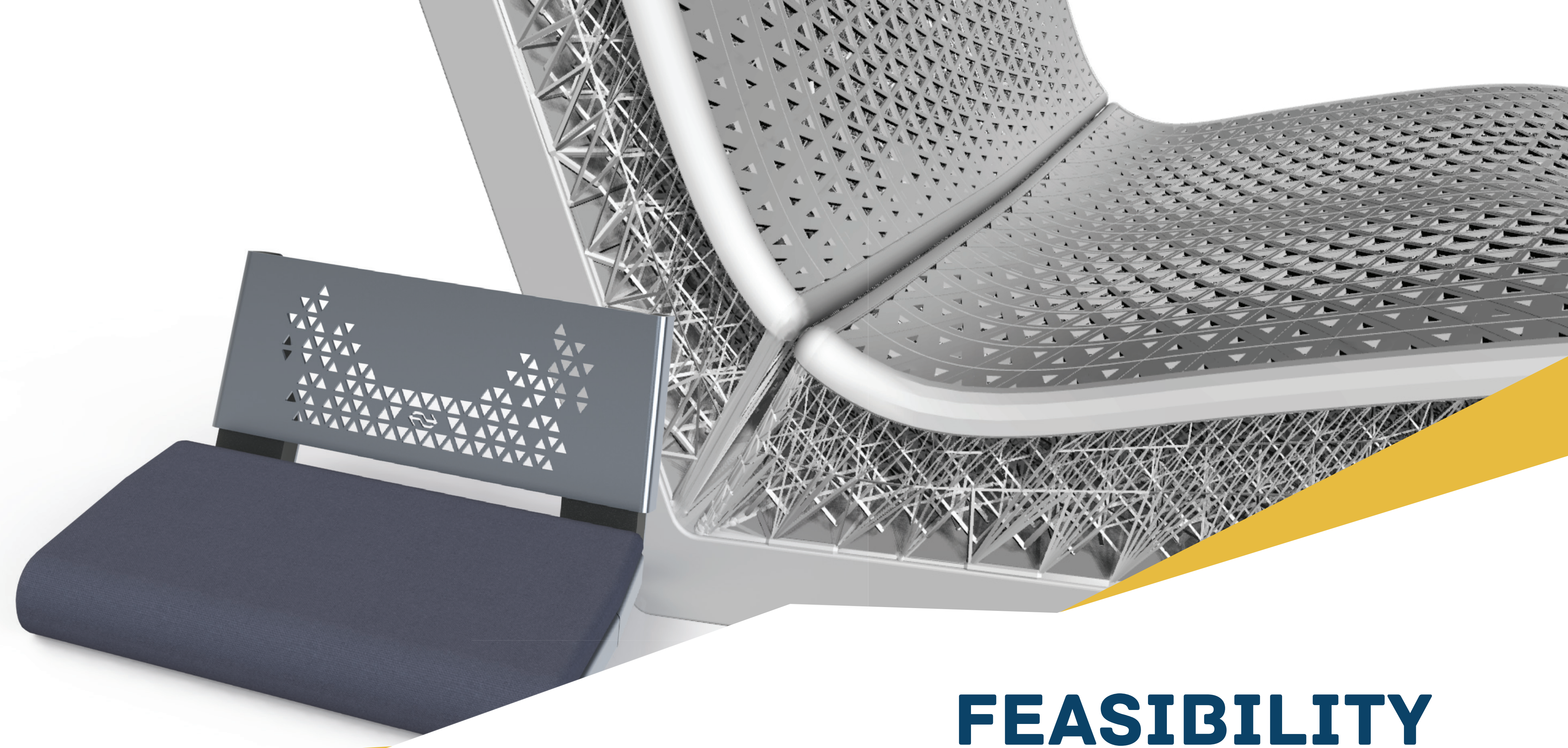


FEASIBILITY OF AGILE MANUFACTURING

NAME
Christy Do Quang

STUDY NUMBER
4162870

EDUCATION
TU Delft
Industrial Design Engineering

COACHES
Sander Minnoye
Adrie Kooijman
Joost van der Made
Brigitte Matheussen

ACKNOWLEDGEMENT

This report only shows a small part of how the project has been. There were many challenges, and I would not be able to reach this milestone without the help of all the people supporting me.
First, I would like to thank my supervisory team for their guidance throughout the entire project.
Sander and Adrie, I would like to thank you for all your valuable suggestions and knowledge. Your insightful annotations guided me to improve throughout the entire project. It is a pleasure to work with you. You see my efforts and helped to keep me motivated throughout the project to do the best I can.
To Joost and Brigitte, my company mentors, I want to express my gratitude for involving me in the NS. It has been fun working together and your help through the entire trajectory of the project has been extremely important for me. Your efforts made it possible for me to find valued insights.
Furthermore, I want to thank the people of the NS who cleared their busy schedule to meet me. You provided me with important feedback and ideas.
A big thank you for all the participants of my CF sessions and brainstorming session. Sharing your thoughts and actively participating helped me to create a fruitful session. Also, many thanks to the staff of the technical support of Applied labs at IO and Demo at EWI and 3ME.
For my gratitude in my personal surroundings, Gwen and Irene, thank you for taking the time to read the assignment. I am especially thankful for Rewi, Sanne and Danny. You really helped me a lot with this project and helped me make the best of this assignment.
I want to thank Duncan in particularly for his continuous support. You have always been there for me and helped me out multiple times in my project, and I immensely appreciate your everyday support.
Last but not least, I want to thank both my parents. Mom and dad, you have always believed in me, and I hope this will make you proud.

ABSTRACT

Agile manufacturing is a method of integration where organisation, people and technology act as a whole. The NS has proposed an interior vision for 2025. The goal of this thesis is to “assess the feasibility of Agile Manufacturing for the interior vision of 2025”. Is the application of Agile Manufacturing feasible within the organisation NS? Are the application costs realistic for the company? Moreover, are the changes to adapt agile production desirable within the organisation? To answer these questions, extensive research has been done which has been divided into four main chapters in this report: Discover, Design, Develop and Deploy.

The Discover phase consists of a thorough analysis of the subject by doing desktop research, field research, interviews and more methods to thoroughly analyse the subject. Requirements were based on the discovery and the norms regarding the safety of the EU. Multiple interviews and brainstorming sessions were held with experts of different backgrounds,
The Design phase focused on the technological aspect of Agile Manufacturing. Therefore, with a focus on Digitalisation, Fabrication and Design automation, multiple ideas where created. This resulted in an App and two demonstrations that were developed in the development phase.
In the Develop phase, the App was designed and programmed to give designers and engineers a quick tool to process different manufacturing techniques, including most types of 3D printing. The two demonstrations were made to exploit the possibilities within a type of production. Laser cutting and CFF (Continuous Fiber Fabrication) were chosen to test de possibilities. The App and two demonstrators were tested on NS employees for their desirability.
The Deploy phase resulted that the App was wanted. However, more development was needed to make the App work properly. The Laser cut demonstrator needs more design attention with regards to aesthetics and comfort. The CFF demonstrator was not desirable due to its price. Future developments that make the print cheaper, ecological and quicker to produce would regain their interest.

CONTENT

GLOSSARY

This glossary only gives a quick description on several terms named in the assignment. Please note that some terms are explained more elaborately further in the chapters.

Additive Manufacturing:
(Abbreviation being AM) - is better known as 3D printing. It is the production of products typically made layer after layer. The process is computer controlled by slicing software. (Tofail et al., 2018; Karunakaran et al., 2010).

Agile Manufacturing:
A management philosophy of production operations which has the main focus on quick responses to consumer needs and market changes - while still controlling costs and quality. (Gunasekaran, 1998).

Application Programming Interface:
(Abbreviation being API) - is an interface that allows a more readily use with a low level of abstraction. An example is the use of the Azure cognitive services - it is relatively easy to use a face recognition tool API without needing to understand how the software works.

Circular economy:
Sustainable design to keep product and materials in use, prevent waste and pollution and regenerate natural systems.

Digital Manufacturing:
The approach to a production that is centred around a digital platform. This platform includes digital design, a digital network and digital tooling. (Minnoye, 2018).

Digital Twin:
A digital duplicate of a physical product (Constructible.trimble.com, n.d.).

Enterprise asset management:
(Abbreviation being EAM) - is a system that manages assets and inventory. The main goal is to achieve a high rate of uptime and reliability of the equipment.

Enterprise resource planning:
(Abbreviation being ERP) - is a supportive software that is used within enterprises. Subprograms within the ERP divide the tasks related to resource planning.

Formative Manufacturing:
(Abbreviation being FM) - includes production processes like injection moulding and casting. These production methods are relatively cheaper and faster than additive or subtractive manufacturing when producing in large volumes. (Tofail et al., 2018).

Flexible Manufacturing Systems:
A systems within a company that allows a certain level of flexibility to react to changes. (Gunasekaran, 1998; Shang et al., 1995; Yusuf et al., 1999).

Industry 4.0:
The revolution in manufacturing technologies towards a world where everything is interconnected.

Infrastructure as Code:
(Abbreviation being IaC) - is the concept of managing and implementing infrastructures via scripting and configurations. Example of software that enables this automatisation is Microsoft Flow. (Hummer et al., 2013).

Key Performance Indicator:
(Abbreviation being KPI) - The variables that analyses performances.

Lean Manufacturing:
A management philosophy of production operations which has the main focus on maximum quality with a minimum rate of waste. (Womack, 2007).

Product Data Management:
(Abbreviation being PDM) - is according to Gunpinar et al. (2008) the improved management of the design and engineering process through better control of data, activities, changes and configurations.

Product Lifecycle Management:
(Abbreviation being PLM) - is the process of monitoring and controlling the life cycle of a product.

Robotic Process Automatisation:
(Abbreviation being RPA) - is a technology where existing activities of human in the real world are automated by robots. Easy tasks can be automated without having to adjust the underlying systems. (Lacity et al., 2015).

Subtractive Manufacturing:
(Abbreviation being SM) - includes all production processes that remove material to create a certain product. Computer Numerical Control (CNC) machines utilize multiple tools to move and remove material. (Karunakaran et al., 2010).

Total Cost of Ownership:
(Abbreviation being TCO) - is the total amount of costs of a product including the whole usage cycle. Examples of cost factors are costs for maintenance, repair, insurance, licenses, warranties, fees, distribution, etc.

DESIGN BRIEF

Customer service is key in the new vision of the NS (Hoogkamer, 2018). The current train interior is outdated - according to award winning architect Francine Houben. The focus on the new interior should be the modern passenger (Stuij, 2018). Therefore, Mecanoo and Gispen designed an innovative and sustainable train that fits the needs of the train traveller. They conducted an extensive analysis for the NS researching the activities and profiles of train passengers. They developed a pallet of interior elements which optimally supports the various activities. The new train is more than a vehicle that gets you from point A to point B. It becomes a vehicle with room for your activities and own free interpretation (InnovationExpo, 2018). An extensive explanation of the new vision can be found in Chapter 2.

The production of interior components will become easier due to the growth of technological developments. For example, design partner Gispen has already shown the added potential of 3D printing technology in the production of its bank 'Sett' (Galen, 2018). Agile Manufacturing helps this production because it allows the NS to respond to the customer and market changes while controlling costs and quality. The NS is interested in the role that Agile Manufacturing can play in the realisation of the NS' train interior vision for 2025. Therefore the project brief is:

> **“**
> ‘Assess the feasibility of Agile Manufacturing for the interior vision of 2025.’

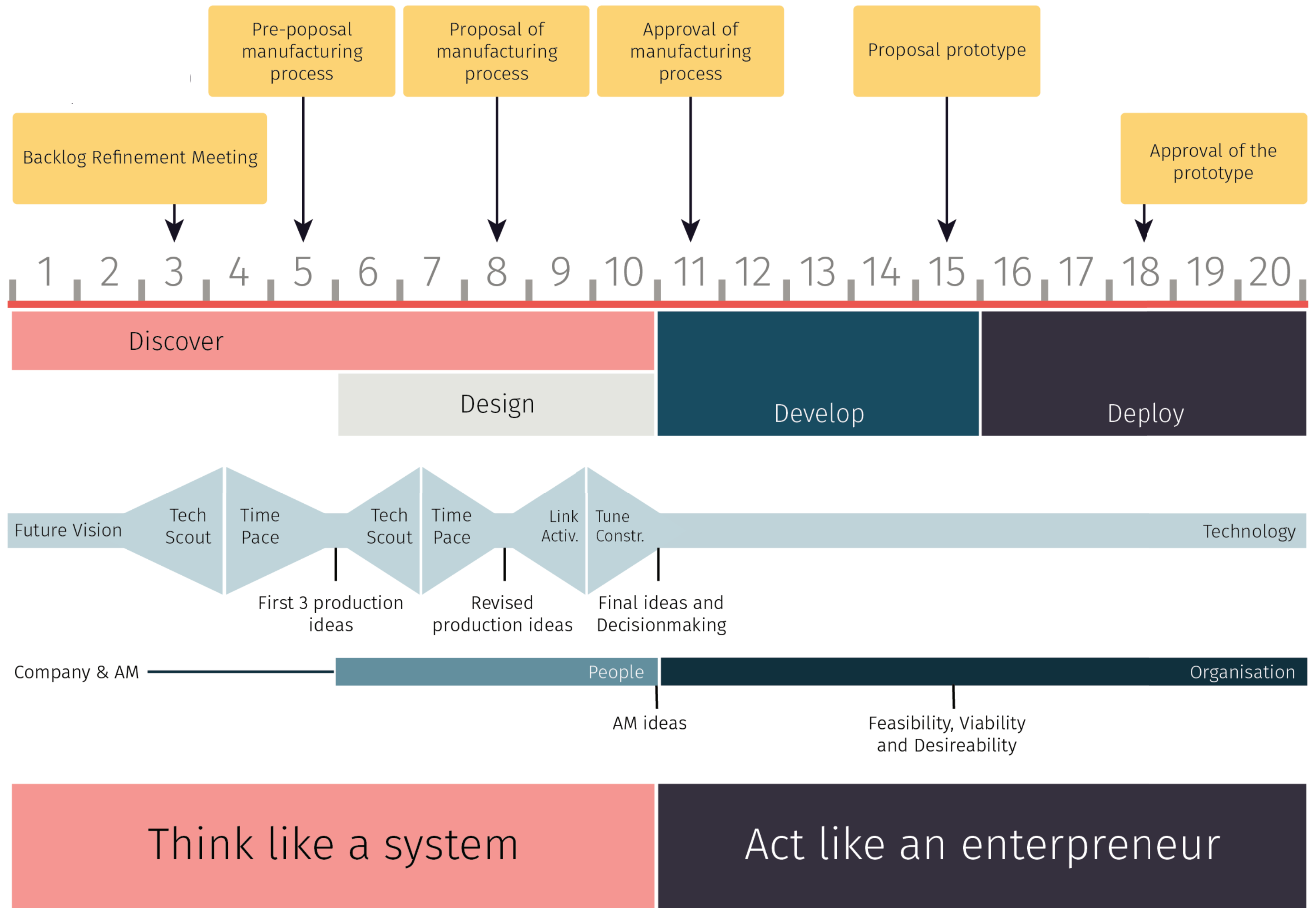
What is Agile Manufacturing exactly and what can the NS do with it? Agile Manufacturing is a method of integration where organisation, people and technology act as a whole. The definition is elaborated in Chapter 4.

New developments also bring limitations and uncertainties. Is the application of Agile Manufacturing feasible within the organisation NS? Are the application costs realistic for the company? Moreover, are the changes to adapt agile production desirable within the organisation? The goal of the project is to answer these questions.
The scope revolves around the possible appliances of Agile Manufacturing in the new interior vision for the NS in 2025. Only three interior elements are selected to keep the project manageable within a hundred days. These interior elements are the barstool, the stit and the handle. The primary objective is to test the feasibility of Agile Manufacturing. The viability and desirability will also be discussed. Research on these three pillars will be implemented on the three aspects of Agile Manufacturing - Organisation, people and technology - with the primary focus on 'technology'.

PLANNING

The project planning is divided into the Discover, Design, Develop and Deploy categories. The three aspects of Agile Manufacturing are all researched, starting with 'technology'. First, a desk study is performed on the technology aspect to gather innovations. Then, ideas are generated quickly with a creative facilitation session. These ideas are evaluated during interviews with stakeholders. These iterations are repeated for the 'people' aspect and the 'organisation' aspect, while the ideas are evaluated continuously.

Concepts are developed and one will be chosen to be modelled, prototyped and tested. Deployment of the concept will be tested by NS employees.



DISCOVER

INTERNAL

THE NS

HISTORY

The past has shown that something as common as steam could literally move the world. The invention of the steam engine by James Watt in 1765 was the beginning of the first industrial revolution. The Englishman Richard Trevithick complemented this invention in 1804 by putting iron wheels underneath the steam engine. The first train was born and was mainly used to carry heavy iron ore. Over time, this revolutionary invention also provided people with a means of transport. In 1830, the first relevant commercial train for travellers was introduced in England. The Dutch government knew they could not fall behind and founded a railway company in 1837. The precursor of the NS – the HIJSM (Hollandsche Ijzeren Spoorwegen Maatschappij) – was born (NS, 2018).

The railway construction did not go as fast as anticipated, therefore the Dutch government decided to establish the SS (Explotatie van Staatspoorwegnet), a privately-owned company designated to operate most train lines. Railway construction became significantly faster with this set-up. By 1900 most of the main railway network was built as we know it today. In 1937 an interest in cooperation grew between the HIJSM and the SS, on the first of January 1938 this resulted in the foundation of the Nederlandse Spoorwegen (abbr. NS). The NS became an NV – the abbreviation of Naamloze Vennootschap – with the government as the sole shareholder.

The rise of the car and bus in the 60s caused a revenue decline for the NS, the Ministry of Traffic and Water management had to help financially to keep the NS running.

In 1992, the Dutch government opened a debate about the self-dependence of the NS. The immediate cause was the EU's demand to separate the railway construction, maintenance and repair with the transport producer. Competition would benefit the overall development of the railway network, and therefore the NS became a self-dependent organisation.

The NS split in 1995 on behalf of the government into two groups: The commercial NS group (market sector) and ProRail (task sector). The focus of NS would be on efficient growth while ProRail became responsible for the railway construction, management (timetabling) and maintenance.

The Dutch government granted the NS concession from 2015 to 2025; this means they have a permit allowing them to hold a monopoly. It is vital for the NS to perform well to keep this concession.

The triple P – People, Planet and Profit – are increasingly common terms in big organisations. The NS desires to become a company that facilitates these three requirements. They want to give the customer a high-quality experience with low ecological costs while maintaining a profit (NS, 2018).

COMPANY ANALYSIS

COMPANY STRUCTURE

On an organisational level, the NS consists of several divisions as listed here below:

NS Reiziger – This division – NS traveller – is responsible for the train services for passengers and employing staff in the trains, thus the train drivers and conductors.

NS Stations – The NS stations division is the result of a merger of the NS stations that comprises all 404 stations in the Netherlands and the NS Vastgoed (Real Estate) who are responsible for the 48 km2 of land (for development of offices and traffic nodes).

NedTrain – In charge of the train maintenance and repair.

NS Commercie – This division (Commerce) is responsible for the product- and customer management, which includes business and product development, marketing, sales and customer service.

NS International – Responsible for the international trains, including the IC Berlin, IC Brussel, ICE, Thalys and the Swiss CityNightLine.

Abellio – Abellio was founded as NedRailways in 2001 and is fully owned by the NS. They operate their transport services in Germany, the Czech Republic and England.

CURRENT PRODUCTS

The NS runs three train types in the Netherlands – the Sprinter, the Intercity and International transport. The Sprinter is meant for short distance commutes and stops between every station on the route. This train type is capable of fast acceleration and has an excellent interior overview – which contributes to the feeling of social safety. The Intercity is for longer distances and only stops on the stations of bigger cities. All Intercitys have a silenced zone. The modernized double-deck trains offer an upper floor that allows for activities such as reading and working. These are therefore often the silenced zones. The lower floor has an active interior meant for interaction where the chairs are across each other. Art is often found within these two NS types as they are one of the recognizable characteristics of the NS brand. The international transport resources like the IC Berlin or the Thalys allow high-speed mobility across countries (NS,2018)

SPRINTERS

STL

Made by Siemens/Bombardier in 2009-2012
Toilets will be added in 2017-2020

SGM

Made by Talbot (Bombardier) in 1975-1984
Revision in 2003-2009

DDAR

Made by Talbot (Bombardier) in 1991-1998
Revision in 2014-2015 (Technical)
Doubledecker applied as a Sprinter

DDMI

Made by Talbot (Bombardier) in 1984-1986
Revision in 2016 (Technical)
Supported with the loc 1700

Stadler/Flirt

Made by Stadler in 2015-2017
Applied in the South-East of the Netherlands in 2017
Toilet included

CAF/Civity

Made by CAF in 2017-2019
First train will appear in 2018
Toilet included

INTERCITIES

DDZ

Made by Talbot (Bombardier) in 1984-1986
Revision in 2012-2014
Included with concentration and interaction zones

VIRM

Made by Talbot (Bombardier) in 1991-2009
Revision in 2016-2020
Some included with concentration and interaction zones (2016-2020)

ICMm

Made by Talbot (Bombardier) in 1991-1998
Revision in 2007-2011

INTERNATIONAL TRANSPORT

Intercity Direct

Made by Bombardier
Revision in 2014-2016
Drives on the HSL (Hoge SnelheidsLijn)

IC Berlin

Made by Alstom in 1965-1988

IC Brussel

Made by Bombardier
Revision in 2014-2016
Use of loc

ICE

Made by Siemens in 1998-2000
Revision in 2017-2019
NS owns 3 units

Thalys

Made by Alstom in 1995-1996
NS owns 2 units

(NS, 2018)
(Treinposities.nl, n.d.)
(alegandraliliana [VIDEO], 2013)

DIGITAL PRODUCTS AND SERVICES

Within the NS, the following digital products or services are used in relation to production. Please note that some of the Microsoft tools are new to the NS and are therefore not fully implemented.

TEAMWORK AND NETWORKING TOOLS

iNSite – The NS site for employees, covering administrative and informative applications

Sharepoint – A platform created by Microsoft that functions as a website to share data and supports online collaboration. It compares to the more well-known Google Drive. The benefits of Sharepoint are its intelligent security and its integrated simplicity which increases agility (Microsoft, 2018).

Yammer – This is the internal 'LinkedIn' or 'Facebook' of the NS. A means to connect and engage the organisation in an open and dynamic community. Enhanced communication is stimulated to build a culture of transparency and keep employees informed and aligned.

TOOLS FOR ANALYTICS

Azure – A set of cloud services helping with the development, management and implementation of frameworks. Examples of the AI services of Microsoft are the Cognitive Services and the Bot Services - which include API's with face recognition and chatbots.

Power BI – A business analytics service that delivers insight to enable quick decisions. (SIt gathers and connects the NS to a wide range of data and transforms it into visual, interactive dashboards. It can help by improving insights by combining data from production to distribution. Advantages are the three following points. First, live dashboards allow lead stand-up meetings on the factory floor. Then, Power BI optimizes the manufacturing processes. Lastly, areas for process improvements are more easily identified. The BI allows store containment to keep teams of the same page by sharing the latest data. Inventories are managed with live metrics and trends are easily spotted to prioritize product focus. Claims analysis are available to respond faster to shipping gaps, stock shortages and other time sensitive wants (Microsoft, 2019; nsdigitaal.sharepoint, 2019).

TOOLS FOR PDM

(According to a technical advisor & support engineer)

Pro.file
– Gathers all CAD-files and parts lists on one location with a Product Data Backbone and integrates the ERP-system of the NS. (Profile, 2019).

nfor PLM10 – The product life cycle management software helps with managing data and decision making from conceptual design to production. The software is integrated with CloudSuite PLM technology, modern machine learning and the Infor Nexus network. According to the Infor site (part of Brist), the Infor software has analytical processes as well (Infor, 2019).

SAP – Within the NS, the SAP software functions as an intermediate station between different applications. While Infor PLM10 - this year's PLM version - is the source of processes, SAP configures data from Infor PLM10 to make it applicable for other applications. According to Frijman the usage of SAP can be treated as an intermediating station due to the complications involved. However, SAP software does have the capability to perform PLM tasks and additionally supporting analytical services such as Power BI from Microsoft. (SAP, 2019).

Maximo – The EAM of IBM is used to manage the assets within the NS when mechanics are short of parts. They inform Infor PLM10 while SAP configures the data to Maximo including name, article number, article status, article production, etc. Maximo as an EAM system is then able to order a new part.

Microsoft Flow – Automation of workflow processes by connecting hundreds of popular apps and services. An example is the email automation approval by cell phone to simplify the workflow.

TOOLS FOR FABRICATION

SolidWorks – CAD modelling program.

SolidEdge – A CAD modelling program created by Siemens. They are direct competitor of Solidworks.

TOOLS FOR INNOVATION

Innovatieportaal.ns.nl
– An innovation portal since February. The application includes trends related to automation, fabrication, digitalisation and human-machine interaction.

SolidEdge – A CAD modelling program created by Siemens. They are direct competitor of Solidworks.

FABRICATION OF INTERIOR ELEMENTS

In the 40s, 50s and 60s, trains were made by the NS themselves with close collaboration with the concerned train manufacturer. However, in the 70s due to economization Dutch politics - Ministerie van Verkeer en Waterschap - decided to outsource the production. Currently, the train operator is limited to choosing what is available in the industry. Small adjustments to the interieur are possible, but bigger ones often concerns a higher price.

OBSERVATIONS

In the project brief, a selection was made to develop three interior elements - the barstool, the stit and the handle. The handles and stits are within the existing train supplier catalog, while the barstool is not. Therefore, normal seats are observed an inspiration for the barseat.

THE HANDLE

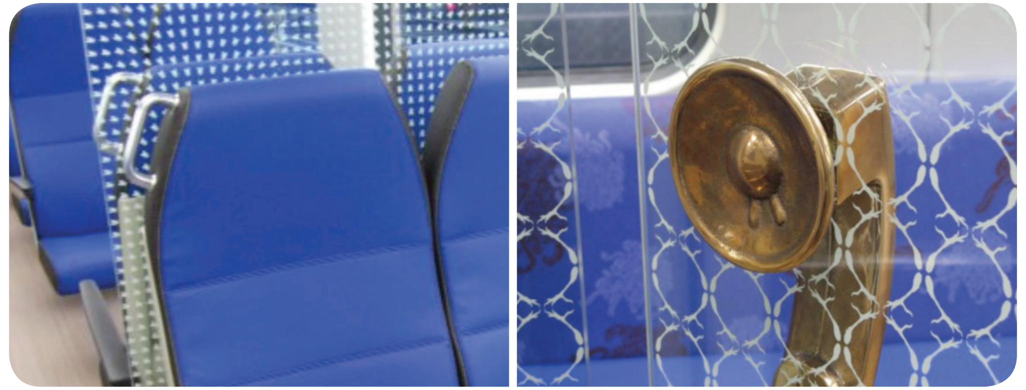
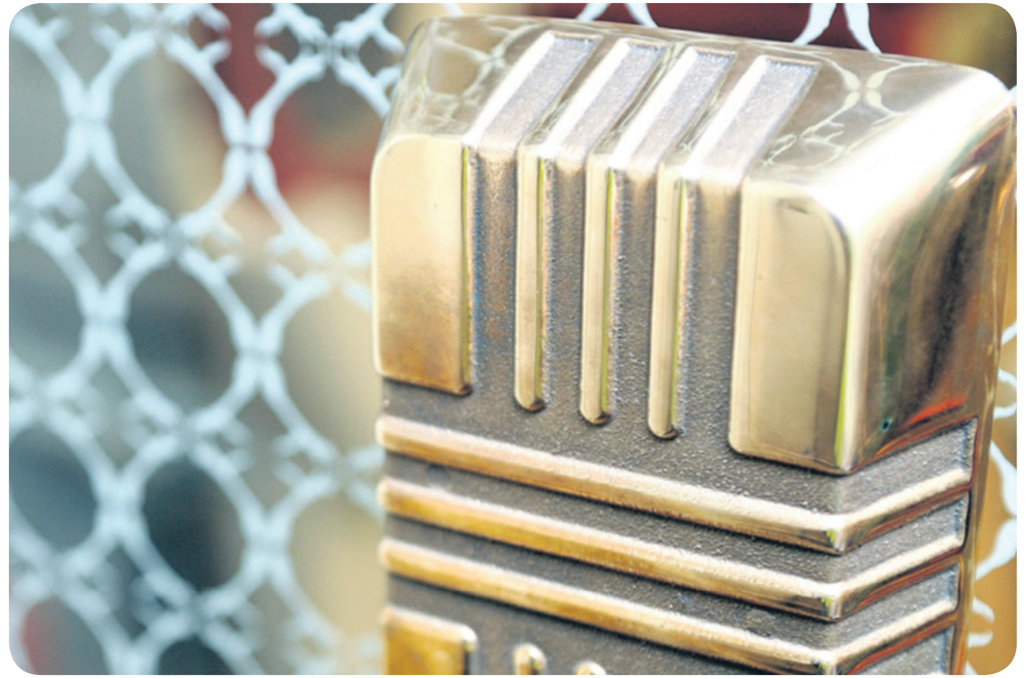


Figure 1: The handholds

PRODUCTION OF HANDLE

There are various handle designs. The simple looking handle is with certainty cheaper than the brass colored handles (Figure 1). The simple handle is casted to avoid folds of the upholstery within the snap fit system - making the mechanical connection less tight.

The brass colored handle (Figure 2) are variety of sand casted product. This is visible through the parting lines and the product's grainy texture. The replacements are not readily and cheaply available compared to standardised products



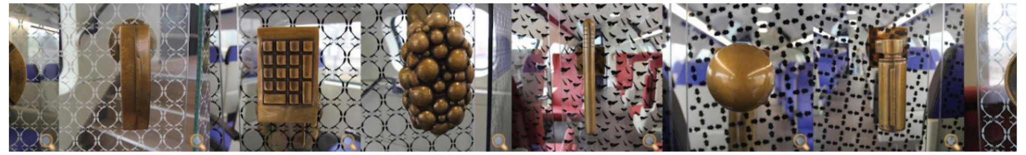


Figure 2: The Undesirables - Top - French fries tray. From left to right - The Ashtray, telephone, keyboard, bubblegum, baton, emergency button, graffiti bottle and speaker. Made by artist Onno Poiesz.

THE STIT

PRODUCTION OF THE STIT

The stit can be produced in two different ways. One is the method where foam is cut and the upholstery is glued onto the foam. The soft components are glued to a stiff part after. The other method is to form an inner pipe that functions as the support structure. The formed pipe is placed inside a mold and foam is extruded around it. An U-profile is fastened to the pipe - creating an attachment for the train chassis.

Insight note: Passengers may litter if the design allows gaps

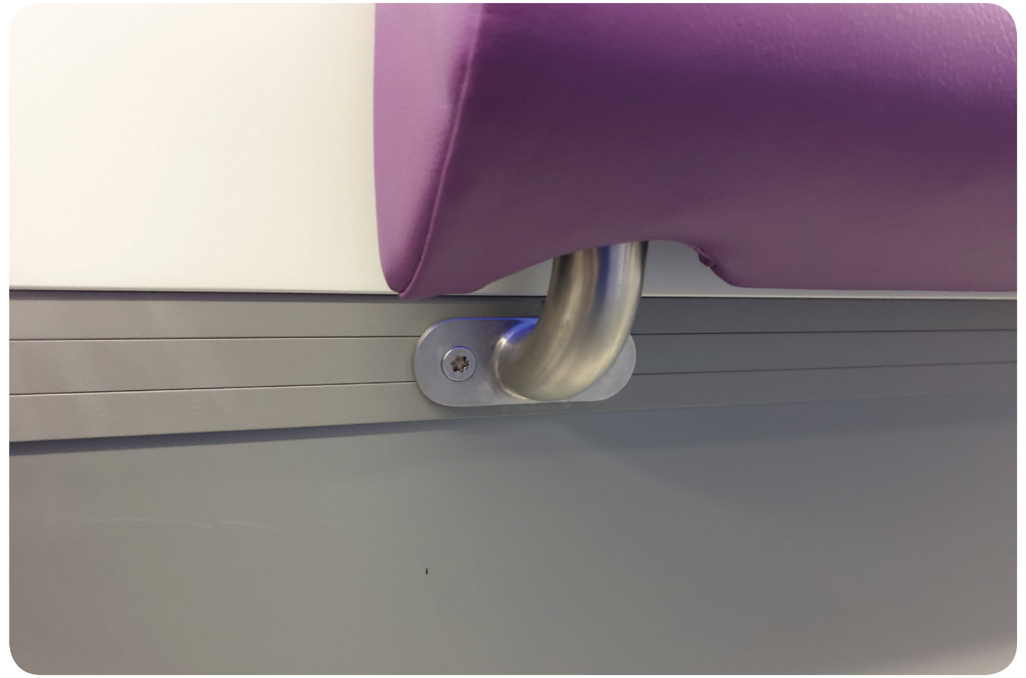


Figure 3: The stit in the Flirt (left) and a stit in the tram (right)

THE BAR SEAT

Normal train seats are taken as an inspiration for the design of the barseat. The structural seat design in older train models are made from wood. As time passes by, the overall design becomes lighter. First, a black plastic structure is created with ribs that are to carry the weight of the passenger. Then the plastic structure is replaced by a foam-based composite. The shape of the structure is created in a manner that it guides applied forces to the structure's stronger parts made from aluminium. The gray circles on the foam are the clamping point to hold the cushioning in place - this method is common in the making of seats (Figure 4).

PRODUCTION OF BAR SEAT

The production of the bar seat will likely involve a structural design that functions as a support. To make it comfortable – a soft foam-like material is needed. An upholstery will keep the parts together.

Figure 4: Three different train seat designs

MODERISATION

The train modernization is often cheaper than buying entirely new trains. The NS supports modernization and revision of bigger material series. Most of these activities are performed in Haarlem – NS Centre of modernization.

Figure 5: The tour though the fabric hall

COMPETITORS ANALYSIS

The Dutch government has granted the NS concession till 2025, and therefore the NS has a monopoly position in the Dutch train market. However, the past has shown us that keeping a broad view of the competition is important, i.e.s a significant drop in revenue due to the rise of the car and bus in the 60s. The definition of the market is therefore the:

Medium- and Long-distance public transportation sector

FORM

NS's direct competitors within the Product Form (inner circle) are Arriva (part of the German DB Schenker Rail) and Syntus (part of the French Keolis). See Figure 7.

Arriva is the biggest transport organization in Europe. They offer bus, water bus and train transportation in the Netherlands, UK, Denmark, Hungary, Italy, Croatia, Portugal, Poland, Servia, Slovenia, Slovakia, Spain, Croatia and Sweden. Arriva became active in the Dutch market by buying the Dutch market shares from American Vancom – who owned them since 1995.

Syntus – synergy between train and bus – was founded in a collaboration between the NS and the regional transport service called GSM, which mainly operates in the east of the Netherlands. Together with Keolis, the NS was shareholder of Syntus. Keolis became the sole shareholder by purchasing all the NS's Synthus shares, when the NS was going through a financial set-back . With this, the French company has full access to the Dutch market.

CATEGORY

The Product Category contains the other long-distance transport services available to the public in the likes Uber and Greenwheels, planes, taxis, car manufacturers with the upcoming autonomous vehicles (abbr. AV's) and long-distance buses.

Planes, taxis and services like Uber and Greenwheels are relatively expensive compared to trains but do offer the benefits of taking customers door-to-door, the freedom of leaving whenever you want and the benefit of having a shorter travel time. Car manufacturers with their developments in AV's are a more significant threat to the NS as they can offer cheaper medium-distance transport where no drivers or personnel are needed.

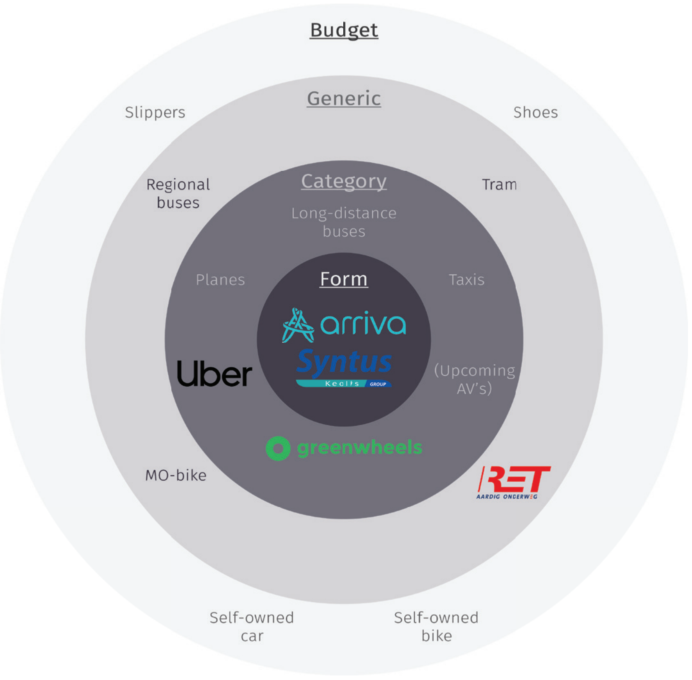


Figure 6: An image of the competitor's analysis. The analysis method is based on the competitors analysis by Day (1990) that analyses the customer's perspective.

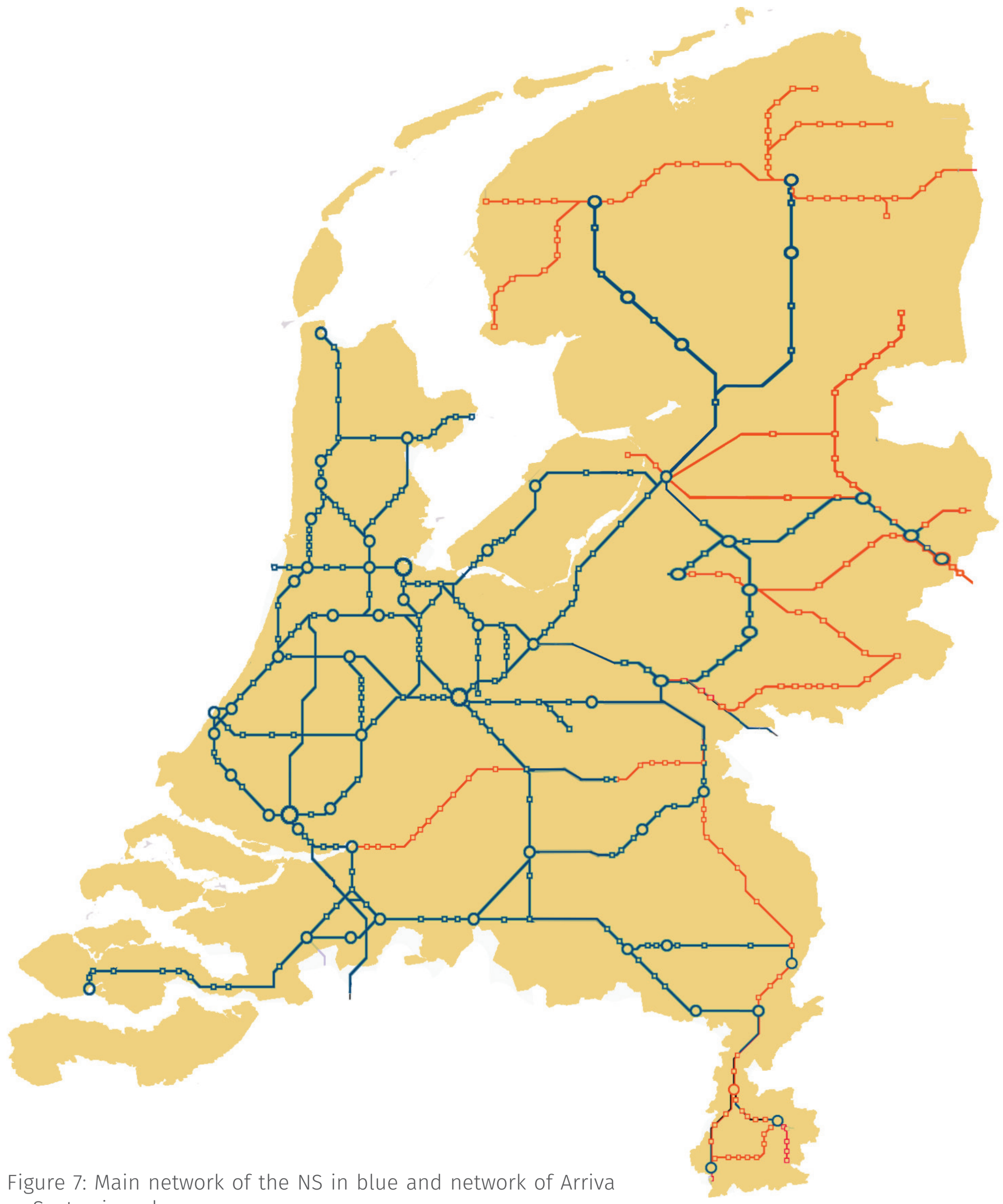


Figure 7: Main network of the NS in blue and network of Arriva or Syntus in red

GENERIC

Here are the services that provide the mobility, but mainly for short distances. These services are the RET Randstad, Tram, Metro, Regional busses, ov-fiets, ov-step.

BUDGET

On this level every other product that can be bought with the budget for travelling can be found. This includes self-owned cars, self-owned bikes, shoes, rental apartments etcetera.

n general, the NS has a strong competitive position, as It is one of the progressive operators in the EU in terms of digital growth. However, the NS must keep an eye out for the Deutschen Bahn who owns Arriva in the Netherlands. They are one of the market leaders in the EU and more involved with collaborations with progressive companies such as Stratasys, which is a 3D printing entreprise. With Stratasys, they have already created multiple parts with a visible and functional function that is used in the train interior (Businesswire, 2019) .

On top of that, the Deutschen bahn has launched 'Mobility goes Adaptive', a international network for the industrial additive manufacturing world (Mobilitygoesadditive.org). According to a NS supply chain manager, they aim to place themselves in a competitive position against other train operators.

CONCLUSION OF THE COMPANY ANALYSIS

Motivation – The NS has a growing interest to increase their ecological impact in the world.

Suppliers – Their main trains suppliers are Siemens, Bombardier, Talbot, Stadler, CAF and Alstom.

Teamwork – Sharepoint – a tool comparable to Google Drive is used increasingly.

Digitalisation – The NS does have a PDM (Product Data Management) system, they use multiple different software that combined form the PDM system. However, this is very prone to errors. Furthermore, after researching the expensive software capabilities, it can be concluded that the advantages are not used to their full potential. For example, SAP has the ability to perform PLM tasks and analytical tasks, but is only used as an intermediation station. The complexity of the intertwined software makes it hard for the NS to switch to another software. They are therefore reliable on the companies who currently serve them. Thus, rate of digital flexibility could be improved. However, change might be already on its way, as on the 11th of April there are multiple Microsoft workshops on multiple topics including analytics and management.

Digital Fabrication – The NS uses both SolidWorks and SolidEdge. They are direct competitors from each other. Conflict can occur when collaborating with teams that work with different software – configurations can take time and can enlarge the total fabrication time. However, the NS is a large enterprise, managing teams well and avoiding these teams working together should provide a simple solution.

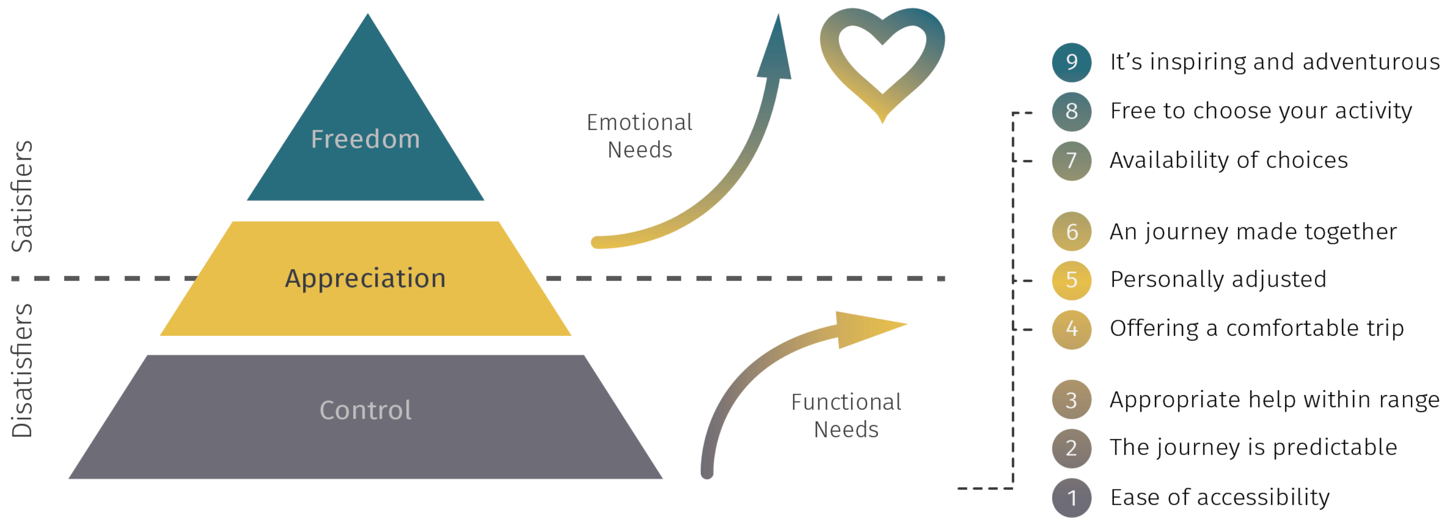
Physical fabrication – The new interior vision is bound to be more expensive. The focus should therefore lie on the actual interior elements production and less on inspiring but expensive parts (the brass door handles). It is desirable to produce the interior elements as cheap as possible (high variety rate). A net must be able to maintain the repair and maintenance (The railway network must be easy to maintain and repair). Clever and cheap design like the seats with foam composites are therefore of great interest.

DESIGN VISION OF 2025

MAIN NEEDS AND WANTS

Current train interiors often have a 'old-fashioned' interior meant for families – where two children would sit across their parents traveling to their destination for their day off. This era's travelers have more peculiar needs as they often travel alone. To specify these needs and design a new interior, the NS collaborated with Mecanoo and Gispen. Mecanoo is a well-known architect bureau with more than 30 years of experience. Their area of expertise varies from theaters to hotels to parks to libraries. Their main impellent is Francine Houben, founder of the company.
Gispen is design company focused on sustainable design. They aim to deliver sustainable solutions for work-, study- and hospital related surroundings. They have been around for more than 100 years and strive to apply a circular economy.

Travelling only has a functional need when the passenger has the feeling that his journey is only meant to get him from A to B, . Receiving a high grade for the journey is therefore not obvious. (See Figure 8). Adding travelservice experiences can increase the grading. The experience of getting a freedom of choice can be the needed extra value. To enable this, a coherent design is needed that can satisfy the needs of the passenger. Not one type of seat, but a variation of interior elements will support the activities. The train will become a place to work, relax or socialize. With this experience, the train is no longer a means of travel to get from A to B.



INTERIOR VISION

PASSENGER ACTIVITY RESEARCH

Within the NS, the following digital products or services are used in relation to production. Please note that some of the Microsoft tools are new to the NS and are therefore not fully implemented. Earlier research showed that the overall journey rating can be improvement by changing the client experience and passenger capacity within a train. To improve client experiences, a travellers profile is created, which shows the different people who often travel with the NS. Five main archetypes are clustered from the travel crowds:

Figure 8: Main needs and wants of the passenger. The NS want to improve their client experience from a 7.3 to a 7.5. To achieve this, satisfiers need to be optimized.

The Support employee - Travels within rush hours, five times a week and often alone.
The Student - Travels within rush hours and stagnation, five times a week and often alone.
The Mother - Travels in the weekends or stagnation, once a week and often with her children.
The Businessman - Travels within rush hours and stagnation, four times a week and either alone or with a colleague.
The International - Travels within rush hours and stagnation, two times a week and often alone.

The NS studied their activities with 'Meet4Reseach' and found three core activities - concentrating, relaxing and socializing. For concentration zones, passengers expect seats with tables including charging possibilities to be able to work. An addition could be a reading lamp. Passengers who want to relax, generally expect seats where they can sit to read, eat or think. For socializing or recreational activities, assemblies of multiple seats are wanted to support group of passengers or ' the Mothers' who can bring gadgets like prams. These activities are reflected within the new interior design made by Mecanoo and Gispen.

CONCENTRATION

The concentration zone of the first class compartments includes a bar with charging applications. A bigger table allows 'The Businessmen' to hold conferences efficiently.

RELAXING

Mecanoo and Gispen designed seats with multiple screens in the relaxing zone to embrace privacy within the compartment.

SOCIALIZING

The socializing zone is made more playful by adding a tribune - this stimulated social behaviour in trains which is favourable for passengers who make the journey with bigger groups.

Figure 9: the three zones based on activity

POSITIONING THE THREE ZONES

The three developed zones are evolved for the travellers activities.The positioning of the three zones is based on two principles. The first social principle is the behaviour of passengers based on their trip duration. Travellers tend to put less effort to obtaining a seat during shorter commutes. While long distance travellers are more inclined to walk a bit further to reach a comfortable seat (NS Brand Design Book, 2018). The second principle is based on the inflow of passengers. Most travellers get in at the end of the train - therefore, the ends of the trains are often more crowded compared to the centre of the train. (NS Brand Design Book, 2018)

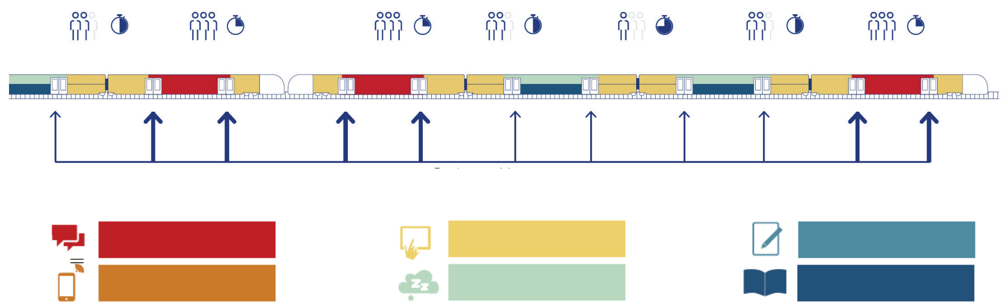


Figure 10: Train positioning with social (red), relax (yellow) and concentration (blue)

In current trains, there is little motivation to walk to the end of platforms due to the similarity of the interior (NS Brand Design Book, 2018). The NS expects to control the behaviour and inflow of passengers by rewarding them with an activity-based zones. For example, 'concentration' zones are positioned in the centre of trains. This motivates long duration passengers to walk to the next cabin since they know they can find working facilities. Short durations travellers are rewarded by staying in the 'social' zone as there are facilities that support social interaction to 'quickly check your phone'.

POLICY OF THE TRAIN FORMULA

The vision for the positioning of the zones provides an understanding of controlling passenger behaviour. However, the current train platform already has differences in travel distances. There are Long Distance Train (abbr. LDT - e.g. International trains), Middle long Distance Trains (abbr. MDL - e.g. Intercity's) and Short Distance Trains (abbr. SDT - e.g. Sprinters). The zones are positioned dependent on the distance and travel time - therefore, the policy of the train formula.

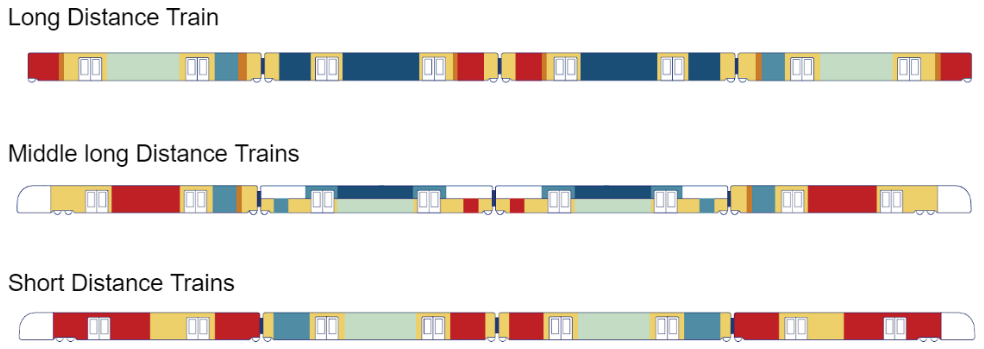


Figure 11: Types of trains

THE DIFFERENT INTERIOR ELEMENTS

Different interior solutions require the different activity-based facilities. Twelve interior elements are created to prevent mass customization, since a large variety production could become expensive. Figure 12 shows these twelve interior elements.

Figure 12: The 12 interior elements

BETTER EXPERIENCE IN A HIGH CAPACITY SPACE

Earlier in the sub-chapter about Passenger Activity Research, it was mentioned that the overall train journey rating could be improved by enhancing the trip experience and increasing passengers capacity. The addition of the stits and the yellow overhang allow a few passengers to lean or sit during rush hour. Figure 13. This improves the overall grade of the passenger journey experience.
Figure 14 was made to prove that the design with the different interior elements does not sacrifice seats. According to prior research, 427 passengers fit into a cabin. These two aspects combined result in the maximum experience rate with a grade of a potential 8,0 (NS Brandboek, 2018).

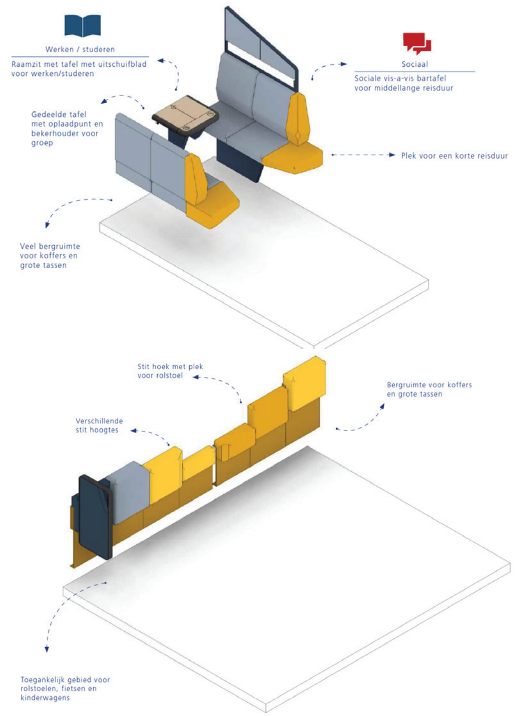


Figure 13: The 2 interior elements - the 'vis a vis' and the 'stits'.

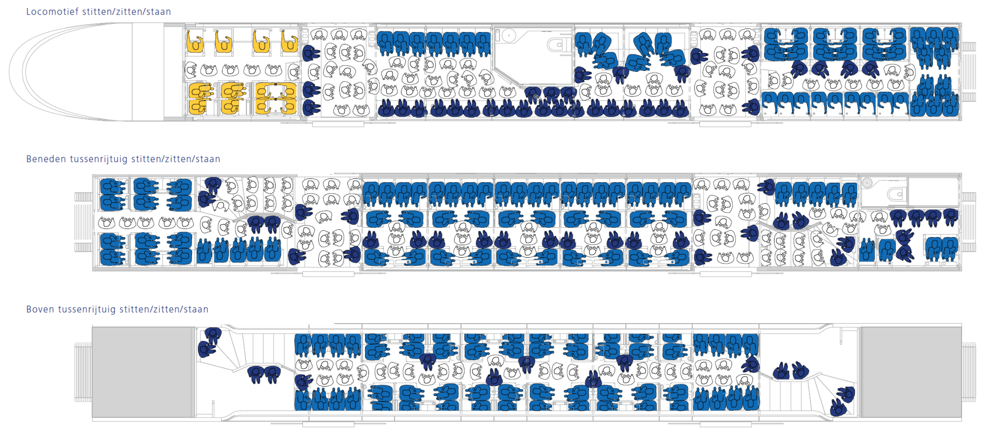


Figure 14: The new train interior allows 427 passengers.

MODULARITY | DESIGN DIVERSITY AND CIRCULAR ECONOMY

Design diversity
An additional idea on top of the activity-based interior is the appliance of a modular systems for twelve interior elements. By using the interior elements as building blocks, diversity and changes are easily realised. These building blocks from the ground to build different trains interiors.
Not only does the realisation of modularity design give freedom to the train interior, it is also beneficial as it adds to logistical freedom. Imagine every trains having a modular system where each of these twelve interior elements fit onto. Suddenly, it will be possible to turn LDT into a SDT - which allows a higher passenger capacity.

Circular economy
Another benefit of adding the concept of modularity is the possibility of adding a circular economy. Several aspects are needed to establish a circular economy - among which modularity.

A circular economy is a sustainable way of design to keep product and materials in use, to prevent waste and pollution, and to regenerate natural systems. A common exercise is the appliance of (bio)-compostable material into products, components or their packaging, resulting in no loss of resources during production. However, not everything can be made out of compostable material. Products like train seat structures are an example of products where the use of compostable material is not feasible.
Another way of thinking is required, to maintain the valuable material quality for an individual product beyond the shelf life. Instead of the linear approach, where products are thrown away after usage, the circular approach adopts a 'return' and 'renew' cycle. Products are designed to be disassembled and regenerated. Goods of today can be the resources of tomorrow.
Appliance of the circular economy does not involve just one company, but requires an overall infrastructure of companies including their interconnectivities. It is about energy and rethinking the operational system. The circular model builds economic, natural and social capital - underpinned by a transition to renewable energy sources (Ella Macarther Foundation, 2019).

An increasingly frequent solution of a circular method is the change in thinking of ownership where products can be licensed from the manufactures. After usage, products can return to the manufacturer and their technical materials can be reused while their biological parts can increase agricultural value.
The solution made up by Gispen involves a relatively similar purchase cost. However, there is an operating system where the manufacturer can 'resurrect' a product multiple times - which leads to an overall higher life cycle. Figure 15 shows a graph with the economical life cycles against the technical life cycle. This method allows a more sustainable approach to the overall product ownership, but needs a modular product that allows 'resurrection'. Products should therefore allow ease in disassemblement and regeneration - and with this not only the interior elements within the train - but also the train as a modular product itself. Therefore, the suggestion of Gispen to apply a rail to the sides of the train to 'hook on' the twelve interior elements - consequently allowing modularity for a circular approach.

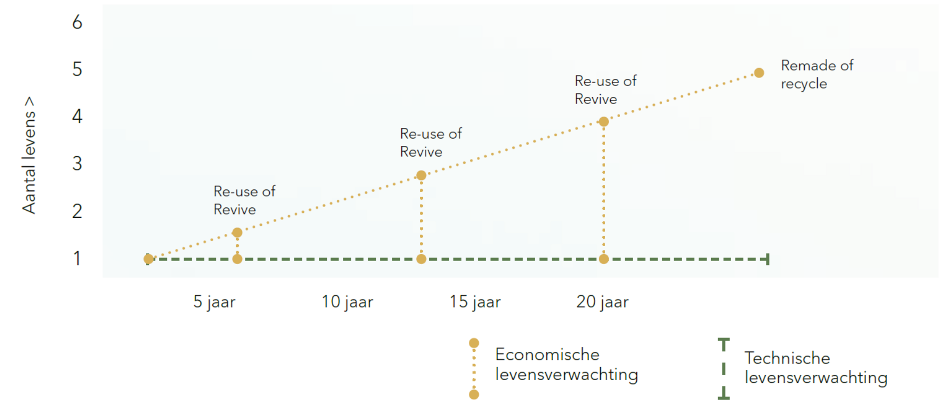


Figure 15: Plot of the economical life cycle against the technical life cycle.

IMPLEMENTATION: TWO END-SCENARIOS

Realisation of the vision involves two end scenarios. The first scenario is an accomplishment of the whole vision. A large amount of parts of the twelve interior elements are replaced by standard catalog products and the appearance is stored by the usage of color and material. The parts not available by the train supplier will be customised.

Figure 16: accomplishment of the whole vision

The second scenario is replacing the whole interior with the available catalog products of the train supplier. The train interior stands out due to its appearance by using the same material and colors.

The real life situation will likely toggle between these two scenarios - favourably closest to the first scenario with the fully integrated interior vision. The appliance of agile manufacturing can help to get closer to interior vision by taking on the parts that need to be customised. More of this philosophy will be discussed further in chapter 4.

Figure 17: replacing the whole interior with the available catalog products.

CONCLUSION OF VISION

Based on a research from Meet4Research', Gipsen and Mecanoo developed a new interior design that fully focuses on the passenger's activities. They developed three zones for 'concentration', 'socialising' and 'relaxing'. The positioning of these three zones in a train are based on two main principles: the social principle and the principle of the inflow of the passengers. The NS offers different types of train - thus every train should be designed accordingly to its varying needs. The policy of for the train interior elaborates on this matter. Besides the focus on passenger's activities, Gispen and Mecanoo also targeted their attention to aim for a higher passenger experience grade during a high capacity travel. They developed interior elements like the stits to enhance the standing comfort during the journey. According to their research - the expected grade should rise to a 8.0. A modular design is needed to implement the different zones accordingly per train as modularity allows design diversity. An added value of adding a modular interior design is the addition of a circular economy which helps with the ecological needs within the organisation (Triple P - People, Planet and Profit). Implementation of this vision is divided in two end-scenarios - a scenario where the design vision is entirely integrated and a scenario where little of the vision is realised. The main goal is to realise the vision where the whole vision is integrated.

DISCOVER
EXTERNAL

DEPEST ANALYSIS

Demographic
- The world population is growing more than 1 percent per year (NextBIGfuture, 2018)
- Growth of the population mainly in urban areas (CBS, 2019)

Economic
- Growth of the production industry in the Netherlands (CBS, 2019)
- Rise of the Sharing Economy (Economist, 2013)
- The founding of EuroSpecs to increase reliability, simplification of the various requirements regarding train production and standardization of products and costs (EuroSpecs, 2016)

Political
- Premier Rutte is talking with private instances gathering money for public transportation (NRC, 2019)
- The EC is working towards a unified European railway network - the Single European Railway Area (SERA). The main objective is to tackle major issues like the rising traffic demand, congestion and climate change (Shift2rail, 2019)

Environmental
- Pressing cases to work on climate change (Heilbron [NRC], 2018)
- U.N. Secretary-General Antonio Guterres states climate change as an existential threat to humankind. He presses a sustainable approach regarding sustainable energy production, economical growth, green investments and usage of natural sources (Guterres, 2018)

Sociocultural
- Employees desire more flexibility at work regarding location and schedule (Dean & Auerbach [Harvard Business Review], 2018)

Technology
- Integrated smart mobility in 2030 (Hannon et al. [McKinsey], 2016)
- Rise of additive manufacturing (Mueller [PwC], 2018)
- Faster and Greener production of Carbon Fiber Composites (SolvayGroup, 2017)
- The appliance of the Blockchain technology for the supply chain (Columbus [Forbes], 2018)
- Growth of the Industry 4.0 (i-scoop, 2018)

OPPORTUNITIES

Between cities, it will become more crowded due to urban growth in the Netherlands. This trend combined with the investments in public transport will transform how mobility looks today. Trains need to be prepared to carry a higher passenger capacity. This reconfirms the research done by 'Meet4Research'. Smart mobility trends involving Autonomous Vehicles (AV) and electric driving can help distributing the travellers' load. Either way, the disruption is to be expected. How cities react to this, is depended on their population, current infrastructure, wealth and ability to implement new innovations (Hannon et al. [McKinsey], 2017). When applied accordingly, a great acceleration of mobility innovations can occur that can lead to other benefits. E.g. An increase in the usage of trains and AV means higher electric consumption - which leads to possible greener usage.

THREATS

The industrial world in the Netherlands experiences growth. New manufacturing tooling processes can help the NS develop. However, environmental factors are a threat to the industry due to the increasing sustainability demand.

MANUFACTURING IN GENERAL

Before diving into the world of agile manufacturing, first, an introduction is given to explain manufacturing itself and its corresponding developments. This chapter explains the manufacturing revolutions, industry 4.0 and its enabling factors, the different types of manufacturing, a deeper dive into the 3D printing world, digital scanning and topology optimalisation.

THE PROCESS INDUSTRY

The making of products on an industrial scale where producers use chemical, mechanical, biochemical and physical processes is the definition of manufacturing. Here, products are made in a highly automated environment based on formulas and production recipes (Dal, 2012). More information on the process industry can be found in Appendix B.

THE REVOLUTIONS OF MANUFACTURING

The invention of the steam engine made it possible to automate machines and allowed mechanization of production processes. This was the beginning of the first industrial revolution. The second revolution was started by Ford - the automotive company - starting near the 20th century. Henry Ford went on a trip to Cincinnati and was inspired by the efficiency of the processes based on divisions of labour. This led to the beginning of mass production. The third revolution started with the first programmable logic controller. This revolution includes the use of electronics and IT to achieve further automation of production processes (SAP, 2019).
Currently, manufacturing is in its fourth revolution - commonly called Industry 4.0. This is the transformation of industries that involve intensive use of the interconnectivity between data, people, processes, services, systems and IoT-assets. Decision-making processes are automated by cyber-physical systems and machines that react accordingly to their strategic and staged approach (i-scoop.eu, 2019).

THE DEFINITION OF INDUSTRY 4.0

There are several different definitions of industry 4.0. Multiple well-known instances like McKinsey and SAP formulated a different meaning to the same term. See Figure 18. In this report, the definition of industry 4.0 is defined as:

> "
> 'The revolution in manufacturing technologies towards a world where everything is interconnected.'

Therefore, this definition is mostly similar to the definition used by EU - who do not narrow down the definition to mainly Digitalisation.

MCKINSEY

The next phase in the digitalisation of the manufacturing world - driven by four disruptions: The rise of data, computational power and connectivity, the emerge of analytics and business-intelligence capabilities. (Baur et al., 2015)

SAP

The collective term for technologies and concepts of value chain organisations. The industry 4.0 is based on the technological concept of Cyber-Physical systems, IoT anf the Internet of service. It supports the vision of the Smart Factory. (Gandhi, 2015)

EU

The EU - The application to a group of rapid transformations on the design, manufacturing, operating and service systems and products. It is the successor to the three earlier industrial revolutions that caused the leaps in productivity with manufacturing processes. (Davies, 2015)

Figure 18: Different definitions of the term industry 4.0 according to the following well-known instances.

ENABLING AN INDUSTRY 4.0

The automatisation trend and data exchange is not realised overnight. Comparable to IoT-systems, it requires a strategic approach within an infrastructure where several elements are integrated with one another. The elements that are the building blocks to create a 'Smart' surrounding are shown in Figure 19.

Figure 19: The elements that help creating a smart infrastructure for industry 4.0 (I-scoop.eu, n.d.).

THE RISE OF ROBOTICS

One of the enabling factors to realise Industry 4.0 is the usage of robotics.
The efficiency of a flow process within a factory is depended on how several machines work together. For example, 3D printing techniques can accelerate the time-to-market by reducing its overall development and production time. However, if a technique requires extensive post-processing with human labour, the production time can increase immensely. Robots can help production by taking over manual tasks.
In Moving Upstream (2018) - one of the series from the Wall Street Journal - in episode on the Robot Revolution, director Erik Brynjolfsson from MIT on the digital economy argues that in the past, robots had to be handled step by step - engineers had to program them to tell them what to do. Now, machine learning is enabling the machines to figure out on their own how to make decisions and how to solve problems. Robots are getting more intelligent and are excellent in completing their task with high accuracy.

TYPE OF ROBOTS

High paced robots are often sealed off since they are making fast (and sometimes powerful) movements that can injure employees. However, there is an increase in robots that work alongside humans. These are called Co-Bots. The international federation of robots forecasts that Co-bots will lead the robotics industry. These robots are often slower and lighter to minimize possible injuries. But safety is not the only benefit from Co-bots - the collaboration proves to be more efficient and productive according to MIT researchers. Human-machine groups were more efficient than the other groups - See Figure 20. The research also found that human idle time was reduced by 85 percent.

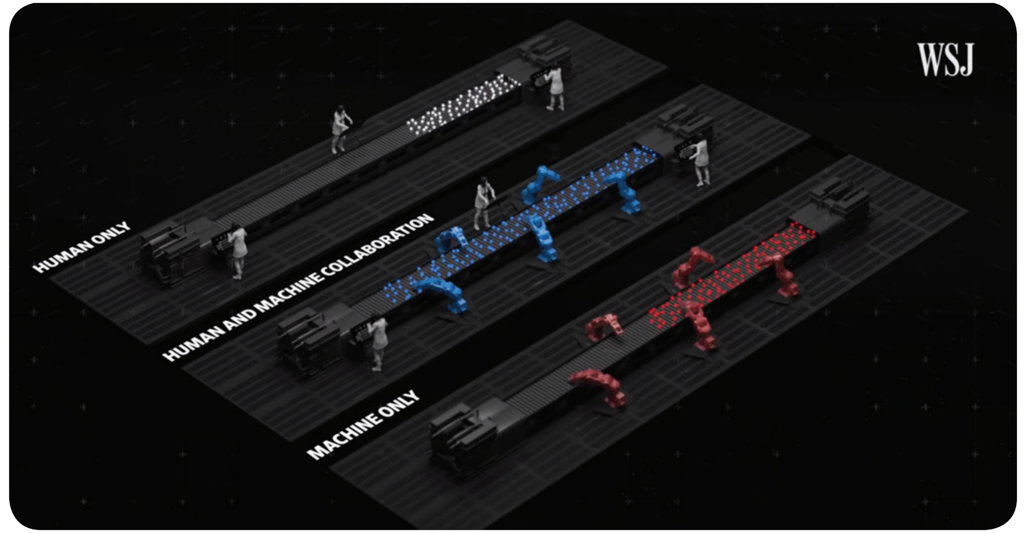


Figure 20: The Different groups in the MIT research.

DIFFERENT TYPES OF TOOLING PROCESSES

There are several types of manufacturing that exist. In this report, the techniques are separated into three categories - Formative manufacturing (FM), Subtractive manufacturing (SM) and Additive Manufacturing (AM). Formative manufacturing involves every technique that creates goods by forming techniques. Examples are Injection moulding, Casting techniques and Blow moulding techniques. Subtractive Manufacturing is associated with techniques that involve the material removal. Examples are Laser cutting, Water Jetting and Milling. Additive Manufacturing - better known as 3D printing - is the production of parts where layers of material are processed on top of each other. More on this type of manufacturing is elaborated in the following sub-chapter.

Although it is not applicable to all cases, a general assumption can be made regarding FM, SM and AM. With large batch sizes, it is more logical to use FM techniques as they often allow the production of large quantities.

The difference between SM and AM are stated with the complexity of the shape of the product. See Figure 21. According to John Hart, a professor specialised in AM techniques at MIT, the more complex the shape of the product is - the cheaper it will become to 3D print the product. SM removes material and if the production requires much removal, it will result in much waste and long production time. With AM it is the other way around, creating something complex will often save material and will save time producing the part.

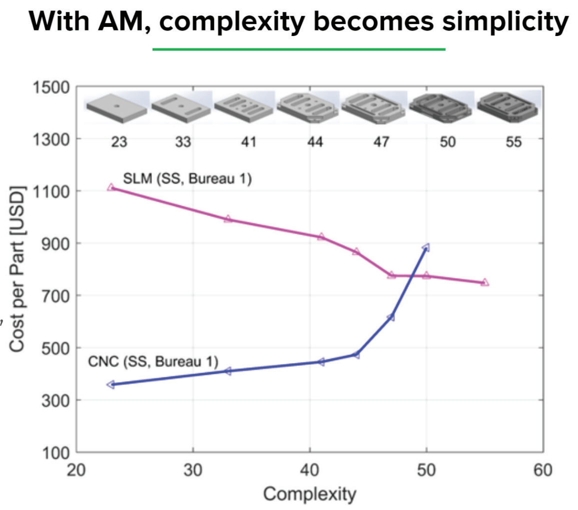


Figure 21: The price-complexity diagram by John Hart (MIT, 2019).

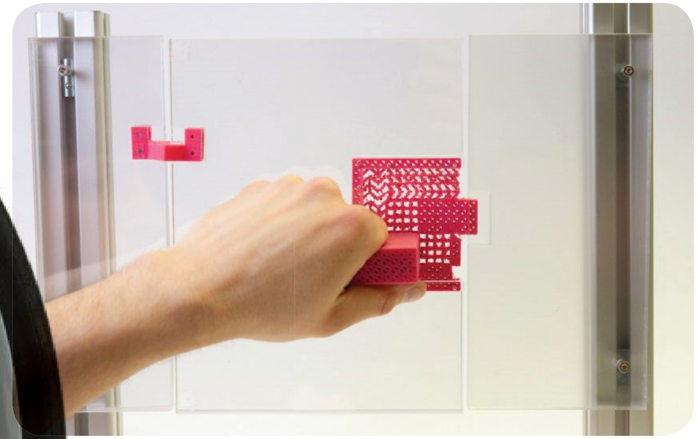
A DEEPER DIVE INTO THE WORLD OF 3D PRINTING

The AM world is an exciting world where it feels like anything can be made instantly. Multiple instances have made inspiring products as shown in the college in Figure 22. More inspiring products can be found in Appendix C. However, these products are currently still in their concept phase. Depending on the type of 3D printing technique, additively manufactured parts are either questionable in their functionality or extremely expensive.

Nonetheless, there are cases where additive manufacturing was more advantaged compared to FM and SM techniques. According to Tofail et al. (2018), Quan (2016) and AM Sub-Platform (2014), 3D printing is generally beneficial under the following circumstances:

- Making of **prototypes** - the direct creation of a design into a component
- Generating parts that require **customisation** with no additional production costs
- **Smaller operational foot-print** while maintaining a large variety of parts
- **Complex structures** that are harder to realise or cannot be realised with FM or SM.
  - Lightweight structures with hollow or lattice structures
  - Complex internal structures
- **Merged assemblies** to one part - which allows less assembling labour (Figure 23 with the example from General Motors).
- **Small batches** under 100 parts
- Potential to a **zero waste production** - which is especially beneficial when using expensive material
- **Quick time-to-market** benefit due to the reduction in the overall development and production time
  - On-Demand production - Orientation of production saved as a G-code
  - Outstanding scalability functionalities

Figure 22: Visual representation of inspiring products made by various instances that are still in their concept phase. (Morby, 2016; Sabina, 2016; Sabina, 2019; Materialise, n.d.; Clarke, 2017)



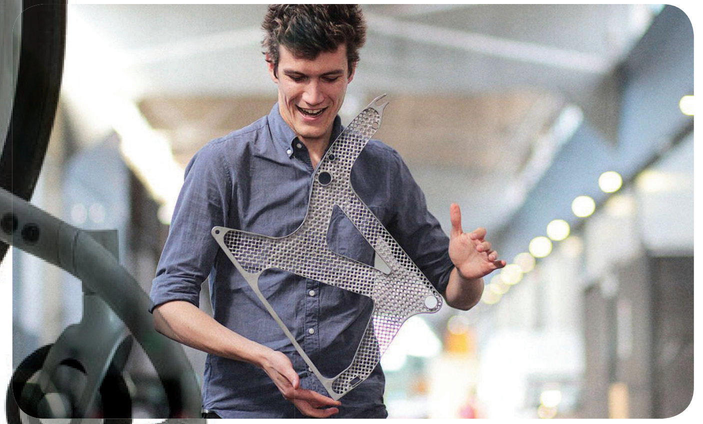


Figure 23: A display of cases that used AM to their benefit. These are examples were successfully implemented. For more successful cases - see Appendix D.

There is a huge variety of 3D printing techniques. Wohler Associates has the largest worldwide industrial network - including academic and professional data. From the Wohlers association, the report of 2018 informed to gain reliable 3D printing data on industrial leading Additive Manufacturing systems. The association divides these techniques into 7 categories; Material Extrusion, VAT polymerisation, Powder Bed Fusion, Material Jetting, Binder Jetting, Direct Energy Deposition and Sheet Lamination. Within these types matching sub-types are connected. Appendix E includes the whole datasheet with the minimum build size (mm), Typical Range production volume, Possibilities for the shape complexity, available material, mechanical properties (range of the Young's modulus tensile, impact strength and max. service temperature), precision (tolerances, holes, embossed and engraved details, horizontal bridges and minimum features), surface finish, reproducibility and lead time (production rate in units and total lead time). Please note that only industrial-focused companies are added in the data.

To get a better understanding of the 3D-printing techniques, a glossary is made including a collection of other synonyms for the specific technique, description with design guidance, possible material with its mechanical properties, strength and weaknesses, participating companies and the successful cases. This glossary can be found in Appendix E or in de APP with the following QR-code.

3D SCANNING

3D scanning is one of the analysis tools from industry 4.0. 3D scanning accurately scans people or products and digitize them in a CAD model. Digital scanning has a huge advantage in making personalized products. E.g. Hearing aids can ergonomically adapt to the shape of the ear.

SIMULATION | TOPOLOGY OPTIMIZATION

Currently, there is an increase in the production of lightweight products. Instances used topology optimisation (or generative design) to realise weight reduction.
The term optimisation has been circling within engineering for a long time. It is the mathematical technique to find the highest achievable performance under given constraints. Desired factors are maximized and undesired factors minimized. The theory was founded by Mitchell (1904), who proclaimed that it could optimize a part by applying the stiffest structure with the lightest weight - where the load is accurately transmitted to the fixture the most efficient way,

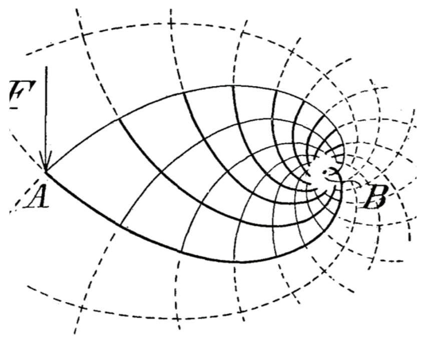


Figure 24: The continuous lines represent the desired factors

Figure 24 gives a representation of the theory. Point A has a loading and point B is a fixture. The purpose of the part is to connect the two points and transition the load to the point of the fixture (B). The continuous lines are the maximum strain lines are desired factors.
Nowadays digital developments have increased immensely - making topology studies more accessible. It is easier for designers to use the theory. E.g. CAD SolidWorks has a topology function since 2018.

CONCUSION OF MANUFACTURING

The possibilities in industry 4.0 are growing and one of the enabling factors is the rise of robotics. Production flows are dependent on how several machines cooperate. Placing robotics as transitional stages can increase production efficiency. Especially Co-bots have found to be beneficial.
There are three types of tooling processes: FM, SM and AM. AM - also 3D printing - has many advantageous factors, however, much consideration should taken on the downside of AM as it can be extremely expensive or simply too weak.
Another advantageous benefit of the industry 4.0 is the immense use of simulations. Topology optimisation has benefits in finding the stiffest yet lightest structure.
The available of knowledge in the manufacturing industry is growing, making it more or less accessible due to technological challenges. It can be difficult to deal with provided material like computational optimisation, behaviour simulations and related software support (Doubroski et al. (2011). Nonetheless, a good application of integrating an 'infrastructure 4.0' can change an organisation immensely in its strategic sustainable position.

AGILE MANUFACTURING

AGILITY

Many people think agility is the same as flexible – which is not the case. Agility is defined as quick, moving and active. While flexibility means adaptivity and versatility. According to Gunasekaran (2001), flexibility is a must in today's market - but on its own – it will not deliver agility. A combination of flexibility and speed is needed to achieve agility.

"Flexibility is not the same as agility. To achieve agility, flexibility needs to be combined with speed."

-

(KIDD, 1995)

THE PURPOSE OF AGILE MANUFACTURING

Traditional firms are usually fragmented (Booth, 1995). With agile manufacturing, the objective is to combine organisation, people and technology into an integrated and coordinated way (Ganasekuran, 2001). The organisation is the management and its employees. The strategy and goals must be understood and practised by everyone within the company. The gap between management and employees must be minimal to ensure transparency. The use of agile manufacturing will improve transparency in the entire company, which results in quick adaptability.

DIFFERENCES IN THE UNDERSTANDING OF THE DEFINITION

Gunasekaran (2001) argues that agile manufacturing (AM) is a business philosophy - that allows quick turnaround for a competitive price while sustaining quality. However, there are many other implementations of the concept.

Slack (1992) stated agile manufacturing as strategy and management operations where the context is related to organisations coping with uncertainty and turbulence. However, according to Gunasekaran, this definition is mainly associated with 'flexible manufacturing'. These typically bring flexibility to the customer by offering choices in things like speed-of-response. These are solutions for a particular time, that can become inappropriate later on. New developments in a time-sensitive context may result in disruption of the current production.

Boynton (1993) and Pine (1993) refer to agile manufacturing as 'mass customisation' – where firms exploit new technologies and organisational forms to offer customer-specific products. An example is the Mini from the BMW Group – where parts with low functionality are customised. See Figure 25.

Another aspect of agile manufacturing is the usage of agile networks. Forms of inter-firm co-operation are created – where different 'isolated' firms are clustered into a sectional or regional grouping which results in a collective efficiency (Best,1990; Piore et al., 1982; Grandori et al., 1995). In a way, Gipsen utilizes agile manufacturing within this definition, they have divided their specialities among their ex-competitors (Ahrends). E.g. Gispen is good at producing recycled steel parts. While Ahrend lacked in that department – they were better with their textiles. Therefore, Ahrend cancelled their steel production and collaborated with Gispen. Agile networks are relatively standard in industries that are isolated (furniture, textiles, prototyping, etc.) as they offer a viable solution to this weakness.

Current discussions on agile manufacturing focus on technological developments, mainly information and communication technologies. In an interview with Erik Tempelman, Associate Professor at the TU Delft specialised in Advanced Manufacturing; agile manufacturing is realised within a company when they effectively use PDM systems (Product Data Management). PLM (Product Lifecycle Management) is part of a PDM and helps with the traceability of products and their components.

Some instances relate structural changes to agile manufacturing. For example, firms that are focused on services tend to explain it with behavioural aspects. Here, teamwork, learning and employee involvement are stressed above all (Pfeffer et al. 1999).

Figure 25: Customised low-functional components. (BMW Group, n.d.)

THE DEFINITION IN THIS ASSIGNMENT

Agile manufacturing can be interpreted in multiple ways according to the text above. In this assignment, the definition of agile manufacturing is used as follows.

'Agile manufacturing is the approach to the customer. Where organisation, people and technology are integrated as a whole. It's the movement towards understanding the customer and quickly providing them with exactly what they need.'

This is visualized in the infographic in Figure 26.

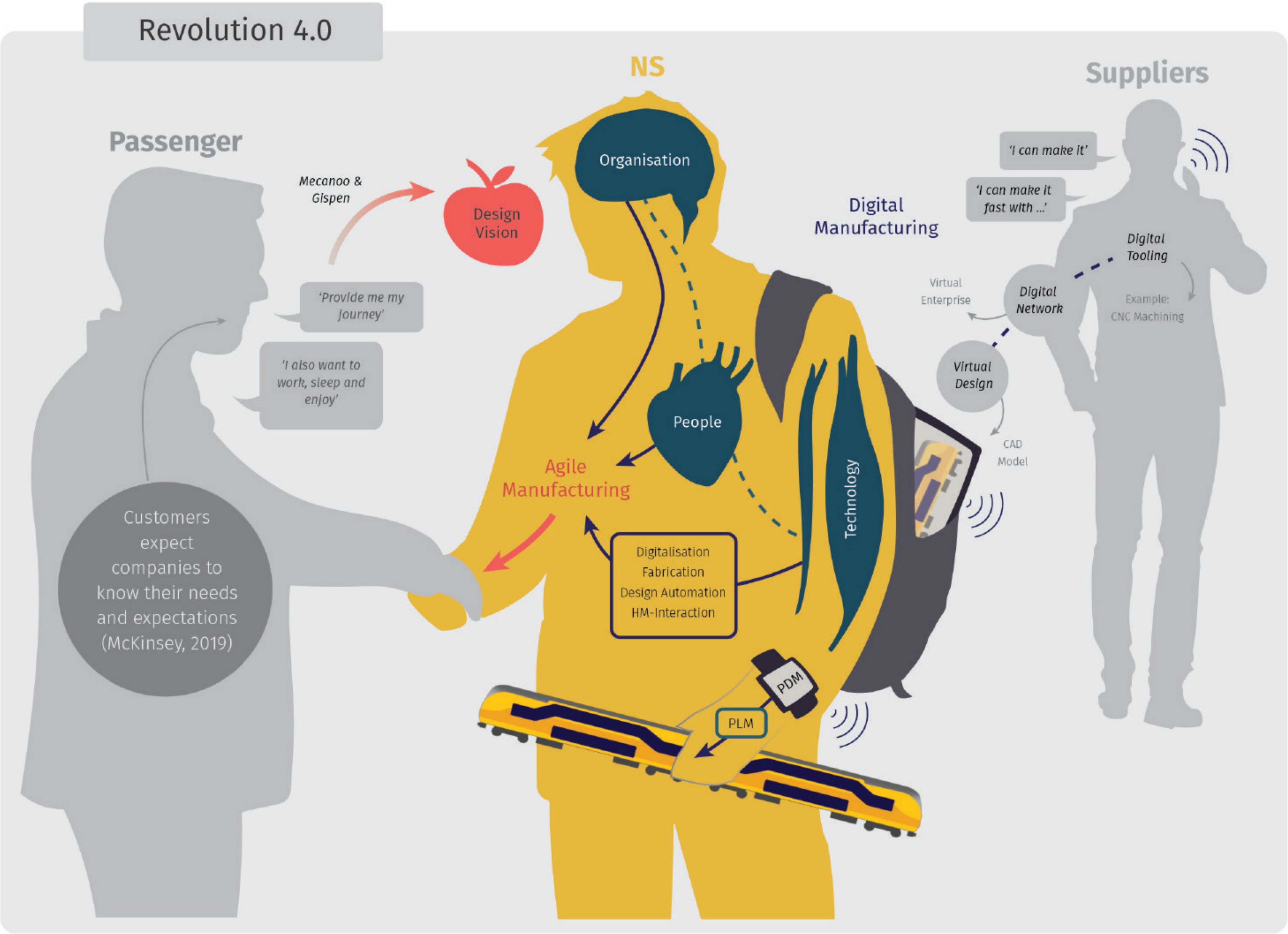


Figure 26: Infographic Agile manufacturing

EXPLANATION OF THE INFOGRAPHIC

Agile manufacturing is the movement towards the customer to understand them and provide for them. To do that, all three aspects of the organisation have to work together as a whole. In this definition, agile manufacturing is not something that can be realised overnight. Comparable to the entertainment industry – you can apply it and become excellent at it – but there is always the chance that people change their mind or lose interest. They might want something else in a short period of time. The same trend is occurring in the transport industry. The traveller does not only want to get from their destination A to B. They have demands to be able to work or to relax in the train. The NS should provide them with the means, and agile manufacturing can be the answer to deliver to them.

In the infographic, the brain of the NS explains its management. Here, job functions like supply chain managers and business strategists fill the spot. They set up strategies and coordinate the flow of components. In its heart are the people of the NS. They realise the work and see the advantages and disadvantages of a particular innovation. It is therefore essential to include them early on in the design process. Examples of job functions that belong to the heart of the NS are the designers, engineers, train inspectors, etc. The technology is the muscle of the NS. It supports the organisation and its people with the means to work efficiently and adaptively. Digitalisation, Design Automation, Fabrication, and Human-Machine interaction are the pillars carrying the activities within technology. The digital manufacturing platform runs behind the organisation of the NS. Digital manufacturing is the approach to a production that is centred around a digital platform. This platform includes digital design, a digital network and digital tooling. (Minnoye, 2018). Orders from the NS are connected to different suppliers in a digital manufacturing environment through a virtual enterprise. Adding a new CAD design can give a quick quotation of the price and delivery.
All these developments are part of the fourth industrial revolution (also Industry 4.0).

THE BENEFITS AND DISADVANTAGES

Reasons to apply agile manufacturing can be divided into two sections – The market and consumer demand (Ganesekaran, 2001). With today's market, many companies are in fierce competition with each other and try to gain a competitive edge. In addition to that, unpredictable changes in the market occur, which means that the companies must act quickly. The consumer of today wants products of higher quality at a low price and demands the products to be tailored to their needs. This persuades companies to become more adaptable to the occurring changes in the market and customers, by making the company agile.

Benefits of agile manufacturing (Ganesekaran, 2001; Kidd, 1995).

- Higher productivity
- More efficiency
- Cost-effectiveness
- Speed
- Flexibility
- Quality control

When implementing agile manufacturing, many challenges may occur for existing businesses. Since the changes needed to adopt are of considerable size, they can be both challenging and expensive to implement (Planettogether, 2018).

Another issue with agile manufacturing is that the performance cannot be measured in numbers – meaning that it is not possible to know if the investment will pay off as it is based on the assumptions concerning the value of a close consumer, supplier and organisational relationships and adaptability in a fast-changing market (Planettogether, 2018). However, if the focus lies primarily on technology, a transparent result in numbers is possible. (E.g. a more cost-efficient business model due to agile technical changes in the design process which makes fabrication quicker).

STEPS TO AGILITY

Implementing agile manufacturing invokes multiple complications due to its challenging nature. It requires more skills from employees. However, The NS rarely manufactures their products. Generally, they design the products and outsource further development. Apart from the Modernisation Factory in Haarlem, there is little contact with machines – thus little Human-Machine interaction. The focus is herewith digitalization, fabrication and design automation. These terms are explained as followed:

DIGITALISATION

Digitalisation is, according i-scoop.eu (2018), change in interactions, communications, business functions and business models into digital ones. This results in smart manufacturing with autonomous, semi-autonomous and manual operations. It is the transformation of analogue to digital of a physical product with the goal to digitize and automate processes or workflows.

FABRICATION

Production in which pre-processes, tooling processes and post-processes define the output. The Chapter 'Manufacturing in General' elaborates involved processes.

DESIGN AUTOMATION

The meaning of Design Automation is the automation of time-sensitive and repetitive upfront activities. Automation enables more time to innovate and add value to the produced products. With this the market position is improved, a higher quality value is achieved and more businesses are won.

Enabling agile manufacturing within the NS put more pressure on the designers and engineers. The need to be able to create documents and drawings increased quickly. Less time is spent on re-engineering existing design, updating drawings and quality control. The design process is prone to errors, rework, backlogs and delays, which can lead to profit margins and damage reputation.

Design Automation enables the NS to turn proposals quickly, design and manufacture efficiently and deliver quickly to their passengers – all while maintaining a healthy profit.

An example of Design Automation is the appliance of straightforward rules and decision logic in CAD programs. When the NS creates a new train, the organisation needs to capture and re-use the combined knowledge of their most experienced designers and engineers. However, storing and sharing this knowledge with others is difficult. A solution is the automated addition of geometric and equation-driven dimensions. When changes are made to a certain dimension, changes to the product are automatically made, unravelling the complex design references.

Other examples of Design Automation are the automated creation of detailed drawing, the generated Bills of Materials for production and the automatically created quotations of cover letters. All leading to the reduction of errors and saving time.

AGILE AND LEAN MANUFACTURING

Agile means being prepared for unexpected responses from customers' demands through agile production design, while lean means minimizing waste and costs through continuous improvements and measurements in the supply chain (Shah et al., 2003). However, while different– both of these philosophies focus on the same goal – increasing the business sustainability for manufacturers. It comes down to agile manufacturing being able to handle unexpected customer demands and market changes by using flexibility and speed, while lean manufacturing is being able to reduce waste and costs to improve the value for the customer (Gunasekaran, 2001).

For other agile tools meant for the organisation and people please inform Appendix G.

CONCLUSION ON AGILITY

This assignment, agile manufacting is the approach to the customer. Where organisation, people and technology are integrated as a whole. It's the movement towards understanding the customer and quickly providing them with exactly what they need. To get an higher level of agility, digitalization, fabrication and design automation should be applied. Appliance will result in Higher productivity, More efficiency, Cost-effectiveness, Speed, Flexibility and Quality control. These are the benefits from agile manufacturing.

REQUIREMENTS

The list of requirements is mainly related to the three interior elements - the handle, barstool and stit. These requirements are gathered from the RIS (Regeling Indienstelling Spoorvoertuigen), TSI LOC&PAS (Technische Specificatie inzake Interoperabiliteit – Locomotives and Passengers), TSI PRM (People with Reduced Mobility), TecRec (Technical Report for Interior Passive Safety from UNIFE), GM/RT2100 and Eurospecs for Seat Comfort, Enumeration of cleaning equipment.

The RIS are Dutch regulations and the TSI are European regulations. Most of the local Dutch regulations refer to the TSI. For example, the TSI demands PRM requirements weights over the Passive Safety requirements in wheelchair production facilities – this is due to the wide range of wheelchair types and sizes that are available. Passive safety requirements are not possible since wheelchair design, dimensions and mechanical characteristics are beyond the control of the rail vehicle operator (UNIFE, 2014 - TecRec: 6.5.2.).

The TecRec for interior Passive Safety has similar requirements as the GM/RT2100 – which also mandates the requirements for the design and integrity of interior crashworthiness. The most strict/conservative requirement is used in this study by comparing the two documents.

The Eurospecs was established by rolling stock manufacturers, railway operators (e.g. NS and DB) and passengers to harmonize the passenger rolling stock. Manufacturers used to have trouble with processes, structures and requirements of the market, while the operators where dissatisfied about the duration of procurement for trains and wanted a controlled uptake for innovations and improvements for costs, quality and reliability. On top of that, passengers expected a qualitative level of comfort. The potential of the Eurospecs lies in defining a common base in areas of user interest and eliminating the differences in a non-competitive domain. Eurospec allows experts and design managers to meet each other halfway and share experiences and long-term ideas. An example is the published toilet module – where they provide specifications of the requirements for toilets in rolling stock. The module was approved by UNIFE and the UIC. One version still in progress is the seat comfort module for seat comfort (Appendix H). However, the seat comfort requirements are currently used for the comfort specifications for the barstool (Eurospec, 2019).

The full translated list of requirements regarding the three interior elements can be found in Appendix I.

FIELD RESEARCH

Several stakeholders were interviewed to gather insights. The interviewees were chosen based on their involvement in the interior vision of 2025. All the interview guides of interviewees can be found in Appendix J. Some include a personalised presentation - depending on their knowledge of the vision. Figure 27 show the clusters created from these insights. The colors define where the insights come from. Red and dark blue are both senior engineers. Light blue is someone who makes sure the train is up to standard. Green is an external designer working on the interior vision. Black is an internal designer within the company. Yellow is a supply chain manager. Purple is a project manager within the company.

Quality control:

- There will be an extensive selection process, lasting 4 to 6 months.
- The NS is continuously developing its products together with its suppliers.
- The current materials used in the train are challenging to clean because this requirement, easy to clean, is often underestimated. Especially the fabrics encounter issues.
- When you talk about composites, it must still be tested in the final form, so upholstery and foam together, which results in a fire-blocker as the foam is usually hard to make fire-proof on its own.
- The entire marketing department works on agile for six months now. They have been trained.
- Not every cabin is the same within a train since the interior sizes differ from each other.
- The barstool… I'm not certain whether it is going to work. It is claimed that it will not go at the cost of seating places. I have my doubts about that. If you create space on two sides of a piece of furniture - because you need space to go around - then you lose space somewhere as well. So I have my doubts when you talk about maintenance or increased capacity.
- The bar stool will probably not be included. Bar stools in trains do exist, but to have regulations that comply with it for that bar stool is another thing.
- There are no specific rules for the stits; you will have to work with the regulations around it.
- Weight between standard chairs differs drastically, on average it will be about 20 kilograms, could be 18 or 25 for individual chairs.
- We had a headrest design with a quick release, with two thumbs between the pillows you would be able to release the headrest. Maintenance immediately says this will not be implemented, if it is posted on twitter once then all the headrests can be found in the stations.
- There is no problem if it breaks, but it may not become a murder weapon when something breaks, and of course, it should easily be replaceable.
- The main frame must not be replaceable, with some exceptions.
- I think that hybrid testing, the way you mentioned it, can enable the NS to implement 3D printing earlier.
- Regulations make things harder; we introduced a new sticker which was very pretty, with the idea that it would work against graffiti with its black and white pattern. That did not pass because the chemical substance would not work within a train.

Flexibility:

- What happens behind the interior vision is a dynamic project, so I am not fully updated on everything.
- When you say, I will take out this chair. Even if it is the same chair but a different supplier, you still will have the obligation of proof due to regulations.
- There is the ability to manage a wider variety of interior elements in an economical, sustainable and controllable manner.
- Currently, many things have to be standardized and stocked, and we are not able to do anything.
- I prefer to keep the different shapes of the stit in it; this makes the train more playful.
- For example, parts are no longer produced, producing such a part will cost a significant amount of money in those cases.
- The stit - is something we already do - so more variants, that is possible. In the current variant of the modernization of the Virm, we have different issues of the stit. Due to the design of the existing train, many designs have been dropped. However, that does not mean, if a new train is purchased it is not possible, because in that case you should keep thought of it.
- Digital warehouse. You will always want to have something on the shelves if something breaks, the NS seeks to replace this immediately. C: this is 6 hours, is that correct? R: No, that depends, whether it is a critical safety part. For example, the stits, as long as it will temporarily not pose a significant safety issue, there is no need to repair it in 6 hours. Then it can run an entire shift without a problem. The 6-hour cases are, for example, the opening of a door, or the switch of a door. Then it will have to be repaired as soon as possible.
- The part for the chair, I would weld it to a plate and attach the chair shape to that.
- Last, as long as a train does, foam and upholstery are replaced.
- Within supply chain management, there are many complications related to supply. DB is, however, already working on 3d printing.
- I am responsible for one of the older trains and maintenance can be hard for those.

Design freedom:

- I think the idea is possible, but it is entirely different from what people are used to. In that sense, it is far from lean or agile.
- It will quickly derail as soon as the capacity comes at stake. What strongly shears with the development of new trains is capacity, which is leading to development. As soon as the choice has to be made between a place where six people fit and a place where two people fit, the choice is clear.
- If you look at how a train is permitted, there are limitations. That is mainly for the usage of materials, so when you change a product, it has to contain the same materials.
- If the handle is on the chair, we can ask the supplier for a proposition. Afterwards, we evaluate this and for instance, ask if certain aspects can be rounder. The suppliers are incredibly familiar with the regulations. In almost all parts it will be a casted part, and we want it to be brushed of anodized. This is needed for the required contrast.
- In the current design, the handle does not comply, for more contrast you could, for instance, anodize it blue.
- You could use this for the ceiling to 3d print with wood filament.

Cost efficiency:

- Train manufacturers try to build a train for a broad audience; on the inside, they will only want to change colours. They want to deliver a standard product which they can sell to as many countries with as little adjustments as possible.
- Eventually, everything becomes more expensive, and other variants will be made.
- Short answer, yes it is possible, but entirely dependent on the bag of money that comes with it. For regulations, I see some minor issues, but those can be sorted out.
- A first-class double seater, with USB hubs and all the extras, will not cost more than 2000 euro, a single seated second class seat costs no less than 500 euro, so a barstool like that will cost (since it is a somewhat weird apparatus) somewhere between 500 and 1000 euro, that is a rough estimate. There is little processing on it, so that is why I estimate this price.

Sustainability:

- The parts of the NS trains are not easily interchangeable, which makes it difficult to make revisions in the train interior. Currently, these revisions cost lots of money, energy and are not sustainable.
- Sustainability focuses on the life expectancy of products, but also at the ease in which it can be upgraded. Once you have thought about that and made products easier to replace, then you are working in an agile way.
- Sustainability is still a small part and is not integrated into tenders.
- There is a small increase in sustainable awareness within the company, but the desirability to become sustainable is relatively low. The aesthetics of the train is more important than sustainability.

Figure 27: Clusters from insights

CONCLUSION DISCOVER

The NS already participates in the agile movement. However, their agile manufacturing skills, related to different techniques and production processes, are still behind in comparison to other companies like their competitor Arriva (Deutschen Bahn). The NS should apply digitalisation, fabrication and design automation to their workflow to gain more agility.
By clustering insights the conclusion was drawn that quality control, flexibility and design freedom were highly demanded features. These features are divided among each Design Direction. Within the NS, other highly desirable features are cost-efficiency and sustainability, thus each Design Direction should incorporate these. An elaboration of these Design Directions can be found in the Design Chapter.
The Senior Engineer at the engineering department in Haarlem argues that the production of variation in stits should not be a problem. Due to the different trains in operation a large variation is already present. The production of the handhold should not bring any issues. From the three earlier chosen interior elements, it is the bar seat that brings the biggest problems. Therefor, the decision was made to focus on the bar seat.

Figure 27: Clusters from insights

DESIGN

DESIGN DIRECTIONS

In the discover chapter, the features to achieve a higher level of agility with technological regards were discussed; Digitalisation, Fabrication and Design Automation. Clusters from the insights concluded that the highly desired needs are Quality control, Flexibility and Design Freedom. The agile manufacturing features and needs have been combined to the three Design Directions shown in Figure 28.

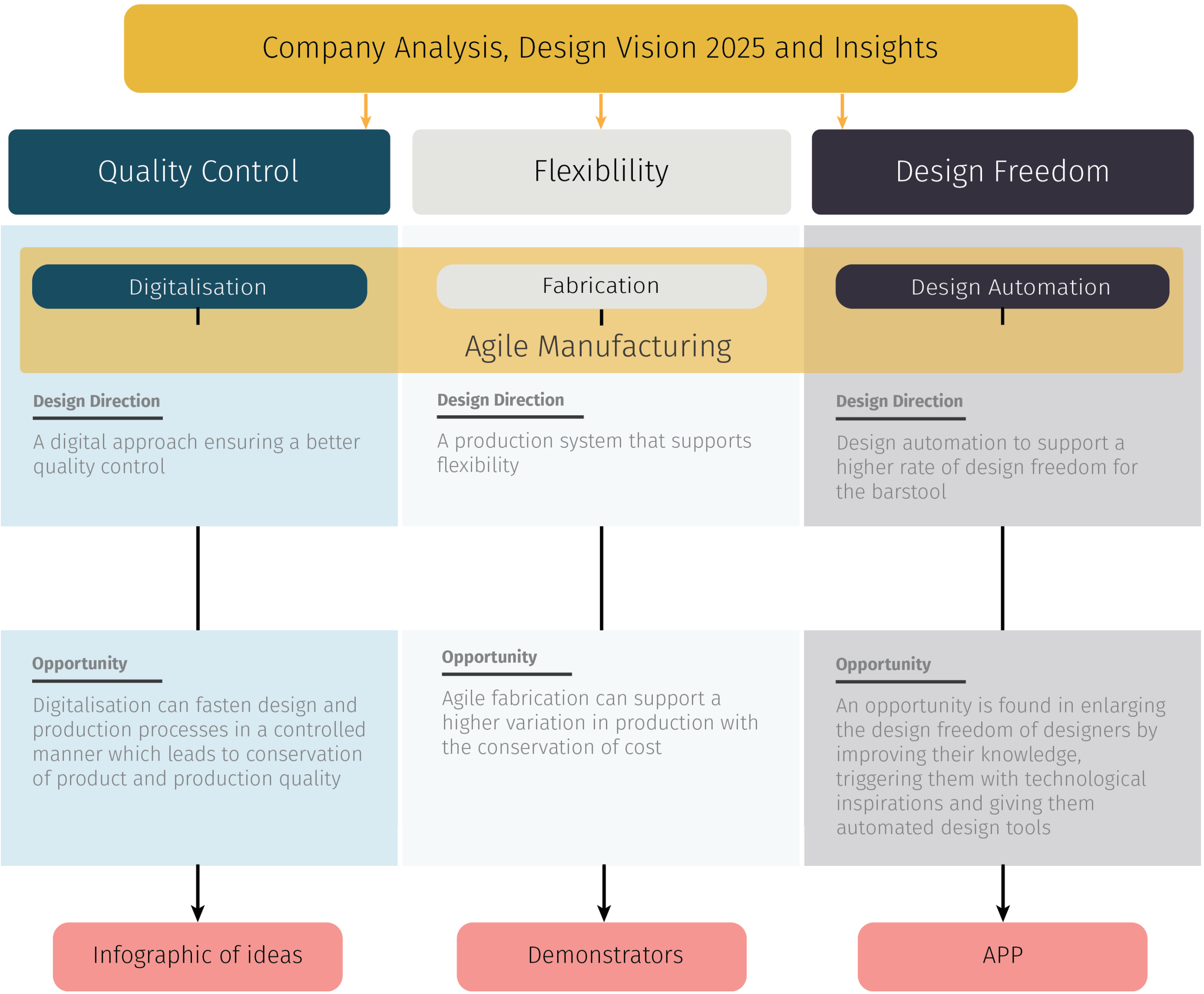


Figure 28: Design Directions and Opportunities

CLUSTERING OF THE ALL DATA

Found insights, developments, trends and statements from academic research are clustered in the three agility features - Digitalisation, Fabrication and Design Automation. The result of this full-scale data clustering can be found in Appendix K. Sub-clusters were created within the 'agility' clusters. These sub-clusters will help during the next phase with ideation.

All three Design Directions are ideated upon as elaborated in the following chapters.

IDEATION DIGITALISATION | MORPHOLOGIC CHART

Sub-clustering of the digitalisation feature revealed the following titles: Digital archive, Easy Production through digitalisation, Analytics, Processing and Control. These are all related to Quality control. These titles are on the Y-axis of the Morphologic chart. Insights and other data were then placed accordingly. The chart which was made with the H2 method can be found in Appendix L.

IDEAS

Ten ideas were generated by using Morphological chart. These are all related to Quality control of the design and production processes. The ideas can be found in Appendix M. Three potential ideas where chosen as shown in Figure 29.

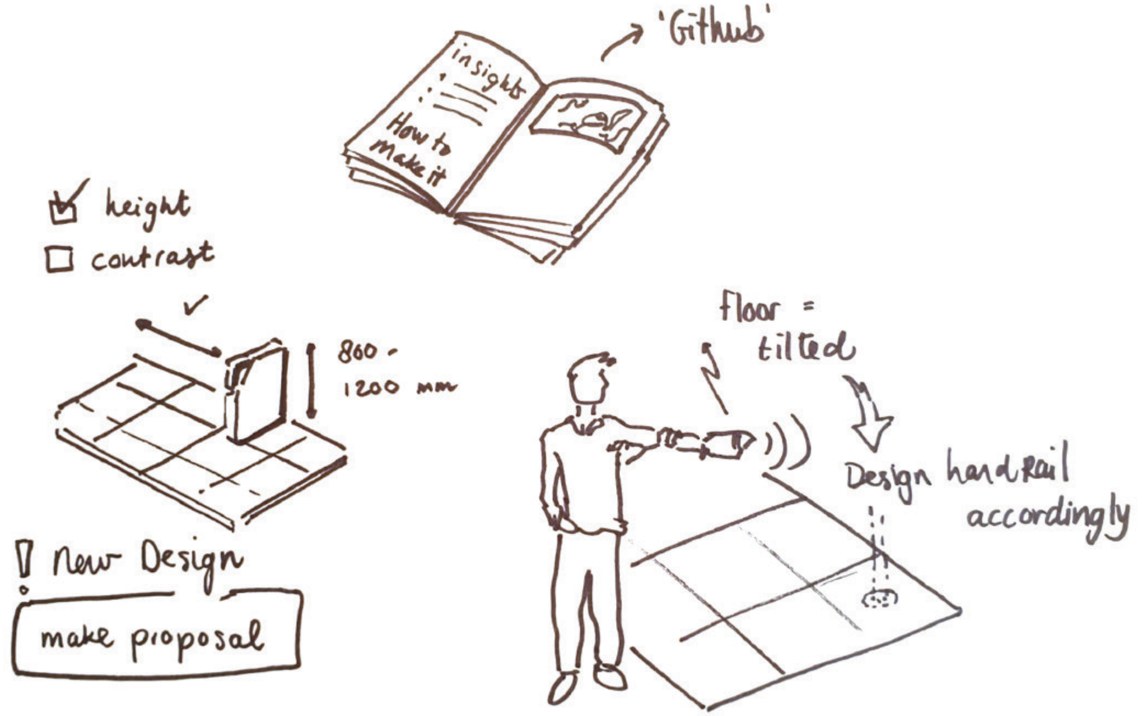


Figure 29: Digitalisation Ideas

IDEA 1: NORM CONTROL

The first idea 'Norm Control' is based on the communication errors between designers (some from external parties) and NS engineers. Requirements (RIS, TSI, etc.) are not transparent due to the abundance of rules. Furthermore, the rules are constantly shifting. Norm control can help designers with an app that allows them to test their design in an interactive environment of a train chassis. Designers import their CAD design in the virtual environment where it automatically checks if the design conforms to the norms. E.g. After import, the app tells the designer that the height of the handle is placed too high. This app allows designers to quickly test their design, giving them more time to discuss other issues with the engineers.
In case of a new design, like the bar seat, the app will automatically generate an innovation proposal, since new innovations need to be checked by the EU.

IDEA 2: TRAIN TETRIS

The second idea 'Train Tetris' is based on the insight that every chassis differs from each other. The idea is to 3D scan the interior chassis without the interior component and place customised interior afterwards. An employee (from the train supplier) will 3D scan the interior during the chassis production. This analysis states the exact differences in trains, giving exact tolerance guidance. For example, a train seat might fit near the balcony, but tolerances can differ near the centre of the chassis. This is problematic for standardized products. Especially after years of usage when maintenance has to replace the seat. Not having the exact dimensions will result in carrying more 'repair baggage' to the designated location. The Train Tetris solves this problem by archiving the dimensions in a digital library. Customised dimensions of products are hereby 'ready to grab' when needed.

IDEA 3: NS INTERIOR CONSULTANT

The last idea is based on the data management, in particular the gathering of insights. The NS is a large organisation with an abundance of knowledge making it difficult to control all flows of data. However, data can be organised more efficiently to help employees work faster. The 'NS interior consultant' is a platform which stores insights related to interior design. E.g. The insight 'Passengers often leave trash in small holes' is frequently recalled. Storing these insights and allowing easy access will result in more productivity.

IDEATION FABRICATION | CREATE DEMONSTRATIONS

The company analysis states that the NS does not manufacture their trains or accessory components. However, they did design a new interior vision with newly introduced furniture. The barseat is one of these pieces of furniture. Although they will not produce the seat, they can **choose** how it is made in the design.

The benefits of Agile manufacturing can only be realised when fabrication allows for a sense of automation. Flexible tooling processes like 3D printing or CNC cutting, combined with smart robotics and a digital platform (Digital warehouse) can achieve this. Especially when combined with Design Automation, AM will make it possible to quickly create a variety of products. Cost-efficiency is not only accomplished considering the fact that less labour is necessary. It also reduces cost in a later stage of fabrication. Having a digital platform also lowers costs by reducing the amount of physical warehouses and removing the chance of suppliers selling expensive 'rare' components. (See Figure 30).

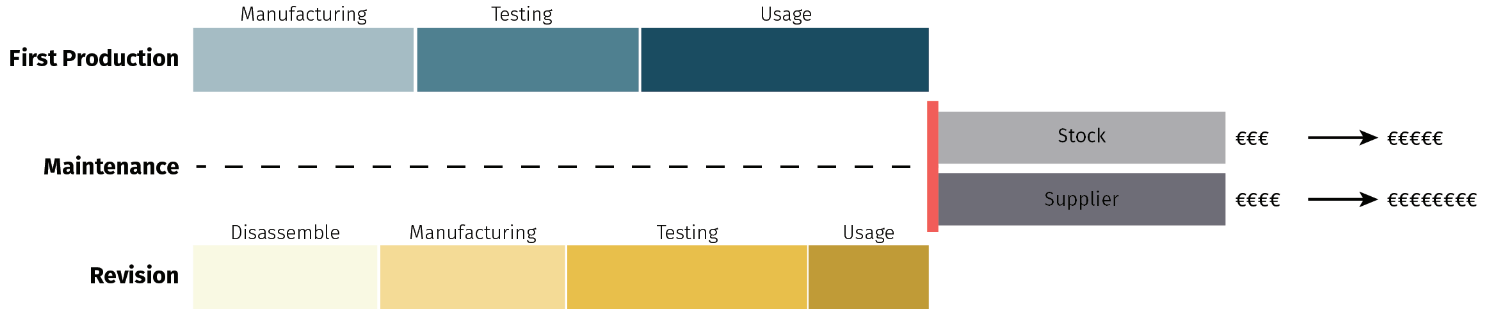


Figure 30: Current situation after usage

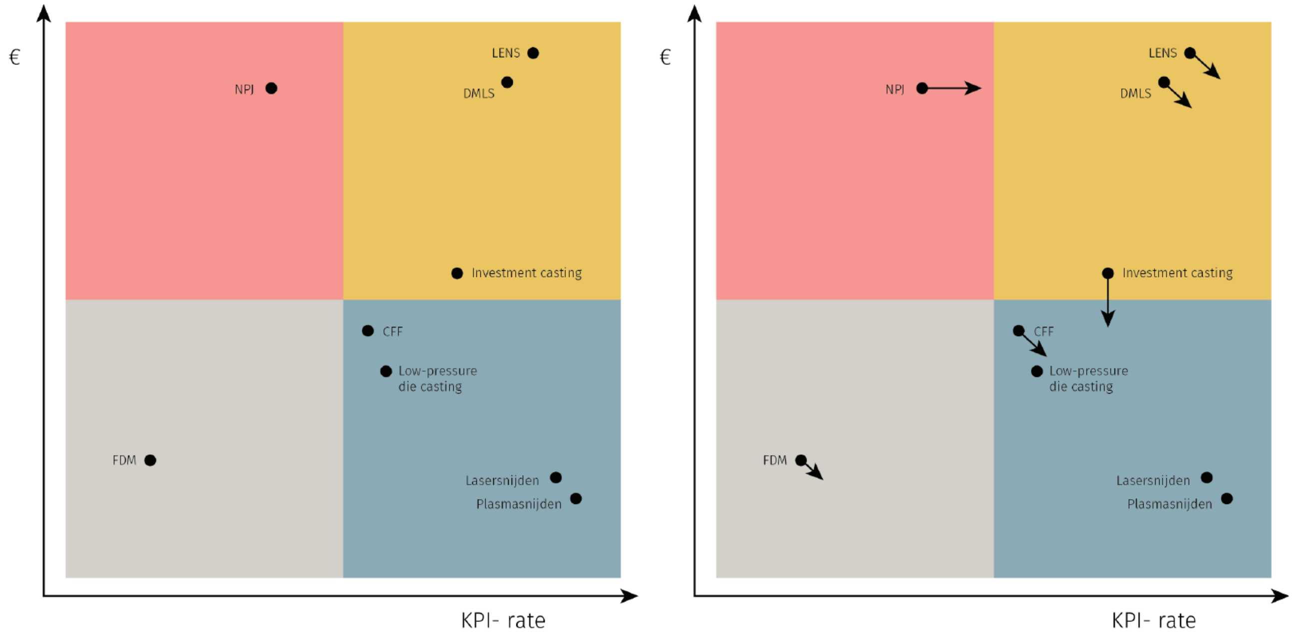


Figure 31: Current tooling processes for the production of the bar seat (left), and expected changes in 2025 due to technological developments (right).

To demonstrate the theory, two differently produced bar seats are designed. Several tooling types for production were analysed (incl. the Production Estimator), the results can be found in figure 31.

The blue area is considered most beneficial due to the low price and high KPI-rate. With regards to the future (Figure 31 - right), a decision is made to include CFF (Continuous Fiber Fabrication) and Investment casting for their growing potential in the future.

Figure 32 explains the expected developments in a technological roadmap where the tooling process box represents their current stage.The color of the arrow represents the rate of agility. Blue is beneficial, yellow is relatively beneficial and red is not beneficial for agility.

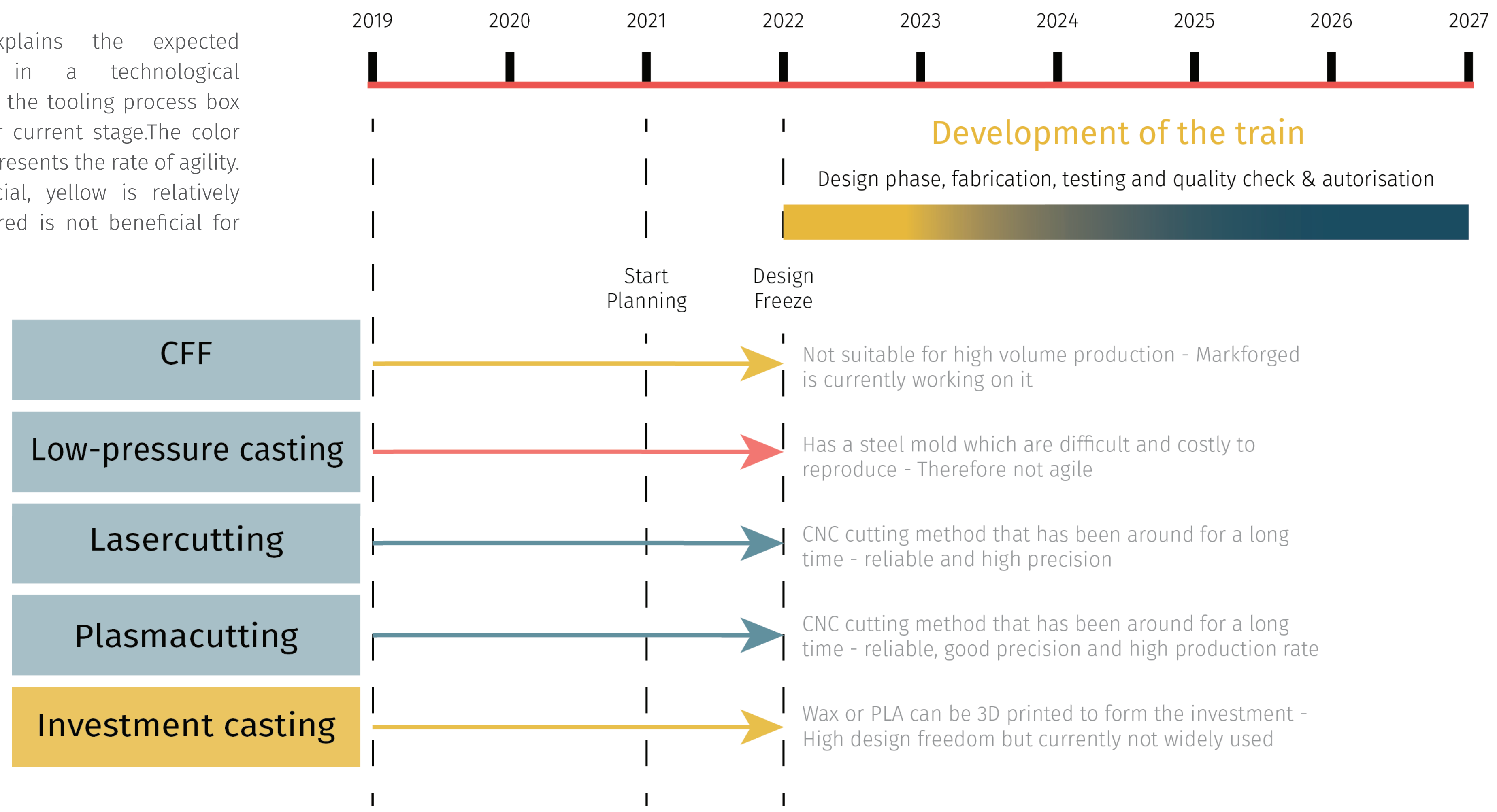


Figure 32: The tooling processes plotted in the technological roadmap

Two demonstrations will be created. The first logical option is to choose laser cutting (SM). The second choice is preferably an AM technique - which is more compelling after consulting the roadmap in this case. On top of that, this was initiated by NS stakeholders who desired an agile demonstration of 3D printing techniques. The two demonstrations are currently at different levels of agility. However, developments in 3D printing are growing, making the use of 3D printing techniques for bar seats a feasible future. (See Figure 33).

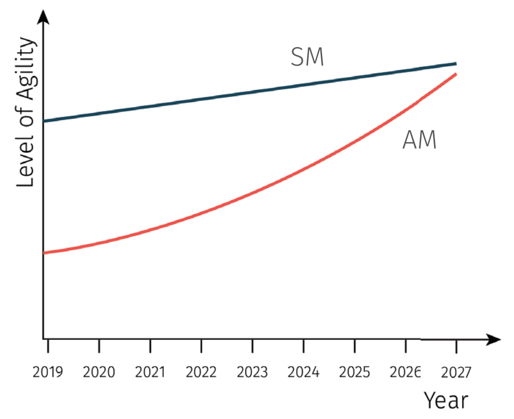


Figure 33: Developments should increase the level of agility for AM.

THE TWO DEMONSTRATIONS

These demonstrations will put emphasis on all the benefits of the technique. Thus, a list is made which regards the benefits per technique. Both are already agile in means of archiving files and production processes (Digital Libary/Warehouse) and access to automated processes. Figure 34 visualises the two demonstrations.

CFF

- High rate of design freedom
- Lightweight due to material usa
- Possible to make it lighter with Topology Optimisation
- Aesthetical designs are easily reached
- Little to no assembly needed

Laser cutting

- Highly sustainable options
- Easy maintenance
- Possible to make it lighter with Topology Optimisation
- Short Lead time
- Recyclable

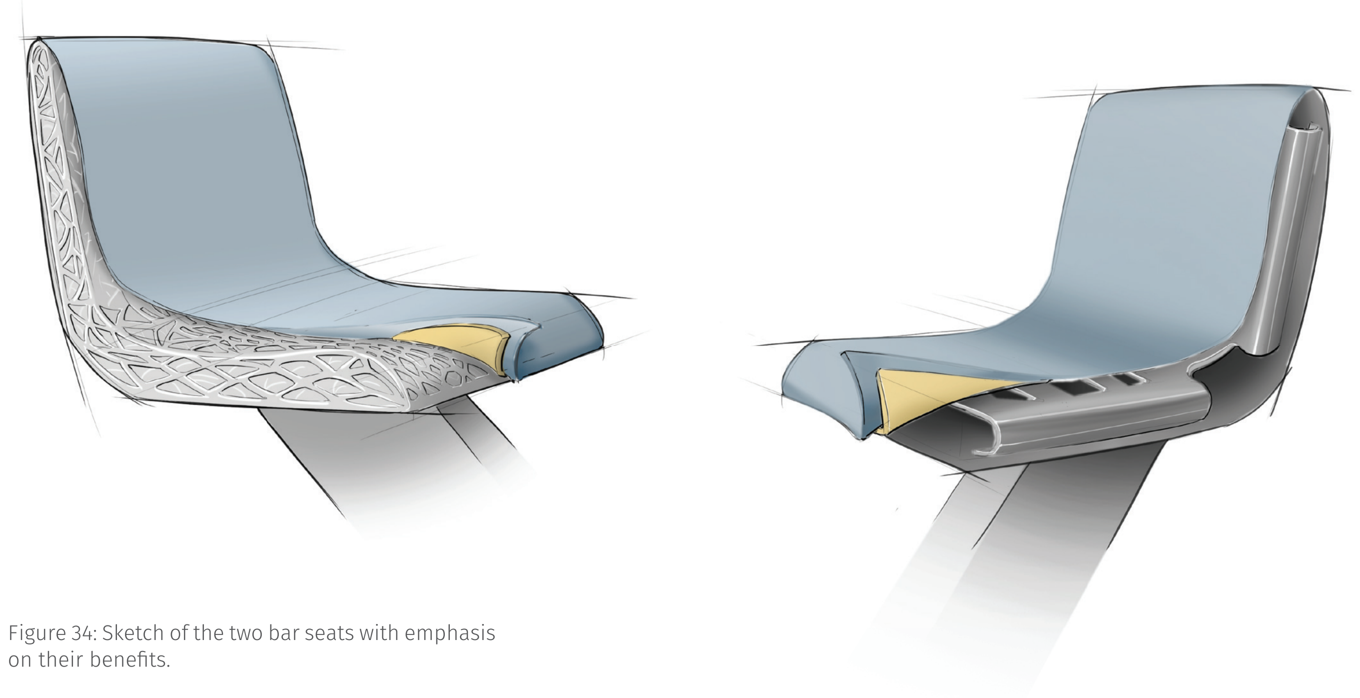


Figure 34: Sketch of the two bar seats with emphasis on their benefits.

IDEATION DESIGN AUTOMATION

The Design automation cluster contains multiple insights, trends, etc. that could spark ideas during ideation. A brainstorm session on post-IT's was initiated to help with the generation of ideas. Eight ideas where set-up (Appendix N). The three potential ideas could be combined into one app. Therefore, the interface found in Figure 35 was created.

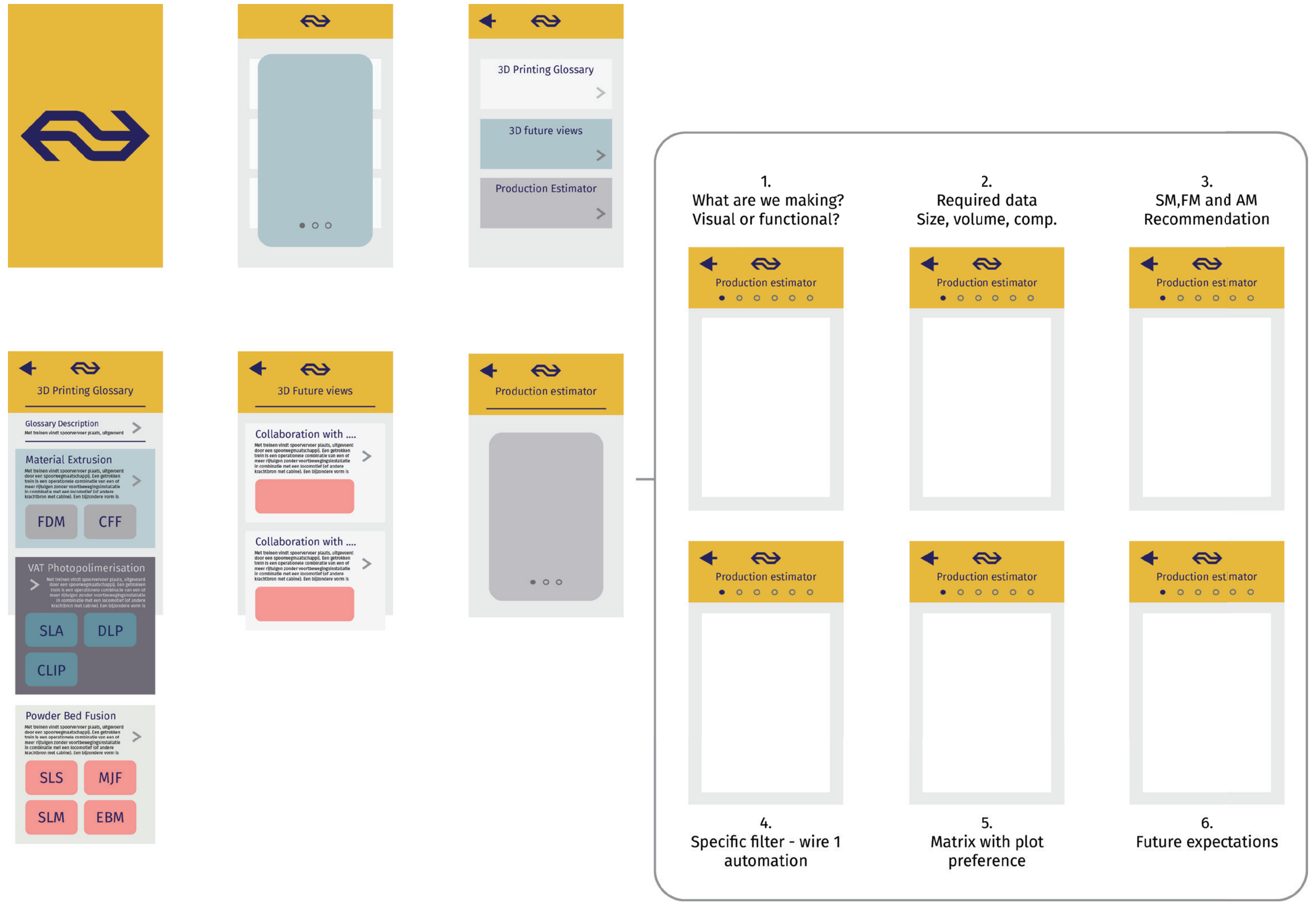


Figure 35: The App

The app is based on the insight of the knowledge gap between designers and engineers. The effect of this gap is visualized in Figure 36. The lack in design knowledge raises design freedom. The knowledge gap in fabrication must be tightened to avoid situations like Figure 37.

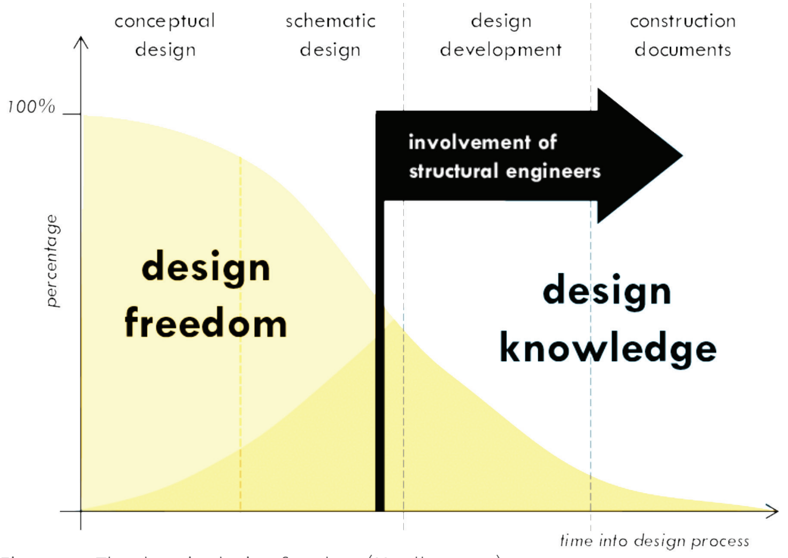


Figure 36: The drop in design freedom (Mueller, 2014)

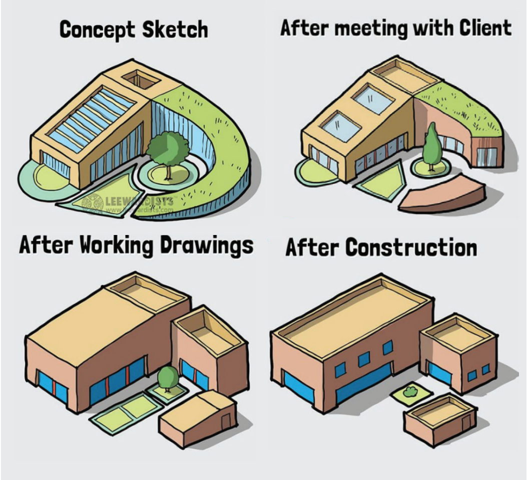


Figure 37: The four phases of design without proper design knowledge (Leewartist, 2017)

THE THREE LEVELS OF KNOWLEDGE

The App presents knowledge on three different levels (the three ideas). The production glossary provides basic knowledge presenting information on FM, SM and AM techniques. This glossary comes with: design guidance descriptions, the advantages and disadvantages, the companies applying the technology and cases earlier performed. This level focuses on cases that have been done successfully.

The second level of knowledge focuses on the trends and evolving matter within the 3D printing world. An example is the collaboration between the binder jetting company FormNext and HP's multi jet fusion technology (3dprintmagazine, 2018). With the collaboration of these companies it can be expected that HP will start printing industrial metal parts in the near future.

The third level of knowledge is based on accessibility. Accessible knowledge is provided early in the process. The NS does not have a lot of information about all the different 3D printing techniques and some designers have a background without technical knowledge. This level contains a production estimator, which can estimate which production type is best suited. Besides additive manufacturing tools, it contains subtractive manufacturing and formative manufacturing tools as well, to provide a complete oversight of the possibilities within the manufacturing world.

DECISION MAKING

Each design direction has its own potential for further development. Further concept development is chosen with the following method. (See Figure 38).

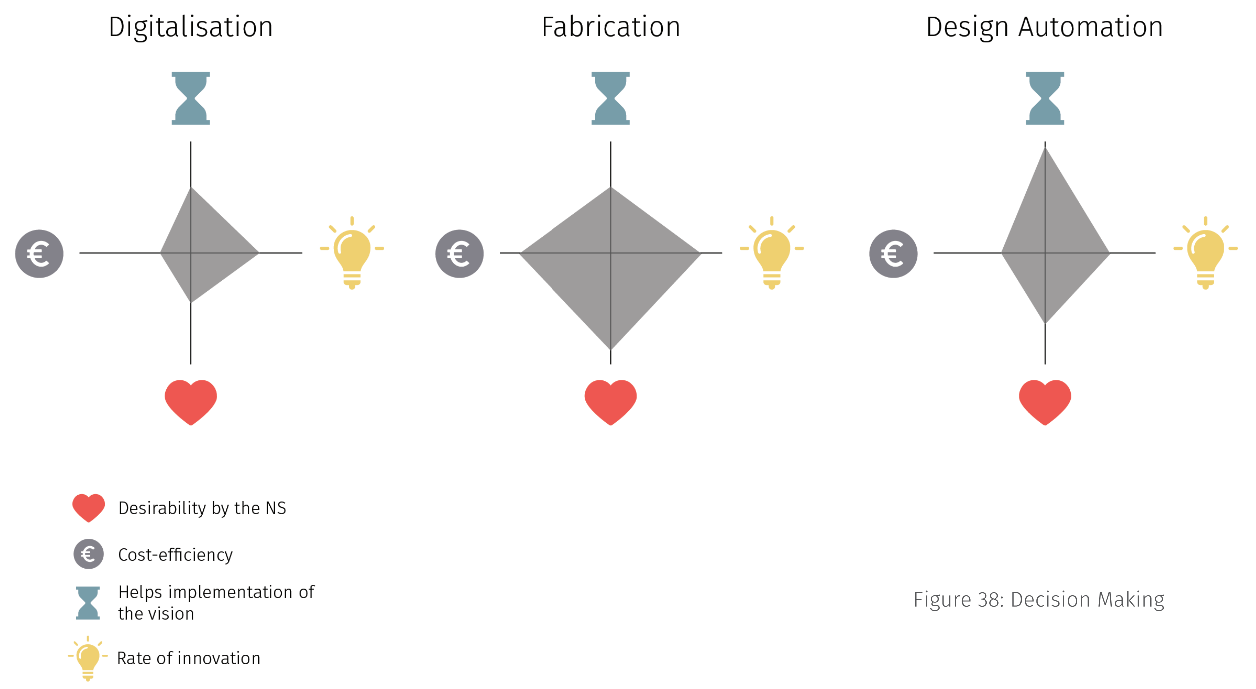


Figure 38: Decision Making

CONCLUSION DESIGN

Further development of the demonstration is highly desired as the NS can directly implement design features into the vision of 2025. Furthermore, creating the two demonstrations can function as a physical trigger to inspire NS designers and engineers. However, ifone of the demonstrators pushes to a future with AM, a tool to introduce AM must be realised. Knowledge on 3D printing is still insufficient within the organisation and therefore more knowledge should be gathered on the matter itself. The app can prepare designers and engineers for a future where3D printing techniques are involved.

DEVELOP

DEVELOPMENT OF THE APP

Figure 39: Scan the QR-code to open the app!

THE THREE LEVELS OF KNOWLEDGE

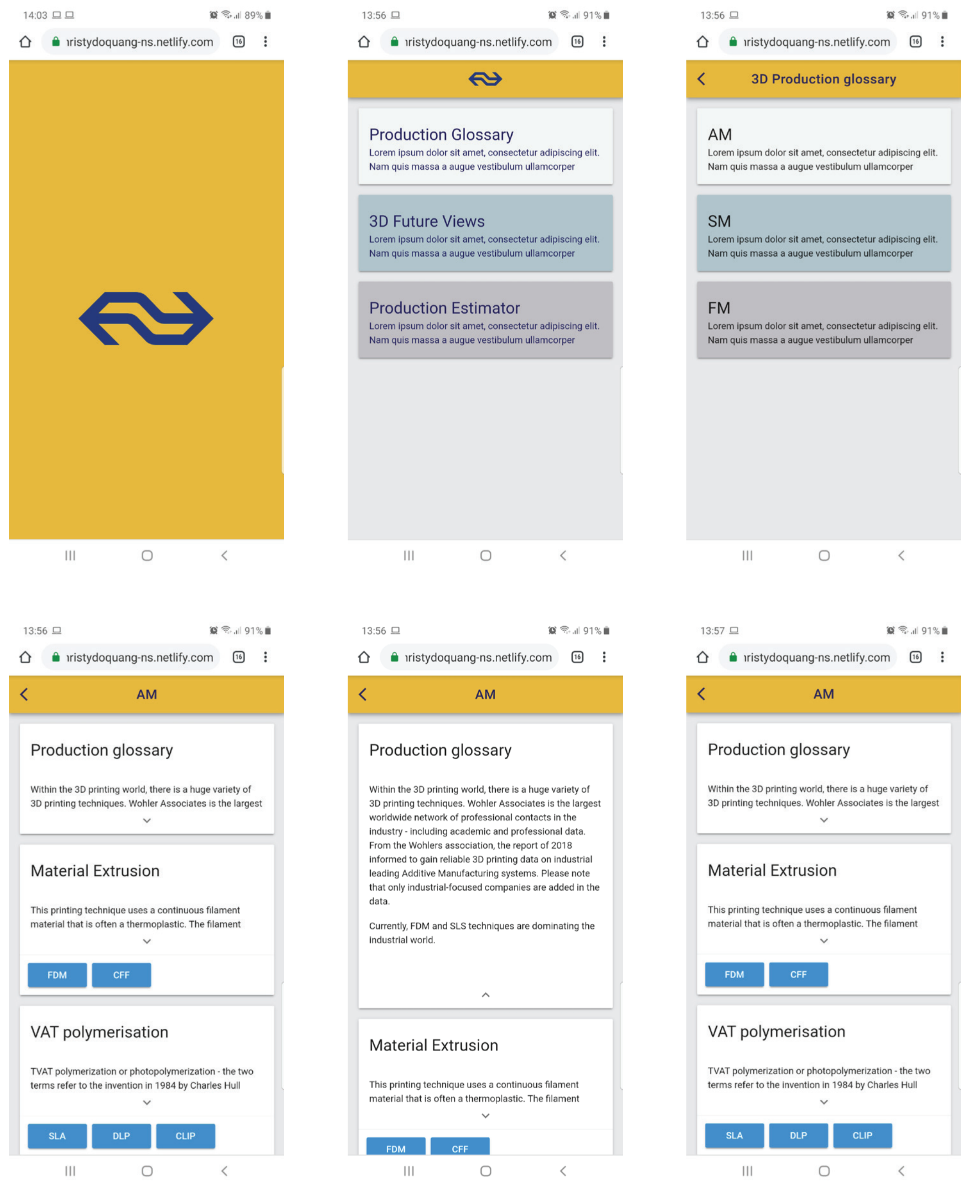
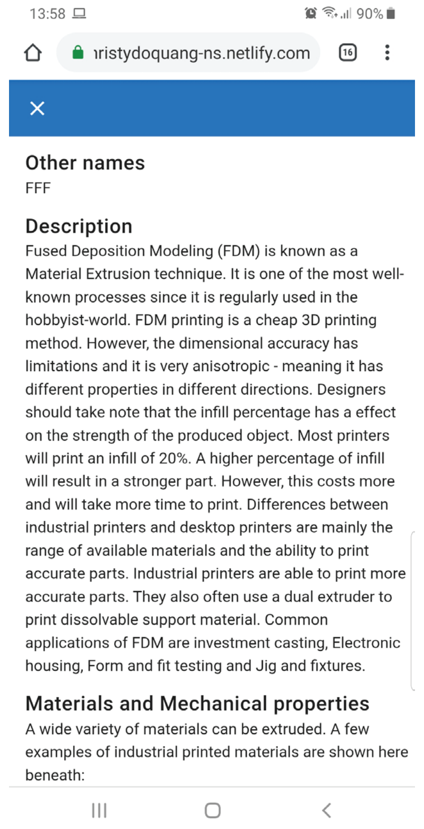


Figure 40: The Production Glossary

The first two levels of the app are relatively simple as it only redirects the user to information. The first level - basic knowledge - Is called the 'Production Glossary'. It redirects the user to the page, where they can choose between the three types of manufacturing - AM, SM and FM. AM is chosen as an example in the reports, as it contains the most data.

The AM tab contains a description that swipes down after clicking. It is partly hidden to prevent the user from receiving too much information at once. The gathered data is presented. The same swiping function is applied to each of the seven 3D printing categories. Each category card gives a short description of its principle.

The estimator is made in 2019. With the inclusion of the rapidly growing Additive Manufacturing industry, the data is constantly changing. Subtractive and Formative Manufacturing techniques have been around and been established for a longer period of time, thus less changes are expected in these fields.
To give an overview of future possibilities, an estimation is made for the Additive manufacturing techniques by Associated Professor Zjenja Doubouski (expert in the field of 3D printing innovation) and Joris van Tubergen (3D printing expert and co-creator of Ultimaker in its early stages).



Subtypes of the category-tab can be selected to read more about e.g. FFF.

The second level of the app, covers new trends and developments regarding production. This is named '3D future Views' because most innovation is associated with AM. Further development of this level will be done in the future.

Figure 41: The Production Glossary and 3D future trends

THE PRODUCTION ESTIMATOR

Nowadays, computational software are widely used in engineering practices throughout the design process. These enforce and reflect the currently existing design strategies (Hue & Liu, 2000; Wang et al., 2002). The digital production estimator is created to simplify the design process and bring more design knowledge to designers in an accessible way. The ability to have an estimated overview of the possibilities also makes the overall design process faster.

The scope of the production estimator is the interior design of the NS - meaning that the database only contains production processes and related companies that produce industrial worthy products.

THE PROCESS STEPS WITHIN THE PRODUCTION ESTIMATOR

This part will explain how the estimator works in use. It starts by asking designers to give information on the produced that is to be produced. This is based on the visible and functional diagram (Figure 42). The first screen presents four images to give an overview to help the user in choosing the appropriate option. In this example the barseat is used as the product to be produced. For the barseat a part will be produced that is not visible, the structural design part.

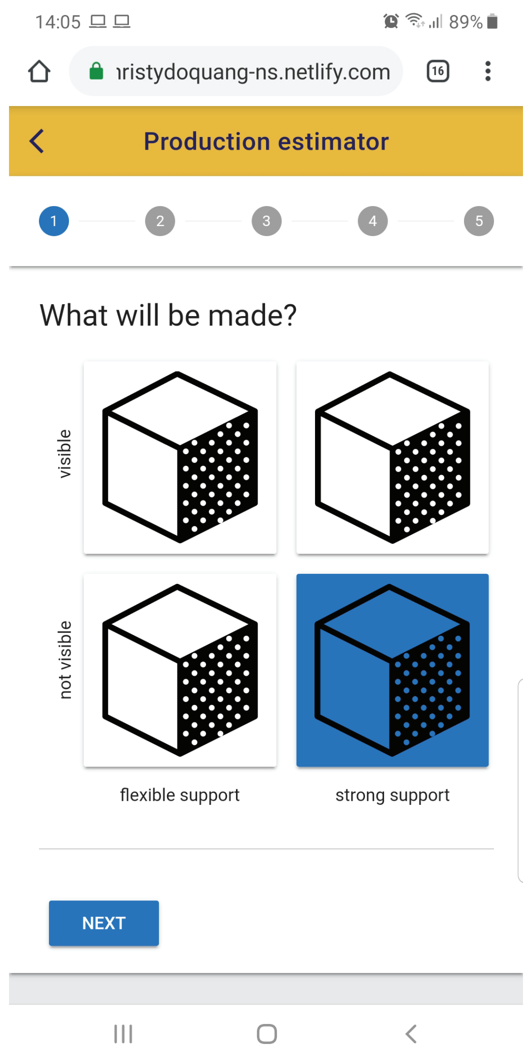


Figure 42.: Screen with the visible and functional diagram

The application then guides the user to the next screen. In this screen, characteristics of the product are to be filled in. These parameters along with the underlying algorithm give an outcome. The parameter for product complexity is the most difficult to fill in and therefore images are used to give the user a better overview of what the options mean.
The algorithm will guide the user to a specific type of suitable manufacturing method by comparing the batch size and the complexity of the product. The results can be divided into additive, formative and subtractive manufacturing. When one manufacturing type is recommended it is still possible to add another type of manufacturing. For example if the application recommends subtractive manufacturing it is still possible to add another type like 3D printing. (Figure 43).

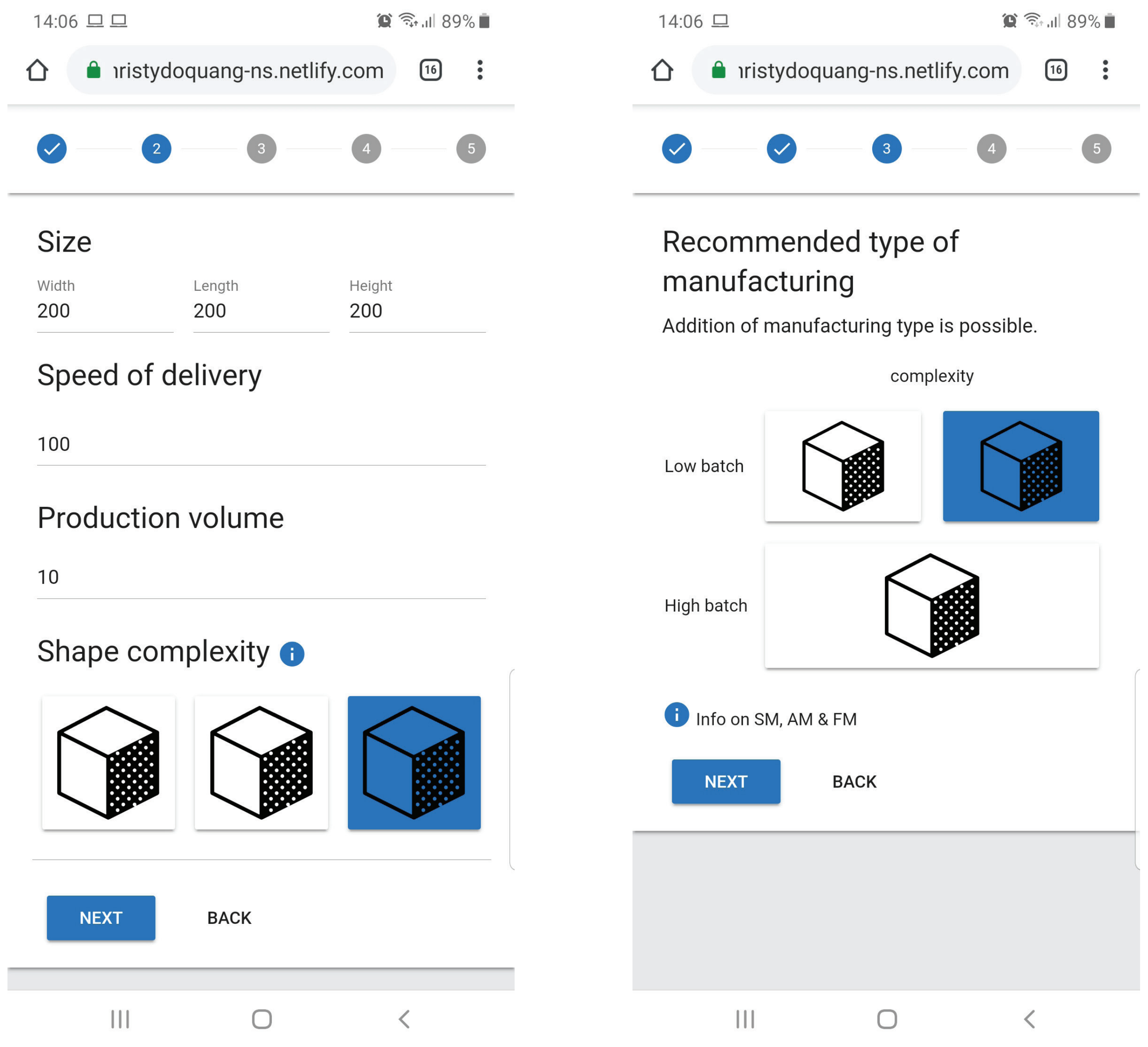


Figure 43: Adding data and recommendations .

Next are the advanced settings since they might want to add specific parametres. The final screen depicts a diagram with the relative costs of production on the y-axis and the KPI rate on the x-axis. This algorithm for the KPI rate is elaborated in the next chapter. (Figure 44),

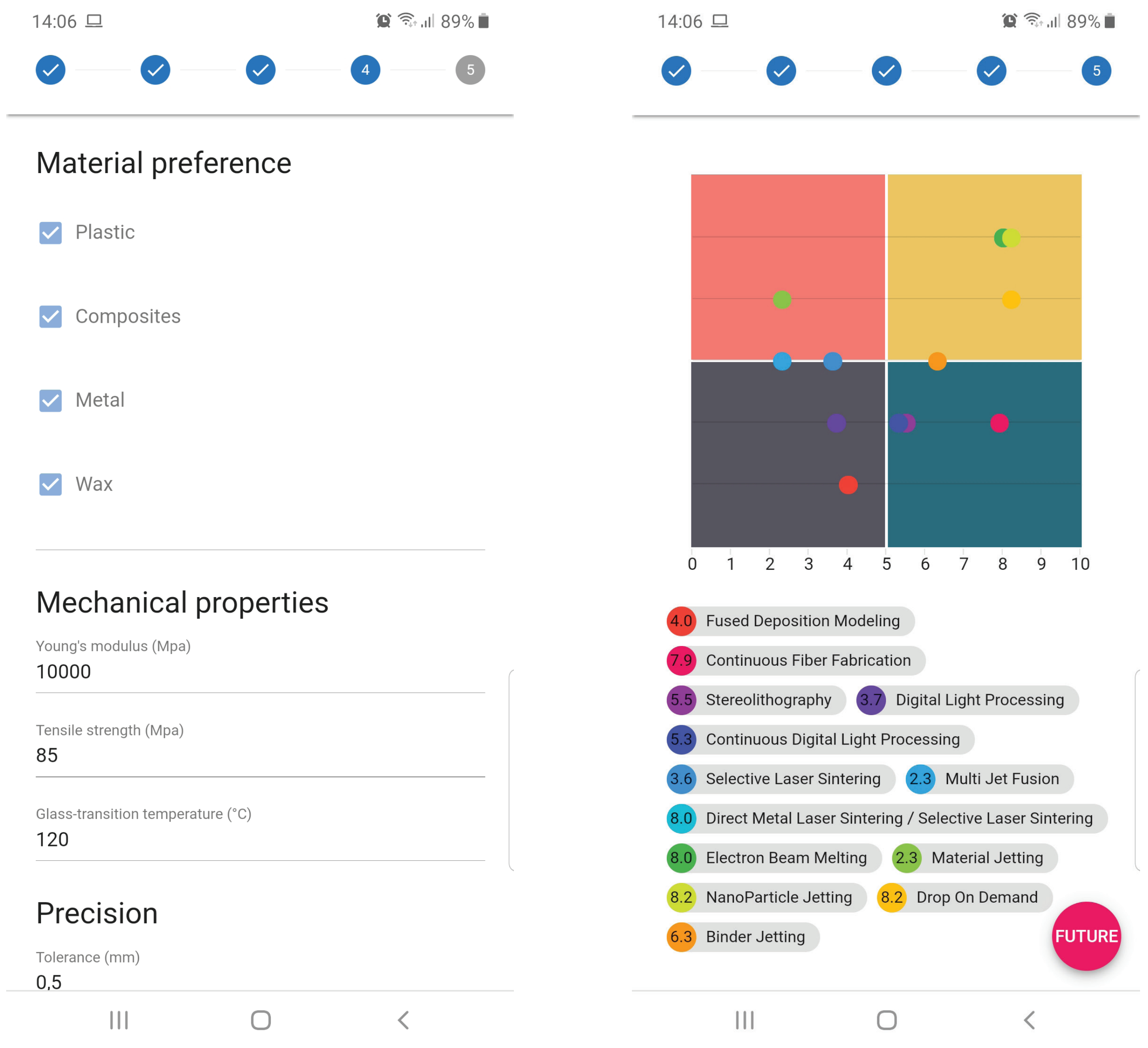


Figure 44: Advanced settings and the estimator

THE ALGORITHM

The app starts by choosing what is going to be produced, in the functional/visual diagram. This defines the numbers (scale) assigned to the weighted objectives method (Delft Design Guide). The criteria to which this scale is connected are based on the characteristics found in the excel sheet in appendix E. In the barstool's case, the choice will be made for functionality while not focussing on the visual aspect. The criteria are then weighted as follows:

Mechanical properties: 70 points
Precision: 5 points
Surface finish: 5 points
Reproducibility: 15 points
Lead time: 5 points

Giving a total of 100 points

Within the mechanical properties criterium, there are 3 sub criteria, meaning each of these sub criteria can score 23.333 points.

So the total weighted score is:

$$(23.333 \bullet \text{Rating } 1) + (23.333 \bullet \text{Rating } 2) + (23.333 \bullet \text{Rating } 3)$$

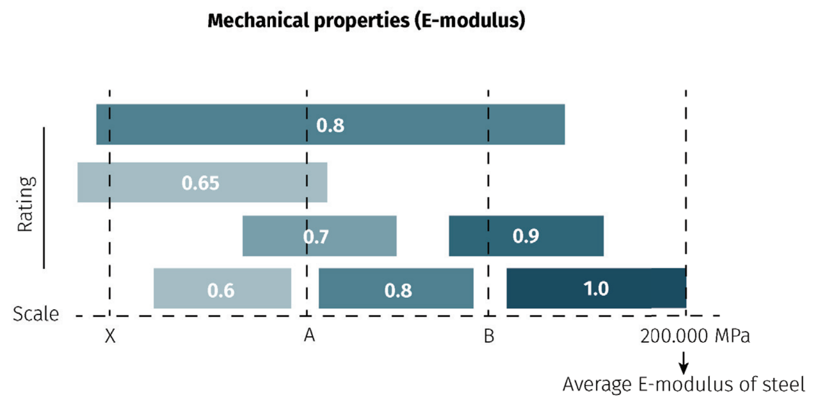
This means that if all 3 criteria score well for a certain technique, it scores a total of 70 points on mechanical properties. When designing a stool for in a train, the strongest material found in a train is steel. For steel an average E-modulus of 200 GPa was found. This gives sufficient stiffness with a high value. Because it involves a stool, a minimum stiffness is required as well, within the standard settings that is set to 10 GPa. The 10 GPa in this case is the x, as it is a variable. An axis where the variable x has been filled is on the opposite side of the average E-modulus of steel.

The excel sheet contains a range of the minimum and maximum E-modulus, because multiple materials are available within a production. To give a rating to this production range the line is split in 3 parts with points A and B.

To calculate the location of point A the following formula is required:

$$A = \frac{200000 - x}{3} + x$$

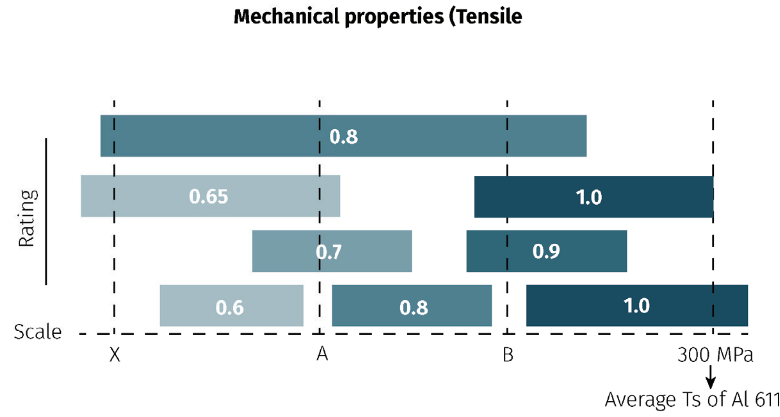
The distance between x and 200 is divided by 3. by going a step +x forward, point A is reached. For point B the same is done but in this case two steps instead of one. This way the x-axis is divided. The division of the rating is visualized in figure 45. This shows how the values are divided, so when a production technique scores a rating between A and B, the rating will be 0.8. If it falls on B, the rating will be 0.9 and so forth.



$$A = \frac{200000 - x}{3} + x \qquad B = 2 * \frac{200000 - x}{3} + x$$

Figure 45: Calculations for E-modulus rating

The next sub criterion, tensile strength, works according to the same principle. Here the ultimate value used is that of aluminum which is applied in the automotive industry (AL 6111-T41). This material is used for car chassis' and has a value of 284 MPa, which is the ultimate value in this case. The typical value (so, the x) is 85 MPa, this value is used by 3Dhubs for the production of functional parts.



$$A = \frac{300 - x}{3} + x \qquad B = 2 * \frac{300 - x}{3} + x$$

Figure 46: Calculations for Tensile rating

The next criterion, temperature (Figure 47), has a highest value of 590 degrees Celcius. 120 degrees Tg, is the limit which materials must be able to withstand according to TSI's. So anything above 120 degrees will get a rating of 1. If the range is falls over 120 degrees the rating is 0.8, in case the range is below there will be no points, the answer is 0 in that case. This has been chosen because materials that can not withstand those temperatures are not suitable to be used in trains.

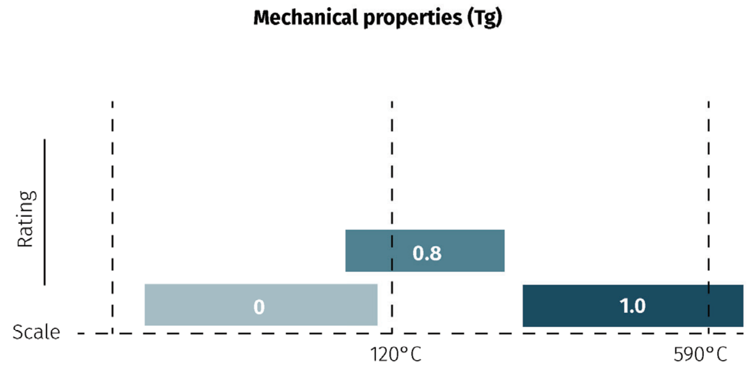


Figure 47: Calculations for Tg rating

Precision has 4 sub-criteria. With a weight of 5 this leads to 1.25 points per sub-criteria. The rating is dependent on the advanced settings. If the data is smaller than the given X-value, full points are awarded. Otherwise 0 points are given, these are then added with each other. For example, if a tolerance of at least 0.1 is chosen, when looking at sls, with a tolerance of 0.01, 1.25 points (full points) are awarded.

Surface finish, which has a total of 5 points in this case as well. This is done with a drop-down menu. Table 1 displays the values awarded with the chosen option in the upper row and the given characteristic in the first column

	Rough (X)	Average (X)	Smooth (X)	Very smooth (X)
Rough	5	4	1	1
Average	5	5	4	3
Smooth	5	5	5	4
Very smooth	5	5	5	5

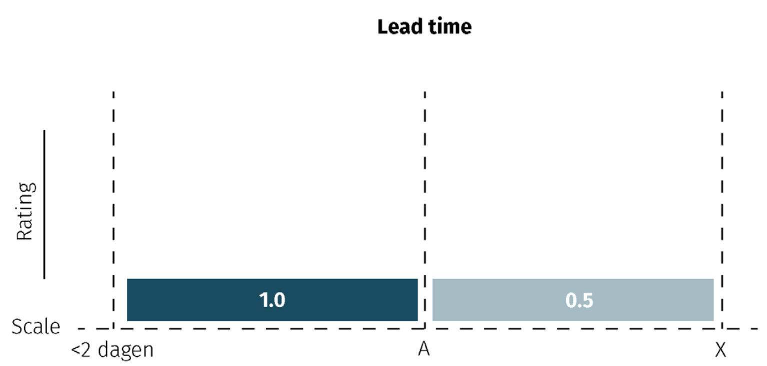
Table 1 Points for surface finish

Reproducibility works similar as surface finish does. In the case of the bar stool 15 points can be achieved here. It also works with a dropdown menu with the options very high, high, good, average. The scores are as shown in table 2, with the chosen option in the upper row and the given characteristic in the first column:

	Very high (X)	High (X)	Good (X)	Average (X)
Very high	15	15	15	15
High	8	15	15	15
Good	5	8	15	15
Average	1	5	8	15

Table 2 Points for reproducibility

The final criteria is lead time (Figure 48). This also has an x-axis but the x and maximum value are mirrored. On the left side there is <2 days (maximum possible lead time) and on the right side the ultimate x-value, A is in the center. A=x-2/2. Lead time between <2 and A results in 5 points, between A and x results in 2.5 points.



$$A = \frac{x-2}{2}$$

Figure 48: Lead time rating

DEVELOPMENT OF THE SEATS

DESIGN OF THE BAR SEAT

Two demonstrations of the barseat have been made - both with different production techniques. The main objective is to show the efficiency in cost and fabrication while using agile manufacturing. Other benefits are dependent on the type of technique used.

Since two demonstrations are made, it was decided to focus on the manufacturing of the seat and not the construction underneath. To start, research on the current design was performed to get an overview of the construction, functionality and seat qualities. See figure 49.

Figure 49: Current design by Mecanoo

Construction and functionality

The dimensions of the bar seat in Figure 49 shows that it is a smaller type o seating furniture than current types. Ir the world of furniture, there is an increase in need for dynamic seatings. A trenc for chair design is to motivate people to stay healthy. A higher seat, where a person sits more upright, supports a healthier blood flow. This ensures work can be performed more efficiently (Inside Information, 2018). Considering that the bar seat is meant for optimal working shows that the construction of the seat fits its functionality.

This health benefit explains the size of the bar seat. Only a small part o the buttocks rests on the seat with this height.

Figure 50: 'Sta-zit stoel' helps with keeping a good posture.

Qualities

Safety and comfort are highly desired requirements for the NS.These requirements are expeted. Sustainability is gaining in importance, but is still far from becoming a main priority.

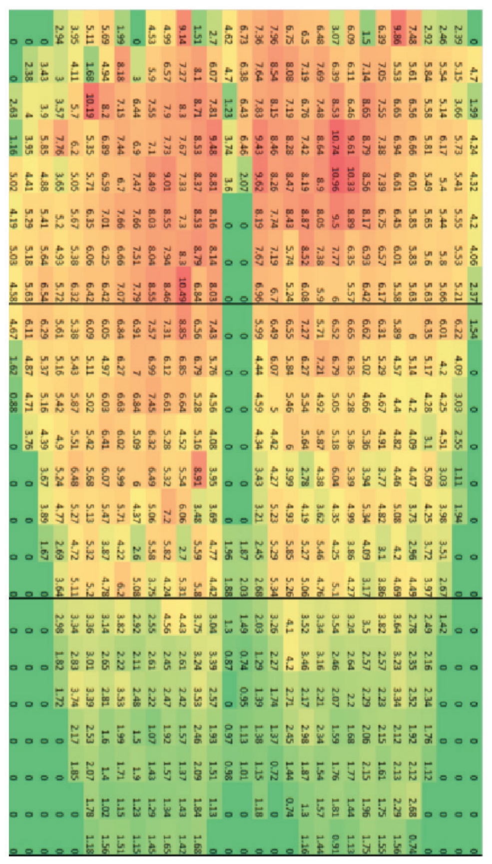


Figure 50: Pressure map of a person sitting. (Dangal, 2019)

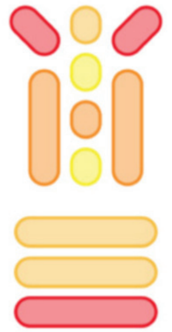


Figure 51: Sensitivity pattern. (Vink & Lips, 2017).

Comfort

Vink & Lips (2017) suggest that inside a car seat, the inner part (towards the backrest) must be harder while the outer part (towards the knees) must be softer. This is due to the differences in tissues in the legs and buttocks. (Figure 51). Considering that the passengers will only rest rest their buttocks on the seat (where no sensitive tissue is pressed) - it can be concluded that it is not necessary to make the bar seat as soft as the front part of a car seat. The hypophysis is that a stiffer bottom is comfortable as well. Nonetheless, the edge of the bar seat must have a large radius or good layer of cushioning to prevent any obstruction of blood flow through the legs.

Safety

The objective of the demonstration is to prove the benefits of agile manufacturing. The emphasis on the benefits will determine the design. To increase the amount of design freedom, most requirements made from the TSI's and UNIFE are abandoned. Requirements are taken into account but except for one not applied, to test the strength and stiffness. Lacking design features are discussed further in the report.

Important requirement:
The bar seat should be able to withstand a force of up to 1500 N perpendicular to the centre of the longitudinal edge. This requirement is based on the requirements for the handhold.

To take in to account:
- The product cannot have gaps larger than 8 mm or smaller than 25 mm.
- Corners of 90 degrees must have a radius of 20 mm.
- The seat must have a backrest to give a level of containment.

When there are different floor levels, the raised area should not directly face a lower area, to prevent passengers being projected towards the top of the lower areas.
- Repairs must be taken care of within 6 days.

For more information or exact referencing on safety, see Appendix H.

Sustainability

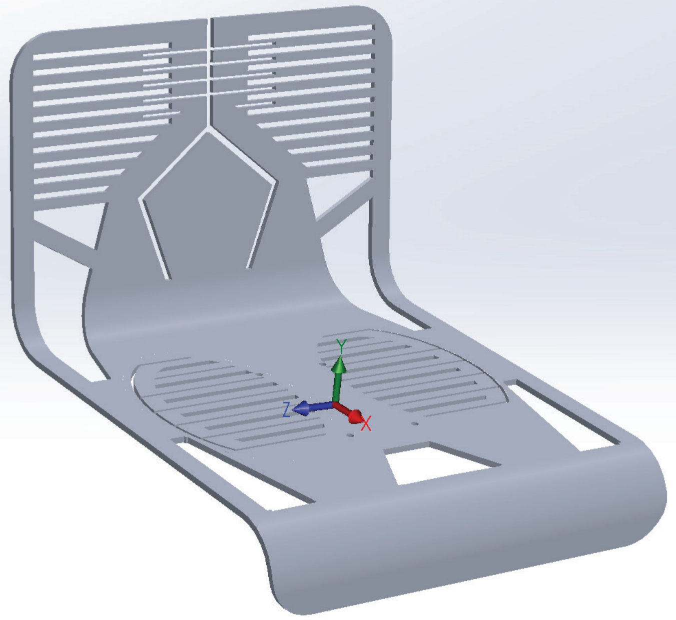
A lighter train seat is desirable due to the expected increase in capacity of train cabins. A lighter train will result in more energy-efficiency (as all NS trains run on green energy). According to the NS Senior Engineer - the train seat for second class cabins are approximately 15 kg. The bar seat must therefore be lighter than 15 kg.

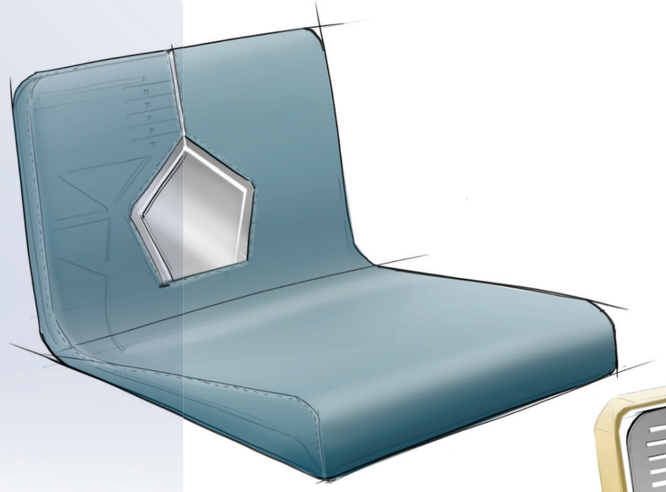
THE SHEET METAL SEAT: PLATEAU

First iteration

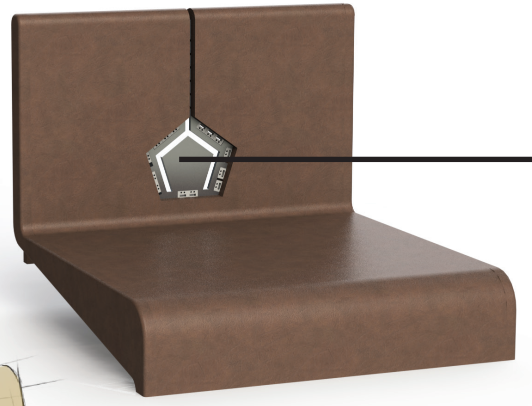
Appliance of Topology Optimalisation to find out where material can be removed.

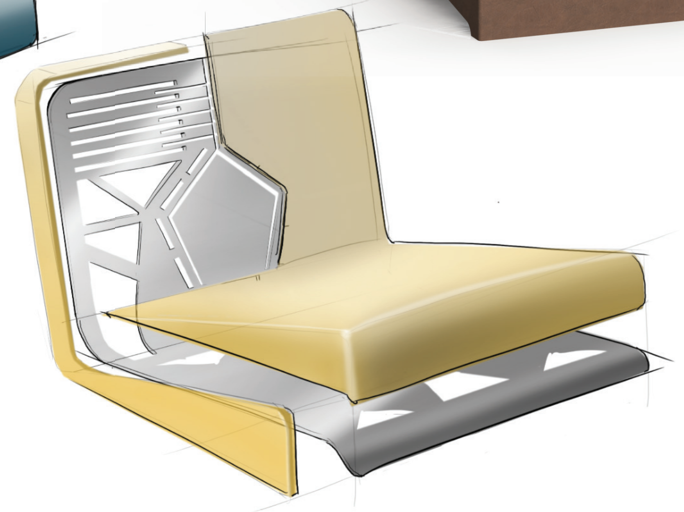
Simple shape was created - easy production. Compliant mechanism added to function as springy support.





Adding the foam and upholstery





Render of the whole assembly. Snapfit mechanism makes it possible to show the edge of the metal - while the holstery is fixed on both sides.

Figure 52: First iteration - The holstery covered to much of the sheet metal. This was therefore not suitable for the demonstation.

Second iteration

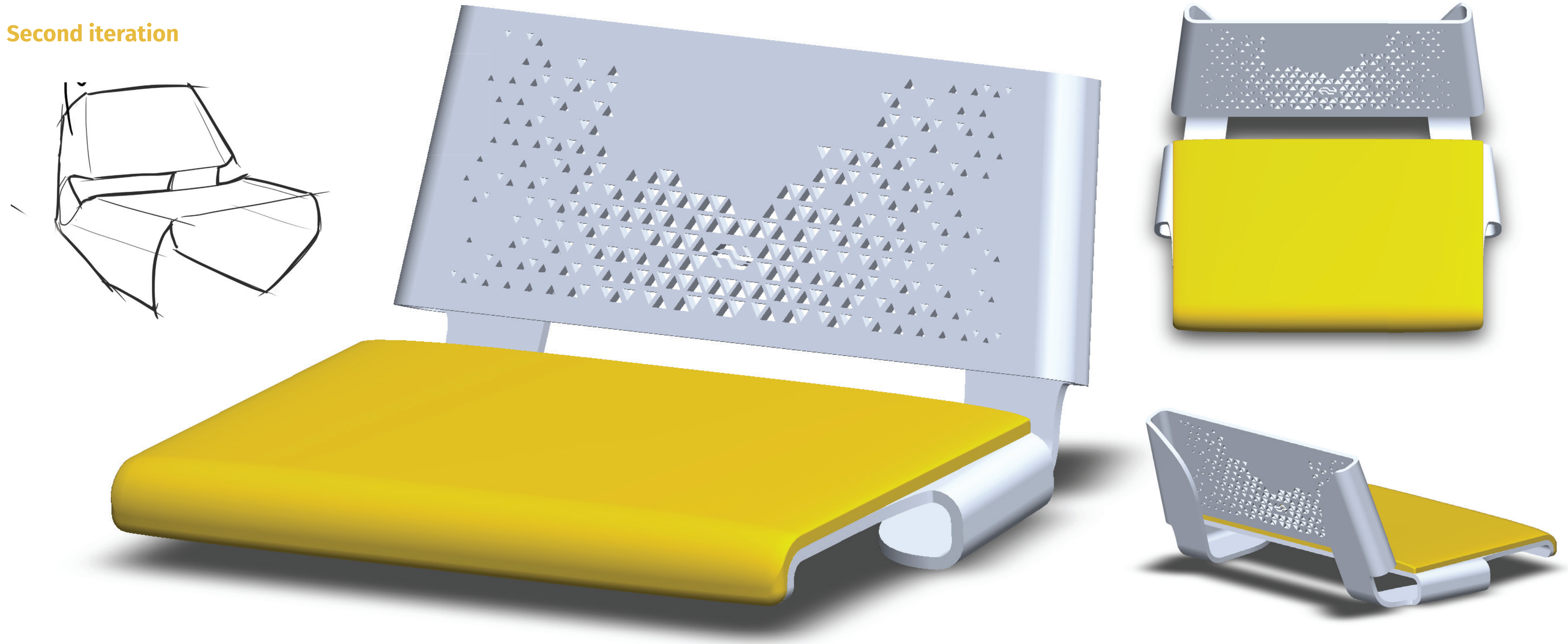
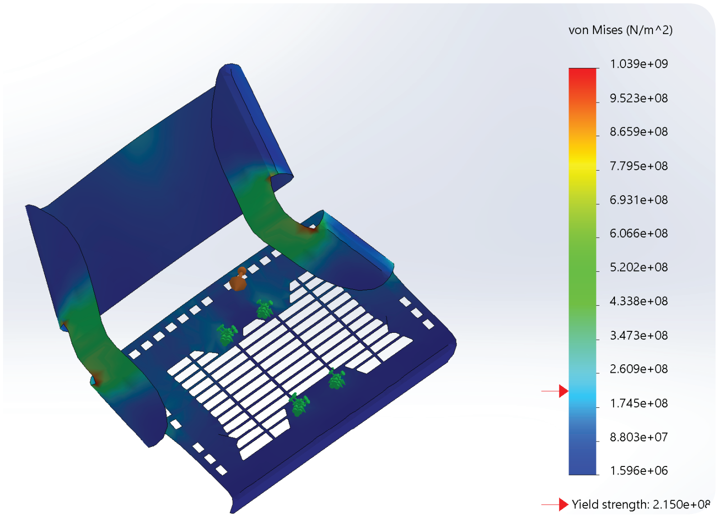
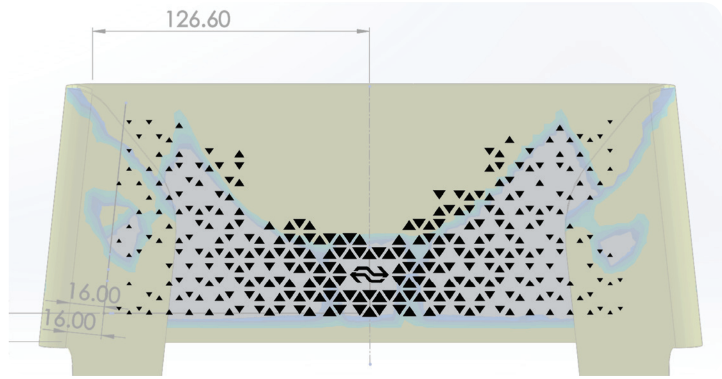
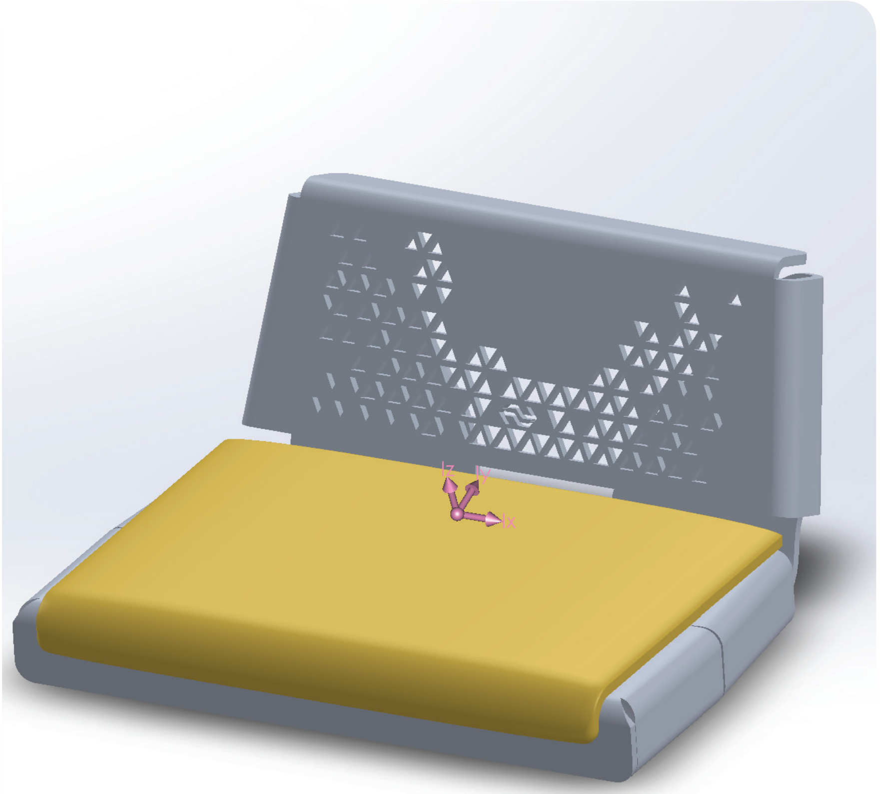


Figure 53: Second iteration. - Multiple modifications took place before a few companies concluded that is was not possible to bend the sheet metal to a seat.







The new shape was inspired from the drawing. Static studies showed that with aluminium, a thickness of 3 mm is insufficient. However, It was discouraged to thicken the sheet. Using plastic supports for the back would be a better solution - considering lightweight products.
Topology optimisation was applied to the seat. Material on the backrest had to be removed asthetically since people could see the pattern. The pattern had to bigger than 5 mm wide due to the limitations of the laser cutter, while they could not become bigger than 8 mm wide due to TSI. This is the reason why the pattern above differs from the picture on the left.

Third iteration

A test was conducted with cardboard on the bending machine In the DreamHall to see where it would collide. However, it was possible to create a seat without collision with the machine. Next step was to try it out with aluminium. The idea was to cut the shape with a laser cutter. However, this process did not go well. Aluminium has excellent conduction characteristics, which disintegrates with the cutting process. Many lines Unproperly cut. Because of this, the sheet on the picture is 2 mm.

It is recommended to use the water cutter the next time for aluminium. Not only is a thicker plate cut-able with water cutting, but it is also a lot faster than laser cutting. 3 mm Al laser cutting would take 3,5 hours, while the estimated time according to located staff would be 30 min for water cutting.

Figure 54: Testing with sheet metal.

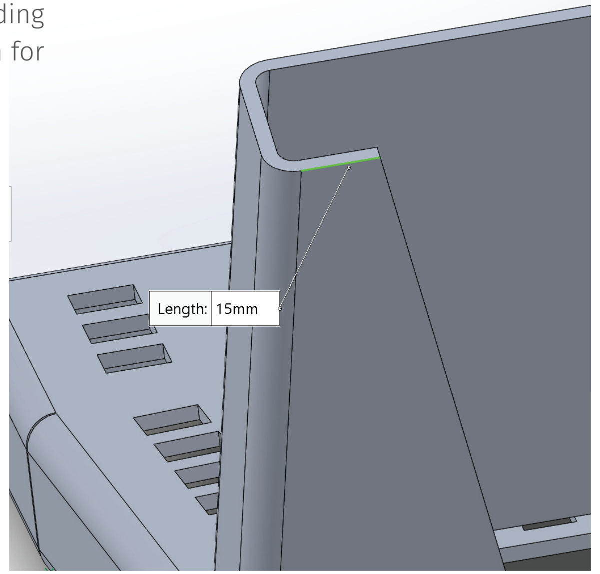
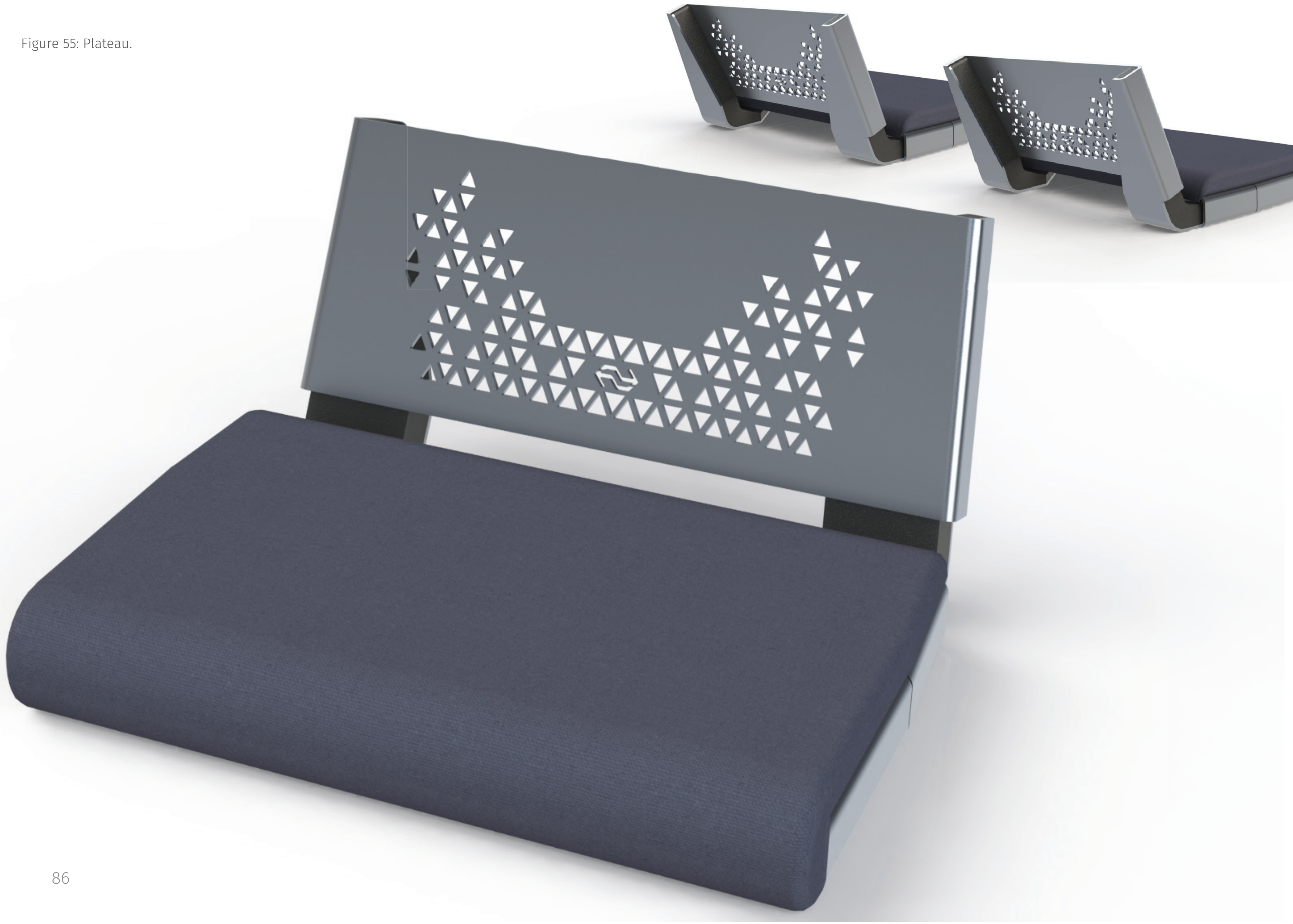


Figure 55: Plateau.



CURRENT DESIGN

The sheet metal chair is designed out of a single aluminium metal plate. Aluminium has been chosen for the chair after research on different thicknesses for aluminium and steel, combined with the forces on the chair. The shape is realised with C-profiles. The sides of the chair have been bent to form A C-profile shape. The profile automatically makes the sides of the chairs less sharp as the sharp edges of the sheet metal are now below the part to sit on.

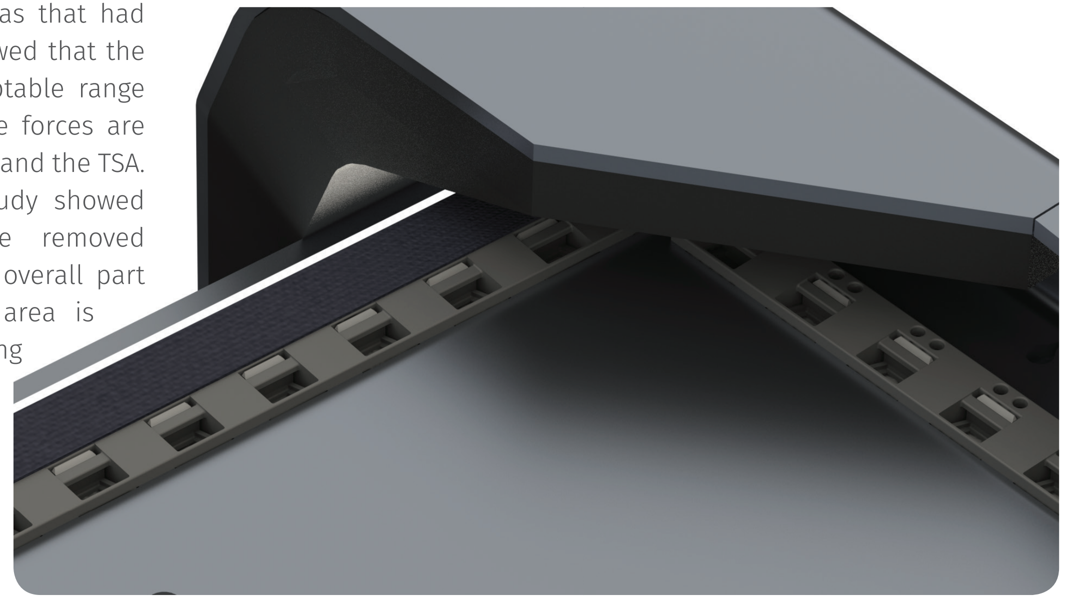
It was decided to use aluminium with a thickness of 5 mm. Steel is stronger but the aluminium is chosen for its weight. Another benefit of 5 mm aluminium is found in the snap-fit mechanism. The snap Fit mechanism has a thickness of 5 mm and therefore precisely fits the sheet metal.

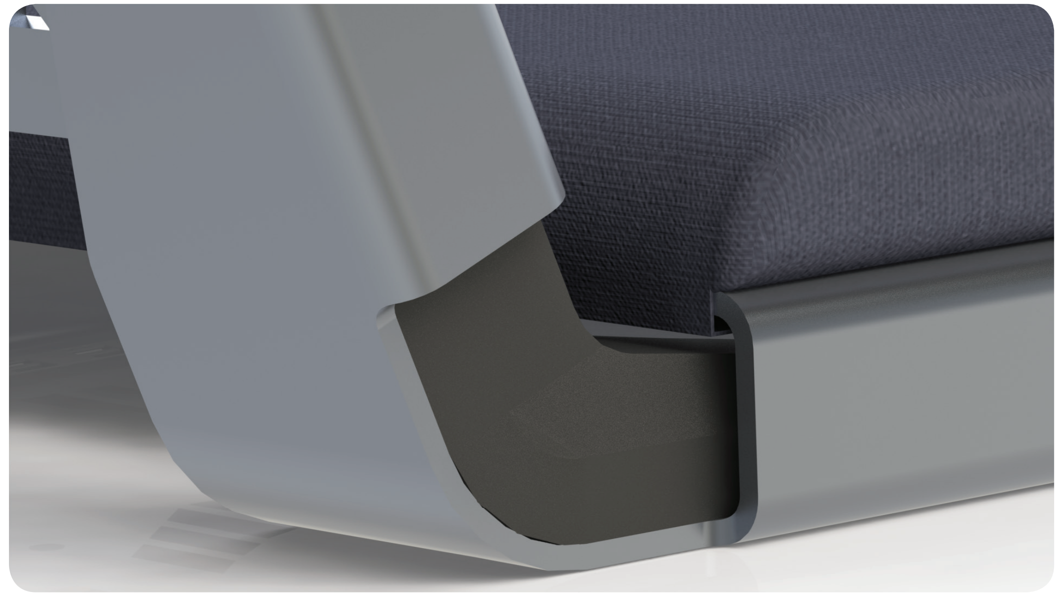
The sides of the chair are slightly bent in an angle of 5 degrees to make the chair less statical.

The dimensions of the chair are based on the limitations of the machines used for production. A D10 stamp is used which is limited to dimensions of 30 mm by 55 mm. Therefore the back of the seat is 55 mm wide.

The shape has been tested in static studies and with topology optimisation. The static study visualizes the stresses on the part and marks areas that had to be made stronger. It showed that the deflection was within acceptable range with the applied forces. The forces are based on the rules of the EU and the TSA. A topology optimisation study showed where material could be removed from the part to make the overall part lighter. While the seating area is fully optimised by removing material, the back support part is optimised by removing material based on aesthetics, as this part stays visible.

The holes that are removed range between 5 and 8 mm, these measurements are in line with the regulations of the EU. The 5-mm lower limitation is caused by the minimum feature measurement for the laser cutter





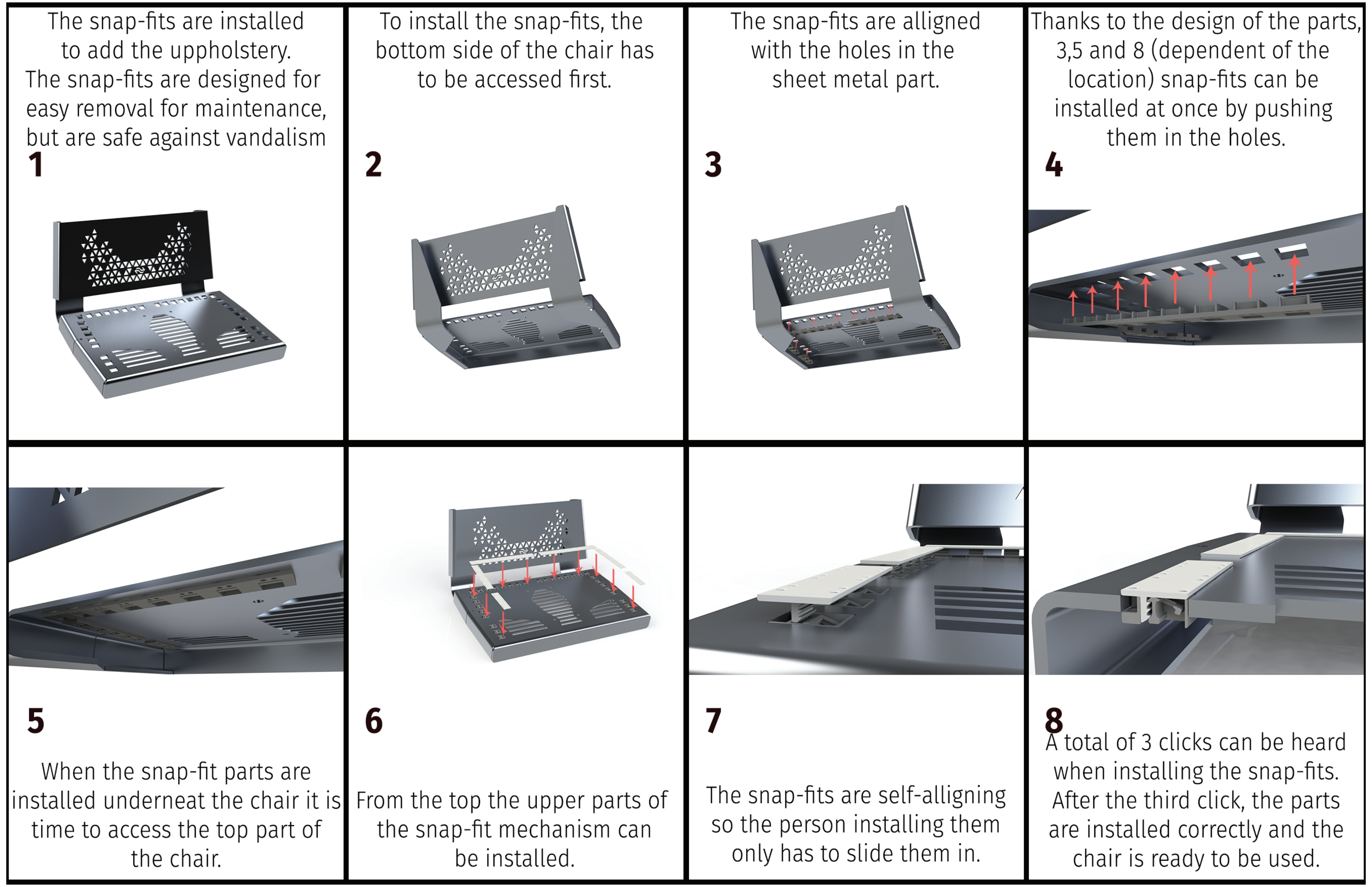


Figure 56: Snapfit Manual.

SNAP-FIT SYSTEM

The purpose of the snap-fit mechanism is to hold the upholstery and the foam together on the chair. The snap-fit mechanism exists of two parts. Both parts contain holes which can be compared to the holes in buttons. This allows for the snap fit mechanism to be sewn onto the upholstery.
The snap-fit mechanism consists of 8 parts joined together by a thin beam. The beam allows the snap-fit mechanism to be aligned and fixed on the sheet metal. It is held together by the second part of the snap-fit which is placed on the other side of the sheet metal. The Beam aligns the snap-fit parts correctly for the holes in the sheet metal.
For eventual implementation it is likely that the snap-fit mechanisms will be produced by injection moulding. Later in the process, if a part breaks and the warehouse doesn't have the part anymore it can be 3D printed with SLS techniques. This can already be implemented in the near future as it is a part without a critical function. Its main function is to hold the upholstery and foam together on the sheet metal plate.

Prints made of nylon (PA) have desirable material properties for the snap-fits which includes the favourable fatigue and flexible properties.
The snap-fit mechanism is a reusable system allowing the two parts to be released, this contributes to the idea of circular economy promoted in the proposed Vision.
The snap Fit mechanism has a pulling system which is only accessible with an additional tool. This way it is easy for maintenance to repair the barstool while it's hard for passengers to remove the holstery

It is produced with sls printing - more suitable compared to fff due to its functioning and part properties.

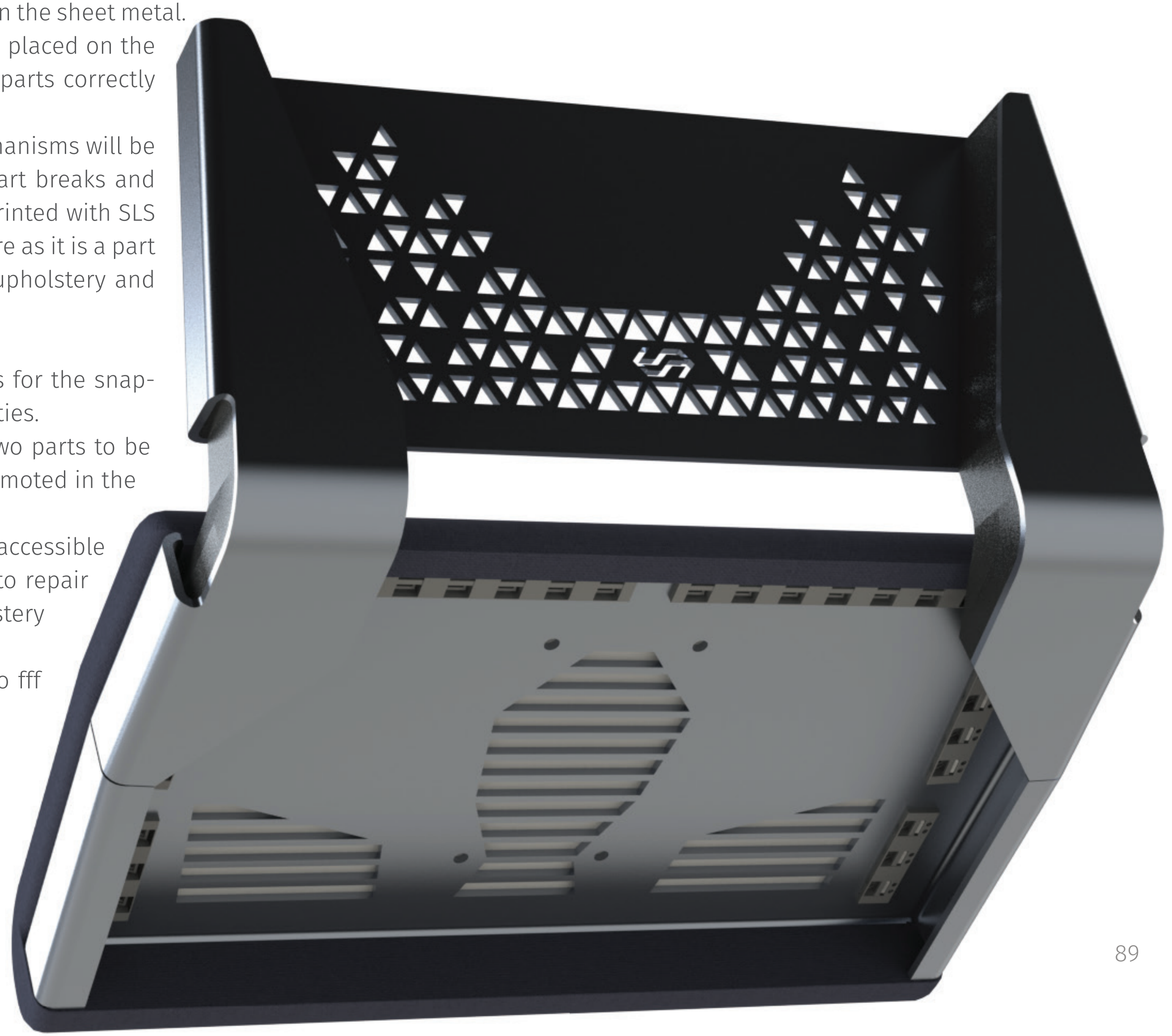
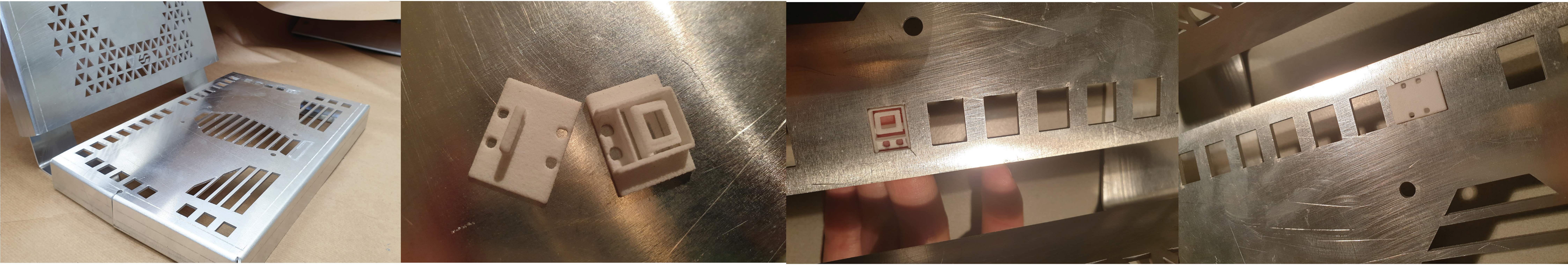
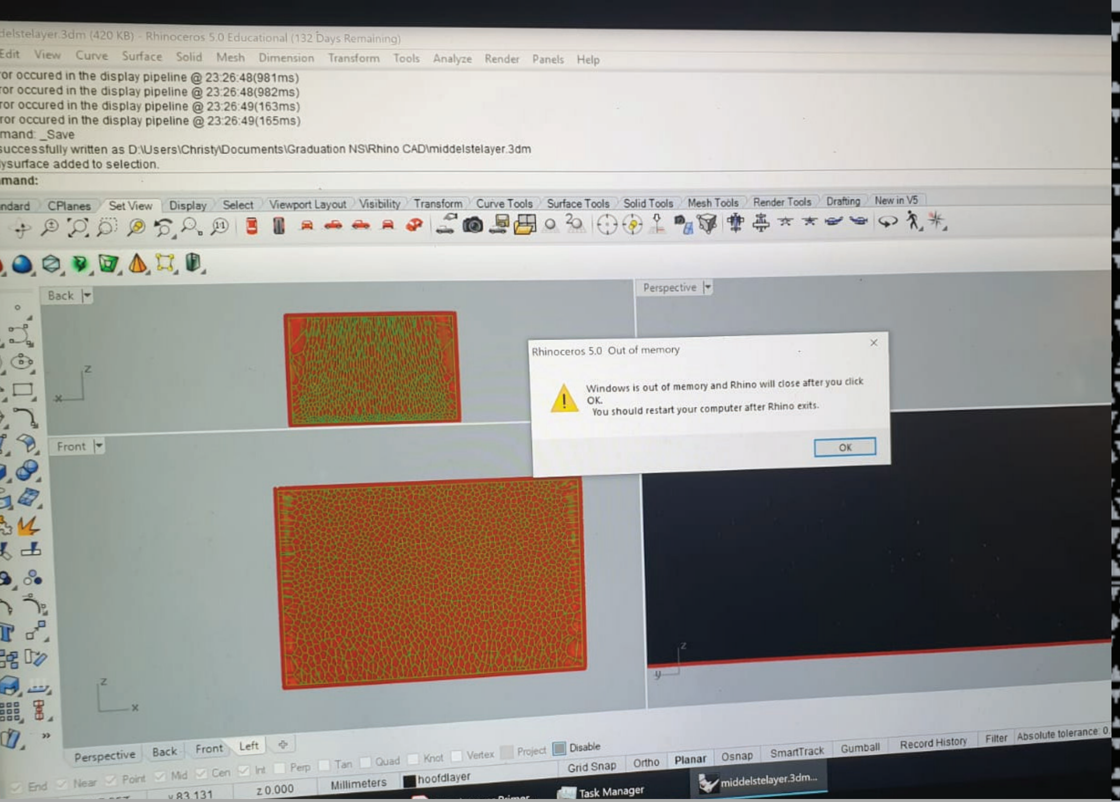
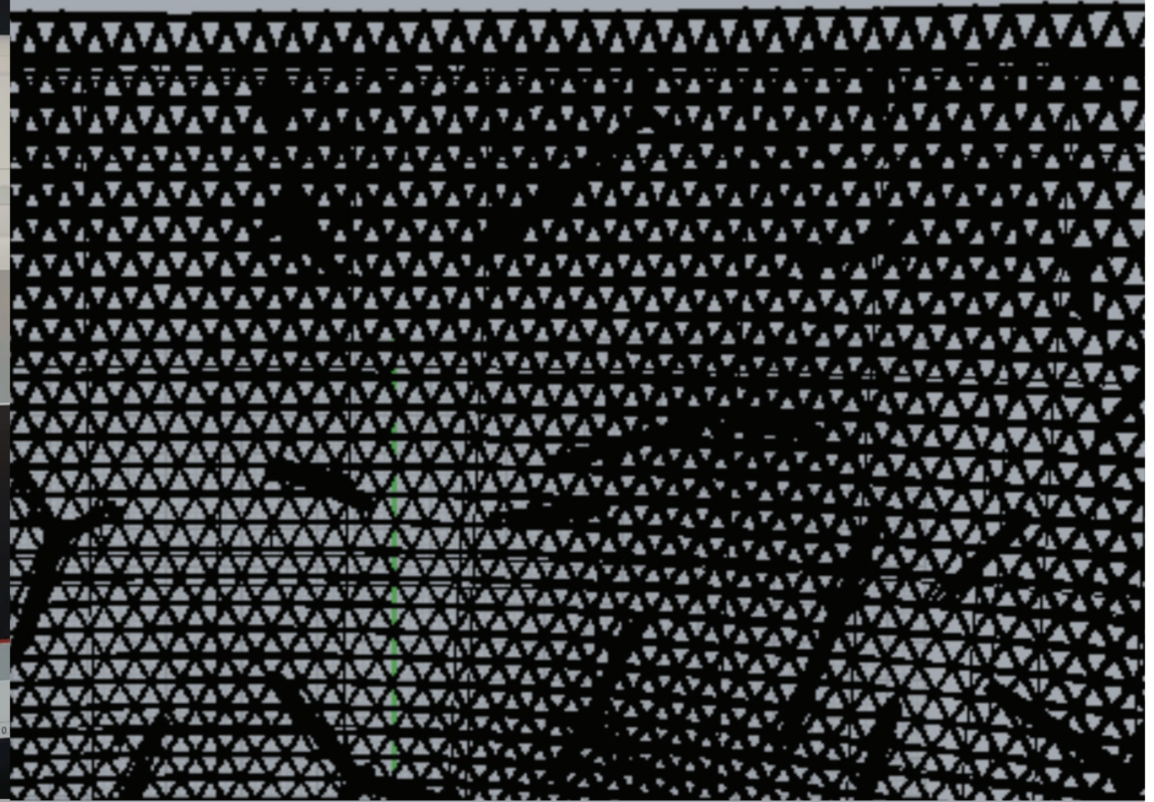


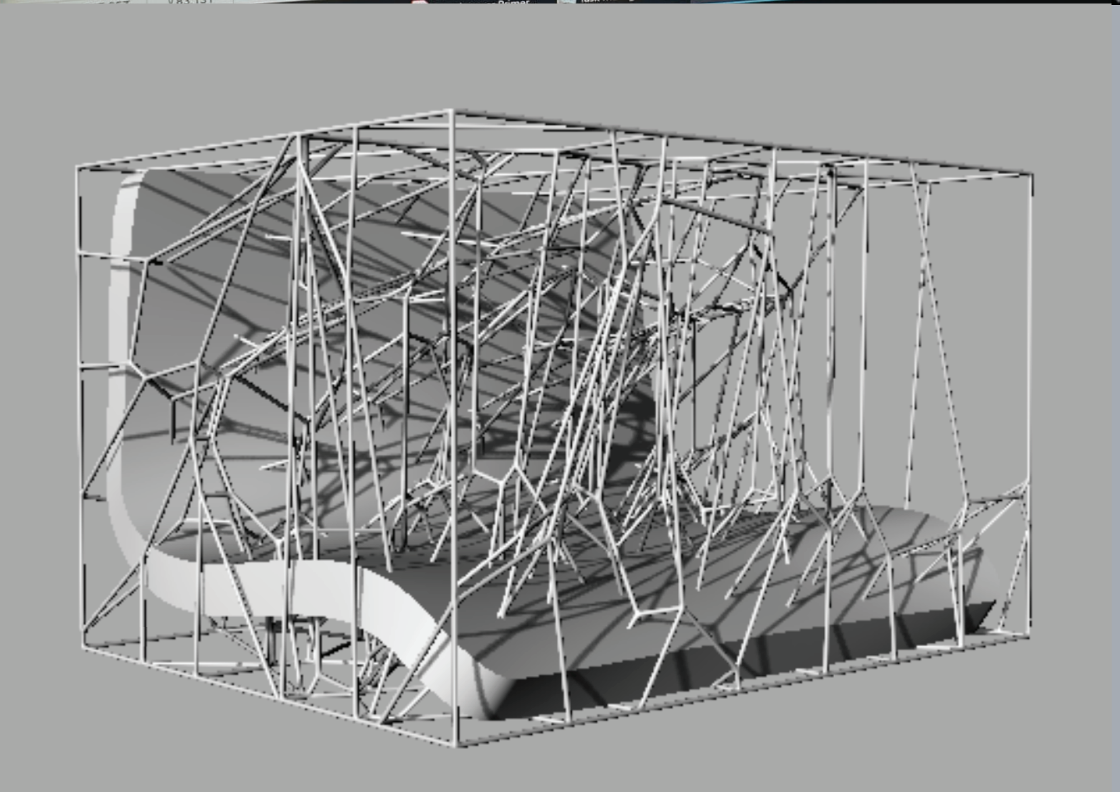
Figure 57: Snapfits at the bottom of the seat.

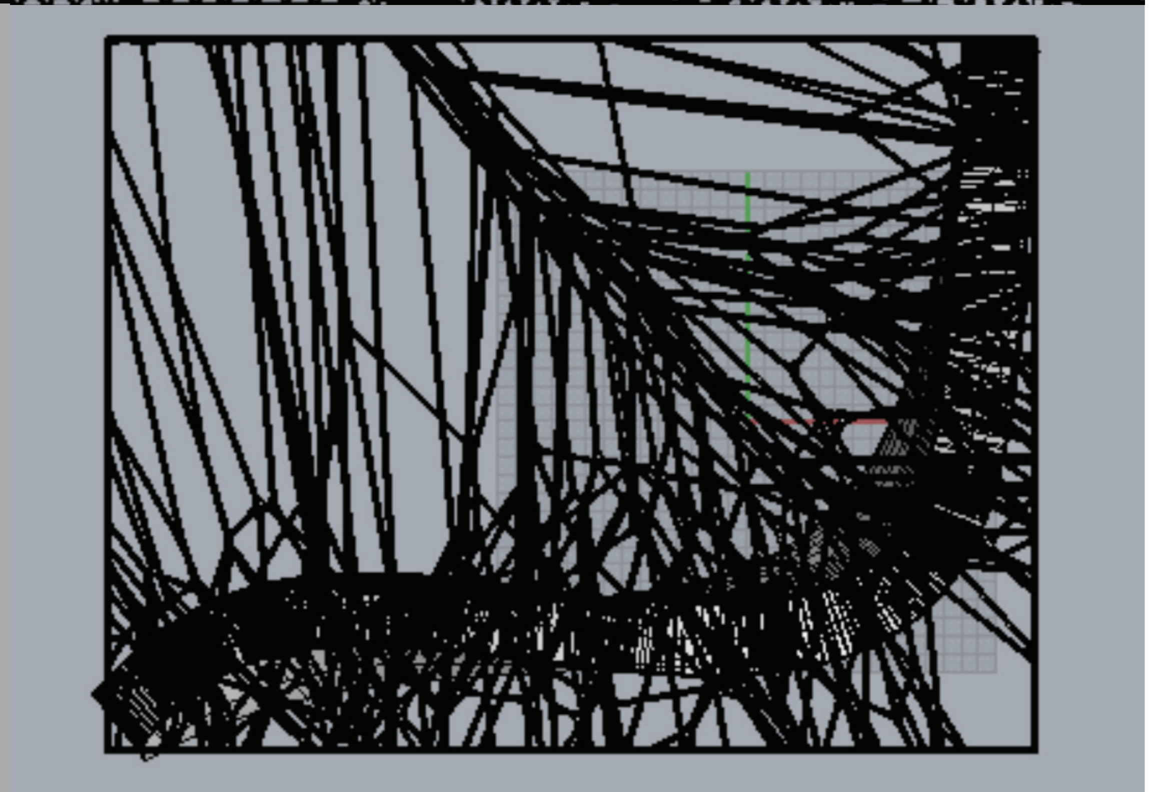


Figuur 58: SLS nylon (PA12) snapfits in the gezetten prototype.









THE 3D PRINTED SEAT: FUTURY

First iteration

The research started with a biomimicry search. Within nature, we see that humans have ideal soft tissue. It has a upholstery that holds everything together- which is the skin - with underneath a layer of fat tissue or muscle tissue which can stretch. The bone tissue is the structure that holds everything together. These elements of the human being are imitated in the design for a 3D printed chair.
The CAD model is made in Rhino with the plugin of Grasshopper. First, the skin layer is researched. This has a thickness appointed accordingly. A ballpoint construction made out of several points forms the thicker structure. this thickness is based on the topology study created earlier before.

Notice that in Grasshopper, there are sliders. This makes it excellent to change variables later one when E.g. the design needs one specific part to be thicker.

The problem with the 'fat tissue' was that the laptop used was not sufficient enough due to the amount of processing needed. (Many lines equal a lot of processing). The work could only be finished with the help of a supercomputer.

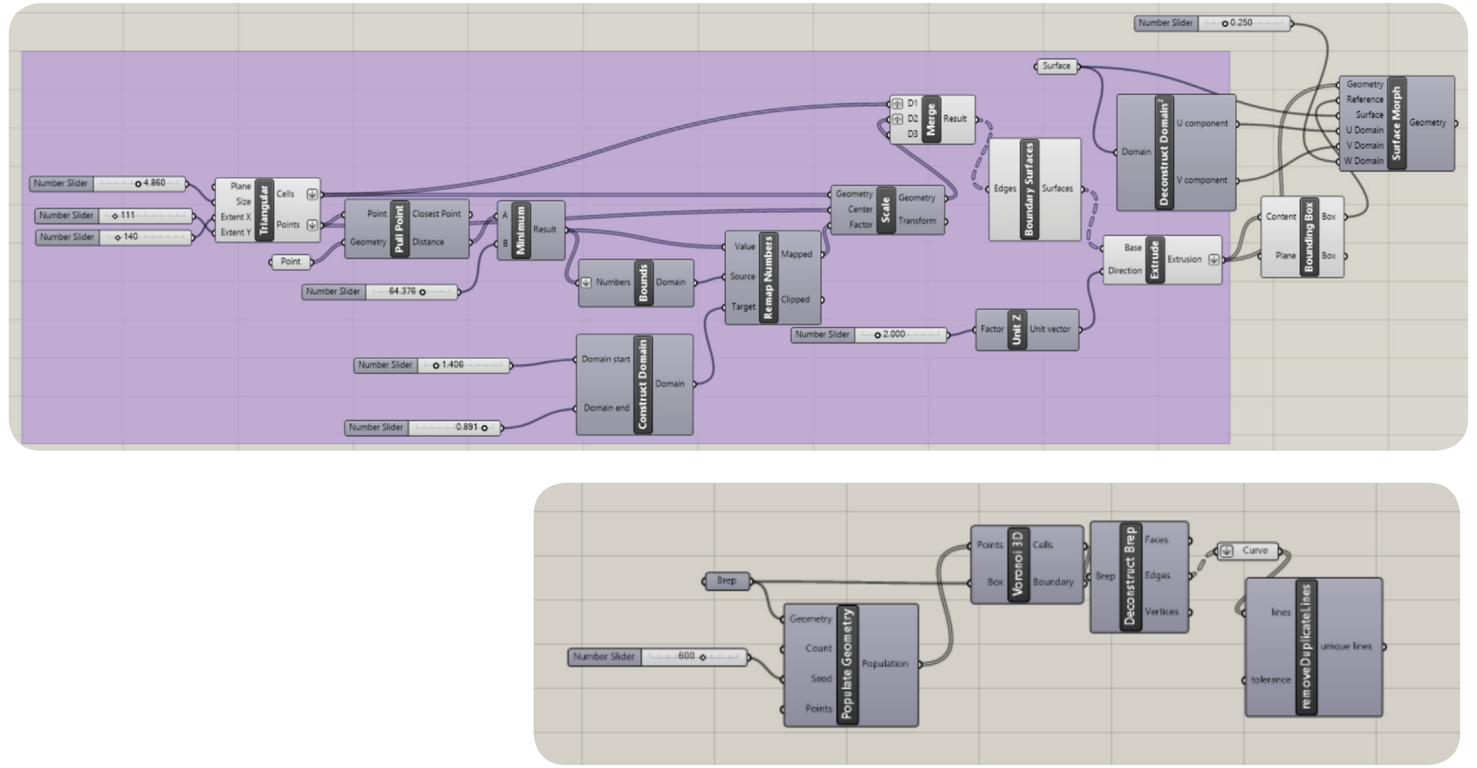


Figure 59: The code for the upholstery and the foam.

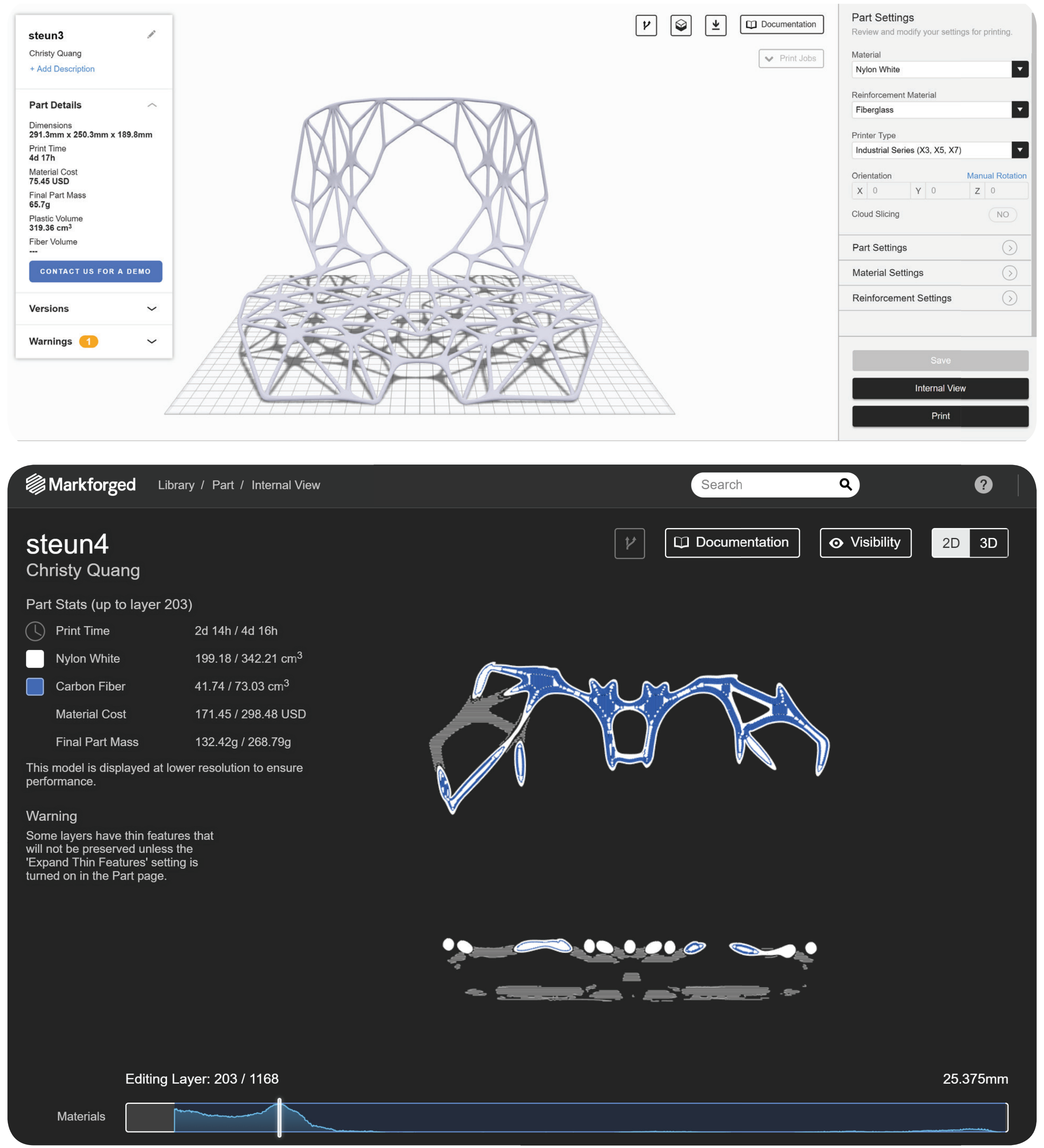


Figure 60: : Eiger - the slicer of MarkForged

Second iteration / Current Design

The Markforged printer has a kinematic coupling beneath its printing surface. A supplier with knowledge on how to manipulate the printing process – can print fibre in multiple orientations. With this the print will not be weak between de layer lines.
However, in the Netherlands there are only a few suppliers with an industrial Markforged Printer. The
Regarding supplier did not have this knowledge. Thus, the production of the bone structure on the left with CFF was not possible.

The image (Figure 60) shows how fibers are added, but do not function properly, since the construction is still weak in the z-direction. The following design (Figure 61) was made to solve this issue.

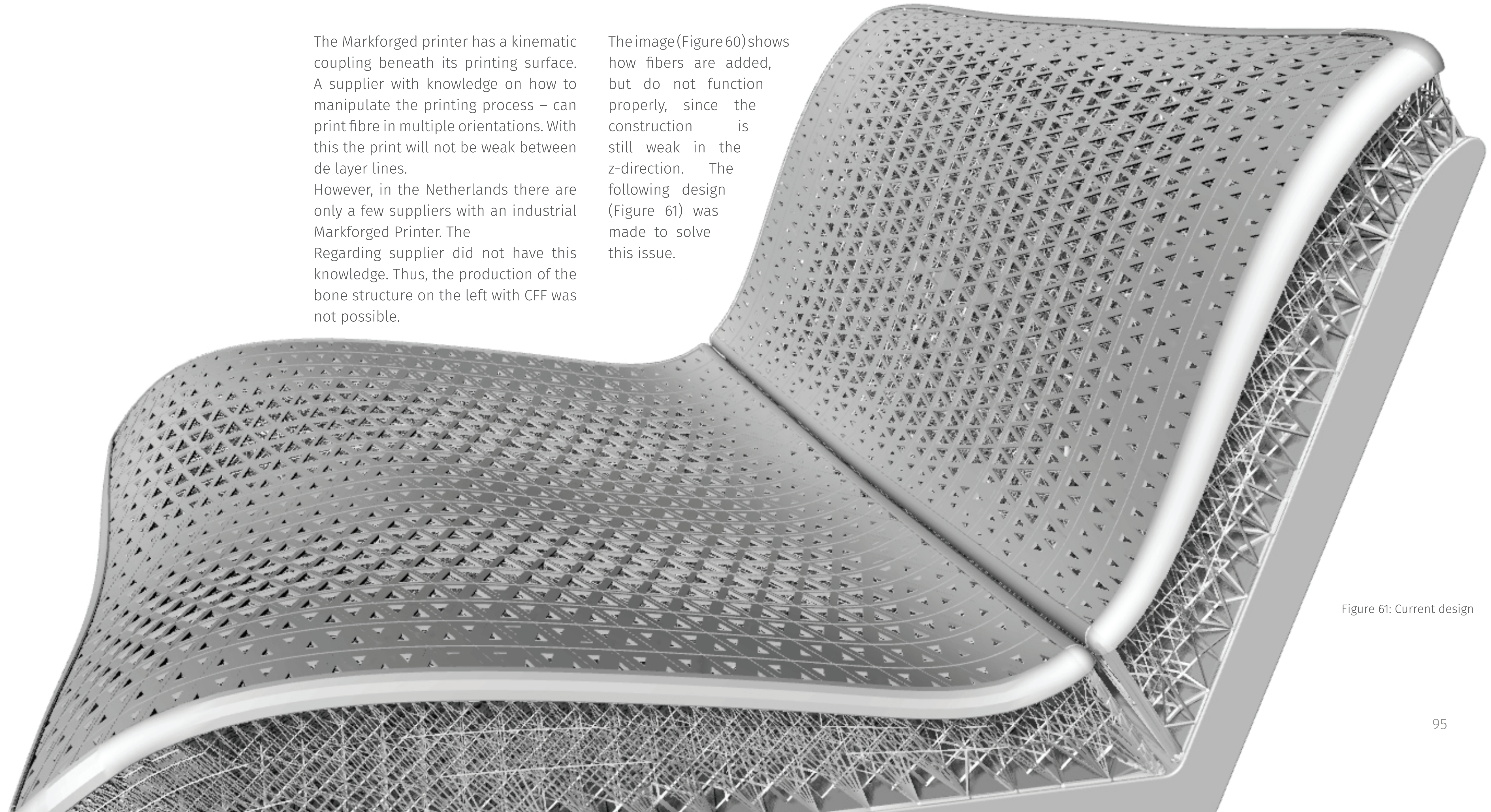


Figure 61: Current design

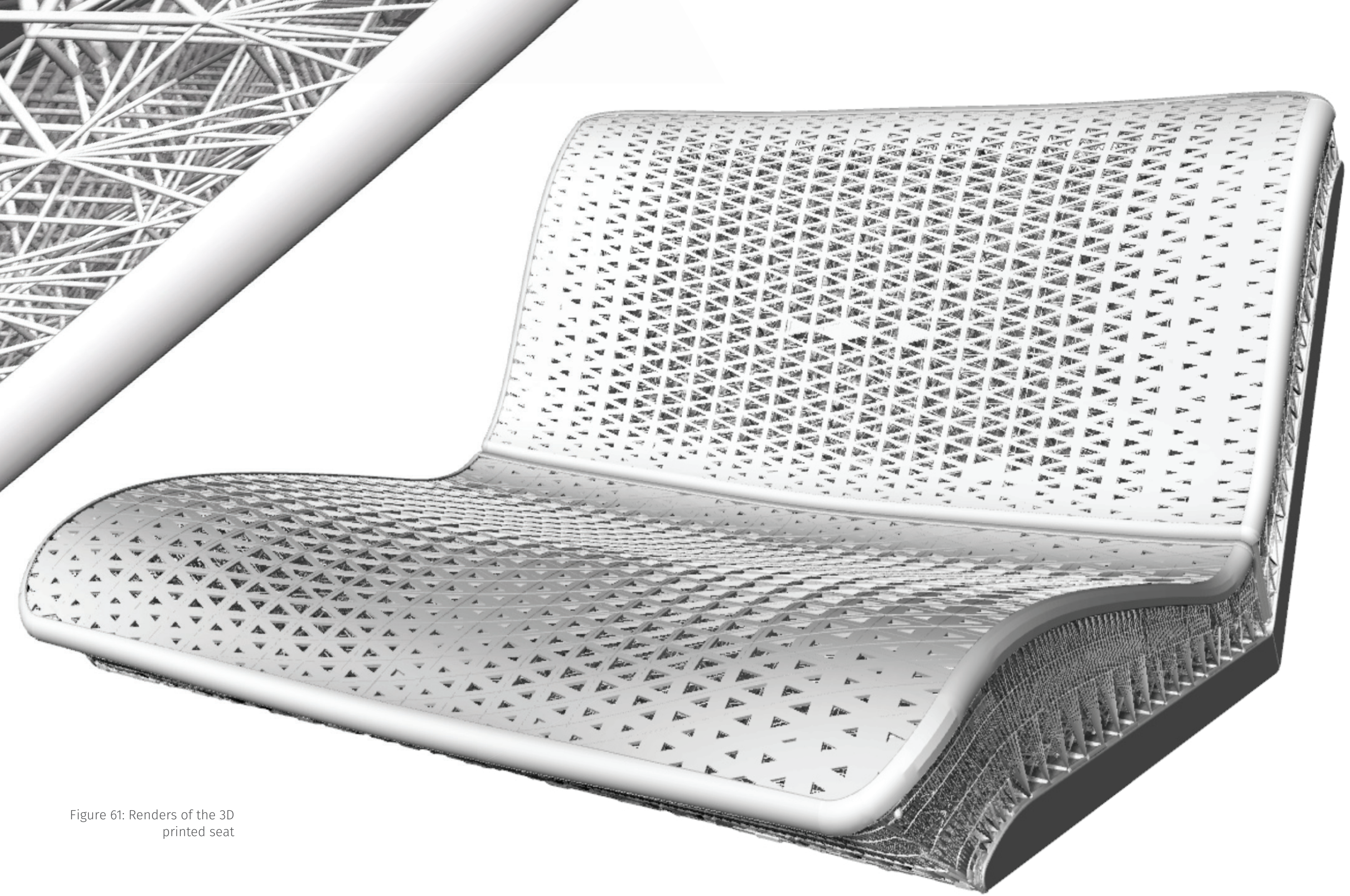
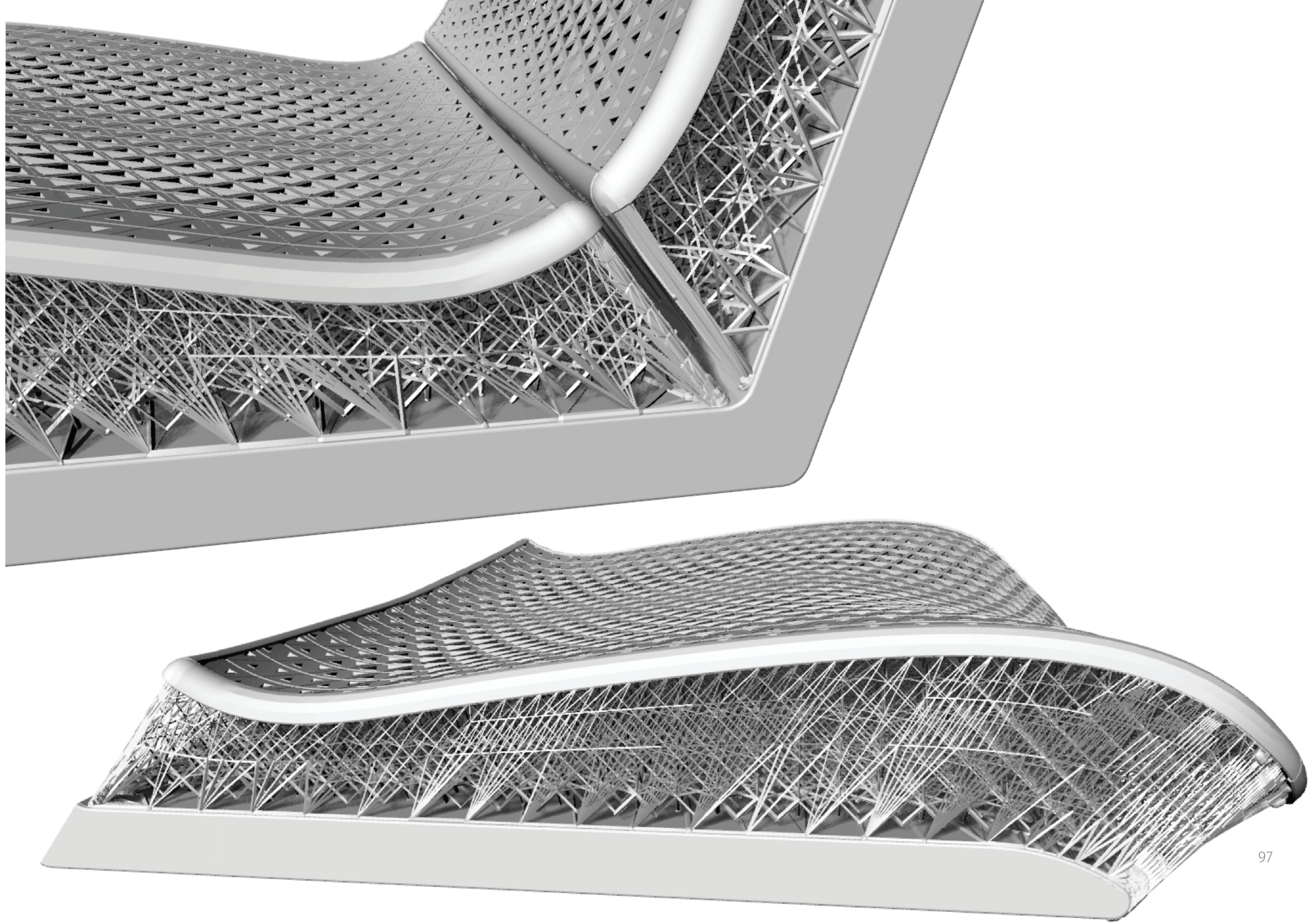


Figure 61: Renders of the 3D printed seat



CONCLUSION DEVELOP

Although the development of the app is not completed, the base algorithm is there to improve further. The concept needs further testing to measure if the current interaction and understood need to be improved.

The development of the bar seat added several benefits. For the sheet metal seat called plateau – added features like the snap fit system made the bar seat easier to maintain and repair. On top of that, Not glueing it together makes it's applicable a circular economy. By producing it in larger quantities (1000ps), the costs would be around 30-50 euros per piece. The seat is lightweight with its 1073 grams. The techniques used are suitable for automation. Per piece is the lead time 2-3 days. The downside is that it's mainly bent from sheet metal. Bending materials adds several limitations to the production, which are not only technical but also supplier dependent. E.g. Bending C-profiles is possible for most companies, but they might not have the right press brake tools for specific C-profiles. These limitations lessened design freedom.

Futury, the 3D printed bar seat, is excellent in its variety in design freedom since the production allows the creation of complex structures. Another benefit is that the seat a lightweight product of 960 grams. The disadvantage is that currently, the fabrication of 1000 pieces is expensive. The costs would be around 1000-1200 euros per piece due to the use of reinforced materials. It takes three days to print one side of two sides the part. The bar seat is not ecological – composites are hard to recycle. However, sustainable filaments and sustainable composites already exist. Although it is currently not possible for the Markforged to use those materials, this might be possible in the future.

DEPLOY

TEST THE APP

The app is not in its final form, however, testing the app early is part of working agile. The research was performed in a relatively informal manner. The tests have been conducted with a NS Senior engineer and a NS Designer. Their insights were:

Senior Engineer
'I would like to know more about 3D printing'
'I would change functional to flexible and strong' What will be made
'Adding pictures would help the process' Standard data
'What are the units?' Additional data
'So when is it finalized?'

Designer
'How do you know exactly how complex your shape is?' Standard data
'What does SM and all mean? Are these the types?' - Type of manufacturing
'This is quite complex. How do you know if it's correct? - Additional data

The app is wanted by the senior engineer as it sparked his interest. Most of his comments have been processed in the current version app. However, the app seemed to overwhelm the designer. Too many unknown data made it difficult to get him to properly test the functionality of the app.

It is recommended that the 'Type manufacturing' screen is removed as designers do not always understand what the different types of manufacturing really are. It was found that this screen will only cause confusion as there is too much information. The 'Additional data' screen will be minimized to a tab. The option to change data should be accessible at any time. Further development and deployment must follow to optimise the bar seat

TEST THE DESIRABILITY OF THE DEMONSTRA-TIONS

The desirability of the demonstrators is tested among the NS employees. It was determined to conduct this test because of the agile nature of inclusion of the employees. Staff often has their own interpretation on matters, which is normally not communicated or gets lost in a pile of data. Adding their opinion can give the demonstrators a good foundation to improve further.
The questionnaire is distrubuted via Yammer, the social platform of the NS. 51 participants took part in the test. The data of the results can be found in Appendix O.

NS Vision 2025

Beste Collega's,
Voor een onderzoek naar de wenselijkheid van interieuronderdelen in de visie van 2025 heb ik jullie mening nodig.
Het invullen duurt 1 minuut.

Ik hoor graag van jullie!

*Vereist

1. Wat is uw functie binnen de NS? *

Stelt u zich eens voor. Het is het jaar 2025 en het interieur van de trein ziet er uit als op de foto. Er wordt er van uitgegaan dat de plaatsing van de barkruk gegarandeerd is. De krukken zijn niet draaibaar.

De focus ligt voor nu enkel op de barkruk. Er staat bij dat het uiterlijk nog aan te passen is naar je wensen, maar de essentie van de barkurk is:

Barkruk 1
30,-
Beschrijving:
Gebogen uit 1 plaat aluminium 3mm dik. Melamine foam met bekleding voor het zitgedeelte. Patroon is er uitgesneden om de stoel lichter te maken. Gaten zijn kleiner dan 8 mm. Het geheel is nergens verlijmd - het zit aan elkaar vast met een herbruikbaar snapfit mechanisme.

+Lichtgewicht 1073 gram
+Snelle levertijd 2-3 dagen
+Gemakkelijk te repareren
+Goed te recyclen door snapfit mechanisme

-Behoud van een 'plaat' uiterlijk
-Beperkt in vormvrijheid bij veranderen van uiterlijk

2. Hoe wenselijk is het design van de barkruk 1 voor u als NS-medewerker? *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Niet wenselijk	○	○	○	○	○	○	○	Heel wenselijk

3. Waarom?

Nu loopt u iets verder en er staat een andere barkruk. Ook hier kan u het uiterlijk van de barstoel nog aanpassen. De essentie van deze barkruk is:

Barkruk 2
999,-
Beschrijving:
Barkruk bestaat uit 2 onderdelen die beide in 1 keer zijn gemaakt met 3D printen. Onderkant is gemaakt van PA12 versterkt met carbon fiber. Verend gedeelte heeft een lattice structuur die dikker is aan de onderkant - dit versterkt de verbinding. De hoes is ook meegeprint.

+Lichtgewicht 450 gram
+Veel vormvrijheid bij veranderen van uiterlijk
+Organische vormen en structuren mogelijk

-Lange levertijd 7-15 dagen
-Niet ecologisch

4. Hoe wenselijk is het design van de barkruk 2 voor u als NS-medewerker? *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Niet wenselijk	○	○	○	○	○	○	○	Heel wenselijk

5. Waarom?

Ontwikkelingen gaan erg snel. Een verbeterde versie van barkruk 2 komt met een aanbieding voor een lagere prijs beschikbaar. Ook zijn de levertijden verlaagd.

NS Vision 2025

Aanbieding

Barkruk 2
50,-
Nu 2-3 dagen verzendtijd!
Beschrijving:
Barkruk bestaat uit 2 onderdelen die beide in 1 keer zijn gemaakt met 3D printen. Onderkant is gemaakt van PA12 versterkt met carbon fiber. Verend gedeelte heeft een lattice structuur die dikker is aan de onderkant - dit versterkt de verbinding. De hoes is ook meegeprint.

+Lichtgewicht 450 gram
+Snelle levertijd 2-3 dagen
+Veel vormvrijheid bij veranderen van uiterlijk
+Organische vormen en structuren mogelijk
+Gemaakt van recyclebaar PA

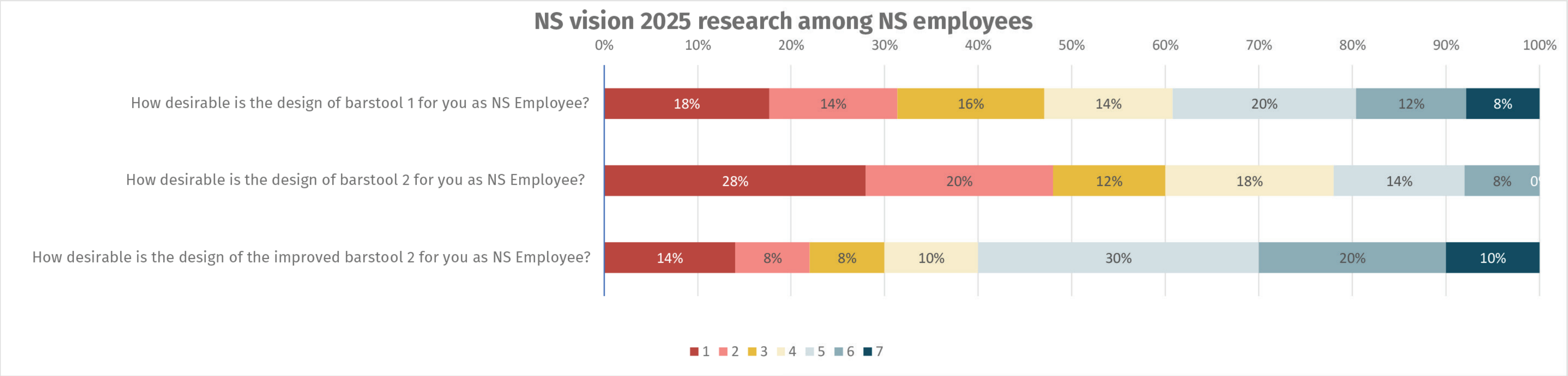
6. Hoe wenselijk is het design van de verbeterde barkruk 2 voor u als NS-medewerker? *
Markeer slechts één ovaal.

	1	2	3	4	5	6	7	
Niet wenselijk	○	○	○	○	○	○	○	Heel wenselijk

7. Waarom?

Figure 62: Questionnaire

RESULTS



For more results, consult Appendix O. Here the comments are included too.

CONCLUSION DEPLOY

The results of the test with the 51 employees are the following:

Plateau

- Positive comments regarding the functionality of the product. The employees where content with the snap fit system and how it made it easier to maintain and repair the seat.
- Negative comments were related to the aesthetics of the seat. Another improvement is comfort

Futury

- Positive comments were mainly related to the aesthetics and comfort of the seat.
- Negative comments mostly related to the price of the seat. Sustainability was also highly considered.

Futury in the future

- More Positive comments. Employees will choose the Futury if it becomes quicker to produce, cheaper and more ecological.
- Negative comments were related to cleaning the product and distrust in the 'springy-effect' of the lattices.

DISCUSSION AND RECOMMENTATIONS

The app

Although the app does work, its estimation is not completely correct yet. One of the main issues in the current version is the pricing system. One price is placed on a production technique, but there are variables that can influence that price, for instance different materials (Materials often have a different price).This issue can be solved by adding all the data of the specific materials related to the type of tooling. For this assignment, it was chosen not to do so as it would take too much time. For further development, it is highly recommended to do so for a more accurate estimation.

The lacking pricing system is also the reason why the chosen CFF technique became expensive in the app. Even though printing parts with the Onyx material from Markforged is not as expensive in comparison to printing with Carbon Fiber.

The algorithm of the app is based on the Excel sheet. However, this Excel sheet is not fully complete. Some companies not to share enough data of their 3D printing capabilities. It is expected that if the NS were to contact these 3D printing companies, they would be more willing to share the information. As they might see the NS as a potential client. Sustaining these networks also helps with data management since those companies can update the NS whenever they introduce new innovations.

The mechanical properties in the Excel sheet include a range of the Young's modulus, a range of tensile strength and the maximum service temperature. It was then recommended that the specific modulus should be used to test the functionality of materials.

Current data gives an elaborated overview of 3D printing techniques. Subtractive manufacturing and formative manufacturing techniques are still limited in the app. Completing the information on these techniques in the app will make the estimation more accurate.

The tests with the NS designer and engineer of did prove the fact that there is interest in the app. The app was however, difficult to understand for the designer who was in the target group. Further interaction development of the app is recommended. The designer also stated that the last screen was too full of information to get a good overview. Therefore, the number of colours should be decreased to maintain simplicity.

The algorithm is based on the weighted objectives method. Nonetheless, users can adjust the predefined settings to their preferred requirements. There should be an option to make this accessible. Note: This cannot pop up too visually as it can confuse a designer that uses the app for the first time.

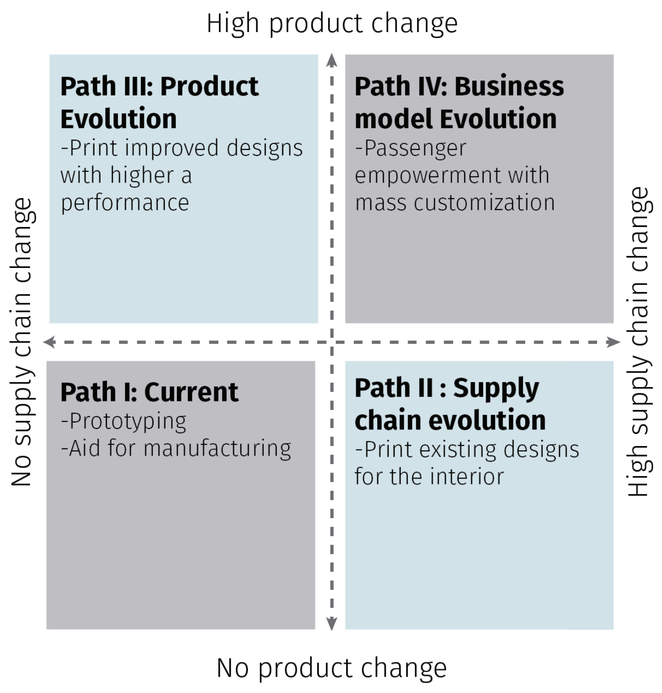
The demonstrations

The demonstrations of the bar stools show that it is feasible to apply agile manufacturing in the process. However, the stools are still lacking in viability and/or desirability. This conclusion was made after reading the comments on the desirability of the stools. The comments from the test should be re-evaluated to improve the designs further.
Plateau: The 'Plateau' from sheet metal was beneficial in multiple ways, although it was not aesthetically pleasing and employees we're not convinced about the comfort of the chair. On top of that, the design freedom for the sheet metal chair is limited due to the production processes. Packing all of the sheet metal into upholstery can be the answer to make the stool more aesthetically pleasing. A disadvantage with that solution is the fact that more assembly is needed, in turn increasing the costs. Comfort can be a factor that could change the employees' views. However, adding organic forms in the foam increases the costs of production. The best course is to re-use the snap-fit system for a new redesign for the sheet metal part. Not all design options are discovered yet.

The 3D printed chair is currently not viable nor desirable, but future developments might have the answer for the NS. The primary issues are the price of 3D printing, the lead time and the fact that it's not sustainable. Nonetheless, multiple industries are working on 3D printing techniques to make it suitable for industry 4.0. Implementation of industry 4.0 should drop the price and also drastically decrease the lead time for products. Concerning sustainable means; it is expected that sustainable solutions are available in 2025. The ecological material already exists but is not integrated yet in the industry. For the 3D printed seat, it is recommended to split the structural design from the flexible foam design. This requires more assembly, but since seats are intensively used products, it is wise to make the 'foam' replaceable. Possibly, the snap fit-systems can be used to snap the design pieces together.

Main recommendation

The two seats demonstrate what currently is possible and desired. With Futury following the path of Product Evolution as can be seen in Figure 63. The app, however, is the next step for the NS to implement 3D printing (and other production techniques) in their workflow by giving designers accessible data. With a few clicks, a designer can quickly see what is possible and then contact a potential supplier for specific questions or immediate prototyping. It is, therefore recommended to focus on the development of the app. A higher level of Agile manufacturing will follow from the collaboration with other designer and engineers.



Source: Cotteleer, M. & Joyce, J. (2014). 3D opportunity: Additive manufacturing paths to performance, innovation, and growth. Deloitte Review.

Figure 63: Innovation diagram

REFERENCES

3D Print Magazine. (2018). Waarom binder jetting 3D metaalprinten vleugels kan geven. Retrieved from https://3dprintmagazine.eu/waarom-binder-jetting-3d-metaalprinten-vleugels-kan-geven/

3D printmarkt. (2016). Airbus neemt Sciaky EBAM 110 3D metaalprinter in gebruikt. Retrieved from https://3dprintmagazine.eu/airbus-neemt-sciaky-ebam-110-3d-metaalprinter-in-gebruik/

Accumolli, A. (1996). Manufacturing Process Problem Analysis Using Monte Carlo Simulation. Quality and Reliability Engineering International,12(1), 39-41. doi:10.1002/(sici)1099-1638(199601)12:13.0.co;2-l

AM Sub-Platform. (2014). Additive Manufacturing: Strategic Research Agenda. Retrieved from http://www.rm-platform.com/linkdoc/AM SRA - February 2014.pdf

ASTM International. (2019). Standard Specification for Additive Manufacturing Nickel Alloy (UNS N07718) with Powder Bed Fusion. Retrieved from https://www.astm.org/Standards/F3055.htm

Auerbach, A. D. (2019). 96% of U.S. Professionals Say They Need Flexibility, but Only 47% Have It. Retrieved from https://hbr.org/2018/06/96-of-u-s-professionals-say-they-need-flexibility-but-only-47-have-it

BMW Group. (2017). MINI Yours Customised. Retrieved from https://www.press.bmwgroup.com/netherlands/video/detail/PF0005769/mini-yours-customised

Booth, P. (1995). Fragmented firms.

Bournias Varotsis, A. (2017). HP MJF vs. SLS: A 3D Printing Technology Comparison. Retrieved from https://www.3dhubs.com/knowledge-base/hp-mjf-vs-sls-3d-printing-technology-comparison

Boynton, A., & Pine, B. (1993). AM 2.

Businesswire. (2018). Angel Trains, ESG Rail and Stratasys Tackle Obsolescence in the Rail Industry with UK's First 3D Printing Manufacturing Solution. Retrieved from https://www.businesswire.com/news/home/20181210005455/en/Angel-Trains-ESG-Rail-Stratasys-Tackle-Obsolescence

CBS. (2019). Bevolkingsgroei in 2018 vooral in de Randstad. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2019/01/bevolkingsgroei-in-2018-vooral-in-de-randstad

CBS. (2019). Productie industrie ruim 2 procent hoger in november. Retrieved from https://www.cbs.nl/nl-nl/nieuws/2019/02/productie-industrie-ruim-2-procent-hoger-in-november

Chakravarti, D., & Day, G. S. (1990). Market Driven Strategy: Processes for Creating Value. Journal of Marketing,55(4), 116. doi:10.2307/1251961

Chris Chappell. (2017). Retrieved from https://www.youtube.com/watch?v=1lBamVErVPM

Clarke, C. (2017). AUTODESK BELIEVES 3D PRINTED AIRPLANE SEAT COULD SAVE AIRLINES MILLIONS OF DOLLARS. Retrieved at 16th March from https://3dprintingindustry.com/news/autodesk-believes-3d-printed-airplane-seat-save-airlines-millions-dollars-113082/

Coenen, F. (2017). Kortzichtigheid politiek én gebrek digitale skills breekt AM industrie op. Retrieved from https://3dprintmagazine.eu/kortzichtigheid-politiek-breekt-am-industrie-op/

Columbus, L. (2018). How Blockchain Can Improve Manufacturing In 2019. Retrieved from https://www.forbes.com/sites/louiscolumbus/2018/10/28/how-blockchain-can-improve-manufacturing-in-2019/#17ff4e245db6

Constructible. (2017). What are Digital Twins? Retrieved from https://constructible.trimble.com/construction-industry/what-are-digital-twins

Dal, P. (2012). Process engineering and industrial management. London: ISTE Ltd.

David Guyton. (2017). Retrieved from https://www.youtube.com/watch?v=8hiZ_1lzvkI

Domingo-Espin, M., Travieso-Rodriguez, J. A., Jerez-Mesa, R., & Lluma-Fuentes, J. (2018). Fatigue Performance of ABS Specimens Obtained by Fused Filament Fabrication. Retrieved from https://www.mdpi.com/1996-1944/11/12/2521

Doubrovski, Z., Verlinden, J. C., & Geraedts, J. M. (2011). Optimal Design for Additive Manufacturing: Opportunities and Challenges. Volume 9: 23rd International Conference on Design Theory and Methodology; 16th Design for Manufacturing and the Life Cycle Conference. doi:10.1115/detc2011-48131

EBAM. (2018). Make Metal Parts Faster & Cheaper Than Ever with Electron Beam Additive Manufacturing (EBAM®) Systems or Services. Retrieved from http://www.sciaky.com/additive-manufacturing/electron-beam-additive-manufacturing-technology

Economist. (2013). The rise of the sharing economy. Retrieved from https://www.economist.com/leaders/2013/03/09/the-rise-of-the-sharing-economy

Ella Macarther Foundation,. (2019). What is a Circular Economy? Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy/concept

Eurospec. (2018). Next step in harmonisation of passenger rolling stock. Retrieved from https://eurospec.eu/wp-content/uploads/2019/02/eurospec-general-presentation.pdf.

Evans, J. (2019). Carbon M1 Review 2019 - Is This 3D Printer Worth The Money? Retrieved from https://www.3dbeginners.com/carbon-m1-review/

Fabritius,, J. (2012). Agile manufacturing. Retrieved from https://assets.mckinsey.com/practice-clients/operations/agile-manufacturing

Formlabs. (2018). SLA vs. DLP: A 3D Printing Technology Comparison. Retrieved from https://formlabs.com/blog/3d-printing-technology-comparison-sla-dlp/

Fountain, M. (2017). The comprehensive guide to Agile Manufacturing. Retrieved from https://www.sageautomation.com/blog/the-comprehensive-guide-to-agile-manufacturing

Friel, R. (2015). Power ultrasonics for additive manufacturing and consolidating of materials. Power Ultrasonics,313-335. doi:10.1016/b978-1-78242-028-6.00013-2

Galen, M. (2018). Searious Business – Sofa printen. Retrieved from https://www.marcelvangalendesign.nl/project/gispen.php

Gibson, I., Rosen, D. W., & Stucker, B. (2010). Direct Digital Manufacturing. Additive Manufacturing Technologies,378-399. doi:10.1007/978-1-4419-1120-9_14

Gillespie, R. (1993). Manufacturing Knowledge: A History of the Hawthorne Experiments. By Richard Gillespie. Cambridge: Cambridge University Press, 1991. Pp. x, 282. $39.50. The Journal of Economic History,53(1), 209-210. doi:10.1017/s002205070001281x

GommeBlog.it: Car & Performance. (2018). Retrieved from https://www.youtube.com/watch?v=BoDyP8j8k64

Gunasekaran, A. (1998). Agile manufacturing: Enablers and an implementation framework. International Journal of Production Research,36(5), 1223-1247. doi:10.1080/002075498193291

Gunasekaran, A. (2001). Agile manufacturing the 21st century competitive strategy. Oxford: Elsevier.

Gunpinar, E., & Han, S. (2008). Interfacing heterogeneous PDM systems using the PLM Services. Advanced Engineering Informatics,22(3), 307-316. doi:10.1016/j.aei.2007.08.009

Gurit. (2016). COMPOSITE MATERIALS FOR RAIL.

Guterres, A. (2018). Secretary-General outlines vision for 2019 Climate Change Summit. Retrieved from https://www.un.int/news/secretary-general-outlines-vision-2019-climate-change-summit

Hannon, J. (2016). An integrated perspective on the future of mobility. Retrieved from https://www.mckinsey.com/business-functions/sustainability/our-insights/an-integrated-perspective-on-the-future-of-mobility

Heilbron, B. (2018). 'Klimaatinspanning moet worden verdrievoudigd, na 2030 is het te laat'. Retrieved from https://www.nrc.nl/nieuws/2018/11/28/verenigde-naties-klimaatinspanning-moet-worden-verdrievoudigd-na-2030-is-het-te-laat-a2756756

Hoogkamer, S. (2018).). Marketing Tribune. Innovaties van NS gericht op verbetering klantbeleving. Retrieved from https://www.marketingtribune.nl/b2b/nieuws/2018/10/innovaties-van-ns-gericht-op-verbetering-klantbeleving/index.xml

How it's Made. (2015). Retrieved from https://www.youtube.com/watch?v=IJXM5SF7-Tk

Howson, C., Richardson, J., Sallam, R., & Kronz, A. (2019). Magic Quadrant for Analytics and Business Intelligence Platforms. Retrieved from https://www.gartner.com/doc/reprints?id=1-3TXXSLV&ct=170221&st=sb

HP. (2019). HP 3D Printing materials. Retrieved from http://www8.hp.com/h20195/v2/GetPDF.aspx/4AA7-1533ENA.pdf

Hummer, W., Rosenberg, F., Oliveira, F., & Eilam, T. (2013). Testing Idempotence for Infrastructure as Code. Middleware 2013 Lecture Notes in Computer Science,368-388. doi:10.1007/978-3-642-45065-5_19

Infor. (2019). Improve each step of product lifecycle. Retrieved from https://www.infor.com/products/cloudsuite-plm

Kaplan, R. S., & Anderson, S. R. (2003). Time-Driven Activity-Based Costing. SSRN Electronic Journal. doi:10.2139/ssrn.485443

Karunakaran, K., Suryakumar, S., Pushpa, V., & Akula, S. (2010). Low cost integration of additive and subtractive processes for hybrid layered manufacturing. Robotics and Computer-Integrated Manufacturing,26(5), 490-499. doi:10.1016/j.rcim.2010.03.008

Koubek, R. (1995). Kidd, paul, agile manufacturing: Forging new frontiers, Addison Wesley Ltd. International Journal of Human Factors in Manufacturing,5(3), 343-343. doi:10.1002/hfm.4530050310

Lacity, M., Willcocks, L., & Craig, A. (2015). The Robot Revolution: The New Age of Manufacturing | Moving Upstream.

Mar. (2018). Datasheet MARKFORGED MATERIAL PROPERTIES. Retrieved from https://www.conceptsinproduction.com/wp-content/uploads/2017/09/MaterialDatasheetSlick.pdf

Markforged. (2019). Material datasheet Composites. Retrieved from http://static.markforged.com/downloads/composites-data-sheet.pdf

McKinsey. (2019). Customer First: Personalizing the customer care journey. Retrieved from Customer First: Number 2, January 2019 Personalizing the Customer-Care Journey.

Meade, L. M., & Sarkis, J. (1999). Analyzing organizational project alternatives for agile manufacturing processes: An analytical network approach. International Journal of Production Research,37(2), 241-261. doi:10.1080/002075499191751

Microsoft. (2018). Microsoft 365 Enterprise. Retrieved from https://www.microsoft.com/en-us/microsoft-365/enterprise?rtc=1

Microsoft. (2019). Power BI: Interactive Data Visualization BI Tools. Retrieved from https://powerbi.microsoft.com/en-us/

Microsoft. (2019). Customer Success Stories: Microsoft Power BI. Retrieved from https://powerbi.microsoft.com/en-us/departments/operations/

Microsoft. (2019). Minder werken, meer doen. Retrieved from https://flow.microsoft.com/nl-nl/

MIT OpenCourseWare. (2017). Retrieved from https://www.youtube.com/watch?v=OgO1gpXSUzU

Mitchell, A. (1904). The limits of economy in frame structures, Philo, Mag. Sec, 6(8),. Retrieved from https://www-tandfonline-com.tudelft.idm.oclc.org/doi/pdf/10.1080/14786440409463229?needAccess=true.

Morby, A. (2016). Benjamin Hubert's 3D-printed wheelchair to launch during Clerkenwell Design Week. Retrieved at 16th March from https://www.dezeen.com/2016/05/18/benjamin-hubert-layer-3d-printed-wheelchair-launch-clerkenwell-design-week/

Mueller, C. (2014). Computational exploration of the structural design space.

Mueller, C. (2018). Industrial Manufacturing Trends 2018-19. Retrieved from https://www.strategyand.pwc.com/trend/2018-manufacturing

Naylor, J. B., Naim, M. M., & Berry, D. (1999). Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain. International Journal of Production Economics,62(1-2), 107-118. doi:10.1016/s0925-5273(98)00223-0

NS. (2018). Materieel: Over. Retrieved from https://www.ns.nl/over-ns/treinen-van-ns

NS. (2018). Geschiedenis: Over NS. Retrieved from https://www.ns.nl/over-ns/wie-zijn-wij/geschiedenis

Pires, R. (2018). DLP vs SLA – 3D Printing Technologies Shootout. Retrieved from https://all3dp.com/2/dlp-vs-sla-3d-printing-technologies-shootout/

PlanetTogether. (2018). Agile Manufacturing Advantages and Disadvantages. Retrieved from https://www.planettogether.com/blog/agile-manufacturing-advantages-and-disadvantages

Profile. (2019). Product en Document Lifecycle Management. Retrieved from https://www.profile-plm.nl/applicaties/#product-data-management

Publicatieblad van de Europese Unie. (2014). VERORDENING (EU) Nr. 1300/2014 VAN DE COMMISSIE. Retrieved from https://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?uri=CELEX:32014R1300&from=EN.

Rafi, H. K., Karthik, N. V., Gong, H., Starr, T. L., & Stucker, B. E. (2013). Microstructures and Mechanical Properties of Ti6Al4V Parts Fabricated by Selective Laser Melting and Electron Beam Melting. Journal of Materials Engineering and Performance,22(12), 3872-3883. doi:10.1007/s11665-013-0658-0

Redwood, B., Schöffer, F., Garret, B., & Fadell, T. (2017). The 3D printing handbook: Technologies, design and applications. Amsterdam: 3D Hubs.

Roy, S., Tarafdar, M., Ragu-Nathan, T., & Marsillac, E. (2009). The Effect of Misspecification of Reflective and Formative Constructs in Operations and Manufacturing Management Research. Retrieved from https://www.researchgate.net/profile/Aboobucker_Ilmudeen/post/Can_anyone_explain_reflective_vs_formative_measurement_models_with_examples_please/attachment/59d6400d79197b807799c53d/AS:429393576239108@1479386814880/download/Reflective and Formative measures in manufacturing and opertion management.pdf.

Sabina, R. (2016). Metamaterials make it possible to create mechanisms from a single piece of plastic. Retrieved at 16th March from https://www.dezeen.com/2016/09/27/metamaterials-mechanisms-design-3d-printed-plastic-door-handle-hasso-plattner-institute-technology/

Sabina, R. (2019). Columbia University researchers create 3D-printed "wood" with realistic internal grain. Retrieved at 16th March from https://www.dezeen.com/2019/01/04/3d-printed-wood-columbia-university/

SAO. (2019). Softwareproducten voor best-run businesses. Retrieved from https://www.sap.com/netherlands/products.html

Schreuder, A. (2012). Treinen zijn wel hufterproof maar niet botsveilig. Retrieved from https://www.nrc.nl/nieuws/2012/12/12/treinen-zijn-wel-hufterproof-maar-niet-botsveilig-1187004-a335503

Science Channel. (2013). Retrieved from https://www.youtube.com/watch?v=CWs3LilbsWU

Shah, R., & Ward, P. T. (2002). Lean manufacturing: Context, practice bundles, and performance. Journal of Operations Management,21(2), 129-149. doi:10.1016/s0272-6963(02)00108-0

Shang, J., & Sueyoshi, T. (1995). A unified framework for the selection of a Flexible Manufacturing System. European Journal of Operational Research,85(2), 297-315. doi:10.1016/0377-2217(94)00041-a

Sharifi, M., & Zhang, Z. (2001). Agile manufacturing in practice. Application of a methodology. Retrieved from https://www.emeraldinsight.com/doi/pdfplus/10.1108/01443570110390462

Shift2rail. (2019). Capabilities. Retrieved from https://shift2rail.org/capability/

SolidEdge. (2019). Siemens: 3D Design, Simulation, Manufacturing. Retrieved from https://solidedge.siemens.com/en/

SolvayGroup. (2017). Composites for faster, lighter, greener mobility. Retrieved from https://medium.com/solvaygroup/composites-for-faster-lighter-greener-mobility-9af5e8e6b0a8

Star Rapid. (2014). Plastic injection molding tolerances guide.

Stevenson, K. (2016). Carbon Announces the M1 3D Printer, With A Shocking Surprise. Retrieved from https://www.fabbaloo.com/blog/2016/4/1/carbon-announces-the-m1-3d-printer

Stuij, K. (2018). Hangen, zitten en werken in de trein van de toekomst. Retrieved from https://www.metronieuws.nl/in-het-nieuws/2018/10/hangen-zitten-en-werken-in-de-trein-van-de-toekomst

Tofail, S. A., Koumoulos, E. P., Bandyopadhyay, A., Bose, S., O'Donoghue, L., & Charitidis, C. (2018). Additive manufacturing: Scientific and technological challenges, market uptake and opportunities. Materials Today,21(1), 22-37. doi:10.1016/j.mattod.2017.07.001

UNIFE. (2014). UNIFE TECHNICAL REPORT INTERIOR PASSIVE SAFETY. Retrieved from http://www.unife.org/publication-press/publications/92-unife-technical-report-interior-passive-safety.html

Van Lieshout, I. (2018). Deze huizen kwamen uit 3D-printers. Retrieved from https://www.bright.nl/trends/artikel/4222401/3d-geprinte-huizen-3d-print-woning-huis-geprint

Wall Street Journal. (2018). Retrieved from https://www.youtube.com/watch?v=HX6M4QunVmA&t=397s

Wang, B. (2018). World population is now over 7.6 billion and should reach 8 billion by 2023. Retrieved from https://www.nextbigfuture.com/2018/03/world-population-is-now-over-7-6-billion-and-should-reach-8-billion-by-2023.html

Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination. Computer Networks,101, 158-168. doi:10.1016/j.comnet.2015.12.017

Wetten.overheid.nl. (2019). Regeling indienststelling spoorvoertuigen. Retrieved from https://wetten.overheid.nl/BWBR0031350/2017-02-14

XJET3D. (2016). XJET ANNOUNCES 3D CERAMIC CAPABILITIES. Retrieved from https://xjet3d.com/pr/xjet-announces-3d-ceramic-capabilities/

Yusuf, Y., Sarhadi, M., & Gunasekaran, A. (1999). Agile manufacturing:: The drivers, concepts and attributes. International Journal of production economics,. International Journal of Production Economics,62(1-2), 33-43. doi:10.1016/s0925-5273(98)00219-9