aicelwood ESD 10 mm (250x2000 mm) kostar 1320 kr/ark

Aicelwood är alltså betydligt dyrare än PVC men används ändå när känsliga komponenter ska förvaras och transporteras då de skyddas bättre. Aicelwood i ESD utförande är i sin tur ungefär dubbelt så dyrt som Aicelwood utan ESD.

Hur länge har ni funnits i Linköping och fungerar produktionen bra?
Produktionen startade först i Göteborg men har funnits i 2,5-3 år i Linköping. Vi är fyra personer som jobbar i Linköping. Planer finns för att automatisera vissa delar av produktionen. Lokalen är dock ganska liten så ett bättre grundkoncept för produktionen efterfrågas.

Det är ofta stressigt i produktionen med korta deadlines vilket leder till att lösningarna som görs inte alltid dokumenteras.

Vilka önskemål finns på eventuella nya material?
Viktigt att nya material inte har sämre egenskaper vid bearbetning än de nuvarande materialen som används. Om de nya materialen går att kemsvetsa så vore det bra. Leverantören för material är också väldigt viktigt, helst korta leverantörstider med mera, att ha en billig leverantör i Kina är inte att föredra då det kan bli väldigt dyrt i slutändan.

Har ni några övriga önskemål?
Ja, vi skulle behöva en justersåg för att kunna kapa till skivorna själva och en spånsug.

Vad kostar mest, materialinköpen eller bearbetning och montering?
Rent generellt så är materialkostnaderna betydligt större än arbetskostnaderna för bearbetning och montering.

A.1.3 Customer Visit Volvo Group

This observation and interview was conducted in Swedish so the notes from the interview is therefore in Swedish. A summary of the visit is presented in chapter 3.2.3. First are the notes from the observation presented which includes spontaneous questions and information from the employees, thereafter is the more structured interview presented.

Fabriken har mest materialtåg som levererar fram materialet till monteringslinan. Volvos lastbilar går att få i många olika varianter, ungefär 20.000 unika utföranden, Scania har endast cirka 30 unika utföranden. Detta ställer höga krav på materialförsörjningen, vissa typer av lastbilar tillverkas endast i 20 exemplar om året. Det finns även specialmontörer som monterar specialutrustning på lastbilarna.

Varje monteringsstation har en sprinthållare (monteringsunderlag) som säger vilka komponenter som ska monteras och på vilket ställe. På varje lastbil finns även ett chassinummer som kontrolleras med en scanner så att rätt komponenter monteras på rätt lastbil. Ergonomi är viktigt, plockläget för montörerna ska vara i rätt höjd.

Om en komponent saknas av någon anledning så tar man ut lastbilen ur monteringslinan och fortsätter monteringen först när komponenten finns på plats. Varje lastbil som inte färdigställs i tid innebär en kostnad på cirka 50.000 kr. Det är dock väldigt sällan som materialet inte är i tid till monteringen (cirka 1%). För att få jobba som montör måste man vara utbildad och certifierad.

För att ha en så effektiv produktion som möjligt så ska antalet olika komponenter vara få, då kan yta sparas in i produktionen vilket innebär ekonomiska fördelar.

Volvofabriken som besöktes tillverkar alla balkar själva, stålet kommer in i stora rullar. Balkarna distribueras även till de andra Volvofabrikerna. Hytternas skal tillverkas i Umeå medan motorerna tillverkas i Skövde. De färdiga lastbilarna levereras oftast utan skåp, vissa specialapplikationer kan dock göras.

Truck- och materialtågsförarna fyller på skruvar och muttrar etcetera, ibland får monteringspersonalen ringa och beställa. De har ett pull-system så att montören scannar en streckkod om komponenter börjar ta slut. Materialet kommer oftast på pallar från leverantörerna, särskilt större delar. Inte ovanligt att man tar delarna direkt från dessa. Små komponenter som skruvar, muttrar och diverse plastdetaljer ligger i kartonglådor som går att packa tätt i deras flowracks/rullbaneställ. Mindre plastbackar används också till detta. Inte ovanligt att plastbackar fästs med buntband till ramen om dom ska stå i vinklade positioner. Plastbackarna (V-EMB) är deras eget "förpackningssystem". Logistiktekniker håller koll på materialflödet så att det flyter på.

Finns "kryddställ" gjorda av halverade rör, klädda med flockmatta. I dessa ligger det olika sorts axlar, ofta ganska tunga. Finns också "tiltställ" som gör att man kan gunga ställningen för att få ett bra plockläge.

Vagnar med presenningar används till höga/stående/smala eller lättare delar som är repkänsliga. Presenningsvagnarna är dyra eftersom dom behöver förberedas i ett väveri för att anpassas till ramarna.

Trilogiq och Indeva är två andra leverantörer som Volvo använder sig av utöver Virtual Manufacturing. I fabriken finns en pilotmonteringslina där nya produktvarianter testas vilket också inkluderar nya hjälpmedel såsom materialvagnar. När nya komponenter ska börja användas i lastbilarna krävs oftast nya kitlösningar. Generellt tar det runt ett halvår för en idé med en ny lösning att förverkligas i produktionen.

Det finns några anställda som jobbar med att optimera kitlösningarna samt att bygga nya varianter. Detta görs för att förbättra arbetsförhållandena för montörerna. Kitlösningarna går oftast sönder på grund av att de blir påkörda. Förr hade de personal som åkte runt och lagade vagnarna men idag så har varje station ansvar för sina materialvagnar. Dåliga hjul på dagens materialvagnar är ett stort problem då de kan låta mycket, dammar och kan gå sönder om det vill sig illa. Det är viktigt att produkterna är bättre än vad de är snygga så med andra ord går funktionalitet före estetik. Föredrar vagnarna med "kromad" yta på rören, dom vita ser skitiga och slitna ut snabbare.

Vilka typer av komponenter förvaras i kitlösningarna och kan de kategoriseras?
Kan vara allt möjligt som styrenheter, rör, slangar, ljudpaneler, etcetera. Oftast enklare "mekaniska" delar. Fungerar bra att kategorisera dem som okänsliga, känsliga, ESD och oljiga komponenter.

Vad är bra respektive dåligt med dagens lösningar?
Flexibiliteten är bra då alla kitlösningar ser olika ut. Hjulen fungerar ofta mindre bra samt Trilogiqs vagnar är vita vilket gör att de ser smutsiga och slitna ut efter ett tag när dom blivit påkörda. Kitlösningar över lag är dyra lösningar så att hitta billigare och mer ergonomiska lösningar är centralt.

Vad är det viktigaste med kitlösningarna?
De ska vara billiga, ergonomiska och driftsäkra, idag kostar en vagn runt 15.000-20.000 kr vilket gör att det kan vara svårt att motivera inköpen.

Finns det möjlighet att standardisera boxarna?
Det är viktigt att boxarna är för stora för komponenten så att det är enkelt att komma åt komponenten. Det kan därför bli svårt att ha standardiserade lådor då hoppen mellan de olika storlekarna riskerar att bli för stora.

Hur är hållbarheten på kitlösningarna idag?
Lösningarna som är konstruerade i Wellplast fungerar mindre bra, materialet är inte så hållbart. Över lag så får materialen inte damma eller flisa samt bli smutsiga. 10 års hållbarhet vore önskvärt men produkterna måste samtidigt vara ekonomiska. Till exempel så måste många vagnar ändras eller bytas ut när en ny lastbilsmodell ska börja tillverkas. Eftersom saker ändras ofta är det då inte alltid viktigt att det håller länge.

Hur fungerar materialen som används idag?
PVC fungerar bra, är enkelt och flexibelt att bearbeta och är dammfritt men ser fult ut efter ett tag då materialet suger åt sig smuts. På en del stationer är PVC:n klädd i flockmatta för att se bättre ut och vara mjukare att ställa saker på. Plywoodlådor för större och tyngre grejer funkar bra för att materialet nöts ner långsamt, vilket gör att man kan använda lådan länge. Hade det vart PVC hade det gått sönder direkt för att det är mycket hårdare och sprött.

Vilka förhållanden utsätts lösningarna för idag?
Utsätts inprincip endast för neutrala pH-värden, inga lösningar som används förvaras ute. Solljus- och vattenbeständighet är därför inte prioriterat. Det finns heller ingen städrutin för kitlösningarna.

A.1.4 Customer Visit Adient

This observation and interview was conducted in Swedish so the notes from the interview are therefore in Swedish. A summary of the visit is presented in chapter 3.2.4. First, a guided tour were conducted in the factory and afterwards a structured interview was made. The notes from the interview is presented hereafter.

Adient är ett företag som tillverkar stolar till bilindustrin. Just i fabriken som besöktes i Göteborg så tillverkas alla säten till Volvo Cars bilar som tillverkas i Göteborgsfabriken. Adient använder huvudsakligen kitvagnar med uppspänd presenning då många komponenter som förvaras i kitvagnarna är av känslig karaktär.

Vilka typer av komponenter förvaras i kitvagnarna och kan de kategoriseras?
Främst klädsel, skum, plastdetaljer, metallkomponenter och elektronik. Airbagen är den enda komponenten som är ESD-klassad, men annars finns det både okänsliga och känsliga komponenter.

Vad är bra respektive dåligt med dagens vagnar?
Vagnarna håller inte särskilt bra, slits snabbt och rivs upp. Vagnarna skyddar komponenterna på ett bra sätt.

Vad är det viktigaste med kitvagnarna?
Vikten på vagnarna är viktig då de delvis flyttas manuellt samt att de ska skydda komponenterna, ingen vill ha en ny bil där bilstolen är skadad.

Finns det möjlighet att standardisera boxarna?
De delar som transporteras i kitvagnar kan ha varierande storlek och det är viktigt att få plats med så många komponenter som möjligt i en vagn, därför kan det vara svårt att standardisera facken i en vagn.

Saknar ni möjligheten att kunna konstruera om vagnarna?
Det är alltid en fördel om man kan återanvända vagnarna, idag är det mer regel att vagnarna byts ut när en ny bilmodell ska börja tillverkas.

Hur är hållbarheten på kitvagnarna idag?
Vagnarna slits snabbt och håller i cirka fem år, dock blir många vagnar påkörda av truckar vilket leder till att vagnar går sönder i förtid.

Hur fungerar materialen som används idag?
Materialen som används för vagnarna fungerar i allmänhet bra men det händer att vagnarna har vassa kanter vilket leder till att komponenter skadas.

Brukar vagnarna leva upp till förväntningarna?
Mestadels, de nyaste vagnarna är beställda från Flexqube och de ser bra och stabila ut samt fungerar bra. De är vita vilket leder till att de ser smutsiga ut. Det finns ingen taktik eller rutin för vilken färg vagnarna har.

Vilka förhållanden utsätts vagnarna för idag?
De utsätts i princip endast för neutrala pH-värden, händer att vagnar som inte används för stunden förvaras ute. Det finns heller ingen städrutin för vagnarna.

A.1.5 Customer Visit Volvo Cars

This observation and interview was conducted in Swedish so the notes from the interview are therefore in Swedish. A summary of the visit is presented in chapter 3.2.5. First, a guided tour was conducted in the fabric and afterwards a structured interview was made. The notes from the interview are presented hereafter.

Volvo Cars tillverkar Volvobilar av modellerna XC90, XC60 och V90 i fabriken i Torslanda utanför Göteborg. Idag levererar Virtual Manufacturing ställage med rullbanor till fabriken medan Wellplast AB förser fabriken med kitlådor. Virtual Manufacturing har levererat en kitlåda i Aicelwood som ska hålla bättre än Wellplastlådorna som används idag. Aicelwoodlådan gick dock sönder efter endast några veckor.

Vilka typer av komponenter förvaras i lådorna?
Alla möjliga sorters komponenter, säkerhetsbälten, kåpor etcetera av både plast och metall. Komponenterna har olika storlek och känslighet.

Kan de klassificeras på något sätt?
Det finns tre olika typer av komponenter, okänsliga, känsliga och ESD komponenter.

Vad är bäst med kitlådorna idag?
Lätta, kort leveranstid, villiga att försöka hitta lösningar (Wellplast AB). Om lådorna inklusive innehåll väger mer än 7 kg krävs lyftverktyg, över 5 kg måste ett straff betalas per låda, man betalar i tid)

Vad är största problemet med kitlösningarna idag?
Största problemet är att de går snabbt sönder, de håller även inte formen vilket resulterar till att dockningsfunktionen för ställagen inte fungerar. Senaste kitlådan höll i 6 dygn. Att dockningsfunktionen inte fungerar kan också skada lådorna.

Saknar ni möjligheten att kunna konstruera om lådorna?
Det hade varit bra om det gick att konstruera om lådorna, på lång sikt är det ett starkt önskemål.

Vilka krav och önskemål har ni på kitlådorna?
De får väga max 2 kg, helst 1,5 kg. De måste också bibehålla sin form så att dockningsfunktionen fungerar. Lådorna får inte repa bilar eller detaljer, inga metallskruvar eller detaljer på lådorna. Inget flisigt material, ska kunna ta stryk men inte kunna gå sönder. Väggarna på lådan bör inte vara tjockare än 10 mm.

Hur viktigt är det att lådorna är exakt måttsatta efter komponenterna, gör det något om de är lite större (standardiserad lösning)?
Måtten är viktiga, ska passa i stället, får inte heller vara för små fack så att komponenterna inte får plats.

Hur är hållbarheten på lådorna idag?
Väldigt dålig, från några veckor till något år, men då är de helt trasiga.

Hur lång hållbarhet förväntar ni er?
Aicelwoodlådan kostade 3.500kr, höll två till tre veckor, ska kunna hålla fem år då den kostade så mycket. Kitlådor i Wellplast kostar cirka 500-600 kr, bör också hålla längre än idag. Ju längre lådorna håller desto mer får de kosta.

Är det svårt att göra beställningar från Virtual Manufacturing?
Har fungerat bra, lite sega, men trevliga.

Vad tycker du är bra med materialen som används till kitlådorna?
Wellplast är ett lätt material vilket är bra, dock lite dyrt. Wellplast skadar inte detaljerna vilket naturligtvis är bra.

Hur ofta städar ni kitlådorna?
Det finns ingen rutin. Kitlösningarna kan dock torkas av ibland.

Vilka pH-värden utsätts produkterna för? Utsätts den för några andra omständigheter?
Inga syror eller baser, förvaras alltid inomhus. ESD på en station. Ingen fukt rent generellt.

Vad för sorts utrustning köper ni från Virtual Manufacturing?
Endast ställ förutom en testlåda i Aicelwood.