DEGREE PROJECT

Robot Racking

A Racking Solution for Autonomous Production

Zakarias Envall

Industrial Design Engineering, master's level (60 credits)
2018

Luleå University of Technology
Department of Business Administration, Technology and Social Sciences

Robot Racking

- A Racking Solution for Autonomous Production

Zakarias **Envall**
2018

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MSc in INDUSTRIAL DESIGN ENGINEERING
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Luleå 19th of June, 2018
Zakarias Envall

Abstract

As an engineering student, the most natural way of summarizing this thesis project is by relating it to a mathematical equation. The solution to this equation is given, and it is in the form of a racking concept that enables the use of robots. The other side of the equation is however a bit more complex. This side contains several undefined variables, which can only be solved by delving into various theoretical fields and exploring unchartered depths of the creative space.

The project's main objective is to design a concept rack for Gestamp HardTech in Luleå, Sweden, for storage and in-house transport of the beams which are produced at the HardTech facility. The rack is meant to be loaded both into and out of by robots and should suit an as wide array of beams as possible. To determine the possibilities and limitations of the rack's robot-user, several automation aspects are researched, centered on industrial robots and machine vision. The beams which are produced at the Gestamp HardTech Luleå production plant today are analyzed, whereby twelve of them are ultimately chosen for the rack's design to be focused on. What follows this is a creative process consisting of a creative idea-generating phase, an evaluative phase focused on implementation of the ideas, and a refinement phase where the rack concept is finalized. The process includes various methods of idea generating, a great deal of sketching, physical testing of the concepts, and finally CAD-modeling. The result, named 4.0-Rack, is in the form of a modular rack-concept which balances the aspects of flexibility, by suiting ten of the reviewed beams, with a high packing-grade, providing a mean packing-grade of 83% in relation to the way the beams are currently packed.

KEYWORDS: ROBOT RACK, AUTOMATED RACKING, PALLETIZING, DESIGN FOR AUTOMATION, MACHINE VISION, INDUSTRY 4.0

Sammanfattning

Som en ingenjörsstudent är det mest naturliga sättet att sammanfatta detta examensarbete genom att relatera det till en matematisk ekvation. Lösningen till denna ekvation är given, och den är i form av ett rack-koncept som möjliggör användning av robotar. Den andra sidan av ekvationen är dock lite mer komplex. Den här sidan innehåller flera odefinierade variabler, som bara kan lösas genom att dyka in i olika teoretiska områden och utforska outforskade djup i den kreativa rymden.

Projektets huvudsyfte är att utforma ett koncept-rack för Gestamp HardTech i Luleå, för lagring och intern transport av balkarna som produceras på HardTech-anläggningen. Racket är menat att laddas både in i och ut ur av robotar och borde passa så många balkar som möjligt. För att bestämma möjligheterna och begränsningarna hos rackens robot-användare undersöks flera automationsaspekter, centrerade kring industrirobotar och vision-system. De balkar som produceras på Gestamp HardTech Luleås produktionsanläggning idag analyseras, varav tolv av dem slutligen väljs för att fokusera rackens design på. Vad som följer detta är en kreativ process som består av en kreativ idégenereringsfas, en utvärderingsfas som fokuserar på implementering av idéerna, och slutligen en förfiningsfas där rack-konceptet färdigställs. Processen innehåller olika metoder för att idégenerering, en stor del skissande, fysiska tester av koncepten, och slutligen CAD-modellering. Resultatet, som kallas 4,0-rack, är i form av ett modulärt rack-koncept vilket balanserar flexibilitetsaspekter, genom att passa tio av de granskade balkarna, med en hög packningsnivå, då det medför en genomsnittlig packningsgrad på 83% i förhållande till hur balkarna packas idag.

NYCKELORD: ROBOTRACK, AUTOMATISK ROBOTPACKNING, PALLETERING, DESIGN FÖR AUTOMATISERING, VISION-SYSTEM, INDUSTRI 4.0

Content

List of appendices

1 Introduction

This master thesis in Industrial Design Engineering at Luleå University of Technology was performed at Gestamp HardTech in Luleå during the spring semester of 2018. Gestamp HardTech is a company that manufactures press-hardened beams for the automotive industry, along with tools used to produce these beams, with offices and production plants all over the world. The Luleå branch delivers products to a wide range of clients in the automotive industry, including Volvo and Scania.

The current thesis project aims to design a concept for a rack-solution meant to be used for in-house logistics. The purpose of this rack is to enable a robot to load and unload the produced beams in order to limit the amount of manual handling used today. The racks are meant to be used for storing and transporting products between the stamping lines and the next machining processes. A large factor concerning automation is that many of the products stick to each other when stored. The rack therefore needs to be designed in a way where the products can be stored without sticking to each other. However, it still needs to fit a considerable portion of the products in relation to the amount that can be stored when inserted manually. The objective is primarily to design rack-solutions that suits a portion of the beams being produced, but the long-term goal is to ultimately use the solutions for automating the loading and unloading of all the products.

1.1 BACKGROUND

The goal for many production sites today is increasing the automatization of the production process. With less manual labor both costs and the margin of error, such as miscounting or approving products with insufficient quality, are meant to decrease. Less manual labor could lead to lower costs in the long run, which in turn leads to the possibility of lowering prices in order to increase a company's competitiveness in the marketplace.

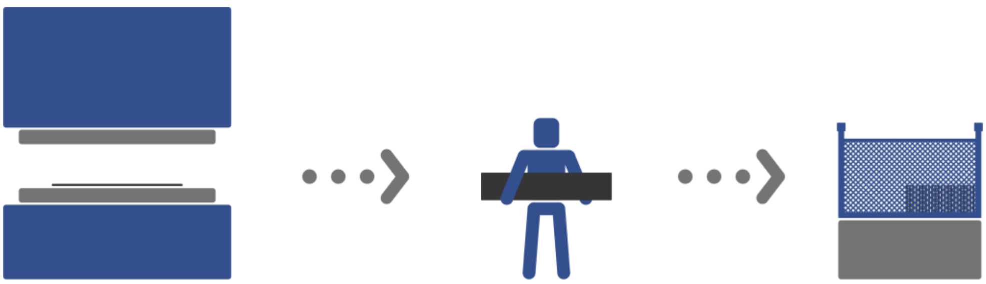

Figure 1. Displaying the manual loading from a stamping-tool into a rack. Illustration: Z. Envall.

At the Gestamp HardTech production plant in Luleå much of the work today is done by hand (see fig. 1). Machine operators load in and out of various machines, often using a standard foldable HardTech-rack, regularly referred to as a HT-rack (see fig. 2). The HT-rack is used to store and transport the products during the production process. These racks come in two sizes, a smaller one which is most commonly used, and a larger one used for larger products.

Figure 2. The most common rack inside Gestamp HardTech Luleå, referred to as a HT-rack. Photo: Z. Envall.

The reason for this project is mainly automatization of the production process. The company believes that the manual handling of products coming out of the stamping lines and going into the laser cutters is unnecessary and obsolete, and that robotic loading of the products is a better and more efficient solution. The problem is that the HT-racks that are used today are not compatible with robotic loading. There is a need for developing a rack that allows this, by providing a uniform placement option that keeps the beams separate from one another. An issue that comes with this is the fact that with designated placement options, the rack is most likely going to hold fewer products than today. The difference in storing capacity between the HT-racks and the robot racks needs to be as small as possible.

The rack development is initially going to focus on all the beams that are produced today, in order to find corresponding features. Eventually a few beams will be selected and used for developing a detailed design, depending on which beams are deemed suitable for the project. The aim is ultimately to use the results from this thesis as a base for eventually developing rack solutions for all the products that are produced at the site. A successful rack-development process requires a solid foundation consisting of a thorough understanding of qualities related to the relevant products. In order to enable for robot interaction with the rack, the limitations for robotics also needs to be studied through benchmarking and theory immersion.

1.2 STAKEHOLDERS

The project's primary stakeholder is Gestamp HardTech Luleå, mainly production manager Magnus Eriksson as the initiating supervisor for the project. Gestamp HardTech will both own and further develop the robot rack concept after the project's completion.

Secondary stakeholders are the machine operators that will be affected by the concept. By switching to robot handling of the produced beams, the work tasks of the machine operators will be altered. A significant decrease in lifting and carrying operations can be predicted, whereby the physical ergonomic situation is also likely to improve.

There is however a risk that a higher level of automatization can lead to less machine operators being needed in the production, possibly resulting in downsizing, which in turn could lead to negative health effects such as stress and increased absence from work, according to studies reviewed by Westgaard and Winkel (2011).

Logistics personnel such as forklift operators will also be affected, being that they are responsible for handling and transporting the racks between the machines. Other affected entities include the facility where the rack is ultimately going to be produced and assembled, and Gestamp HardTech's various clients.

1.3 OBJECTIVE AND AIMS

The project's objective is to provide Gestamp HardTech with a rack concept, which is meant to increase the possibilities for a higher level of automation in the production. As explained by Magnus Eriksson[1], the biggest problem with transitioning into an automated production site is the storage of products between the different machining processes. Having a robot unload beams from the stamping lines into product-specific racks is not much of a challenge, but the problem comes with storing these different racks. Moreover, with a constantly changing product flora new racks would be needed often, and the cost of constantly buying new racks for the added products is unsustainable. The objective of the project is thus to develop a rack concept with a high flexibility for various products that still offers a relatively high packing-grade. This rack is meant to enable robot handling of the produced beams in order to reduce the need for manual handling (see fig. 3).

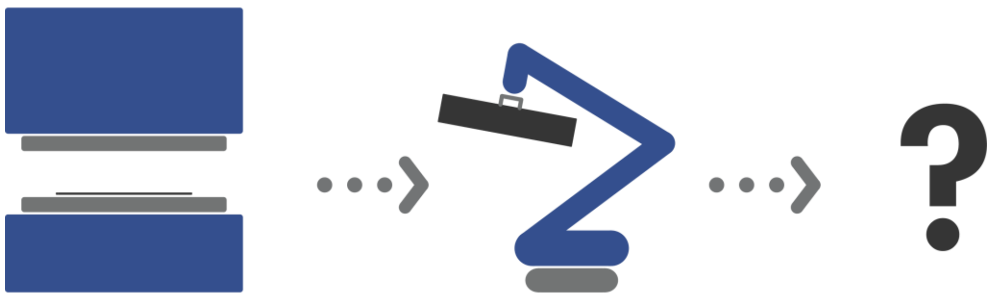

Figure 3. Displaying the project aim of automating the loading/unloading process. Illustration: Z. Envall.

The project aims to contribute to Gestamp HardTech by aiding the automatization of the production process. This contribution is also thought to benefit the machine operators by enabling the possibility for developing a less routine and ergonomically challenging working situation by reducing the amount of manual handling. Automatizing the production process is primarily economically motivated in the sense of lowering the need for human operators, but using robots also opens up more opportunities for increasing quality control by utilizing artificial intelligence to analyze the products. Jobs that are more routine, according to Westgaard and Winkel (2011), increase the risks for various health consequences due to poor ergonomics. Reducing the amount of manual labor could therefore contribute to society by reducing negative health effects such as upper limb musculoskeletal disorders. This is of course a long-term effect, assuming that the project is successful and that the rack,

[1] M. Eriksson, personal communication, December 12, 2017.

or variations thereof, can be used for a larger number of products, possibly even in other factories. By altering the production process at Gestamp HardTech, the project is also likely to contribute to their customers, predictably resulting in reduced costs and increased product quality.

1.4 PROJECT SCOPE

The scope of the project is limited to developing a solution for in-house logistics. The solution is not meant to be used for shipping the products and is therefore not constrained by customer specifications regarding packing. Factors concerning robot functions are going to be designed for but not altered, by programming for example. There is however a possibility that the storage solution could include equipping the robot with various accessories. The project is also focused on developing a rack around a few of the produced products, but should take other products into account by way of not implementing a design that inhibits the storage of these.

1.5 THESIS OUTLINE

The thesis is structured to take the reader from initially understanding the objective and context, to reviewing the theory, then through the developmental process, from early ideas to ending with a final concept, followed by reflections and a discussion concerning the results. The chapters can be described as follows:

1. **Introduction** – The project is introduced.
2. **Context** – Information about the setting for the project.
3. **Theoretical Framework** – The additional theory needed for the project.
4. **Method & Implementation** – How the product development was performed.
5. **Results** – The results achieved through the process.
6. **Discussion** – Reflections about the various phases of the project.
7. **References** – List of all the references used.

2 Context

The Context chapter contains information about the current state at Gestamp HardTech Luleå, along with relevant products and production sites elsewhere in the world. The current state gives insight into the production at HardTech, from coils of sheet metal coming into the plant, to the hardened beams getting shipped to various car manufacturers.

The benchmarking section includes an analysis of various racks being sold and used in other production sites, along with studies of autonomous systems found in different manufacturing plants.

2.1 CURRENT STATE

The production at Gestamp HardTech Luleå mainly rests on their stamping technology. The stamping process hardens the produced beams, increasing their ability for withstanding various forces caused by impact. The stamping presses are coupled with several other types of machining, altogether making the plant a flexible production site that produces many different parts for various top-tier car manufacturers around the world, including clients such as Volvo, BMW, Audi, and Range Rover amongst others. Unlike the fixed nature caused by a production of specific models often found in automotive industry production plants, the flexibility needed at HardTech has resulted in a production site that is made up of several downstream machining areas, between which the different steel beams are transported by forklift-trucks. The downstream processing machining areas consist of a laser-cutting area, an assembly cell area, and a hole-punching area.

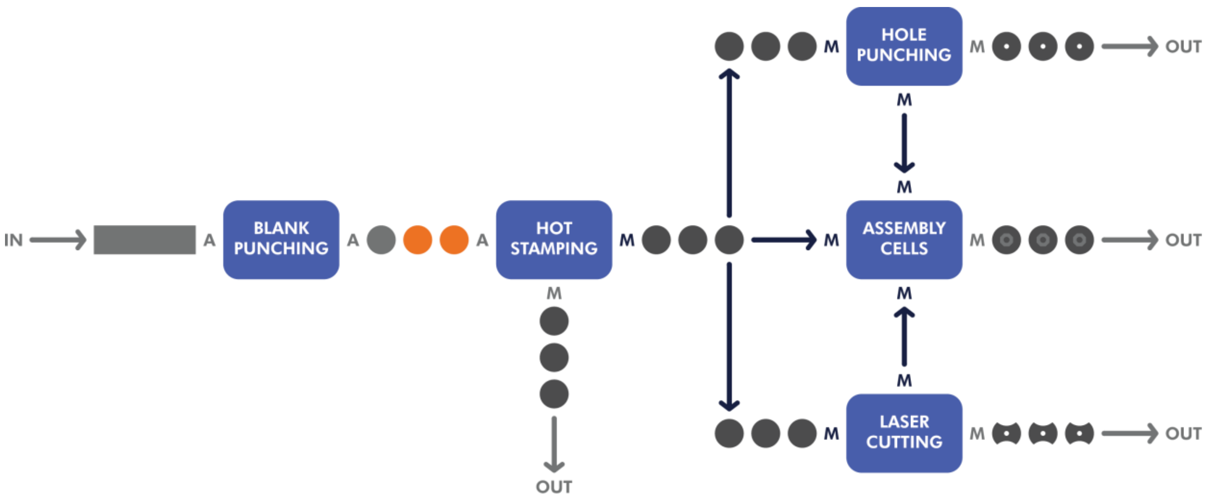

Figure 4. Simplified visualization displaying the production process at Gestamp HardTech Luleå. The letter *A* symbolizes automatic loading/unloading and the letter *M* symbolizes manual loading/unloading. The blue M's represent the manual loading and unloading that is the focus of this project.

The production process, shown in fig. 4, starts out with coils of sheet metal being delivered to the plant. These coils are automatically unwound and cut into the correct shapes, regularly referred to as blanks, in a punching press. After going through the punching press these blanks are automatically placed into what is referred to as a pin pallet, which is used for transporting the blanks to a hot-stamping line. A forklift-truck delivers the pallets to the start of the line, where they are automatically fed into a robot picking area. Robots pick the flat pieces of steel out of the pallet, one at a time, and place them on a conveyor which transports them through a long oven where the beams are heated for a specific period of time. The blanks are then stamped and fed out on a conveyor belt, from which they are loaded into racks by hand. The process following the stamping lines differ for the various products, depending on their design specifications. Some of the products are ready for shipping after the stamping, while others go through hole punching, laser cutting, or are processed in assembly cells before they can be shipped. A few products are both laser cut and put through an assembly cell, alternatively hole punched and put through an assembly cell. The production process for one of the products is displayed in fig. 5.

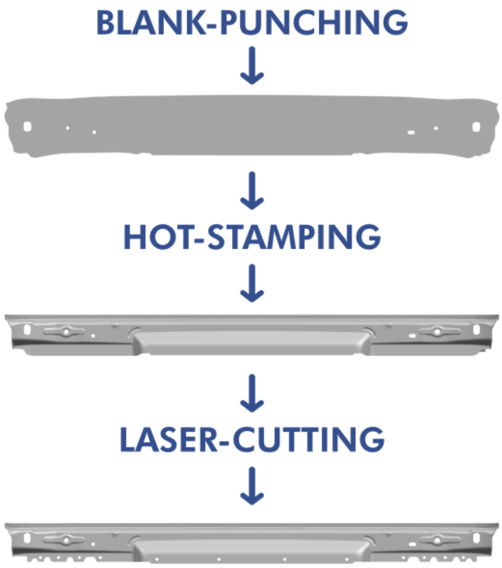

Figure 5. Displaying how the Volvo Trucks Windscreen beam is produced, and what is achieved by each production step.

The racks used at the site depends on a product's destination at any given time. Product-specific pin pallets are used for storing the blanks and transporting them to the stamping lines. Throughout the rest of the production the products are most commonly stored in HT-racks between machining processes, and placed into various customer-specified shipping-racks once they are finished.

2.1.1 HOT-STAMPING

The stamping machines are located at two different sectors of the production plant. Here a flat piece of steel travels through an oven until it reaches a desired temperature and comes out glowing in an orange hue. The heated and softened material is then pressed into the right shape by a stamping tool. Blanks are loaded into the input area by forklift-trucks and placed on ceramic rolls which transport them through the long oven by robots that use grippers equipped with air pressurized suction cups (see fig 6).

Figure 6. Input area for Stamping Line 6. The blanks on the picture are stored in the so-called pin pallets. the Photo: Z. Envall.

After being heated the blanks come out of the oven and are recognized by a vision system. They are then picked up and placed into the stamping die by a robot. Another vision system sits inside the large stamping tool. This system is used to determine if the blank is in the right place for stamping and if it is within the right temperature range. To discern whether the blank has been placed correctly, the vision system camera searches for the top ends of guide pins which are supposed to have passed through various holes on the blanks. The pins appear very dark to the camera in comparison to the piece of heated steel, which appears very bright. If the camera is unable to register these various guide pins, the blank is not stamped and must be discarded. If the material is not at the right temperature, the camera will pick this up as the blank not appearing within the correct range of brightness. The same goes for if two blanks have been placed on top of each other. These would then take longer to cool down, in turn appearing much brighter to the camera than what is allowed.
Once the blanks have been stamped, they are placed on the outgoing conveyor belt by a robot. This belt moves in intervals with operators standing alongside it, analyzing the stamped parts and placing them into racks (see fig. 7).

Figure 7. Outgoing conveyor from Stamping Line 6. Photo: Z. Envall.

2.1.2 HOLE-PUNCHING

The hole-punching area is made up of four robots and one hole-punching machine inside a large cell (see fig 8).

Figure 8. Hole-punching machine and loading station. Photo: Z. Envall.

Incoming parts are loaded onto a conveyor belt by hand, with two operators working simultaneously on each side of the conveyor. The parts are fed to a robot in intervals, two at a time. A vision system first has to recognize the parts, after which a robot picks both the parts up using a double magnet-gripper, placing them on a transfer-fixture. Another robot takes both the parts from the fixture and transports them into the punching machine using a double gripper equipped with clamps. After they have been punched, the parts are moved from the punching die by a third robot, also using a double clamp-gripper, onto a second transfer-fixture. The last robot in line uses clamps to finally transport the two parts from the fixture onto the outgoing conveyor belt where they are packed into racks by the operators.

2.1.3 LASER-CUTTING

The laser-cutting is done in seven enclosed cells, with rotating fixtures that the parts are placed into (see fig. 9). While one part is being cut, the operator removes the finished part from the fixture on the opposite side and loads it with a new part. When the cutting is done the fixtures rotate and the process is repeated. The parts are manually unloaded from incoming racks and loaded into outgoing racks. The racks that are used depend on the parts being produced and whether these are designated for further machining.

Figure 9. Operator waiting for the laser cutting to finish at Laser Cell 10. Photo: Z. Envall.

One of the laser cells combines laser cutting and welding (Laser Cell 11). The part is loaded into the fixture manually in the same way as it is done in the other laser cells, but the finished part is removed from the fixture by a robot and is then taken through additional welding operations and finally placed in an outgoing pallet. This robot uses two different grippers during the process. One for taking the parts through the welding operations and for packing the parts in the output-pallet, and the other is used to fetch and place liners used to separate rows of parts in the pallets which they are unloaded into. The gripper used for part handling has an extra rotation axis, similar to the human wrist joint, in order to enable for sufficient movement throughout the process. The robot is rigidly programmed to follow a number of production steps and finally place the part in the output-pallet, steadily keeping count and adjusting its operations according to the amount of produced parts.

2.1.4 ASSEMBLY CELLS

The assembly cells are located in a different section of the production plant from the laser cells. The assembly cells mainly perform welding operations, fastening objects such as nuts and bolts to the various beams. The process performed in these cells is done by industrial robots, while the loading and unloading is done by hand (see fig. 10). In most of the cells incoming parts are loaded from racks onto conveyor belts in a uniform manner, which transports them into the cells.

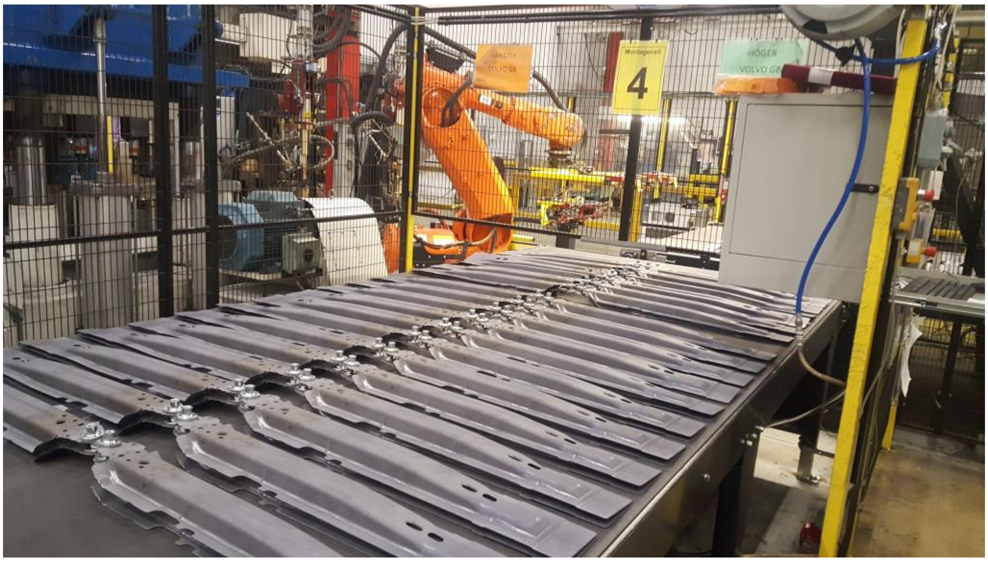

Figure 10. Outgoing conveyor belt from Assembly Cell 4. Photo: Z. Envall.

The conveyor belts move in intervals and stop once the part that is going to be worked on has reached its desired position, which is controlled by a sensor that determines when the parts have reached a certain point. From this point the belt moves for a certain specified period of time, e.g. 300 ms, which places the part in a specified search-area for the vision system used by the robot. The search area should be large enough to allow certain variations in part placement, but not large enough for the robot to identify other closely placed parts. The vision systems consist of cameras which are aided by light tubes that sit directly above the search-area, flooding the scene with light. Contrasts created by the lighting helps the system interpret various features on a part, usually holes, whereby it creates an axis in order to distinguish the part's orientation. The robot is then able to use detachable grippers to pick the part up and move it around the different production steps inside the assembly cell.

The different grippers that are used vary depending on part design and other factors concerning the surroundings, but mainly consist of dowel pins and magnets in the assembly cells. The dowel pins are placed through holes on the parts in order to fixate the grip. Using magnets has the downside of attracting steel dust, but a benefit is that they are good for retrieving parts from flat surfaces. The magnets are controlled by pressurized air, which moves them back and forth in their casings, in order to pick the steel components up and to release them.

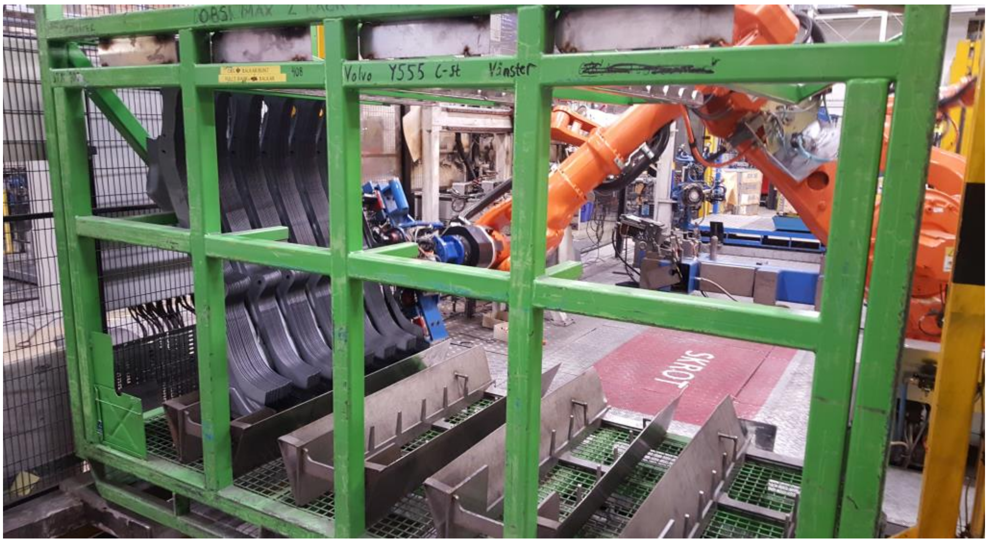

Figure 11. Robotic loading of Y555 C-st (C-pillar) beams into Assembly Cell 1. Photo: Z. Envall.

One of the assembly cells (MC 1) differs slightly from the others, being that the parts are loaded and unloaded by robots directly from and into racks or pallets (see fig. 11). This cell is used to produce two types of C-pillars for Volvo Cars. Both of these C-pillars are hung by their T-shaped bottoms in large racks specifically designed for each of the parts. The robot uses a laser sensor, administering three points on each part in order to interpret their orientation, whereby it is able to attach the gripper to these and take them through the production process. The unloading is done similarly to the way it is done at Laser 11, by placing the components into the output rack or pallet depending on the amount that has previously been produced in the work cycle.

2.1.5 HARDTECH RACKS

While the racks most widely used at Gestamp HardTech Luleå are the HT-racks, some other racks and pallets can be seen in the production (see fig. 12). These include longer HT-racks, pin pallets, product-specific racks, and various racks used for shipping the products to the respective customers.

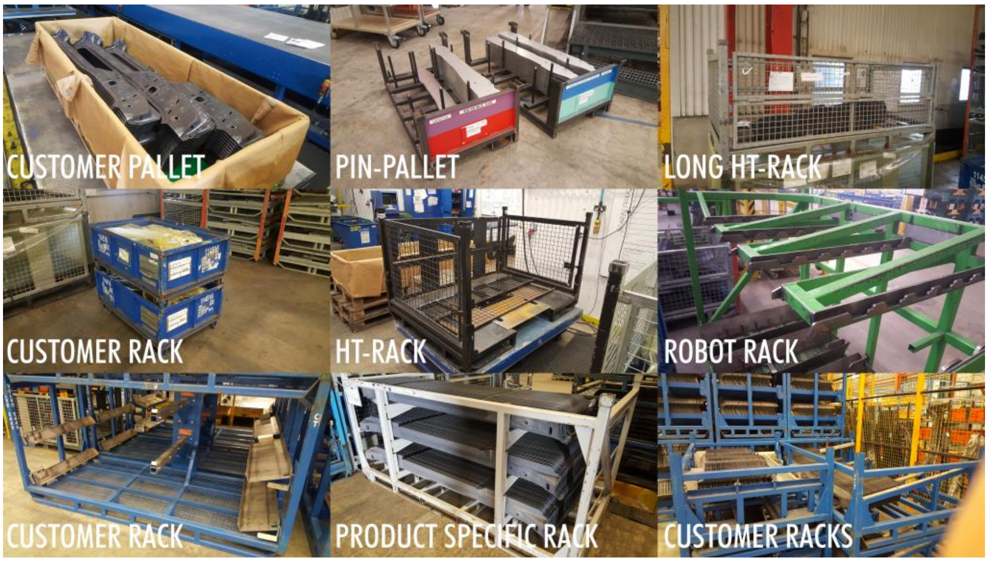

Figure 12. A variation of the racks that can be seen in the production. Photo: Z. Envall.

The racks in fig. 10 include customer racks and pallets used for shipping products to Scania (photo 1), Audi (photo 4), and Volvo (photos 7 and 9), as well as a blanks-rack (photo 2), a Volvo Trucks Windscreen rack (photo 8), a Y555 C-st robot rack (photo 6), a long HT-rack (photo 3), and a standard HT-rack (photo 5).

2.2 BENCHMARKING

The benchmarking showed a wide variety of racks being sold and used in the automotive industry. Many rack manufacturers display their standard racks along with some examples of various racks that have been designed to suit different purposes according to specified customer needs.

Automated racking solutions and various ways of dealing with the challenges brought on by automation were also found, mainly in articles but also by watching videos from various production sites. Automated production was further researched close hand through a field study at Scania Oskarshamn.

2.2.1 RACKS

The material reviewed in the benchmarking shows countless variation of racks being used and sold across the world. These can essentially be separated into standard racks and modified racks. Standard racks, such as the HT-racks being used at Gestamp HardTech Luleå, provide no specific placement-options and can be used for storing various objects of different shapes and sizes. The modified racks use some sort of additional feature to ease the loading, unloading, or storage of objects.

The material mainly consisted of various racks being used and sold in the automotive industry. The most common solution for storing various parts, mainly sheet metal stampings, that was observed is by using slots (see "Slot Fixtures" in fig. 13). These slots come in various shapes and sizes, with various frequencies, and allow the produced parts to be placed uniformly into a rack. Slot-solutions can come in different materials, mostly with a lower density than the metal racks they are attached to, such as plastic or rubber. Parts such as car doors and side panels are also hung on smooth horizontal fixtures (see “Smooth Fixtures” in fig. 13), but the slot-solutions seem to be preferred.

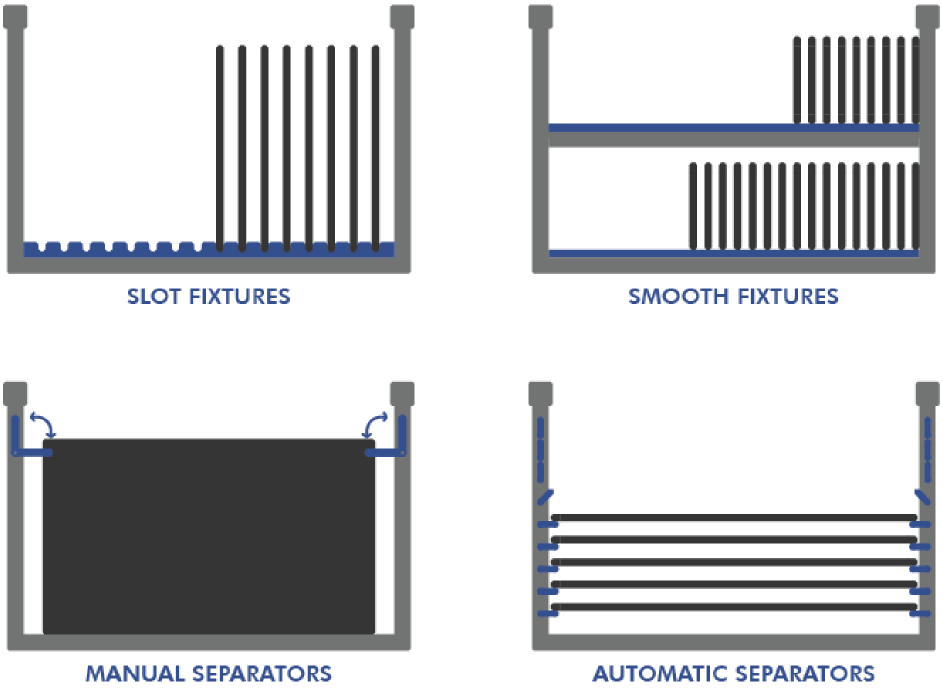

Figure 13. The 4 general types of racks identified in the benchmarking. Illustration: Z. Envall.

There are other solutions which keep the produced parts separate from each other similarly to the slots, but with designs that differ. These designs can be large metal tubes between which parts are placed, as well as various lever mechanisms that rotate into position, either automatically or manually. The manual versions (see “Manual Separators” in fig. 13) are often utilized for separating objects such as windscreens, but can also be observed keeping stamped metal parts separate from one another. The automatic versions (see “Automatic Separators” in fig. 13) explained in fig. 14 use small separators which can assume three different positions. They are initially vertical, hidden inside a housing, unable to interfere with the parts. When a part is placed on a separator it rotates out 90 degrees, carrying the part on one end, while its rear, inside the housing, is pushed up into the rear of the next separator, causing it to rotate out halfway. When a part is placed on the next separator it too rotates out to a full 90 degrees, causing the next separator in line to rotate out halfway. This chain reaction keeps occurring until all the available separators are rotated out and the rack is full.

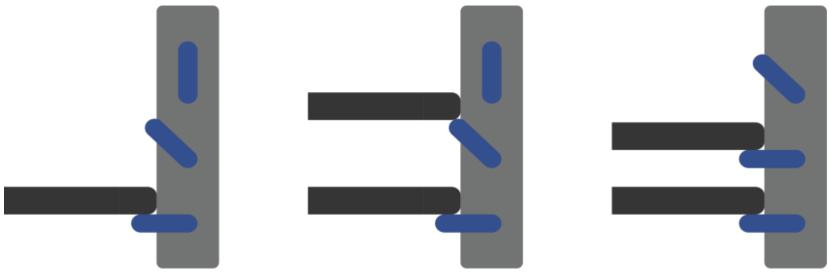

Figure 14. The mechanism used by the "Automatic Separators". Illustration: Z. Envall.

The modified racks come in several other variations and are often built for specific parts. Although some can collapse in order to increase storage capacity for empty racks, most of the modified racks seem to be fixed. Only a few can be observed being used for robot racking, and these all utilize slot-solutions.

2.2.2 AUTOMATED RACKING

Factories that utilize automated racking seems to be somewhat of a common occurrence. It is a practice that is most likely only going to grow in usage and popularity. Different instances of automated racking have been observed throughout the benchmarking, dating back to as far as 1998. Most of these are explained to work by using vision sensors, and all of them use product-specific racks, often having much empty space between the parts. Videos of robots racking parts in Toyota, Hyundai, Mazda, and Skoda factories have been observed, and other robot racking practices described in articles and observed on a field study are detailed below.

FORD I

Pierce (2008) describes an instance of Ford Manufacturing Company using automation to rack and de-rack stampings, in Buffalo, NY. With the goal of fully automating the stamping plant's sub-assembly lines, this factory utilizes both vision guided robotics as well as automated guide vehicles (AGVs) working in tandem. At more than half of the automated production cells, vision systems are used to recognize racks and stampings, while AGVs transport racks to and from the robots. The single-camera 3D-vision systems are said to be most important for capturing the rack locations, being that the AGVs are unable to stop in the exact same position every time. The rack re-design needed for the robot retrofitting of the factory is said to have been minor, with the vision system easily recognizing and adapting to variations. By having the single vision-system camera mounted to the robot, calibration is explained to be needed with lower frequency, as well as being much easier than for fixed multiple-camera systems. One of the types of racks used for robot racking at the Ford Manufacturing Company in Buffalo is shown to use metal slot-solutions to store the stampings (Pierce, 2008).

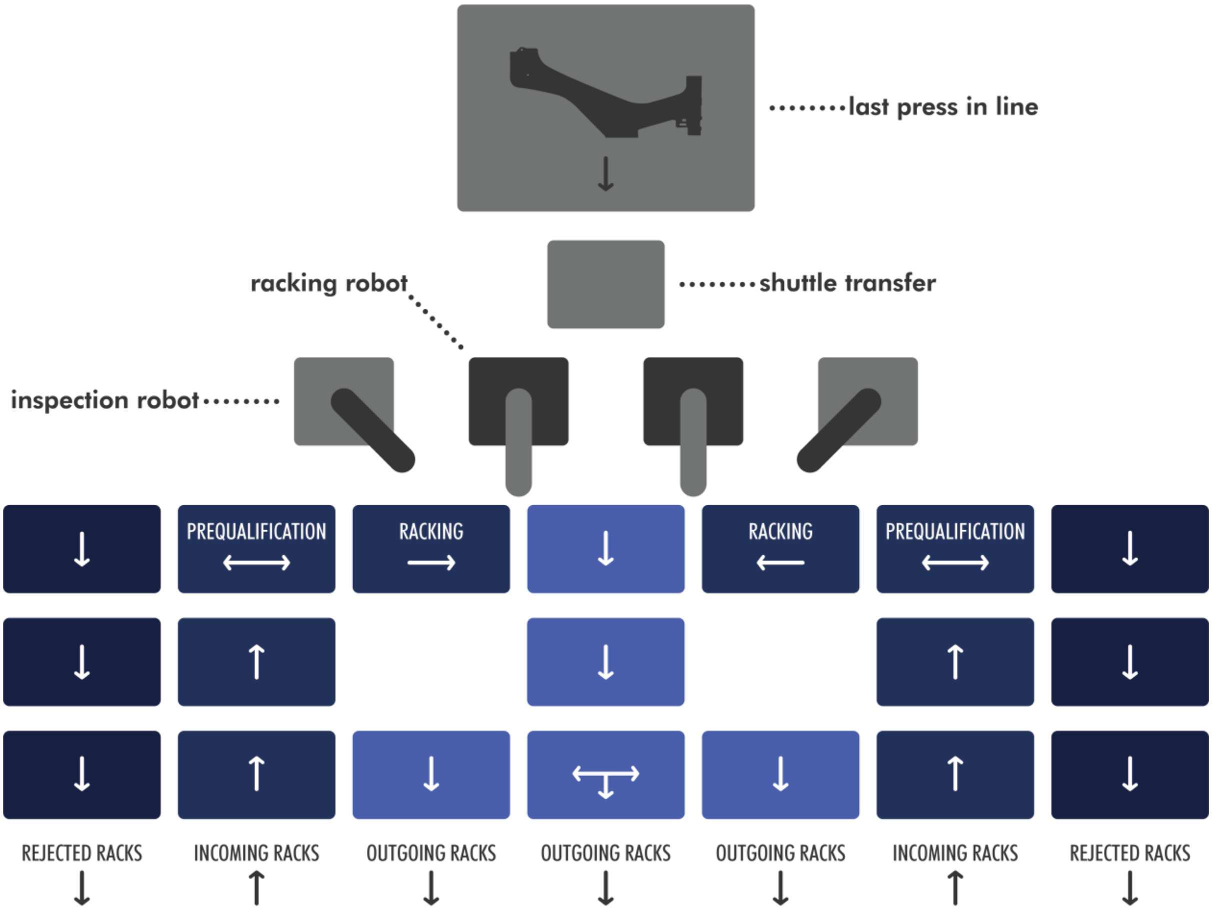

Figure 15. An automated racking system observed by Mitchell (1998) at the Ford Motor Company facilities. Illustration: Z. Envall.

FORD II

Mitchell (1998) describes another automated racking system that can be observed at the Ford Motor Company facilities, visualized in fig. 15. The parts are manufactured along a press line and transported by robots between the presses. Robots are also used for unloading from shuttle transfers into racks at the end of the press line. To achieve high-speed production runs four robots are used for racking the parts; two for loading and two for prequalifying the racks. Six-axis robots are used to prequalify the empty racks, rejecting those that do not meet the correct criteria. The rejected racks are sent back out for manual inspection, while the accepted racks are passed along for loading. The robots utilize a bar code scanner and vision systems to first identify the rack type as well as the specific rack by a serial number. Thereafter the robot checks predetermined points on the rack and compares these to standard parameters stored in a database. If the rack is pristine or if it is found to be altered or damaged within certain tolerances the rack is passed on to the loading robot, which receives an updated electronic image of the rack in order to load it in accordance to possible alterations. The rejected racks are passed back out off-line for repair, for which the system generates a report describing where the rack deviates from the set parameters (Mitchell, 1998).

SVIA

Perks (2006) examines a vision system developed by SVIA (Svensk Industriautomation AB) called Pick-Vision. These systems combine vision technology with ABB robots resulting in what the author calls "future proof" and flexible automation lines. By using recycling conveyor systems to feed components between loading and unloading, and having the vision system determining the position of these components, the need for a fixed pick-up position is eliminated. SVIA uses high frequency 150W light tubes placed above the picking area to combat ambient light sources, having the vision system search for various geometric features in the parts.

The system uses a 1-megapixel industrial camera with 30 to 40 ms processing speed and only needs a standard industrial computer system. Having a user-friendly interface is said to be the main goal of the system, eliminating problems stemming from knowledge deficiencies. A step-by-step wizard style approach is said to have a first-time programmer soon using the system to pick parts, while more advanced users will benefit from additional options, in turn being able to increase the system's overall efficiency. Teaching the vision system to detect a new part is said to take less than 15 minutes and is done by placing the part under the camera and going through the user-friendly step-by-step process. SVIA has systems for picking small as well as large parts randomly fed to the robot. However, parts that are too large or too complex in shape need to be manually positioned on a conveyor belt and fed to the robot (Perks, 2006).

SCANIA

In the outskirts of a small city called Oskarshamn, truck-cabin production facilities for Scania Trucks can be found. The production plant is divided into five factories. The first one is a press shop that produces metal stampings. These metal stampings along with other metal parts provided by various sub-suppliers are joined together in the second factory, mainly through welding, ultimately making up the truck-cabin body. The third and fourth factories are paint shops. One is responsible for laying the base paint and in the other one the final paint coating is applied. The fifth and last factory in the process consists of an assembly line where the truck-cabin is assembled and finalized. Together with robot specialist Jörgen Boman three of these factories were analyzed: The press shop, welding shop, and assembly plant.

The press shop can be likened to the Gestamp HardTech Luleå plant and consists of a press line where sheet-metal coils are automatically unwound, punched, stamped, and lastly loaded into racks. Ceiling-mounted robots make this process possible, both transferring the metal parts between the presses as well as fetching the finished parts off a conveyor belt and loading them into racks. The racking is done by three robots which are explained to each have two available racks for loading parts into. When one of the racks is full the robot starts loading into the other rack while a forklift-truck exchanges the full rack for an empty one. A vision system is used for locating the parts on the conveyor belt, consisting of ceiling mounted cameras accompanied by light tubes flooding the scene with light. The end-effectors being used for racking utilize pneumatic suction cups to grip the stampings. A large area of approximately 100 m^2 beside the press line is used to store the different types of end-effectors that are not presently being used.

The welding shop, built in 2014, is almost entirely automated. It can be explained as consisting of several robotic assembly cells where various parts are welded together into subassemblies. These subassemblies are then in turn welded together with other subassemblies, finally making up the whole truck-cabin body. The cells consist of robots that de-rack the parts and robots that take the parts through different welding operations. The general practice is that the racking robots places parts in a fixture that uses gravity to allow the part to fall into place, similarly to the way it is done at Gestamp HardTech Luleå. By doing this the part is always presented to the next robot in the exact same manner. The robots inside the welding shop do not use machine vision for localizing the parts inside the racks, but instead utilize a combination of laser and tactile sensors. Laser beams are used to determine when a part is within a certain distance, where after the robot slows down and moves toward the part until a tactile sensor signals that a part can be gripped. This type of sensor combination is said to be reliable as long as the parts are placed correctly in their respective racks. The end-effectors used to grip the various parts were explained to use both pneumatic suction cups together with magnets, in order to avoid parts slipping from the robot's grip. Four types of automated racking solutions can be observed supplying the assembly cells with parts.

The parts produced in the press shop are supplied to the robots in racks, which either use slot solutions, automated separators, or a combination of the two. In most of the racks the parts are placed laterally in rows, but in some they are stacked vertically. Built-in dynamic mechanical fixtures keep the parts in place during transport and different types of lever mechanisms are used to open and close these fixtures. Some of the lever mechanisms are operated by robots and others by the forklift-truck drivers. The part of the fixtures touching the metal stampings mostly consist of solid plastic, but some have plastic brush-like designs. The racks are supplied to the robots inside the assembly cells through rack-cages, which have fine tolerances and specific placement options. Solid fixtures inside these cages hold all of a rack's corners in place, and there are also holes on opposite corners of the bottom of the rack which are placed on large guide pins, fixing the rack's position additionally. All of the racks have individual QR-codes by which they can be specifically identified. The racks are also color coded, with components touching the metal parts such as slots and fixture surfaces often orange, movable parts such as the dynamic fixture mechanisms yellow, and an off-white base paint for the rest of the rack. These colors, especially yellow and the off-white, is used in a similar manner throughout the entire factory.

Parts that arrive to the factory from various suppliers do not use the same racks as the Scania-produced parts and are therefore manually unloaded from their respective transport racks or pallets into rack-solutions incorporated with the assembly cells. These rack-solutions mostly consist of separate single rows of parts that can be moved in and out of the cells and are often loaded vertically using automatic separators to keep the parts apart.

Two other less common variations of this rack-solution can be seen in the factory. One where parts such as B-pillars are hung on conveyors that transport them into an assembly cell, and one that leans down into the cell, where smaller parts are fed to the robot through gravity.

3 Theoretical Framework

The theory that was reviewed for the project, displayed in fig. 16, is centered around robotics, with an additional focus on machine vision systems.

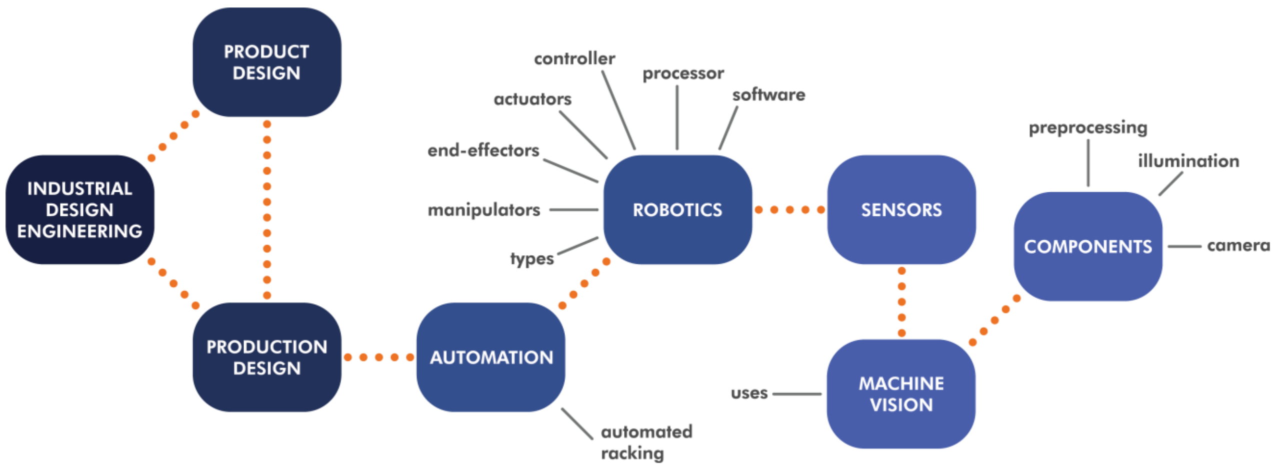

Figure 16. Theory Mapping displaying the reviewed theory. Illustration: Z. Envall.

As a master thesis in Industrial Design Engineering the theory originates from Industrial Design Engineering and is based on the knowledge gained throughout the education. With the goal of ultimately developing a product it is a Product Design project, based in a production environment, therefore also touching on the subject of Production Design.

The product design is set in the context of robotics and automation, which places it inside the field of production design. The theory also contains further exploration into the fields of robotic sensors, focusing on machine vision systems and the components included in these systems.

3.1 INDUSTRIAL DESIGN ENGINEERING

Industrial Design Engineering can be described as the combination of the industrial design and engineering design practices, located on the border between the two (Wikberg Nilsson & Törlind, 2016). Smets and Overbeeke (1994) locate the field similarly, describing it as being comprised of both design engineering and design aesthetics, requiring a high degree of technical and technological knowledge.

Industrial design is a term that is defined as design regarding the visual appearance of three-dimensional machine-made products according to Merriam Webster (n.d.). Dorst and Cross (2001) describe industrial design as searching for integrated solutions to complex multidisciplinary problems. The before mentioned integration is explained to include ergonomic, construction, engineering, aesthetic and business aspects, giving the discipline a somewhat broader description than Merriam Webster (Dorst & Cross 2001). According to Cuffaro et al. (2013) an integral difference between design and fine arts is that design often deals with products meant for "make more than one"-production, while artworks are often singularly produced.

Pahl and Beitz (2013) describe engineering design as finding solutions to technical problems and optimizing these solutions according to constraints and requirements posed by material, technological, economic, legal, environmental, and human-related factors. Design as an engineering activity is said to provide the fundamentals for the physical realization of ideas while being scientifically based, building upon special experience, and having the possibility to affect almost all areas of human life (Pahl & Beitz, 2013).

This thesis relates to Industrial Design Engineering by having a goal that entails finding a solution to a multidisciplinary problem, matching the description of industrial design offered by Dorst and Cross (2001), touching on various aspects such as robotics, construction, business and production. By stemming from a technical problem and requiring a scientific base along with special experience the project also falls under the definition of engineering design as described by Pahl and Beitz (2013). The thesis thus combines the fields of industrial design and design engineering, which corresponds to Wikberg Nilsson's et al. (2016) definition of Industrial Design Engineering.

3.2 PRODUCTION DESIGN

Bellgran and Säfsten (2010) describe production development as a concept that deals with the creation of efficient production processes and the development of productional capabilities. Production development is said to include both the design of new production systems as well as improving existing systems. The authors also state that focusing on the area of production is now more important than ever for manufacturing companies in the western world (Bellgran & Säfsten, 2010).

Outsourcing industrial production to low-wage countries has been a growing trend over the past decades (Bellgran & Säfsten, 2010). Blanchet, Rinn, Von Thaden, and De Thieulloy (2014) cite statistics showing that 40% of worldwide production is performed in emerging countries, which is a share that has doubled over the past two decades. Western Europe's manufacturing value added has instead dropped from 36% to 25% (Blanchet, et al., 2014). However, Bellgran and Säfsten (2010) claim that the possible advantages of outsourcing have lately been questioned. The main concern that is raised relates to losing the ability of producing products. The authors claim that the chain connecting product development, industrialization, and production is important, and that if one link is missing all links are likely to suffer (Bellgran & Säfsten, 2010).

3.3 PRODUCT DESIGN

Product Design is a discipline that according to Milton and Rodgers (2011) includes the areas lighting, furniture, graphic, fashion, interaction, and industrial design. Milton and Rodgers (2011) state that one of the central aspects of product design is about improving the quality of life for the users. Product design is also explained to be a commercial activity highly intertwined with businesses (Milton & Rodgers, 2011). Cuffaro et al. (2013) echo this sentiment, claiming that design was conceived to meet a business need or serve a business purpose. They go on to explain by stating that design is about helping businesses attain a market advantage and increased profits by attracting consumers (Cuffaro et al., 2013). Milton and Rodgers (2011) sum product design up as making things better, for customers, businesses and the world. The term 'product' is explained to be a word used very widely to describe what is referred to as 'everything' (Milton & Rodgers, 2011). Milton and Rodgers (2011) however go on to classify various types of products:

- **Consumer products –** Such as cars, domestic appliances, and furniture.
- **One-off artistic works –** Artistic products not meant for mass production
- **Consumables –** Such as motor oil, bottled water, and newspapers
- **Bulk or continuous engineering products –** Such as foils, rods, and laminates
- **Industry products –** Such as bearings, motors, and circuit boards
- **Industrial equipment products –** Such as machine tools, goods vehicles, and work-stations
- **Special purpose products –** Such as jigs, fixtures, and special purpose robotics machinery
- **Industrial plant –** Industrial equipment products and devices

Wikberg Nilsson, Ericson and Törlind (2015) use the word product to describe the result of a design process, giving the term product a broad definition including physical objects, systems, environments, services, processes, and methods as examples of products.

Cuffaro et al. (2013) states that product development in the industrial design sense is rarely based on a common and concise source of information. The necessary information for designing details is often found in the depths of various sources.

3.4 AUTOMATION

According to Bellgran and Säfsten (2010), the term automation is often defined as mechanical, electronic, and computer-based systems that perform, inspect, and control various operations in a production. Depending on the degree of human involvement, production operations can be divided into three levels: manual, semi-automatic, and automatic (Bellgran & Säfsten, 2010). Popovic (2000) states that the progress in automation systems used in production plants has followed the evolution of instrumentation and computer technology.

What many are calling "Industry 4.0" is described by Blanchet et al. (2014) as the predicted results of a fourth industrial revolution. This revolution will lead to a higher level of IT-connectivity within industries, with complex IT-systems built around machines, storage systems, and supplies, turning them into "cyber-physical systems". The results of this are explained as including more efficiency in production systems, allowing production processes to be changed at short notice with minimal downtimes (Blanchet et al., 2014). Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel, and Harnisch (2015) describe what they refer to as the nine technological advancements that will form the foundation for Industry 4.0. These are said to consist of data and analytics, autonomous robots, simulations, horizontal and vertical system integration, the "Industrial Internet of Things", cyber security, cloud technology, additive manufacturing, and augmented reality.

The previous industrial revolution is explained to have accelerated the level of electronic automation, and according to Blanchet et al. (2014) included the initial shift from manual labor to robotics. This change is predicted to propagate further in the fourth revolution, resulting in more complex tasks being done by robots, along with humans and robots working hand in hand through smart human-machine interfaces. The widening use of robots is even going to enable remote control of the workflow according to these authors (Blanchet et al., 2014). Rüßmann et al. (2015) state that the advancement in automation is going to result in robots being more autonomous, flexible and cooperative, also predicting that humans and robots will work side-by-side. Lasi, Fettke, Kemper, Feld and Hoffman (2014) explain these "smart factories" as having manufacturing completely equipped with sensors, actors, and autonomous systems.

Industry 4.0 is explained to be a way for Europe to increase its market share, regaining what was lost in the deindustrialization that has been occurring over the past two decades (Blanchet et al., 2014).

3.5 ROBOTICS

With the aim of combining high quality, productivity, and adaptability at minimal cost, industrial robots are considered as "*the cornerstone of competitive manufacturing*" according to Hägele, Nilsson, and Pires (2008, p. 963). More than 60% of the over 1 million industrial robots reportedly being used in 2007 were performing tasks in the automotive industry (Hägele et al., 2008). Corke (2012) defines a robot as a machine that is goal-oriented which can plan, sense, and act. 'Sense' is described as an answer to the questions 'where am I?' and 'where are you?'. Manufacturing educators SME (2018) define industrial robots as "multi-functional manipulators designed to move materials, parts, tools, or specialized devices through various programmed motions". Hunt (1983) first offers a broad definition, implying that robots are designed to resemble humans in form and function. Similarly to SME, he then goes on to state that *"an industrial robot is a programmable multifunctional device designed to both manipulate and transport parts, tools, or specialized manufacturing implements through variable programmed paths for the performance of specific manufacturing tasks"* (Hunt, 1983, p. 22).

A robotic system is explained to consist of seven central components: A manipulator, an end effector, actuators, a controller, a processor, software, and sensors. A robot is said to be characterized by its payload, reach, precision and repeatability. The payload defines the amount of weight a robot can carry, and the reach determines a robot's maximum dexterity within its work envelope. Its precision is defined by the robot's accuracy in reaching a specific point, and its repeatability characterizes how well the robot can repeatedly move with accurate precision (Niku, 2011).

3.5.1 MANIPULATOR

The manipulator is the main body of the robot, consisting of links, joints, and other structural elements (Niku, 2011). Siciliano, Sciavicco, Villani, and Oriolo (2010) also define a manipulator as being made up of rigid links interconnected by mobilizing joints, subdividing the manipulator into a mobile arm, a dexterous wrist, and also the end effector used for performing a required task. A manipulator usually consists of an open kinematic chain, defined as having one sequence of links connecting the two ends of the chain, while a closed kinematic chain instead forms a loop. The joints are explained to each add one degree of freedom (DOF) to an open kinematic chain, being either prismatic or revolute. Prismatic joints allow for translational motion between two links, while revolute joints allow links to move rotationally in relation to one another. The number of DOF determine a robot's ability to move freely through three-dimensional space, and six DOF are generally required for this (Siciliano et al., 2010). Many of the industrial robots used today in Gestamp HardTech Luleå as well as other factories are six axes robots (see fig. 17), allowing movement within six degrees of freedom (RobotWorx, 2018).

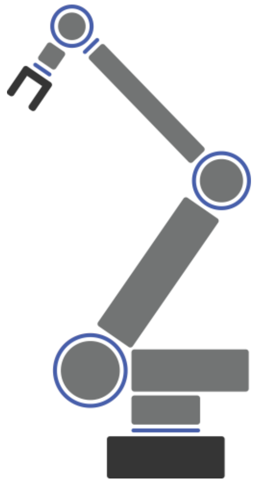

Figure 17. . Generalization of a six-axis robot, with the axes displayed in blue. Illustration: Z. Envall.

Siciliano et al. (2010) state that manipulators can be classified as either Cartesian, cylindrical, spherical, SCARA, or anthropomorphic depending on the type and sequence of the arm's DOFs. Cartesian manipulators have three prismatic joints, often positioned orthogonally in relation to each other. While providing good mechanical stiffness and accuracy, Cartesian geometry lacks in dexterity. If the first joint is switched from prismatic to revolute, the manipulator is instead classified as cylindrical. Cylindrical structures also offer good mechanical stiffness, decreasing wrist positioning accuracy while increasing the horizontal stroke. If the second joint is also switched to a revolute joint, the geometry of the manipulator is defined as spherical. This lowers the mechanical stiffness along with the wrist positioning accuracy but increases the radial stroke. SCARA geometry uses two revolute joints along with one prismatic joint, with all the joints having parallel axes of motion. SCARA manipulators have a high level of stiffness for vertical loads but lack in wrist positioning accuracy. Anthropomorphic manipulators have three revolute joints, with the first joint being orthogonal to the other two, which in turn are parallel to one another. Providing motion possibilities similar to the human arm, the second and third joints on anthropomorphic arms are often referred to as the shoulder and elbow. Anthropomorphic manipulators have the highest level of dexterity, but the wrist positioning accuracy is decreased (Siciliano et al., 2010).

Siciliano et al. (2010) cite a 2005 report issued by the International Federation of Robotics stating which types of geometries are used for robots internationally. 59% of the manipulators are said to be anthropomorphic, 20% Cartesian, 12% cylindrical, and 8% using SCARA geometry.

3.5.2 END-EFFECTOR

The end-effector, essentially the robot's "hand", is connected to the robot's last joint, and is used to perform the required tasks, such as manipulating objects and making connections to other machines, according to Niku (2011). Typical examples of end-effectors include welding torches, paint spray guns, glue laying devices, and part handlers (Niku, 2011). Siciliano et al. (2010) add mills, drills, and screwdrivers to the list. In most industrial object manipulation applications, typical grippers are used as end-effectors, according to Siciliano et al. (2010). Niku (2011) states that robot manufacturers generally supply only a simple gripper, leaving end-effector design and manufacturing to other entities. End-effectors are usually designed by either a company's engineers or outside consultants to be used for specific purposes. (Niku, 2011). Siciliano et al. (2010) also point to the end-effector often being designed to suit a specific task.

3.5.3 ACTUATORS

The actuators can be viewed as the "muscles" of a manipulator, moving its links and joints according to signals received from the controller. Examples of actuators include servomotors and stepper motors, along with pneumatic and hydraulic actuators (Niku, 2011). Siciliano et al. (2010) describe actuating systems as being comprised of a power supply, a power amplifier, a motor, and a transmission.

Siciliano et al. (2010) state that the power supply is the system's primary power supplier, providing power to the amplifier. The amplifier then modulates the power flow to the motor according to signals from the controller. The motor's job is to activate the joints in order to produce the desired movement. Depending on the type of input power, Siciliano et al. (2010) divide motors into three groups:

- *Pneumatic motors* – Powered by pneumatic energy supplied by a compressor.
- *Hydraulic motors* – Powered by hydraulic energy from a reservoir.
- *Electric motors* – Powered by electric energy provided by an electric distribution system.

Pneumatic energy is usually in the form of compressed air transmitted through flexible tubes, according to Coiffet and Chirouze (1983). Hydraulically powered systems most often use mineral oils of varying viscosity, providing a good power-to-weight ratio but also introducing several problematic factors. Electrical energy is easily available, non-polluting, and can be transmitted through cables. The downside is in the electrical system's power-to-weight ratio, being lower than both the other types of power supplies (Coiffet & Chirouze, 1983). According to Siciliano, et al. (2010) electric servomotors are most commonly used in robotics applications.

Siciliano et al. (2010) explain that joint motion in manipulators require low speeds and high torques. Servomotors are said to typically provide high speeds and low torques, in turn requiring a transmission. Transmissions come in different variations, and which type to use depends on the power requirements, the desired motion, and the motor location (Siciliano et al., 2010).

3.5.4 CONTROLLER

The controller can be likened to the human cerebellum, controlling the different motions performed by the actuators. Receiving its data from the processor, the controller tells the robot how to move, and gets feedback from sensors monitoring the various joints (Niku, 2011). The principal control task, according to Taylor and Kleeman (2006), is to accurately, rapidly, and repeatably move the end-effector through the desired motions. Siciliano et al. (2010) explains this as the controller signaling the amplifier the amount of power needed to perform a certain movement. Craig (2005) classifies control of the manipulator as being either linear or nonlinear. Linear-control techniques are used for systems that can be modeled mathematically by linear differential equations. Linear control is however said to be approximate methods when it comes to manipulator control, and although the dynamics of a manipulator are bettered represented by nonlinear differential equations, the linear methods are more commonly used in the current industrial practice (Craig, 2005).

3.5.5 PROCESSOR & SOFTWARE

The processor is in turn viewed as the "brain" of the robot, calculating its motions and overseeing the controller and the sensors. The processor normally consists of a computer and is sometimes integrated with the system's controller (Niku, 2011).

The system's software can be divided into three groups. The first is the operating system that operates the processor. The second is robotic software used to calculate how the joints need to move in order to perform the required tasks. The third consists of application-oriented routines and programs which determine the tasks that need to be performed (Niku, 2011).

3.5.6 SENSORS

Sensors are used to provide the robot with information, either regarding its internal state or its surroundings. Similar to the human senses, different sensors are used depending on what information the robot needs to perform certain tasks in a safe and efficient manner (Niku, 2011).

Christensen and Hager (2008) explain two ways of classifying sensors, either into passive and active sensors, differentiating the two by if they emit some kind of energy into the environment or not, or proprioceptive and exteroceptive sensors, which either measure factors concerning the internal robot body or the external environment. Proprioceptive sensors are usually passive, measuring physical factors concerning robot function such as velocity, acceleration, joint position, and motor torque amongst others. Various sensors and their classifications are shown in table 1.

The exteroceptive sensors can be further divided into contact and non-contact sensors. Sensors frequently used in robotics are claimed to be tactile sensors, haptic sensors, motor/axis sensors, heading sensors, beacon-based sensors, ranging sensors, speed/motion sensors, and identification sensors (Christensen & Hager, 2008).

According to the forum Robot Platform (2018) many hundreds of different sensors exist today, made to sense virtually anything. They list light sensors, sound sensors, temperature sensors, contact sensors, proximity sensors, distance sensors, pressure sensors, tilt sensors, positioning sensors, acceleration sensors, among many others.

Table 1. Various sensor categories. The objective is either exteroceptive (EC) or prorioceptive (PC). The method is either passive (P), active (A), or a combination of the two (P/A). Illustration: Z. Envall.

CLASSIFICATION	SENSOR TYPE	OBJECTIVE	METHOD
TACTILE SENSORS	SWITCHERS/BUMPERS	EC	P
	OPTICAL BARRIERS	EC	A
	PROXIMITY	EC	P/A
HAPTIC SENSORS	CONTACT ARRAYS	EC	P
	FORCE/TORQUE	PC/EC	P
	RESISTIVE	EC	P
MOTOR/AXIS SENSORS	BRUSH ENCODERS	PC	P
	POTENTIOMETERS	PC	P
	RESOLVERS	PC	A
	OPTICAL ENCODERS	PC	A
	MAGNETIC ENCODERS	PC	A
	INDUCTIVE ENCODERS	PC	A
	CAPACITY ENCODERS	EC	A
HEADING SENSORS	COMPASS	EC	P
	GYROSCOPES	PC	P
	INCLINOMETERS	EC	P/A
BEACON BASED SENSORS	GPS	EC	A
	ACTIVE OPTICAL	EC	A
	RF BEACONS	EC	A
	ULTRASOUND BEACONS	EC	A
	REFLECTIVE BEACONS	EC	A
RANGING SENSORS	CAPACITIVE SENSORS	EC	P
	MAGNETIC SENSORS	EC	P/A
	CAMERA	EC	P/A
	SONAR	EC	A
	LASER RANGE	EC	A
	STRUCTURES LIGHT	EC	A
SPEED/MOTION SENSORS	DOPPLER RADAR	EC	A
	DOPPLER SOUND	EC	A
	CAMERA	EC	P
	ACCELEROMETER	EC	P
IDENTIFICATION SENSORS	CAMERA	EC	P
	RFID	EC	A
	LASER RANGING	EC	A
	RADAR	EC	A
	ULTRASOUND	EC	A
	SOUND	EC	P

3.5.7 ROBOT TYPES

Mitchell (1998) discusses the robot types used for part transfer in metal pressing applications, listing robotic shuttle devices, swing-arm robots, and pendulum-arm robots. Robotic shuttle systems are made up of three parts: Two press-mounted robots and one floor-mounted part transfer shuttle. The robots are usually mounted inversely to the press and can have two to six axes of motion. Swing-arm robots are described to consist of a six-axis articulated-arm robot that is mounted to a supporting swing-arm seventh axis. The robot moves the parts being produced by swinging back and forth between two presses. Normally mounted to a slide or track, the swing-arm robots consist of fewer units than the robotic shuttle systems and are said to increase flexibility and equipment reliability. The pendulum-arm robot typically consists of four axes, moving in a pendulum-motion between the presses. The pendulum-motion allows for a very long reach, and the robot can be mounted to the side of the presses, reducing the need for repositioning during die changes (Mitchell, 1998).

3.5.8 AUTOMATED RACKING

Declaring that the idea of automated parts racking is not especially new, Mitchell (1998) explains the obstacles that are often encountered as being due to costly rack designs, fleet management factors, and a lack of flexibility. However, it is stated that the combination of flexible robots, vision systems, and a creative process development has resulted in feasible automated racking solutions. Many of the more advanced solutions are said to use specially-designed and positively-located racks implementing sophisticated and costly dunnage system designs.

By using vision technology and adaptive motion control, racking systems have the capability of producing a minimum of 500 parts per hour, supporting up to 14 different parts, all while using simple racks and dunnage solutions. The main needs for these rack- or dunnage-solutions are enabling the robot to locate the parts, and preventing damage during storage and transport (Mitchell, 1998).

3.6 MACHINE VISION SYSTEMS

Taylor and Kleeman (2006, p. 3) state that "*robot vision explores how visual information can be to drive interactions with the world, by linking perception to action*". Perks (2006) points to the fact that although this technology is not especially new, the advancement in computer power over the last decades has enabled these systems to be used much more proficiently.

Hunt (1983) explains machine vision as a computer interpreting brightness variations in a visual image by analyzing an array of pixels. Taylor and Kleeman (2006) describe an image as a quantized two-dimensional signal provided by sampling the intensity and frequency of light on the image plane. These samples are formed by capturing light particles over a brief period of time on a 2D sensor array, such as a charge coupled device (CCD). The term pixel is used to describe one element of the array. The process of capturing an image can be described as a transformation between the three-dimensional Euclidian space and the two-dimensional space of the image plane (Taylor & Kleeman, 2006). Perks (2006) states that many shortcomings of vision systems often have to do more with poor implementations due to a lack of knowledge, rather than faults concerning the system itself.

Perks (2006) defines vision systems as being comprised of a camera and a microprocessor or computer, along with some sort of associated software. According to Thörnberg (2013) the key components of a machine vision system consist of a camera and some means of illumination. The illumination is used to increase the visual properties of the captured images. The observed 3-dimensional scene is illuminated, whereby the reflected light passes through the camera lens and strikes the surface of a pixel sensor (Thörnberg, 2013). According to Siciliano, et al. (2010) this photosensitive sensor transforms the light energy into electric energy and is usually a CCD (charge coupled device) or CMOS (complementary metal-oxide-semiconductor) sensor. A CCD sensor is made up of a rectangular array of photosites and transforms the energy through a photoelectric effect caused by photons striking a semiconductor surface. CMOS sensors are instead made up of a rectangular array of photodiodes that discharge when hit by photons. The main difference between the two is that the CCD sensors measure volume while CMOS sensors measure throughput. By measuring throughput CMOS sensors never allow saturated pixels to overflow, which can happen with CCD sensors, causing an effect known as "blooming" (Siciliano et al., 2010).

3.6.1 CAMERA

Siciliano et al. (2010) describe a camera as a complex system mainly consisting of a shutter, a lens, a photosensitive sensor, and analog preprocessing electronics. The light reflected from an object passes through the shutter, is focused by the lens, and registered by the sensor in order to then be processed and converted into electric energy, visualized in fig. 18 (Siciliano et al., 2010). Beyerer, Puente León, and Frese (2016) describe this electric energy as analog, usually in the form of electric voltage.
According to Perks (2006), the camera used in vision systems can be anything from standard compact camera systems with integrated vision, to laser sensors and high speed high resolution cameras. Combining several cameras to build 3D images is also a possibility, which enables a robot to pick randomly placed components out of a container, often referred to as "bin picking" (Perks, 2006).

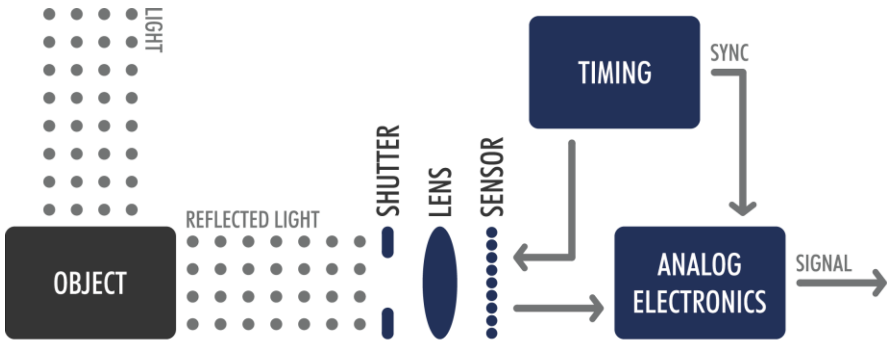

Figure 18. Generalized visualization of a camera's function. Illustration: Z. Envall.

Industrial camera manufacturer Basler AG (2015) categorizes the cameras being used in vision systems into two types, either an area scan or line scan version. The line scan camera has one single line sensor and records the scene line by line. This is suited for objects that are moved along a conveyor belt for example. The area scan camera has a large area sensor and can record large areas simultaneously. This also works on conveyer belts, although there is a risk of motion blur if the object is moving rapidly

(Basler AG, 2015). Robotics and automation instructor Peter Dettmer (2013a) goes further, explaining this phenomenon as the balance between conveyor belt speed and the camera's shutter speed. The longer the shutter is open, the more detailed an image will be, but if the photographed object is moving, a slower shutter speed will lead to an increased motion blur. He states that the way this problem is often tackled today is by using a fast shutter speed and a high intensity light source, capturing as much light as possible in an as short time frame as possible.

The resolution requirements for the cameras being used in industrial vision systems is much lower than what is available on the camera-market resolution-wise. The reason for this is that higher resolution images take longer time to process, and the component features used for interpretation by the system are often adequately captured by lower resolution cameras (Dettmer, 2013a).

Dettmer (2013a) stresses the importance of camera set-up, explaining the layout as being a balance between the field of view, standoff distance, CCD width, and focal length. He recommends initial testing on a stationary prototype set-up before implementing the camera, but also provides an equation for calculating the set-up, stating that the quotient of the focal length divided by the CCD width should equal the quotient of the standoff distance divided by the field of view.

3.6.2 ILLUMINATION

Perks (2006) states that ambient light caused by for example windows or skylights is a common problem for vision systems. Dettmer (2013a) states that 70% of a successful vision system set-up is driven by the lighting arrangements. Advanced Illumination Sales and Support Manager Daryl Martin (2012) describes lighting as a critical aspect in utilizing vision technology successfully.

Martin (2012) explains illumination techniques as comprised of bright-field (partial), dark-field, backlight or diffuse lighting (full bright-field) solutions (see fig. 19).

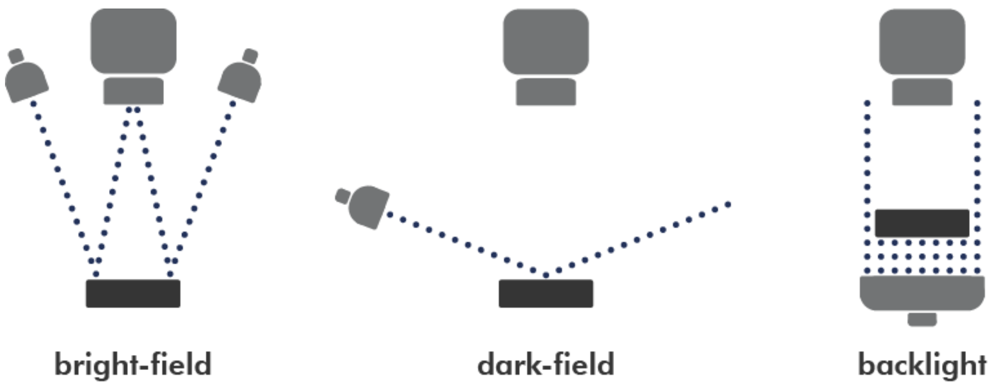

Figure 19. Generalized visualization of different lighting techniques. Illustration: Z. Envall.

Partial bright-field is stated to be the most common lighting solution in vision systems. This type of lighting is directional, usually from a point source, and is used to achieve contrasts and to enhance the topographic detail (Martin, 2012). According to Dettmer (2013a) bright-field illumination often consists of a light right around the camera pointing straight down, and is a good way of providing an object with a high level of illumination. Martin (2012) however states that bright-field solutions can cause trouble when specular surfaces are examined, being that a "hotspot" reflection is easily generated. According to Dettmer (2013a) a specular reflection comes from positioning a direct light source at a certain angle from the object, causing the reflected light to travel directly into the camera lens.

Martin (2012) uses car lights as an example to explain dark field lighting. By having the lights positioned close to the ground a contrast between small surface inconsistencies is created. Dettmer (2013a) states that placing a light source in the dark-field area aids in identifying for example irregular surfaces on a flat object. Martin (2012) compares reflections from a mirror caused by bright field and dark field lighting. The bright field lighting results in a glossy reflection while the dark field lighting is reflected only by a small scratch on the mirror's surface.

By resulting in a dark silhouette against a bright background, a backlight technique is described to be useful for hole-detection, measuring, and part orientation (Martin 2012). Using a backlight solution means that the object is going to block a certain amount of the light, resulting in aiding the identification of an object's outlines (Dettmer, 2013a). A common backlighting approach, as described by Mersch (1986), is place fluorescent light tubes inside a box with an open top, covering the top of the box with translucent Plexiglas. By putting a part on the Plexiglas, the lighting will cause a large contrast between the part and the background, resulting in a clear silhouette view.

Martin (2012) claims that diffuse lighting is most commonly used on shiny specular parts as well as parts with mixed reflectivity. 3 commonly used implementations are described: Dome diffuse, axial diffuse, and flat diffuse. Dome diffuse lights are effective for lighting curved and specular surfaces, often found in the car industry for example. In axial diffuse lighting, the specular glare is used to define various flat features on a part. An example of this is detecting damages on the top sealing surfaces of a plastic bottles (Martin, 2012). The implementation described as flat diffuse is explained by Dettmer (2013a) as flooding an object with light from above, causing the reflected light to diffuse out in all directions.

According to Basler AG (2015), when using a monochrome camera to identify objects of a certain color, the color of the light source should match the color of the object. For example, the light source for identifying red objects should be red. The reason for this is that out of the objects being inspected the red objects reflect the red light the best, making them appear very bright to a monochrome camera, in comparison to other colored objects which absorb more of the red light, making them appear darker. Dettmer (2013b) however points out that when the robot needs to identify for example red object from a differently colored background, a green light should be used. This is explained by the fact that by using complementary colors to illuminate the objects being examined, the contrast increases, and the object becomes much clearer in relation to the background. Another way of dealing with differently colored objects is by using band pass filters, blocking out certain wavelengths and thus making certain colors appear brighter and increasing the desired contrasts.

3.6.3 PREPROCESSING

Machine vision systems are computer systems that according to Beyerer, Puente León, and Frese (2016) interpret image data through a number of computational steps, shown in fig. 20.

Figure 20. The computational steps performed in vision system preprocessing, with the results from each step displayed in grey. Illustration: Z. Envall

The electrical signal produced by the captured light is discretized and limited regarding space and amplitude. The raw data usually contains various levels of disturbances such as noise and inhomogeneities. The goal of the following restoration process is to retain the relevant data by compensating for various disturbances. This improved image data is separated into different regions in the segmentation step, after which the different parameters relevant to the task are extracted. Based on this condensed information decisions can be made. These include things such as detection, classification, and interpretation. Depending on the decision made, an action can finally be taken (Beyerer et al., 2016).

Beyerer et al. (2016) stresses the importance of the image acquisition step. If the captured image lacks in quality, fixing this by the subsequent processing steps is said to be difficult or even impossible, depending on the requirements. Much effort should therefore be spent on designing the image acquisition setup regarding things such as light sources, test objects, optics, and sensors.

Thörnberg (2013) describes the computational steps involved in machine vision systems as including image acquisition, preprocessing, segmentation, labeling, feature extraction, and classification. Dettmer (2013a) explains the computational process similarly, but reduces the steps to include capturing an image, transferring the image data, preprocessing, measurement processing, and outputting the results. Coiffet and Chirouze (1983) offer the description of a vision system being comprised of: signal emitting, signal reception, signal conversion, image preprocessing, image representation, and recognition.

3.6.4 MACHINE VISION USES

Dettmer (2013a) cites inspecting quality and amounts, along with measuring dimensions and determining positions as the major uses of vision systems. When it comes to robotics, error proofing and inspecting a component's location and orientation are said to be the main ways in which vision systems are used. Improvements that can be achieved by using a vision system are stated as a reduction in human error, an increased throughput, improved product quality, and increased safety (Dettmer, 2013a).

4 Method and Implementation

This chapter describes the methods used in this master thesis project and includes the initial project planning, a context description in the form of an analysis of the current state at Gestamp HardTech Luleå, followed by benchmarking studies analyzing relevant information from different places around the world. It furthermore gives an insight into how the design process was performed, consisting of the phases Conceive, Design, Implement, and Operate. The chapter concedes with a method discussion, where the entire process is lastly reflected upon.

4.1 PROCESS

This project can essentially be viewed as a traditional product development project, differing by the fact that the user who the design is normally centered on is replaced by a robot. By viewing the project as a traditional product development project, the design process was structured as a traditional stage-gate process with 4 stages. The structure is based on the process described as CDIO by The CDIO™ Initiative (2018) as well as the similar Engineering Design Process described by Michael J. French in 1985 (Dubberly, 2004).

CDIO is an acronym, with the different letters representing each of the 4 stages: Conceive, Design, Implement and Operate. The CDIO™ Initiative (2018) describe the 4 stages as (C) finding the needs, (D) creating the design, (I) the transformation of the design into the product, and (O) using the implemented product to deliver the intended value. Dubberly (2004) describes the Engineering Design Process as having a structure similar to CDIO, starting off with an analysis of the problem, followed by conceptual design, embodiment of schemes, and lastly detailing. In this process the various gates are also defined, along with continuous assessment.

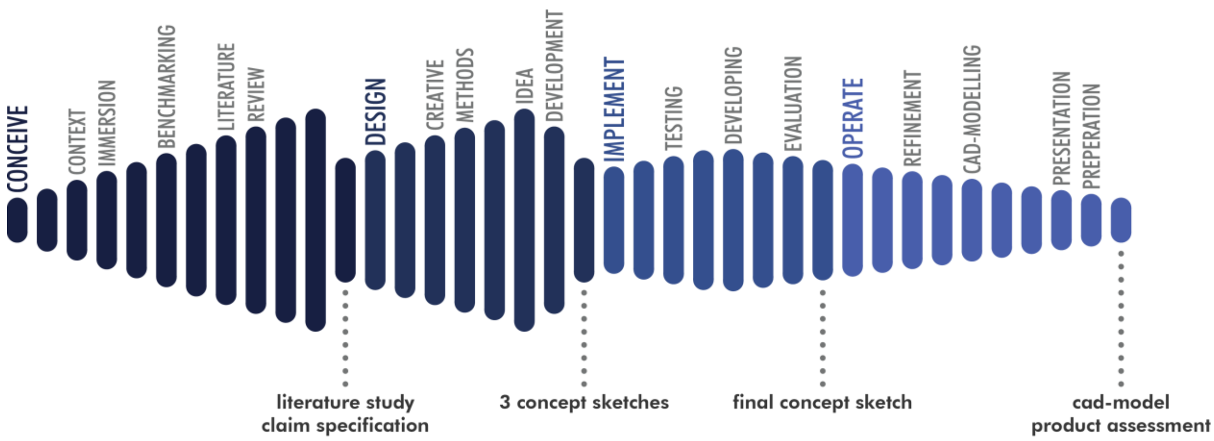

Figure 21. Visualization of the process, including the content of the stages and the various deliverables required at each gate. Illustration: Z. Envall.

The stages in this project were planned and structured according to the specific requirements needed for reaching the envisioned objectives. The process is visualized in fig. 21. The plan was to start with a Conceive phase assessing the problem and reviewing the required theory. With a thorough understanding of the context and the robot-user, it was then planned to resume through a Design phase focused on solving the problem, then enter an Implementation phase including further development, prototyping, and testing. The Operate phase was planned to be centered on supplying the final deliverables.

4.2 PROJECT PLANNING

The project was planned by estimating what needed to be done in order to ultimately reach the desired results. This was done by analyzing the current situation, defining the scope of the project, assessing the resources, designing the process, and managing the time required for each of the stages. The planning in the form of a Gantt-chart is displayed in fig. 22.

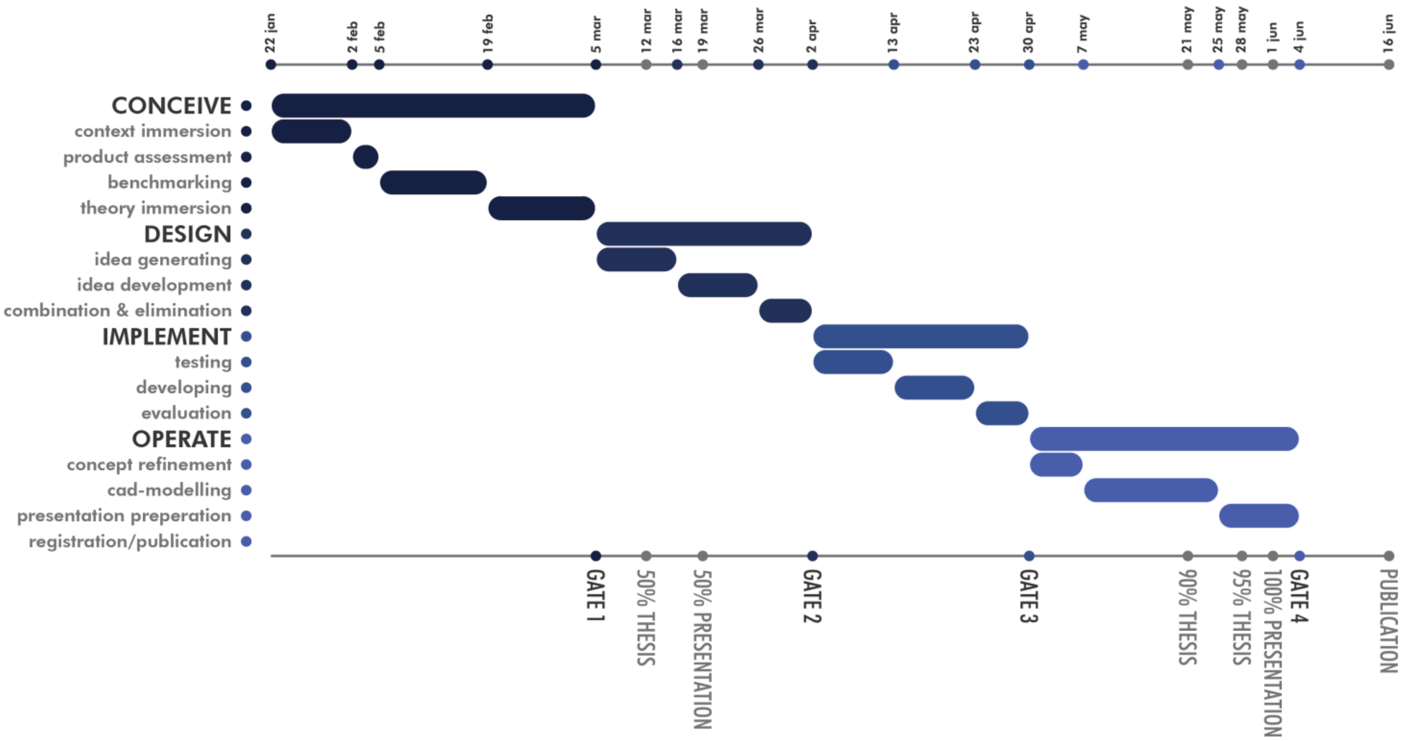

Figure 22. The project planning in the form of a Gantt-chart. Illustration: Z. Envall.

The current situation was analyzed by examining the production and by reviewing the information supplied by the Gestamp HardTech supervisor as well as other Gestamp HardTech personnel. This information was acquired both literary and verbally. Defining the project scope mainly consisted of understanding the objective and assessing the time limitations. By reviewing what resources were available the process could be designed, and the various time restrictions could be defined.

4.3 CONTEXT IMMERSION

The context of this project consists of three main parts: Examining the Gestamp HardTech Luleå production site, examining automated production in general, and assessing the various products produced at Gestamp HardTech Luleå. The analysis of the HardTech production site in Luleå consisted of examining the entire production, as well as immersing into automation solutions, robotics, and machine vision. Various other automated production solutions were examined both by reviewing articles and production videos, as well as performing a field study at the Scania production facilities in Oskarshamn.

4.3.1 CURRENT STATE

Understanding the production at Gestamp HardTech Luleå is a wide task, and the aim was therefore to focus on aspects central to this project. Prior working experiences at the production plant summing up to thousands of hours provided a good foundational view of the current situation. This was added to by several field studies inside the factory guided by knowledgeable personnel, each focusing on different aspects of the production. Walk-throughs with two different staff members at Gestamp HardTech were centered around material handling, Magnus Eriksson explained various specifics, and technician David Hedlund provided detailed information concerning robotics and the machine vision systems in use, both through a field study and an interview.

The first walk-through with a Gestamp HardTech process engineer provided a more comprehensive overview of the production, and the different automated systems presently being used in the plant were described and analyzed. The goal of the second walk-through with a Gestamp HardTech production technician was mainly to find full racks of all the various products to photograph and take notes concerning packing and amounts. The production flow was also discussed, along with other theoretical implications of more lean production flows and what these would mean for the racks needed.

The specifics analyzed with Magnus Eriksson were mainly focused on the so called "Newton Tables" used in some of the assembly cells (see fig. 23), which enable the robot to grip each part in the same way. The functionality of different motors used to power both the robots and the conveyor belts was also explained.

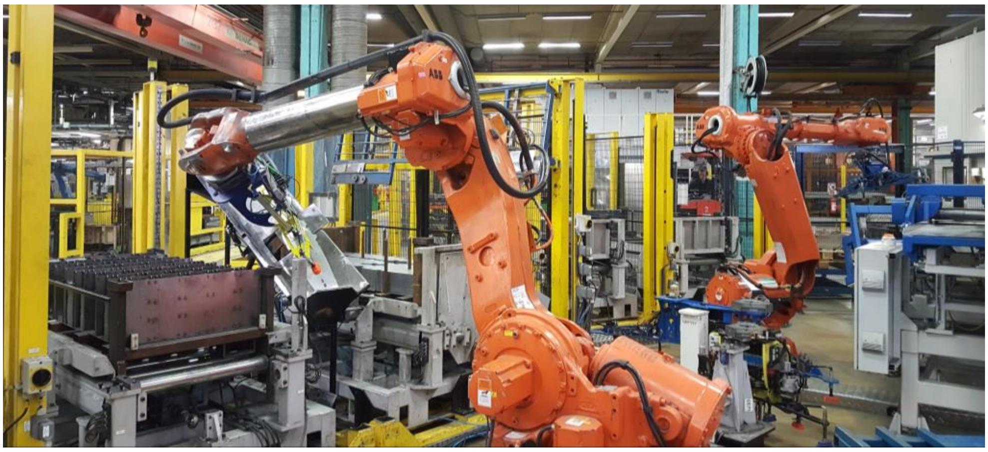

Figure 23. Robot picking a blank off the so called "Newton Table". Photo: Z. Envall.

Together with David Hedlund a vision system in one of the assembly cells (MC4) was analyzed. He explained details concerning how the system works, along with various details relevant to the system's functionality. Further discussion with David provided more in-depth information concerning robotics and vision systems both at HardTech and in general.

The production site was further observed numerous times without guidance, focusing on general aspects of the production as well as various parameters concerning the products and product handling.

4.3.2 BENCHMARKING

Other production sites were examined both online, through articles and videos, as well as offline in the form of a field study at Scania Oskarshamn. The online immersion mainly consisted of reviewing YouTube videos displaying the production at various production sites, primarily in the car industry. The videos were watched at a speed of 1.5 and paused whenever racks or relevant types of automation was showed. Some stills from the video review are displayed in fig. 24.

Figure 24. Different racking solutions observed in other production sites. Photo: Z. Envall

The field study at Scania Oskarshamn lasted for approximately four hours and consisted of a walk-through with robot specialist Jörgen Boman. The production sites that were reviewed were a press shop, weld shop, and an assembly line. The largest focus was put on the weld shop, both because Jörgen Boman had been involved in designing the production, but also because it had the most automation solutions out of the three sites. The press shop was also highly relevant due to its likeness to the production at Gestamp HardTech Luleå, but it could only be observed standing still, being that it was down for maintenance for the day. The assembly line was reviewed briefly, also focusing on different types of automation. After the three sites had been observed, the weld shop was revisited in order to secure that nothing was missed during the visit.

A couple of articles about automated solutions used in similar production sites were also found by searching for terms combining the words "robot", "automated", "racks", "racking", "stamping", and "automotive" in various ways on Google and Google Scholar.

4.3.3 PRODUCT ASSESSMENT

The goal of developing a flexible rack solution suitable for an as large number of the products as possible calls for thorough knowledge of the products. During work at the production plant prior to the project, all the beams relevant to the project had been personally loaded or unloaded at some stage of the production process at least a couple of times within the years 2016-2018.

The initial assessment of the products started with determining and listing which products were relevant to design for. Some of the products presently being produced were going to be moved to other production sites, so these were removed from the list. Pictures of the various products in the correct production steps were then traced in Adobe Illustrator to aid the assessment. Different parameters deemed relevant to robot racking were afterwards decided, by which the various products were compared. The initial comparisons searched for characteristics that could be used to categorize the different products, and was also done in Adobe Illustrator by using the previously traced products (see fig. 25).

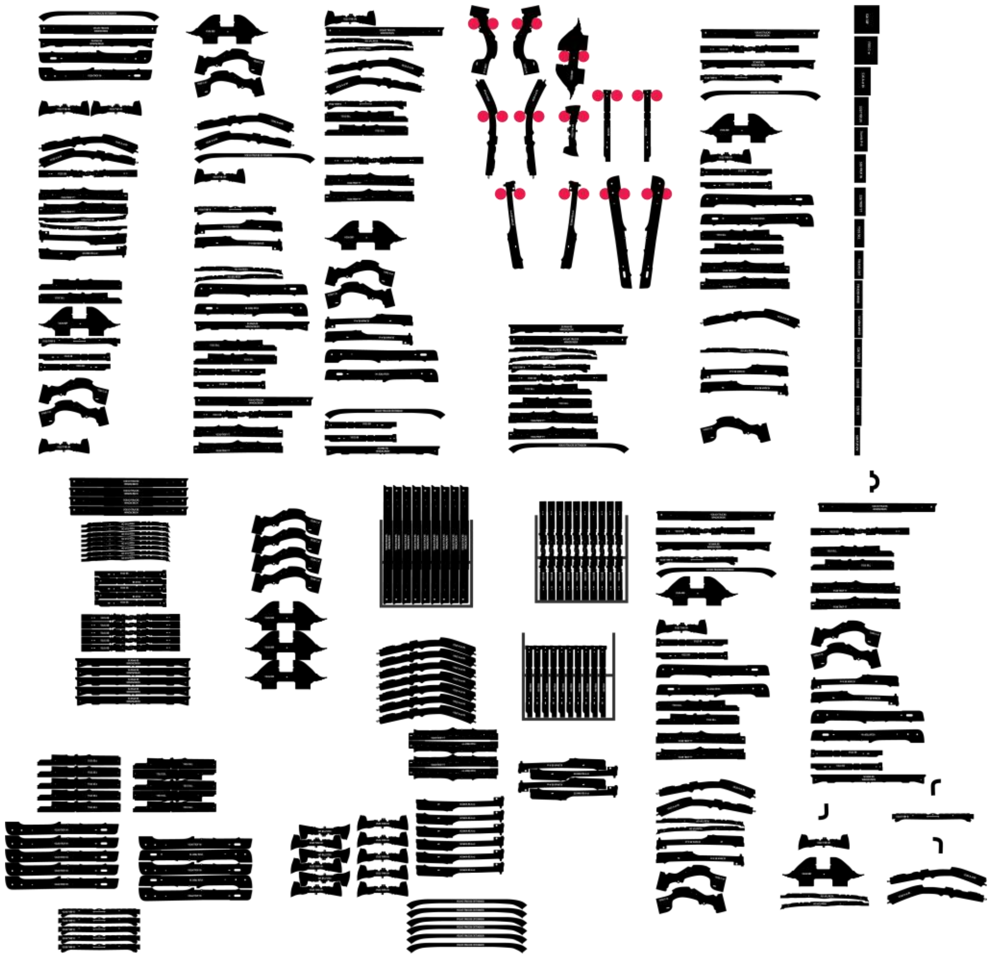

Figure 25. Various comparisons of the beams done in Adobe Illustrator. Illustration by Z. Envall.

In order to compare such a large and diverse set of data two types of matrix-methods were used. The two methods were based on the structures Quality Function Deployment (MIT OpenCourseWare, 2012) and Design Structure Matrix (Yassine & Braha, 2012). The process of assessing the products continued further and ultimately took the form of an Excel chart. This chart included 15 products which were analyzed by reviewing:

- The number of products per rack coming from the stamping lines
- The type of rack that was used for each product
- The number of rows/columns per rack
- Whether the rack's short sides were used or not
- What was used to separate the rows/columns
- The main angles of each product's two long edges
- How each product's short edges are bent
- The length, width, and height of each product
- Whether each product's shape is symmetric or not
- Which production steps each product goes through
- Which stamping line each product is produced in
- The number of holes each product has
- Whether a product is hangable, and if it is due to its shape, holes, or both

The answers to the different questions were attained by observing the production site, reviewing the CAD drawings, and by consulting with staff at Gestamp HardTech. The resulting values in the Excel chart were color coded to ease the overview and interpretation of the results. The parameters concerning the various products' shapes were analyzed through a simplification of their shapes in order to aid categorization, mainly focusing on the different edges. This was done by reviewing CAD-drawings of the various products in the correct production step, and sketching copies of these in order to fully understand the shapes.

The specific beams used for the product assessment shifted somewhat during the process due to new information being received regarding continued production plans and also due to decisions that were made according to knowledge gained regarding the different product's production processes and existing storage solutions. As the final stage in the product assessment various beam characteristics deemed relevant were classified into eight categories.

4.4 LITERATURE REVIEW

Being that the main parts of the theory, robotics and machine vision, were almost completely new subjects, the theory gathering had to start from the basics. The theory was initially collected primarily by watching introductory lectures from different schools into the subjects of robotics and machine vision on YouTube. Once a somewhat general foundation had been achieved, further literature was reviewed focusing on qualitative data based on the literature review method described by Milton and Rodgers (2013). This method consists of formulating research questions, collecting data, evaluating the data, analyzing the data, and finally presenting the review. The research questions were formulated as follows:

- *How does machine vision work?*
- *What are the limitations for machine vision?*
- *What constitutes a robot, and how do they work?*
- *What robots are used in industrial production settings?*
- *What are the robot's needs concerning the rack design?*
- *What materials can be used for designing the rack and its accessories?*

The collecting of data was pursued by using the Google, Google Scholar, and LIBRIS search engines. Since a lot of the desired data was of a somewhat more basic nature, LIBRIS turned out to be favorable. Many textbooks and handbooks on robotics and machine vision were reviewed, and evaluated by the number of citations, the

publisher, and the year of publication. Some articles were also found, mainly concerning machine vision and lighting, these were evaluated in the same way as the books. The search terms used to retrieve the data about robotics included "introduction robotics", "robotics handbook", "robots", and "automation". Some of the concepts concerning robotics needed to be researched further and were thereby also included in the searches, such as "robotics controller", "robotics software", and "robotics actuators". Machine vision was researched by using search terms such as "introduction vision", "machine vision", "robot vision", "vision guided robotics". The data collected about machine vision called for a further investigation of the concept of lighting and different lighting techniques. These were researched by searching for "lighting robotics", "lighting techniques", "lighting methods", "lighting camera", along with specific techniques such as "bright field lighting", "dark field lighting" and so on. In order to try to retrieve newer data on robotics, a concept called "industry 4.0" was also researched by searching for the term "industry 4.0".
The collected data was further evaluated and analyzed by how well it corresponded to data from other sources about the same subject, and the data deemed to lack relevance to the thesis were discarded. The data was finally presented in a categorized manner, based around robotics and then branching out to include sensors, with one of these being machine vision.

4.5 DESIGN

Because of the wide range of products being designed for, the design phase had a broad focus centered on developing different ways of separating generic beams from one another. These generic beams were simplified representations of the various Gestamp HardTech Luleå products, see fig. 26.

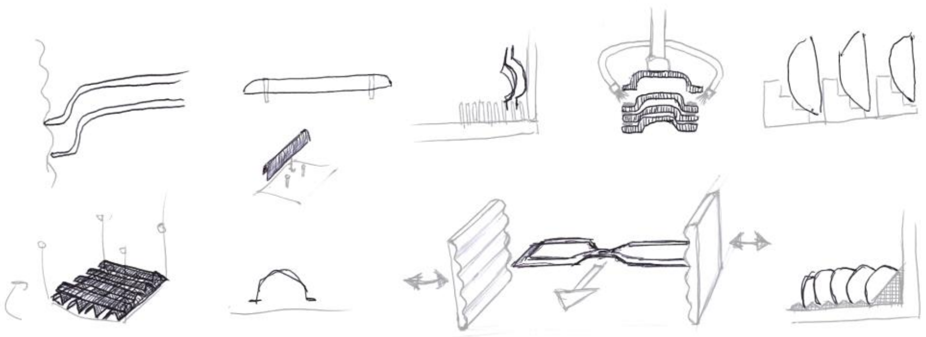

Figure 26. Examples of the various "generic beams" that were designed for. Illustration: Z. Envall.

The early creative work was fueled by inspiration acquired from the Conceive phase, including ideas brought on by the theory and context immersion as well as ideas provided by the supervisors Magnus Eriksson and Peter Törlind along with other Gestamp HardTech employees. Once the inspiration started to run dry, a creative method referred to as "The 100" was used to create a multitude of quick and simple ideas, focusing on quantity rather than quality. These ideas created a base for further exploration, with the remaining creative work aiming at conceptualizing these basic "outside the box" ideas by developing the core of an idea into something more feasible. The Design phase included outside input in the forms of continuous discussions with Magnus Eriksson, evaluating and developing various ideas, as well as a brainstorming session along with other Gestamp HardTech staff selected by Magnus Eriksson.

The general process during this phase started with an idea of how to keep the beams separate in one row or column. The next portion focused on how another row or column could be added. The biggest challenge here was separating the rows, being that they are stacked on top of each other, compared to the columns which have less of an effect on each other. The final part of the idea generation process looked at how well a robot could access the different loading spaces that had been designed for each idea, whereby the ideas were developed further.

4.5.1 INITIAL MINDMAPPING

The extensive search for information and context immersion in the Conceive phase provided some inspiration, and several ideas were noted during this phase for further development (see fig. 27). During various Conceive-phase discussions with both thesis supervisor Peter Törlind and project supervisor Magnus Eriksson ideas were mentioned and briefly discussed. These ideas were also noted and parked awaiting further development.

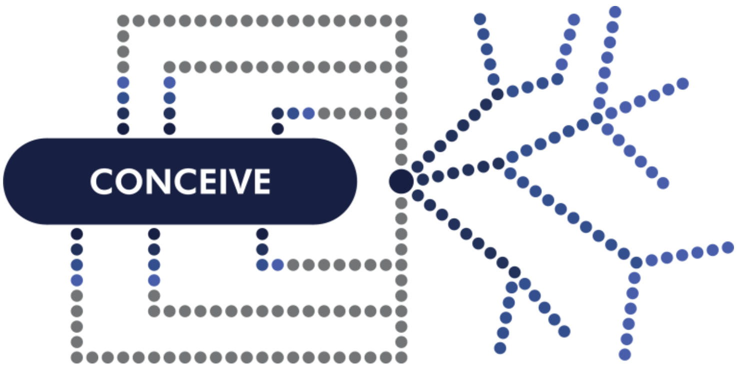

Figure 27. Visualization of the birth, parking, and development of ideas inspired by the Conceive phase. Illustration: Z. Envall.

The early stage of the Design phase consisted of using a Mind Mapping method as described by Wikberg Nilsson et al. (2015), based around the initial ideas, viewing various aspects in various ways searching for feasible solutions. The nature of the project led to many ideas having trouble to live up to the desired goal, and therefore much time was spent evaluating and sketching several variations of different details in order to increase an idea's feasibility.

4.5.2 HARDTECH BRAINSTORMING

A brainstorming session was performed with selected Gestamp HardTech staff, based around the method as described by Wikberg Nilsson et al. (2015). This session started with a brief presentation of the work that had been done, which ended with the various ideas that had been generated. Following this, some ideas were discussed along with aspects concerning which products needed special racks and the feasibility of automated racking in relation to the overall production. Robotic capabilities were also discussed in relation to what is required for a rack concerning each of the various products.

4.5.3 THE 100

The method “List 100 Scenarios” described by Christensen (2013) was used as the framework for achieving a high and wide idea quantity. By listing 100 unique ideas, the method is explained to push into a world of originality. The method is simple, and the only rules are to abstain from any sort of criticism and to generate 100 unique ideas within 15 minutes, equaling to one idea every 9 seconds. The application of the method however turned out to be much more time demanding.

Thirty ideas were generated during the first thirty minutes, after which the search for originality became harder, leading to the time required for each idea growing exponentially. After the initial time limit was breached the rules of the method were shifted, and the new goal became to generate one hundred ideas as fast as possible. Once a piece of paper was full of ideas it was put on the wall and used as inspiration as well as a reminder of what ideas had already been created (see fig. 28).

Figure 28. Sketches from the method "The 100" that were gradually pinned to the cubicle wall. Photo: Z. Envall.

Avoiding criticism was somewhat tough and was dealt with by constant reminders to not overthink any of the ideas. Not duplicating ideas became much harder during the latter half of the process, leading to a deeper search within undiscovered creative spaces, in turn resulting in an increased time consumption. Getting stuck with a loss of ideas was unavoidable during the process, and this was combatted by either drawing a robot with a beam to spark an idea, starting to draw either a rack or a beam without any clearly formulated idea, or by taking a break. The method turned out to be very draining, taking several hours instead of the initially stated 15 minutes. It was also not performed continuously but instead in intervals over a couple of days.

4.5.4 FURTHER DEVELOPMENT

The ideas generated by the previously described methods were analyzed, and those deemed feasible and useful were marked for further development. This development consisted of morphing the ideas into realizable concepts and included combining various aspects of different ideas.

This was fueled by inspiration coming mainly from the previously formulated ideas and was performed continuously to morph the ideas into concepts during the rest of the phase. The work consisted of sketching an idea followed by a quick evaluation leading to a new idea, and this process was performed repeatedly until the ideas ran dry. Dead ends and a lack of ideas were dealt with by taking breaks and focusing on other work. Outside support was also received from Magnus Eriksson during this process through discussions about the various ideas regarding developmental possibilities.

4.5.5 ELIMINATION

The elimination focused on the separation methods each concept presented, not considering factors regarding having different rack sizes with different numbers of rows or stacks. The reason for this was that the concepts were going to be further developed, and that no absolute limitations concerning different rack sizes had been set. The rack-concepts were initially compared by their theoretical packing grades, how many different products they could be used with, and their theorized costs.

The packing grades were calculated by hypothesizing how closely the products could be packed while using the given separation method accompanying each concept. Determining which products each concept suited was done by analyzing a product's edges relevant to each concept and assuming what would work in reality. The costs were theorized by looking at the overall complexity of the various concepts and assuming that concepts with more advanced mechanisms would cost more to produce and buy.

The final round of elimination was done by consulting with Magnus Eriksson and discussing the various concepts, weighing packing grades in relation to various factors affecting costs, while also taking the concept's overall feasibility into account.

4.6 IMPLEMENT

The Implement phase consisted of concept evaluation in the form of physical tests with the products, along with a final detail development process.

Physical tests with the products were performed to determine the feasibility of the various concepts, and to determine how well each concept suited each product. This was done by physically examining each product regarding different factors relevant to the concepts. The tests were performed in two rounds, with the first round focusing more on beams' stacking factors, and the second focusing on factors concerning beams placed in rows.

Before the final elimination, the concepts were analyzed and developed to increase their feasibility and effectiveness, largely based on the results from the testing. Through a process of combination and elimination a final concept was lastly decided upon and sketched.

4.6.1 TESTING I

The first round of testing was performed by manually examining the 12 products with the help of wax-strips and an empty HT-rack. The products were supplied in racks and the factors that were tested consisted of:

- If the beams stick to each other
- The current distance between the beams
- If the beams are stackable
- The height of the maximum stackable amount
- The amount that can be stacked
- The number of stacks that fit in a HT-rack
- The lowest possible non-stick distance between the beams
- Concept-specific solutions

If a product sticks together was examined by pressing two beams into each other and then attempting to take them apart. This factor was further examined throughout the testing process, which included removing beams from rows and stacks repeatedly. Once the beams were pressed together the distance between them was also measured, showing how close the beams can be packed.

Determining if a product is stackable was done by attempting to stack the beams on a flat surface and noting the maximum stack-height that could be achieved (see fig. 29), along with the corresponding number of beams in the stack. A maximum limit for the stack-height was set to 800 mm in accordance to the HT-racks. Once the stacks started swaying and showing signs of instability the measurements were taken frequently until the stack finally fell or reached the maximum limit of 800 mm.

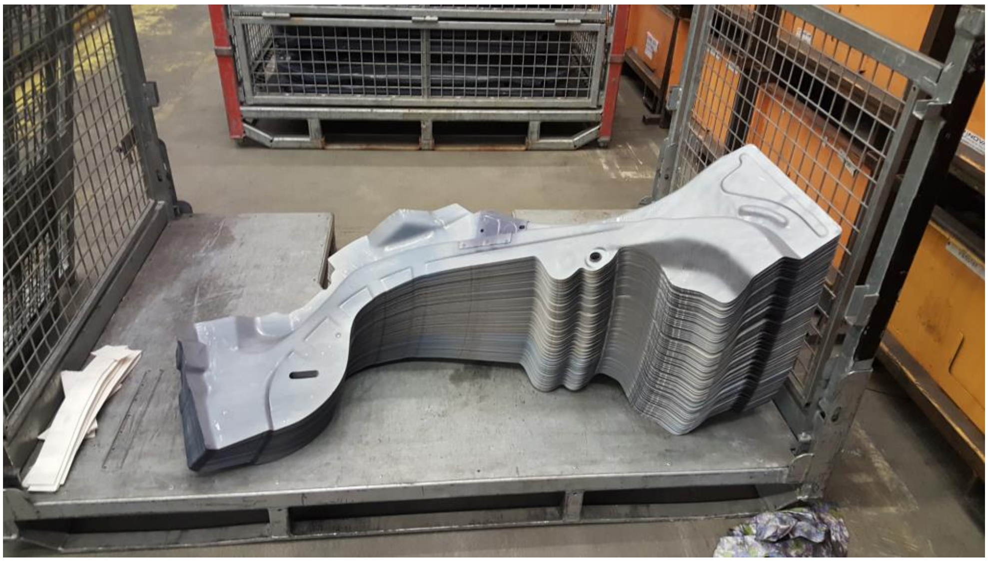

Figure 29. Stack of the Y555 C-st beam. Photo: Z. Envall.

By placing the beams next to each other at the bottom of a HT-rack the number of possible stacks were analyzed. For the specific products that resulted in leaning stacks, in turn taking up more space, this factor was also taken into consideration.

The lowest possible non-stick distance between each product was tested by using thin wax-strips to separate two beams stacked on top of each other. The strips were placed in two different formations, each of them having two separate strip-placement areas (see fig. 30). The number of wax-strips was increased sequentially until the beams no longer stuck together when the top one was lifted. Both of the non-stick distances between the beams produced by the two wax-strip formations were measured, and the smallest distance was deemed the lowest possible non-stick distance.

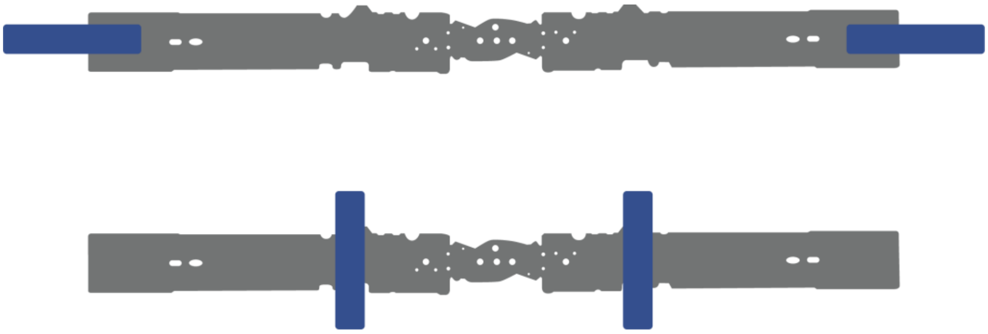

Figure 30. Visualization of how the wax strips (displayed in blue) were positioned. Illustration: Z. Envall.

The two wax-strip formations were at the same time used to test the concepts "Strings" and "Clap", which keep the beams separate in the same manner as the wax-strips. The number of wax-strips used in each formation was thereby also noted and measured, producing the thickness needed for separation for each concept.

4.6.2 TESTING II

The second testing session was focused on placing the beams in rows. The testing consisted of determining which beams were suitable for the concept "Borst", which is a concept that uses brush to keep the beams separate. It was also evaluated which beams could be placed horizontally without aid, and which beams needed the racks to be leaned back during loading and unloading in order to not fall over. Additionally, it was determined whether a beam could be directly picked up from the conveyor belt and placed in the rack, or if the grip needed to be shifted. The minimum distance needed between rows was also measured. Svensk Borstteknik had sent 3 different brushes to aid with the testing of the "Borst" concept (see fig. 31).

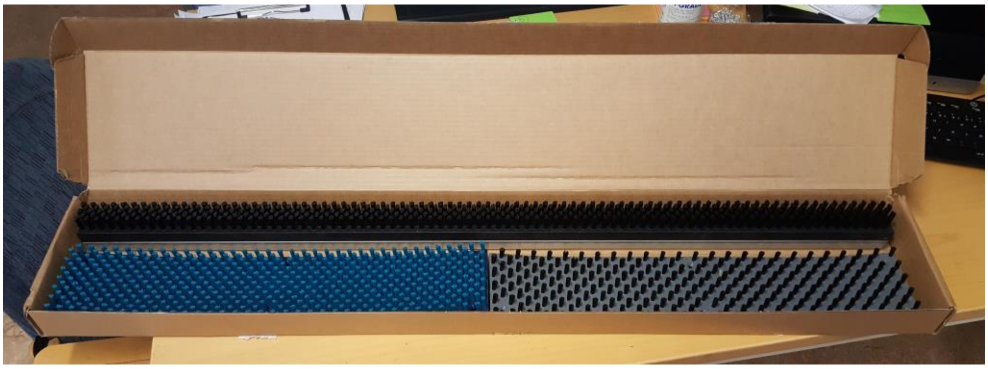

Figure 31. The three brushes received for the testing, courtesy of Svensk Borstteknik (www.borsten.se). Photo: Z. Envall.

Being a way to keep the beams separate, the testing of the "Borst" concept was centered on the beams that had previously been determined to stick to each other. Some other beams were however also tested depending on their need for additional stability. The concept was tested both by placing the beams on a horizontally aligned brush as well as a brush with one end elevated to simulate a leaning rack (see fig. 32). The beams were initially loaded horizontally, and those that showed a poor balance were also tested on the leaning brush.

The three brushes received from Svensk Borstteknik came in two different shapes with three different brush materials. These were all tested initially, but it was easily determined that the one with the hardest brush material was superior, after which this brush was solely used in the tests.

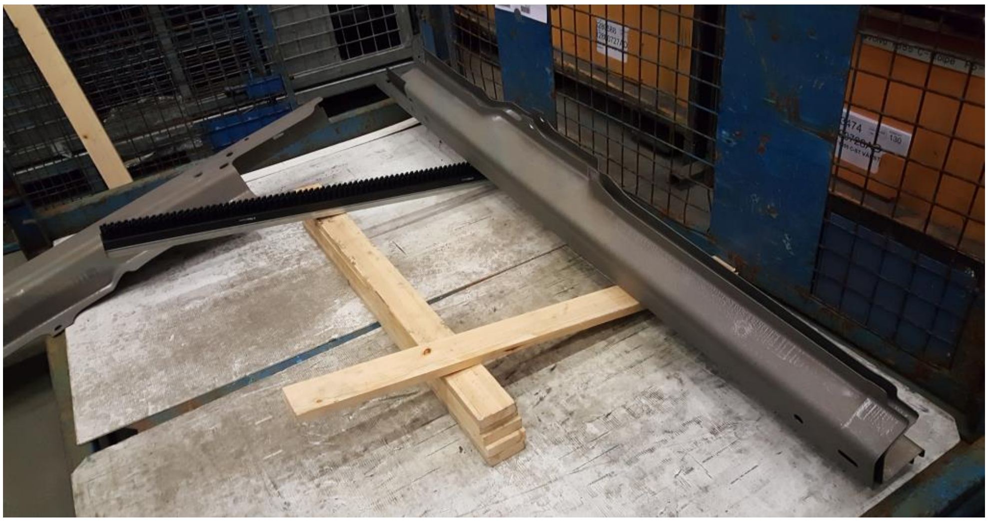

Figure 32. Brush with one end elevated to simulate a leaning rack. Photo: Z. Envall.

The beams that had been determined to not stick to each other were tested similarly to the process previously described, but with wooden planks instead of the brush. The wooden planks were placed both flat on the bottom of the racks as well as with one side elevated. The beams that showed poor stability in these tests were also tested with a brush.

If a beam required for a robot to change its grip was tested by attempting to place the beams in a rack in the manner they would be if they were picked up straight off the conveyor belt leading them out from the stamping line. The minimum distance needed between rows was determined by placing two beams next to each other and measuring the minimum distance needed between them in order to keep them separate.

4.6.3 EVALUATION

The results from the testing were interpreted and converted into packing-grades for each of the beams correlating to each of the concepts. The packing-grades determine how many beams can be packed into a rack while using the different separation techniques, in relation to the original amount that is currently packed in the HT-racks, and are presented as percentages.

4.6.4 CONCEPT DEVELOPMENT

One concept was directly eliminated based on results from the testing, and the other two were developed further focusing on a number of details aiming at improving the overall feasibility. This development was centered on deciding how the different separation techniques would best be implemented in a rack, with respect to total packing-grade, beam sizes, and simplicity. The development consisted of individual brainstorming and took the form of different sketches and calculations. Two new simple concept variations were also generated, stemming from new insights about beam separation needs gained from the testing.

4.6.5 FINAL ELIMINATION

To aid with the eliminatory process a meeting was held with Magnus Eriksson and logistics engineer Martin Holmbom, who was completely new to the project. After presenting prior work and the two final concepts Borst and Strings, discussions were held about which concept was preferred along with developmental possibilities and ideas for future implementation further down the line. The final eliminatory decision was made by taking earlier calculated packing-grades and the opinions from Magnus Eriksson and Martin Holmbom into account, where after only one concept remained.

4.7 OPERATE

The Operate phase consisted of applying the finishing touches to the concept and finalizing the last deliverables. The concept design was initially refined regarding various details, and then a CAD model was made.

4.7.1 REFINEMENT

With the basic functions of the final concept somewhat decided, the work during the refinement focused more on various details such as how to make the rack foldable, stackable, and cost effective to produce. Much effort was also put on refining the design of the separators, both regarding producibility as well as robot handling. During the refinement of the concept calculations were also made to determine certain dimensions required for the concept's functionality. The refinement was mostly done through sketching and evaluation performed iteratively, supported by meetings with Magnus Eriksson and Martin Holmbom who helped with the evaluation and offered new ideas and views.

4.7.2 CAD-MODELING

The CAD model of the concept was done in Siemens NX and was based around the original HT-racks regarding measurements and overall function. A central goal was to make the rack work logistically just like the HT-rack, both when open and folded. To achieve this, a number of details were copied from the HT-rack. Drawings of the HT-racks were supplied by Gestamp HardTech, and the measurements from these were combined with the measurements that had been calculated for the concept.

4.7.3 PRODUCT ASSESSMENT

A final product assessment was also made. This assessment was a categorization of the reviewed beams and was based on the product assessment that had been performed throughout the project. Generic beam characteristics were derived from the various parameters that had been examined earlier. The generic characteristics that were deemed suitable for the final concept were also specified.

4.8 METHOD DISCUSSION

This section contains a brief discussion regarding the reliability and effectiveness of the methods that were used.

4.8.1 CONCEIVE

The Conceive phase can essentially be divided into 4 parts: Context Immersion, Theory Immersion, and Product Assessment.

Understanding the context was done through many ways, both online, at Gestamp HardTech Luleå, and in Scania Oskarshamn. The online studies were mainly focused on finding racks used for automation. Although this was somewhat tough, many racks used in various instances were found in several places. The Benchmarking was partly done on YouTube, reviewing several different production facilities from various car manufacturers in order to increase the span of the search. The search for racks also included websites of rack manufacturers, thereby also stepping somewhat outside the automotive industry. A larger search outside the automotive industry would probably have aided the project. The Benchmarking lacked relevant solutions being used in other settings.

The Theory Immersion was mainly done through searching in books about the various subjects, with the larger part of these being textbooks. Peer reviewed articles are generally a more secure source of information, and although some articles were reviewed it would have been preferred if more of the theory was based on articles.

The Product Assessment started off structured, with the guidance of Peter Törlind, but as time went on it took a more iterative approach. In order to secure that the work being done is efficient and correctly structured, basing the assessment more on defined methods could possibly have aided the work.

4.8.2 DESIGN

Although the Design phase included some creative methods, it was mainly in the form of individual sketching and idea developing. Whether this was an as efficient method as it could have been is hard to discern, but including more outside help for idea generation would probably have aided the process. Using methods that are not based on sketching would also probably have opened up new doors and increased the flow of creativity.

The final evaluation and elimination of ideas could also have been eased by using some sort of elimination method, but with the ideas that had been generated it was not something that felt necessary, as determining which ideas were worth developing did not result in much of a struggle.

4.8.3 IMPLEMENT

The Implement phase was largely centered around testing numerous factors regarding the products. Although these tests were empirical and resulted in clear statistics, the method in which they were performed could at times have had some implications on the resulting statistics. Some of the tests included handling the beams like a robot would, which was done by hand, and therefore could differ some from having an actual robot performing the tests. This is especially true regarding testing with the brush, where the manual handling could have the largest implications. The different measurements being made were also done manually by using a ruler, and could therefore also lack somewhat in quality. The factor of how close the beams can be packed resulted in distances which, although the beams do not stick at these, they are not necessarily the absolute minimum packing-distances.

4.8.4 OPERATE

The work performed concerning refining the concept mainly consisted of sketching. A more secure result would probably have been attained if the sketching was coupled with prototyping, and thereby actually testing the various design alterations.

The CAD-modeling in the Operate phase was based on dimensions from the actual drawings for the HT-racks. Because of this, the concept rack should have the correct dimensions needed for stacking with the HT-racks. The designed parts do however have some features that might need to be adjusted should the rack be produced. This concerns things such as distances between features and the space required for welding. A more precise and producible CAD-model would have been provided if more production factors would have been taken into consideration, preferably by consulting with knowledgeable people.

5 Results

The Results chapter presents all the results attained from the various methods used throughout the project. The chapter consists of results from the Conceive, Design, Implement, and Operate phases, starting with the product assessment and ending with the final concept.

5.1 CONCEIVE

Mainly consisting of literary reviews, the Conceive phase resulted primarily in knowledge regarding robotics and machine vision, displayed in the Theory section. Another significant part of the Conceive phase consisted of benchmarking and an analysis of the current state, the results from which are presented in the Context chapter. The phase also focused on assessing the different beams produced at Gestamp HardTech Luleå, initially through structures provided by the methods Quality Function Deployment (QFD) and Design Structure Matrix (DSM). The phase ultimately resulted in a specification of requirements, see table 2.

Table 2. Specification of requirements. Illustration: Z. Envall.

REQUIREMENTS

- The rack shall allow for robotic loading and unloading.
- The rack shall allow for robotic localization of the products.
- The rack shall allow for logistic handling by a forklift truck.
- The rack shall be transportable, both when full and empty.
- The rack shall be stackable with itself.
- The stacks shall be transportable.
- The rack shall be able to tolerate predictable forces concerning loading, unloading, and logistic handling.
- The rack shall have a designated logistic-label placement option.

DESIRABLE

- The rack shall be foldable.
- The rack shall allow for robotic loading and unloading of more than one type of product.
- The rack shall be inexpensive to manufacture.
- The rack shall hold the same amount of products as the racks in use presently do.

5.1.1 PRODUCT ASSESSMENT

A number of 15 beams were originally chosen for the product assessment, due to discussions with Magnus Eriksson. The 15 beams are displayed in fig. 33.

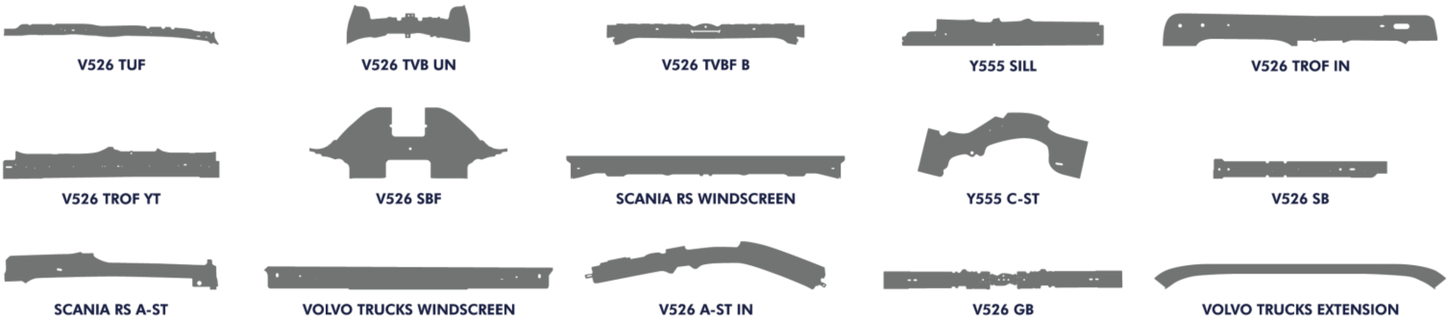

Figure 33. The 15 beams originally chosen to be designed for. Illustration: Z. Envall.

The initial product assessment process resulted in two matrices which are presented below, one as a cluster-matrix and the other as a bar chart. Results from the QFD are displayed in fig. 34, showing the expected ease of robot-racking implementation for each product. V526 SB is deemed to be best suited for automated racking, only receiving low scores in the parameter concerning the quantity of products being produced at the plant. The product receiving the lowest score is V526 A-st IN, which is a bit too long for the HT-racks, easily sticks together, is curved, and therefore doesn't pack well in a square rack.

Figure 34. Diagram showing how well the various products are deemed to be suited for robot racking. The longer the bar, the better suited the product is presumed to be. Illustration: Z. Envall.

The method based on DSM resulted in a clustering of the various products according to different parameters, see fig. 35. The darker the color of a dot is in the figure, the better the specific product answers to the given parameter. The products have been placed in an order that produces the clearest perceived clusters.

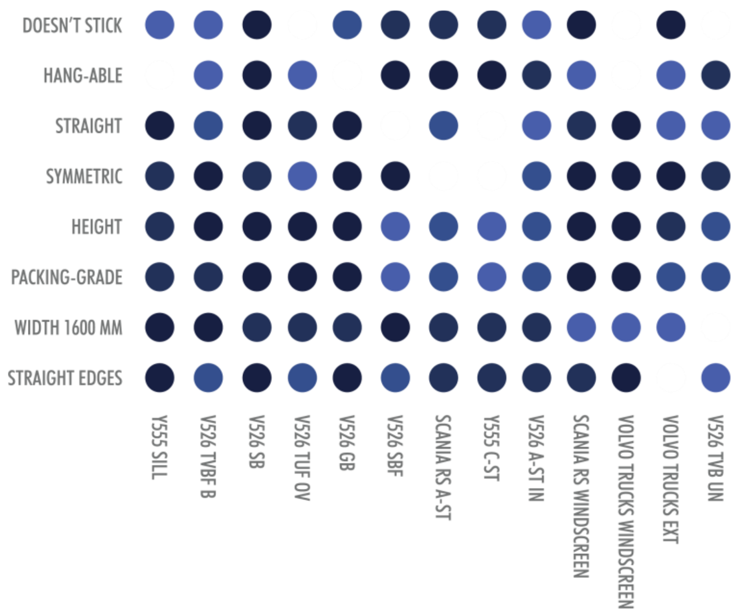

Figure 35. Matrix showing the clustering of products according to various reviewed parameters. Illustration: Z. Envall.

The five beams on the left side of the diagram in fig. 35 (Y555 Sill, V526 TVBF B, V526 SB, V526 TUF OV, V526 GB) have corresponding lengths, can be packed closely, have similar height, and are reasonably straight and symmetric. The four products slightly to the right of the middle (V526 SBF, Scania RS A-st, Y555 C-st, V526 A-st IN) are all perceived to be hang-able, have reasonably straight edges, with somewhat similar heights and lengths. The longer products on the right side of the matrix (V526 A-st IN, Scania RS Windscreen, Volvo Trucks Windscreen, Volvo Trucks Ext.) are all considerably longer than the width of the HT-racks. Apart from the V526 A-st IN, they are all symmetrical and have similar heights. The product on the far right (V526 TVB UN) has been perceived to be a stand-out, lacking relevant coinciding parameters relative to the other products.

Further product assessment was done for 15 products, which are displayed in fig. 36. Although the number of products is the same as earlier, the specific products have shifted somewhat, due to additional information being gained regarding future production plans. The total results from the further product assessment can be found in Appendix 1.

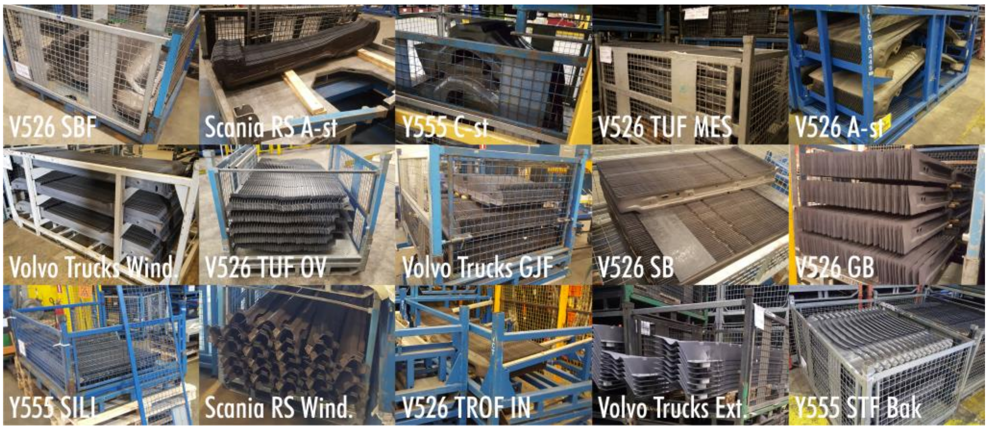

Figure 36. The 15 beams used for further assessment. Photo: Z. Envall.

Among the products, the number of beams per rack along with the number of rows or stacks varies greatly depending on the product. Several types of racks are used, and between the stamping lines and the next machining process most beams (80%) are stored in traditional HT-racks, which have their sides stripped off for five of the products (33%). One third of the products are only laser cut before being finished, while the downstream machining regarding the rest of the products varies.

Six of the fifteen products have all horizontal edges, with the rest having some vertically aligned edges, but none with all vertical edges. 67% of the products have primarily horizontal edges on their long sides, and only one product (Y555 STF Bak) has vertical edges on both of its long sides. Almost half of the beams are longer than the HT-racks, with the longest being the V526 A-st YT beam at 2360 mm. The most commonly used stamping line is Stamping Line 6, where 73% of the products being reviewed are produced.

Almost half of the reviewed products are symmetrical, and all except the Volvo Trucks Extension beams have at least 1 hole after being stamped. The only beam with solely 1 hole is V526 SBF. Seven of the analyzed beams were deemed hangable from their holes, and seven beams were deemed hangable due to their shape.

One of the chosen products, V526 TROF IN, only goes through the stamping line before being shipped to Volvo and is therefore directly placed into specific Volvo-racks. Because of this they were eliminated from the list of products to be designed for. The Volvo Trucks Extension beam was also removed from the product assessment due to its rarity in the production along with its high weight, which would require an extra person to help with lifting for the upcoming testing in the Implement phase. The remaining products are displayed in fig. 37, where the nearly identical V526 TUF OV and V526 TUF MES beams have been combined in order to ease the upcoming testing.

Figure 37. The products remaining after the assessment. Illustration: Z. Envall.

The generic beam characteristics that were formulated are displayed in fig. 38 and include the categories sticking, non-sticking, straight edge, bent edge, bent, straight, symmetrical, and asymmetrical beams.

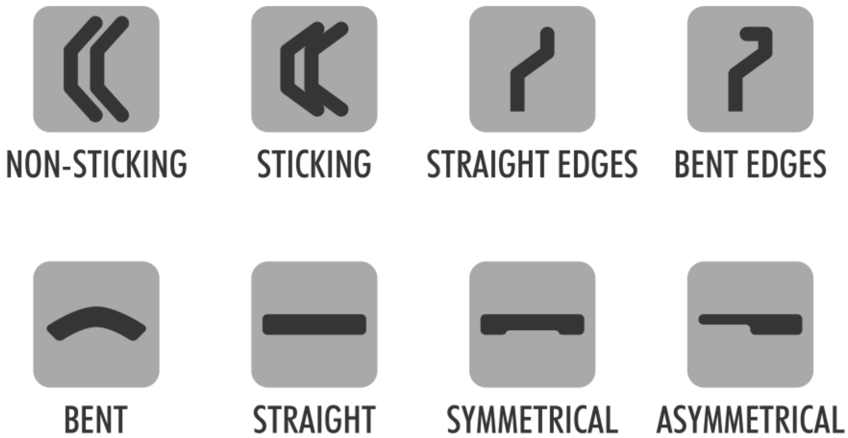

Figure 38. The generic beam characteristics that were defined.

5.2 DESIGN

The results from the Design phase starts from the initial idea generation and ends with the final concepts that survived the elimination process. What follows are the results from the methods previously described as "Initial Mind Mapping", "HardTech Brainstorming", "The 100", and "Further Development".

5.2.1 INITIAL MIND MAPPING

The method resulted in a wide range of primitive ideas shown in fig. 39. The original categorization included the categories:

- **Top** – Ideas where beams are stored on top of each other
- **Slots** – Ideas where different kinds of slots are used to keep beams apart
- **Soft Materials** – Ideas utilizing soft materials such as brush or foam
- **Gravity** – Ideas having to do with leaning the racks or leaning the beams
- **Separators** – Ideas where beams are separated by placing various objects between them
- **Hanging** – Ideas where the beams are hung
- **Other** – Ideas not fit for any of the other categories

The soft materials came to include an idea utilizing springs, while lacking any ideas explicitly using foam. Designing solutions for the robot end-effector was also attempted, along with ideas having to do with the way the beams are loaded. The majority of the ideas were however centered on brush or slot solutions.

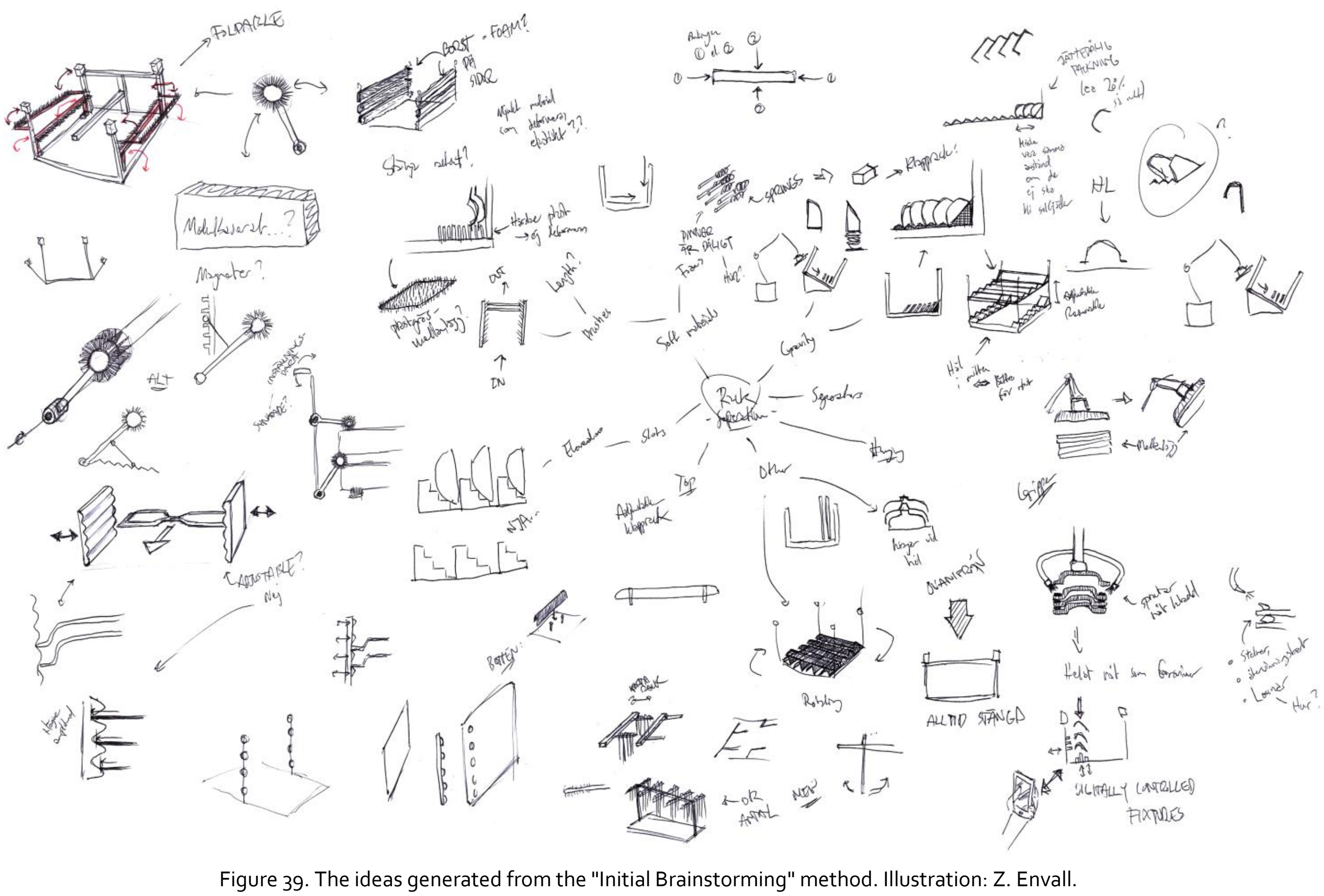

Figure 39. The ideas generated from the "Initial Brainstorming" method. Illustration: Z. Envall.

5.2.2 HARDTECH BRAINSTORMING

The Brainstorming performed with HardTech staff did not result in any concrete ideas. Using magnets or foam balls to separate the beams was mentioned but did not lead to much of a discussion. What was discussed was mainly how lower packing volumes would affect the production, as for which it was said that lower volumes could work well with a leaner production strategy. Discussions also arose about whether a rack design was even necessary, or if a robot equipped with a vision system would be able to load and unload the beams from a generic rack, as long as the beams were placed randomly to keep from sticking to each other.

5.2.3 THE 100

The method described as "The 100" resulted in slightly over one hundred ideas, each developed to be as unique as possible in relation to each other. The ideas are presented in fig. 40.

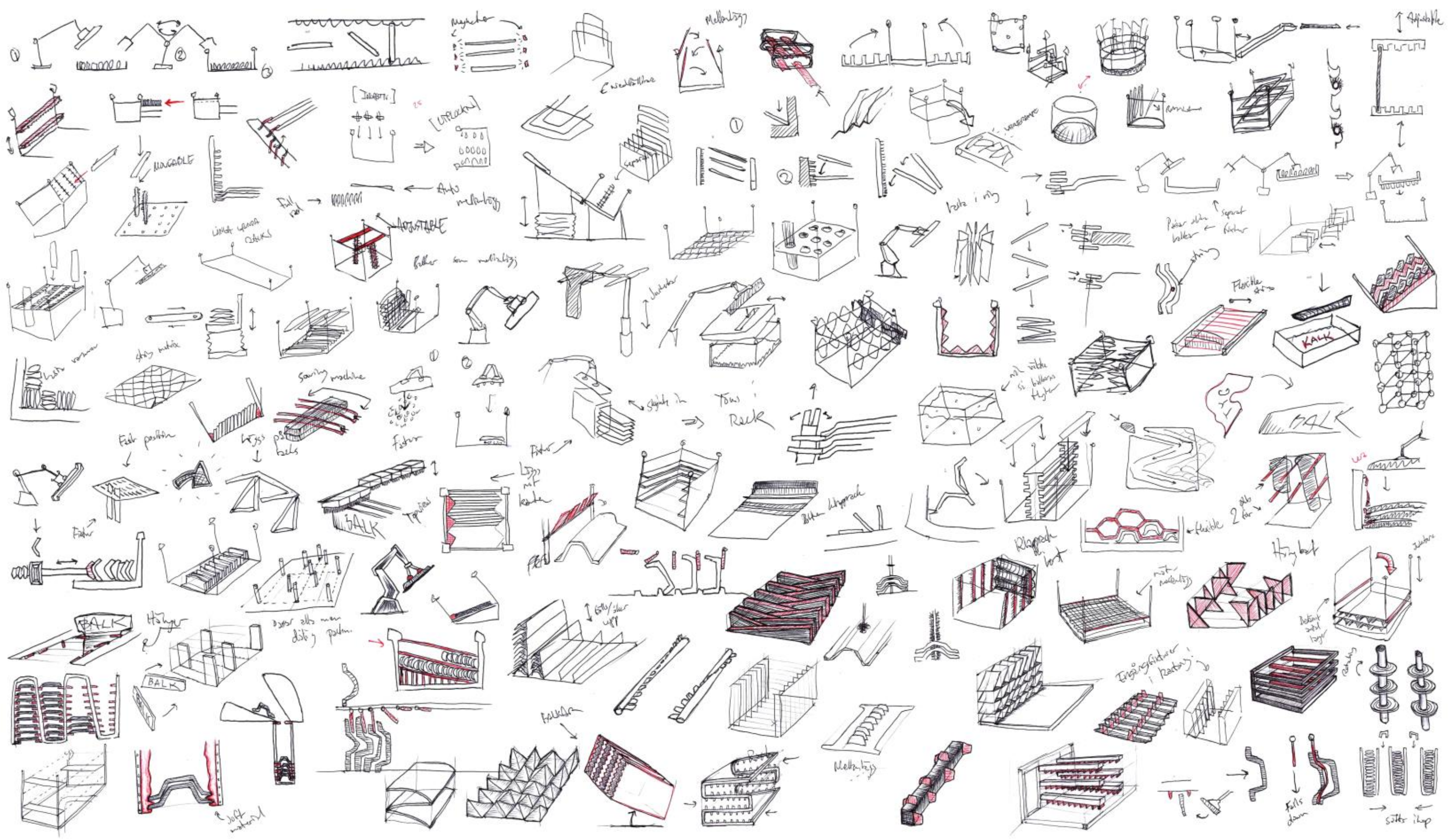

Figure 40. The ideas developed in the method "The 100". Illustration: Z. Envall.

The ideas generated by the method further explored the categories previously defined in the "Initial Mind Mapping" method, and also added solutions that use fixtures, various placement mechanisms, along with using different materials such as chalk or liquid to keep the beams apart.

Inspiration for further development was provided by ideas that used various methods to separate the beams. These included strings, fabric, fixtures, pins and brushes. The main ideas from "The 100" that turned out to inspire future ideas are shown in fig. 41.

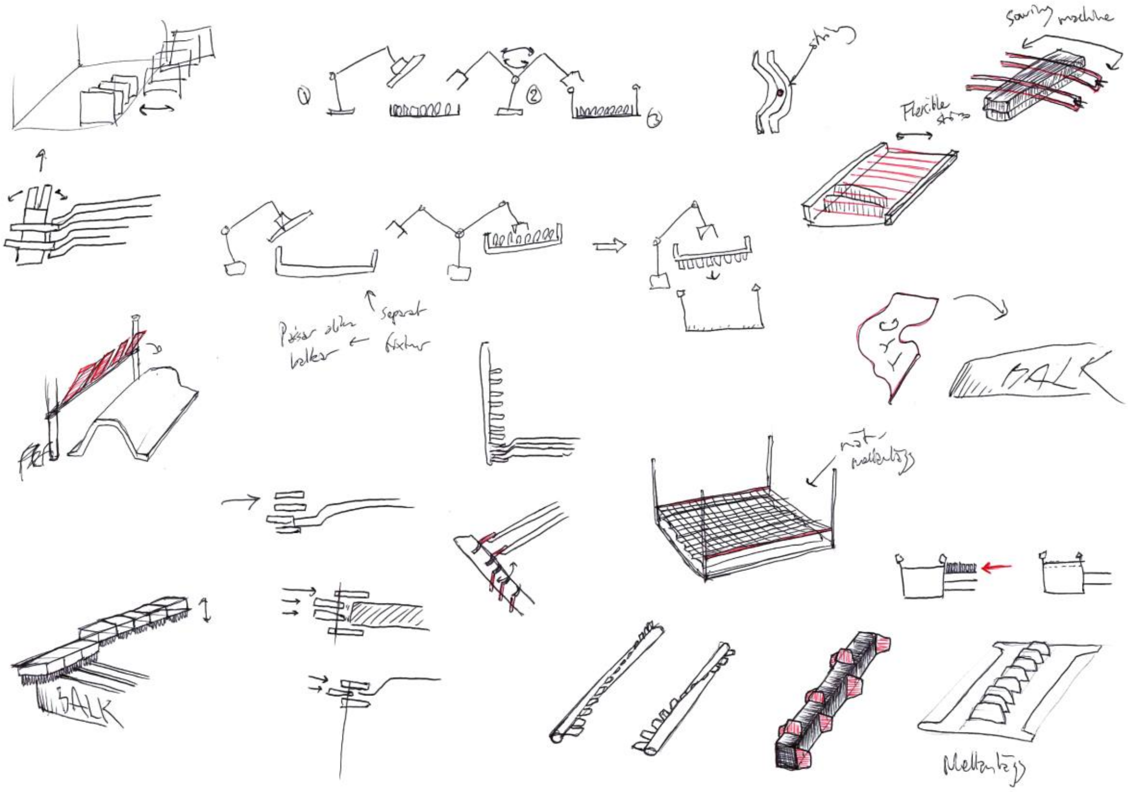

Figure 41. Some ideas from the method "The 100" that inspired further development. Illustration: Z. Envall.

5.2.4 FURTHER DEVELOPMENT

The creative work performed in the Design phase ultimately resulted in six different concepts. The concepts are displayed in figs. 42–48 along with the various ideas they stemmed from.

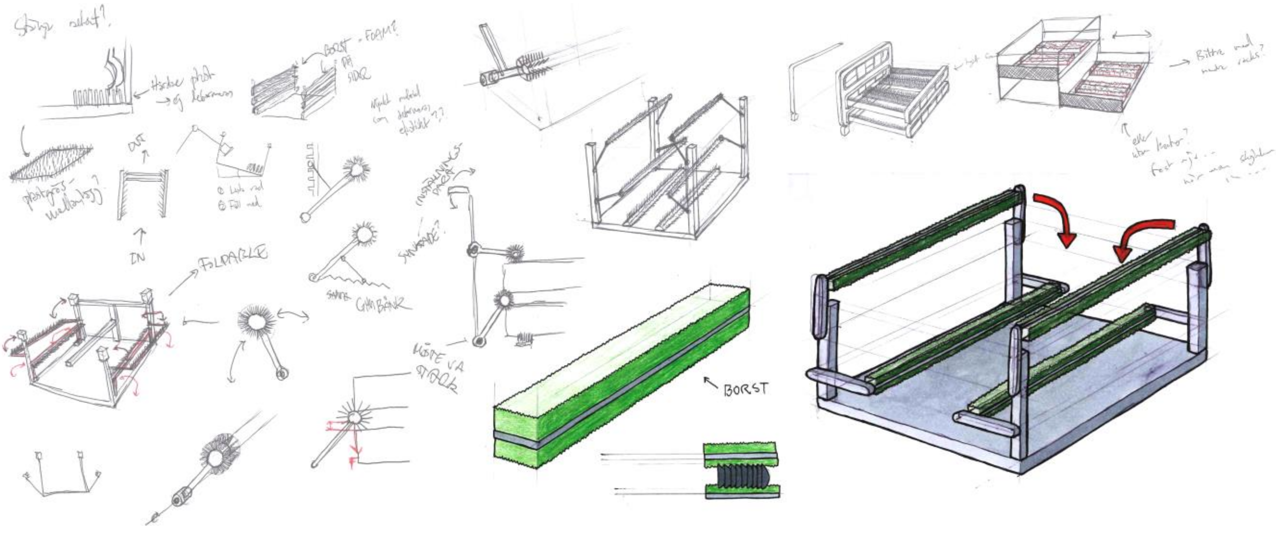

Figure 42. Borst concept. Illustration: Z. Envall.

The Borst concept (fig. 42) dealt with beams placed in horizontal rows and was centered on using some type of brush material to keep the beams separate. The concept took two forms: A rack with built-in brush accessories, or the simpler brush separators. The built-in brush accessories were meant to rotate into the racks after the rows of beams had been placed. In order to keep underlying and overlying rows fixated brush is used on both sides of each separator. The other option used the same type of brush separators, but these were instead meant to be placed into generic racks, between the rows of beams. The plan with this option was to have the robot place the separators into the racks in between placing the rows of beams.

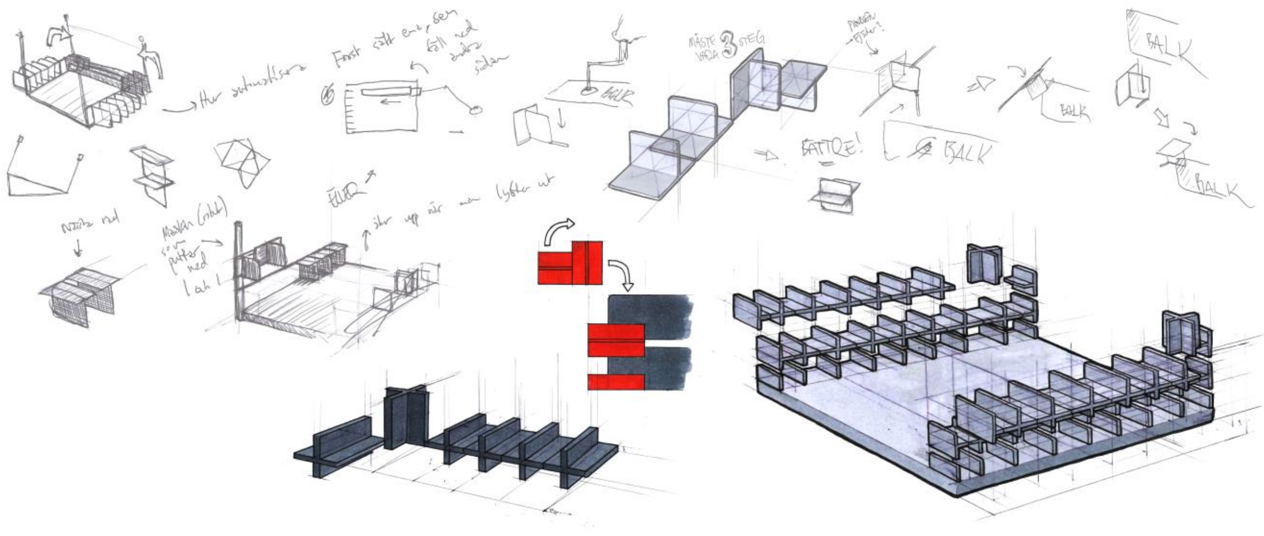

Figure 43. Boxn1 concept. Illustration: Z. Envall.

The Boxn1 concept (fig. 43) was also designed for beams placed in horizontal rows. This concept was a variation of the automatic separators seen in the benchmarking studies. The plan with this concept was to have the separators rotate in as a beam was being placed, in turn boxing the beam in and keeping it separate from the rest of the beams in the rack.

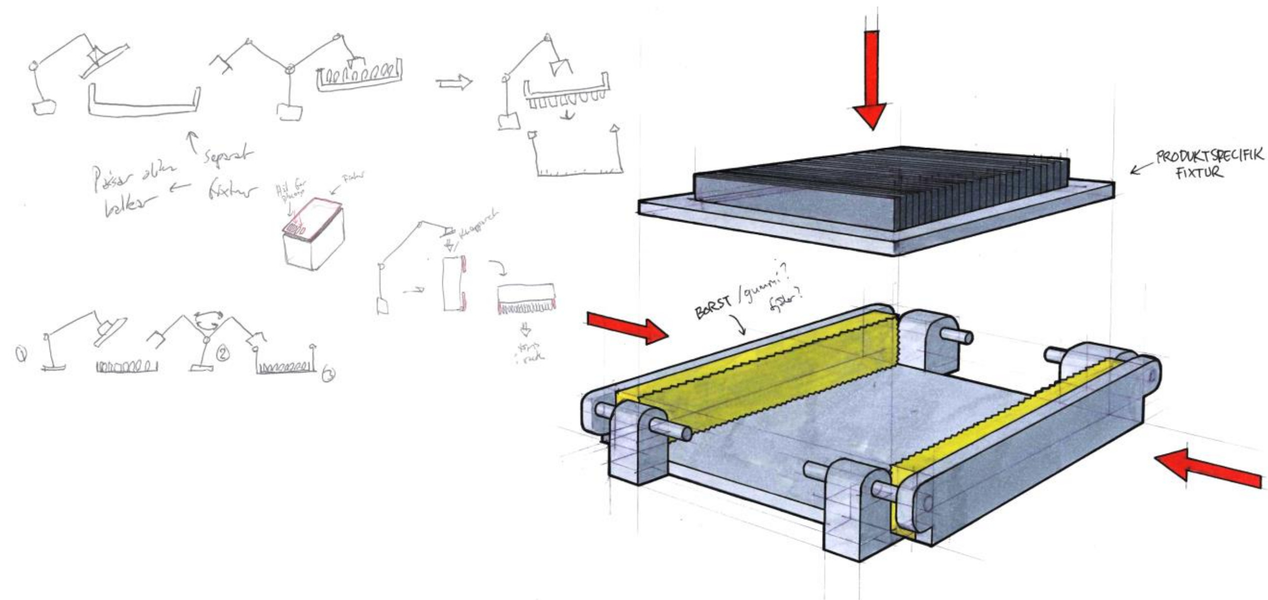

Figure 44. Fixture concept. Illustration: Z. Envall.

The Fixture concept (fig. 44) was designed with the possibility of having the beams being stacked vertically or placed in horizontal rows initially, to then have the entire rows or stacks being placed into a rack. The initial placement of the beams was planned to be done into a product-specific fixtures, by which an entire row would be transported and unloaded into the rack. The fixture would then be returned to the robot for loading the next row or stack, while the row that was unloaded into the rack would be fixated from two sides by adjustable mechanisms coated with a soft material such as brush, rubber or foam.

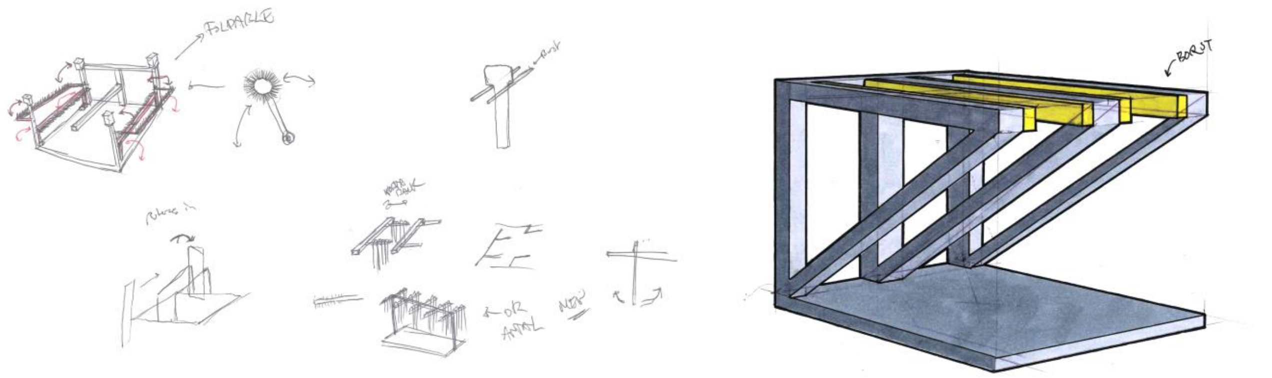

Figure 45. Hang concept. Illustration: Z. Envall.

The Hang concept (fig. 45) was designed to have the beams being hung from it. The concept was planned to use a soft material such as brush to keep the beams being hung separate from each other. The beams were planned to be hung by their edges.

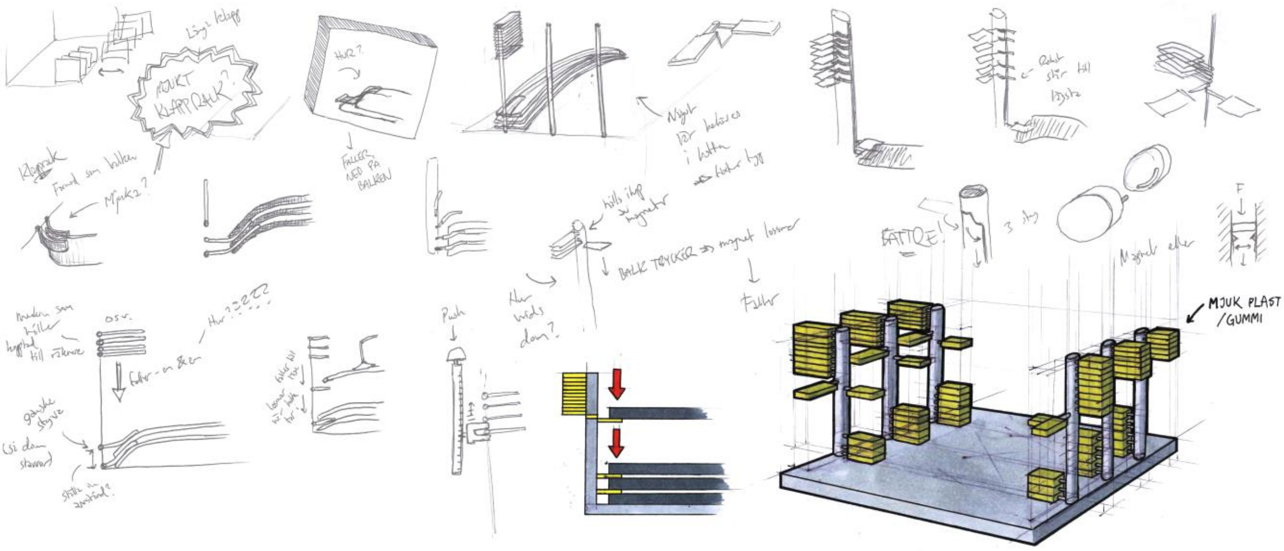

Figure 46. Soft concept. Illustration: Z. Envall.

The Soft concept (fig. 46) was also inspired by the automatic separator-mechanisms seen in the benchmarking. This concept was designed to have the beams being placed in stacks, with one separator on each side of each beam. The separators were planned to be made in a soft plastic or rubber material and thick enough to keep the beams apart. The separators were meant to rotate into the rack, with a possibility of assuming three different positions. The separator at the bottom of the stack is always facing the rack, and once the robot brings a beam down, it pushes the separator, after which it falls down onto the underlying beam while the next separator is automatically rotated into the rack.

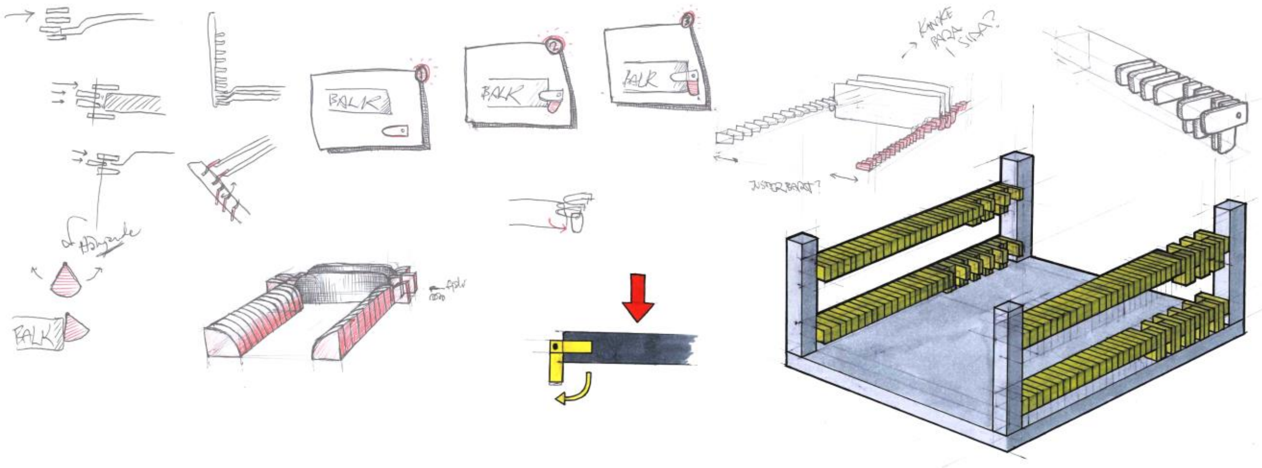

Figure 47. Down concept. Illustration: Z. Envall.

The Down concept (fig. 47) was designed for the beams to be placed in rows. The ends of the beams would interact with an automatic separator-mechanism, also inspired by the automatic separators from the benchmarking studies. The separators were designed to have the possibility of rotating between two positions, always being pushed upward by springs. An empty rack was meant to have all the separators positioned horizontally, to be rotated down when pushed down by a beam. When the beams were to be loaded into the rack, at least one separator was meant to remain horizontal between the beams, keeping them separate from each other.

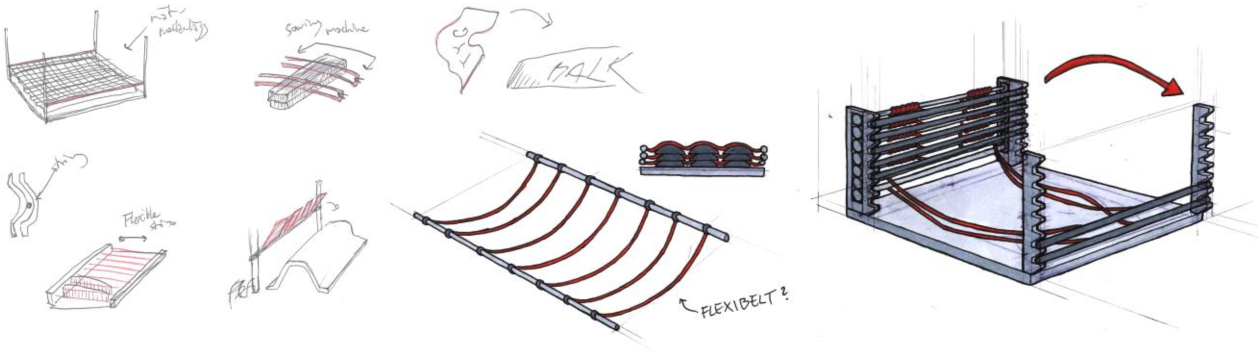

Figure 48. Strings concept. Illustration: Z. Envall.

The Strings concept (fig. 48) was meant for the beams to be stacked vertically, using strings with a soft and flexible material and to separate them. After a row of beams had been placed, the strings are used as a separator, put onto the beams before the next row of beams are loaded into the rack. The concept had two options, one having string mechanisms built in, where the strings are rolled up until the robot pulls them out and lays them over the beams. The other option was to use more simple string separators which were meant to be stored separately and laid on top of each row of beams.

5.2.5 ELIMINATION

The initiating elimination process resulted in a matrix where the concepts received different scores according to their presumed packing-grade, versatility, and cost (see table 3).

Table 3. Comparison of the concepts. Illustration: Z. Envall.

concept	packing	versatility	cost	score
BORST	GOOD	GOOD	LOW	10.5
BOXN1	BAD	GOOD	MEDIUM	6.5
DOWN	OK	OK	MEDIUM	7
SOFT	GOOD	GOOD	MEDIUM	9.5
STRINGS	GOOD	GOOD	MEDIUM	9.5
HANG	GOOD	BAD	LOW	8.5
FIXTURE	GOOD	GOOD	HIGH	8.5

The concept that received the highest score was the Borst concept, followed by the Soft and Strings concepts. The Hang and Fixture concepts also received fairly high ratings, but both each lacked greatly in one area.

Due to the elimination matrix along with discussions with Magnus Eriksson three of the concepts were chosen for testing and further development in the following phase, namely the Borst, Soft, and Strings concepts.

5.3 IMPLEMENT

The Implement phase consisted of two rounds of testing along with concept development. The testing resulted in various statistics regarding beam properties and statistics in relation to the three concepts Borst, Strings, and Soft. The concept development resulted in three final concepts leading up to a final elimination process.

5.3.1 TESTING I

The results from the first round of testing (see table 4 and Appendix 2) showed that almost half (46%) of the tested beams stick to each other when placed closely together. The highest stackable amount was 95 beams consisting of the Y555 C-St beams. The product that stacked the worst was the Scania RS Windscreen beam, with only 7 pieces being able to be placed on top of each other. The other products could be stacked in various amounts, with a mean value of 32 beams and a median value of 33 beams.

Table 4. The results from the first round of testing. The non-stick distances displayed in dark grey signify the beams that were determined to stick together.

	original distance	non-stick distance	stackable amount	stackable height	number of stacks
SCANIA RS WIND.	65 mm	65 mm	7	600 mm	4
SCANIA RS A-ST	10 mm	10 mm	33	330 mm	4
VOLVO TRUCKS WIND.	7 mm	17 mm	24	550 mm	4
VOLVO TRUCKS GJF	8 mm	8 mm	41	350 mm	5
Y555 SILL	7 mm	11 mm	40	550 mm	4
Y555 STF BAK	55 mm	65 mm	14	800 mm	4
Y555 C-ST	6 mm	6 mm	95	800 mm	2
V526 A-ST YT	19 mm	19 mm	15	400 mm	1
V526 SBF	9 mm	9 mm	40	800 mm	2
V526 SB	9 mm	13 mm	52	600 mm	7
V526 GB	20 mm	21 mm	40	800 mm	7
V526 TUF OV	15 mm	21 mm	8	250 mm	8
V526 TUF MES	15 mm	21mm	8	250 mm	8

The number of stacks of each beam that fit in the 800 by 1600 mm rack ranged from the V526 SBF and V526 A-St YT beams at 2 stacks, to the V526 TUF OV and MES at 8 stacks. The mean number of stacks was approximately 5, and the median value was 4 stacks.

The maximum stacking height was set to 800 mm, which 4 of the beams reached (Y555 STF Bak, Y555 C-st, V526 SBF, and V526 GB). The product that stacked the worst was V526 TUF OV and MES, only reaching 250 mm before falling. The mean stacking height was 545 mm with a median of 550 mm.

The testing of the non-stick distance in comparison to the minimum distance between the beams resulted in minimum packing-grade percentages. The 7 beams that did not stick together all showed packing-grades of 100%, with the rest of the products coming in at between 41-85%. The minimum packing-grade percentage of the beams that stuck together showed a mean value of 67% with a median of 70%.

The testing showed that 8 of the 13 products leaned when being stacked, 6 of the products stacked unevenly, and 5 of the products showed signs of deformation at the bottom of the stacks.

The testing of the concepts showed that the concept Strings worked for all six of the beams that stuck together. The testing showed that the string thickness needed in order to keep all six of these beams apart was 10 mm.

The Soft concept worked for five of the beams that stuck together, also needing a separator with a thickness of 10 mm to keep all the 5 beams apart. The one sticking beam that the concept did not suit was Y555 STF Bak, with the reason being that the beam got stuck in its center region, while the separation distance at its ends remained high. The Soft concept would theoretically also work for this beam, but would require separators with a thickness of 50-100 mm.

The testing furthermore resulted in discontinuing the development of the Soft concept, stemming partly from the fact that it suited fewer of the products than the Strings concept while being a similar solution. Its design also led to the racks having a fixed number of stacks, which would either result in many different racks or poor packing grades. The separation technique of using separators on the ends of the beams also proved to be problematic in relation to using separators closer to the middle of the beams, being that the beams more often had irregular shapes at their ends than in the middle.

5.3.2 TESTING II

The second bout of testing dealt with beams being placed in rows and testing the concept Borst, and the full results can be found in Appendix 3.

The tests showed that all of the products except Y555 Sill could be picked up directly from the conveyor belt and loaded into a rack, while the Y555 Sill beam required for a change of grip before being placed in the rack, in order to keep it from falling over. 8 of the products would benefit from leaning the rack upon loading and unloading, and all the products could be loaded into and out of leaning racks.

The concept testing showed that keeping all 6 of the products that stick together apart would work with the Borst concept, and it would also ease the loading and storage of the Scania RS Windscreen beam by providing increased stability. Upon using brush to separate the beams, the number of beams that fit in each 1200 mm row ranged from 9 to 48 for the seven products. The maximum number of rows that would fit in a rack with a height of 800 mm, separated by brush separators, ranged from 3 to 7 rows. The Borst concept provided packing-grade distances of between 15 to 107 mm, with a mean value of 44 mm and a median value of 30 mm.

Smooth separators in the form of wooden planks were shown to suit 4 of the non-sticking products, while not being as suitable for the two products with more rounded shapes (V526 A-St YT and Y555 C-St). The minimum distance needed to keep the different rows of beams from intersecting ranged from 0 to 55 mm. However, this distance varied depending on where the separators were placed in relation to the shapes of the various products.

5.3.3 CONCEPT EVALUATION

The concept testing provided statistics used for calculating packing grades for the different concepts. These are displayed in table 5.

Table 5. Packing-grades for the various products in relation to the two concepts. Illustration: Z. Envall.

	BORST	STRINGS
SCANIA RS WIND.	72%	
SCANIA RS A-ST		
VOLVO TRUCKS WIND.	58%	75%
VOLVO TRUCKS GJF		
Y555 SILL	80%	84%
Y555 STF BAK	93%	73%
Y555 C-ST		
V526 A-ST YT		
V526 SBF		
V526 SB	59%	78%
V526 GB	75%	
V526 TUF OV	84%	64%*
V526 TUF MES	84%	64%*

The percentages in table 5 are listed according to which solutions suit each product. The percentages are calculated for equal rack sizes. In reality the beams in the Strings concept can only be stacked with a height of 400 mm, while the Borst concept allows for a height of 800 mm. Therefore, the real percentages for the Strings concept would be somewhat lower than that listed in table 5. The V526 TUF OV and MES beams are calculated as stacks with a height of 200 mm on top of each other, kept apart by some sort of separators.

5.3.4 CONCEPT DEVELOPMENT

The concept development dealt with the Borst and Strings concepts from the Design Phase, see fig. 49).

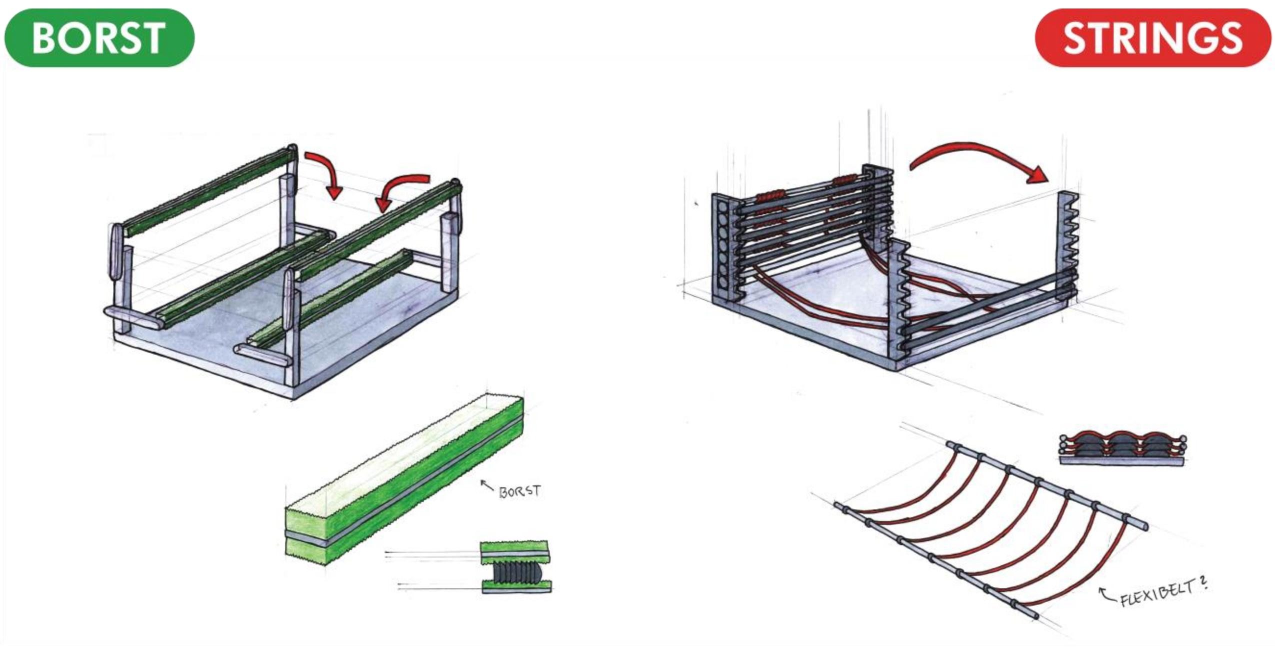

Figure 49. The Borst and Strings concepts. Illustration: Z. Envall.

The results included numerous ways of implementing the two separation techniques into racks, focusing on decreasing dead space and easing the robot handling. The concept development ultimately resulted in a modular solution, where the concepts merged together and were implemented in the same rack solution (see fig. 50).

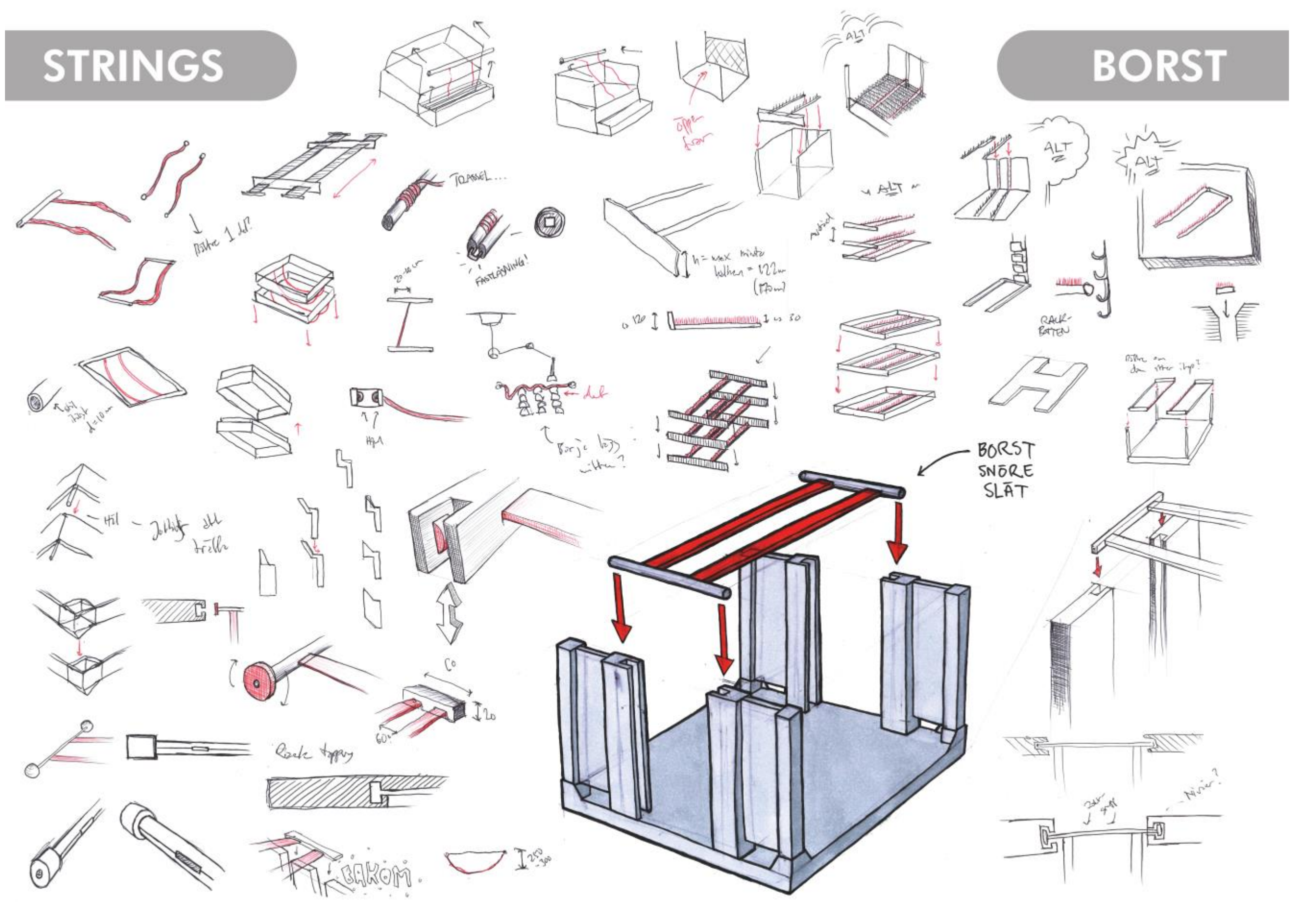

Figure 50. The different ideas for implementation of the Borst and Strings concepts, ultimately resulting in a combined rack concept. Illustration: Z. Envall.

The results from the development of the Strings concept resulted in a wide array of ideas solving the problems of entanglement of the separating strings, loading into the racks, stacking, and reacting to the next layer of beams. To keep the strings from getting tangled up the proposed ideas included different forms of constraints and rolling, but ultimately took the form of constraining the two strings by combining them into one separator and by making them rectangular instead of round. Ideas dealing with loading the separators into the racks initially tackled the problem by different Lego-like mechanisms, but lastly ended up using slots which the ends of the separators would be placed into.

Adding wheels to the ends of the separators was an idea for solving the problem of what happens to the ends of the separators once the next layer of beams is placed in the rack. This was however finally dealt with by using round ends on the separator, meant to be light enough that they would be able to adjust to the next layer of beams. The Borst concept development produced ideas that dealt with problems consisting of rack loading accessibility, separator placement, and separator loading. The ideas dealing with loading accessibility initially consisted of separators that had end parts which would keep each row of beams from falling out, but this problem ultimately ended up being solved by having an opening on the sides of the racks, providing accessibility and keeping the rows of beams intact at the same time.

The separator design and placement options took a few different forms which could be generally categorized as resting on the beams or resting on the rack. The end result ended up having the separators resting on the beams. The separator loading could therefore be done in the same way as for the Strings concept – by having the ends of the separators placed in slots on the racks.

The end result of the concept development took the form of a modular rack, enabling use of three different separators. These included separators used in the Strings concept and the Borst concept. The third separator resembled the Borst concept separators but without the brush, instead having smooth surfaces in a plastic or rubber material, meant to keep the rows apart for the products that were found not to stick together in the testing. This separator will furthermore be referred to as the Smooth concept.

5.3.5 FINAL ELIMINATION

The opinions of both Magnus Eriksson and Martin Holmbom was that the Borst concept was preferred, regarding both cost and handling. The packing-grade comparison in table 5 shows that the Strings concept allows for a slightly higher packing grade for half of the beams suited by both concepts, with a mean packing-grade of 73%. The Borst concept is however suitable for more products, but has the lowest packing grades for some products (V526 SB and Volvo Trucks Windscreen). The concept has a mean packing grade of 76%.

According to the packing-grades, the number of suitable products, along with the opinions of Magnus Eriksson and Martin Holmbom the final concept was chosen to be the Borst concept, including the additional Smooth separators for the beams that do not need the brush material for keeping them apart.

5.4 OPERATE

The Operate phase included further concept refinement concerning various details having to do with different aspects concerning functionality. A CAD-model of the refined concept was also produced.

5.4.1 REFINEMENT

The refinement work resulted in various concept alterations concerning the design of the gates and pole-hinges, along with ideas that dealt with being able to stack the racks, both when folded and opened (see fig. 51).

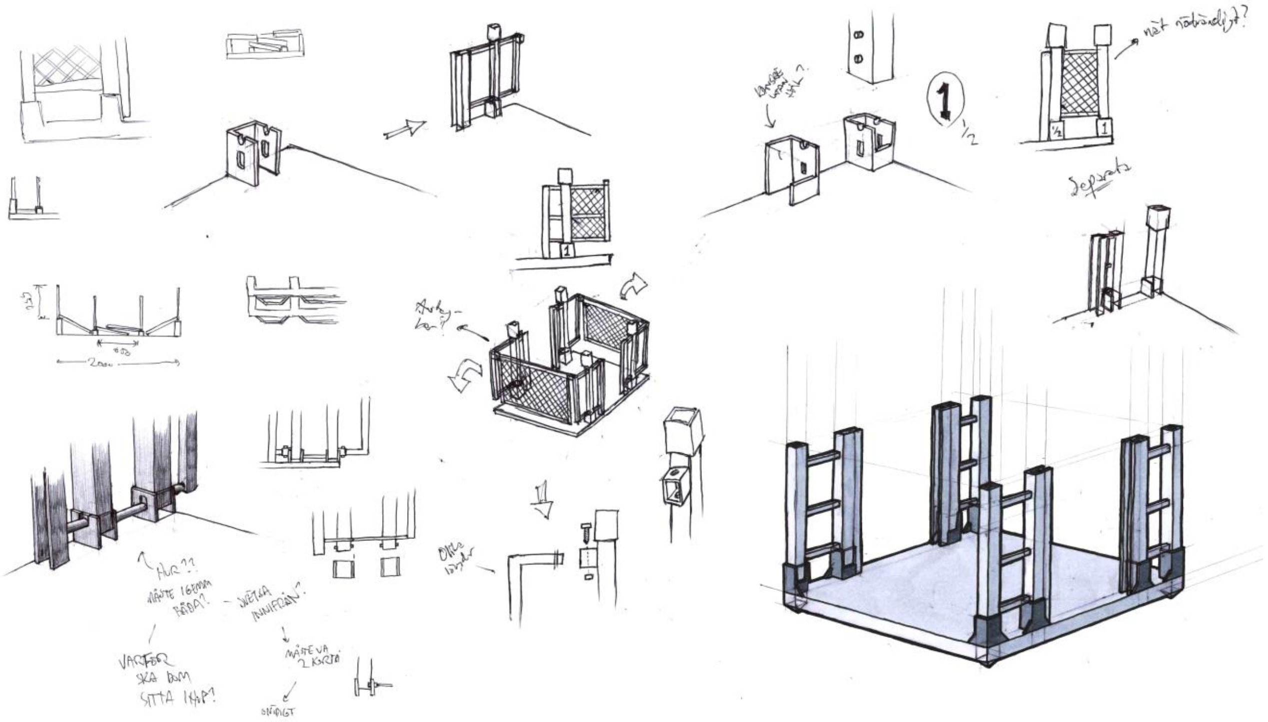

Figure 51. Sketches produced during the concept refinement. Illustration: Z. Envall.

The design for the gates and pole-hinges was ultimately decided to be based off the HT-rack, being that it is a solution that has been proven to work, along with the fact that developing ideas for various rack details would be too time consuming for this project.

5.4.2 CAD-MODELLING

The CAD-modelling in Siemens NX resulted in a CAD-model of the concept (see fig. 52). The model took the form of an assembly being made up of various parts, from the gates and poles to the small rotation-pins that enable the folding of the poles.

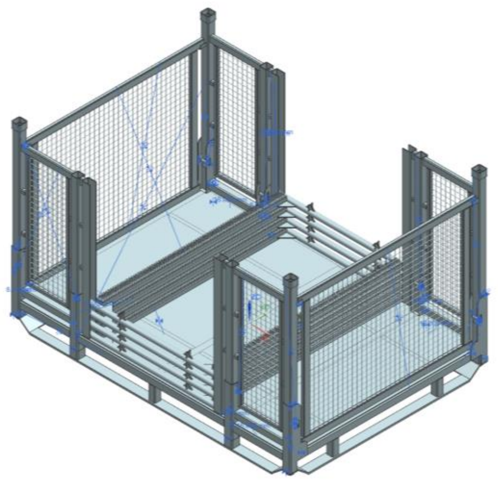

Figure 52. Finished CAD-model of the concept.

5.5 FINAL RESULT

The final concept was given the name 4.0-Rack, referencing both to what is described as "Industry 4.0" by Blanchet et al. (2014) amongst others, as well as the HT-rack. The concept is an implementation of the results from the project into the existing HT-rack design, and is a modular solution consisting of a rack and two types of separators (see fig. 53).

Figure 53. 4.0-Rack concept, displaying the rack and the two separators "Borst" and "Smooth". Rendering: Z. Envall.

Although there is a strong likeness to the HT-rack, the concept differs in a number of ways, including:

- The poles fold along the racks short sides instead of along the long sides
- The poles at each corner are welded together 2 and 2
- The rack only has 2 removable gates
- The rack has 4 long slots welded to each pair of poles used for separator placement

The rack concept has an opening on both long sides, which is meant to be shorter than all the beams which are planned to be stored in the rack. This opening reduces the weight somewhat, but is mainly there to aid the robot in recognizing and attaching its end-effector to the beams. The opening is meant to leave room for the robot to move in and out of the racks with ease when loading and unloading beams.

The process of loading into the racks (described in fig. 54) is planned to be done by robots, both concerning the packing of beams and the placement of separators. Folding and opening the racks is however planned to be done manually. The separators are one-sided and are meant to be placed with the coated face against a row of beams. A minimum of two separators are therefore needed between each row.

Figure 54. The loading process for the rack. Photo: Z. Envall.

5.5.1 SEPARATORS

The separators come in two versions, either with a brush coating, derived from the Borst concept, or with a smooth plastic coating. The brush (see fig. 55) is meant to be used for the beams that have a tendency to stick together along with beams that need the additional stability provided by the brush in order to be packed closely and securely. These separators have additional vertical details welded onto the tubes, which are meant to keep the brushes from getting deformed when the separators are stacked, in turn easing the storage possibilities.

Figure 55. The two different kinds of separators. Photo: Z. Envall.

The smooth separators are meant to be used to separate rows of beams that do not stick together, in the same way things such as wooden planks are used today. These can also be stacked and combined with the brush separators to provide a larger separation-distance whenever it is needed (see fig. 56).

Figure 56. Example of how the "Smooth" separators can be used for storing the Scania RS A-st beam.

Some beams, such as the Scania A-st in fig. 56, have an asymmetrical shape that causes the separators to lay at an angle. The dimensions used for the separators and slots in the concept allow the separators to be lay at an angle of approximately 20 degrees without one side slipping out of the slots.

5.5.2 STACKABILITY & MATERIAL

The racks are stackable with themselves and with the regular HT-racks, both when they are folded and when they are opened (see fig. 57).

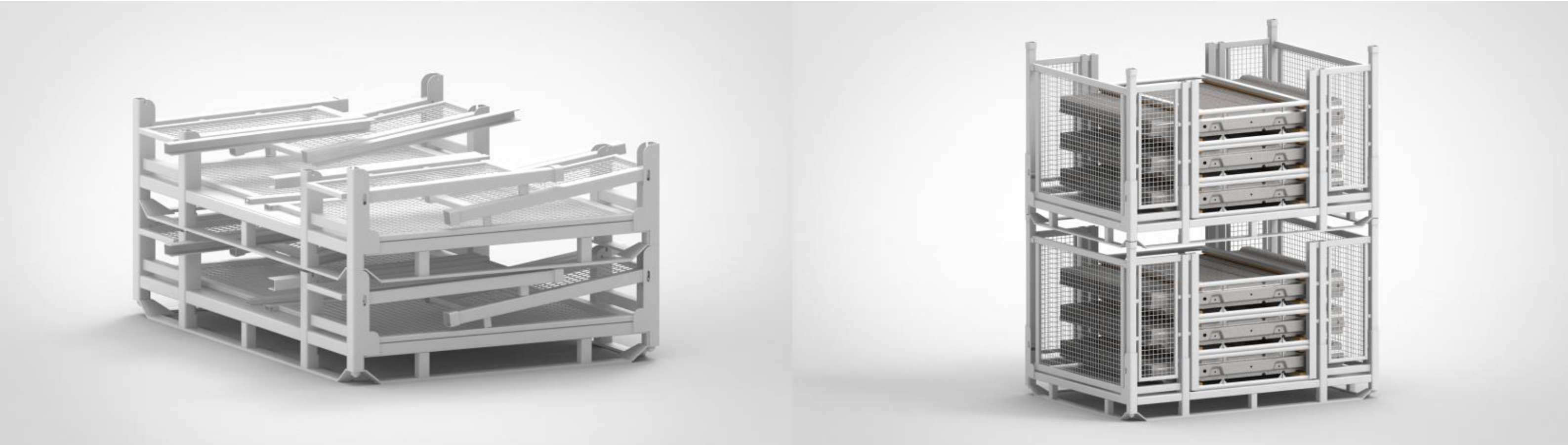

Figure 57. Displaying the stacking of folded and opened racks.

The rack is meant to be comprised of hollow steel beams which are welded together, similarly to the HT-racks. The same goes for the separators, apart from the black rounded ends, and the faces that come in contact with the beams. The ends are planned to be made of plastic, in order to ease movement through the long separator-slots. The faces on the smooth separators that come in contact with the beams are meant to be comprised of a plastic material. The brush separators are thought to consist of a plastic brush mat, that is fastened to the separators by screws. For the brush itself, a material called Pekalon is planned to be used, which is a plastic material with good wear resistance and flexural strength that can withstand temperatures of up to 200° C.

5.5.3 PRODUCT SUITABILITY

The 4.0-Rack can theoretically be used for all twelve of the reviewed products. Two of the beams are however not deemed suitable for the rack, namely the Y555 STF Bak and V526 A-st YT beam. The conclusion that was made was that the Borst separators should be used for 6 of the beams, and the Smooth separators for 3 of the beams. One of the beams (V526 SBF) doesn't stick and can only fit one row, whereby it needs no separators, but can still be stored in the rack.

Figure 58. Displaying which products are deemed suitable for use of each separator, along with the calculated packing-grades. Illustration: Z. Envall.

The final number of beams deemed suitable for the rack is thus 10 out of the 12 beams (see fig. 58). The mean packing grade is 83%, with only the Borst separators resulting in packing grades lower than 100%. The beams that are deemed to be used with the Borst separators have a mean packing grade of 71% and a median value of 78%.

The generic characteristics deemed suitable for the Borst separator (see fig. 59) include beams that stick and beams with straight edges, along with beams that have a straight shape. Both symmetrical and asymmetrical beams are meant to be stored in the rack.

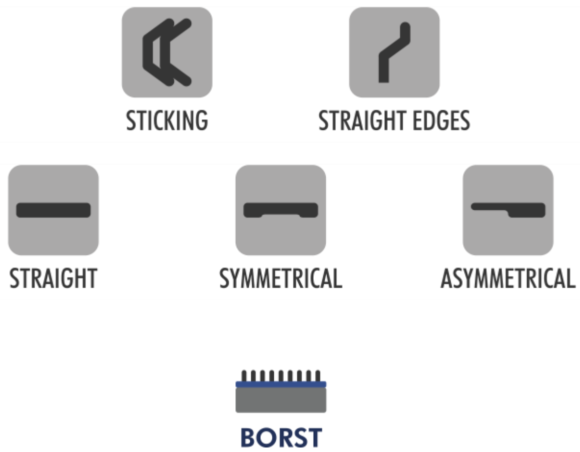

Figure 59. The generic categories deemed suitable for the "Borst" separators. Illustration: Z. Envall.

The Smooth separator suits more of the generic characteristics (see fig. 60), with the main characteristic being beams that do not stick. The other characteristics include beams with both straight and bent edges, beams that have both bent and straight shapes, along with symmetrical as well as asymmetrical beams.

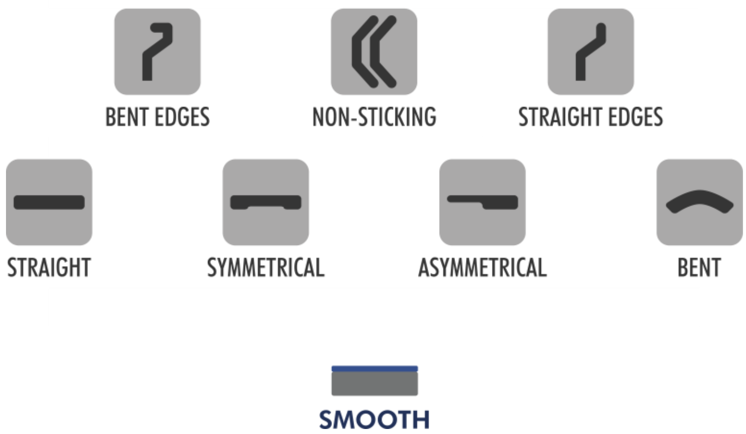

Figure 60. The generic categories deemed suitable for the "Smooth" separators. Illustration: Z. Envall.

6 Discussion

The Discussion chapter includes discussions about the results of the project, including feasibility, relevance, and reflections along with recommendations for further development of the rack concept.

6.1 FEASABILITY

According to Mitchell (1998), the main needs for a rack that is designed for robotic loading and unloading are enabling the robot to locate the parts and preventing damage during transport. One factor that can be added to this as a result from the testing is keeping the parts being stored in the rack from sticking to each other. Localization of the parts is highly dependent on the implementation of machine vision and illumination in relation to the rack design. Preventing damage has to do with rack design and the materials used for the rack. The best option for keeping the beams apart has been determined to be brush through the work performed in this project, but what materials and dimensions that are required for this is also a large factor.

The overall consensus from analyzing the rack concept in relation to the reviewed theory is that a robot equipped with the suitable sensors should be able to load beams and separators in an out of the 4.0-Rack. However, the largest difficulty in assessing this theoretically comes from the many variables that have an effect on especially the vision systems.

6.1.1 MACHINE VISION & ILLUMINATION

Martin (2012) and Dettmer (2013a) for example place a large focus on lighting arrangements, with Martin (2012) stating that it is a critical aspect in a successful implementation of machine vision systems. Since no lighting is implemented into the concept design, lighting thus becomes a free variable in determining the feasibility of the concept. The design does however allow for direct illumination of the beams from the top and through the openings on the front and back of the rack. The theory that was reviewed points to the fact that a bright-field lighting technique best seems to suit the purpose of identifying a beam in the rack, which is especially important during unloading. This is something that is backed by the fact that bright field is the most common lighting solution, according to Martin (2012). A bright field lighting solution for illuminating beams stored in the 4.0-Rack implies a light positioned so that the beams (or particles) travel horizontally and hit the faces of the beams stored in the rack. A possible complication is the fact that the beams are stored at different positions in space, as opposed to when they are picked from a conveyor belt. This could raise the need for a light positioned over the rack, shining directly down on the edges of the beams, in order to aid the robot in determining the position of each beam, along with enabling loading of the beams at uniform distances (see fig. 61).

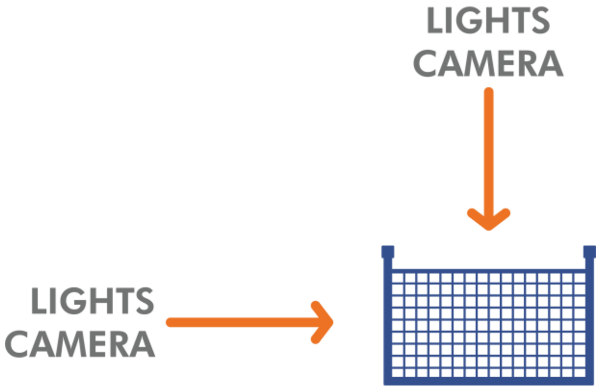

Figure 61. Discussed light and camera positions. Illustration: Z. Envall.

The camera positioning of the vision system needs to correspond with the lighting, in order to retain the necessary information about the robot's environment. For loading and unloading from the concept rack, using two cameras seems to be the most secure option. Perks (2006) mentions the usage of multiple cameras as something that can be used for building 3D images, commonly used for bin-picking. Although bin-picking is somewhat more complicated than picking uniformly placed parts, it is more similar to what is required for the 4.0-Rack than picking parts off of a conveyor belt is. For the rack concept, having one horizontally positioned camera that registers the front of the rack, along with a camera looking down at the rack should provide the robot with sufficient information for successfully loading into and loading out of the rack. A variation to the horizontally positioned camera could be instead positioning the camera near the end-effector on the robot, and in turn always having a clear field of view, as opposed to a fixed camera that would have its field of view partially blocked every time the robot moves in or out of the rack. Another option to this is positioning the horizontal camera at an angle, limiting the area of its field of vision that is blocked by the robot. Calculating the resulting perspective view could however be somewhat more complicated than having the horizontal camera positioned so that it gets more of a 2D view of the beams.

6.1.2 DAMAGE PREVENTION

Preventing damage to the rack and beams during transport is dependent on rack design, material properties, along with logistic rules and guidelines. The design of the 4.0-Rack is very similar to the design of the HT-rack, and is meant to be comprised of similar materials and produced in a similar manner. The two racks are displayed in fig. 62.

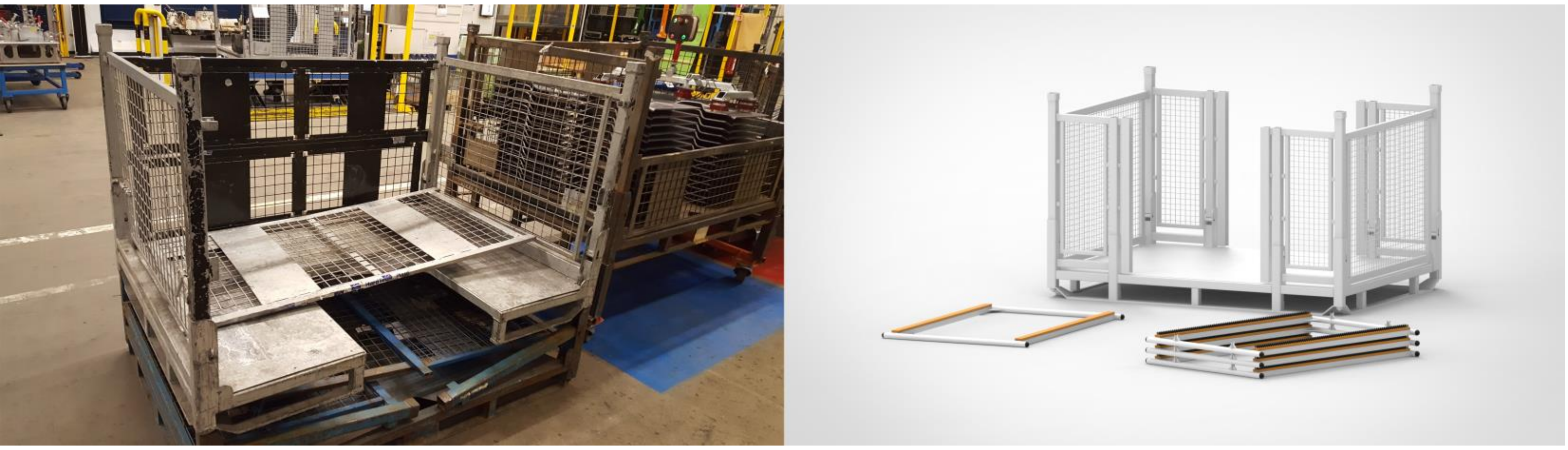
Figure 62. The HT-rack and 4.0-Rack side-by-side.

Since the HT-rack is a solution that has proven to work well for transporting and storing beams, if the 4.0-Rack provides the same structural integrity as the HT-rack it should provide sufficient damage prevention.

The main difference between the two racks is the design of the long sides. While the HT-rack has 2 corner poles along with a wide removable gate on each side of the rack, the 4.0-Rack has two smaller gates that each are fixed to two poles on both sides of the rack, leaving an opening in the middle. This opening provides no direct protection of the products except for the cylinders that make up the ends of the separators. The 4.0-Rack therefore offers the same, if not more protection overall, but leaves room for direct damage through both of the openings. Damage to the beams would occur if the forklift-truck driver collides with an object that is less than 755 mm wide and thus would fit through the opening.

6.1.3 BEAM SEPARATION

How to keep the beams separated from each other while still being packed as closely as possible has been the main focus of this project. Through physical testing with the chosen beams brush was determined to be best suited for this task. The tests proved that when the beams were placed onto a brush material, at a certain distance from each other, they were kept separate. The racks were however not moved in the testing, whereas the brush's ability to keep the beams separate during transport was not empirically tested. Being that this is a large concern, an additional brush separator was added to the top of each row of beams in the concept, in order to provide the beams with a higher level of stability. The usage of the brush separators is therefore only a theoretical solution which has not yet been tested during transport of the racks. Although the testing that was performed proved positive for the brush, the entire concept has not been tested, so the feasibility of the usage of brush in the concept is only an assumption.

6.2 RELEVANCE

The project first and foremost provides Gestamp HardTech with a concept rack that is meant to aid in implementing an increased level of automation, in turn leading to increased quality and lower personnel costs. Before the project, the question of what racks to use for robotic handling at HardTech were merely ideas, whereas now a concept backed by a design process and physical tests exists. Although the concept might have some possibilities for improvement and is not a finished product ready for production, it is something concrete to base further development on.

Apart from the rack, the thesis project has also had a large focus on assessing the beams produced at Gestamp HardTech Luleå. This product assessment and categorization resulted in various generic beam-categories. These could aid in an eventual categorization of future products, in turn also helping with the choice of racks for new products, especially for determining which products are suited for the 4.0-Rack. On a wider scale, the concept rack offers a flexible storage solution that is rather unique in comparison to what was observed in the benchmarking. If further tests and an eventual implementation of the 4.0-Rack proves to be successful, the solution could be beneficial for several other companies and production sites both within and outside of the automotive industry.

6.3 REFLECTION

The project can essentially be divided into three main focus areas: the development of flexible racking-solutions for keeping the beams separate, beam analysis and assessment, along with a theory immersion centered on understanding the limitations of robots and machine vision systems. The development of racking-solutions and the beam assessment were necessary keys for reaching the desired results, but the theory immersion was only necessary due to a lacking knowledge within the field of robotics. Someone with a better initial understanding of this area could have minimized this portion, and instead focused on other aspects relevant to the rack development. The project additionally ended up focusing more on the beams and developing solutions fit for these, and less on the robot-aspects in relation to the rack design. Having the theory review include relevant flexible-design aspects along with various methods for categorization while including somewhat less information about robots and machine vision would probably have been better suited for the developmental process that transpired.

Another factor that had a big effect on the final result was the testing. Although it resulted in many relevant statistics and parameters, it could have been better planned and more accurately performed. By also having the testing include more tests, especially regarding transport of the beams, it would have had clearer results, in turn resulting in a more accurate concept evaluation. Other tests that probably would have aided the concept evaluation are testing the brush with more than one row of beams, actually leaning the racks during testing, along with determining suitable angles. The reason that these tests were not performed was due to a combination of factors. The first is that the tests required outside help for fetching the various products and would therefore have needed additional assistance for performing the earlier mentioned tests. The second reason is that the testing was very time consuming, and the project planning only left so much time for performing them, whereby the tests focused more on comparing the concepts, rather than evaluating exactly how well the concepts worked. The testing process is also a part of the project that could have given more and better results if less time was spent on reviewing theory about robotics.

6.4 CONCLUSIONS

The conclusions that could be drawn after the project are displayed below. These include conclusions about the project's objective and aims along with answers to the various research questions that the theory immersion was structured around.

6.4.1 PROJECT OBJECTIVE & AIMS

The project's objective was defined as providing Gestamp HardTech with a rack concept that enables the use of robots for handling beams. The handling included loading beams coming out from the stamping lines into racks, and then unloading the beams for the next machining process. The rack concept was meant to be flexible by suiting many different products, while still allowing for a relatively high packing grade.

The testing in the Implement phase showed that 6 out of the 12 beams stick together when they are packed closely. It also showed that all of these six could be loaded and unloaded using a brush similar to the Borst separator successfully without sticking.
The project's resulting rack concept, with both kinds of separators, can be used for

all of the 12 reviewed products. Some of the beams were however not deemed suitable for the rack, namely the Y555 STF Bak and V526 A-st beam. The final number of beams deemed suitable for the rack is thus 10 out of the 12 beams, accounting for 83% of the reviewed products. The mean overall packing grade is approximately 83%, with all the beams in need of the Bost separators being lower than 100%, ranging from 84% to 58% with a mean value of 71%. Although no concrete packing grade percentage was specified in the objective, 83% could be viewed as relatively high.

The project's aim was to contribute to an automation of the production process at Gestamp HardTech Luleå, which in turn was assumed to lead to lower costs and contribute to the machine operators along with the company's various clients.

Being that the project only resulted in a concept, determining whether it met its aim is more predictive than the objective. However, since it can be viewed as achieving the objective, also meeting the aim should be a likely consequence. Whether this turns out to happen depends on the results from further testing and eventual implementation, along with various other unforeseeable events that lie outside the scope of this project.

6.4.2 RESEARCH QUESTIONS

The following question contains the various research questions that were stated initially, along with answers to these.

- *How does machine vision work?*

Machine vision systems use cameras to capture brightness variations in an image, in the form of reflected light. The main components of these systems are a camera and some means of illumination. The illumination is supplied by a light source, which is positioned to achieve a reflection that best suits the desired purpose. Reflected light particles are captured by a pixel sensor inside the camera and converted into an image, whereby the relevant data is extracted and interpreted through a number of computational steps. The interpretation leads to a decision being made, according to which an action can be taken.

- *What are the limitations for machine vision?*

Perks (2006) claims that limitations in vision systems more often have to do with poor implementations than the actual systems. He also states that the biggest hinderance historically for these systems has been due to a lack of computer power. As Dettmer (2013a) states, the camera resolution needs that are required by vision systems is commonly much lower than what is available on the market, and that the reason high resolution images are not used is due to longer processing times.
Dettmer (2013a) and Martin (2012) both stress the importance of lighting arrangements when it comes to vision systems. A common problem for lighting arrangements is ambient light, caused by things such as windows or skylights (Perks, 2006).

- *What constitutes a robot, and how do they work?*

Robot is a broadly defined term, explained by both SME (2018) and Hunt (1983) as a multifunctional device or machine that in some way manipulates other objects. A robotic system can be divided into seven components, which according to Niku (2011) are a manipulator, an end-effector, actuators, a controller, a processor, software, and sensors. The manipulator is the body of the robot and can be likened to the human arm. The end-effector is used to interact with the surroundings and can be viewed as the hand of the robot. Actuators connect the links and joints of the robot similarly to muscles. The robots motions are calculated and controlled by the processor, software, and the controller, acting as the robot's brain and cerebellum. Various sensors can in turn be seen as the senses of the robot, providing information about its surroundings (Niku, 2011).

- *What robots are used in industrial production settings?*

Industrial robots are the most common robots used in industrial settings, with 60% of all industrial robots being used in the automotive industry (Hägele, Nilsson, & Pires, 2008). Mitchell (1998) classifies industrial robot arms into five types: Cartesian (rectangular), cylindrical, spherical, jointed or articulated,
and selective compliance assembly robot arms (SCARA). What differentiates these types of robot arms is how their various joints move and how many degrees of freedom they can move in.

- *What are the robot's needs concerning the rack design?*

A robot equipped with machine vision and motion control can load in and out of simple racks, according to Mitchell (1998). The requirements mentioned for these racks is that they need to allow the robot to locate the parts, and to prevent damage during transport (Mitchell, 1998). Locating the parts by vision in turn requires the racks to allow a camera to see the parts, and lighting arrangements to properly illuminate the scene.

6.5 RECOMMENDATIONS

With the project resulting in a concept rack, a good deal of work remains before the rack can be implemented into the production. The main focus of the project dealt with on developing solutions that are flexible and keeps beams from sticking together. Other rack details were thus not as prioritized and might have some possibility for improvement. The predictable steps needed before implementation from the current situation are displayed below.

6.5.1 SLOT DESIGN

The first and most central recommendation is to review the design of the slots. The current design could work but it requires the robot to place the separators with a relatively high level of precision. How well the separators move through the slots could also be a problem, and needs to be reviewed and tested, suggestively through simple miniature prototypes.

6.5.2 BRUSH SPECIFICS

The next predictable step is determining the right brush type for the task. The most suitable brush length needs to be determined, as the brush samples that were used in the testing that was performed did not provide enough of a foundation for securely determining this. The material that was assigned to the brush for the concept was Pekalon, but this was solely due to the material's theoretical characteristics, and it also needs to be reviewed and tested. From the experience gained through the tests a suggestion would be to try shorter brush lengths, such as 10-20 mm. A shorter brush length should be more durable and also allow for a closer packing of the beams.

6.5.3 LEANING

The testing showed that the loading of all beams would benefit from leaning the rack. The testing did however not determine at which angle the different beams needed the rack to lean. How the leaning should work and at what angle the rack should lean is thus something that also needs to be determined, suggestively through testing.

6.5.4 RACK DETAILS

A possible problem with the rack design is the folding of the poles. With the current design the stacking of folded racks places the folded poles in the lower rack very close to the bottom of the rack that is placed on top of it. This is not necessarily problematic but simple design variations could increase the tolerances. Another factor that needs to be determined is the width of the racks. The concept rack is dimensioned according to the HT-rack (approximately 1700 mm wide), but the reviewed beams had a length varying from 1200 to 2185 mm and would provide the best packing grades in racks suitable to the beam lengths.

6.5.5 TESTING

Before eventual implementation the rack needs to be tested more thoroughly. Suggestively this would include fully packed racks with similar separators which are transported. Robotic loading and unloading from the racks of course also needs to be tested, for which personnel knowledgeable in the field of machine vision should be present.

7 References

Arezes, P. M., Dinis-Carvalho, J., & Alves, A. C. (2010). Threats and Opportunities for Workplace Ergonomics in Lean Environments: *Proceedings of the 17th International Annual EurOMA Conference-Managing Operations in Service Economics, Catholic University of Portugal (CUP), Porto, Portugal, 6-9 June 2010.* (p. 1-10). Porto, Portugal: EurOMA.

Basler AG. (2015, August 3). What is a Vision System? - Vision Campus [Video file]. Retrieved from https://youtu.be/atoUpGgw2fE

Bellgran, M. & Säfsten, K. (2010). Production Development: Design and Operation of Production Systems. London: Springer-Verlag.

Beyerer, J., Puente León, F., & Frese, C. (2016). *Machine Vision: Automated Visual Inspection: Theory, Practice and Applications.* Berlin Heidelberg: Springer-Verlag.

Blanchet, M., Rinn, T., Von Thaden, G., & De Thieulloy, G. (2014). *Industry 4.0: The new industrial revolution-How Europe will succeed.* München: Roland Berger Strategy Consultants GmbH.

Christensen, H. I. & Hager, G. D. (2008). Sensing and Estimation. In B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics* (2008th ed., p. 87-106). Berlin Heidelberg: Springer-Verlag.

Coiffet, P. & Chirouze, M. (1983). *An Introduction to Robot Technology.* New York, N.Y.: McGraw-Hill Inc.

Collins, D. (2006). Checklist Assists in Designing for Automation. Retrieved 2018-01-25 from http://medicaldesign.com/components/checklist-assists-designing-automation

Craig, J., J. (2005). *Introduction to Robotics: Mechanics and Control* (3. ed.). Upper Saddle River, N.J.: Pearson Education, Inc.

Cuffaro, D. F., Paige, D., Blackman, C. J., Laituri, D., Covert, D. E., Sears, L. M., Nehez-Cuffaro, A., & Zaks, I. (2013). *The Industrial Design Reference + Specification Book.* Beverly, MA: Rockport Publishers Inc.

Dettmer, P. [Robotics & Automation - AMST]. (2013a, March 18). Intro to Machine Vision and Robotics - part 1 [Video file]. Retrieved from https://youtu.be/SVcOWYfsBkc

Dettmer, P. [Robotics & Automation - AMST]. (2013b, April 1). Intro to Machine Vision and Robotics - part 2 [Video file]. Retrieved from https://youtu.be/RS-MXFX0ehs

Dorst, K., & Cross, N. (2001). Creativity in the Design Process: Co-Evolution of Problem-Solution. *Design Studies, 22*(5), 425-437. doi:10.1016/S0142-694X(01)00009-6

Dubberly, H. (2004). *How do you design? A Compendium of Models.* San Francisco, CA: Dubberly Design Office.

Hunt, V., D. (1983). *Industrial Robotics Handbook* (4. ed.) New York, N.Y.: Industrial Press Inc.

Hägele, M., Nilsson, K., Pires, J., N. (2008). Industrial Robotics. In B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics* (2008th ed., p. 963-986). Berlin Heidelberg: Springer-Verlag.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239-242. doi:10.1007/s12599-014-0334-4

Martin, D. (2012). A Practical Guide to Machine Vision Lighting. Retrieved 2018-03-07 from http://www.advancedillumination.com/sites/all/themes/advill/images/resource/files/practicallightingv3.pdf

Merriam Webster (n.d.). Dictionary: Industrial Design. Retrieved 2018-05-16 from https://www.merriam-webster.com/dictionary/industrial%20design

Mersch, S. (1986). Overview of Machine Vision Lighting Techniques. In D., J. Svetkoff (Ed.), *Optics, Illumination, and Image Sensing for Machine Vision: Proceedings of Cambridge Symposium_Intelligent Robotic Systems, Cambridge, MA, October 28-31, 1986.* (p. 36-38). Cambridge, MA: Cambridge Symposium.

Milton, A., & Rodgers, P. (2011). *Product Design.* London: Laurence King Publishing

Milton, A., & Rodgers, P. (2013). *Research Methods for Product Design.* London: Laurence King Publishing.

MIT OpenCourseWare (2012, July 24). *4. Quality Function Deployment (QFD) and House of Quality* [Video file]. Retrieved from https://youtu.be/u9bvzE5Qhjk

Mitchell, P., E. (Ed.). (1998). *Tool and Manufacturing Engineers Handbook Vol 9: Material and Part Handling in Manufacturing* (4th ed.) Dearborn, Michigan: Society of Manufacturing Engineers.

Niku, S., B. (2011). *Introduction to Robotics: Analysis, Control, Application* (2. ed.). Hoboken, N.J.: John Wiley & Sons, Inc.

Pahl, G., & Beitz, W. (2013). *Engineering design: a systematic approach.* Berlin: Springer Science & Business Media.

Perks, A. (2006). Advanced vision guided robotics provide 'future-proof' flexible automation. *Assembly Automation, 26*(3), 216-220. doi:10.1108/01445150610679759

Pierce, L. (2008). Smart Sight Makes for a Smart System. *ABB Automotive Magazine, 1*, 4-6. https://library.e.abb.com/public/0a9b4ef9f9679de7c12574780024b952/FordBuffalo_abb_auto_108.pdf

Popovic, D. (2000). Distributed Control Systems. In R., L., Shell & E., L., Hall (Eds.), *Handbook of Industrial Automation* (p. 185-216). New York, NY: Marcel Dekker, Inc.

RobotWorx. (2018). What are the Main Parts of an Industrial Robot?. Retrieved 2018-01-26 from https://www.robots.com/faq/show/what-are-the-main-parts-of-an-industrial-robot

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Retrieved 2018-03-12 from http://www.inovasyon.org/pdf/bcg.perspectives_Industry.4.0_2015.pdf

Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. (2010). *Robotics: Modelling, Planning and Control.* London: Springer-Verlag.

Smets G., & Overbeeke, K. (1994). Industrial Design Engineering and the Theory of Direct Perception. *Design Studies 15*(2), 175-184. doi: 10.1016/0142-694X(94)90023-X

Taylor, G. & Kleeman, L. (2006). *Visual Perception and Robotic Manipulation: 3D Object Recognition, Tracking and Hand-Eye Coordination.* Berlin Heidelberg: Springer-Verlag.

The CDIO™ Iinitiative (2018). Retrieved 2018-01-17 from http://www.cdio.org/

Thörnberg, B. [Benny Thörnberg]. (2013, September 13). Introductory Lecture in Machine Vision [Video file]. Retrieved from https://youtu.be/GrG9nGAQ6Jw

Westgaard, R. H., & Winkel, J. (2011). Occupational Musculoskeletal and Mental Health: Significance of Rationalization and Opportunities to Create Sustainable Production Systems – A Systematic Review. *Applied Ergonomics 42*(2), 261-296. doi:10.1016/j.apergo.2010.07.002

Wikberg Nilsson, Å., Ericson, Å., & Törlind, P. (2015). *Design – Process och metod.* Lund: Studentliteratur AB.

Wikberg Nilsson, Å., & Törlind, P. (2016). Student Competence Profiles – A Complementary or Competitive Approach to CDIO?. In J. Björkqvist, K. Edström, R. J. Hugo, J. Kontio, J. Roslöf, R. Sellens, & S. Virtanen (Eds.), *The 12th*

International CDIO Conference: Proceedings of The 12th International CDIO Conference, Turku, Finland, June 12-16, 2016. (p. 844-858). Turku: Turku University of Applied Sciences.

Yassine A, & Braha D (2003). Complex Concurrent Engineering and the Design Structure Matrix Approach. *Concurrent Engineering: Research and Applications, 11*(3), 165-177. doi:10.1177/1063293O3034503

	Amount	Rack	Rader	Sides	Separators	Long Edges	Short Edge 1	Short Edge 2	Length	Width	Depth	Symmetry	Produktion	SL	Holes	Hangable
Scania RS Wind	50	HT	Stacks	Off		x-x	3 Bent	3 Bent	2100	170	220	Yes	SL-L	9 (6)	2	Holes, Shape
Scania RS A-st	200	HT	2	Off	Plastic	x-x	3 Bent	Straight	1600	350	80	No	SL-L	9 (6)	2	Holes, Shape
Volvo Trucks Wind	150	Volvo	3	(Off)	Rack	x-x	2 Bent	2 Bent	2185	181	132	Yes	SL-L	6 (9)	6	Holes
Volvo Trucks GJF	300	HT	3	On	Wood	x-x	Straight	Straight	1400	163	90	Yes	SL-L	6 (9)	2	Holes
Volvo Trucks Ext		HT	2 stacks	Off	Blocks	x-y	Straight	Straight				Yes	SL-L-W	6 (9)	0	No
Y555 Sill	180	HT	3	On	Wood	x-x	Straight	Straight	1565	230	82	No	SL-HP	6 (9)	3	No
Y555 STF BAK	60	HT	4	On	Plastic	y-y	Straight*	Straight*	1320	180	160	Yes	SL-HP-CMT	6 (9)	3	Holes
Y555 C-st	200	HT	2	On	Plastic	x(y)-x	1 Bent	Straight	1200	530	360	No	SL-L-A	6 (9)	4	Holes, Shape
V526 A-st YT	79	Volvo	2	(Off)	Rack	x-y	Straight	Straight	2360	830	200	No	SL-L	6 (9)	2	Holes, Shape
V526 SBF	80	HT	1	On		x-x	Straight	Straight	1450	500	300	Yes	SL-L-A	6 (9)	1	Shape
V526 SB	340	HT	4	On	Plastic	x-x	Straight	Straight	1310	160	40	No	SL-A	2 (6)	9	Shape
V526 TROF IN	80	Volvo	1	(Off)		x-x	Straight	Straight	2100	265	85	No	SL	6 (9)	5	Holes, Shape
V526 GB	160	HT	4	Off	Wood	x-x	Straight	Straight	1700	122	40	Yes	SL-A	6 (9)	20	No
V526 TUF OV	200	HT	5	Off	Plastic	x-y	3 Bent	Straight	1615	110	155	No	SL-HP-A	6 (9)	8	No
V526 TUF MES	200	HT	5	On	Plastic	x-y	3 Bent	Straight	1550	110	155	No	SL-HP-A	6 (9)	8	No

	Sticks	Stackable	Stacks	Stack Height	Non-Stick Dist.	Min. Dist.	Percentage	Strings	Soft	Leans	Uneven	Deforms	
Scania RS Wind	No	7*	4	600 mm	65 mm	65 mm	100%			No	No	No	*very unstable
Scania RS A-st	No	33	4	330 mm	10 mm	10 mm	100%			Yes	Yes	No	
Volvo Trucks Wind	Yes	24	4	550 mm	17 mm	7 mm	41%	10 mm	8,6 mm	Yes	No	No	
Volvo Trucks GJF	No	41	5	350 mm	8 mm	8 mm	100%			Yes	No	Yes	
Y555 Sill	Yes	40	4	550 mm	11 mm	7 mm	64%	8,6 mm	8,6 mm	Yes	Yes	Yes	
Y555 STF BAK	Yes	14	5	800 mm	65 mm	55 mm	85%	5,7 mm	No	No	No	No	
Y555 C-st	No	95	3	800 mm	6 mm	6 mm	100%			No	Yes	Yes	
V526 A-st YT	No	15	2	400 mm	19 mm	19 mm	100%			Yes	Yes	Yes	
V526 SBF	No	40	2	800 mm	9 mm	9 mm	100%			Yes	No	Yes	
V526 SB	Yes	52	7	600 mm	13 mm	9 mm	69%	2,9 mm	10 mm	No	No	No	
V526 GB	No*	40	7	800 mm	20 mm	20 mm	100%			No	No	No	*does not stick if gripped far apart
V526 TUF OV	Yes	8	8	250 mm	21 mm	15 mm	71%	4,3 mm	5,7 mm	Yes	Yes	No	
*V526 TUF MES**	Yes	8	8	250 mm	21mm	15 mm	71%	4,3 mm	5,7 mm	Yes	Yes	No	*based on TUF OV

	Borst Amount/Row	Borst Rows	Borst Dist.	OK Dist/Row	Smooth	Leaned	Direct Placement
Scania RS Wind	9	4	107 mm	28 mm		Yes	Yes
Scania RS A-st				55 mm	Yes	Yes	Yes
Volvo Trucks Wind	23	4	45 mm	0 mm			Yes
Volvo Trucks P2540				0 mm	Yes	Yes	Yes
Y555 Sill	48	3	15 mm	30 mm		Yes	No
Y555 STF BAK	15	4	60 mm	35 mm		Yes	Yes
Y555 C-st							
V526 A-st YT							
V526 SBF					Yes	Yes	Yes
V526 SB	31	5	23 mm	15 mm		Yes	Yes
V526 GB				0 mm	Yes	Yes	Yes
V526 TUF OV	24	7	30 mm	10 mm			Yes
V526 TUF MES	24	7	30 mm	10 mm			Yes

Robot Racking

- A Racking Solution for Autonomous Production

Zakarias **Envall**
2018

SUPERVISOR: Peter **Törlind**
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Melanie **Boman**
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MSc in INDUSTRIAL DESIGN ENGINEERING
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Luleå University of Technology

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Luleå 19th of June, 2018
Zakarias Envall

Abstract

As an engineering student, the most natural way of summarizing this thesis project is by relating it to a mathematical equation. The solution to this equation is given, and it is in the form of a racking concept that enables the use of robots. The other side of the equation is however a bit more complex. This side contains several undefined variables, which can only be solved by delving into various theoretical fields and exploring unchartered depths of the creative space.

The project's main objective is to design a concept rack for Gestamp HardTech in Luleå, Sweden, for storage and in-house transport of the beams which are produced at the HardTech facility. The rack is meant to be loaded both into and out of by robots and should suit an as wide array of beams as possible. To determine the possibilities and limitations of the rack's robot-user, several automation aspects are researched, centered on industrial robots and machine vision. The beams which are produced at the Gestamp HardTech Luleå production plant today are analyzed, whereby twelve of them are ultimately chosen for the rack's design to be focused on. What follows this is a creative process consisting of a creative idea-generating phase, an evaluative phase focused on implementation of the ideas, and a refinement phase where the rack concept is finalized. The process includes various methods of idea generating, a great deal of sketching, physical testing of the concepts, and finally CAD-modeling. The result, named 4.0-Rack, is in the form of a modular rack-concept which balances the aspects of flexibility, by suiting ten of the reviewed beams, with a high packing-grade, providing a mean packing-grade of 83% in relation to the way the beams are currently packed.

KEYWORDS: ROBOT RACK, AUTOMATED RACKING, PALLETIZING, DESIGN FOR AUTOMATION, MACHINE VISION, INDUSTRY 4.0

Sammanfattning

Som en ingenjörsstudent är det mest naturliga sättet att sammanfatta detta examensarbete genom att relatera det till en matematisk ekvation. Lösningen till denna ekvation är given, och den är i form av ett rack-koncept som möjliggör användning av robotar. Den andra sidan av ekvationen är dock lite mer komplex. Den här sidan innehåller flera odefinierade variabler, som bara kan lösas genom att dyka in i olika teoretiska områden och utforska outforskade djup i den kreativa rymden.

Projektets huvudsyfte är att utforma ett koncept-rack för Gestamp HardTech i Luleå, för lagring och intern transport av balkarna som produceras på HardTech-anläggningen. Racket är menat att laddas både in i och ut ur av robotar och borde passa så många balkar som möjligt. För att bestämma möjligheterna och begränsningarna hos rackens robot-användare undersöks flera automationsaspekter, centrerade kring industrirobotar och vision-system. De balkar som produceras på Gestamp HardTech Luleås produktionsanläggning idag analyseras, varav tolv av dem slutligen väljs för att fokusera rackens design på. Vad som följer detta är en kreativ process som består av en kreativ idégenereringsfas, en utvärderingsfas som fokuserar på implementering av idéerna, och slutligen en förfiningsfas där rack-konceptet färdigställs. Processen innehåller olika metoder för att idégenerering, en stor del skissande, fysiska tester av koncepten, och slutligen CAD-modellering. Resultatet, som kallas 4,0-rack, är i form av ett modulärt rack-koncept vilket balanserar flexibilitetsaspekter, genom att passa tio av de granskade balkarna, med en hög packningsnivå, då det medför en genomsnittlig packningsgrad på 83% i förhållande till hur balkarna packas idag.

NYCKELORD: ROBOTRACK, AUTOMATISK ROBOTPACKNING, PALLETERING, DESIGN FÖR AUTOMATISERING, VISION-SYSTEM, INDUSTRI 4.0

Content

List of appendices

1 Introduction

This master thesis in Industrial Design Engineering at Luleå University of Technology was performed at Gestamp HardTech in Luleå during the spring semester of 2018. Gestamp HardTech is a company that manufactures press-hardened beams for the automotive industry, along with tools used to produce these beams, with offices and production plants all over the world. The Luleå branch delivers products to a wide range of clients in the automotive industry, including Volvo and Scania.

The current thesis project aims to design a concept for a rack-solution meant to be used for in-house logistics. The purpose of this rack is to enable a robot to load and unload the produced beams in order to limit the amount of manual handling used today. The racks are meant to be used for storing and transporting products between the stamping lines and the next machining processes. A large factor concerning automation is that many of the products stick to each other when stored. The rack therefore needs to be designed in a way where the products can be stored without sticking to each other. However, it still needs to fit a considerable portion of the products in relation to the amount that can be stored when inserted manually. The objective is primarily to design rack-solutions that suits a portion of the beams being produced, but the long-term goal is to ultimately use the solutions for automating the loading and unloading of all the products.

1.1 BACKGROUND

The goal for many production sites today is increasing the automatization of the production process. With less manual labor both costs and the margin of error, such as miscounting or approving products with insufficient quality, are meant to decrease. Less manual labor could lead to lower costs in the long run, which in turn leads to the possibility of lowering prices in order to increase a company's competitiveness in the marketplace.

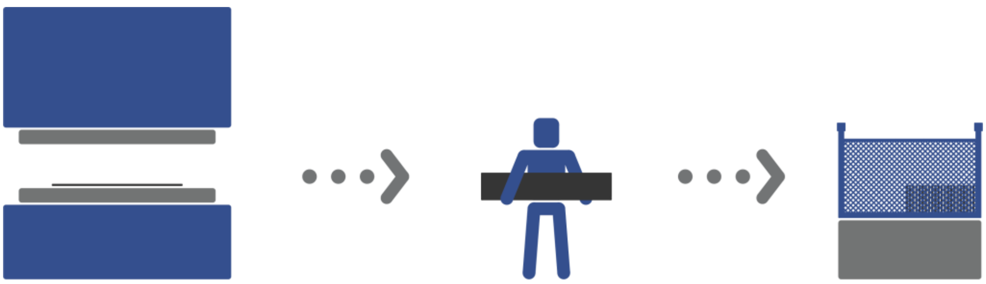

Figure 1. Displaying the manual loading from a stamping-tool into a rack. Illustration: Z. Envall.

At the Gestamp HardTech production plant in Luleå much of the work today is done by hand (see fig. 1). Machine operators load in and out of various machines, often using a standard foldable HardTech-rack, regularly referred to as a HT-rack (see fig. 2). The HT-rack is used to store and transport the products during the production process. These racks come in two sizes, a smaller one which is most commonly used, and a larger one used for larger products.

Figure 2. The most common rack inside Gestamp HardTech Luleå, referred to as a HT-rack. Photo: Z. Envall.

The reason for this project is mainly automatization of the production process. The company believes that the manual handling of products coming out of the stamping lines and going into the laser cutters is unnecessary and obsolete, and that robotic loading of the products is a better and more efficient solution. The problem is that the HT-racks that are used today are not compatible with robotic loading. There is a need for developing a rack that allows this, by providing a uniform placement option that keeps the beams separate from one another. An issue that comes with this is the fact that with designated placement options, the rack is most likely going to hold fewer products than today. The difference in storing capacity between the HT-racks and the robot racks needs to be as small as possible.

The rack development is initially going to focus on all the beams that are produced today, in order to find corresponding features. Eventually a few beams will be selected and used for developing a detailed design, depending on which beams are deemed suitable for the project. The aim is ultimately to use the results from this thesis as a base for eventually developing rack solutions for all the products that are produced at the site. A successful rack-development process requires a solid foundation consisting of a thorough understanding of qualities related to the relevant products. In order to enable for robot interaction with the rack, the limitations for robotics also needs to be studied through benchmarking and theory immersion.

1.2 STAKEHOLDERS

The project's primary stakeholder is Gestamp HardTech Luleå, mainly production manager Magnus Eriksson as the initiating supervisor for the project. Gestamp HardTech will both own and further develop the robot rack concept after the project's completion.

Secondary stakeholders are the machine operators that will be affected by the concept. By switching to robot handling of the produced beams, the work tasks of the machine operators will be altered. A significant decrease in lifting and carrying operations can be predicted, whereby the physical ergonomic situation is also likely to improve.

There is however a risk that a higher level of automatization can lead to less machine operators being needed in the production, possibly resulting in downsizing, which in turn could lead to negative health effects such as stress and increased absence from work, according to studies reviewed by Westgaard and Winkel (2011).

Logistics personnel such as forklift operators will also be affected, being that they are responsible for handling and transporting the racks between the machines. Other affected entities include the facility where the rack is ultimately going to be produced and assembled, and Gestamp HardTech's various clients.

1.3 OBJECTIVE AND AIMS

The project's objective is to provide Gestamp HardTech with a rack concept, which is meant to increase the possibilities for a higher level of automation in the production. As explained by Magnus Eriksson[1], the biggest problem with transitioning into an automated production site is the storage of products between the different machining processes. Having a robot unload beams from the stamping lines into product-specific racks is not much of a challenge, but the problem comes with storing these different racks. Moreover, with a constantly changing product flora new racks would be needed often, and the cost of constantly buying new racks for the added products is unsustainable. The objective of the project is thus to develop a rack concept with a high flexibility for various products that still offers a relatively high packing-grade. This rack is meant to enable robot handling of the produced beams in order to reduce the need for manual handling (see fig. 3).

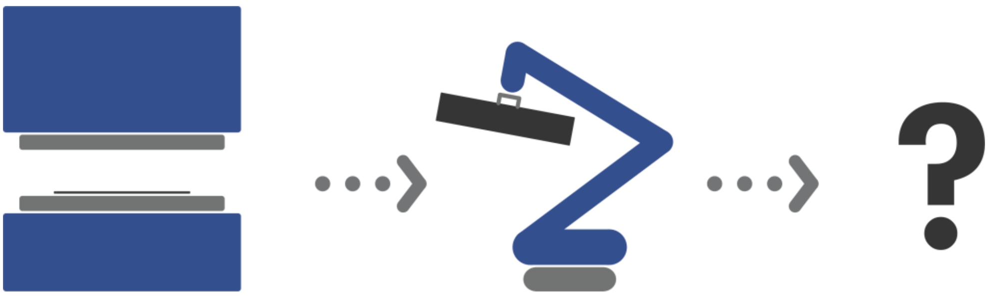

Figure 3. Displaying the project aim of automating the loading/unloading process. Illustration: Z. Envall.

The project aims to contribute to Gestamp HardTech by aiding the automatization of the production process. This contribution is also thought to benefit the machine operators by enabling the possibility for developing a less routine and ergonomically challenging working situation by reducing the amount of manual handling. Automatizing the production process is primarily economically motivated in the sense of lowering the need for human operators, but using robots also opens up more opportunities for increasing quality control by utilizing artificial intelligence to analyze the products. Jobs that are more routine, according to Westgaard and Winkel (2011), increase the risks for various health consequences due to poor ergonomics. Reducing the amount of manual labor could therefore contribute to society by reducing negative health effects such as upper limb musculoskeletal disorders. This is of course a long-term effect, assuming that the project is successful and that the rack,

[1] M. Eriksson, personal communication, December 12, 2017.

or variations thereof, can be used for a larger number of products, possibly even in other factories. By altering the production process at Gestamp HardTech, the project is also likely to contribute to their customers, predictably resulting in reduced costs and increased product quality.

1.4 PROJECT SCOPE

The scope of the project is limited to developing a solution for in-house logistics. The solution is not meant to be used for shipping the products and is therefore not constrained by customer specifications regarding packing. Factors concerning robot functions are going to be designed for but not altered, by programming for example. There is however a possibility that the storage solution could include equipping the robot with various accessories. The project is also focused on developing a rack around a few of the produced products, but should take other products into account by way of not implementing a design that inhibits the storage of these.

1.5 THESIS OUTLINE

The thesis is structured to take the reader from initially understanding the objective and context, to reviewing the theory, then through the developmental process, from early ideas to ending with a final concept, followed by reflections and a discussion concerning the results. The chapters can be described as follows:

1. **Introduction** – The project is introduced.
2. **Context** – Information about the setting for the project.
3. **Theoretical Framework** – The additional theory needed for the project.
4. **Method & Implementation** – How the product development was performed.
5. **Results** – The results achieved through the process.
6. **Discussion** – Reflections about the various phases of the project.
7. **References** – List of all the references used.

2 Context

The Context chapter contains information about the current state at Gestamp HardTech Luleå, along with relevant products and production sites elsewhere in the world. The current state gives insight into the production at HardTech, from coils of sheet metal coming into the plant, to the hardened beams getting shipped to various car manufacturers.

The benchmarking section includes an analysis of various racks being sold and used in other production sites, along with studies of autonomous systems found in different manufacturing plants.

2.1 CURRENT STATE

The production at Gestamp HardTech Luleå mainly rests on their stamping technology. The stamping process hardens the produced beams, increasing their ability for withstanding various forces caused by impact. The stamping presses are coupled with several other types of machining, altogether making the plant a flexible production site that produces many different parts for various top-tier car manufacturers around the world, including clients such as Volvo, BMW, Audi, and Range Rover amongst others. Unlike the fixed nature caused by a production of specific models often found in automotive industry production plants, the flexibility needed at HardTech has resulted in a production site that is made up of several downstream machining areas, between which the different steel beams are transported by forklift-trucks. The downstream processing machining areas consist of a laser-cutting area, an assembly cell area, and a hole-punching area.

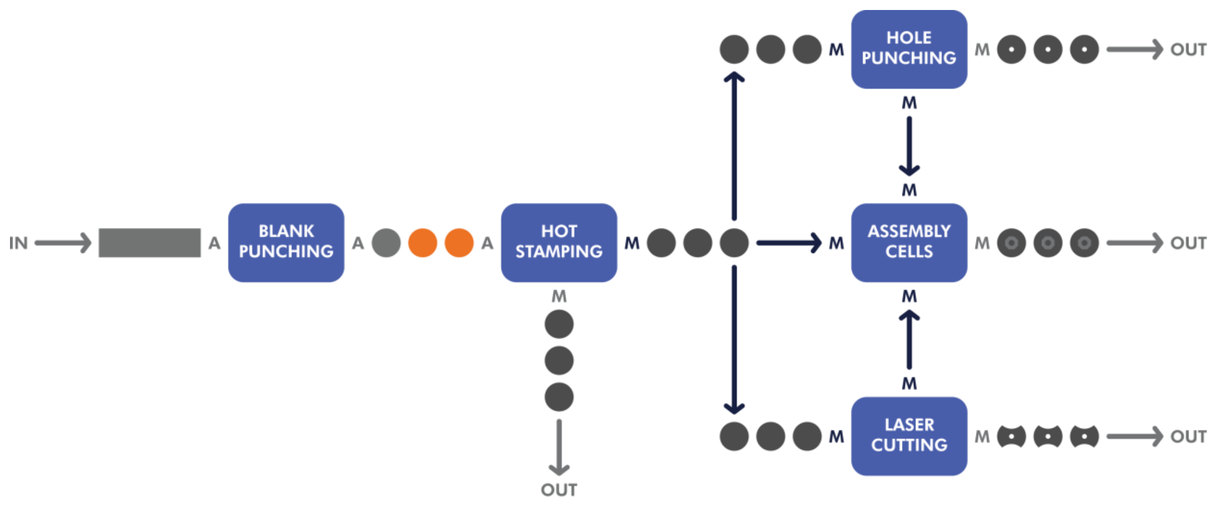

Figure 4. Simplified visualization displaying the production process at Gestamp HardTech Luleå. The letter *A* symbolizes automatic loading/unloading and the letter *M* symbolizes manual loading/unloading. The blue M's represent the manual loading and unloading that is the focus of this project.

The production process, shown in fig. 4, starts out with coils of sheet metal being delivered to the plant. These coils are automatically unwound and cut into the correct shapes, regularly referred to as blanks, in a punching press. After going through the punching press these blanks are automatically placed into what is referred to as a pin pallet, which is used for transporting the blanks to a hot-stamping line. A forklift-truck delivers the pallets to the start of the line, where they are automatically fed into a robot picking area. Robots pick the flat pieces of steel out of the pallet, one at a time, and place them on a conveyor which transports them through a long oven where the beams are heated for a specific period of time. The blanks are then stamped and fed out on a conveyor belt, from which they are loaded into racks by hand. The process following the stamping lines differ for the various products, depending on their design specifications. Some of the products are ready for shipping after the stamping, while others go through hole punching, laser cutting, or are processed in assembly cells before they can be shipped. A few products are both laser cut and put through an assembly cell, alternatively hole punched and put through an assembly cell. The production process for one of the products is displayed in fig. 5.

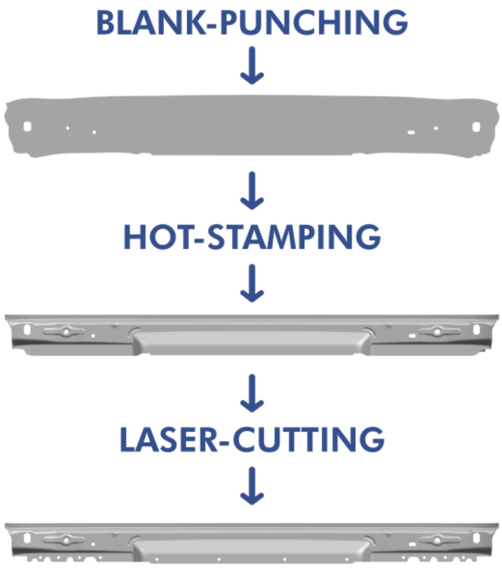

Figure 5. Displaying how the Volvo Trucks Windscreen beam is produced, and what is achieved by each production step.

The racks used at the site depends on a product's destination at any given time. Product-specific pin pallets are used for storing the blanks and transporting them to the stamping lines. Throughout the rest of the production the products are most commonly stored in HT-racks between machining processes, and placed into various customer-specified shipping-racks once they are finished.

2.1.1 HOT-STAMPING

The stamping machines are located at two different sectors of the production plant. Here a flat piece of steel travels through an oven until it reaches a desired temperature and comes out glowing in an orange hue. The heated and softened material is then pressed into the right shape by a stamping tool. Blanks are loaded into the input area by forklift-trucks and placed on ceramic rolls which transport them through the long oven by robots that use grippers equipped with air pressurized suction cups (see fig 6).

Figure 6. Input area for Stamping Line 6. The blanks on the picture are stored in the so-called pin pallets. the Photo: Z. Envall.

After being heated the blanks come out of the oven and are recognized by a vision system. They are then picked up and placed into the stamping die by a robot. Another vision system sits inside the large stamping tool. This system is used to determine if the blank is in the right place for stamping and if it is within the right temperature range. To discern whether the blank has been placed correctly, the vision system camera searches for the top ends of guide pins which are supposed to have passed through various holes on the blanks. The pins appear very dark to the camera in comparison to the piece of heated steel, which appears very bright. If the camera is unable to register these various guide pins, the blank is not stamped and must be discarded. If the material is not at the right temperature, the camera will pick this up as the blank not appearing within the correct range of brightness. The same goes for if two blanks have been placed on top of each other. These would then take longer to cool down, in turn appearing much brighter to the camera than what is allowed.
Once the blanks have been stamped, they are placed on the outgoing conveyor belt by a robot. This belt moves in intervals with operators standing alongside it, analyzing the stamped parts and placing them into racks (see fig. 7).

Figure 7. Outgoing conveyor from Stamping Line 6. Photo: Z. Envall.

2.1.2 HOLE-PUNCHING

The hole-punching area is made up of four robots and one hole-punching machine inside a large cell (see fig 8).

Figure 8. Hole-punching machine and loading station. Photo: Z. Envall.

Incoming parts are loaded onto a conveyor belt by hand, with two operators working simultaneously on each side of the conveyor. The parts are fed to a robot in intervals, two at a time. A vision system first has to recognize the parts, after which a robot picks both the parts up using a double magnet-gripper, placing them on a transfer-fixture. Another robot takes both the parts from the fixture and transports them into the punching machine using a double gripper equipped with clamps. After they have been punched, the parts are moved from the punching die by a third robot, also using a double clamp-gripper, onto a second transfer-fixture. The last robot in line uses clamps to finally transport the two parts from the fixture onto the outgoing conveyor belt where they are packed into racks by the operators.

2.1.3 LASER-CUTTING

The laser-cutting is done in seven enclosed cells, with rotating fixtures that the parts are placed into (see fig. 9). While one part is being cut, the operator removes the finished part from the fixture on the opposite side and loads it with a new part. When the cutting is done the fixtures rotate and the process is repeated. The parts are manually unloaded from incoming racks and loaded into outgoing racks. The racks that are used depend on the parts being produced and whether these are designated for further machining.

Figure 9. Operator waiting for the laser cutting to finish at Laser Cell 10. Photo: Z. Envall.

One of the laser cells combines laser cutting and welding (Laser Cell 11). The part is loaded into the fixture manually in the same way as it is done in the other laser cells, but the finished part is removed from the fixture by a robot and is then taken through additional welding operations and finally placed in an outgoing pallet. This robot uses two different grippers during the process. One for taking the parts through the welding operations and for packing the parts in the output-pallet, and the other is used to fetch and place liners used to separate rows of parts in the pallets which they are unloaded into. The gripper used for part handling has an extra rotation axis, similar to the human wrist joint, in order to enable for sufficient movement throughout the process. The robot is rigidly programmed to follow a number of production steps and finally place the part in the output-pallet, steadily keeping count and adjusting its operations according to the amount of produced parts.

2.1.4 ASSEMBLY CELLS

The assembly cells are located in a different section of the production plant from the laser cells. The assembly cells mainly perform welding operations, fastening objects such as nuts and bolts to the various beams. The process performed in these cells is done by industrial robots, while the loading and unloading is done by hand (see fig. 10). In most of the cells incoming parts are loaded from racks onto conveyor belts in a uniform manner, which transports them into the cells.

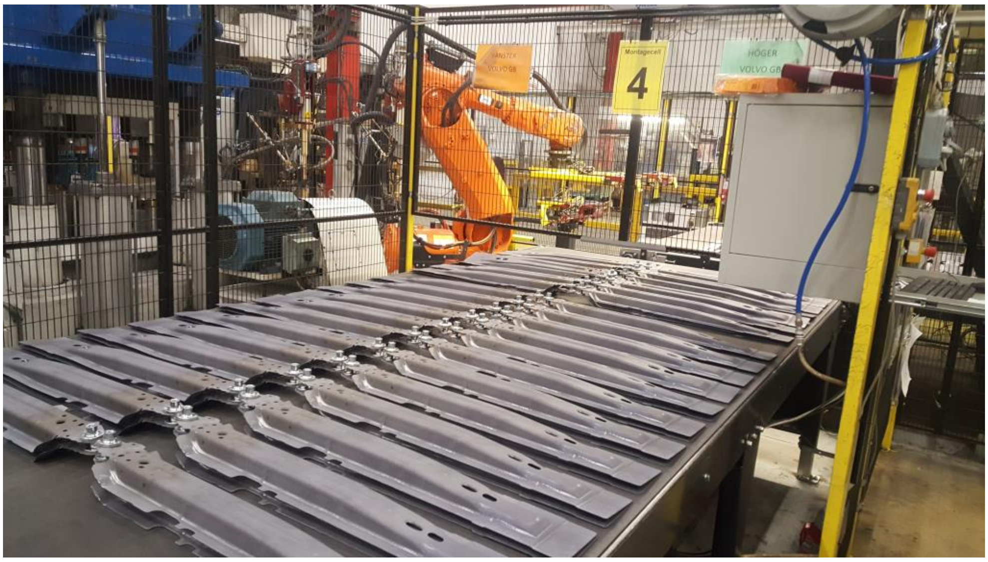

Figure 10. Outgoing conveyor belt from Assembly Cell 4. Photo: Z. Envall.

The conveyor belts move in intervals and stop once the part that is going to be worked on has reached its desired position, which is controlled by a sensor that determines when the parts have reached a certain point. From this point the belt moves for a certain specified period of time, e.g. 300 ms, which places the part in a specified search-area for the vision system used by the robot. The search area should be large enough to allow certain variations in part placement, but not large enough for the robot to identify other closely placed parts. The vision systems consist of cameras which are aided by light tubes that sit directly above the search-area, flooding the scene with light. Contrasts created by the lighting helps the system interpret various features on a part, usually holes, whereby it creates an axis in order to distinguish the part's orientation. The robot is then able to use detachable grippers to pick the part up and move it around the different production steps inside the assembly cell.

The different grippers that are used vary depending on part design and other factors concerning the surroundings, but mainly consist of dowel pins and magnets in the assembly cells. The dowel pins are placed through holes on the parts in order to fixate the grip. Using magnets has the downside of attracting steel dust, but a benefit is that they are good for retrieving parts from flat surfaces. The magnets are controlled by pressurized air, which moves them back and forth in their casings, in order to pick the steel components up and to release them.

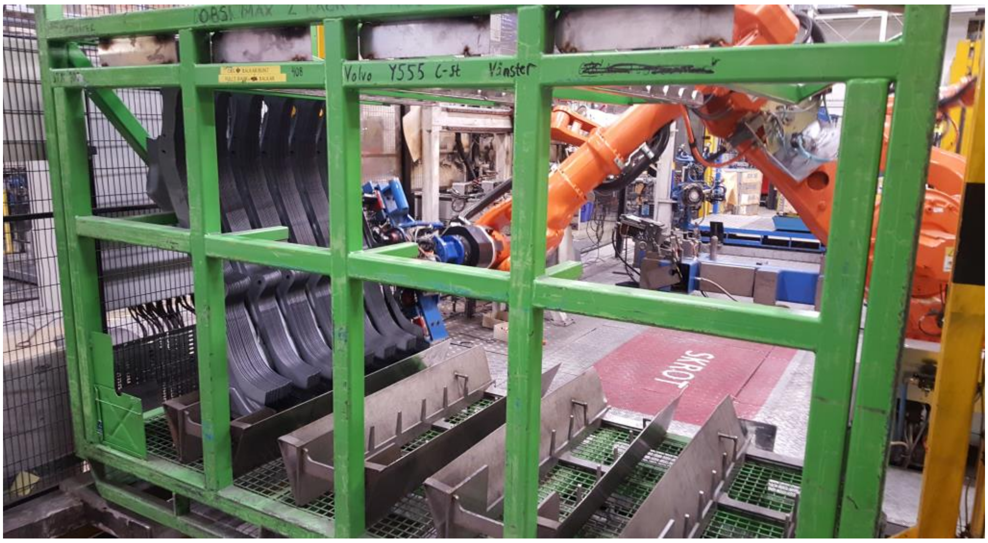

Figure 11. Robotic loading of Y555 C-st (C-pillar) beams into Assembly Cell 1. Photo: Z. Envall.

One of the assembly cells (MC 1) differs slightly from the others, being that the parts are loaded and unloaded by robots directly from and into racks or pallets (see fig. 11). This cell is used to produce two types of C-pillars for Volvo Cars. Both of these C-pillars are hung by their T-shaped bottoms in large racks specifically designed for each of the parts. The robot uses a laser sensor, administering three points on each part in order to interpret their orientation, whereby it is able to attach the gripper to these and take them through the production process. The unloading is done similarly to the way it is done at Laser 11, by placing the components into the output rack or pallet depending on the amount that has previously been produced in the work cycle.

2.1.5 HARDTECH RACKS

While the racks most widely used at Gestamp HardTech Luleå are the HT-racks, some other racks and pallets can be seen in the production (see fig. 12). These include longer HT-racks, pin pallets, product-specific racks, and various racks used for shipping the products to the respective customers.

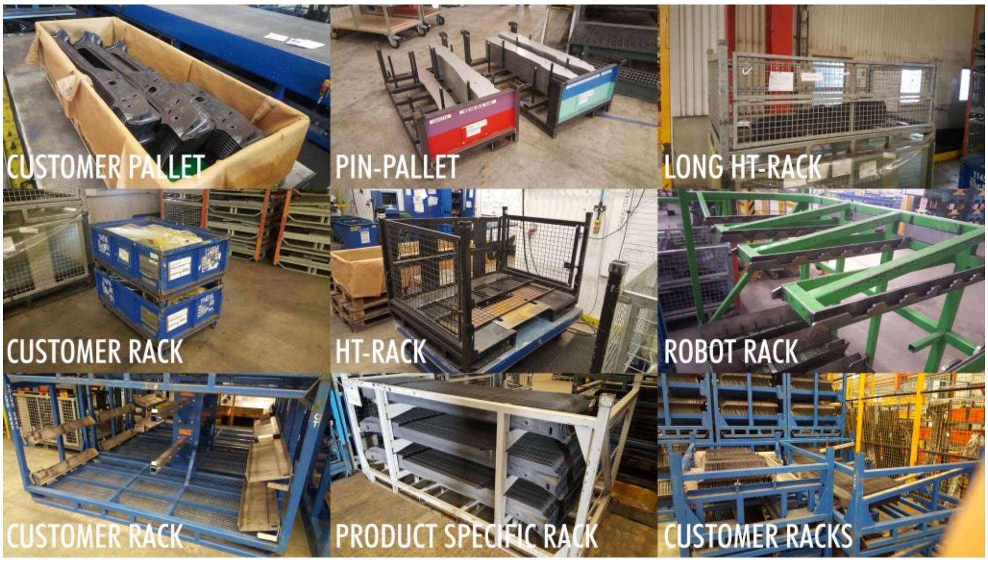

Figure 12. A variation of the racks that can be seen in the production. Photo: Z. Envall.

The racks in fig. 10 include customer racks and pallets used for shipping products to Scania (photo 1), Audi (photo 4), and Volvo (photos 7 and 9), as well as a blanks-rack (photo 2), a Volvo Trucks Windscreen rack (photo 8), a Y555 C-st robot rack (photo 6), a long HT-rack (photo 3), and a standard HT-rack (photo 5).

2.2 BENCHMARKING

The benchmarking showed a wide variety of racks being sold and used in the automotive industry. Many rack manufacturers display their standard racks along with some examples of various racks that have been designed to suit different purposes according to specified customer needs.

Automated racking solutions and various ways of dealing with the challenges brought on by automation were also found, mainly in articles but also by watching videos from various production sites. Automated production was further researched close hand through a field study at Scania Oskarshamn.

2.2.1 RACKS

The material reviewed in the benchmarking shows countless variation of racks being used and sold across the world. These can essentially be separated into standard racks and modified racks. Standard racks, such as the HT-racks being used at Gestamp HardTech Luleå, provide no specific placement-options and can be used for storing various objects of different shapes and sizes. The modified racks use some sort of additional feature to ease the loading, unloading, or storage of objects.

The material mainly consisted of various racks being used and sold in the automotive industry. The most common solution for storing various parts, mainly sheet metal stampings, that was observed is by using slots (see “Slot Fixtures” in fig. 13). These slots come in various shapes and sizes, with various frequencies, and allow the produced parts to be placed uniformly into a rack. Slot-solutions can come in different materials, mostly with a lower density than the metal racks they are attached to, such as plastic or rubber. Parts such as car doors and side panels are also hung on smooth horizontal fixtures (see “Smooth Fixtures” in fig. 13), but the slot-solutions seem to be preferred.

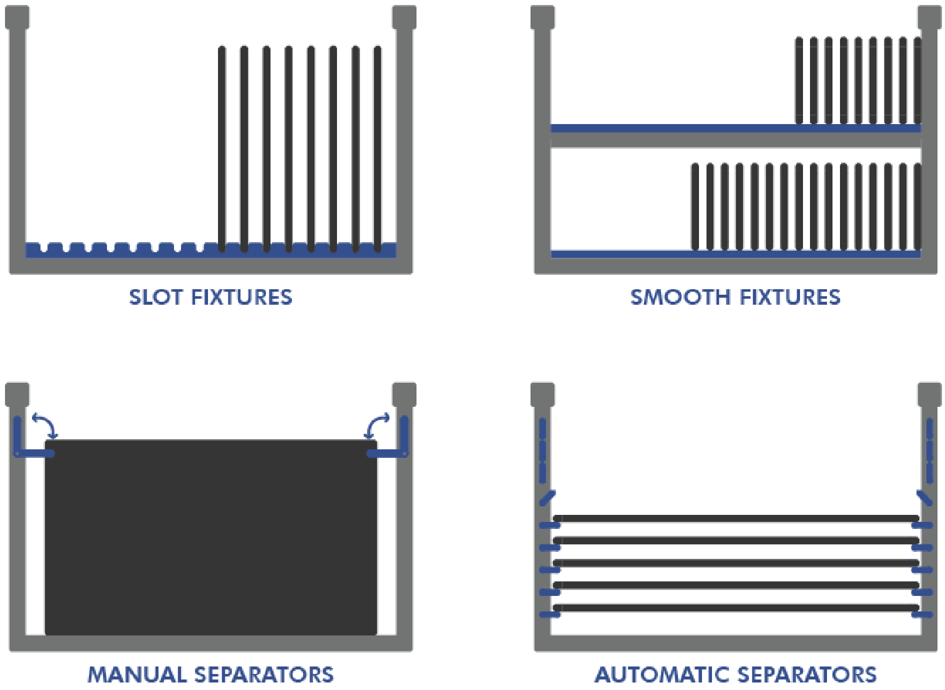

Figure 13. The 4 general types of racks identified in the benchmarking. Illustration: Z. Envall.

There are other solutions which keep the produced parts separate from each other similarly to the slots, but with designs that differ. These designs can be large metal tubes between which parts are placed, as well as various lever mechanisms that rotate into position, either automatically or manually. The manual versions (see “Manual Separators” in fig. 13) are often utilized for separating objects such as windscreens, but can also be observed keeping stamped metal parts separate from one another. The automatic versions (see “Automatic Separators” in fig. 13) explained in fig. 14 use small separators which can assume three different positions. They are initially vertical, hidden inside a housing, unable to interfere with the parts. When a part is placed on a separator it rotates out 90 degrees, carrying the part on one end, while its rear, inside the housing, is pushed up into the rear of the next separator, causing it to rotate out halfway. When a part is placed on the next separator it too rotates out to a full 90 degrees, causing the next separator in line to rotate out halfway. This chain reaction keeps occurring until all the available separators are rotated out and the rack is full.

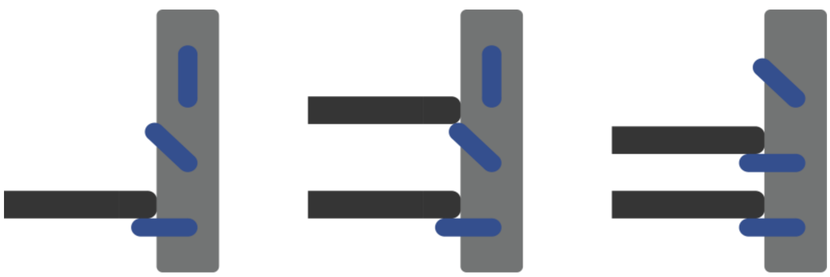

Figure 14. The mechanism used by the "Automatic Separators". Illustration: Z. Envall.

The modified racks come in several other variations and are often built for specific parts. Although some can collapse in order to increase storage capacity for empty racks, most of the modified racks seem to be fixed. Only a few can be observed being used for robot racking, and these all utilize slot-solutions.

2.2.2 AUTOMATED RACKING

Factories that utilize automated racking seems to be somewhat of a common occurrence. It is a practice that is most likely only going to grow in usage and popularity. Different instances of automated racking have been observed throughout the benchmarking, dating back to as far as 1998. Most of these are explained to work by using vision sensors, and all of them use product-specific racks, often having much empty space between the parts. Videos of robots racking parts in Toyota, Hyundai, Mazda, and Skoda factories have been observed, and other robot racking practices described in articles and observed on a field study are detailed below.

FORD I

Pierce (2008) describes an instance of Ford Manufacturing Company using automation to rack and de-rack stampings, in Buffalo, NY. With the goal of fully automating the stamping plant's sub-assembly lines, this factory utilizes both vision guided robotics as well as automated guide vehicles (AGVs) working in tandem. At more than half of the automated production cells, vision systems are used to recognize racks and stampings, while AGVs transport racks to and from the robots. The single-camera 3D-vision systems are said to be most important for capturing the rack locations, being that the AGVs are unable to stop in the exact same position every time. The rack re-design needed for the robot retrofitting of the factory is said to have been minor, with the vision system easily recognizing and adapting to variations. By having the single vision-system camera mounted to the robot, calibration is explained to be needed with lower frequency, as well as being much easier than for fixed multiple-camera systems. One of the types of racks used for robot racking at the Ford Manufacturing Company in Buffalo is shown to use metal slot-solutions to store the stampings (Pierce, 2008).

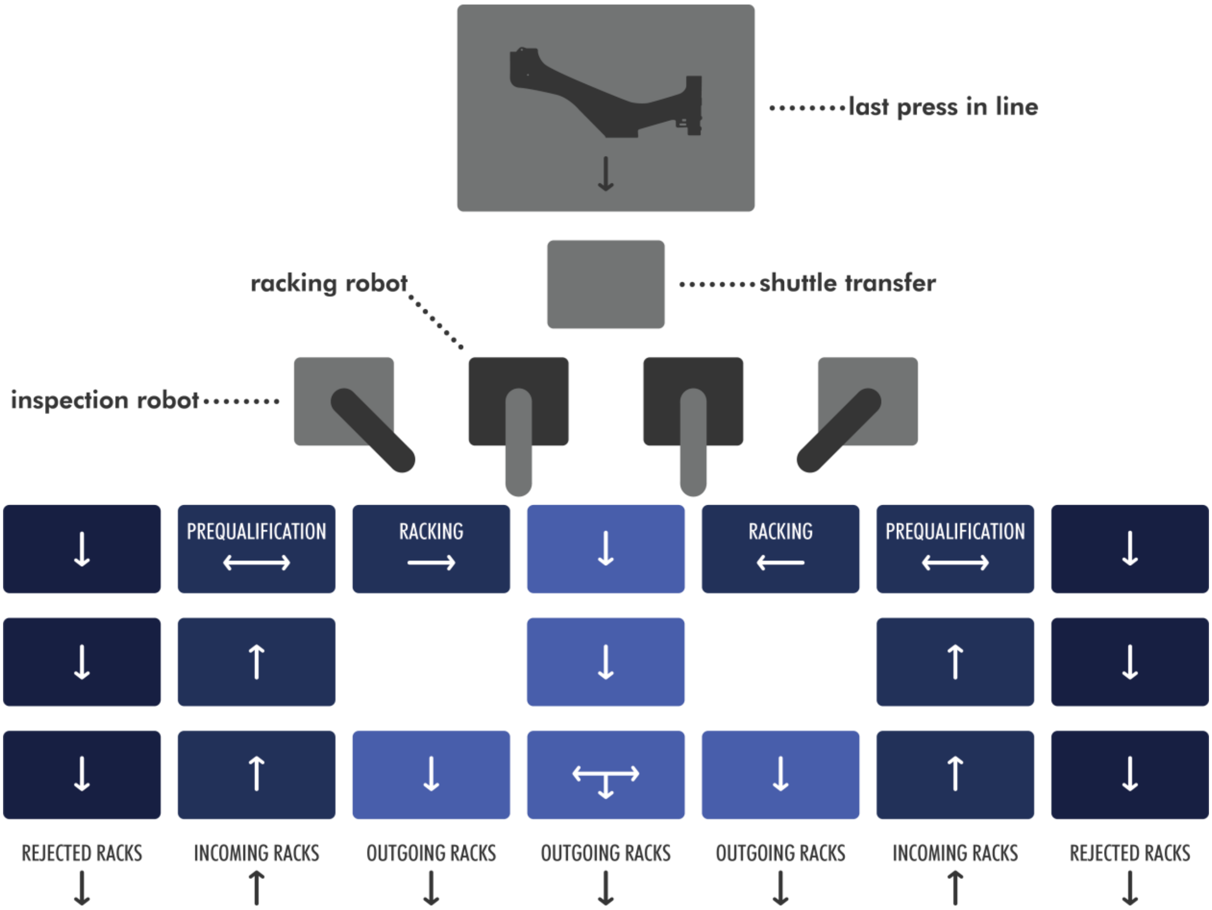

Figure 15. An automated racking system observed by Mitchell (1998) at the Ford Motor Company facilities. Illustration: Z. Envall.

FORD II

Mitchell (1998) describes another automated racking system that can be observed at the Ford Motor Company facilities, visualized in fig. 15. The parts are manufactured along a press line and transported by robots between the presses. Robots are also used for unloading from shuttle transfers into racks at the end of the press line. To achieve high-speed production runs four robots are used for racking the parts; two for loading and two for prequalifying the racks. Six-axis robots are used to prequalify the empty racks, rejecting those that do not meet the correct criteria. The rejected racks are sent back out for manual inspection, while the accepted racks are passed along for loading. The robots utilize a bar code scanner and vision systems to first identify the rack type as well as the specific rack by a serial number. Thereafter the robot checks predetermined points on the rack and compares these to standard parameters stored in a database. If the rack is pristine or if it is found to be altered or damaged within certain tolerances the rack is passed on to the loading robot, which receives an updated electronic image of the rack in order to load it in accordance to possible alterations. The rejected racks are passed back out off-line for repair, for which the system generates a report describing where the rack deviates from the set parameters (Mitchell, 1998).

SVIA

Perks (2006) examines a vision system developed by SVIA (Svensk Industriautomation AB) called Pick-Vision. These systems combine vision technology with ABB robots resulting in what the author calls "future proof" and flexible automation lines. By using recycling conveyor systems to feed components between loading and unloading, and having the vision system determining the position of these components, the need for a fixed pick-up position is eliminated. SVIA uses high frequency 150W light tubes placed above the picking area to combat ambient light sources, having the vision system search for various geometric features in the parts.

The system uses a 1-megapixel industrial camera with 30 to 40 ms processing speed and only needs a standard industrial computer system. Having a user-friendly interface is said to be the main goal of the system, eliminating problems stemming from knowledge deficiencies. A step-by-step wizard style approach is said to have a first-time programmer soon using the system to pick parts, while more advanced users will benefit from additional options, in turn being able to increase the system's overall efficiency. Teaching the vision system to detect a new part is said to take less than 15 minutes and is done by placing the part under the camera and going through the user-friendly step-by-step process. SVIA has systems for picking small as well as large parts randomly fed to the robot. However, parts that are too large or too complex in shape need to be manually positioned on a conveyor belt and fed to the robot (Perks, 2006).

SCANIA

In the outskirts of a small city called Oskarshamn, truck-cabin production facilities for Scania Trucks can be found. The production plant is divided into five factories. The first one is a press shop that produces metal stampings. These metal stampings along with other metal parts provided by various sub-suppliers are joined together in the second factory, mainly through welding, ultimately making up the truck-cabin body. The third and fourth factories are paint shops. One is responsible for laying the base paint and in the other one the final paint coating is applied. The fifth and last factory in the process consists of an assembly line where the truck-cabin is assembled and finalized. Together with robot specialist Jörgen Boman three of these factories were analyzed: The press shop, welding shop, and assembly plant.

The press shop can be likened to the Gestamp HardTech Luleå plant and consists of a press line where sheet-metal coils are automatically unwound, punched, stamped, and lastly loaded into racks. Ceiling-mounted robots make this process possible, both transferring the metal parts between the presses as well as fetching the finished parts off a conveyor belt and loading them into racks. The racking is done by three robots which are explained to each have two available racks for loading parts into. When one of the racks is full the robot starts loading into the other rack while a forklift-truck exchanges the full rack for an empty one. A vision system is used for locating the parts on the conveyor belt, consisting of ceiling mounted cameras accompanied by light tubes flooding the scene with light. The end-effectors being used for racking utilize pneumatic suction cups to grip the stampings. A large area of approximately 100 m^2 beside the press line is used to store the different types of end-effectors that are not presently being used.

The welding shop, built in 2014, is almost entirely automated. It can be explained as consisting of several robotic assembly cells where various parts are welded together into subassemblies. These subassemblies are then in turn welded together with other subassemblies, finally making up the whole truck-cabin body. The cells consist of robots that de-rack the parts and robots that take the parts through different welding operations. The general practice is that the racking robots places parts in a fixture that uses gravity to allow the part to fall into place, similarly to the way it is done at Gestamp HardTech Luleå. By doing this the part is always presented to the next robot in the exact same manner. The robots inside the welding shop do not use machine vision for localizing the parts inside the racks, but instead utilize a combination of laser and tactile sensors. Laser beams are used to determine when a part is within a certain distance, where after the robot slows down and moves toward the part until a tactile sensor signals that a part can be gripped. This type of sensor combination is said to be reliable as long as the parts are placed correctly in their respective racks. The end-effectors used to grip the various parts were explained to use both pneumatic suction cups together with magnets, in order to avoid parts slipping from the robot's grip. Four types of automated racking solutions can be observed supplying the assembly cells with parts.

The parts produced in the press shop are supplied to the robots in racks, which either use slot solutions, automated separators, or a combination of the two. In most of the racks the parts are placed laterally in rows, but in some they are stacked vertically. Built-in dynamic mechanical fixtures keep the parts in place during transport and different types of lever mechanisms are used to open and close these fixtures. Some of the lever mechanisms are operated by robots and others by the forklift-truck drivers. The part of the fixtures touching the metal stampings mostly consist of solid plastic, but some have plastic brush-like designs. The racks are supplied to the robots inside the assembly cells through rack-cages, which have fine tolerances and specific placement options. Solid fixtures inside these cages hold all of a rack's corners in place, and there are also holes on opposite corners of the bottom of the rack which are placed on large guide pins, fixing the rack's position additionally. All of the racks have individual QR-codes by which they can be specifically identified. The racks are also color coded, with components touching the metal parts such as slots and fixture surfaces often orange, movable parts such as the dynamic fixture mechanisms yellow, and an off-white base paint for the rest of the rack. These colors, especially yellow and the off-white, is used in a similar manner throughout the entire factory.

Parts that arrive to the factory from various suppliers do not use the same racks as the Scania-produced parts and are therefore manually unloaded from their respective transport racks or pallets into rack-solutions incorporated with the assembly cells. These rack-solutions mostly consist of separate single rows of parts that can be moved in and out of the cells and are often loaded vertically using automatic separators to keep the parts apart.

Two other less common variations of this rack-solution can be seen in the factory. One where parts such as B-pillars are hung on conveyors that transport them into an assembly cell, and one that leans down into the cell, where smaller parts are fed to the robot through gravity.

3 Theoretical Framework

The theory that was reviewed for the project, displayed in fig. 16, is centered around robotics, with an additional focus on machine vision systems.

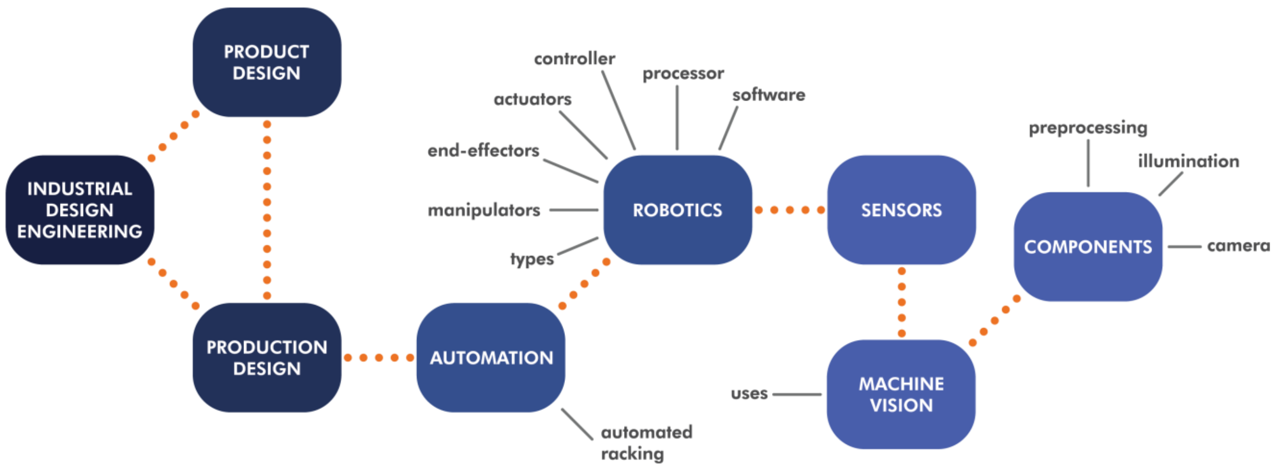

Figure 16. Theory Mapping displaying the reviewed theory. Illustration: Z. Envall.

As a master thesis in Industrial Design Engineering the theory originates from Industrial Design Engineering and is based on the knowledge gained throughout the education. With the goal of ultimately developing a product it is a Product Design project, based in a production environment, therefore also touching on the subject of Production Design.

The product design is set in the context of robotics and automation, which places it inside the field of production design. The theory also contains further exploration into the fields of robotic sensors, focusing on machine vision systems and the components included in these systems.

3.1 INDUSTRIAL DESIGN ENGINEERING

Industrial Design Engineering can be described as the combination of the industrial design and engineering design practices, located on the border between the two (Wikberg Nilsson & Törlind, 2016). Smets and Overbeeke (1994) locate the field similarly, describing it as being comprised of both design engineering and design aesthetics, requiring a high degree of technical and technological knowledge.

Industrial design is a term that is defined as design regarding the visual appearance of three-dimensional machine-made products according to Merriam Webster (n.d.). Dorst and Cross (2001) describe industrial design as searching for integrated solutions to complex multidisciplinary problems. The before mentioned integration is explained to include ergonomic, construction, engineering, aesthetic and business aspects, giving the discipline a somewhat broader description than Merriam Webster (Dorst & Cross 2001). According to Cuffaro et al. (2013) an integral difference between design and fine arts is that design often deals with products meant for "make more than one"-production, while artworks are often singularly produced.

Pahl and Beitz (2013) describe engineering design as finding solutions to technical problems and optimizing these solutions according to constraints and requirements posed by material, technological, economic, legal, environmental, and human-related factors. Design as an engineering activity is said to provide the fundamentals for the physical realization of ideas while being scientifically based, building upon special experience, and having the possibility to affect almost all areas of human life (Pahl & Beitz, 2013).

This thesis relates to Industrial Design Engineering by having a goal that entails finding a solution to a multidisciplinary problem, matching the description of industrial design offered by Dorst and Cross (2001), touching on various aspects such as robotics, construction, business and production. By stemming from a technical problem and requiring a scientific base along with special experience the project also falls under the definition of engineering design as described by Pahl and Beitz (2013). The thesis thus combines the fields of industrial design and design engineering, which corresponds to Wikberg Nilsson's et al. (2016) definition of Industrial Design Engineering.

3.2 PRODUCTION DESIGN

Bellgran and Säfsten (2010) describe production development as a concept that deals with the creation of efficient production processes and the development of productional capabilities. Production development is said to include both the design of new production systems as well as improving existing systems. The authors also state that focusing on the area of production is now more important than ever for manufacturing companies in the western world (Bellgran & Säfsten, 2010).

Outsourcing industrial production to low-wage countries has been a growing trend over the past decades (Bellgran & Säfsten, 2010). Blanchet, Rinn, Von Thaden, and De Thieulloy (2014) cite statistics showing that 40% of worldwide production is performed in emerging countries, which is a share that has doubled over the past two decades. Western Europe's manufacturing value added has instead dropped from 36% to 25% (Blanchet, et al., 2014). However, Bellgran and Säfsten (2010) claim that the possible advantages of outsourcing have lately been questioned. The main concern that is raised relates to losing the ability of producing products. The authors claim that the chain connecting product development, industrialization, and production is important, and that if one link is missing all links are likely to suffer (Bellgran & Säfsten, 2010).

3.3 PRODUCT DESIGN

Product Design is a discipline that according to Milton and Rodgers (2011) includes the areas lighting, furniture, graphic, fashion, interaction, and industrial design. Milton and Rodgers (2011) state that one of the central aspects of product design is about improving the quality of life for the users. Product design is also explained to be a commercial activity highly intertwined with businesses (Milton & Rodgers, 2011). Cuffaro et al. (2013) echo this sentiment, claiming that design was conceived to meet a business need or serve a business purpose. They go on to explain by stating that design is about helping businesses attain a market advantage and increased profits by attracting consumers (Cuffaro et al., 2013). Milton and Rodgers (2011) sum product design up as making things better, for customers, businesses and the world. The term 'product' is explained to be a word used very widely to describe what is referred to as 'everything' (Milton & Rodgers, 2011). Milton and Rodgers (2011) however go on to classify various types of products:

- **Consumer products –** Such as cars, domestic appliances, and furniture.
- **One-off artistic works –** Artistic products not meant for mass production
- **Consumables –** Such as motor oil, bottled water, and newspapers
- **Bulk or continuous engineering products –** Such as foils, rods, and laminates
- **Industry products –** Such as bearings, motors, and circuit boards
- **Industrial equipment products –** Such as machine tools, goods vehicles, and work-stations
- **Special purpose products –** Such as jigs, fixtures, and special purpose robotics machinery
- **Industrial plant –** Industrial equipment products and devices

Wikberg Nilsson, Ericson and Törlind (2015) use the word product to describe the result of a design process, giving the term product a broad definition including physical objects, systems, environments, services, processes, and methods as examples of products.

Cuffaro et al. (2013) states that product development in the industrial design sense is rarely based on a common and concise source of information. The necessary information for designing details is often found in the depths of various sources.

3.4 AUTOMATION

According to Bellgran and Säfsten (2010), the term automation is often defined as mechanical, electronic, and computer-based systems that perform, inspect, and control various operations in a production. Depending on the degree of human involvement, production operations can be divided into three levels: manual, semi-automatic, and automatic (Bellgran & Säfsten, 2010). Popovic (2000) states that the progress in automation systems used in production plants has followed the evolution of instrumentation and computer technology.

What many are calling "Industry 4.0" is described by Blanchet et al. (2014) as the predicted results of a fourth industrial revolution. This revolution will lead to a higher level of IT-connectivity within industries, with complex IT-systems built around machines, storage systems, and supplies, turning them into "cyber-physical systems". The results of this are explained as including more efficiency in production systems, allowing production processes to be changed at short notice with minimal downtimes (Blanchet et al., 2014). Rüßmann, Lorenz, Gerbert, Waldner, Justus, Engel, and Harnisch (2015) describe what they refer to as the nine technological advancements that will form the foundation for Industry 4.0. These are said to consist of data and analytics, autonomous robots, simulations, horizontal and vertical system integration, the "Industrial Internet of Things", cyber security, cloud technology, additive manufacturing, and augmented reality.

The previous industrial revolution is explained to have accelerated the level of electronic automation, and according to Blanchet et al. (2014) included the initial shift from manual labor to robotics. This change is predicted to propagate further in the fourth revolution, resulting in more complex tasks being done by robots, along with humans and robots working hand in hand through smart human-machine interfaces. The widening use of robots is even going to enable remote control of the workflow according to these authors (Blanchet et al., 2014). Rüßmann et al. (2015) state that the advancement in automation is going to result in robots being more autonomous, flexible and cooperative, also predicting that humans and robots will work side-by-side. Lasi, Fettke, Kemper, Feld and Hoffman (2014) explain these "smart factories" as having manufacturing completely equipped with sensors, actors, and autonomous systems.

Industry 4.0 is explained to be a way for Europe to increase its market share, regaining what was lost in the deindustrialization that has been occurring over the past two decades (Blanchet et al., 2014).

3.5 ROBOTICS

With the aim of combining high quality, productivity, and adaptability at minimal cost, industrial robots are considered as "*the cornerstone of competitive manufacturing*" according to Hägele, Nilsson, and Pires (2008, p. 963). More than 60% of the over 1 million industrial robots reportedly being used in 2007 were performing tasks in the automotive industry (Hägele et al., 2008). Corke (2012) defines a robot as a machine that is goal-oriented which can plan, sense, and act. 'Sense' is described as an answer to the questions 'where am I?' and 'where are you?'. Manufacturing educators SME (2018) define industrial robots as "multi-functional manipulators designed to move materials, parts, tools, or specialized devices through various programmed motions". Hunt (1983) first offers a broad definition, implying that robots are designed to resemble humans in form and function. Similarly to SME, he then goes on to state that *"an industrial robot is a programmable multifunctional device designed to both manipulate and transport parts, tools, or specialized manufacturing implements through variable programmed paths for the performance of specific manufacturing tasks"* (Hunt, 1983, p. 22).

A robotic system is explained to consist of seven central components: A manipulator, an end effector, actuators, a controller, a processor, software, and sensors. A robot is said to be characterized by its payload, reach, precision and repeatability. The payload defines the amount of weight a robot can carry, and the reach determines a robot's maximum dexterity within its work envelope. Its precision is defined by the robot's accuracy in reaching a specific point, and its repeatability characterizes how well the robot can repeatedly move with accurate precision (Niku, 2011).

3.5.1 MANIPULATOR

The manipulator is the main body of the robot, consisting of links, joints, and other structural elements (Niku, 2011). Siciliano, Sciavicco, Villani, and Oriolo (2010) also define a manipulator as being made up of rigid links interconnected by mobilizing joints, subdividing the manipulator into a mobile arm, a dexterous wrist, and also the end effector used for performing a required task. A manipulator usually consists of an open kinematic chain, defined as having one sequence of links connecting the two ends of the chain, while a closed kinematic chain instead forms a loop. The joints are explained to each add one degree of freedom (DOF) to an open kinematic chain, being either prismatic or revolute. Prismatic joints allow for translational motion between two links, while revolute joints allow links to move rotationally in relation to one another. The number of DOF determine a robot's ability to move freely through three-dimensional space, and six DOF are generally required for this (Siciliano et al., 2010). Many of the industrial robots used today in Gestamp HardTech Luleå as well as other factories are six axes robots (see fig. 17), allowing movement within six degrees of freedom (RobotWorx, 2018).

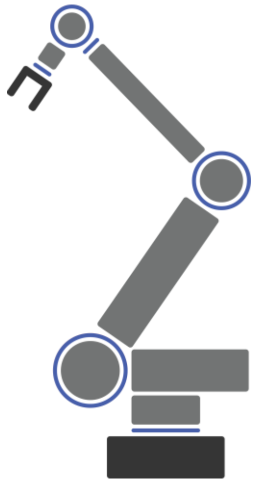

Figure 17. . Generalization of a six-axis robot, with the axes displayed in blue. Illustration: Z. Envall.

Siciliano et al. (2010) state that manipulators can be classified as either Cartesian, cylindrical, spherical, SCARA, or anthropomorphic depending on the type and sequence of the arm's DOFs. Cartesian manipulators have three prismatic joints, often positioned orthogonally in relation to each other. While providing good mechanical stiffness and accuracy, Cartesian geometry lacks in dexterity. If the first joint is switched from prismatic to revolute, the manipulator is instead classified as cylindrical. Cylindrical structures also offer good mechanical stiffness, decreasing wrist positioning accuracy while increasing the horizontal stroke. If the second joint is also switched to a revolute joint, the geometry of the manipulator is defined as spherical. This lowers the mechanical stiffness along with the wrist positioning accuracy but increases the radial stroke. SCARA geometry uses two revolute joints along with one prismatic joint, with all the joints having parallel axes of motion. SCARA manipulators have a high level of stiffness for vertical loads but lack in wrist positioning accuracy. Anthropomorphic manipulators have three revolute joints, with the first joint being orthogonal to the other two, which in turn are parallel to one another. Providing motion possibilities similar to the human arm, the second and third joints on anthropomorphic arms are often referred to as the shoulder and elbow. Anthropomorphic manipulators have the highest level of dexterity, but the wrist positioning accuracy is decreased (Siciliano et al., 2010).

Siciliano et al. (2010) cite a 2005 report issued by the International Federation of Robotics stating which types of geometries are used for robots internationally. 59% of the manipulators are said to be anthropomorphic, 20% Cartesian, 12% cylindrical, and 8% using SCARA geometry.

3.5.2 END-EFFECTOR

The end-effector, essentially the robot's "hand", is connected to the robot's last joint, and is used to perform the required tasks, such as manipulating objects and making connections to other machines, according to Niku (2011). Typical examples of end-effectors include welding torches, paint spray guns, glue laying devices, and part handlers (Niku, 2011). Siciliano et al. (2010) add mills, drills, and screwdrivers to the list. In most industrial object manipulation applications, typical grippers are used as end-effectors, according to Siciliano et al. (2010). Niku (2011) states that robot manufacturers generally supply only a simple gripper, leaving end-effector design and manufacturing to other entities. End-effectors are usually designed by either a company's engineers or outside consultants to be used for specific purposes. (Niku, 2011). Siciliano et al. (2010) also point to the end-effector often being designed to suit a specific task.

3.5.3 ACTUATORS

The actuators can be viewed as the "muscles" of a manipulator, moving its links and joints according to signals received from the controller. Examples of actuators include servomotors and stepper motors, along with pneumatic and hydraulic actuators (Niku, 2011). Siciliano et al. (2010) describe actuating systems as being comprised of a power supply, a power amplifier, a motor, and a transmission.

Siciliano et al. (2010) state that the power supply is the system's primary power supplier, providing power to the amplifier. The amplifier then modulates the power flow to the motor according to signals from the controller. The motor's job is to activate the joints in order to produce the desired movement. Depending on the type of input power, Siciliano et al. (2010) divide motors into three groups:

- *Pneumatic motors* – Powered by pneumatic energy supplied by a compressor.
- *Hydraulic motors* – Powered by hydraulic energy from a reservoir.
- *Electric motors* – Powered by electric energy provided by an electric distribution system.

Pneumatic energy is usually in the form of compressed air transmitted through flexible tubes, according to Coiffet and Chirouze (1983). Hydraulically powered systems most often use mineral oils of varying viscosity, providing a good power-to-weight ratio but also introducing several problematic factors. Electrical energy is easily available, non-polluting, and can be transmitted through cables. The downside is in the electrical system's power-to-weight ratio, being lower than both the other types of power supplies (Coiffet & Chirouze, 1983). According to Siciliano, et al. (2010) electric servomotors are most commonly used in robotics applications.

Siciliano et al. (2010) explain that joint motion in manipulators require low speeds and high torques. Servomotors are said to typically provide high speeds and low torques, in turn requiring a transmission. Transmissions come in different variations, and which type to use depends on the power requirements, the desired motion, and the motor location (Siciliano et al., 2010).

3.5.4 CONTROLLER

The controller can be likened to the human cerebellum, controlling the different motions performed by the actuators. Receiving its data from the processor, the controller tells the robot how to move, and gets feedback from sensors monitoring the various joints (Niku, 2011). The principal control task, according to Taylor and Kleeman (2006), is to accurately, rapidly, and repeatably move the end-effector through the desired motions. Siciliano et al. (2010) explains this as the controller signaling the amplifier the amount of power needed to perform a certain movement. Craig (2005) classifies control of the manipulator as being either linear or nonlinear. Linear-control techniques are used for systems that can be modeled mathematically by linear differential equations. Linear control is however said to be approximate methods when it comes to manipulator control, and although the dynamics of a manipulator are bettered represented by nonlinear differential equations, the linear methods are more commonly used in the current industrial practice (Craig, 2005).

3.5.5 PROCESSOR & SOFTWARE

The processor is in turn viewed as the "brain" of the robot, calculating its motions and overseeing the controller and the sensors. The processor normally consists of a computer and is sometimes integrated with the system's controller (Niku, 2011).

The system's software can be divided into three groups. The first is the operating system that operates the processor. The second is robotic software used to calculate how the joints need to move in order to perform the required tasks. The third consists of application-oriented routines and programs which determine the tasks that need to be performed (Niku, 2011).

3.5.6 SENSORS

Sensors are used to provide the robot with information, either regarding its internal state or its surroundings. Similar to the human senses, different sensors are used depending on what information the robot needs to perform certain tasks in a safe and efficient manner (Niku, 2011).

Christensen and Hager (2008) explain two ways of classifying sensors, either into passive and active sensors, differentiating the two by if they emit some kind of energy into the environment or not, or proprioceptive and exteroceptive sensors, which either measure factors concerning the internal robot body or the external environment. Proprioceptive sensors are usually passive, measuring physical factors concerning robot function such as velocity, acceleration, joint position, and motor torque amongst others. Various sensors and their classifications are shown in table 1.

The exteroceptive sensors can be further divided into contact and non-contact sensors. Sensors frequently used in robotics are claimed to be tactile sensors, haptic sensors, motor/axis sensors, heading sensors, beacon-based sensors, ranging sensors, speed/motion sensors, and identification sensors (Christensen & Hager, 2008).

According to the forum Robot Platform (2018) many hundreds of different sensors exist today, made to sense virtually anything. They list light sensors, sound sensors, temperature sensors, contact sensors, proximity sensors, distance sensors, pressure sensors, tilt sensors, positioning sensors, acceleration sensors, among many others.

Table 1. Various sensor categories. The objective is either exteroceptive (EC) or prorioceptive (PC). The method is either passive (P), active (A), or a combination of the two (P/A). Illustration: Z. Envall.

CLASSIFICATION	SENSOR TYPE	OBJECTIVE	METHOD
TACTILE SENSORS	SWITCHERS/BUMPERS	EC	P
	OPTICAL BARRIERS	EC	A
	PROXIMITY	EC	P/A
HAPTIC SENSORS	CONTACT ARRAYS	EC	P
	FORCE/TORQUE	PC/EC	P
	RESISTIVE	EC	P
MOTOR/AXIS SENSORS	BRUSH ENCODERS	PC	P
	POTENTIOMETERS	PC	P
	RESOLVERS	PC	A
	OPTICAL ENCODERS	PC	A
	MAGNETIC ENCODERS	PC	A
	INDUCTIVE ENCODERS	PC	A
	CAPACITY ENCODERS	EC	A
HEADING SENSORS	COMPASS	EC	P
	GYROSCOPES	PC	P
	INCLINOMETERS	EC	P/A
BEACON BASED SENSORS	GPS	EC	A
	ACTIVE OPTICAL	EC	A
	RF BEACONS	EC	A
	ULTRASOUND BEACONS	EC	A
	REFLECTIVE BEACONS	EC	A
RANGING SENSORS	CAPACITIVE SENSORS	EC	P
	MAGNETIC SENSORS	EC	P/A
	CAMERA	EC	P/A
	SONAR	EC	A
	LASER RANGE	EC	A
	STRUCTURES LIGHT	EC	A
SPEED/MOTION SENSORS	DOPPLER RADAR	EC	A
	DOPPLER SOUND	EC	A
	CAMERA	EC	P
	ACCELEROMETER	EC	P
IDENTIFICATION SENSORS	CAMERA	EC	P
	RFID	EC	A
	LASER RANGING	EC	A
	RADAR	EC	A
	ULTRASOUND	EC	A
	SOUND	EC	P

3.5.7 ROBOT TYPES

Mitchell (1998) discusses the robot types used for part transfer in metal pressing applications, listing robotic shuttle devices, swing-arm robots, and pendulum-arm robots. Robotic shuttle systems are made up of three parts: Two press-mounted robots and one floor-mounted part transfer shuttle. The robots are usually mounted inversely to the press and can have two to six axes of motion. Swing-arm robots are described to consist of a six-axis articulated-arm robot that is mounted to a supporting swing-arm seventh axis. The robot moves the parts being produced by swinging back and forth between two presses. Normally mounted to a slide or track, the swing-arm robots consist of fewer units than the robotic shuttle systems and are said to increase flexibility and equipment reliability. The pendulum-arm robot typically consists of four axes, moving in a pendulum-motion between the presses. The pendulum-motion allows for a very long reach, and the robot can be mounted to the side of the presses, reducing the need for repositioning during die changes (Mitchell, 1998).

3.5.8 AUTOMATED RACKING

Declaring that the idea of automated parts racking is not especially new, Mitchell (1998) explains the obstacles that are often encountered as being due to costly rack designs, fleet management factors, and a lack of flexibility. However, it is stated that the combination of flexible robots, vision systems, and a creative process development has resulted in feasible automated racking solutions. Many of the more advanced solutions are said to use specially-designed and positively-located racks implementing sophisticated and costly dunnage system designs.

By using vision technology and adaptive motion control, racking systems have the capability of producing a minimum of 500 parts per hour, supporting up to 14 different parts, all while using simple racks and dunnage solutions. The main needs for these rack- or dunnage-solutions are enabling the robot to locate the parts, and preventing damage during storage and transport (Mitchell, 1998).

3.6 MACHINE VISION SYSTEMS

Taylor and Kleeman (2006, p. 3) state that "*robot vision explores how visual information can be to drive interactions with the world, by linking perception to action*". Perks (2006) points to the fact that although this technology is not especially new, the advancement in computer power over the last decades has enabled these systems to be used much more proficiently.

Hunt (1983) explains machine vision as a computer interpreting brightness variations in a visual image by analyzing an array of pixels. Taylor and Kleeman (2006) describe an image as a quantized two-dimensional signal provided by sampling the intensity and frequency of light on the image plane. These samples are formed by capturing light particles over a brief period of time on a 2D sensor array, such as a charge coupled device (CCD). The term pixel is used to describe one element of the array. The process of capturing an image can be described as a transformation between the three-dimensional Euclidian space and the two-dimensional space of the image plane (Taylor & Kleeman, 2006). Perks (2006) states that many shortcomings of vision systems often have to do more with poor implementations due to a lack of knowledge, rather than faults concerning the system itself.

Perks (2006) defines vision systems as being comprised of a camera and a microprocessor or computer, along with some sort of associated software. According to Thörnberg (2013) the key components of a machine vision system consist of a camera and some means of illumination. The illumination is used to increase the visual properties of the captured images. The observed 3-dimensional scene is illuminated, whereby the reflected light passes through the camera lens and strikes the surface of a pixel sensor (Thörnberg, 2013). According to Siciliano, et al. (2010) this photosensitive sensor transforms the light energy into electric energy and is usually a CCD (charge coupled device) or CMOS (complementary metal-oxide-semiconductor) sensor. A CCD sensor is made up of a rectangular array of photosites and transforms the energy through a photoelectric effect caused by photons striking a semiconductor surface. CMOS sensors are instead made up of a rectangular array of photodiodes that discharge when hit by photons. The main difference between the two is that the CCD sensors measure volume while CMOS sensors measure throughput. By measuring throughput CMOS sensors never allow saturated pixels to overflow, which can happen with CCD sensors, causing an effect known as "blooming" (Siciliano et al., 2010).

3.6.1 CAMERA

Siciliano et al. (2010) describe a camera as a complex system mainly consisting of a shutter, a lens, a photosensitive sensor, and analog preprocessing electronics. The light reflected from an object passes through the shutter, is focused by the lens, and registered by the sensor in order to then be processed and converted into electric energy, visualized in fig. 18 (Siciliano et al., 2010). Beyerer, Puente León, and Frese (2016) describe this electric energy as analog, usually in the form of electric voltage.
According to Perks (2006), the camera used in vision systems can be anything from standard compact camera systems with integrated vision, to laser sensors and high speed high resolution cameras. Combining several cameras to build 3D images is also a possibility, which enables a robot to pick randomly placed components out of a container, often referred to as "bin picking" (Perks, 2006).

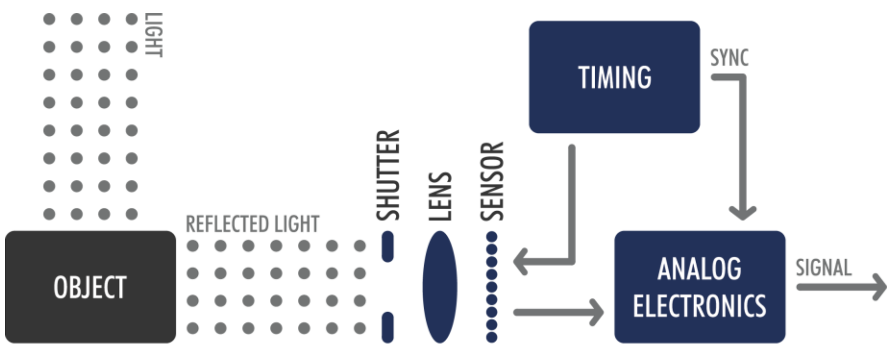

Figure 18. Generalized visualization of a camera's function. Illustration: Z. Envall.

Industrial camera manufacturer Basler AG (2015) categorizes the cameras being used in vision systems into two types, either an area scan or line scan version. The line scan camera has one single line sensor and records the scene line by line. This is suited for objects that are moved along a conveyor belt for example. The area scan camera has a large area sensor and can record large areas simultaneously. This also works on conveyer belts, although there is a risk of motion blur if the object is moving rapidly

(Basler AG, 2015). Robotics and automation instructor Peter Dettmer (2013a) goes further, explaining this phenomenon as the balance between conveyor belt speed and the camera's shutter speed. The longer the shutter is open, the more detailed an image will be, but if the photographed object is moving, a slower shutter speed will lead to an increased motion blur. He states that the way this problem is often tackled today is by using a fast shutter speed and a high intensity light source, capturing as much light as possible in an as short time frame as possible.

The resolution requirements for the cameras being used in industrial vision systems is much lower than what is available on the camera-market resolution-wise. The reason for this is that higher resolution images take longer time to process, and the component features used for interpretation by the system are often adequately captured by lower resolution cameras (Dettmer, 2013a).

Dettmer (2013a) stresses the importance of camera set-up, explaining the layout as being a balance between the field of view, standoff distance, CCD width, and focal length. He recommends initial testing on a stationary prototype set-up before implementing the camera, but also provides an equation for calculating the set-up, stating that the quotient of the focal length divided by the CCD width should equal the quotient of the standoff distance divided by the field of view.

3.6.2 ILLUMINATION

Perks (2006) states that ambient light caused by for example windows or skylights is a common problem for vision systems. Dettmer (2013a) states that 70% of a successful vision system set-up is driven by the lighting arrangements. Advanced Illumination Sales and Support Manager Daryl Martin (2012) describes lighting as a critical aspect in utilizing vision technology successfully.

Martin (2012) explains illumination techniques as comprised of bright-field (partial), dark-field, backlight or diffuse lighting (full bright-field) solutions (see fig. 19).

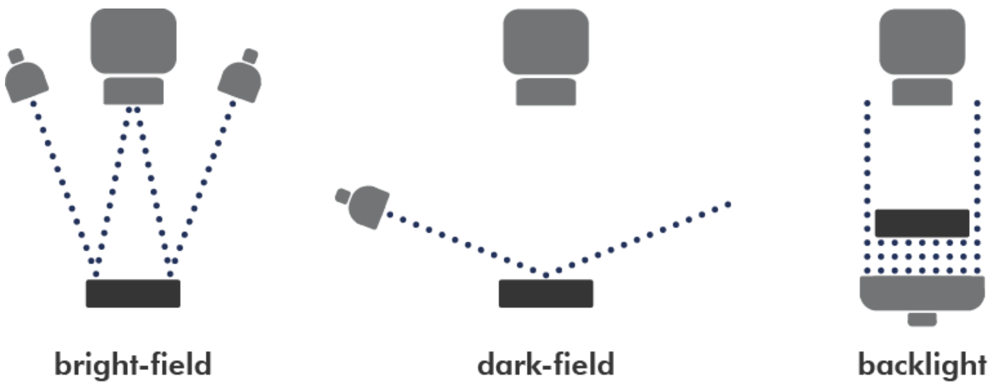

Figure 19. Generalized visualization of different lighting techniques. Illustration: Z. Envall.

Partial bright-field is stated to be the most common lighting solution in vision systems. This type of lighting is directional, usually from a point source, and is used to achieve contrasts and to enhance the topographic detail (Martin, 2012). According to Dettmer (2013a) bright-field illumination often consists of a light right around the camera pointing straight down, and is a good way of providing an object with a high level of illumination. Martin (2012) however states that bright-field solutions can cause trouble when specular surfaces are examined, being that a "hotspot" reflection is easily generated. According to Dettmer (2013a) a specular reflection comes from positioning a direct light source at a certain angle from the object, causing the reflected light to travel directly into the camera lens.

Martin (2012) uses car lights as an example to explain dark field lighting. By having the lights positioned close to the ground a contrast between small surface inconsistencies is created. Dettmer (2013a) states that placing a light source in the dark-field area aids in identifying for example irregular surfaces on a flat object. Martin (2012) compares reflections from a mirror caused by bright field and dark field lighting. The bright field lighting results in a glossy reflection while the dark field lighting is reflected only by a small scratch on the mirror's surface.

By resulting in a dark silhouette against a bright background, a backlight technique is described to be useful for hole-detection, measuring, and part orientation (Martin 2012). Using a backlight solution means that the object is going to block a certain amount of the light, resulting in aiding the identification of an object's outlines (Dettmer, 2013a). A common backlighting approach, as described by Mersch (1986), is place fluorescent light tubes inside a box with an open top, covering the top of the box with translucent Plexiglas. By putting a part on the Plexiglas, the lighting will cause a large contrast between the part and the background, resulting in a clear silhouette view.

Martin (2012) claims that diffuse lighting is most commonly used on shiny specular parts as well as parts with mixed reflectivity. 3 commonly used implementations are described: Dome diffuse, axial diffuse, and flat diffuse. Dome diffuse lights are effective for lighting curved and specular surfaces, often found in the car industry for example. In axial diffuse lighting, the specular glare is used to define various flat features on a part. An example of this is detecting damages on the top sealing surfaces of a plastic bottles (Martin, 2012). The implementation described as flat diffuse is explained by Dettmer (2013a) as flooding an object with light from above, causing the reflected light to diffuse out in all directions.

According to Basler AG (2015), when using a monochrome camera to identify objects of a certain color, the color of the light source should match the color of the object. For example, the light source for identifying red objects should be red. The reason for this is that out of the objects being inspected the red objects reflect the red light the best, making them appear very bright to a monochrome camera, in comparison to other colored objects which absorb more of the red light, making them appear darker. Dettmer (2013b) however points out that when the robot needs to identify for example red object from a differently colored background, a green light should be used. This is explained by the fact that by using complementary colors to illuminate the objects being examined, the contrast increases, and the object becomes much clearer in relation to the background. Another way of dealing with differently colored objects is by using band pass filters, blocking out certain wavelengths and thus making certain colors appear brighter and increasing the desired contrasts.

3.6.3 PREPROCESSING

Machine vision systems are computer systems that according to Beyerer, Puente León, and Frese (2016) interpret image data through a number of computational steps, shown in fig. 20.

Figure 20. The computational steps performed in vision system preprocessing, with the results from each step displayed in grey. Illustration: Z. Envall

The electrical signal produced by the captured light is discretized and limited regarding space and amplitude. The raw data usually contains various levels of disturbances such as noise and inhomogeneities. The goal of the following restoration process is to retain the relevant data by compensating for various disturbances. This improved image data is separated into different regions in the segmentation step, after which the different parameters relevant to the task are extracted. Based on this condensed information decisions can be made. These include things such as detection, classification, and interpretation. Depending on the decision made, an action can finally be taken (Beyerer et al., 2016).

Beyerer et al. (2016) stresses the importance of the image acquisition step. If the captured image lacks in quality, fixing this by the subsequent processing steps is said to be difficult or even impossible, depending on the requirements. Much effort should therefore be spent on designing the image acquisition setup regarding things such as light sources, test objects, optics, and sensors.

Thörnberg (2013) describes the computational steps involved in machine vision systems as including image acquisition, preprocessing, segmentation, labeling, feature extraction, and classification. Dettmer (2013a) explains the computational process similarly, but reduces the steps to include capturing an image, transferring the image data, preprocessing, measurement processing, and outputting the results. Coiffet and Chirouze (1983) offer the description of a vision system being comprised of: signal emitting, signal reception, signal conversion, image preprocessing, image representation, and recognition.

3.6.4 MACHINE VISION USES

Dettmer (2013a) cites inspecting quality and amounts, along with measuring dimensions and determining positions as the major uses of vision systems. When it comes to robotics, error proofing and inspecting a component's location and orientation are said to be the main ways in which vision systems are used. Improvements that can be achieved by using a vision system are stated as a reduction in human error, an increased throughput, improved product quality, and increased safety (Dettmer, 2013a).

4 Method and Implementation

This chapter describes the methods used in this master thesis project and includes the initial project planning, a context description in the form of an analysis of the current state at Gestamp HardTech Luleå, followed by benchmarking studies analyzing relevant information from different places around the world. It furthermore gives an insight into how the design process was performed, consisting of the phases Conceive, Design, Implement, and Operate. The chapter concedes with a method discussion, where the entire process is lastly reflected upon.

4.1 PROCESS

This project can essentially be viewed as a traditional product development project, differing by the fact that the user who the design is normally centered on is replaced by a robot. By viewing the project as a traditional product development project, the design process was structured as a traditional stage-gate process with 4 stages. The structure is based on the process described as CDIO by The CDIO™ Initiative (2018) as well as the similar Engineering Design Process described by Michael J. French in 1985 (Dubberly, 2004).

CDIO is an acronym, with the different letters representing each of the 4 stages: Conceive, Design, Implement and Operate. The CDIO™ Initiative (2018) describe the 4 stages as (C) finding the needs, (D) creating the design, (I) the transformation of the design into the product, and (O) using the implemented product to deliver the intended value. Dubberly (2004) describes the Engineering Design Process as having a structure similar to CDIO, starting off with an analysis of the problem, followed by conceptual design, embodiment of schemes, and lastly detailing. In this process the various gates are also defined, along with continuous assessment.

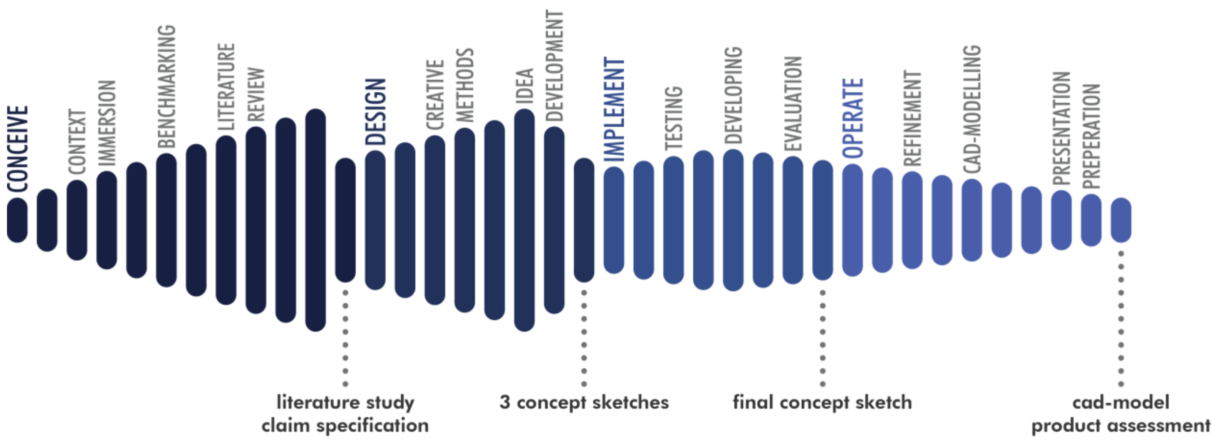

Figure 21. Visualization of the process, including the content of the stages and the various deliverables required at each gate. Illustration: Z. Envall.

The stages in this project were planned and structured according to the specific requirements needed for reaching the envisioned objectives. The process is visualized in fig. 21. The plan was to start with a Conceive phase assessing the problem and reviewing the required theory. With a thorough understanding of the context and the robot-user, it was then planned to resume through a Design phase focused on solving the problem, then enter an Implementation phase including further development, prototyping, and testing. The Operate phase was planned to be centered on supplying the final deliverables.

4.2 PROJECT PLANNING

The project was planned by estimating what needed to be done in order to ultimately reach the desired results. This was done by analyzing the current situation, defining the scope of the project, assessing the resources, designing the process, and managing the time required for each of the stages. The planning in the form of a Gantt-chart is displayed in fig. 22.

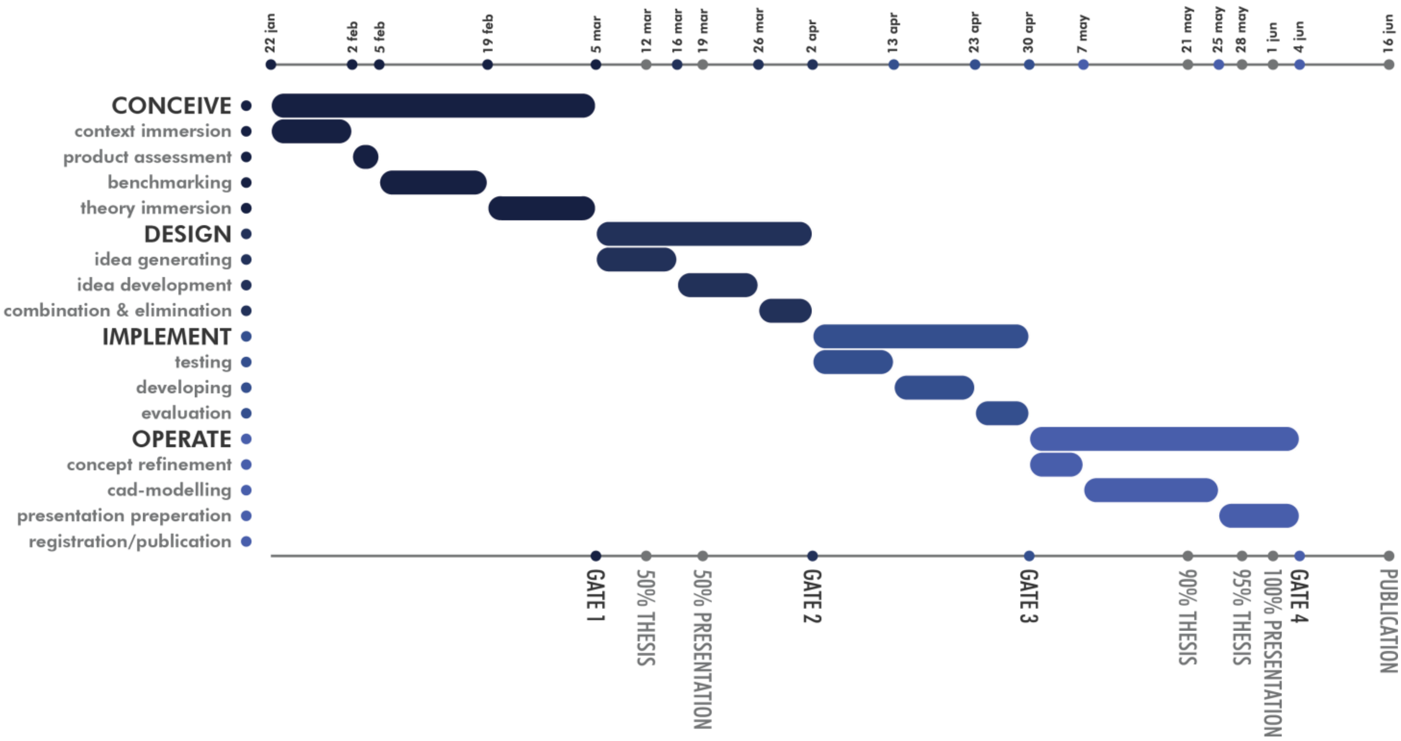

Figure 22. The project planning in the form of a Gantt-chart. Illustration: Z. Envall.

The current situation was analyzed by examining the production and by reviewing the information supplied by the Gestamp HardTech supervisor as well as other Gestamp HardTech personnel. This information was acquired both literary and verbally. Defining the project scope mainly consisted of understanding the objective and assessing the time limitations. By reviewing what resources were available the process could be designed, and the various time restrictions could be defined.

4.3 CONTEXT IMMERSION

The context of this project consists of three main parts: Examining the Gestamp HardTech Luleå production site, examining automated production in general, and assessing the various products produced at Gestamp HardTech Luleå. The analysis of the HardTech production site in Luleå consisted of examining the entire production, as well as immersing into automation solutions, robotics, and machine vision. Various other automated production solutions were examined both by reviewing articles and production videos, as well as performing a field study at the Scania production facilities in Oskarshamn.

4.3.1 CURRENT STATE

Understanding the production at Gestamp HardTech Luleå is a wide task, and the aim was therefore to focus on aspects central to this project. Prior working experiences at the production plant summing up to thousands of hours provided a good foundational view of the current situation. This was added to by several field studies inside the factory guided by knowledgeable personnel, each focusing on different aspects of the production. Walk-throughs with two different staff members at Gestamp HardTech were centered around material handling, Magnus Eriksson explained various specifics, and technician David Hedlund provided detailed information concerning robotics and the machine vision systems in use, both through a field study and an interview.

The first walk-through with a Gestamp HardTech process engineer provided a more comprehensive overview of the production, and the different automated systems presently being used in the plant were described and analyzed. The goal of the second walk-through with a Gestamp HardTech production technician was mainly to find full racks of all the various products to photograph and take notes concerning packing and amounts. The production flow was also discussed, along with other theoretical implications of more lean production flows and what these would mean for the racks needed.

The specifics analyzed with Magnus Eriksson were mainly focused on the so called "Newton Tables" used in some of the assembly cells (see fig. 23), which enable the robot to grip each part in the same way. The functionality of different motors used to power both the robots and the conveyor belts was also explained.

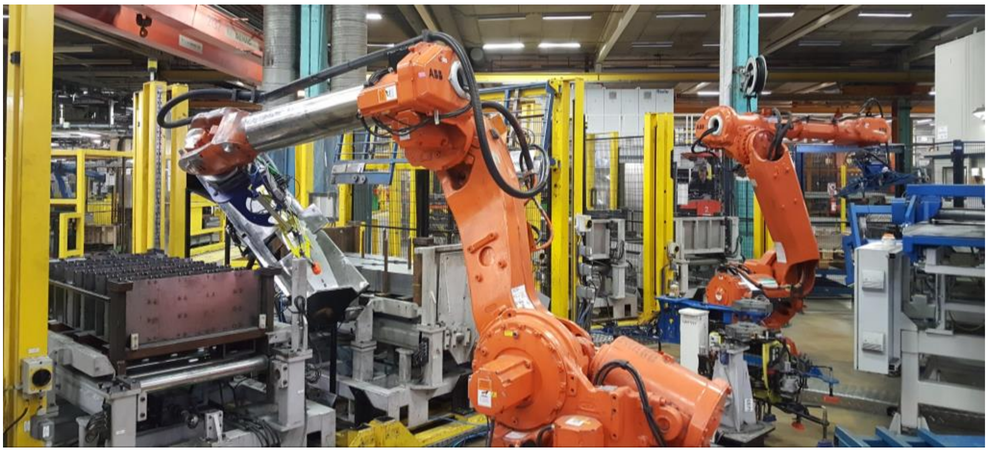

Figure 23. Robot picking a blank off the so called "Newton Table". Photo: Z. Envall.

Together with David Hedlund a vision system in one of the assembly cells (MC4) was analyzed. He explained details concerning how the system works, along with various details relevant to the system's functionality. Further discussion with David provided more in-depth information concerning robotics and vision systems both at HardTech and in general.

The production site was further observed numerous times without guidance, focusing on general aspects of the production as well as various parameters concerning the products and product handling.

4.3.2 BENCHMARKING

Other production sites were examined both online, through articles and videos, as well as offline in the form of a field study at Scania Oskarshamn. The online immersion mainly consisted of reviewing YouTube videos displaying the production at various production sites, primarily in the car industry. The videos were watched at a speed of 1.5 and paused whenever racks or relevant types of automation was showed. Some stills from the video review are displayed in fig. 24.

Figure 24. Different racking solutions observed in other production sites. Photo: Z. Envall

The field study at Scania Oskarshamn lasted for approximately four hours and consisted of a walk-through with robot specialist Jörgen Boman. The production sites that were reviewed were a press shop, weld shop, and an assembly line. The largest focus was put on the weld shop, both because Jörgen Boman had been involved in designing the production, but also because it had the most automation solutions out of the three sites. The press shop was also highly relevant due to its likeness to the production at Gestamp HardTech Luleå, but it could only be observed standing still, being that it was down for maintenance for the day. The assembly line was reviewed briefly, also focusing on different types of automation. After the three sites had been observed, the weld shop was revisited in order to secure that nothing was missed during the visit.

A couple of articles about automated solutions used in similar production sites were also found by searching for terms combining the words “robot”, “automated”, “racks”, “racking”, “stamping”, and “automotive” in various ways on Google and Google Scholar.

4.3.3 PRODUCT ASSESSMENT

The goal of developing a flexible rack solution suitable for an as large number of the products as possible calls for thorough knowledge of the products. During work at the production plant prior to the project, all the beams relevant to the project had been personally loaded or unloaded at some stage of the production process at least a couple of times within the years 2016-2018.

The initial assessment of the products started with determining and listing which products were relevant to design for. Some of the products presently being produced were going to be moved to other production sites, so these were removed from the list. Pictures of the various products in the correct production steps were then traced in Adobe Illustrator to aid the assessment. Different parameters deemed relevant to robot racking were afterwards decided, by which the various products were compared. The initial comparisons searched for characteristics that could be used to categorize the different products, and was also done in Adobe Illustrator by using the previously traced products (see fig. 25).

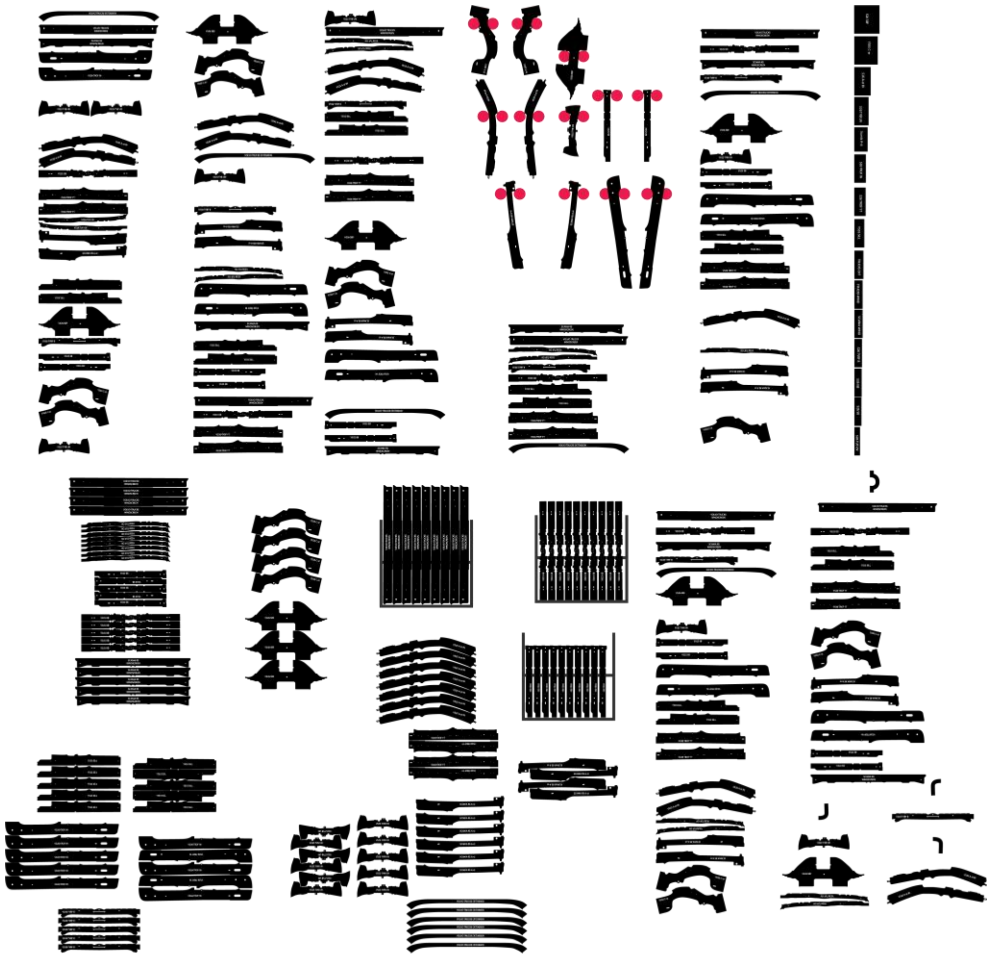

Figure 25. Various comparisons of the beams done in Adobe Illustrator. Illustration by Z. Envall.

In order to compare such a large and diverse set of data two types of matrix-methods were used. The two methods were based on the structures Quality Function Deployment (MIT OpenCourseWare, 2012) and Design Structure Matrix (Yassine & Braha, 2012). The process of assessing the products continued further and ultimately took the form of an Excel chart. This chart included 15 products which were analyzed by reviewing:

- The number of products per rack coming from the stamping lines
- The type of rack that was used for each product
- The number of rows/columns per rack
- Whether the rack's short sides were used or not
- What was used to separate the rows/columns
- The main angles of each product's two long edges
- How each product's short edges are bent
- The length, width, and height of each product
- Whether each product's shape is symmetric or not
- Which production steps each product goes through
- Which stamping line each product is produced in
- The number of holes each product has
- Whether a product is hangable, and if it is due to its shape, holes, or both

The answers to the different questions were attained by observing the production site, reviewing the CAD drawings, and by consulting with staff at Gestamp HardTech. The resulting values in the Excel chart were color coded to ease the overview and interpretation of the results. The parameters concerning the various products' shapes were analyzed through a simplification of their shapes in order to aid categorization, mainly focusing on the different edges. This was done by reviewing CAD-drawings of the various products in the correct production step, and sketching copies of these in order to fully understand the shapes.

The specific beams used for the product assessment shifted somewhat during the process due to new information being received regarding continued production plans and also due to decisions that were made according to knowledge gained regarding the different product's production processes and existing storage solutions. As the final stage in the product assessment various beam characteristics deemed relevant were classified into eight categories.

4.4 LITERATURE REVIEW

Being that the main parts of the theory, robotics and machine vision, were almost completely new subjects, the theory gathering had to start from the basics. The theory was initially collected primarily by watching introductory lectures from different schools into the subjects of robotics and machine vision on YouTube. Once a somewhat general foundation had been achieved, further literature was reviewed focusing on qualitative data based on the literature review method described by Milton and Rodgers (2013). This method consists of formulating research questions, collecting data, evaluating the data, analyzing the data, and finally presenting the review. The research questions were formulated as follows:

- *How does machine vision work?*
- *What are the limitations for machine vision?*
- *What constitutes a robot, and how do they work?*
- *What robots are used in industrial production settings?*
- *What are the robot's needs concerning the rack design?*
- *What materials can be used for designing the rack and its accessories?*

The collecting of data was pursued by using the Google, Google Scholar, and LIBRIS search engines. Since a lot of the desired data was of a somewhat more basic nature, LIBRIS turned out to be favorable. Many textbooks and handbooks on robotics and machine vision were reviewed, and evaluated by the number of citations, the

publisher, and the year of publication. Some articles were also found, mainly concerning machine vision and lighting, these were evaluated in the same way as the books. The search terms used to retrieve the data about robotics included "introduction robotics", "robotics handbook", "robots", and "automation". Some of the concepts concerning robotics needed to be researched further and were thereby also included in the searches, such as "robotics controller", "robotics software", and "robotics actuators". Machine vision was researched by using search terms such as "introduction vision", "machine vision", "robot vision", "vision guided robotics". The data collected about machine vision called for a further investigation of the concept of lighting and different lighting techniques. These were researched by searching for "lighting robotics", "lighting techniques", "lighting methods", "lighting camera", along with specific techniques such as "bright field lighting", "dark field lighting" and so on. In order to try to retrieve newer data on robotics, a concept called "industry 4.0" was also researched by searching for the term "industry 4.0".
The collected data was further evaluated and analyzed by how well it corresponded to data from other sources about the same subject, and the data deemed to lack relevance to the thesis were discarded. The data was finally presented in a categorized manner, based around robotics and then branching out to include sensors, with one of these being machine vision.

4.5 DESIGN

Because of the wide range of products being designed for, the design phase had a broad focus centered on developing different ways of separating generic beams from one another. These generic beams were simplified representations of the various Gestamp HardTech Luleå products, see fig. 26.

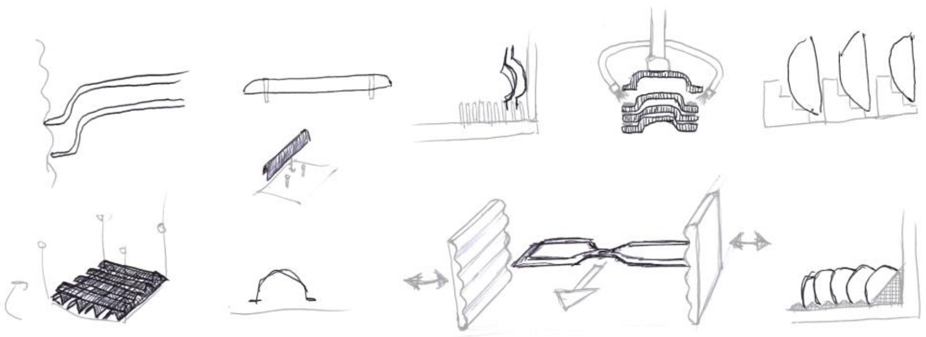

Figure 26. Examples of the various "generic beams" that were designed for. Illustration: Z. Envall.

The early creative work was fueled by inspiration acquired from the Conceive phase, including ideas brought on by the theory and context immersion as well as ideas provided by the supervisors Magnus Eriksson and Peter Törlind along with other Gestamp HardTech employees. Once the inspiration started to run dry, a creative method referred to as "The 100" was used to create a multitude of quick and simple ideas, focusing on quantity rather than quality. These ideas created a base for further exploration, with the remaining creative work aiming at conceptualizing these basic "outside the box" ideas by developing the core of an idea into something more feasible. The Design phase included outside input in the forms of continuous discussions with Magnus Eriksson, evaluating and developing various ideas, as well as a brainstorming session along with other Gestamp HardTech staff selected by Magnus Eriksson.

The general process during this phase started with an idea of how to keep the beams separate in one row or column. The next portion focused on how another row or column could be added. The biggest challenge here was separating the rows, being that they are stacked on top of each other, compared to the columns which have less of an effect on each other. The final part of the idea generation process looked at how well a robot could access the different loading spaces that had been designed for each idea, whereby the ideas were developed further.

4.5.1 INITIAL MINDMAPPING

The extensive search for information and context immersion in the Conceive phase provided some inspiration, and several ideas were noted during this phase for further development (see fig. 27). During various Conceive-phase discussions with both thesis supervisor Peter Törlind and project supervisor Magnus Eriksson ideas were mentioned and briefly discussed. These ideas were also noted and parked awaiting further development.

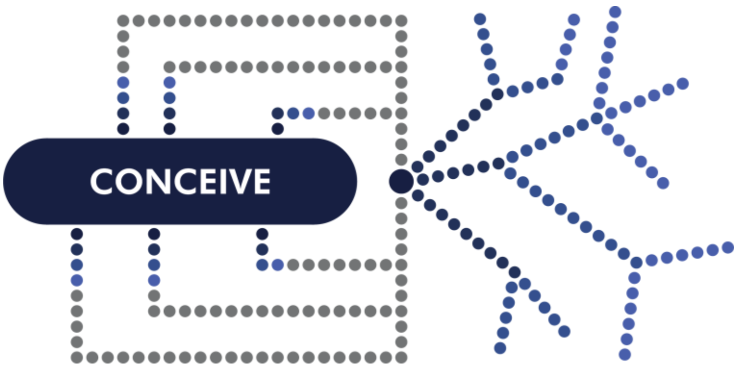

Figure 27. Visualization of the birth, parking, and development of ideas inspired by the Conceive phase. Illustration: Z. Envall.

The early stage of the Design phase consisted of using a Mind Mapping method as described by Wikberg Nilsson et al. (2015), based around the initial ideas, viewing various aspects in various ways searching for feasible solutions. The nature of the project led to many ideas having trouble to live up to the desired goal, and therefore much time was spent evaluating and sketching several variations of different details in order to increase an idea's feasibility.

4.5.2 HARDTECH BRAINSTORMING

A brainstorming session was performed with selected Gestamp HardTech staff, based around the method as described by Wikberg Nilsson et al. (2015). This session started with a brief presentation of the work that had been done, which ended with the various ideas that had been generated. Following this, some ideas were discussed along with aspects concerning which products needed special racks and the feasibility of automated racking in relation to the overall production. Robotic capabilities were also discussed in relation to what is required for a rack concerning each of the various products.

4.5.3 THE 100

The method "List 100 Scenarios" described by Christensen (2013) was used as the framework for achieving a high and wide idea quantity. By listing 100 unique ideas, the method is explained to push into a world of originality. The method is simple, and the only rules are to abstain from any sort of criticism and to generate 100 unique ideas within 15 minutes, equaling to one idea every 9 seconds. The application of the method however turned out to be much more time demanding.

Thirty ideas were generated during the first thirty minutes, after which the search for originality became harder, leading to the time required for each idea growing exponentially. After the initial time limit was breached the rules of the method were shifted, and the new goal became to generate one hundred ideas as fast as possible. Once a piece of paper was full of ideas it was put on the wall and used as inspiration as well as a reminder of what ideas had already been created (see fig. 28).

Figure 28. Sketches from the method "The 100" that were gradually pinned to the cubicle wall. Photo: Z. Envall.

Avoiding criticism was somewhat tough and was dealt with by constant reminders to not overthink any of the ideas. Not duplicating ideas became much harder during the latter half of the process, leading to a deeper search within undiscovered creative spaces, in turn resulting in an increased time consumption. Getting stuck with a loss of ideas was unavoidable during the process, and this was combatted by either drawing a robot with a beam to spark an idea, starting to draw either a rack or a beam without any clearly formulated idea, or by taking a break. The method turned out to be very draining, taking several hours instead of the initially stated 15 minutes. It was also not performed continuously but instead in intervals over a couple of days.

4.5.4 FURTHER DEVELOPMENT

The ideas generated by the previously described methods were analyzed, and those deemed feasible and useful were marked for further development. This development consisted of morphing the ideas into realizable concepts and included combining various aspects of different ideas.

This was fueled by inspiration coming mainly from the previously formulated ideas and was performed continuously to morph the ideas into concepts during the rest of the phase. The work consisted of sketching an idea followed by a quick evaluation leading to a new idea, and this process was performed repeatedly until the ideas ran dry. Dead ends and a lack of ideas were dealt with by taking breaks and focusing on other work. Outside support was also received from Magnus Eriksson during this process through discussions about the various ideas regarding developmental possibilities.

4.5.5 ELIMINATION

The elimination focused on the separation methods each concept presented, not considering factors regarding having different rack sizes with different numbers of rows or stacks. The reason for this was that the concepts were going to be further developed, and that no absolute limitations concerning different rack sizes had been set. The rack-concepts were initially compared by their theoretical packing grades, how many different products they could be used with, and their theorized costs.

The packing grades were calculated by hypothesizing how closely the products could be packed while using the given separation method accompanying each concept. Determining which products each concept suited was done by analyzing a product's edges relevant to each concept and assuming what would work in reality. The costs were theorized by looking at the overall complexity of the various concepts and assuming that concepts with more advanced mechanisms would cost more to produce and buy.

The final round of elimination was done by consulting with Magnus Eriksson and discussing the various concepts, weighing packing grades in relation to various factors affecting costs, while also taking the concept's overall feasibility into account.

4.6 IMPLEMENT

The Implement phase consisted of concept evaluation in the form of physical tests with the products, along with a final detail development process.

Physical tests with the products were performed to determine the feasibility of the various concepts, and to determine how well each concept suited each product. This was done by physically examining each product regarding different factors relevant to the concepts. The tests were performed in two rounds, with the first round focusing more on beams' stacking factors, and the second focusing on factors concerning beams placed in rows.

Before the final elimination, the concepts were analyzed and developed to increase their feasibility and effectiveness, largely based on the results from the testing. Through a process of combination and elimination a final concept was lastly decided upon and sketched.

4.6.1 TESTING I

The first round of testing was performed by manually examining the 12 products with the help of wax-strips and an empty HT-rack. The products were supplied in racks and the factors that were tested consisted of:

- If the beams stick to each other
- The current distance between the beams
- If the beams are stackable
- The height of the maximum stackable amount
- The amount that can be stacked
- The number of stacks that fit in a HT-rack
- The lowest possible non-stick distance between the beams
- Concept-specific solutions

If a product sticks together was examined by pressing two beams into each other and then attempting to take them apart. This factor was further examined throughout the testing process, which included removing beams from rows and stacks repeatedly. Once the beams were pressed together the distance between them was also measured, showing how close the beams can be packed.

Determining if a product is stackable was done by attempting to stack the beams on a flat surface and noting the maximum stack-height that could be achieved (see fig. 29), along with the corresponding number of beams in the stack. A maximum limit for the stack-height was set to 800 mm in accordance to the HT-racks. Once the stacks started swaying and showing signs of instability the measurements were taken frequently until the stack finally fell or reached the maximum limit of 800 mm.

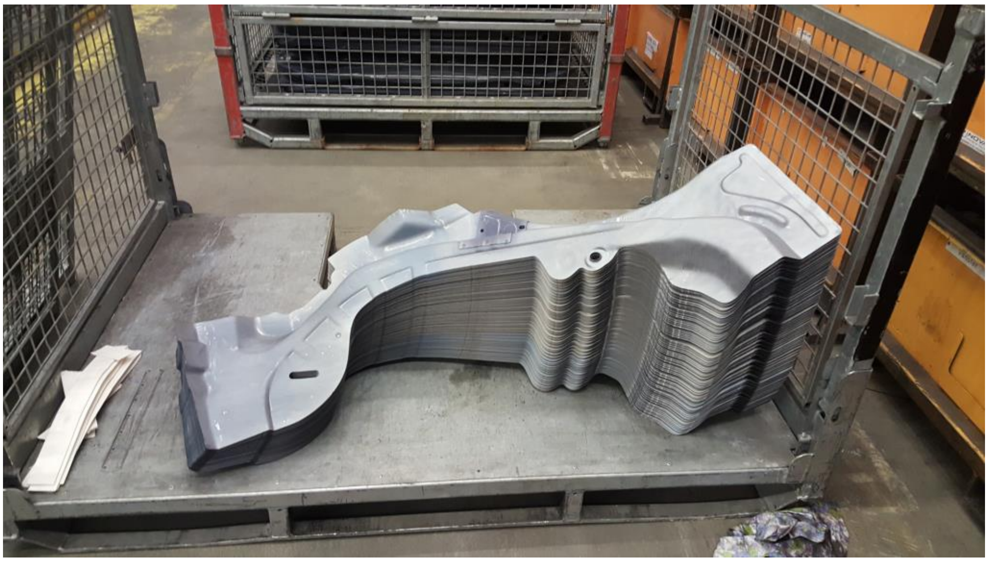

Figure 29. Stack of the Y555 C-st beam. Photo: Z. Envall.

By placing the beams next to each other at the bottom of a HT-rack the number of possible stacks were analyzed. For the specific products that resulted in leaning stacks, in turn taking up more space, this factor was also taken into consideration.

The lowest possible non-stick distance between each product was tested by using thin wax-strips to separate two beams stacked on top of each other. The strips were placed in two different formations, each of them having two separate strip-placement areas (see fig. 30). The number of wax-strips was increased sequentially until the beams no longer stuck together when the top one was lifted. Both of the non-stick distances between the beams produced by the two wax-strip formations were measured, and the smallest distance was deemed the lowest possible non-stick distance.

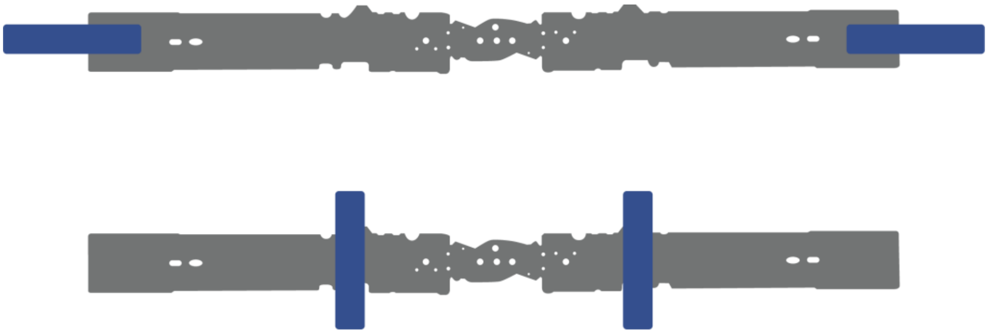

Figure 30. Visualization of how the wax strips (displayed in blue) were positioned. Illustration: Z. Envall.

The two wax-strip formations were at the same time used to test the concepts "Strings" and "Clap", which keep the beams separate in the same manner as the wax-strips. The number of wax-strips used in each formation was thereby also noted and measured, producing the thickness needed for separation for each concept.

4.6.2 TESTING II

The second testing session was focused on placing the beams in rows. The testing consisted of determining which beams were suitable for the concept "Borst", which is a concept that uses brush to keep the beams separate. It was also evaluated which beams could be placed horizontally without aid, and which beams needed the racks to be leaned back during loading and unloading in order to not fall over. Additionally, it was determined whether a beam could be directly picked up from the conveyor belt and placed in the rack, or if the grip needed to be shifted. The minimum distance needed between rows was also measured. Svensk Borstteknik had sent 3 different brushes to aid with the testing of the "Borst" concept (see fig. 31).

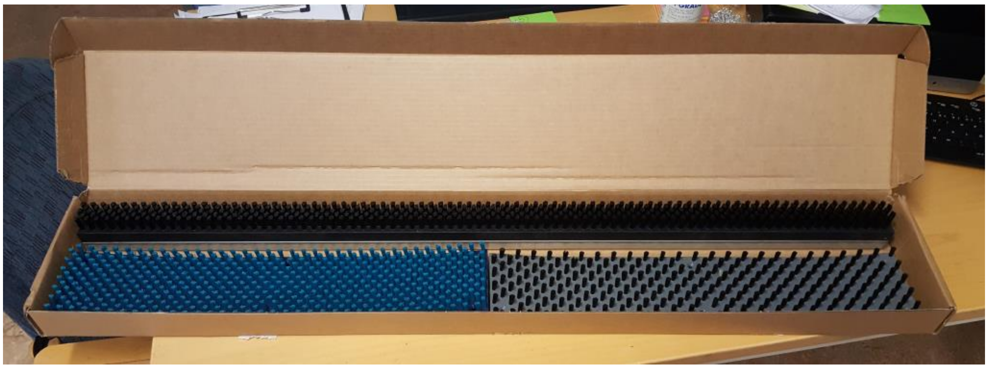

Figure 31. The three brushes received for the testing, courtesy of Svensk Borstteknik (www.borsten.se). Photo: Z. Envall.

Being a way to keep the beams separate, the testing of the "Borst" concept was centered on the beams that had previously been determined to stick to each other. Some other beams were however also tested depending on their need for additional stability. The concept was tested both by placing the beams on a horizontally aligned brush as well as a brush with one end elevated to simulate a leaning rack (see fig. 32). The beams were initially loaded horizontally, and those that showed a poor balance were also tested on the leaning brush.

The three brushes received from Svensk Borstteknik came in two different shapes with three different brush materials. These were all tested initially, but it was easily determined that the one with the hardest brush material was superior, after which this brush was solely used in the tests.

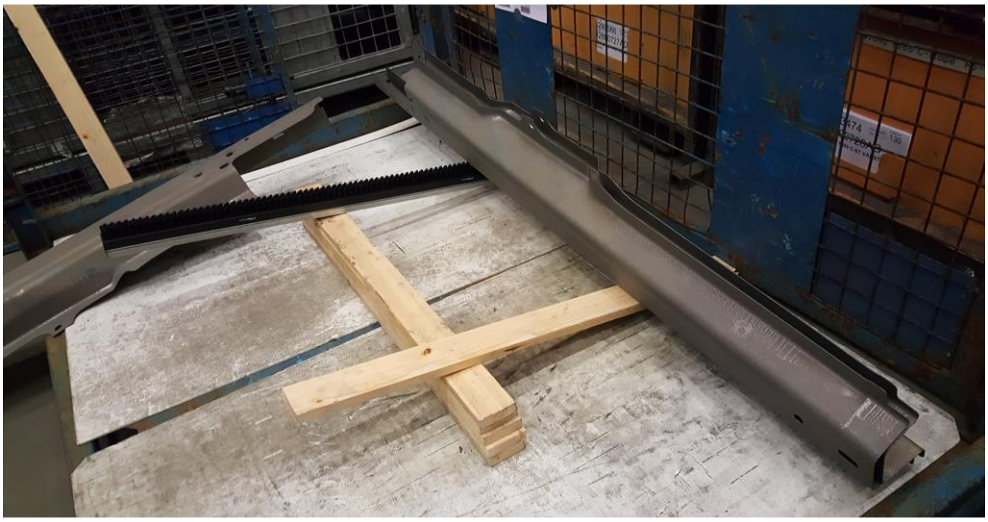

Figure 32. Brush with one end elevated to simulate a leaning rack. Photo: Z. Envall.

The beams that had been determined to not stick to each other were tested similarly to the process previously described, but with wooden planks instead of the brush. The wooden planks were placed both flat on the bottom of the racks as well as with one side elevated. The beams that showed poor stability in these tests were also tested with a brush.

If a beam required for a robot to change its grip was tested by attempting to place the beams in a rack in the manner they would be if they were picked up straight off the conveyor belt leading them out from the stamping line. The minimum distance needed between rows was determined by placing two beams next to each other and measuring the minimum distance needed between them in order to keep them separate.

4.6.3 EVALUATION

The results from the testing were interpreted and converted into packing-grades for each of the beams correlating to each of the concepts. The packing-grades determine how many beams can be packed into a rack while using the different separation techniques, in relation to the original amount that is currently packed in the HT-racks, and are presented as percentages.

4.6.4 CONCEPT DEVELOPMENT

One concept was directly eliminated based on results from the testing, and the other two were developed further focusing on a number of details aiming at improving the overall feasibility. This development was centered on deciding how the different separation techniques would best be implemented in a rack, with respect to total packing-grade, beam sizes, and simplicity. The development consisted of individual brainstorming and took the form of different sketches and calculations. Two new simple concept variations were also generated, stemming from new insights about beam separation needs gained from the testing.

4.6.5 FINAL ELIMINATION

To aid with the eliminatory process a meeting was held with Magnus Eriksson and logistics engineer Martin Holmbom, who was completely new to the project. After presenting prior work and the two final concepts Borst and Strings, discussions were held about which concept was preferred along with developmental possibilities and ideas for future implementation further down the line. The final eliminatory decision was made by taking earlier calculated packing-grades and the opinions from Magnus Eriksson and Martin Holmbom into account, where after only one concept remained.

4.7 OPERATE

The Operate phase consisted of applying the finishing touches to the concept and finalizing the last deliverables. The concept design was initially refined regarding various details, and then a CAD model was made.

4.7.1 REFINEMENT

With the basic functions of the final concept somewhat decided, the work during the refinement focused more on various details such as how to make the rack foldable, stackable, and cost effective to produce. Much effort was also put on refining the design of the separators, both regarding producibility as well as robot handling. During the refinement of the concept calculations were also made to determine certain dimensions required for the concept's functionality. The refinement was mostly done through sketching and evaluation performed iteratively, supported by meetings with Magnus Eriksson and Martin Holmbom who helped with the evaluation and offered new ideas and views.

4.7.2 CAD-MODELING

The CAD model of the concept was done in Siemens NX and was based around the original HT-racks regarding measurements and overall function. A central goal was to make the rack work logistically just like the HT-rack, both when open and folded. To achieve this, a number of details were copied from the HT-rack. Drawings of the HT-racks were supplied by Gestamp HardTech, and the measurements from these were combined with the measurements that had been calculated for the concept.

4.7.3 PRODUCT ASSESSMENT

A final product assessment was also made. This assessment was a categorization of the reviewed beams and was based on the product assessment that had been performed throughout the project. Generic beam characteristics were derived from the various parameters that had been examined earlier. The generic characteristics that were deemed suitable for the final concept were also specified.

4.8 METHOD DISCUSSION

This section contains a brief discussion regarding the reliability and effectiveness of the methods that were used.

4.8.1 CONCEIVE

The Conceive phase can essentially be divided into 4 parts: Context Immersion, Theory Immersion, and Product Assessment.

Understanding the context was done through many ways, both online, at Gestamp HardTech Luleå, and in Scania Oskarshamn. The online studies were mainly focused on finding racks used for automation. Although this was somewhat tough, many racks used in various instances were found in several places. The Benchmarking was partly done on YouTube, reviewing several different production facilities from various car manufacturers in order to increase the span of the search. The search for racks also included websites of rack manufacturers, thereby also stepping somewhat outside the automotive industry. A larger search outside the automotive industry would probably have aided the project. The Benchmarking lacked relevant solutions being used in other settings.

The Theory Immersion was mainly done through searching in books about the various subjects, with the larger part of these being textbooks. Peer reviewed articles are generally a more secure source of information, and although some articles were reviewed it would have been preferred if more of the theory was based on articles.

The Product Assessment started off structured, with the guidance of Peter Törlind, but as time went on it took a more iterative approach. In order to secure that the work being done is efficient and correctly structured, basing the assessment more on defined methods could possibly have aided the work.

4.8.2 DESIGN

Although the Design phase included some creative methods, it was mainly in the form of individual sketching and idea developing. Whether this was an as efficient method as it could have been is hard to discern, but including more outside help for idea generation would probably have aided the process. Using methods that are not based on sketching would also probably have opened up new doors and increased the flow of creativity.

The final evaluation and elimination of ideas could also have been eased by using some sort of elimination method, but with the ideas that had been generated it was not something that felt necessary, as determining which ideas were worth developing did not result in much of a struggle.

4.8.3 IMPLEMENT

The Implement phase was largely centered around testing numerous factors regarding the products. Although these tests were empirical and resulted in clear statistics, the method in which they were performed could at times have had some implications on the resulting statistics. Some of the tests included handling the beams like a robot would, which was done by hand, and therefore could differ some from having an actual robot performing the tests. This is especially true regarding testing with the brush, where the manual handling could have the largest implications. The different measurements being made were also done manually by using a ruler, and could therefore also lack somewhat in quality. The factor of how close the beams can be packed resulted in distances which, although the beams do not stick at these, they are not necessarily the absolute minimum packing-distances.

4.8.4 OPERATE

The work performed concerning refining the concept mainly consisted of sketching. A more secure result would probably have been attained if the sketching was coupled with prototyping, and thereby actually testing the various design alterations.

The CAD-modeling in the Operate phase was based on dimensions from the actual drawings for the HT-racks. Because of this, the concept rack should have the correct dimensions needed for stacking with the HT-racks. The designed parts do however have some features that might need to be adjusted should the rack be produced. This concerns things such as distances between features and the space required for welding. A more precise and producible CAD-model would have been provided if more production factors would have been taken into consideration, preferably by consulting with knowledgeable people.

5 Results

The Results chapter presents all the results attained from the various methods used throughout the project. The chapter consists of results from the Conceive, Design, Implement, and Operate phases, starting with the product assessment and ending with the final concept.

5.1 CONCEIVE

Mainly consisting of literary reviews, the Conceive phase resulted primarily in knowledge regarding robotics and machine vision, displayed in the Theory section. Another significant part of the Conceive phase consisted of benchmarking and an analysis of the current state, the results from which are presented in the Context chapter. The phase also focused on assessing the different beams produced at Gestamp HardTech Luleå, initially through structures provided by the methods Quality Function Deployment (QFD) and Design Structure Matrix (DSM). The phase ultimately resulted in a specification of requirements, see table 2.

Table 2. Specification of requirements. Illustration: Z. Envall.

REQUIREMENTS

- The rack shall allow for robotic loading and unloading.
- The rack shall allow for robotic localization of the products.
- The rack shall allow for logistic handling by a forklift truck.
- The rack shall be transportable, both when full and empty.
- The rack shall be stackable with itself.
- The stacks shall be transportable.
- The rack shall be able to tolerate predictable forces concerning loading, unloading, and logistic handling.
- The rack shall have a designated logistic-label placement option.

DESIRABLE

- The rack shall be foldable.
- The rack shall allow for robotic loading and unloading of more than one type of product.
- The rack shall be inexpensive to manufacture.
- The rack shall hold the same amount of products as the racks in use presently do.

5.1.1 PRODUCT ASSESSMENT

A number of 15 beams were originally chosen for the product assessment, due to discussions with Magnus Eriksson. The 15 beams are displayed in fig. 33.

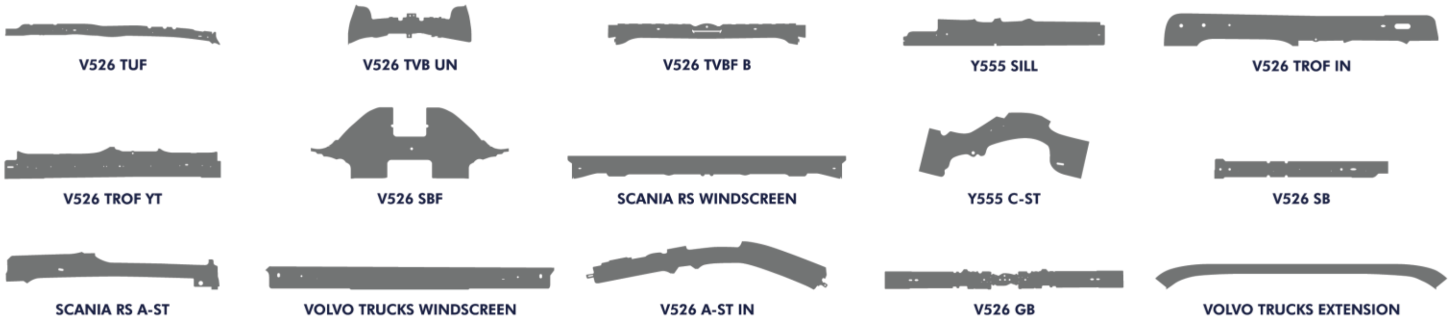

Figure 33. The 15 beams originally chosen to be designed for. Illustration: Z. Envall.

The initial product assessment process resulted in two matrices which are presented below, one as a cluster-matrix and the other as a bar chart. Results from the QFD are displayed in fig. 34, showing the expected ease of robot-racking implementation for each product. V526 SB is deemed to be best suited for automated racking, only receiving low scores in the parameter concerning the quantity of products being produced at the plant. The product receiving the lowest score is V526 A-st IN, which is a bit too long for the HT-racks, easily sticks together, is curved, and therefore doesn't pack well in a square rack.

Figure 34. Diagram showing how well the various products are deemed to be suited for robot racking. The longer the bar, the better suited the product is presumed to be. Illustration: Z. Envall.

The method based on DSM resulted in a clustering of the various products according to different parameters, see fig. 35. The darker the color of a dot is in the figure, the better the specific product answers to the given parameter. The products have been placed in an order that produces the clearest perceived clusters.

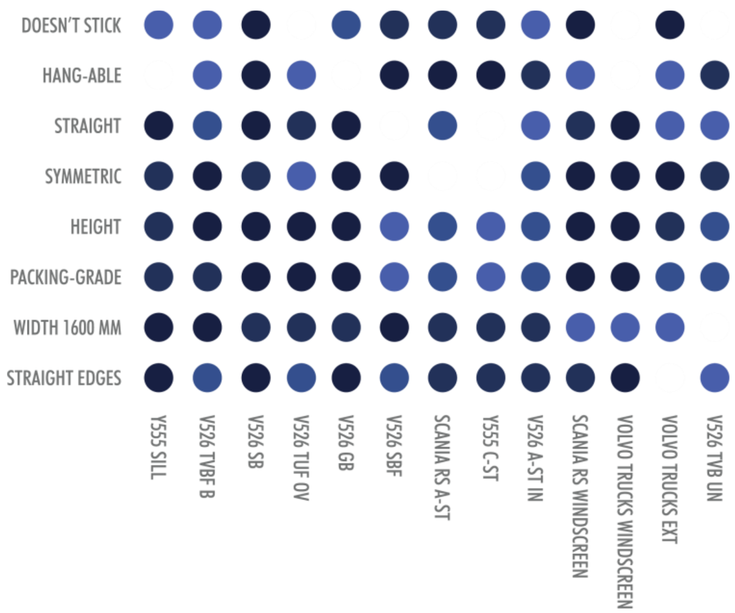

Figure 35. Matrix showing the clustering of products according to various reviewed parameters. Illustration: Z. Envall.

The five beams on the left side of the diagram in fig. 35 (Y555 Sill, V526 TVBF B, V526 SB, V526 TUF OV, V526 GB) have corresponding lengths, can be packed closely, have similar height, and are reasonably straight and symmetric. The four products slightly to the right of the middle (V526 SBF, Scania RS A-st, Y555 C-st, V526 A-st IN) are all perceived to be hang-able, have reasonably straight edges, with somewhat similar heights and lengths. The longer products on the right side of the matrix (V526 A-st IN, Scania RS Windscreen, Volvo Trucks Windscreen, Volvo Trucks Ext.) are all considerably longer than the width of the HT-racks. Apart from the V526 A-st IN, they are all symmetrical and have similar heights. The product on the far right (V526 TVB UN) has been perceived to be a stand-out, lacking relevant coinciding parameters relative to the other products.

Further product assessment was done for 15 products, which are displayed in fig. 36. Although the number of products is the same as earlier, the specific products have shifted somewhat, due to additional information being gained regarding future production plans. The total results from the further product assessment can be found in Appendix 1.

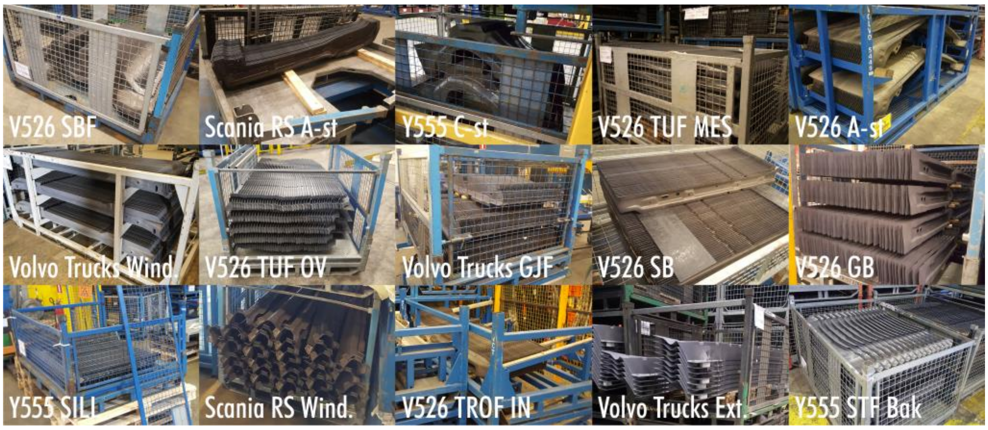

Figure 36. The 15 beams used for further assessment. Photo: Z. Envall.

Among the products, the number of beams per rack along with the number of rows or stacks varies greatly depending on the product. Several types of racks are used, and between the stamping lines and the next machining process most beams (80%) are stored in traditional HT-racks, which have their sides stripped off for five of the products (33%). One third of the products are only laser cut before being finished, while the downstream machining regarding the rest of the products varies.

Six of the fifteen products have all horizontal edges, with the rest having some vertically aligned edges, but none with all vertical edges. 67% of the products have primarily horizontal edges on their long sides, and only one product (Y555 STF Bak) has vertical edges on both of its long sides. Almost half of the beams are longer than the HT-racks, with the longest being the V526 A-st YT beam at 2360 mm. The most commonly used stamping line is Stamping Line 6, where 73% of the products being reviewed are produced.

Almost half of the reviewed products are symmetrical, and all except the Volvo Trucks Extension beams have at least 1 hole after being stamped. The only beam with solely 1 hole is V526 SBF. Seven of the analyzed beams were deemed hangable from their holes, and seven beams were deemed hangable due to their shape.

One of the chosen products, V526 TROF IN, only goes through the stamping line before being shipped to Volvo and is therefore directly placed into specific Volvo-racks. Because of this they were eliminated from the list of products to be designed for. The Volvo Trucks Extension beam was also removed from the product assessment due to its rarity in the production along with its high weight, which would require an extra person to help with lifting for the upcoming testing in the Implement phase. The remaining products are displayed in fig. 37, where the nearly identical V526 TUF OV and V526 TUF MES beams have been combined in order to ease the upcoming testing.

Figure 37. The products remaining after the assessment. Illustration: Z. Envall.

The generic beam characteristics that were formulated are displayed in fig. 38 and include the categories sticking, non-sticking, straight edge, bent edge, bent, straight, symmetrical, and asymmetrical beams.

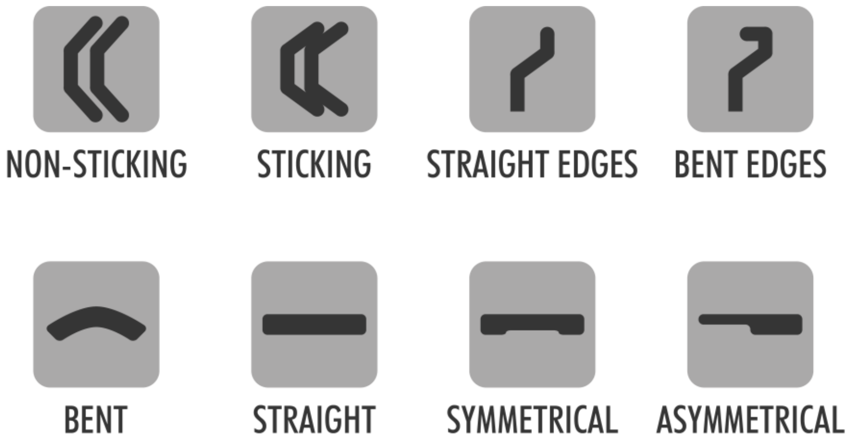

Figure 38. The generic beam characteristics that were defined.

5.2 DESIGN

The results from the Design phase starts from the initial idea generation and ends with the final concepts that survived the elimination process. What follows are the results from the methods previously described as "Initial Mind Mapping", "HardTech Brainstorming", "The 100", and "Further Development".

5.2.1 INITIAL MIND MAPPING

The method resulted in a wide range of primitive ideas shown in fig. 39. The original categorization included the categories:

- **Top** – Ideas where beams are stored on top of each other
- **Slots** – Ideas where different kinds of slots are used to keep beams apart
- **Soft Materials** – Ideas utilizing soft materials such as brush or foam
- **Gravity** – Ideas having to do with leaning the racks or leaning the beams
- **Separators** – Ideas where beams are separated by placing various objects between them
- **Hanging** – Ideas where the beams are hung
- **Other** – Ideas not fit for any of the other categories

The soft materials came to include an idea utilizing springs, while lacking any ideas explicitly using foam. Designing solutions for the robot end-effector was also attempted, along with ideas having to do with the way the beams are loaded. The majority of the ideas were however centered on brush or slot solutions.

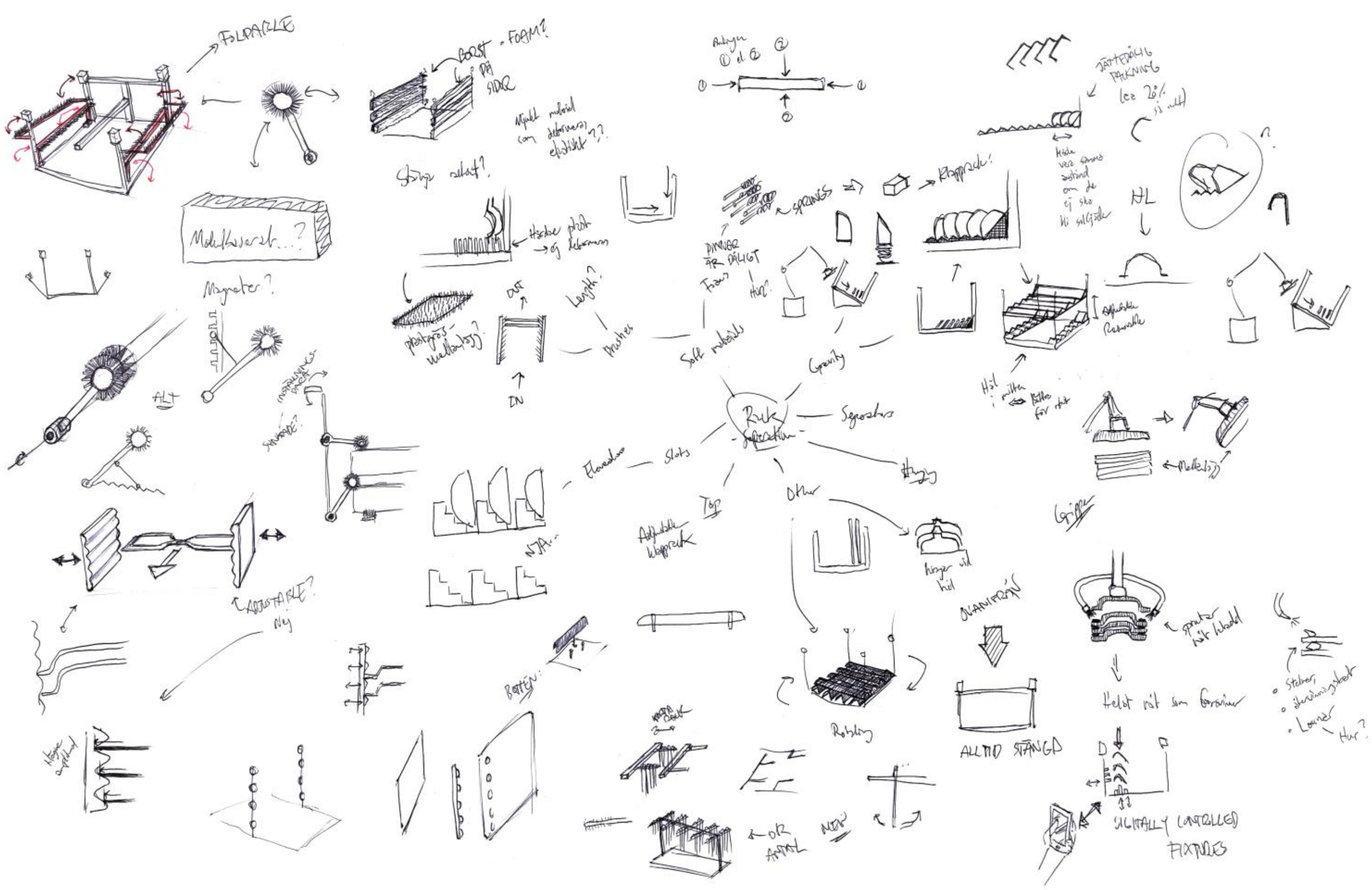

Figure 39. The ideas generated from the "Initial Brainstorming" method. Illustration: Z. Envall.

5.2.2 HARDTECH BRAINSTORMING

The Brainstorming performed with HardTech staff did not result in any concrete ideas. Using magnets or foam balls to separate the beams was mentioned but did not lead to much of a discussion. What was discussed was mainly how lower packing volumes would affect the production, as for which it was said that lower volumes could work well with a leaner production strategy. Discussions also arose about whether a rack design was even necessary, or if a robot equipped with a vision system would be able to load and unload the beams from a generic rack, as long as the beams were placed randomly to keep from sticking to each other.

5.2.3 THE 100

The method described as "The 100" resulted in slightly over one hundred ideas, each developed to be as unique as possible in relation to each other. The ideas are presented in fig. 40.

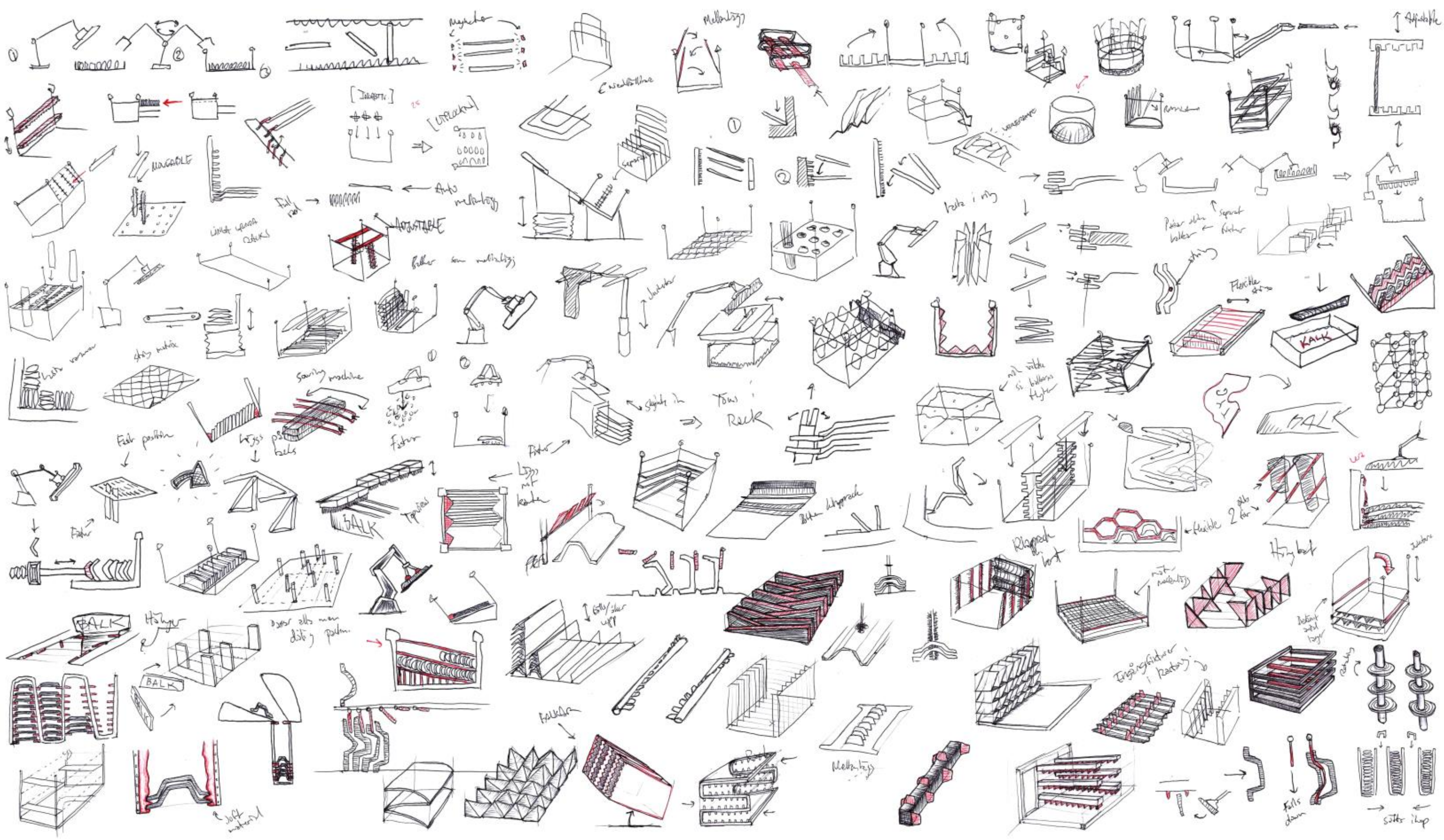

Figure 40. The ideas developed in the method "The 100". Illustration: Z. Envall.

The ideas generated by the method further explored the categories previously defined in the "Initial Mind Mapping" method, and also added solutions that use fixtures, various placement mechanisms, along with using different materials such as chalk or liquid to keep the beams apart.

Inspiration for further development was provided by ideas that used various methods to separate the beams. These included strings, fabric, fixtures, pins and brushes. The main ideas from "The 100" that turned out to inspire future ideas are shown in fig. 41.

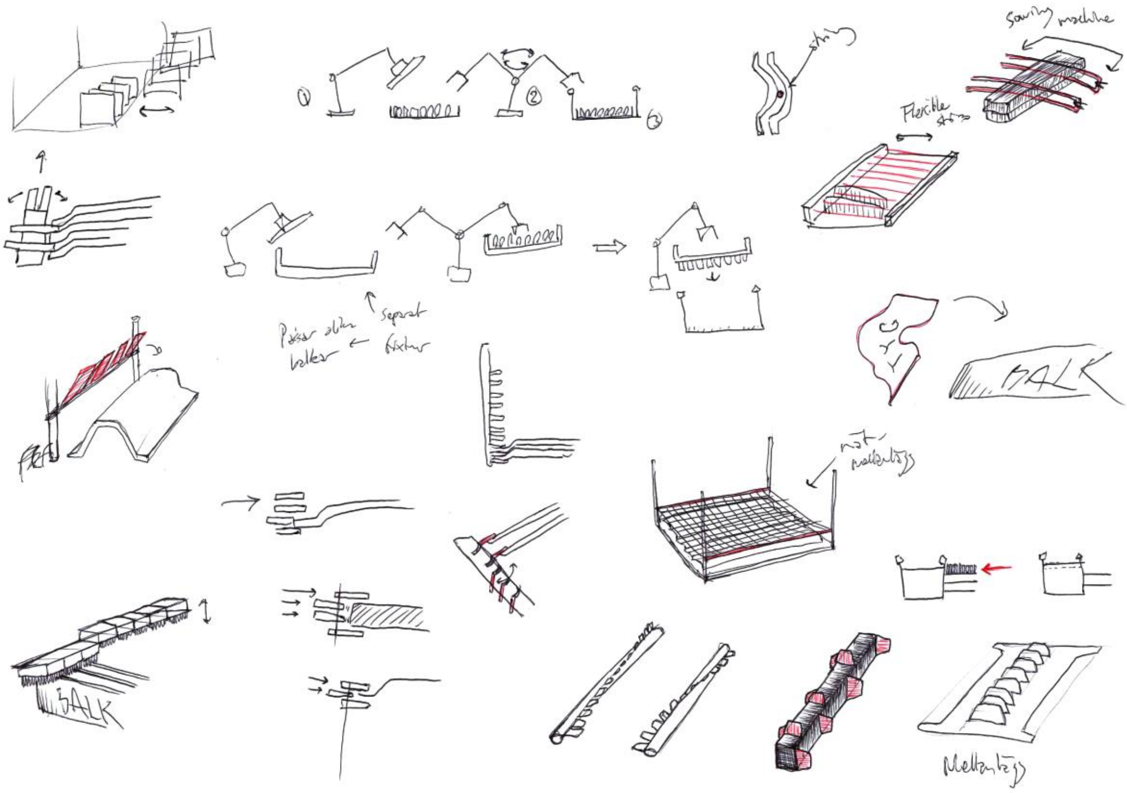

Figure 41. Some ideas from the method "The 100" that inspired further development. Illustration: Z. Envall.

5.2.4 FURTHER DEVELOPMENT

The creative work performed in the Design phase ultimately resulted in six different concepts. The concepts are displayed in figs. 42-48 along with the various ideas they stemmed from.

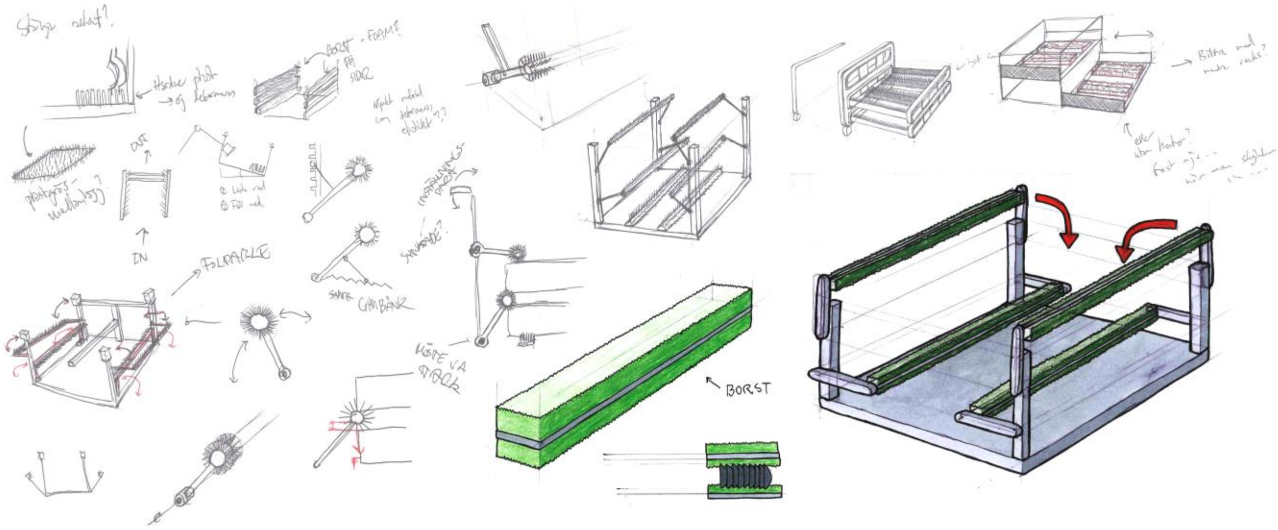

Figure 42. Borst concept. Illustration: Z. Envall.

The Borst concept (fig. 42) dealt with beams placed in horizontal rows and was centered on using some type of brush material to keep the beams separate. The concept took two forms: A rack with built-in brush accessories, or the simpler brush separators. The built-in brush accessories were meant to rotate into the racks after the rows of beams had been placed. In order to keep underlying and overlying rows fixated brush is used on both sides of each separator. The other option used the same type of brush separators, but these were instead meant to be placed into generic racks, between the rows of beams. The plan with this option was to have the robot place the separators into the racks in between placing the rows of beams.

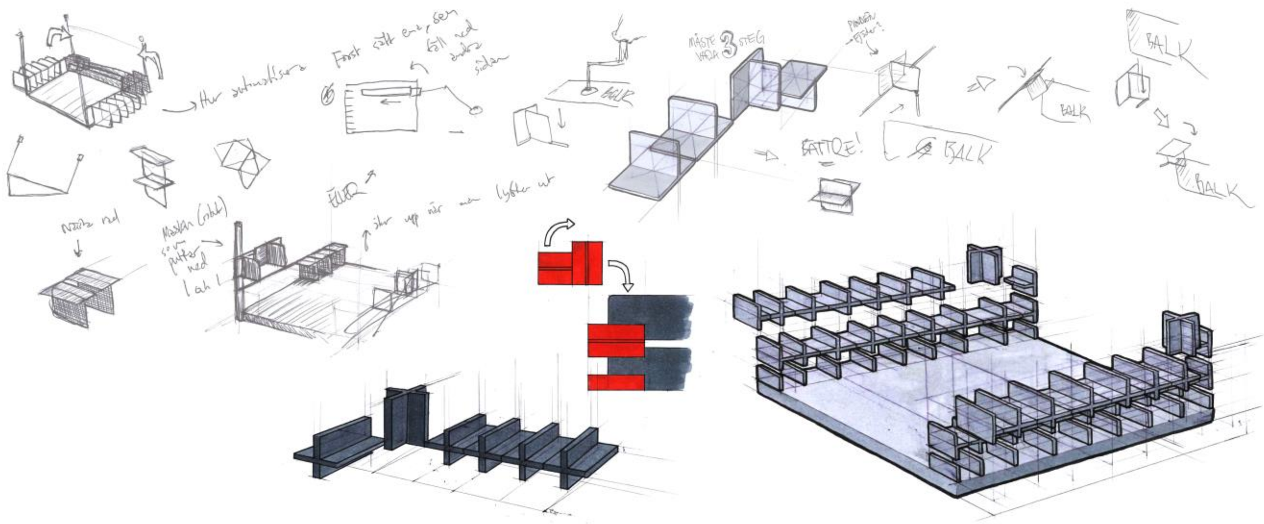

Figure 43. Boxn1 concept. Illustration: Z. Envall.

The Boxn1 concept (fig. 43) was also designed for beams placed in horizontal rows. This concept was a variation of the automatic separators seen in the benchmarking studies. The plan with this concept was to have the separators rotate in as a beam was being placed, in turn boxing the beam in and keeping it separate from the rest of the beams in the rack.

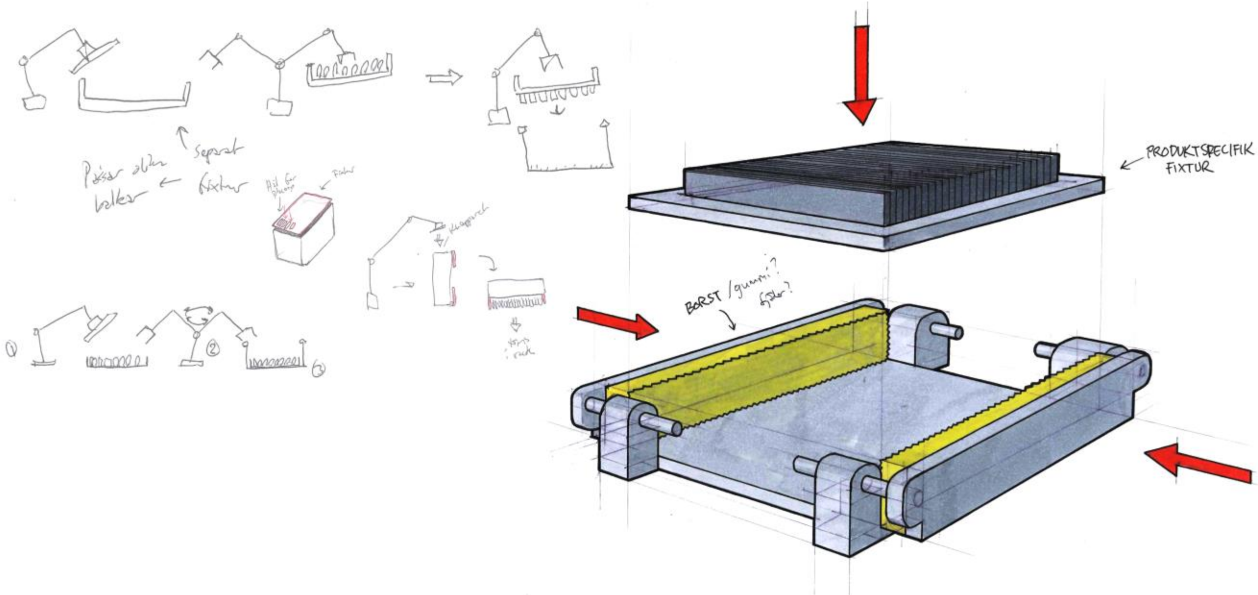

Figure 44. Fixture concept. Illustration: Z. Envall.

The Fixture concept (fig. 44) was designed with the possibility of having the beams being stacked vertically or placed in horizontal rows initially, to then have the entire rows or stacks being placed into a rack. The initial placement of the beams was planned to be done into a product-specific fixtures, by which an entire row would be transported and unloaded into the rack. The fixture would then be returned to the robot for loading the next row or stack, while the row that was unloaded into the rack would be fixated from two sides by adjustable mechanisms coated with a soft material such as brush, rubber or foam.

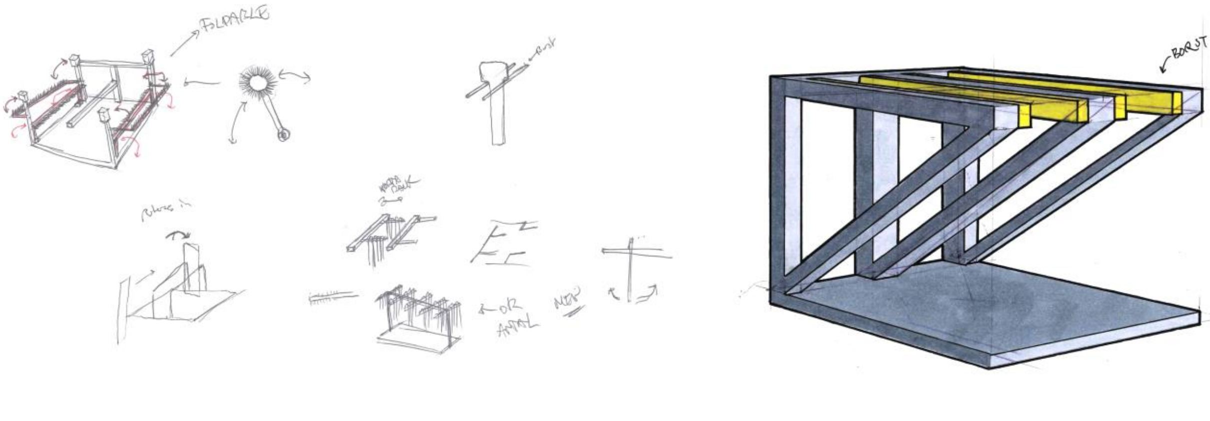

Figure 45. Hang concept. Illustration: Z. Envall.

The Hang concept (fig. 45) was designed to have the beams being hung from it. The concept was planned to use a soft material such as brush to keep the beams being hung separate from each other. The beams were planned to be hung by their edges.

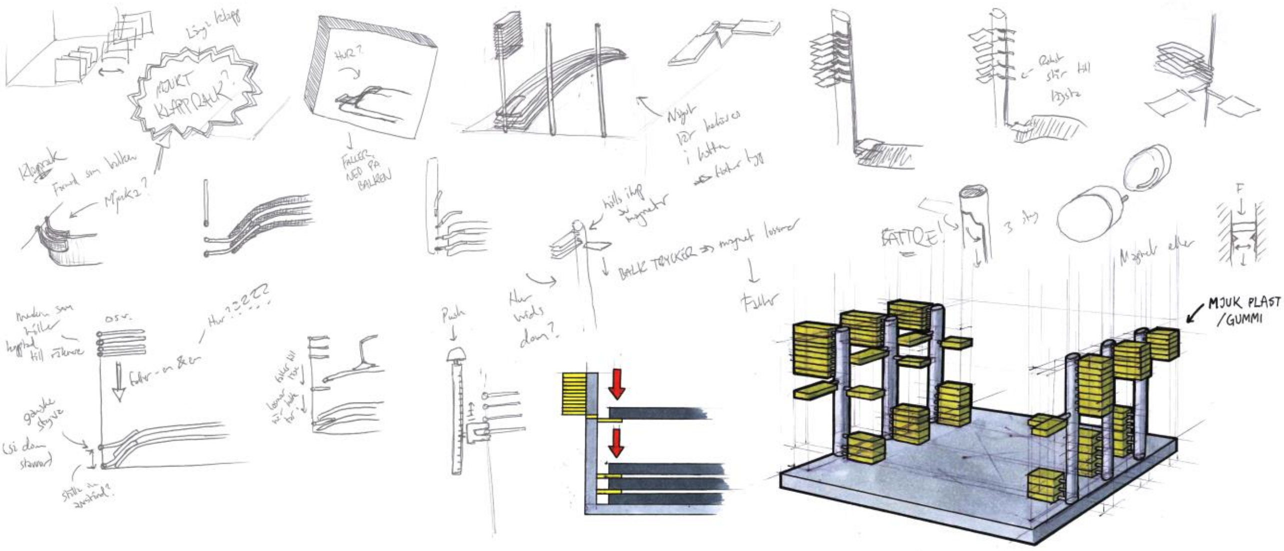

Figure 46. Soft concept. Illustration: Z. Envall.

The Soft concept (fig. 46) was also inspired by the automatic separator-mechanisms seen in the benchmarking. This concept was designed to have the beams being placed in stacks, with one separator on each side of each beam. The separators were planned to be made in a soft plastic or rubber material and thick enough to keep the beams apart. The separators were meant to rotate into the rack, with a possibility of assuming three different positions. The separator at the bottom of the stack is always facing the rack, and once the robot brings a beam down, it pushes the separator, after which it falls down onto the underlying beam while the next separator is automatically rotated into the rack.

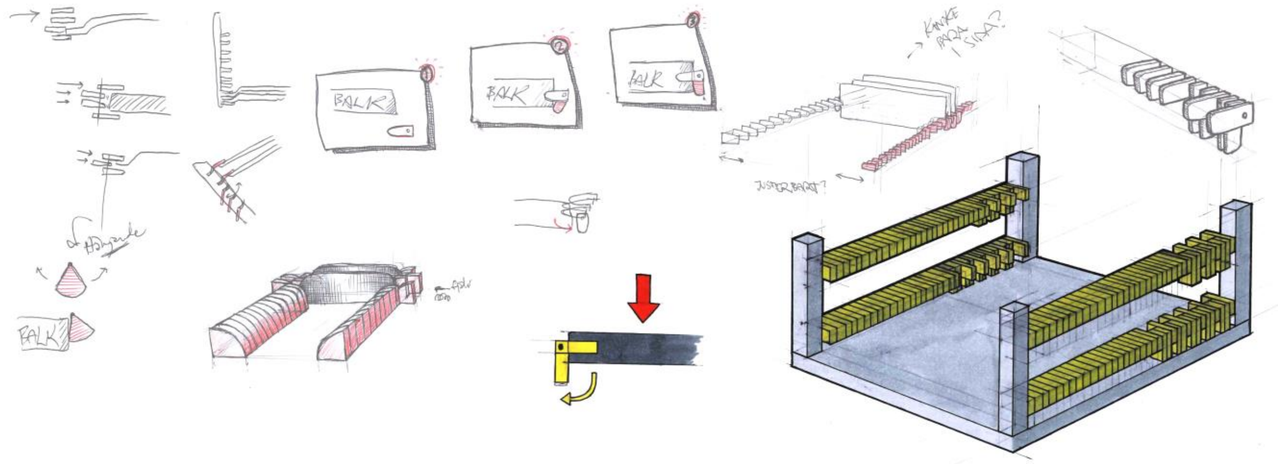

Figure 47. Down concept. Illustration: Z. Envall.

The Down concept (fig. 47) was designed for the beams to be placed in rows. The ends of the beams would interact with an automatic separator-mechanism, also inspired by the automatic separators from the benchmarking studies. The separators were designed to have the possibility of rotating between two positions, always being pushed upward by springs. An empty rack was meant to have all the separators positioned horizontally, to be rotated down when pushed down by a beam. When the beams were to be loaded into the rack, at least one separator was meant to remain horizontal between the beams, keeping them separate from each other.

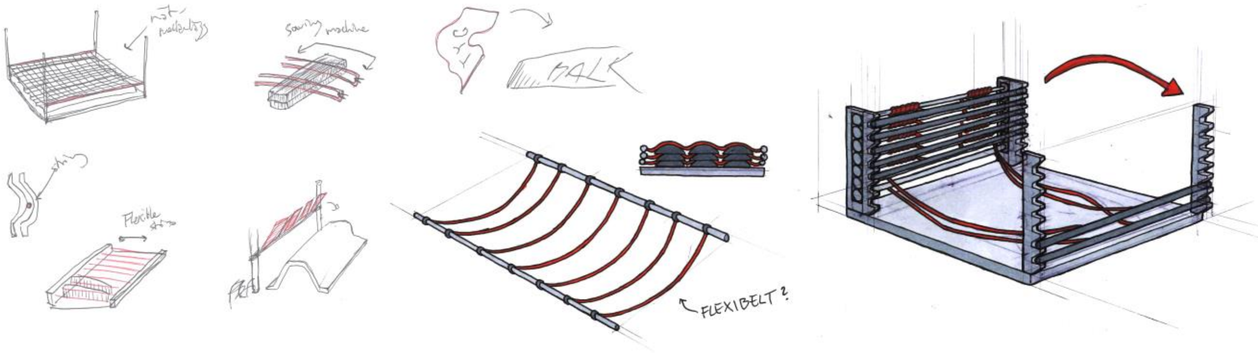

Figure 48. Strings concept. Illustration: Z. Envall.

The Strings concept (fig. 48) was meant for the beams to be stacked vertically, using strings with a soft and flexible material and to separate them. After a row of beams had been placed, the strings are used as a separator, put onto the beams before the next row of beams are loaded into the rack. The concept had two options, one having string mechanisms built in, where the strings are rolled up until the robot pulls them out and lays them over the beams. The other option was to use more simple string separators which were meant to be stored separately and laid on top of each row of beams.

5.2.5 ELIMINATION

The initiating elimination process resulted in a matrix where the concepts received different scores according to their presumed packing-grade, versatility, and cost (see table 3).

Table 3. Comparison of the concepts. Illustration: Z. Envall.

concept	packing	versatility	cost	score
BORST	GOOD	GOOD	LOW	10.5
BOXN1	BAD	GOOD	MEDIUM	6.5
DOWN	OK	OK	MEDIUM	7
SOFT	GOOD	GOOD	MEDIUM	9.5
STRINGS	GOOD	GOOD	MEDIUM	9.5
HANG	GOOD	BAD	LOW	8.5
FIXTURE	GOOD	GOOD	HIGH	8.5

The concept that received the highest score was the Borst concept, followed by the Soft and Strings concepts. The Hang and Fixture concepts also received fairly high ratings, but both each lacked greatly in one area.

Due to the elimination matrix along with discussions with Magnus Eriksson three of the concepts were chosen for testing and further development in the following phase, namely the Borst, Soft, and Strings concepts.

5.3 IMPLEMENT

The Implement phase consisted of two rounds of testing along with concept development. The testing resulted in various statistics regarding beam properties and statistics in relation to the three concepts Borst, Strings, and Soft. The concept development resulted in three final concepts leading up to a final elimination process.

5.3.1 TESTING I

The results from the first round of testing (see table 4 and Appendix 2) showed that almost half (46%) of the tested beams stick to each other when placed closely together. The highest stackable amount was 95 beams consisting of the Y555 C-St beams. The product that stacked the worst was the Scania RS Windscreen beam, with only 7 pieces being able to be placed on top of each other. The other products could be stacked in various amounts, with a mean value of 32 beams and a median value of 33 beams.

Table 4. The results from the first round of testing. The non-stick distances displayed in dark grey signify the beams that were determined to stick together.

	original distance	non-stick distance	stackable amount	stackable height	number of stacks
SCANIA RS WIND.	65 mm	65 mm	7	600 mm	4
SCANIA RS A-ST	10 mm	10 mm	33	330 mm	4
VOLVO TRUCKS WIND.	7 mm	17 mm	24	550 mm	4
VOLVO TRUCKS GJF	8 mm	8 mm	41	350 mm	5
Y555 SILL	7 mm	11 mm	40	550 mm	4
Y555 STF BAK	55 mm	65 mm	14	800 mm	4
Y555 C-ST	6 mm	6 mm	95	800 mm	2
V526 A-ST YT	19 mm	19 mm	15	400 mm	1
V526 SBF	9 mm	9 mm	40	800 mm	2
V526 SB	9 mm	13 mm	52	600 mm	7
V526 GB	20 mm	21 mm	40	800 mm	7
V526 TUF OV	15 mm	21 mm	8	250 mm	8
V526 TUF MES	15 mm	21mm	8	250 mm	8

The number of stacks of each beam that fit in the 800 by 1600 mm rack ranged from the V526 SBF and V526 A-St YT beams at 2 stacks, to the V526 TUF OV and MES at 8 stacks. The mean number of stacks was approximately 5, and the median value was 4 stacks.

The maximum stacking height was set to 800 mm, which 4 of the beams reached (Y555 STF Bak, Y555 C-st, V526 SBF, and V526 GB). The product that stacked the worst was V526 TUF OV and MES, only reaching 250 mm before falling. The mean stacking height was 545 mm with a median of 550 mm.

The testing of the non-stick distance in comparison to the minimum distance between the beams resulted in minimum packing-grade percentages. The 7 beams that did not stick together all showed packing-grades of 100%, with the rest of the products coming in at between 41-85%. The minimum packing-grade percentage of the beams that stuck together showed a mean value of 67% with a median of 70%.

The testing showed that 8 of the 13 products leaned when being stacked, 6 of the products stacked unevenly, and 5 of the products showed signs of deformation at the bottom of the stacks.

The testing of the concepts showed that the concept Strings worked for all six of the beams that stuck together. The testing showed that the string thickness needed in order to keep all six of these beams apart was 10 mm.

The Soft concept worked for five of the beams that stuck together, also needing a separator with a thickness of 10 mm to keep all the 5 beams apart. The one sticking beam that the concept did not suit was Y555 STF Bak, with the reason being that the beam got stuck in its center region, while the separation distance at its ends remained high. The Soft concept would theoretically also work for this beam, but would require separators with a thickness of 50-100 mm.

The testing furthermore resulted in discontinuing the development of the Soft concept, stemming partly from the fact that it suited fewer of the products than the Strings concept while being a similar solution. Its design also led to the racks having a fixed number of stacks, which would either result in many different racks or poor packing grades. The separation technique of using separators on the ends of the beams also proved to be problematic in relation to using separators closer to the middle of the beams, being that the beams more often had irregular shapes at their ends than in the middle.

5.3.2 TESTING II

The second bout of testing dealt with beams being placed in rows and testing the concept Borst, and the full results can be found in Appendix 3.

The tests showed that all of the products except Y555 Sill could be picked up directly from the conveyor belt and loaded into a rack, while the Y555 Sill beam required for a change of grip before being placed in the rack, in order to keep it from falling over. 8 of the products would benefit from leaning the rack upon loading and unloading, and all the products could be loaded into and out of leaning racks.

The concept testing showed that keeping all 6 of the products that stick together apart would work with the Borst concept, and it would also ease the loading and storage of the Scania RS Windscreen beam by providing increased stability. Upon using brush to separate the beams, the number of beams that fit in each 1200 mm row ranged from 9 to 48 for the seven products. The maximum number of rows that would fit in a rack with a height of 800 mm, separated by brush separators, ranged from 3 to 7 rows. The Borst concept provided packing-grade distances of between 15 to 107 mm, with a mean value of 44 mm and a median value of 30 mm.

Smooth separators in the form of wooden planks were shown to suit 4 of the non-sticking products, while not being as suitable for the two products with more rounded shapes (V526 A-St YT and Y555 C-St). The minimum distance needed to keep the different rows of beams from intersecting ranged from 0 to 55 mm. However, this distance varied depending on where the separators were placed in relation to the shapes of the various products.

5.3.3 CONCEPT EVALUATION

The concept testing provided statistics used for calculating packing grades for the different concepts. These are displayed in table 5.

Table 5. Packing-grades for the various products in relation to the two concepts. Illustration: Z. Envall.

	BORST	STRINGS
SCANIA RS WIND.	72%	
SCANIA RS A-ST		
VOLVO TRUCKS WIND.	58%	75%
VOLVO TRUCKS GJF		
Y555 SILL	80%	84%
Y555 STF BAK	93%	73%
Y555 C-ST		
V526 A-ST YT		
V526 SBF		
V526 SB	59%	78%
V526 GB	75%	
V526 TUF OV	84%	64%*
V526 TUF MES	84%	64%*

The percentages in table 5 are listed according to which solutions suit each product. The percentages are calculated for equal rack sizes. In reality the beams in the Strings concept can only be stacked with a height of 400 mm, while the Borst concept allows for a height of 800 mm. Therefore, the real percentages for the Strings concept would be somewhat lower than that listed in table 5. The V526 TUF OV and MES beams are calculated as stacks with a height of 200 mm on top of each other, kept apart by some sort of separators.

5.3.4 CONCEPT DEVELOPMENT

The concept development dealt with the Borst and Strings concepts from the Design Phase, see fig. 49).

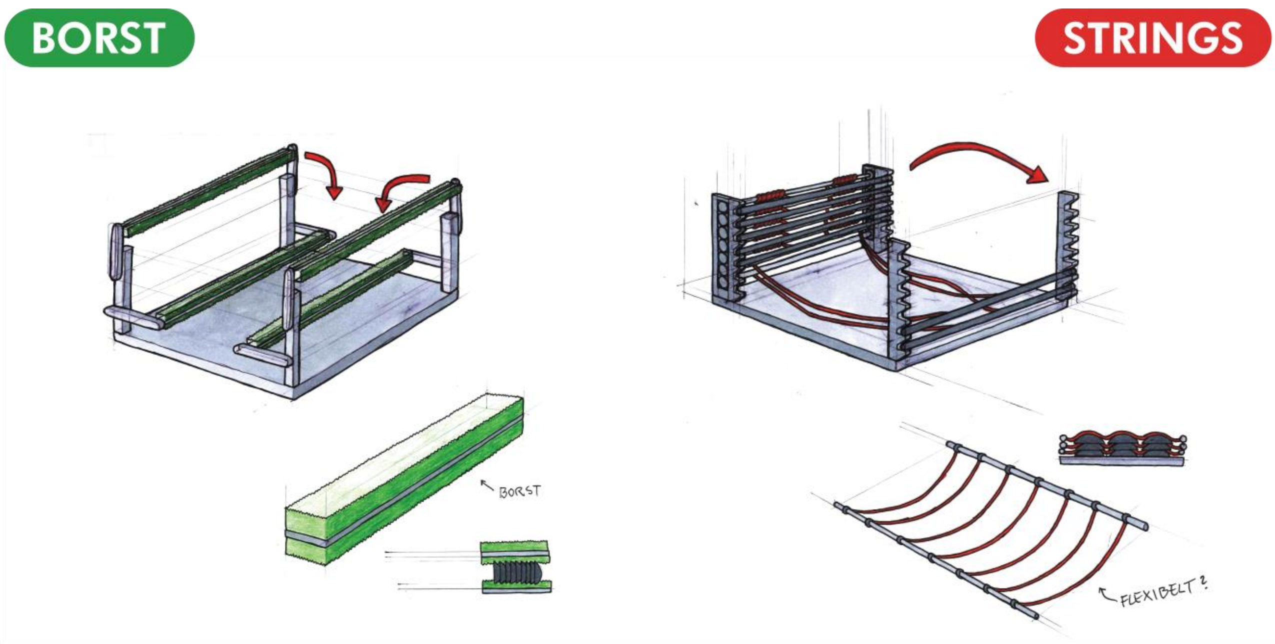

Figure 49. The Borst and Strings concepts. Illustration: Z. Envall.

The results included numerous ways of implementing the two separation techniques into racks, focusing on decreasing dead space and easing the robot handling. The concept development ultimately resulted in a modular solution, where the concepts merged together and were implemented in the same rack solution (see fig. 50).

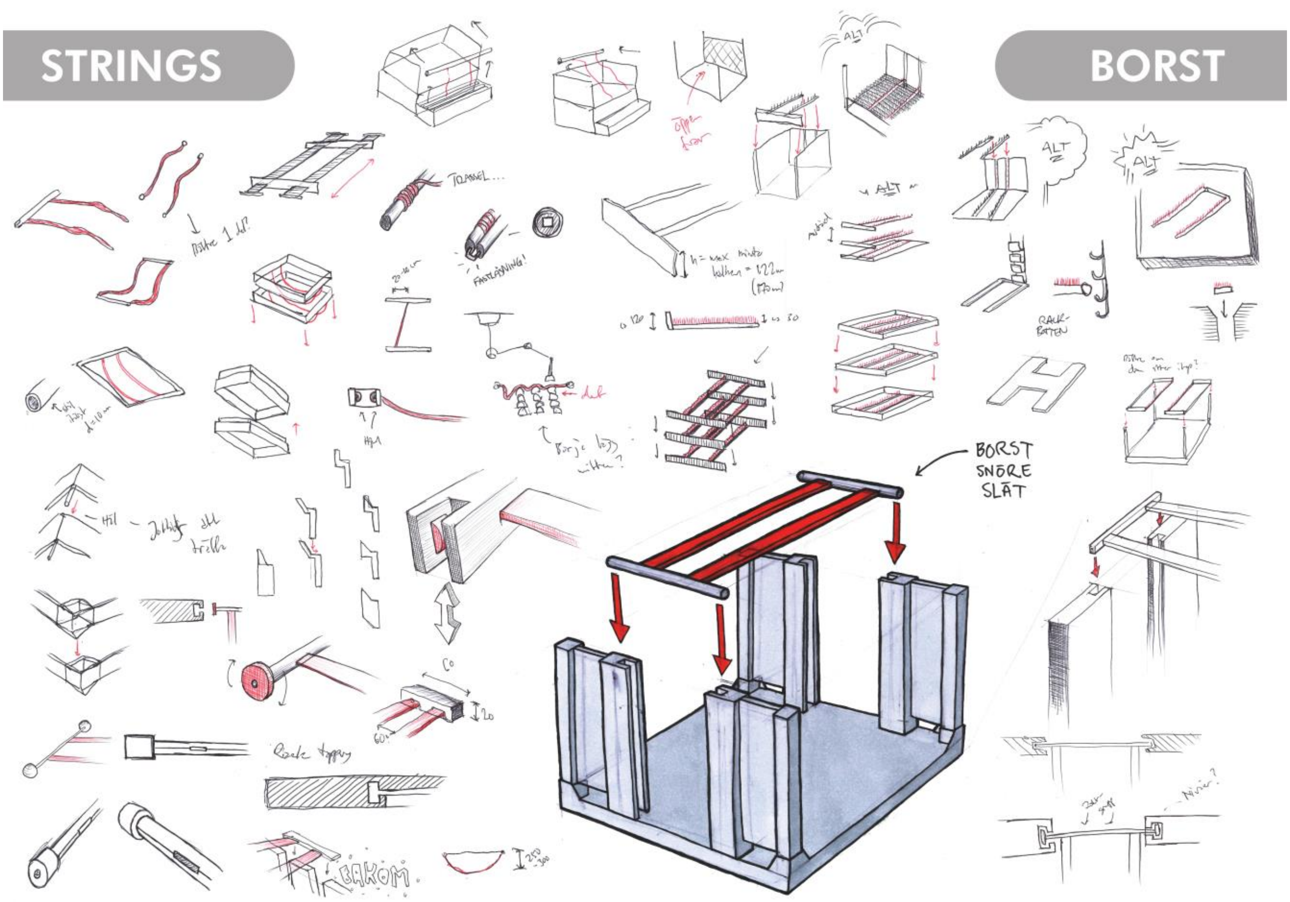

Figure 50. The different ideas for implementation of the Borst and Strings concepts, ultimately resulting in a combined rack concept. Illustration: Z. Envall.

The results from the development of the Strings concept resulted in a wide array of ideas solving the problems of entanglement of the separating strings, loading into the racks, stacking, and reacting to the next layer of beams. To keep the strings from getting tangled up the proposed ideas included different forms of constraints and rolling, but ultimately took the form of constraining the two strings by combining them into one separator and by making them rectangular instead of round. Ideas dealing with loading the separators into the racks initially tackled the problem by different Lego-like mechanisms, but lastly ended up using slots which the ends of the separators would be placed into.

Adding wheels to the ends of the separators was an idea for solving the problem of what happens to the ends of the separators once the next layer of beams is placed in the rack. This was however finally dealt with by using round ends on the separator, meant to be light enough that they would be able to adjust to the next layer of beams. The Borst concept development produced ideas that dealt with problems consisting of rack loading accessibility, separator placement, and separator loading. The ideas dealing with loading accessibility initially consisted of separators that had end parts which would keep each row of beams from falling out, but this problem ultimately ended up being solved by having an opening on the sides of the racks, providing accessibility and keeping the rows of beams intact at the same time.

The separator design and placement options took a few different forms which could be generally categorized as resting on the beams or resting on the rack. The end result ended up having the separators resting on the beams. The separator loading could therefore be done in the same way as for the Strings concept – by having the ends of the separators placed in slots on the racks.

The end result of the concept development took the form of a modular rack, enabling use of three different separators. These included separators used in the Strings concept and the Borst concept. The third separator resembled the Borst concept separators but without the brush, instead having smooth surfaces in a plastic or rubber material, meant to keep the rows apart for the products that were found not to stick together in the testing. This separator will furthermore be referred to as the Smooth concept.

5.3.5 FINAL ELIMINATION

The opinions of both Magnus Eriksson and Martin Holmbom was that the Borst concept was preferred, regarding both cost and handling. The packing-grade comparison in table 5 shows that the Strings concept allows for a slightly higher packing grade for half of the beams suited by both concepts, with a mean packing-grade of 73%. The Borst concept is however suitable for more products, but has the lowest packing grades for some products (V526 SB and Volvo Trucks Windscreen). The concept has a mean packing grade of 76%.

According to the packing-grades, the number of suitable products, along with the opinions of Magnus Eriksson and Martin Holmbom the final concept was chosen to be the Borst concept, including the additional Smooth separators for the beams that do not need the brush material for keeping them apart.

5.4 OPERATE

The Operate phase included further concept refinement concerning various details having to do with different aspects concerning functionality. A CAD-model of the refined concept was also produced.

5.4.1 REFINEMENT

The refinement work resulted in various concept alterations concerning the design of the gates and pole-hinges, along with ideas that dealt with being able to stack the racks, both when folded and opened (see fig. 51).

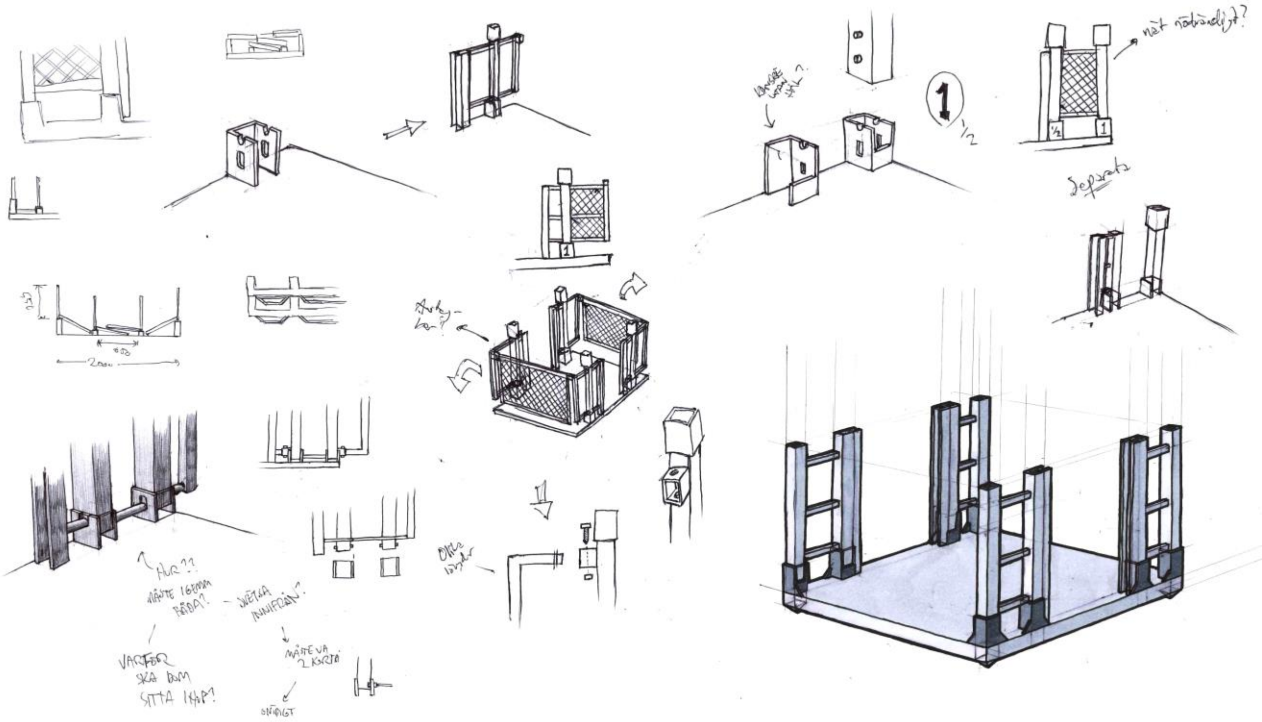

Figure 51. Sketches produced during the concept refinement. Illustration: Z. Envall.

The design for the gates and pole-hinges was ultimately decided to be based off the HT-rack, being that it is a solution that has been proven to work, along with the fact that developing ideas for various rack details would be too time consuming for this project.

5.4.2 CAD-MODELLING

The CAD-modelling in Siemens NX resulted in a CAD-model of the concept (see fig. 52). The model took the form of an assembly being made up of various parts, from the gates and poles to the small rotation-pins that enable the folding of the poles.

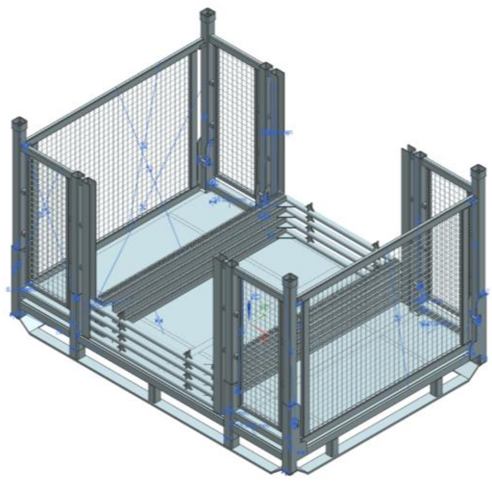

Figure 52. Finished CAD-model of the concept.

5.5 FINAL RESULT

The final concept was given the name 4.0-Rack, referencing both to what is described as "Industry 4.0" by Blanchet et al. (2014) amongst others, as well as the HT-rack. The concept is an implementation of the results from the project into the existing HT-rack design, and is a modular solution consisting of a rack and two types of separators (see fig. 53).

Figure 53. 4.0-Rack concept, displaying the rack and the two separators "Borst" and "Smooth". Rendering: Z. Envall.

Although there is a strong likeness to the HT-rack, the concept differs in a number of ways, including:

- The poles fold along the racks short sides instead of along the long sides
- The poles at each corner are welded together 2 and 2
- The rack only has 2 removable gates
- The rack has 4 long slots welded to each pair of poles used for separator placement

The rack concept has an opening on both long sides, which is meant to be shorter than all the beams which are planned to be stored in the rack. This opening reduces the weight somewhat, but is mainly there to aid the robot in recognizing and attaching its end-effector to the beams. The opening is meant to leave room for the robot to move in and out of the racks with ease when loading and unloading beams.

The process of loading into the racks (described in fig. 54) is planned to be done by robots, both concerning the packing of beams and the placement of separators. Folding and opening the racks is however planned to be done manually. The separators are one-sided and are meant to be placed with the coated face against a row of beams. A minimum of two separators are therefore needed between each row.

Figure 54. The loading process for the rack. Photo: Z. Envall.

5.5.1 SEPARATORS

The separators come in two versions, either with a brush coating, derived from the Borst concept, or with a smooth plastic coating. The brush (see fig. 55) is meant to be used for the beams that have a tendency to stick together along with beams that need the additional stability provided by the brush in order to be packed closely and securely. These separators have additional vertical details welded onto the tubes, which are meant to keep the brushes from getting deformed when the separators are stacked, in turn easing the storage possibilities.

Figure 55. The two different kinds of separators. Photo: Z. Envall.

The smooth separators are meant to be used to separate rows of beams that do not stick together, in the same way things such as wooden planks are used today. These can also be stacked and combined with the brush separators to provide a larger separation-distance whenever it is needed (see fig. 56).

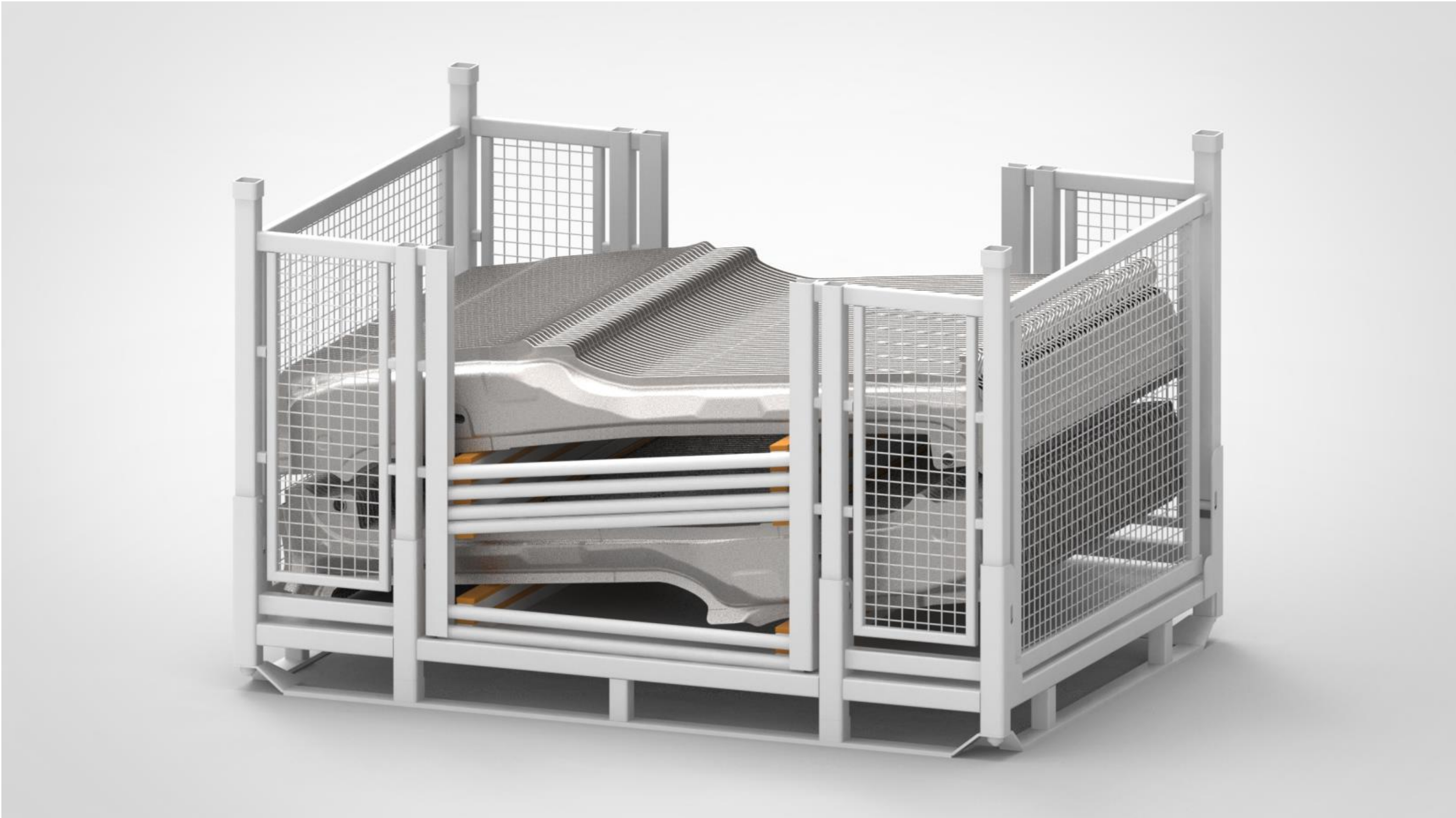

Figure 56. Example of how the "Smooth" separators can be used for storing the Scania RS A-st beam.

Some beams, such as the Scania A-st in fig. 56, have an asymmetrical shape that causes the separators to lay at an angle. The dimensions used for the separators and slots in the concept allow the separators to be lay at an angle of approximately 20 degrees without one side slipping out of the slots.

5.5.2 STACKABILITY & MATERIAL

The racks are stackable with themselves and with the regular HT-racks, both when they are folded and when they are opened (see fig. 57).

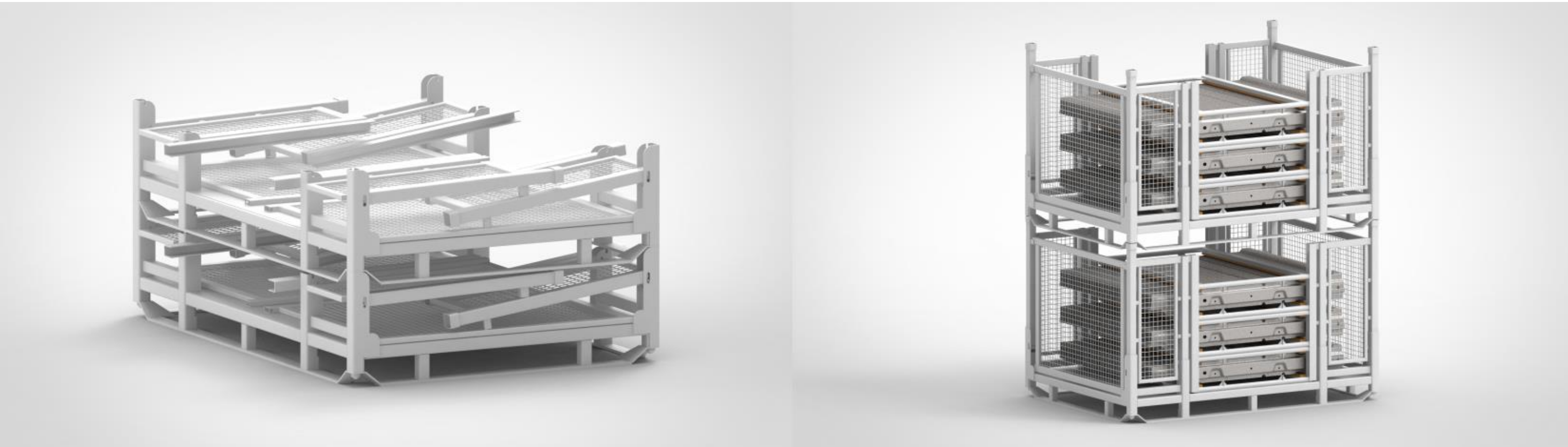

Figure 57. Displaying the stacking of folded and opened racks.

The rack is meant to be comprised of hollow steel beams which are welded together, similarly to the HT-racks. The same goes for the separators, apart from the black rounded ends, and the faces that come in contact with the beams. The ends are planned to be made of plastic, in order to ease movement through the long separator-slots. The faces on the smooth separators that come in contact with the beams are meant to be comprised of a plastic material. The brush separators are thought to consist of a plastic brush mat, that is fastened to the separators by screws. For the brush itself, a material called Pekalon is planned to be used, which is a plastic material with good wear resistance and flexural strength that can withstand temperatures of up to 200° C.

5.5.3 PRODUCT SUITABILITY

The 4.0-Rack can theoretically be used for all twelve of the reviewed products. Two of the beams are however not deemed suitable for the rack, namely the Y555 STF Bak and V526 A-st YT beam. The conclusion that was made was that the Borst separators should be used for 6 of the beams, and the Smooth separators for 3 of the beams. One of the beams (V526 SBF) doesn't stick and can only fit one row, whereby it needs no separators, but can still be stored in the rack.

Figure 58. Displaying which products are deemed suitable for use of each separator, along with the calculated packing-grades. Illustration: Z. Envall.

The final number of beams deemed suitable for the rack is thus 10 out of the 12 beams (see fig. 58). The mean packing grade is 83%, with only the Borst separators resulting in packing grades lower than 100%. The beams that are deemed to be used with the Borst separators have a mean packing grade of 71% and a median value of 78%.

The generic characteristics deemed suitable for the Borst separator (see fig. 59) include beams that stick and beams with straight edges, along with beams that have a straight shape. Both symmetrical and asymmetrical beams are meant to be stored in the rack.

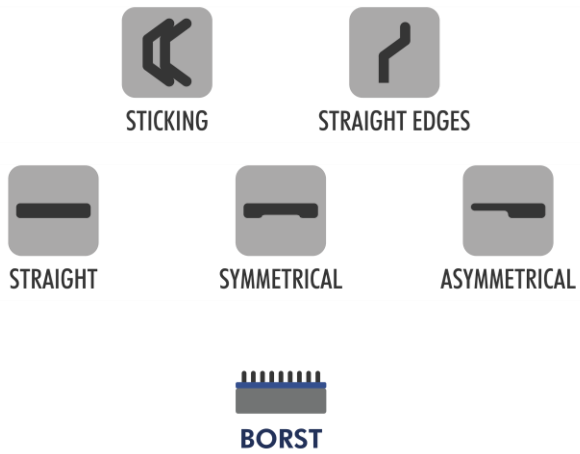

Figure 59. The generic categories deemed suitable for the "Borst" separators. Illustration: Z. Envall.

The Smooth separator suits more of the generic characteristics (see fig. 60), with the main characteristic being beams that do not stick. The other characteristics include beams with both straight and bent edges, beams that have both bent and straight shapes, along with symmetrical as well as asymmetrical beams.

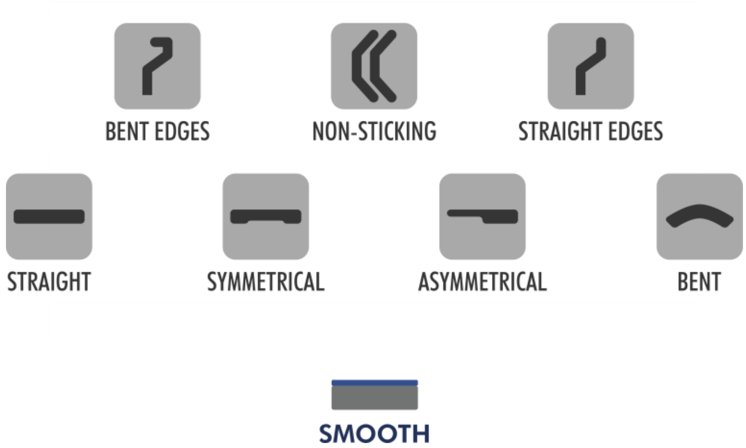

Figure 60. The generic categories deemed suitable for the "Smooth" separators. Illustration: Z. Envall.

6 Discussion

The Discussion chapter includes discussions about the results of the project, including feasibility, relevance, and reflections along with recommendations for further development of the rack concept.

6.1 FEASABILITY

According to Mitchell (1998), the main needs for a rack that is designed for robotic loading and unloading are enabling the robot to locate the parts and preventing damage during transport. One factor that can be added to this as a result from the testing is keeping the parts being stored in the rack from sticking to each other. Localization of the parts is highly dependent on the implementation of machine vision and illumination in relation to the rack design. Preventing damage has to do with rack design and the materials used for the rack. The best option for keeping the beams apart has been determined to be brush through the work performed in this project, but what materials and dimensions that are required for this is also a large factor.

The overall consensus from analyzing the rack concept in relation to the reviewed theory is that a robot equipped with the suitable sensors should be able to load beams and separators in an out of the 4.0-Rack. However, the largest difficulty in assessing this theoretically comes from the many variables that have an effect on especially the vision systems.

6.1.1 MACHINE VISION & ILLUMINATION

Martin (2012) and Dettmer (2013a) for example place a large focus on lighting arrangements, with Martin (2012) stating that it is a critical aspect in a successful implementation of machine vision systems. Since no lighting is implemented into the concept design, lighting thus becomes a free variable in determining the feasibility of the concept. The design does however allow for direct illumination of the beams from the top and through the openings on the front and back of the rack. The theory that was reviewed points to the fact that a bright-field lighting technique best seems to suit the purpose of identifying a beam in the rack, which is especially important during unloading. This is something that is backed by the fact that bright field is the most common lighting solution, according to Martin (2012). A bright field lighting solution for illuminating beams stored in the 4.0-Rack implies a light positioned so that the beams (or particles) travel horizontally and hit the faces of the beams stored in the rack. A possible complication is the fact that the beams are stored at different positions in space, as opposed to when they are picked from a conveyor belt. This could raise the need for a light positioned over the rack, shining directly down on the edges of the beams, in order to aid the robot in determining the position of each beam, along with enabling loading of the beams at uniform distances (see fig. 61).

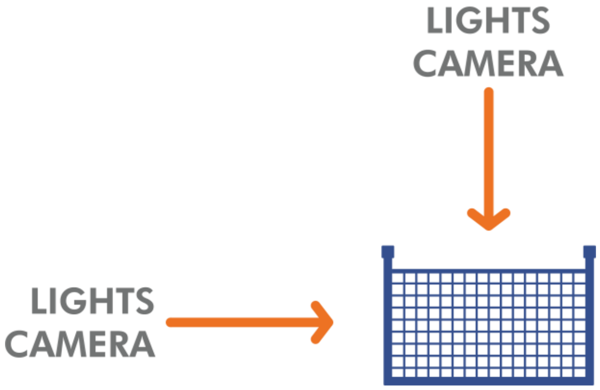

Figure 61. Discussed light and camera positions. Illustration: Z. Envall.

The camera positioning of the vision system needs to correspond with the lighting, in order to retain the necessary information about the robot's environment. For loading and unloading from the concept rack, using two cameras seems to be the most secure option. Perks (2006) mentions the usage of multiple cameras as something that can be used for building 3D images, commonly used for bin-picking. Although bin-picking is somewhat more complicated than picking uniformly placed parts, it is more similar to what is required for the 4.0-Rack than picking parts off of a conveyor belt is. For the rack concept, having one horizontally positioned camera that registers the front of the rack, along with a camera looking down at the rack should provide the robot with sufficient information for successfully loading into and loading out of the rack. A variation to the horizontally positioned camera could be instead positioning the camera near the end-effector on the robot, and in turn always having a clear field of view, as opposed to a fixed camera that would have its field of view partially blocked every time the robot moves in or out of the rack. Another option to this is positioning the horizontal camera at an angle, limiting the area of its field of vision that is blocked by the robot. Calculating the resulting perspective view could however be somewhat more complicated than having the horizontal camera positioned so that it gets more of a 2D view of the beams.

6.1.2 DAMAGE PREVENTION

Preventing damage to the rack and beams during transport is dependent on rack design, material properties, along with logistic rules and guidelines. The design of the 4.0-Rack is very similar to the design of the HT-rack, and is meant to be comprised of similar materials and produced in a similar manner. The two racks are displayed in fig. 62.

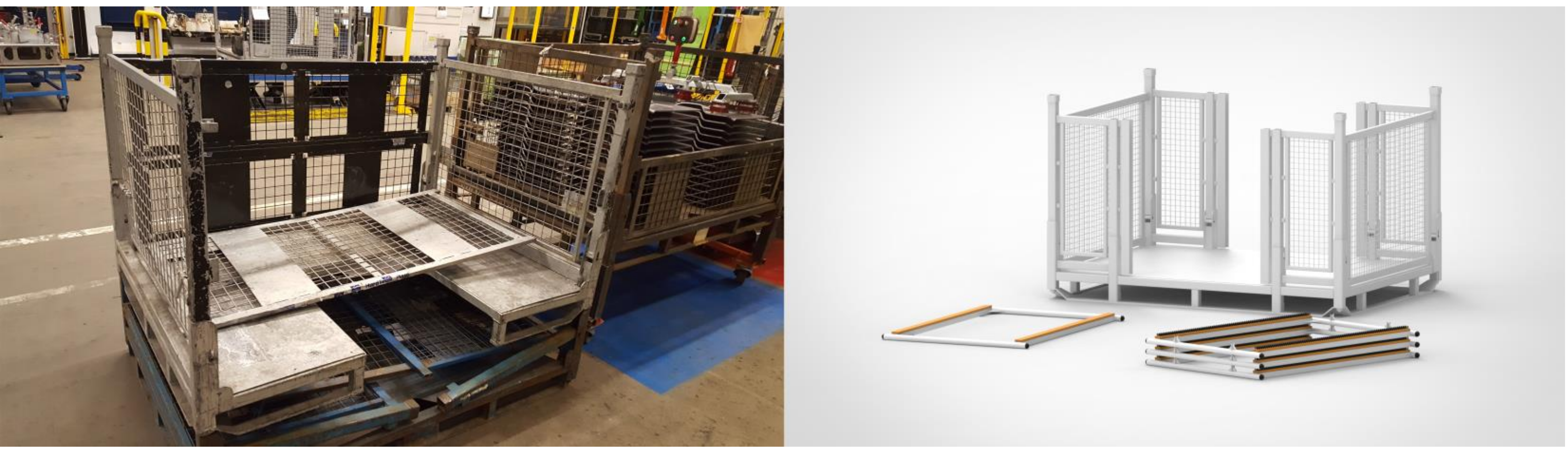
Figure 62. The HT-rack and 4.0-Rack side-by-side.

Since the HT-rack is a solution that has proven to work well for transporting and storing beams, if the 4.0-Rack provides the same structural integrity as the HT-rack it should provide sufficient damage prevention.

The main difference between the two racks is the design of the long sides. While the HT-rack has 2 corner poles along with a wide removable gate on each side of the rack, the 4.0-Rack has two smaller gates that each are fixed to two poles on both sides of the rack, leaving an opening in the middle. This opening provides no direct protection of the products except for the cylinders that make up the ends of the separators. The 4.0-Rack therefore offers the same, if not more protection overall, but leaves room for direct damage through both of the openings. Damage to the beams would occur if the forklift-truck driver collides with an object that is less than 755 mm wide and thus would fit through the opening.

6.1.3 BEAM SEPARATION

How to keep the beams separated from each other while still being packed as closely as possible has been the main focus of this project. Through physical testing with the chosen beams brush was determined to be best suited for this task. The tests proved that when the beams were placed onto a brush material, at a certain distance from each other, they were kept separate. The racks were however not moved in the testing, whereas the brush's ability to keep the beams separate during transport was not empirically tested. Being that this is a large concern, an additional brush separator was added to the top of each row of beams in the concept, in order to provide the beams with a higher level of stability. The usage of the brush separators is therefore only a theoretical solution which has not yet been tested during transport of the racks. Although the testing that was performed proved positive for the brush, the entire concept has not been tested, so the feasibility of the usage of brush in the concept is only an assumption.

6.2 RELEVANCE

The project first and foremost provides Gestamp HardTech with a concept rack that is meant to aid in implementing an increased level of automation, in turn leading to increased quality and lower personnel costs. Before the project, the question of what racks to use for robotic handling at HardTech were merely ideas, whereas now a concept backed by a design process and physical tests exists. Although the concept might have some possibilities for improvement and is not a finished product ready for production, it is something concrete to base further development on.

Apart from the rack, the thesis project has also had a large focus on assessing the beams produced at Gestamp HardTech Luleå. This product assessment and categorization resulted in various generic beam-categories. These could aid in an eventual categorization of future products, in turn also helping with the choice of racks for new products, especially for determining which products are suited for the 4.0-Rack. On a wider scale, the concept rack offers a flexible storage solution that is rather unique in comparison to what was observed in the benchmarking. If further tests and an eventual implementation of the 4.0-Rack proves to be successful, the solution could be beneficial for several other companies and production sites both within and outside of the automotive industry.

6.3 REFLECTION

The project can essentially be divided into three main focus areas: the development of flexible racking-solutions for keeping the beams separate, beam analysis and assessment, along with a theory immersion centered on understanding the limitations of robots and machine vision systems. The development of racking-solutions and the beam assessment were necessary keys for reaching the desired results, but the theory immersion was only necessary due to a lacking knowledge within the field of robotics. Someone with a better initial understanding of this area could have minimized this portion, and instead focused on other aspects relevant to the rack development. The project additionally ended up focusing more on the beams and developing solutions fit for these, and less on the robot-aspects in relation to the rack design. Having the theory review include relevant flexible-design aspects along with various methods for categorization while including somewhat less information about robots and machine vision would probably have been better suited for the developmental process that transpired.

Another factor that had a big effect on the final result was the testing. Although it resulted in many relevant statistics and parameters, it could have been better planned and more accurately performed. By also having the testing include more tests, especially regarding transport of the beams, it would have had clearer results, in turn resulting in a more accurate concept evaluation. Other tests that probably would have aided the concept evaluation are testing the brush with more than one row of beams, actually leaning the racks during testing, along with determining suitable angles. The reason that these tests were not performed was due to a combination of factors. The first is that the tests required outside help for fetching the various products and would therefore have needed additional assistance for performing the earlier mentioned tests. The second reason is that the testing was very time consuming, and the project planning only left so much time for performing them, whereby the tests focused more on comparing the concepts, rather than evaluating exactly how well the concepts worked. The testing process is also a part of the project that could have given more and better results if less time was spent on reviewing theory about robotics.

6.4 CONCLUSIONS

The conclusions that could be drawn after the project are displayed below. These include conclusions about the project's objective and aims along with answers to the various research questions that the theory immersion was structured around.

6.4.1 PROJECT OBJECTIVE & AIMS

The project's objective was defined as providing Gestamp HardTech with a rack concept that enables the use of robots for handling beams. The handling included loading beams coming out from the stamping lines into racks, and then unloading the beams for the next machining process. The rack concept was meant to be flexible by suiting many different products, while still allowing for a relatively high packing grade.

The testing in the Implement phase showed that 6 out of the 12 beams stick together when they are packed closely. It also showed that all of these six could be loaded and unloaded using a brush similar to the Borst separator successfully without sticking.
The project's resulting rack concept, with both kinds of separators, can be used for

all of the 12 reviewed products. Some of the beams were however not deemed suitable for the rack, namely the Y555 STF Bak and V526 A-st beam. The final number of beams deemed suitable for the rack is thus 10 out of the 12 beams, accounting for 83% of the reviewed products. The mean overall packing grade is approximately 83%, with all the beams in need of the Bost separators being lower than 100%, ranging from 84% to 58% with a mean value of 71%. Although no concrete packing grade percentage was specified in the objective, 83% could be viewed as relatively high.

The project's aim was to contribute to an automation of the production process at Gestamp HardTech Luleå, which in turn was assumed to lead to lower costs and contribute to the machine operators along with the company's various clients.

Being that the project only resulted in a concept, determining whether it met its aim is more predictive than the objective. However, since it can be viewed as achieving the objective, also meeting the aim should be a likely consequence. Whether this turns out to happen depends on the results from further testing and eventual implementation, along with various other unforeseeable events that lie outside the scope of this project.

6.4.2 RESEARCH QUESTIONS

The following question contains the various research questions that were stated initially, along with answers to these.

- *How does machine vision work?*

Machine vision systems use cameras to capture brightness variations in an image, in the form of reflected light. The main components of these systems are a camera and some means of illumination. The illumination is supplied by a light source, which is positioned to achieve a reflection that best suits the desired purpose. Reflected light particles are captured by a pixel sensor inside the camera and converted into an image, whereby the relevant data is extracted and interpreted through a number of computational steps. The interpretation leads to a decision being made, according to which an action can be taken.

- *What are the limitations for machine vision?*

Perks (2006) claims that limitations in vision systems more often have to do with poor implementations than the actual systems. He also states that the biggest hinderance historically for these systems has been due to a lack of computer power. As Dettmer (2013a) states, the camera resolution needs that are required by vision systems is commonly much lower than what is available on the market, and that the reason high resolution images are not used is due to longer processing times.
Dettmer (2013a) and Martin (2012) both stress the importance of lighting arrangements when it comes to vision systems. A common problem for lighting arrangements is ambient light, caused by things such as windows or skylights (Perks, 2006).

- *What constitutes a robot, and how do they work?*

Robot is a broadly defined term, explained by both SME (2018) and Hunt (1983) as a multifunctional device or machine that in some way manipulates other objects. A robotic system can be divided into seven components, which according to Niku (2011) are a manipulator, an end-effector, actuators, a controller, a processor, software, and sensors. The manipulator is the body of the robot and can be likened to the human arm. The end-effector is used to interact with the surroundings and can be viewed as the hand of the robot. Actuators connect the links and joints of the robot similarly to muscles. The robots motions are calculated and controlled by the processor, software, and the controller, acting as the robot's brain and cerebellum. Various sensors can in turn be seen as the senses of the robot, providing information about its surroundings (Niku, 2011).

- *What robots are used in industrial production settings?*

Industrial robots are the most common robots used in industrial settings, with 60% of all industrial robots being used in the automotive industry (Hägele, Nilsson, & Pires, 2008). Mitchell (1998) classifies industrial robot arms into five types: Cartesian (rectangular), cylindrical, spherical, jointed or articulated,
and selective compliance assembly robot arms (SCARA). What differentiates these types of robot arms is how their various joints move and how many degrees of freedom they can move in.

- *What are the robot's needs concerning the rack design?*

A robot equipped with machine vision and motion control can load in and out of simple racks, according to Mitchell (1998). The requirements mentioned for these racks is that they need to allow the robot to locate the parts, and to prevent damage during transport (Mitchell, 1998). Locating the parts by vision in turn requires the racks to allow a camera to see the parts, and lighting arrangements to properly illuminate the scene.

6.5 RECOMMENDATIONS

With the project resulting in a concept rack, a good deal of work remains before the rack can be implemented into the production. The main focus of the project dealt with on developing solutions that are flexible and keeps beams from sticking together. Other rack details were thus not as prioritized and might have some possibility for improvement. The predictable steps needed before implementation from the current situation are displayed below.

6.5.1 SLOT DESIGN

The first and most central recommendation is to review the design of the slots. The current design could work but it requires the robot to place the separators with a relatively high level of precision. How well the separators move through the slots could also be a problem, and needs to be reviewed and tested, suggestively through simple miniature prototypes.

6.5.2 BRUSH SPECIFICS

The next predictable step is determining the right brush type for the task. The most suitable brush length needs to be determined, as the brush samples that were used in the testing that was performed did not provide enough of a foundation for securely determining this. The material that was assigned to the brush for the concept was Pekalon, but this was solely due to the material's theoretical characteristics, and it also needs to be reviewed and tested. From the experience gained through the tests a suggestion would be to try shorter brush lengths, such as 10-20 mm. A shorter brush length should be more durable and also allow for a closer packing of the beams.

6.5.3 LEANING

The testing showed that the loading of all beams would benefit from leaning the rack. The testing did however not determine at which angle the different beams needed the rack to lean. How the leaning should work and at what angle the rack should lean is thus something that also needs to be determined, suggestively through testing.

6.5.4 RACK DETAILS

A possible problem with the rack design is the folding of the poles. With the current design the stacking of folded racks places the folded poles in the lower rack very close to the bottom of the rack that is placed on top of it. This is not necessarily problematic but simple design variations could increase the tolerances. Another factor that needs to be determined is the width of the racks. The concept rack is dimensioned according to the HT-rack (approximately 1700 mm wide), but the reviewed beams had a length varying from 1200 to 2185 mm and would provide the best packing grades in racks suitable to the beam lengths.

6.5.5 TESTING

Before eventual implementation the rack needs to be tested more thoroughly. Suggestively this would include fully packed racks with similar separators which are transported. Robotic loading and unloading from the racks of course also needs to be tested, for which personnel knowledgeable in the field of machine vision should be present.

7 References

Arezes, P. M., Dinis-Carvalho, J., & Alves, A. C. (2010). Threats and Opportunities for Workplace Ergonomics in Lean Environments: *Proceedings of the 17th International Annual EurOMA Conference-Managing Operations in Service Economics, Catholic University of Portugal (CUP), Porto, Portugal, 6-9 June 2010.* (p. 1-10). Porto, Portugal: EurOMA.

Basler AG. (2015, August 3). What is a Vision System? - Vision Campus [Video file]. Retrieved from https://youtu.be/atoUpGgw2fE

Bellgran, M. & Säfsten, K. (2010). Production Development: Design and Operation of Production Systems. London: Springer-Verlag.

Beyerer, J., Puente León, F., & Frese, C. (2016). *Machine Vision: Automated Visual Inspection: Theory, Practice and Applications.* Berlin Heidelberg: Springer-Verlag.

Blanchet, M., Rinn, T., Von Thaden, G., & De Thieulloy, G. (2014). *Industry 4.0: The new industrial revolution-How Europe will succeed.* München: Roland Berger Strategy Consultants GmbH.

Christensen, H. I. & Hager, G. D. (2008). Sensing and Estimation. In B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics* (2008th ed., p. 87-106). Berlin Heidelberg: Springer-Verlag.

Coiffet, P. & Chirouze, M. (1983). *An Introduction to Robot Technology.* New York, N.Y.: McGraw-Hill Inc.

Collins, D. (2006). Checklist Assists in Designing for Automation. Retrieved 2018-01-25 from http://medicaldesign.com/components/checklist-assists-designing-automation

Craig, J., J. (2005). *Introduction to Robotics: Mechanics and Control* (3. ed.). Upper Saddle River, N.J.: Pearson Education, Inc.

Cuffaro, D. F., Paige, D., Blackman, C. J., Laituri, D., Covert, D. E., Sears, L. M., Nehez-Cuffaro, A., & Zaks, I. (2013). *The Industrial Design Reference + Specification Book.* Beverly, MA: Rockport Publishers Inc.

Dettmer, P. [Robotics & Automation - AMST]. (2013a, March 18). Intro to Machine Vision and Robotics - part 1 [Video file]. Retrieved from https://youtu.be/SVcOWYfsBkc

Dettmer, P. [Robotics & Automation - AMST]. (2013b, April 1). Intro to Machine Vision and Robotics - part 2 [Video file]. Retrieved from https://youtu.be/RS-MXFX0ehs

Dorst, K., & Cross, N. (2001). Creativity in the Design Process: Co-Evolution of Problem-Solution. *Design Studies, 22*(5), 425-437. doi:10.1016/S0142-694X(01)00009-6

Dubberly, H. (2004). *How do you design? A Compendium of Models.* San Francisco, CA: Dubberly Design Office.

Hunt, V., D. (1983). *Industrial Robotics Handbook* (4. ed.) New York, N.Y.: Industrial Press Inc.

Hägele, M., Nilsson, K., Pires, J., N. (2008). Industrial Robotics. In B. Siciliano & O. Khatib (Eds.), *Springer Handbook of Robotics* (2008th ed., p. 963-986). Berlin Heidelberg: Springer-Verlag.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, *6*(4), 239-242. doi:10.1007/s12599-014-0334-4

Martin, D. (2012). A Practical Guide to Machine Vision Lighting. Retrieved 2018-03-07 from http://www.advancedillumination.com/sites/all/themes/advill/images/resource/files/practicallightingv3.pdf

Merriam Webster (n.d.). Dictionary: Industrial Design. Retrieved 2018-05-16 from https://www.merriam-webster.com/dictionary/industrial%20design

Mersch, S. (1986). Overview of Machine Vision Lighting Techniques. In D., J. Svetkoff (Ed.), *Optics, Illumination, and Image Sensing for Machine Vision: Proceedings of Cambridge Symposium_Intelligent Robotic Systems, Cambridge, MA, October 28-31, 1986.* (p. 36-38). Cambridge, MA: Cambridge Symposium.

Milton, A., & Rodgers, P. (2011). *Product Design.* London: Laurence King Publishing

Milton, A., & Rodgers, P. (2013). *Research Methods for Product Design.* London: Laurence King Publishing.

MIT OpenCourseWare (2012, July 24). *4. Quality Function Deployment (QFD) and House of Quality* [Video file]. Retrieved from https://youtu.be/u9bvzE5Qhjk

Mitchell, P., E. (Ed.). (1998). *Tool and Manufacturing Engineers Handbook Vol 9: Material and Part Handling in Manufacturing* (4th ed.) Dearborn, Michigan: Society of Manufacturing Engineers.

Niku, S., B. (2011). *Introduction to Robotics: Analysis, Control, Application* (2. ed.). Hoboken, N.J.: John Wiley & Sons, Inc.

Pahl, G., & Beitz, W. (2013). *Engineering design: a systematic approach.* Berlin: Springer Science & Business Media.

Perks, A. (2006). Advanced vision guided robotics provide 'future-proof' flexible automation. *Assembly Automation, 26*(3), 216-220. doi:10.1108/01445150610679759

Pierce, L. (2008). Smart Sight Makes for a Smart System. *ABB Automotive Magazine, 1*, 4-6. https://library.e.abb.com/public/0a9b4ef9f9679de7c12574780024b952/FordBuffalo_abb_auto_108.pdf

Popovic, D. (2000). Distributed Control Systems. In R., L., Shell & E., L., Hall (Eds.), *Handbook of Industrial Automation* (p. 185-216). New York, NY: Marcel Dekker, Inc.

RobotWorx. (2018). What are the Main Parts of an Industrial Robot?. Retrieved 2018-01-26 from https://www.robots.com/faq/show/what-are-the-main-parts-of-an-industrial-robot

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries. Retrieved 2018-03-12 from http://www.inovasyon.org/pdf/bcg.perspectives_Industry.4.0_2015.pdf

Siciliano, B., Sciavicco, L., Villani, L., & Oriolo, G. (2010). *Robotics: Modelling, Planning and Control.* London: Springer-Verlag.

Smets G., & Overbeeke, K. (1994). Industrial Design Engineering and the Theory of Direct Perception. *Design Studies 15*(2), 175-184. doi: 10.1016/0142-694X(94)90023-X

Taylor, G. & Kleeman, L. (2006). *Visual Perception and Robotic Manipulation: 3D Object Recognition, Tracking and Hand-Eye Coordination.* Berlin Heidelberg: Springer-Verlag.

The CDIO™ Iinitiative (2018). Retrieved 2018-01-17 from http://www.cdio.org/

Thörnberg, B. [Benny Thörnberg]. (2013, September 13). Introductory Lecture in Machine Vision [Video file]. Retrieved from https://youtu.be/GrG9nGAQ6Jw

Westgaard, R. H., & Winkel, J. (2011). Occupational Musculoskeletal and Mental Health: Significance of Rationalization and Opportunities to Create Sustainable Production Systems – A Systematic Review. *Applied Ergonomics 42*(2), 261-296. doi:10.1016/j.apergo.2010.07.002

Wikberg Nilsson, Å., Ericson, Å., & Törlind, P. (2015). *Design – Process och metod.* Lund: Studentliteratur AB.

Wikberg Nilsson, Å., & Törlind, P. (2016). Student Competence Profiles – A Complementary or Competitive Approach to CDIO?. In J. Björkqvist, K. Edström, R. J. Hugo, J. Kontio, J. Roslöf, R. Sellens, & S. Virtanen (Eds.), *The 12th*

International CDIO Conference: Proceedings of The 12th International CDIO Conference, Turku, Finland, June 12-16, 2016. (p. 844-858). Turku: Turku University of Applied Sciences.

Yassine A, & Braha D (2003). Complex Concurrent Engineering and the Design Structure Matrix Approach. *Concurrent Engineering: Research and Applications, 11*(3), 165-177. doi:10.1177/1063293X03034503

	Amount	Rack	Rader	Sides	Separators	Long Edges	Short Edge 1	Short Edge 2	Length	Width	Depth	Symmetry	Produktion	SL	Holes	Hangable
Scania RS Wind	50	HT	Stacks	Off		x-x	3 Bent	3 Bent	2100	170	220	Yes	SL-L	9 (6)	2	Holes, Shape
Scania RS A-st	200	HT	2	Off	Plastic	x-x	3 Bent	Straight	1600	350	80	No	SL-L	9 (6)	2	Holes, Shape
Volvo Trucks Wind	150	Volvo	3	(Off)	Rack	x-x	2 Bent	2 Bent	2185	181	132	Yes	SL-L	6 (9)	6	Holes
Volvo Trucks GJF	300	HT	3	On	Wood	x-x	Straight	Straight	1400	163	90	Yes	SL-L	6 (9)	2	Holes
Volvo Trucks Ext		HT	2 stacks	Off	Blocks	x-y	Straight	Straight				Yes	SL-L-W	6 (9)	0	No
Y555 Sill	180	HT	3	On	Wood	x-x	Straight	Straight	1565	230	82	No	SL-HP	6 (9)	3	No
Y555 STF BAK	60	HT	4	On	Plastic	y-y	Straight*	Straight*	1320	180	160	Yes	SL-HP-CMT	6 (9)	3	Holes
Y555 C-st	200	HT	2	On	Plastic	x(y)-x	1 Bent	Straight	1200	530	360	No	SL-L-A	6 (9)	4	Holes, Shape
V526 A-st YT	79	Volvo	2	(Off)	Rack	x-y	Straight	Straight	2360	830	200	No	SL-L	6 (9)	2	Holes, Shape
V526 SBF	80	HT	1	On		x-x	Straight	Straight	1450	500	300	Yes	SL-L-A	6 (9)	1	Shape
V526 SB	340	HT	4	On	Plastic	x-x	Straight	Straight	1310	160	40	No	SL-A	2 (6)	9	Shape
V526 TROF IN	80	Volvo	1	(Off)		x-x	Straight	Straight	2100	265	85	No	SL	6 (9)	5	Holes, Shape
V526 GB	160	HT	4	Off	Wood	x-x	Straight	Straight	1700	122	40	Yes	SL-A	6 (9)	20	No
V526 TUF OV	200	HT	5	Off	Plastic	x-y	3 Bent	Straight	1615	110	155	No	SL-HP-A	6 (9)	8	No
V526 TUF MES	200	HT	5	On	Plastic	x-y	3 Bent	Straight	1550	110	155	No	SL-HP-A	6 (9)	8	No

	Sticks	Stackable	Stacks	Stack Height	Non-Stick Dist.	Min. Dist.	Percentage	Strings	Soft	Leans	Uneven	Deforms	
Scania RS Wind	No	7*	4	600 mm	65 mm	65 mm	100%			No	No	No	*very unstable
Scania RS A-st	No	33	4	330 mm	10 mm	10 mm	100%			Yes	Yes	No	
Volvo Trucks Wind	Yes	24	4	550 mm	17 mm	7 mm	41%	10 mm	8,6 mm	Yes	No	No	
Volvo Trucks GJF	No	41	5	350 mm	8 mm	8 mm	100%			Yes	No	Yes	
Y555 Sill	Yes	40	4	550 mm	11 mm	7 mm	64%	8,6 mm	8,6 mm	Yes	Yes	Yes	
Y555 STF BAK	Yes	14	5	800 mm	65 mm	55 mm	85%	5,7 mm	No	No	No	No	
Y555 C-st	No	95	3	800 mm	6 mm	6 mm	100%			No	Yes	Yes	
V526 A-st YT	No	15	2	400 mm	19 mm	19 mm	100%			Yes	Yes	Yes	
V526 SBF	No	40	2	800 mm	9 mm	9 mm	100%			Yes	No	Yes	
V526 SB	Yes	52	7	600 mm	13 mm	9 mm	69%	2,9 mm	10 mm	No	No	No	
V526 GB	No*	40	7	800 mm	20 mm	20 mm	100%			No	No	No	*does not stick if gripped far apart
V526 TUF OV	Yes	8	8	250 mm	21 mm	15 mm	71%	4,3 mm	5,7 mm	Yes	Yes	No	
*V526 TUF MES**	Yes	8	8	250 mm	21mm	15 mm	71%	4,3 mm	5,7 mm	Yes	Yes	No	*based on TUF OV

	Borst Amount/Row	Borst Rows	Borst Dist.	OK Dist/Row	Smooth	Leaned	Direct Placement
Scania RS Wind	9	4	107 mm	28 mm		Yes	Yes
Scania RS A-st				55 mm	Yes	Yes	Yes
Volvo Trucks Wind	23	4	45 mm	0 mm			Yes
Volvo Trucks P2540				0 mm	Yes	Yes	Yes
Y555 Sill	48	3	15 mm	30 mm		Yes	No
Y555 STF BAK	15	4	60 mm	35 mm		Yes	Yes
Y555 C-st							
V526 A-st YT							
V526 SBF					Yes	Yes	Yes
V526 SB	31	5	23 mm	15 mm		Yes	Yes
V526 GB				0 mm	Yes	Yes	Yes
V526 TUF OV	24	7	30 mm	10 mm			Yes
V526 TUF MES	24	7	30 mm	10 mm			Yes