3D PRINTING METAL SPARE PARTS ON-BOARD

The implementation of Additive Manufacturing on-board Heerema Vessels

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Figure 1: Thialf offshore (Heerema)

PREFACE

Graduating at a world leading marine contractor as an Integrated Product Designer; why not?

Spencer Johnson published the book 'Who Moved my Cheese?' in 1998. In this New York Times bestseller Johnson (1998) notes the following:

The four imaginary characters
Depicted in this story—
The mice: "Sniff" and "Scurry," and
The Little people: "Hem" and "Haw"—

Are intended to represent the simple and
The complex parts of ourselves, regardless of
Our age, gender, race or nationality

Sometimes we may act like
Sniff
Who sniffs out change early, or
Scurry
Who scurries into action, or
Hem
Who denies and resists change as he fears
It will lead to something worse, or
Haw
Who learns to adapt in time when he sees
Changing leads to something better!

Whatever parts of us we choose to use,
We all share something in common:
A need to find our way in the maze
And succeed in changing times.

This project recommends a change in the way Heerema is used to order and manufacture spare parts. Let's make sure we sniff this change and scurry into action like Sniff and Scurry do. However, let us not forget Hem and be aware of risks that come along. And hopefully have the same insights as Haw, since this report proves the benefits of the implementation of the 3D printing technology.

This project has offered me the opportunity to help improving the sustainability of an industry that focusses on contributing to the Sustainability Development Goals of the United Nations. An industry that participates in increasing renewable energy sources on our planet.

I would like to thank the following people, you all added a lot of value to my project.

Thank you Vincent for your support being my Company Mentor. Not only did you help me get the best out of my project, you were also very involved in making the right decisions – project, and future related.

I would like to thank Bas and Jeremy for asking the right questions at the right moment. You challenged me to reach my full potential. With your supervision I learned a lot within the field of Additive Manufacturing and Sustainability.

Many thanks to my colleagues at Heerema: the Sustainability Team, the Strategy Department, Team HeereMasks and the Drawing Team, have all been a welcoming environment to work in and with.

Also, a special thanks to the Thialf Crew, who allowed me to investigate the current processes on-board. Hans, thanks a lot for your enthusiasm and support during my research. Additionally, I would like to thank Dennie and Robert of Layertec for their input and effort.

Thank you family and friends for supporting me throughout the project. Bertel, Machteld, Roos, Bob and Romy thank you for being involved in my decision making the past twenty weeks. Also Michiel, Kristien and Magali, thanks for your attention to detail. Rochelle, Carmen and Nathalie, thanks for your creative input.

EXECUTIVE SUMMARY

In this Master Thesis the potential of Additive Manufacturing on-board vessels of Heerema Marine Contractors is looked into, with the goal to design a recommendation for implementing this technology.

Heerema is an offshore construction company that is intrinsically motivated to improve their sustainability. They transport, install and remove all types of offshore facilities. All Heerema vessels have a warehouse on-board, containing spare parts. Spare parts are parts in-stock that will be used to maintain the vessel or execute projects. In total the warehouse contains 300.000 parts, with an average value of 13.000.000 US$. The total weight of the stored material is 1.400.000 kg.

If a needed spare part is not in-stock, it is ordered and brought to the vessel. Both actions take up a lot of time and could risk a project being stopped, which influences the economic pillar of the Triple Bottom Line consisting of people, planet and profit. Having this many parts on-board, and always ordering a 'new part' when something breaks, is not seen as a sustainable project execution. Especially taking into account the possibility of repairing. Next to that, extra transports or air freights are needed to get parts on-board, which influences the sustainable pillar of the Triple Bottom Line. In some cases, parts used to be produced by suppliers that do not exist anymore, which makes it hard to order new ones or obligated to purchase packages.

The preferred situation for Heerema would be to use Additive Manufacturing as an additional production method for spare parts. For the implementation of this technology, a sufficient quality of the printed parts is desired. Sufficiency for critical parts has to be qualified by external certification organizations. Sufficiency for non-critical parts is reached once it functions within the used application. Next to the quality of the prints, the time it takes to print a part is important. Both quality and time depend on the performance of the 3D printer, which will influence the adoption of the crew.

The preferred situation can be seen as the goal Heerema if aiming for. To reach this goal, a Roadmap is recommended. This Roadmap is designed as being the most suitable way of implementing and using 3D printing on-board of their vessels. The Roadmap is based on three different phases: The Research phase, The Printing phase and The Opportunities phase. Within these phases, the printing phase exists of two sub-phases: a plastic and a metal print phase. Each printing phase exists of a testing phase, a limited use phase and an expansion phase.

The transition from one phase to another is based on a stepwise approach to lower the risks that could occur while implementing a complex innovation. The stepwise approach is based on the level of trust among the vessel crew towards the level of complexity of the implemented innovation.

The conducted research supports the proposed solution that leads to the preferred situation. The solution is assessed according the three aspects of the Industrial Design Engineering domain: Technology, Human Values and Business.

The solution is shown to be feasible due to the chosen hardware, the study on printable spare parts, 3D print studies and mechanical tests at the TU Delft.
Additionally, the solution is shown to be viable due to relative low investment costs, a decrease in man-hours and transports and a waste reduction based on Value Stream Mapping.
Also, the solution is shown to be desirable due to the collaboration with current users, a promising partnership with Layertec and the fit with the sustainability aims of Heerema.

The thesis is enclosed by mentioning the research limitations, reflections, recommendations and further research for Heerema.

REPORT STRUCTURE & PROJECT METHODOLOGY

REPORT STRUCTURE

This report is structured according the Pyramid Principle of Barbara Minto (1987). This principle first guides the reader through the **current situation**, the **problems** that occur in this situation and then explains the **preferred situation**. After the introduction, the **solution** is explained and supported by research outcomes according feasibility, viability and desirability. The chapters of this report follow the steps of the Pyramid Principle method as explained.

PROJECT METHODOLOGY

The structure of the report differs from the structure applied during the project. To get to the solution that is presented in this report, a process based on the diverging and converging principle of Roozenburg and Eekels (1998) is applied. This principle is combined with the Design Council's design methodology called the Double Diamond (Design Council, n.d.). As can be seen in Figure 2, the process of this project consists of 4 phases: Discover, Define, Develop and Deliver (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). A more detailed process and planning can be found in Appendix 2 and 3.

1. DISCOVER

Discovering insights and create understanding.

In this first phase, the following questions are asked: how do vessels of Heerema currently get their spare parts? Why is this not the production process Heerema wants to continue with? Which parts commonly fail, and why? What are the pros and cons of the 3D printing process? Next to that, previous studies on the potential of 3D printing within the offshore industry are looked into.

2. DEFINE

Defining for whom and for what problem or challenge we are designing.

The outcome of the analysis leads to a desirable future production process of spare parts. To put this future process into work, Heerema has to tackle certain challenges. During this phase these challenges are selected.

3. DEVELOP

Develop ideas and concepts.

The selected challenges are tackled with the use of the classic design approach in which the problem is defined, and ideas are developed, evaluated and selected in an iterative process. Evaluation is executed with the use of (3D printed) prototypes and interviews with users and stakeholders.

4. DELIVER

Articulate and simulate design proposals.

After the ideation phase, the final result is developed. The aim is a validated solution, designed to solve the selected challenge. This solution exists of a roadmap including a design study.

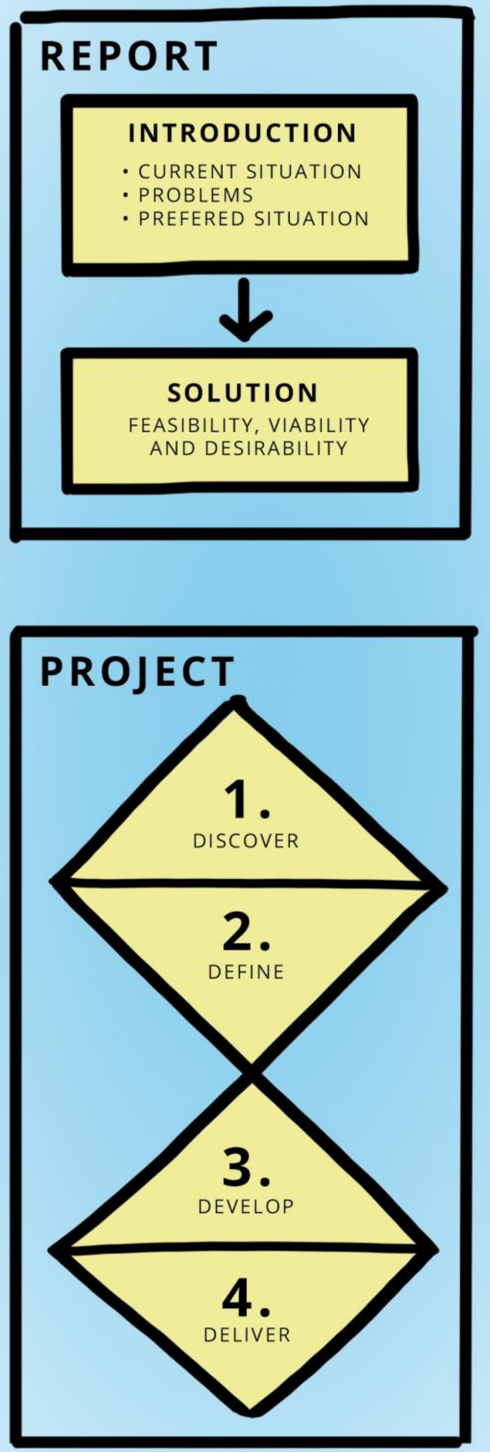

Figure 2: Report and Project structure

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Figure 3: Thialf offshore (Heerema)

DEFINITIONS

ADDITIVE MANUFACTURING
A collective name used for 3D printing technologies.

BOUND METAL DEPOSITION
An Additive Manufacturing method based on metal extrusion (BMD).

CNC MILLING
Milling is a machining production method in which material is removed using a rotating tool.

CAD MODEL
Cad- Aided-Design: a digital three-dimensional model of an object.

FUSED DEPOSITION MODELLING
An Additive Manufacturing method, based on plastic extrusion (FDM).

STL FILES
STL stands for Surface Tessellation Language: description of the surface by tiling. A STL file is used to send the model to the 3D printer.

Figure 4: Warehouse at the Thialf

1. INTRODUCTION

To comprehend the final solution of this project, first the current situation is introduced. Second, the problems that occur in this situation are explained with support of conducted research. Last, the preferred situation is presented to show Heerema's ambitions for solving the explained problems. Once clarified, the final solution is presented and explained.

Figure 5:Thialf offshore (Heerema)

1.1 CURRENT SITUATION

To comprehend the current situation, the company and project context are introduced.

COMPANY

This project is in collaboration with **Heerema Marine Contractors**. A company that transports, installs and removes all types of offshore facilities (Heerema, n.d.). Heerema takes responsibility for the entire supply chain of offshore construction projects, from design through to completion. This responsibility includes engineering, planning, logistics, project management and execution of projects all over the world.

At this moment, the portfolio of Heerema exists of Transport & Installation, Decommissioning and Wind. To execute all projects offshore, Heerema has their own fleet, consisting of the world's largest crane vessels (Heerema Marine Contractors, 2019). This project focuses on the vessel called the '**Thialf**'. The Thialf is the second largest deep-water construction vessel of the fleet, of which Figure 7 provides an impression.

The length of the vessel is equal to the size of a NS Sprinter train. The size of the deck can be compared to approximately two football fields (KNVB, n.d.). The weight the cranes can lift together is equal to 300 sprinters (NS, n.d.). Still hard to imagine? Let's compare it to the faculty of IDE: the Thialf is approximately 2 times the size of it (Figure 6).

Figure 6: Render Thialf at TU Campus (M. Buirma)

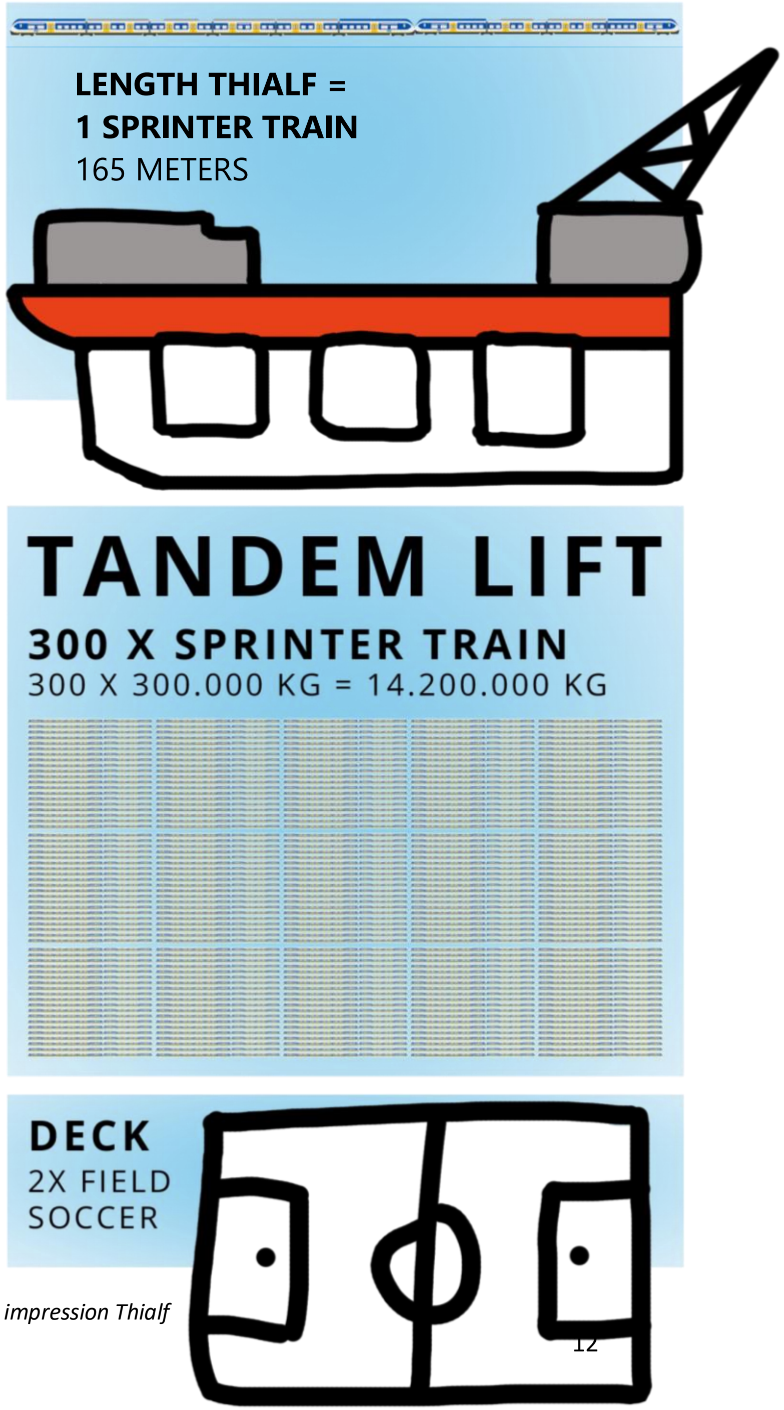


Figure 7: Size impression Thialf

PROJECT CONTEXT

To create understanding of the current situation, it is important to discover insights about the context of the project (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). Aforementioned, the context of this project is the Thialf. On-board of this vessel, the focus is the warehouse (Figure 9). The warehouse is the place where all spare parts and materials are kept on-board. Next to the warehouse is a workshop. This workshop contains CNC-mills, drills, turning and milling machines. Those machines are used to repair or produce parts.

SPARE PARTS

At the vessel, spare parts are used to maintain the vessel and execute projects. In total the warehouse contains 300.000 parts, with an average value of 13.000.000 US$. The total weight of the stored material is 1.400.000 kg, which equals 62 delta flippers of 6.5 metres (Heerema Marine Contractors, 2019). Figure 8 gives an impression of these amounts. For this project the focus is on the smaller spare parts, that are manufacturable by the crew.

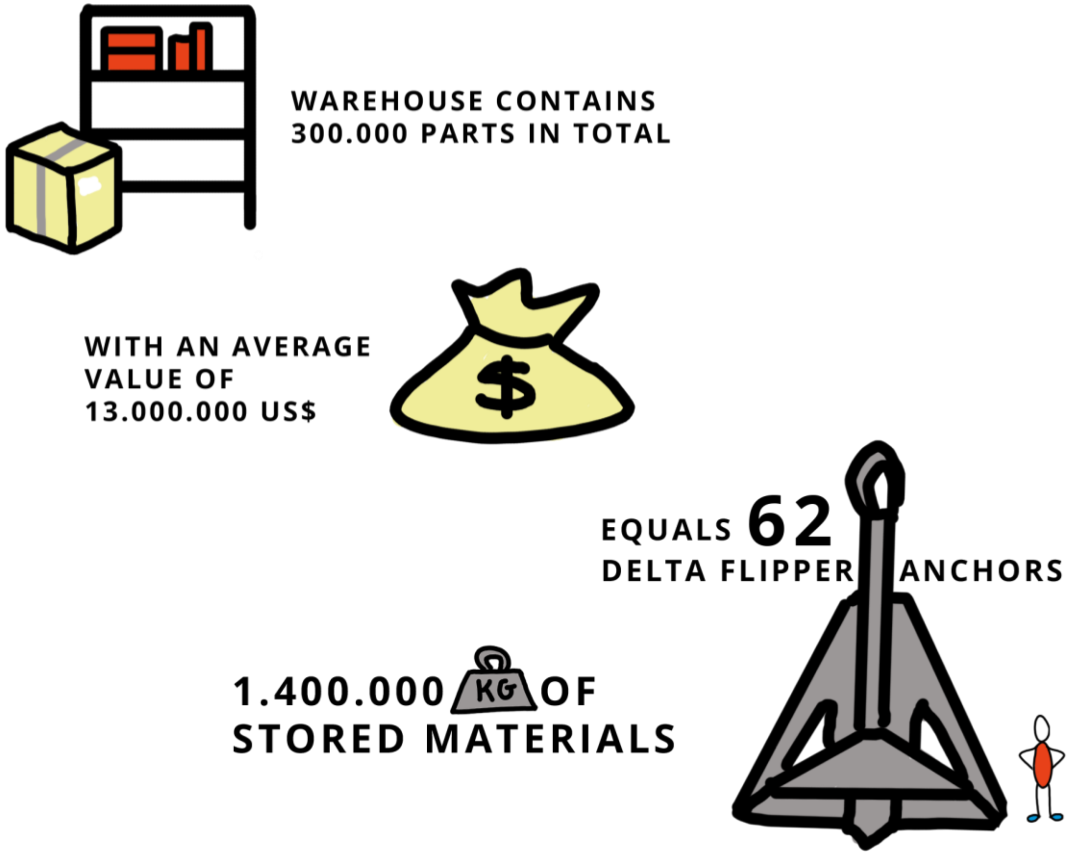


Figure 8: Facts Thialf Warehouse spare parts

Figure 9: Warehouse impression at the Thialf

STAKEHOLDERS

To get an overview of the people involved in the context, a stakeholder overview is created (Figure 10) with the input of experts during interviews (Appendix 4). The stakeholders include:

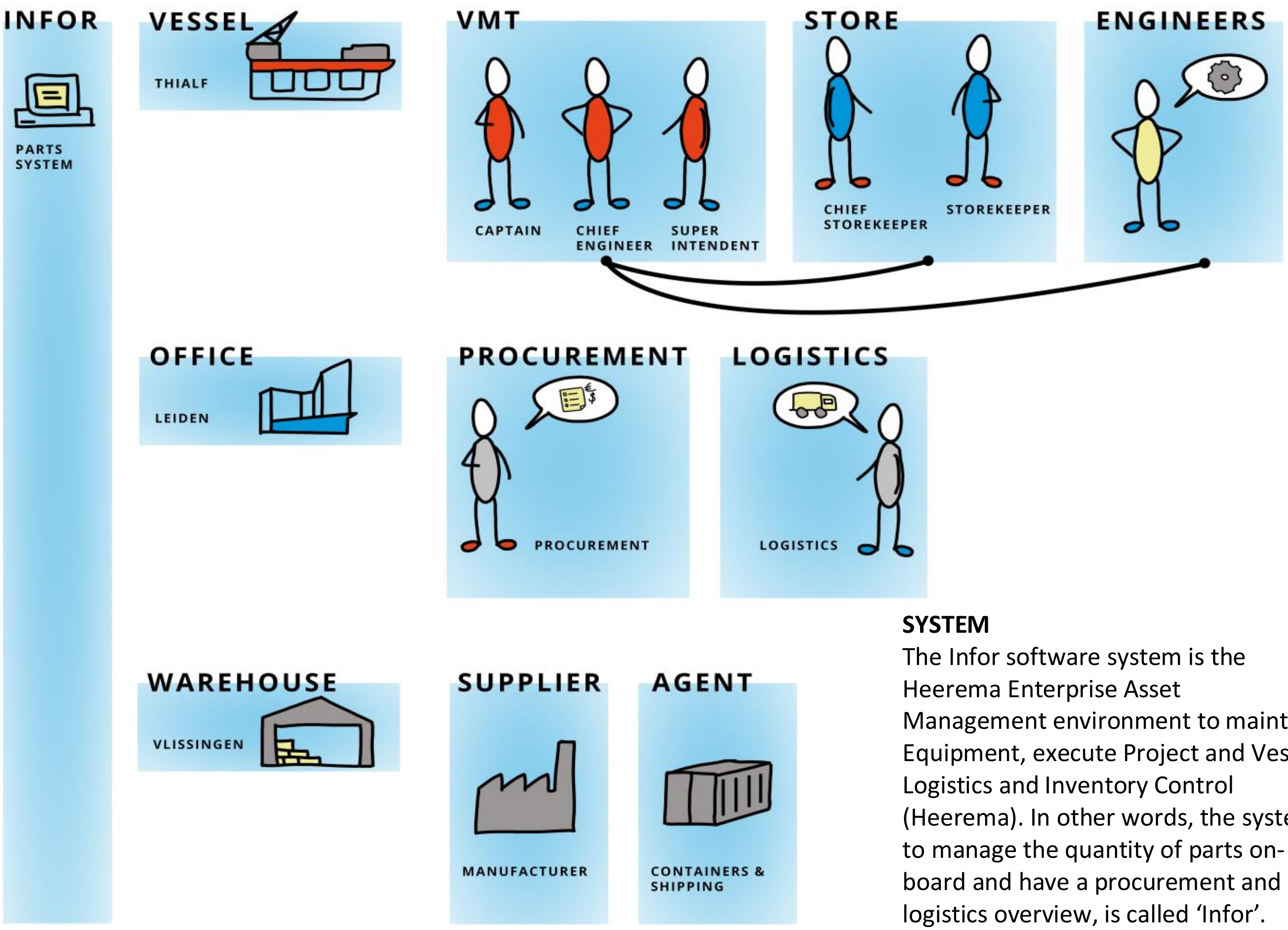


Figure 10: Stakeholder overview

SYSTEM
The Infor software system is the Heerema Enterprise Asset Management environment to maintain Equipment, execute Project and Vessel Logistics and Inventory Control (Heerema). In other words, the system to manage the quantity of parts on-board and have a procurement and logistics overview, is called 'Infor'.

VMT
At the vessel the Vessel Management Team is in charge. This teams consists of a Captain, a Chief Engineer and a Superintendent.

STOREKEEPERS
The warehouse of the vessel is under guidance of the Chief Storekeeper, part of the department of the Chief Engineer (VMT). The Chief Storekeeper has several Storekeepers that help him manage the warehouse, or 'store'.

ENGINEERS
The Engineers on-board of the vessel use parts to fix tasks that include mechanic knowledge. They get the parts at warehouse from the Storekeepers.

PROCUREMENT AND LOGISTICS
In the office there is a Procurement and Logistics department. Procurement orders and pays the parts at suppliers, logistics arranges the transport. The global transport can be by truck, boat, plain or helicopter. Heerema makes use of different agents, which arrange the shipping of containers.

WAREHOUSE
If the vessel is in the harbour, the parts will be transported from the manufacturer to the warehouse, to the vessel. This on-shore warehouse is not the context of this project.

ORDER PROCESS
All stakeholders collaborate in the ordering process. There are different types of ordering processes that occur to get parts on-board of the vessels. **Emergency orders** are this project's focus, because this type of order has a lot of potential in terms of economic and environmental impact. Substantiating this: an order is brought to the vessel because it is urgent, causing an extra transport. An order is urgent at the moment the parts are immediately needed to continue executing the project, but are not on-board (anymore). This situation rarely occurs, but if it occurs all possible ways to get the part on-board as soon as possible will be considered. With this type of order, the preferable time to vessel is *as soon as possible*.

Figure 11: Type of order

An earlier conducted research, named REL, divided parts in-stock in categories. One category is called the 'Strangers'. These kind of parts, are parts that fit within emergency ordered parts. Strangers are not mass manufactured, which makes them unique and thus more expensive and less available.
Other order types are a regular order, a project-specific order and an expensive order (see Appendix 5).

OVERVIEW EMERGENCY ORDER
To understand how the stakeholders work together in the workflow of ordering parts, Value Stream Maps (Barney, 2017) are created (see Appendix 6). Figure 12 shows an overview of the workflow of an emergency order. The Engineer needs a specific part so he will approach the Storekeeper.
The part is not there, so the Chief Storekeeper will be involved in the process. Since it is an Emergency order, the Chief Storekeeper gets in touch with the Chief Engineer (part of the VMT). Together with the Chief Engineer the Chief Storekeeper gets in touch with the office. Procurement and Logistics will make sure the part gets ordered as soon as possible and arrives at the vessel. Once the part is at the vessel, the Chief Storekeeper and Storekeeper make sure the part gets to the Engineer, so he can finish the job. Meanwhile, the Chief Storekeeper keeps the VMT up to date.

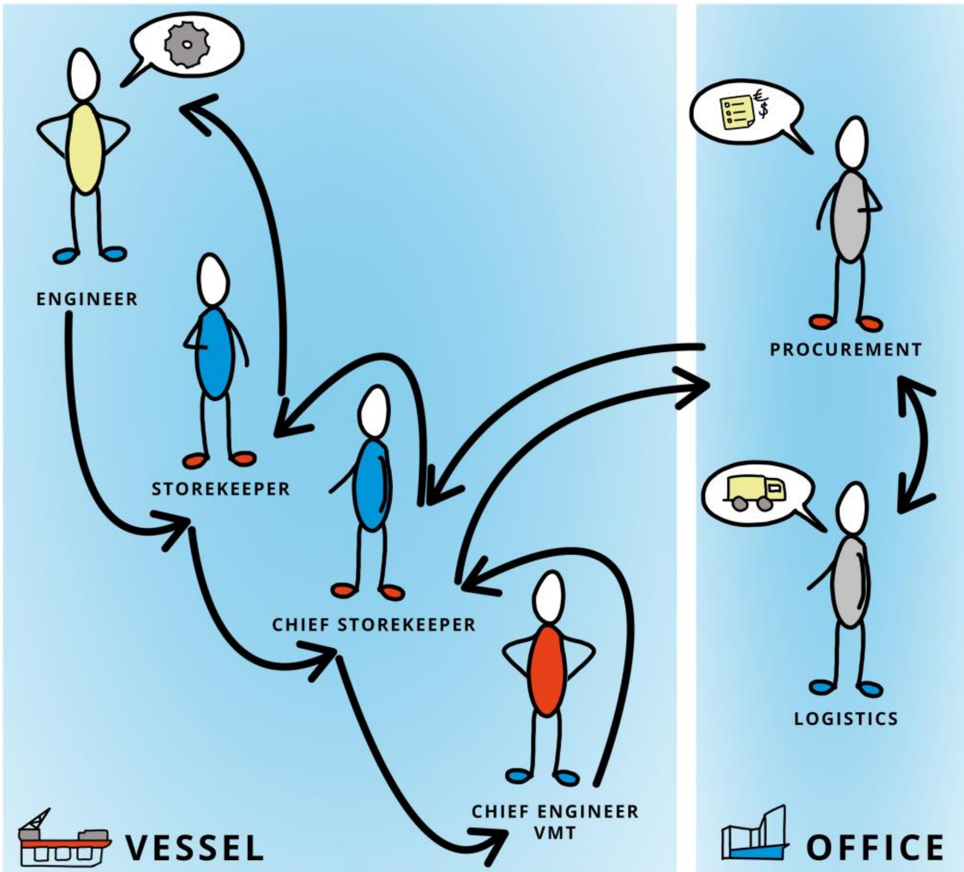


Figure 12: Order process Emergency order

1.2 PROBLEMS

After the introduction of the current situation, the problems that occur in this situation are explained.

Figure 13: Pain points current situation

PAIN POINTS CURRENT SITUATION

In general, inventory management is a complex matter according to Bachetti & Saccani (2011): *"Several aspects make inventory management for spare parts a complex matter: the high number of parts managed; the presence of intermittent or lumpy demand patterns; the high responsiveness required due to downtime cost for by customers; and the risk of stock obsolescence".* These insights are supported by the following results of the conducted research.

DELIVERY TIME 

One of the pains is the delivery time to get a spare part on-board, once it is not in-stock. According to Hans Havermans, Chief Storekeeper at the Thialf, it can currently take a few days, weeks or even months to get ordered parts on-board. "It can take a lot of time to get the parts on-board. It takes a lot of communication before the order can be send out." This pain point is substantiated by the Value Stream Mapping analysis, which showed that forced waiting time for a part can be a bottleneck of the ordering process (Appendix 6).

STOPPING PROJECT 

Jan Pluimgraaff, Superintendent at the Thialf, explained: "Sometimes we have to stop a project because of a missing part. This rarely occurs, but if it happens it costs a lot of money" (Appendix 9). If a part misses because it is not in-stock and projects have to be stopped, it could cost Heerema **1 million $** per day.

AIR FREIGHTS 

To get spare parts on-board, air freights are used, resulting in unnecessary emissions and additional costs. Mike van der Plas works as Senior Equipment Resource Coordinator at Heerema. For the last few years he has tracked all air freights. The so-called emergency orders that have to go to the vessel as soon as possible, are mostly done by plane. According to the documentation of Mike van der Plas (see Appendix 10) all freights containing parts from the categories '*Workshop*', *Parts'* or '*Tooling*', took up 11% of the weight in 2011. This was spread over 10 of the 74 freights in total.
At Heerema, costs of the airfreights are calculated with the ratio 10$/KG. This means, the total amount of freights in 2011 to the Balder only, already costs Heerema **93.240$.**

OLD PARTS NO MANUFACTURING 

Hans Havermans, Chief Storekeeper: "Meanwhile the Thialf is getting older, some parts are not produced anymore". This can be due to the age of the part, or because the manufacturer does not exist anymore. The Thialf is built in 1985 and therefore already 35 years old, so are some of her parts. If it is already known a part will be out of manufacturing within a few years, we are required to purchase a lot of parts. Jan Pluimgraaff, Superintendent at the Thialf, explains: "Some parts are designed so many years ago, that they are not produced anymore. However, we still need them for our fleet. That is why we bought multiple" (Appendix 9).

PURCHASE PACKAGES 

Some part are only available in packages, which forces the crew to by multiple parts at once. Hans Havermans explained: "Sometimes we only need one or two new parts, but the supplier only sells the parts per 50 or even 100 units."

AMOUNT IN-STOCK 

The Value Stream Mapping analysis (Appendix 6) gave the insight of the huge amount of parts in-stock that results in losing overview. Losing overview can be seen as one of the 8 types of waste, considered as anything a customer does not pay for. Reducing it, improves the process (Barney, 2017). According to Hans Havermans the Thialf is "quite big, but by placing all the parts in the store you lose overview." Next to that, Hans thinks space has to be made when Heerema wants to implement new ideas to increase sustainability (like carbon capture). Jan Pluimgraaff explains that the crew always has to take all parts with them, "and there are a lot!"

ADMINISTRATION 

According to Peter de Bree (Appendix 9), the current Infor system makes it hard for Storekeepers to order parts due to the significant amount of time it takes. This insight is supported by the outcome of the Value Stream Mapping analysis (Appendix 6).

ORDERING PROCESS 

Not only the time consuming administration of ordering, but also the steps that have to be taken to get to ordering a part are slowing down the process. While ordering original spare parts for this project, quite some bumps in the road of ordering parts appeared. The details of this process can be found in Appendix 12. Bumps in the road that appeared:

- Requisition codes/numbers not clear.
- Ordering process takes up same amount of time as delivering.
- Two weeks after order got approved, the part seemed to be not produced anymore.

ADDITIONAL: COVID-19 SITUATION

Another problem that occurred during this project, is closed boarders because of the Covid-19 pandemic. Due to the virus, factories, ports and whole cities across China are locked-down. This outbreak shows how fragile, for example a China-only supply chain can be (Economist, 2020).

PROBLEMS DEFINED

The pain points clarify why a solution is needed: if a spare part is not in-stock, it is ordered and brought to the vessel. Both actions take up a lot of time and could risk a project being stopped, which influences the economic pillar of the Triple Bottom Line consisting of people, planet and profit (Slaper & Hall, 2013). Also, having this many parts on-board, and always ordering a 'new part' when something breaks, is not seen as a sustainable project execution. Next to that, extra transports or air freights are needed to get parts on-board, which influences the sustainable pillar of the Triple Bottom Line. In some cases, parts used to be produced by suppliers that do not exist anymore, which makes it hard to order new ones or obligated to purchase packages (Appendix 9).

To solve those problems, challenges have to be faced. A complete overview of all challenges can be found in Appendix 13.

CHALLENGES

From all challenges, the Key Challenges are selected: the challenges within the scope of this project. These challenges are selected to be tackled first, because the outcome is unknown and the knowledge to face the challenges has to be gathered externally (Appendix 13). The Key Challenges are:

1. **Delivery time**
2. **Quality of the prints**
3. **Adoption by vessel crew**

1. DELIVERY TIME

The challenge is to get the spare part on-board of the vessel as soon as possible, without the use of extra transports.

The threshold of each Key Challenge implies at what point the challenge is tackled.
The threshold for this challenge depends on the original order: with an emergency order every hour counts, so every hour that can be saved is a benefit.

2. QUALITY PRINTS

The challenge is to get a sufficient quality out of the manufactured parts. It is important to have insights in the factors that influence the quality.

The threshold of this challenge is set by the original part. However, the crew should be aware that some parts might be designed with an over-dimension. Therefore it is important to take the application into account as well during the redesign and modelling process.

3. ADOPTION BY VESSEL CREW

The challenge is to make sure the crew adopts the proposed solution by experiencing the added value. It is important to get clear the solution supports their job, instead of taking it over.

The threshold of this challenge is specific: the implementation succeeds when the solution is being used to produce parts on-board.

Figure 14: Thialf at Calandkanaal Rotterdam

1.3 PREFERRED SITUATION

The context and its problems are now clarified, which shows the pain points that currently occur in the process of ordering spare parts. These pain points are translated to Key Challenges that have to be tackled.
To set the direction of tackling these challenges, Heerema's ambitions to solve the explained problems are shown by explaining the preferred situation.

Figure 16: Heerema Marine Contractors container

SUSTAINABILITY AT HEEREMA

Heerema is intrinsically motivated to improve their sustainability. To quote Heerema:

> *"We act sustainably because we want to. Not because we have to."*

Heerema aims to be a sustainable company based on the Triple Bottom Line: people, planet and profit (Slaper & Hall, 2013). In order to translate those values into action, Heerema uses the United Nations' Sustainable Development Goals (United Nations, n.d.). The Sustainable Development Goals provide a framework for the long-term policy planning, and a guideline for sustainable development within Heerema (Heerema Marine Contractors, n.d.).

SUSTAINABILITY ROADMAP

This results in the Sustainability Roadmap of Heerema, in which 3D Printing can be found as one of the ambitions (Figure 15).

WHY IS 3D PRINTING AN AMBITION?

With the increasing concerns about global warming, the sustainable impact a company makes, is a much-discussed topic. Especially within big industries, the impact is facing an increasing pressure to be decreased. With 3D printing, Heerema is aiming for an improved economic and environmental sustainability and increasing innovation. To substantiate these motivators, qualitative and quantitative research is conducted, which led to the preferred situation.

Figure 15: Sustainability Roadmap Heerema (Heerema Marine Contractors, n.d.)

PREFERRED SITUATION

To create a new, preferred situation, this project follows-up the Sustainability Roadmap. Therefore, the focus is on the potential of 3D printing spare parts on-board of the vessels of Heerema. As already mentioned, Heerema's interest for this technology is generated by the following motivators: improve environmental and economic sustainability, by using innovation within technology to open up possibilities (see Figure 17).

Figure 17: Motivators Heerema 3D Printing

To set-up the goal of this project, the design vision is created: *"Researching the current situation of purchasing, storing and installing spare parts to find a solution for repairing or producing parts, in which 3D printing the spare parts on-board of vessels of Heerema is integrated."*

ADDITIVE MANUFACTURING

Next to the motivators of Heerema, research of Harris (2017) shows a large number of potential benefits Additive Manufacturing could bring into an organisation: reducing component lead time, cost, material waste, energy usage, and carbon footprint.

According the ISO standard, Additive Manufacturing can be described as: *"the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" -* ISO/ASTM 52900:2015 norm.

Looking for 'Additive Manufacturing technology' on the world wide web results in approximately 2.160.000 hits in Google Scholar (Google, n.d.). It is not surprising that in the past few years, there has been a rapid increase in the publication on Additive Manufacturing, since it promises to have many benefits over traditional manufacturing processes (Durakovic, 2018). This growth will continue according to Song and Zhang (2019), stating that Additive Manufacturing owned a market of $5.93 billion in 2017, which is projected to reach $22.20 billion by 2022.

In line with this development, Heerema already executed an Additive Manufacturing related research in collaboration with the University of Amsterdam. One of Heerema's competitors is the company Huisman. This company also researched Additive Manufacturing (see Appendix 7 for insights of UvA and Huisman).

To work with the Additive Manufacturing technology, specific hardware and software is needed: data from 3D models is converted to files that the printers, the hardware, can translate to a printed 3D object. As mentioned in the book 'Manufacturing and Design' (Tempelman, Shercliff, & van Eyben, 2014), Additive Manufacturing builds up parts gradually by the addition of material under full digital control (Figure 18*). "Typically, but not exclusively, this is done layer by layer. The input for a 3D printer is the raw material plus a computer-aided design (CAD-file), the output is a three-dimensional part ready for finishing".*

In other words, the process of Additive Manufacturing starts with a digital three-dimensional model of the physical object (see Figure 19). The printer's software 'slices' this digital model into flat layers, that will be printed on top of each other. These layers are converted into a

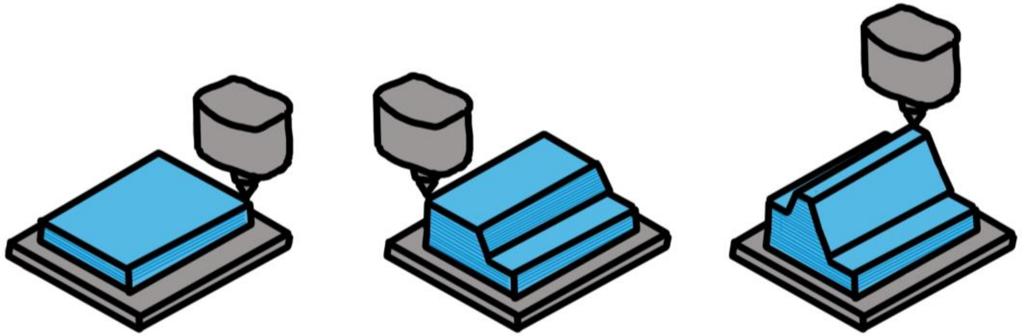


Figure 18: 3D printing principle

document in machine language with the instructions for the printer. This preparing process is similar for all different Additive Manufacturing methods. The execution of the print instructions depends on the chosen method. The cup in Figure 19 is printed with a FDM printer. With this process plastic filaments are melted and extruded on the printing platform through a nozzle (3D Hubs, n.d.). The result is a three-dimensional plastic cup as shown in Figure 19.

According to Dennie Rijk, who is currently working at an Additive Manufacturing company called Layertec, the power of this technology lies in small numbers: models that are difficult to make in other ways of production, custom mass products and testing. Additive Manufacturing seems less suitable when prediction about degradation in the longer term is needed or forged parts are being replaced.

CONCLUSION

The preferred situation for Heerema would be to use Additive Manufacturing (hereafter referred to as 3D printing) as an additional production method for spare parts. For the implementation of this technology, a sufficient **quality** of the printed parts is desired. Sufficiency for critical parts has to be qualified by external certification organizations. Sufficiency for non-critical parts is reached once it functions within the used application. Next to the quality of the prints, the **time** it takes to print a part is important. Both quality and time depend on the performance of the 3D printer, which will influence the **adaptation** of the crew. This future vision can be seen as the hypothesis of this project.

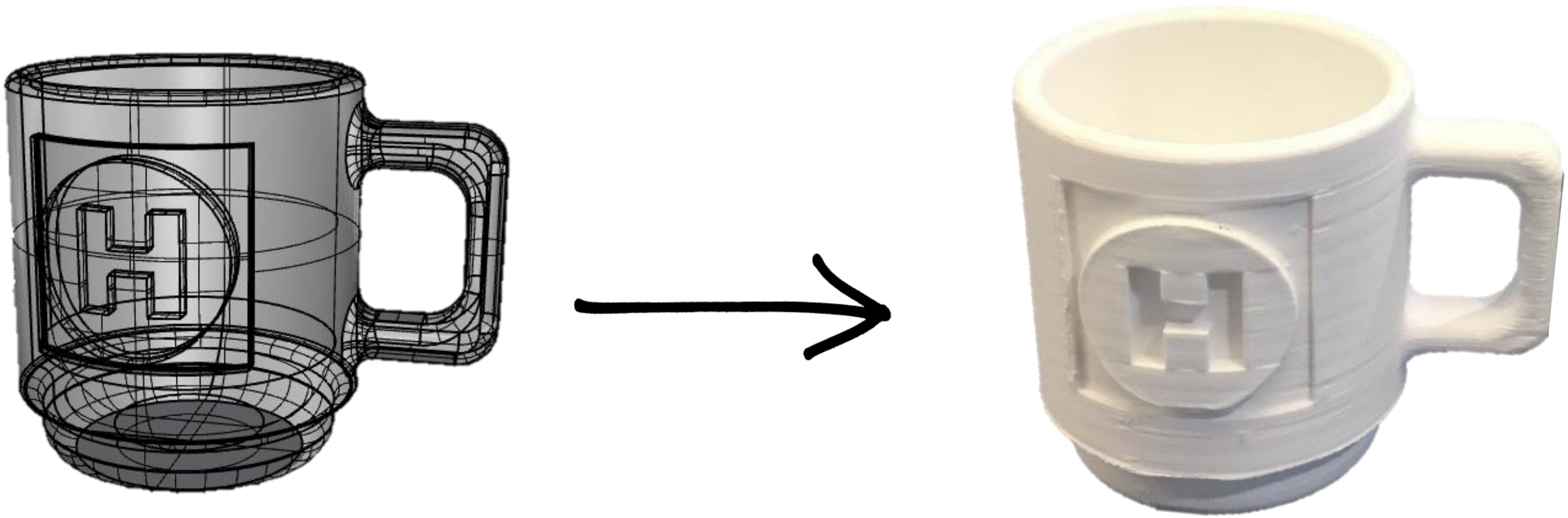


Figure 19: 3D printed Heerema Coffee Cup

2. SOLUTION

The introduction clarified the context, its problems and the preferred situation of Heerema. The preferred situation can be seen as the goal Heerema if aiming for. Knowing this, the following question arises:

How to create this preferred situation?

To answer the question, the solution is presented. After the explanation, design choices are substantiated by conducted research using the three aspects of the Industrial Design Engineering domain: feasibility, viability and desirability.

Figure 20: Thialf offshore (Heerema)

2.1 SOLUTION EXPLAINED

The solution is a Roadmap recommending Heerema the most suitable way of implementing and using 3D printing on-board of their vessels. According Simonse (2017), a roadmap is ‘a visual portray of design innovation elements plotted on a timeline’. The Roadmap of this project is based on three different phases:

Phase 1: The Research phase
Phase 2: The Printing phase
Phase 3: The Opportunities phase

As can be seen in Figure 21, the Printing phase exists of two sub-phases: **a plastic and a metal print phase**. Each printing phase exists of a testing phase, a limited use phase and an expansion phase. This chapter presents the results of the design research by explaining the different phases of the recommended Roadmap.

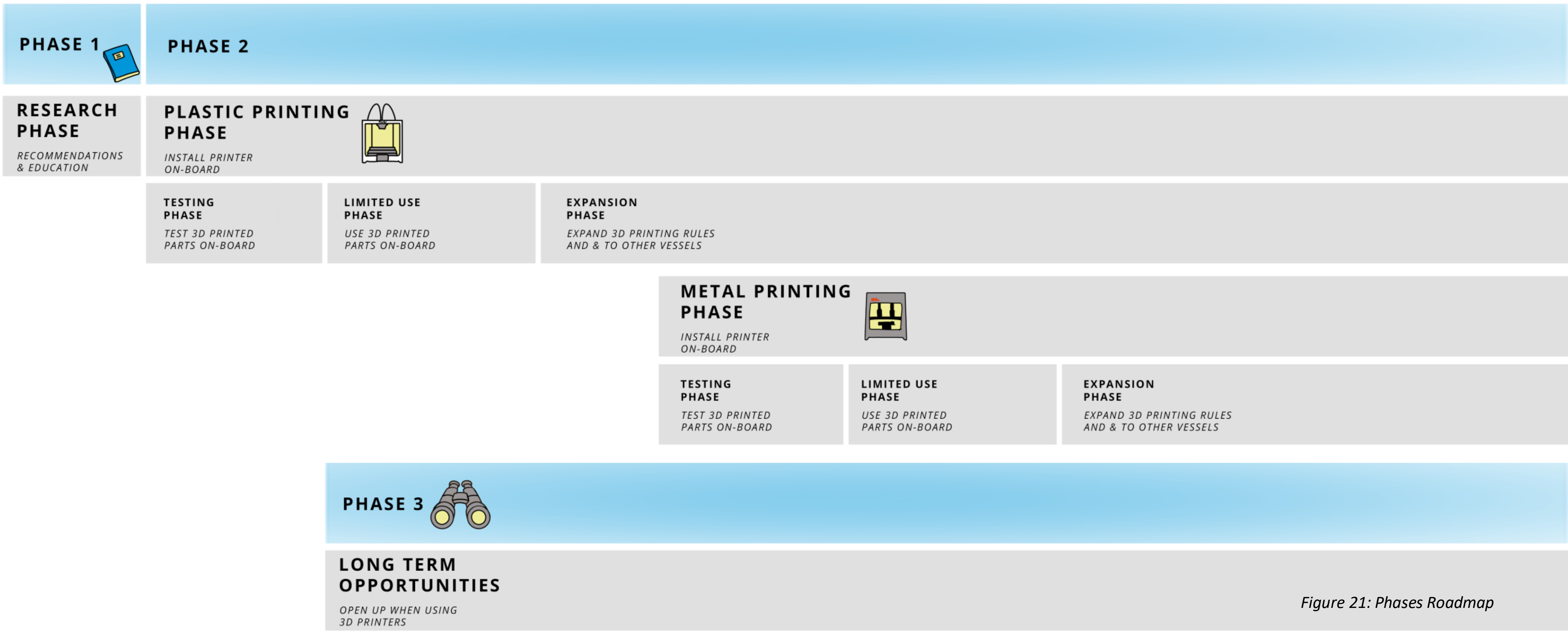


Figure 21: Phases Roadmap

PHASE 1: THE RESEARCH PHASE

As Erik van Hintum, former Captain Thialf, mentioned in one of the interviews, a ‘plug and play’ principle should be used. In other words: once the first printer is installed on-board, the users should be able to start printing immediately. To smoothen this process, the Research Phase is introduced. During the Research Phase, the recommendations should be followed up and stakeholders have to be involved. An important aspect of the Research Phase is the education of the users. The Research Phase can be closed once recommendations are followed up, stakeholders are up to date about the next phase and education is completed.

PHASE 2: THE PRINTING PHASE

Once the Research Phase is closed, the Printing Phase starts. Within this phase, printers are used on-board. The success of this second phase defines the potential of the subsequent opportunities of Phase 3. The implementation of printers is based on the stepwise approach of innovation as mentioned by Huizingh (2009).

STEPWISE IMPLEMENTATION

According to Huizingh (2009) it is preferred to adopt innovation stepwise to balance risks and expected benefits. *“The stepwise approach can minimize the risks of complex innovations. The adoption of this types of innovation involves more levels than simply ‘did not implement’ and ‘did implement’“.* This research is primarily following Rogers’ (1995) innovation adoption model, by investigating the knowledge, perceived potential value, implementation and satisfaction of the users of the innovation.

In addition to the above, Wilkinson (1989) proposes that adoption of a complex technology occurs in a stepwise manner. Components are adopted in an order based on the adopter's perception of their value to the whole. “A complex technology has been regarded previously as monolithic: adopted as a whole, but more slowly than simpler technologies”. Wilkinson redefines a complex technology as one which can be broken up into separate technological components, each of which may be adopted separately.

Erik van Hintum, former captain of the Thialf, confirmed the benefits of a stepwise approach during one of the interviews (see Appendix 14).

Additionally, there are practical examples of a stepwise implementation in similar industries. During interviews, Shell and the Royal Navy mentioned they started 3D printing without conducting detailed research on forehand (Appendix 7). Since Heerema already experiments with plastic 3D printing in the office, the step to put a printer on-board requires less effort. Placing a plastic 3D printer on-board of the vessels can be seen as the first step towards the adoption of 3D printing in general. This approach is in line with the relentless experimentation of the Founder’s Mentality, a program currently worked with at Heerema.

TRANSLATION TO PHASE 2: PRINTING PHASE

Aforementioned, small steps will be taken to accelerate adoption of the 3D printing technology on-board. Or, in other words, to accelerate the acceptance of the crew towards the new technology. As can be seen in Figure 22, the complexity of the implemented 3D printing system will be increased step by step, depending on the crew’s level of trust towards the system.

WHY TRUST?

According to Dervitsiotis (2007), human resources have to be engaged to enable a smooth organizational adaptation. “Achieving this adaptation is only possible in proportion to the degree of trust among the interacting users that act in the context”. In other words, as long as the crew trusts this additional manufacturing method, it will be more easily adopted, and thus adapted to.

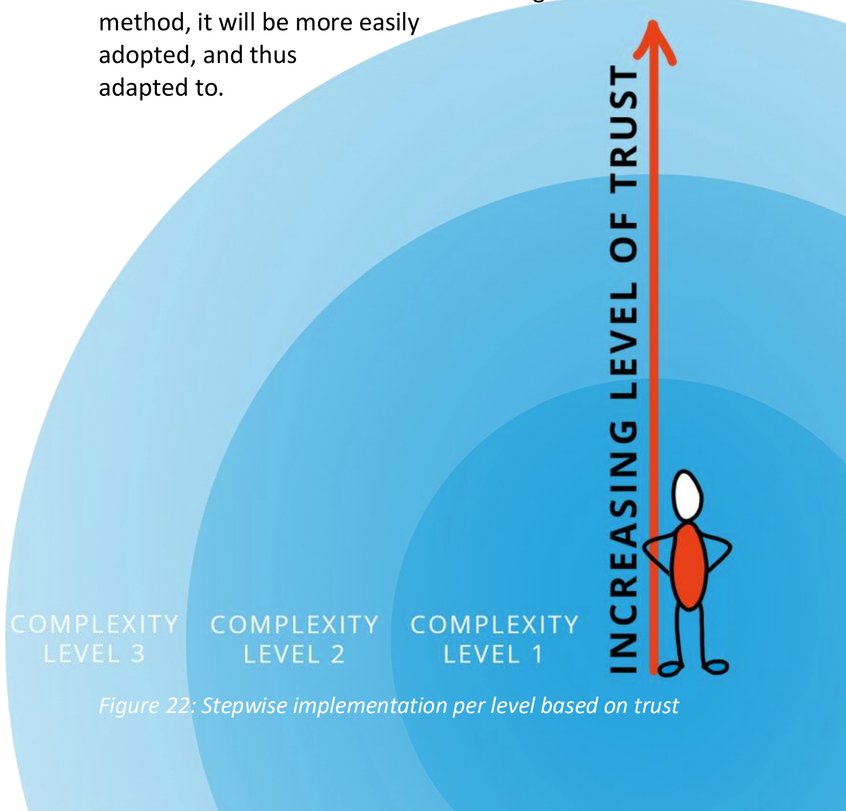


Figure 22: Stepwise implementation per level based on trust

OVERVIEW PHASE 2: PRINTING PHASE

To clarify how this stepwise implementation is translated into action, an overview is provided answering the *what, who, where and when* questions. Taking into account the why question is already answered by highlighting the problems occurring in the current situation. To answer the *what, who, where and when* questions, the Project Management template of Tonnquist (2018) is used.

WHAT?

During the Printing Phase, printers will be implemented on-board. The outcome of this phase suggests how to implement a 3D printer on-board and potentially expand this. Further details of this implementation are discussed in this chapter.

The Printing Phase will be executed with the following goals in mind:

1. Assess the accomplishments for further decision making within 3D printing.
2. Supporting the adaptation of the crew towards 3D printing on board, by; creating trust in the quality, and making crew aware of benefits of 3D printing on-board.

WHO?

For both printing phases, several users and stakeholders are asked to participate. For the printing process the Engineers will be the ones responsible. The Storekeepers will support them with their knowledge in spare parts. An external party, the company Layertec, supports the Printing Phase with installation, education and service.

WHERE?

Both printing phases will be executed at the Thialf since research is conducted at this vessel. All stakeholders of the project are already familiar with the project and even contributed to some decisions made. It is important to involve the crew of the Balder and Aegir (the other Heerema vessels) in this project as well to secure the potential of expanding to those vessels smoothly.

On-board the vessel the printers will be placed in the Warehouse: a clean place that can be locked.

WHEN?

As soon as the users are educated and the printer is installed, the Printing Phase can start. For installation on-board of the Thialf, it is preferable to have her in the Netherlands.

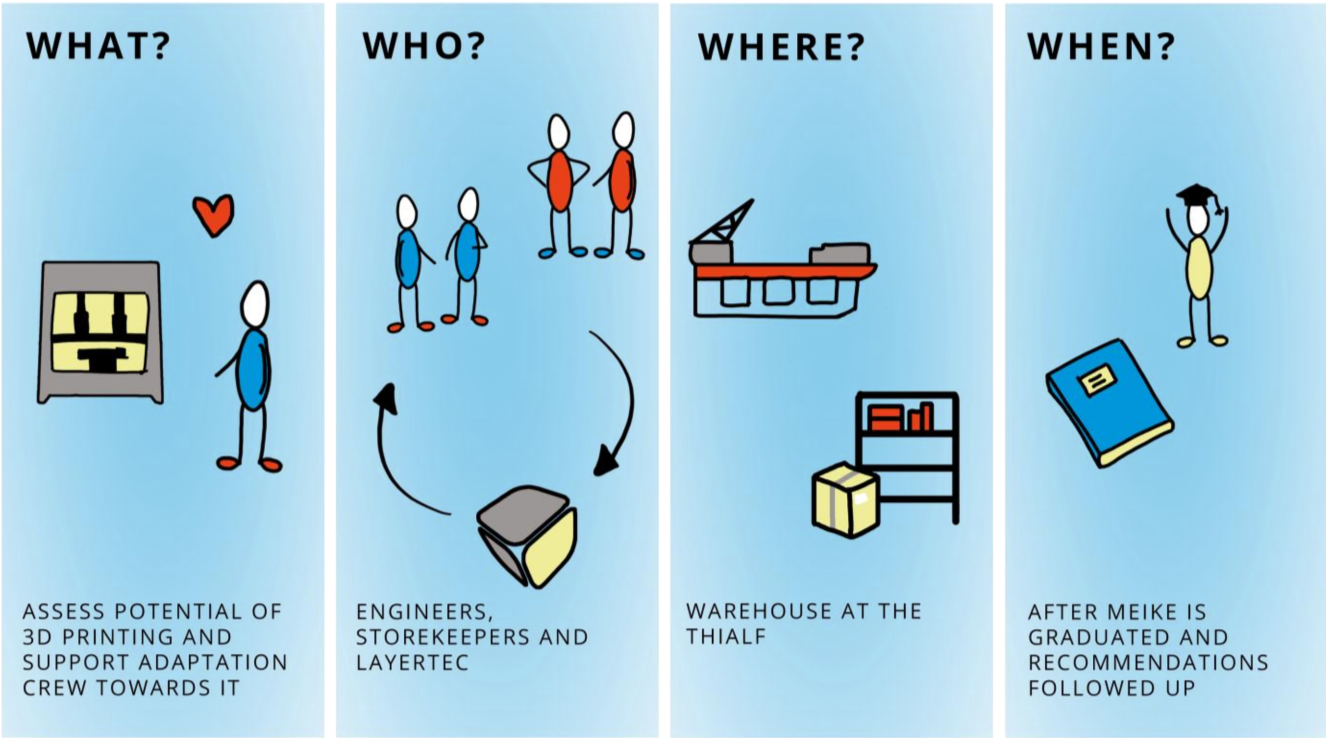


Figure 23: Overview Phase 2: Printing Phase

PRINTING PHASE: WHY PLASTIC AND METAL?

Based on the stepwise implementation, it is decided to split up the Printing Phase into a **plastic** and a **metal** phase. Since plastic printing is already more developed compared to metal printing, and Heerema uses a plastic printer in their office, this printing technology fits the first level of complexity. Appendix 15 explains why printing metal is the ultimate goal.

During the project process, several concepts are created with the use of a Morphological Chart (Appendix 16). This tool helps to “generate principal solutions in an analytical and systematic way” (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). By using this method, all options are extensively considered. To create ideas for the Morphological Chart, several ideation sessions are held (Appendix 17).

Concepts of the Develop Phase are joined into combined concepts (Appendix 18). The chosen combination, joins a concept with a plastic *Fused Deposition Modelling* printer and a concept with a metal *Bound Metal Deposition* printer (Figure 26).

ASSESMENT: WHY THIS COMBINATION?

The combined concept is assessed according criteria, that are set up in collaboration with Heerema, to make a fact-based and deliberately decision. For assessing, the criteria are placed in a Harris Profile (Appendix 19), a ”graphic representation of the strengths and weaknesses of a design concept with respect to predefined design requirements” (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). These requirements and the arguments supporting decisions made, can be found in Figure 25.
Next to this assessment, several interviews are conducted with potential users and stakeholders to use their input in the decision making process. The questions that were asked, and detailed answers of the interviewees can be found in Appendix 14.

According to the Harris Profiles (Appendix 19) and interviews (Appendix 20), it is decided to use **Combination C** (Appendix 18) as the basis of the Roadmap. The separate parts of this combination are presented as Part 2A and Part 2B of the Roadmap.

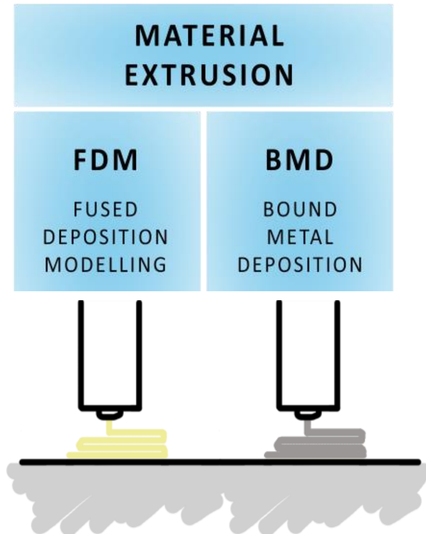


Figure 26: Selected 3D print technologies

EXECUTION	*Is the execution of this solution realistic? Is the quality of the printed parts sufficient?*	All hardware of the chosen combination can be purchased by Layertec, which increases the value of the education prior to using the printer. Also, the users of this combinatuin (Engineers) already have knowledge about CAD Modeling, which works in favor for the execution of this combination.
SAFETY	*Is the solution safe to use? What is the biggest risk?*	This combination works with hardware that both are proven to be safe enough for an office since no powders or high temperatures are included in the manufacture process.
USABILITY	*Is the solution usable for the appointed users?*	According Ultimaker and Desktop Metal the printers are easy to use because of the user friendly interfaces and simplified steps of execution.
COSTS	*How much does the solution cost? What is return of investment?*	Compared to one of the combinations in which only one printing systems has to be invested in (Ultimaker with BASF material, Appendix X), this combination is more expensive on the short-term. The promised success rate however makes this investment less risky.
SUSTAINABLE	*Sustainability beliefs of Heerema*	All combinations received the same score for sustainability since the sustainable impact depends on the printer use.
PLANNING	*Is this solution feasible within the time slot of the Sustainability Roadmap of Heerema?*	This combination is realistic to be implemented within the set time frame since all hardware, software and education can be fixed with one partnership. This advantage will smoothen the process since all lessons learned with the plastic printer can be used in the metal printing phase.

Figure 25: Requirements Harris Profile Combination choice

PHASE 2A:
PLASTIC PRINTING PHASE

During the Plastic Printing Phase, the Engineers use an Ultimaker S5 printer to print plastic parts in the workshop on-board. The decision for this printer is elaborated on in Chapter 2.2. The Engineers will also model the parts they print on-board. Specifications of the Ultimaker S5 can be found in Appendix 21.

Phase 2A exists of three sub-phases: a testing phase, a limited use phase and an expansion phase. The transition from one phase to another happens naturally, depending on the level of adaptation and trust within the crew towards the hardware and quality of printed parts.

BENEFITS/ENABLERS

- Starting with plastic prints is a first step towards metal printing.
- The Engineers and Storekeepers are already part of the vessel crew and therefore this solution does not add people to the current vessel crew.
- Potential of metal prints will be shown by the use of the plastic printer.

DISADVANTAGES/SHOWSTOPPERS

- The Engineers already have their tasks on the vessel, modelling the parts will cost man-hours.
- Education is needed before the project can start.

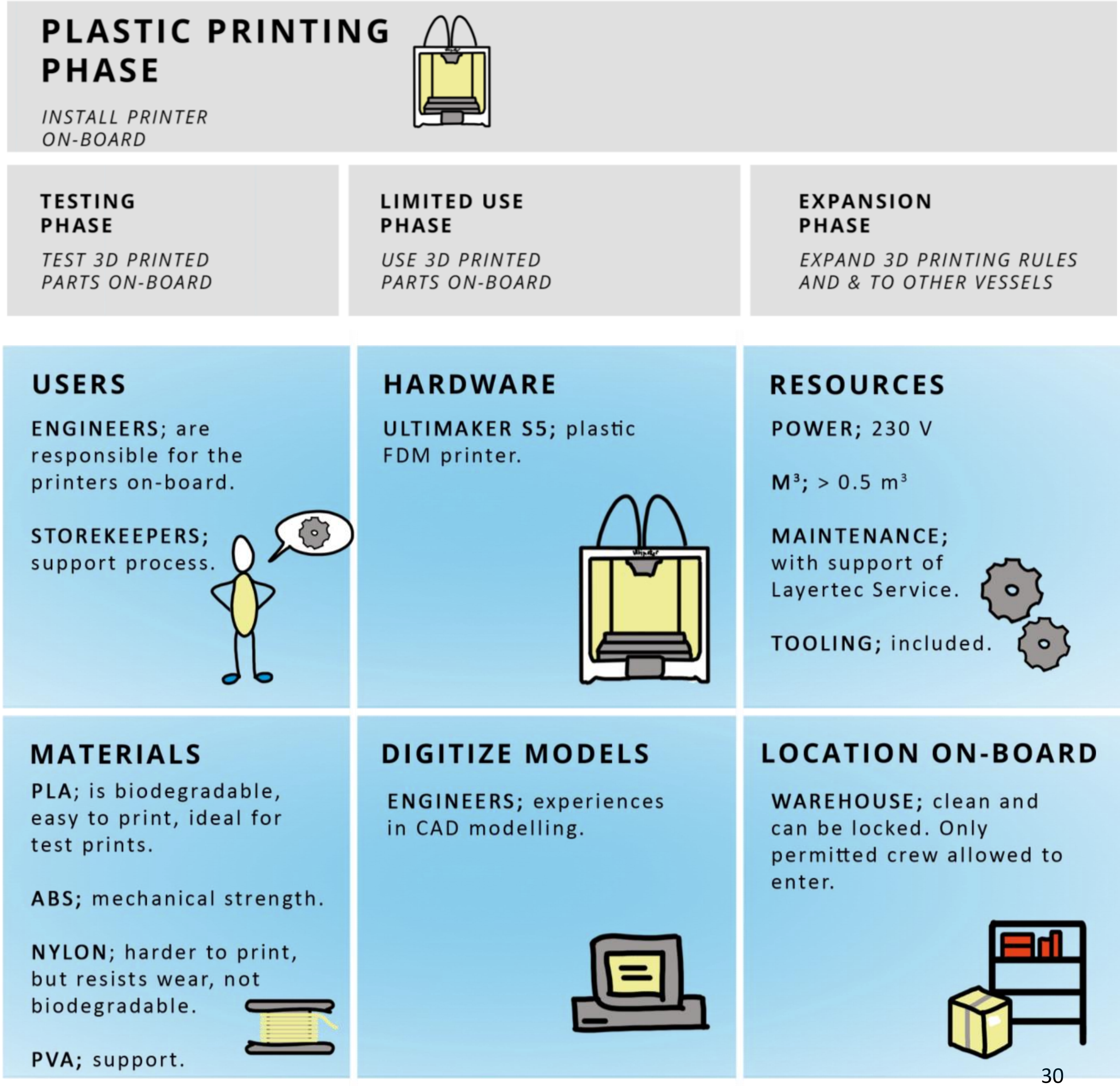


Figure 27: Overview decisions Phase 2A

PHASE 2B:
METAL PRINTING PHASE

After a successful Phase 2A, the step towards metal 3D printing can be made. This means the Engineers will step up to the next level of complexity.
During the Metal Printing Phase, the Engineers use the Desktop Metal Studio System (Figure 29) to print metal parts in the workshop on-board. The decision for this printer is elaborated on in Chapter 2.2. The models of the parts are preferably received from the manufacturer. If this is not possible, the Engineers model the parts on-board. Specifications of the Studio System can be found in Appendix 21.

Just like Phase 2A, Phase 2B exists of three sub-phases: a testing phase, a limited use phase and an expansion phase.

BENEFITS/ENABLERS

- Vessel Crew Members already have a lot of experience with producing parts that will be used on-board.
- The warehouse is a closed area where not all crew members can join.
- The Vessel Crew Members already work on the vessel and therefore this solution does not add people to the current vessel crew.

DISADVANTAGES/SHOWSTOPPERS

- If the manufacturer or supplier does not want to share the digital model, the Engineers have to find another way of modelling the parts.

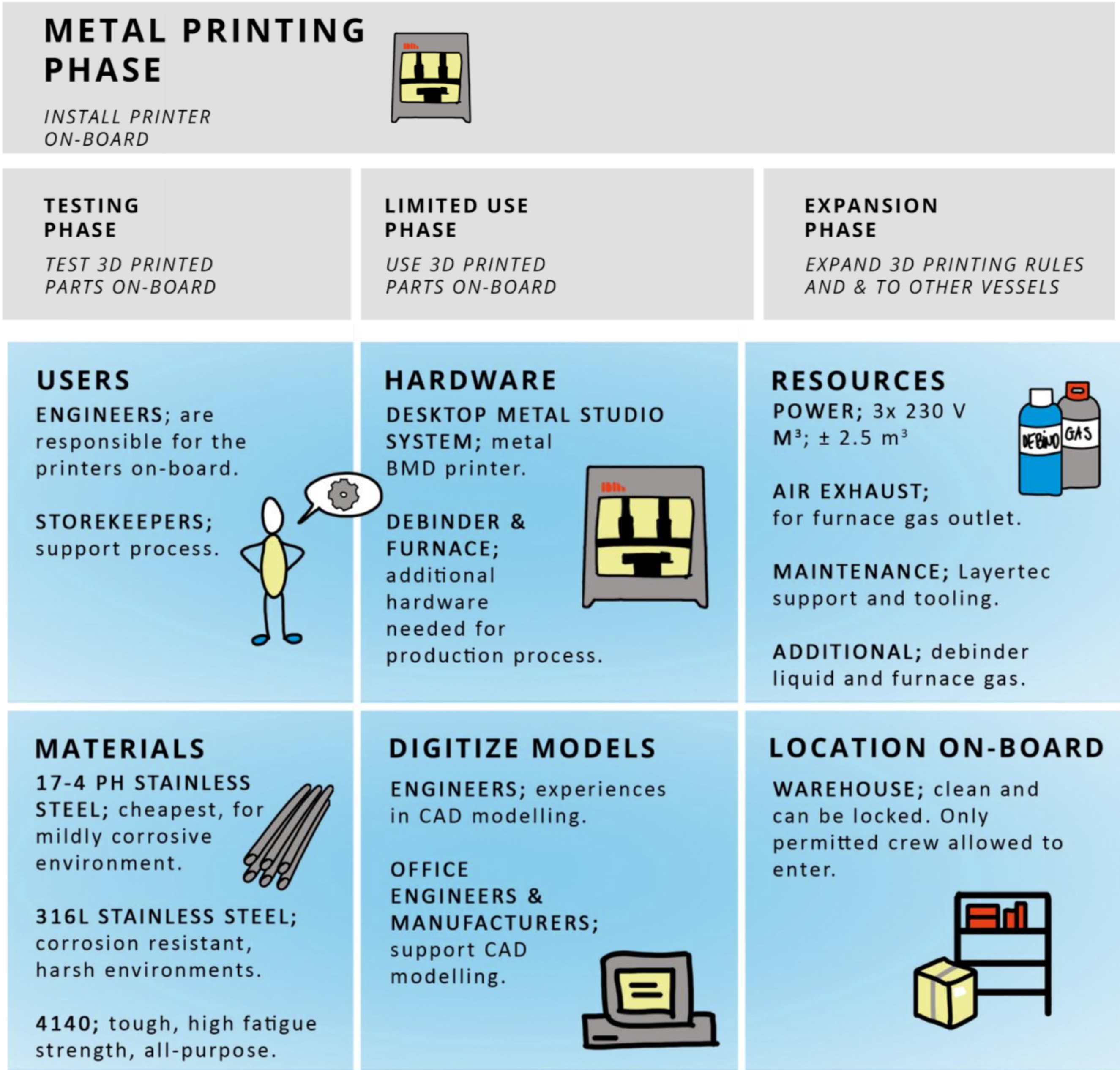


Figure 28: Overview decisions Phase 2B

Figure 29: Desktop Metal Studio System; printer, debinder and furnace (Desktop Metal, n.d.)

ADDITIONAL INSIGHTS PHASE 2

COLLABORATION

Figure 30 shows how the users and stakeholders of the Printing Phase collaborate.

DIGITIZING MODELS

CAD models can be created in a lot of different ways: modelling, 3D scanning, asking the manufacturer for the model or using open resource databases. During the Printing Phase all resources can be used, depending on the part. Based on the possible limitations of modelling a certain part, all interviewees would keep most options open. Because of time, the most preferable situation is the manufacturer having the model available. When the part has to be modelled, Office Leiden could also be approached for support (Strategy & Technology, Simulation).

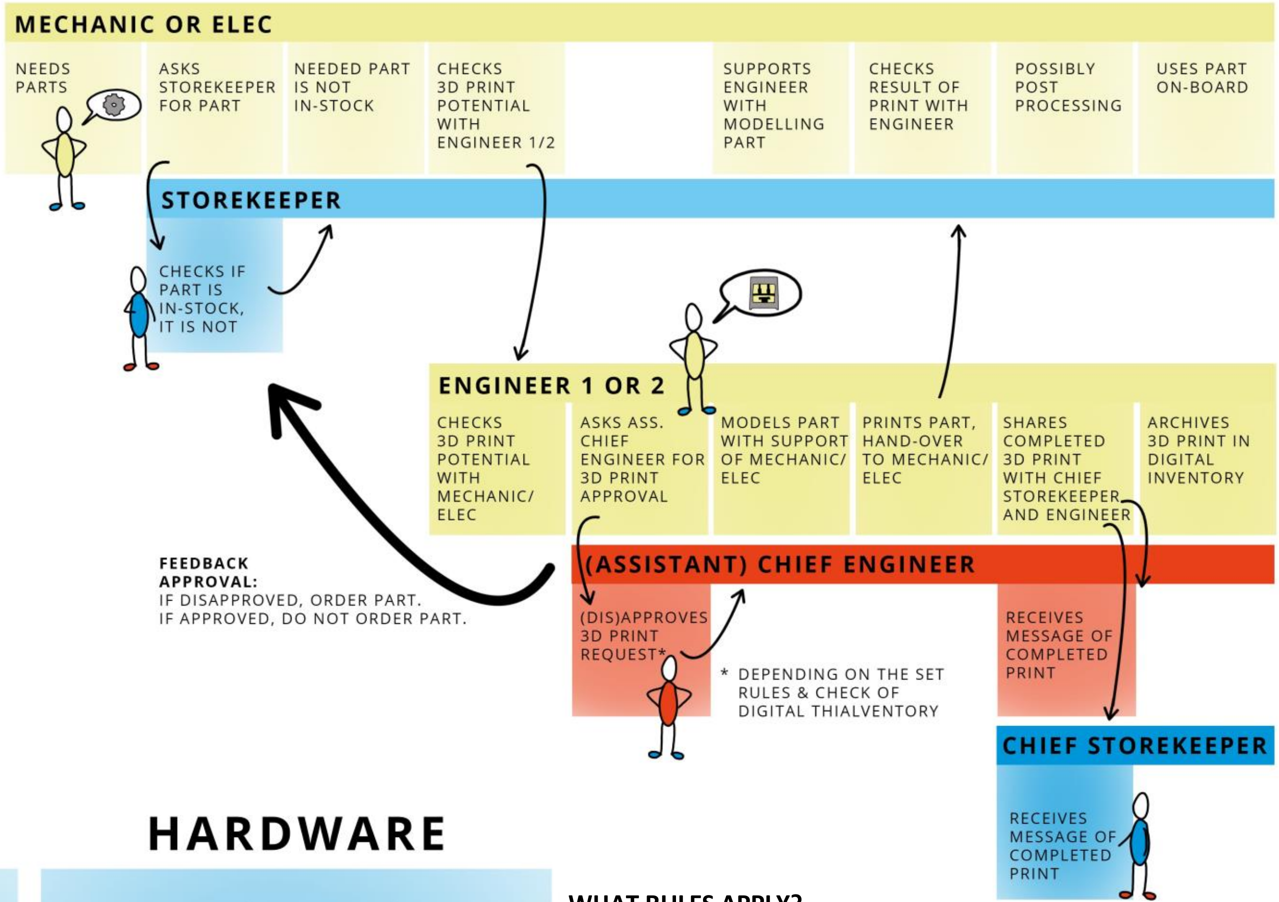


Figure 30: Overview Collaboration users and stakeholders

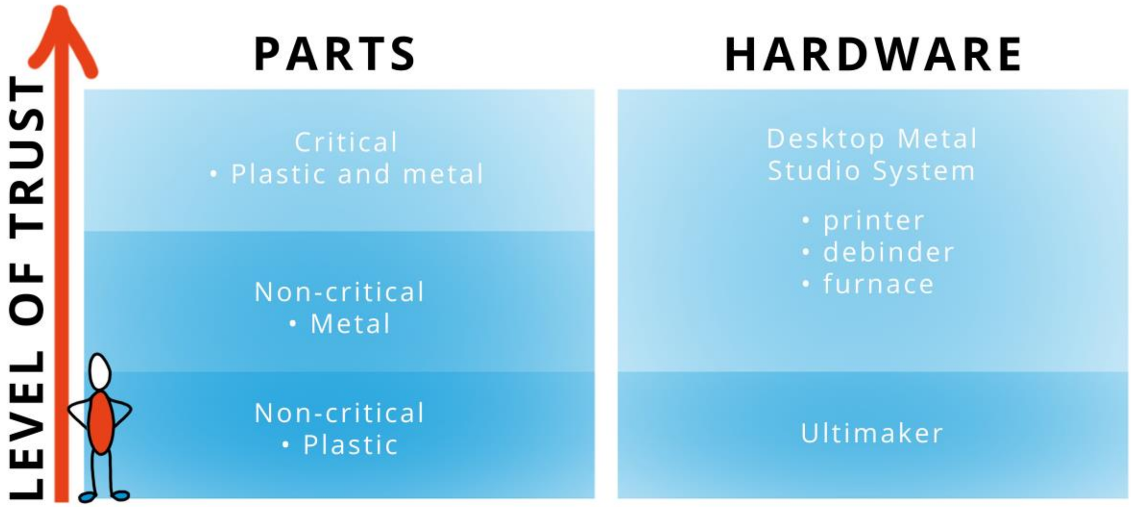


Figure 31: Principle of basic rule

WHAT RULES APPLY?

As can be seen in the collaboration figure, approvals are needed. This means the one approving also is accountable. Therefore rules are needed. The basic rule is based on Figure 31: only if the crew trusts the parts they print, the parts will be used. Additionally, only if the crew is ready to go to the next level of complexity, this next step will be made in terms of parts and hardware. All interviewees agreed to using a system that is already well developed so the quality of the prints would increase the adaptation of the crew. Most of the interviewees agreed with starting the implementation of 3D printing with a plastic printer.

KEY METRIC OF SUCCESS PHASE 2

The set goals are important to clarify why the Printing Phase is executed. Question is; when are these goals achieved? To answer this question, a key metric of success is set. According to DNV GL, the three key enablers for future spread 3D printing in the Oil, Gas and Marine sectors are (DNV GL, n.d.):

- Convince potential users of the benefits.
- Boost trust in 3D printed parts.
- A growing number of success stories to spur general acceptance.

Based on these enablers, the following variables are defined as Key Metric of Success:

KEY METRIC OF SUCCESS

- TRUST
- ADDED VALUE
- DEVELOPMENTS METAL QUALITY
- PARTNERSHIP LAYERTEC

TRUST

When it comes to trust, certification is key for any application of 3D printing with acceptable risk (DNV GL, n.d.), therefore Lloyds and DNV have to be taken into the process of setting up test facilities that proof the quality that is needed.

ADDED VALUE

According to the research conducted, the benefits of placing the 3D printer will be clear, the result of it has to be validated by the crew of the vessel.

DEVELOPMENTS METAL QUALITY

The 3D printers are improving quickly. This growth will drive the change since opportunities open up and limitations vanish.

PARTNERSHIP LAYERTEC

As soon as the partnership with Layertec works well, which means the needed support can be delivered, the collaboration can be seen as a success. If the way of supporting does not fit the execution of the work offshore, other options have to be looked into.

EXIT POINTS/SHOW STOPPERS PHASE 2

It is important to keep the possibility of exiting the 3D printing project open, in case it does not create the added value that is expected. Reasons not to execute phases are collected in Appendix 11. These reasons are translated to risks. Risks that could occur when implementing innovation in an organisation according Luenendonk (2017), are: technological failure of the innovation, financial strain, market failure, redundancy, lack of capacity for implementation, organizational risks and unprecedented risks. Based on these risks, the following exit points are implemented in the Roadmap (Figure 32):

1. Safety or health related problems occur.
2. Client refuses to use machines/assemblies with printed parts.
3. Plastic parts are not being used.
4. There is no need to prints parts in metal.
5. Warranty related problems occur.

Appendix 22 recommends Heerema how to react when a situation occurs that might lead to stopping the project.

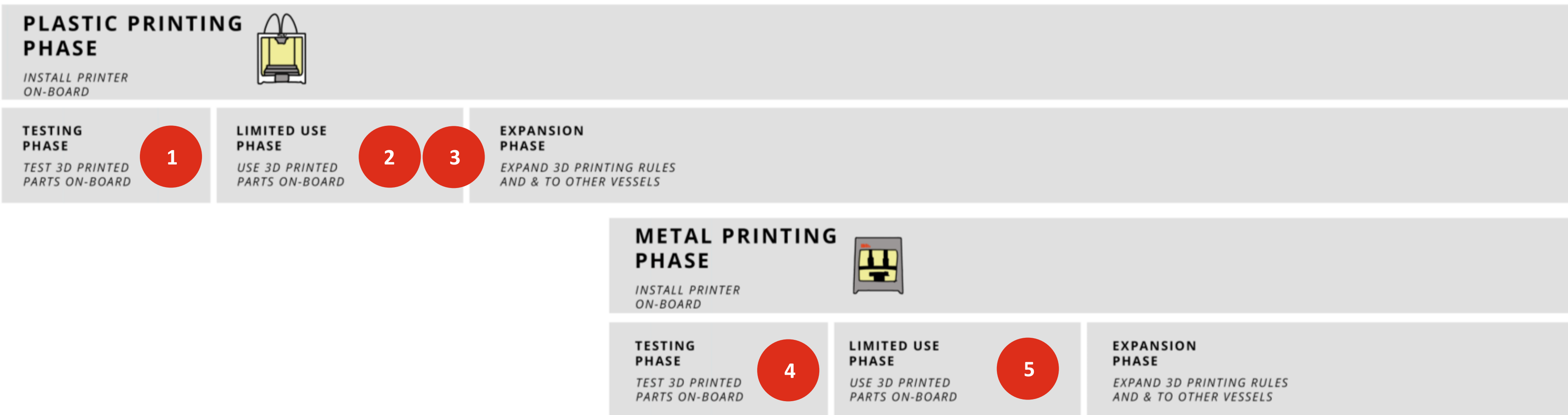


Figure 32: Exit points Roadmap

PHASE 3:
THE OPPORTUNITIES PHASE

Phase 3 is the phase that presents the long term opportunities. It starts once Phase 2A, the Plastic Printing Phase, has been kicked-off. This Roadmap continues along the developments of both Printing Phases. After the success of the Plastic and Metal Printing Phase, the Roadmap still continues and has the potential to be expanded with new ideas. It is recommended to take action on the opportunities of Figure 33, to increase the value of 3D printing on-board of the vessels. The opportunities are presented in three categories: materials, 3D print technologies and other opportunities.

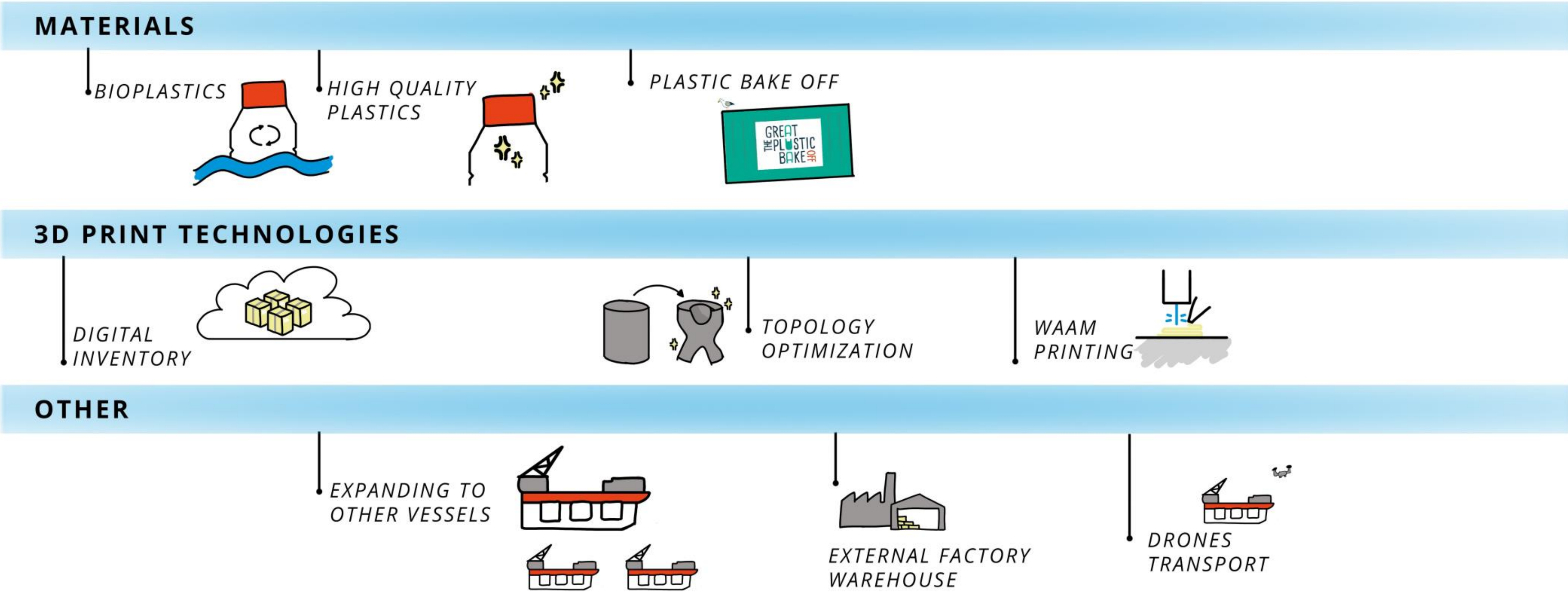


Figure 33: Long term possibilities Roadmap

MATERIALS

BIOPLASTICS

To reduce the sustainable impact of the plastic printed parts, bioplastic can be introduced. Leiden Office already uses PLA, a biodegradable polymer. These materials are especially useful for test parts that will be used only once. Using bioplastics reduces the carbon footprint of the vessel and projects.

HIGH QUALITY PLASTICS

Once the prints with common polymer materials succeed, Heerema could look into materials of high quality. Carbon fibre is a great example of a material that is very stiff and could possibly replace metal in some of the parts as well.

PLASTIC BAKE OFF

An initiative to recycle plastics on-board, mentioned by Marius Ottolini from the Strategy and Technology department. The phases of the Roadmap should integrate with the Plastic Bake Off.

3D PRINT TECHNOLOGIES

DIGITAL INVENTORY

All data gathered about the parts has to be stored in a cloud-based store. After a certain period of using the printers, a digital inventory will grow.

Once there is a digital catalogue with parts, there could be a shift in users. The storekeepers would be the ones that could also start the 3D printer, since the modelling phase is not needed anymore (Rene van der Linde, Appendix 14). Having a store with mostly materials instead of parts could be a next step, once all parts are digitally available.

TOPOLOGY OPTIMIZATION

Topology optimization methods solve a material distribution problem to generate an optimal topology. It is usual for each finite element within the design domain to be defined as a design variable, allowing a variation in density or void-solid (Brackett, Ashcroft, & Hague, 2011).

Simulation-driven topology optimization aids in the creation of structures with minimal mass and maximal stiffness (3D Hubs, n.d.).

Figure 34: Topology optimized metal part (Brackett, Ashcroft, & Hague, 2011)

WAAM PRINTING

As already mentioned, Huisman conducted research on the 3D print technology called WAAM. Taking the success of this project into account, Heerema could consider applying this technology in her organization. It is recommended to get in touch with Ramlab (Ramlab, n.d.) for this opportunity, since they focus on manufacturing large metal parts on demand using Wire Arc Additive Manufacturing (WAAM).

OTHER

EXPANDING TO OTHER VESSELS

As soon as the Plastic Printing Phase at the Thialf is successfully completed, the other vessels of the Heerema fleet can get plastic printers on-board as well. The systems, as proven to work during the Plastic Printing execution, will be installed on-board to be used for the plastic prints according the set rules. After expanding the 3D print plastics, Heerema can continue with expanding the Metal Printing Phase to other vessels as well.

EXTERNAL FACTORY WAREHOUSE

3D Printing can also be implemented on-shore. By placing printers in warehouses, Heerema creates their own factories that can be globally connected. By printing in these 'factories', it is possible to use 3D print techniques that are not safe to use on board: welding and powder. For this idea, the **Production System** of Desktop Metal is suitable since it can be used for mass production of metal parts (Desktop Metal, n.d.).

Figure 35: Desktop Metal Production System (Desktop Metal, n.d.)

DRONES TRANSPORT

Vincent Mullenders graduated on the transportation of parts with drones from shore to vessels. This idea has potential to be used in combination with 3D printing since it the project is in line with decreasing transports from and towards the vessel.

CONCLUSION PHASES

Figure 36 shows a complete overview of all phases of the Roadmap. The overview includes the users and stakeholders, locations, hardware and software as explained. For setting-up the Roadmap, the research of Kim, Beckman and Agogino (2018) is used. The design process of the complete Roadmap can be found in Appendix 23.

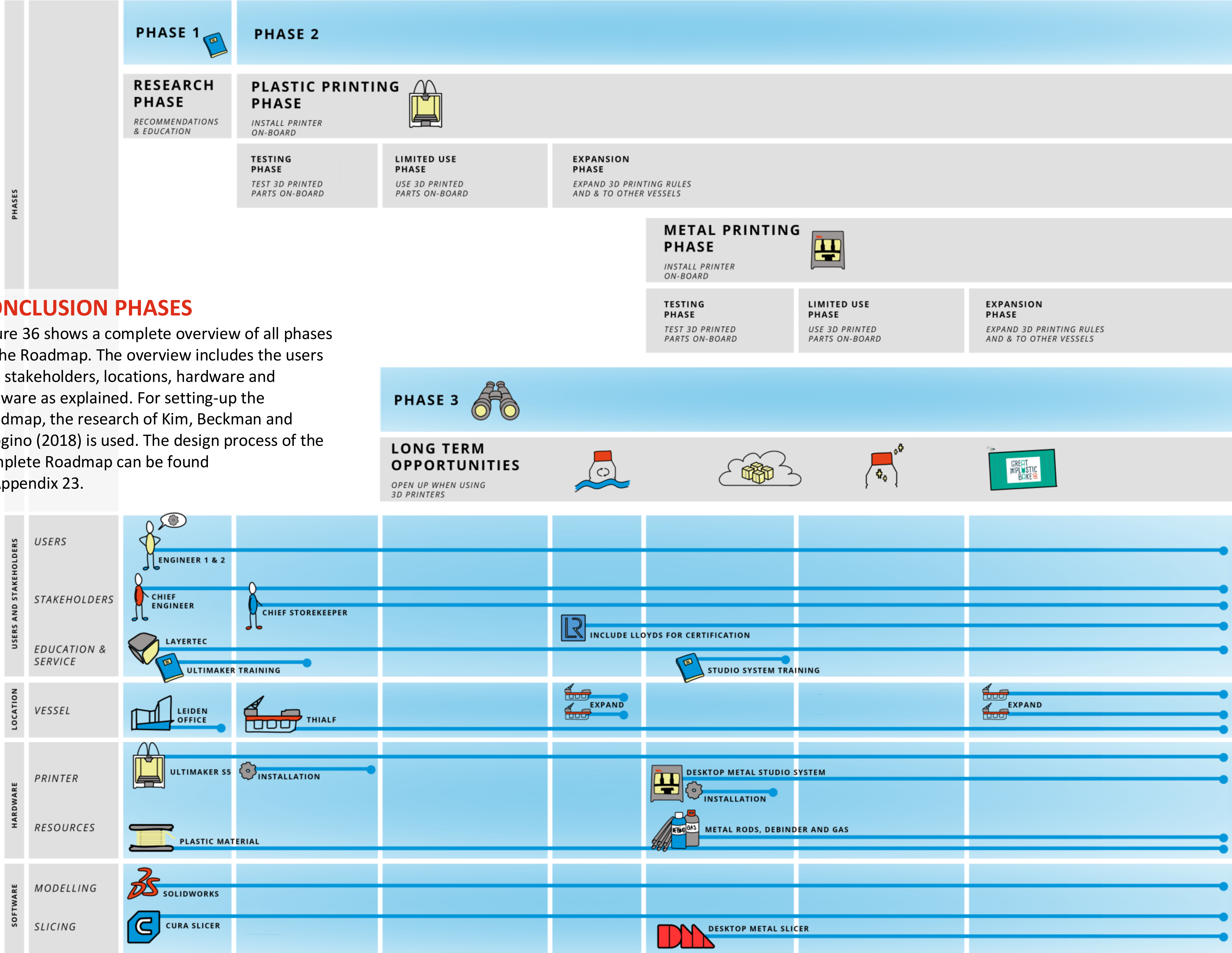


Figure 36: Roadmap implementation 3D printing at Heerema vessels

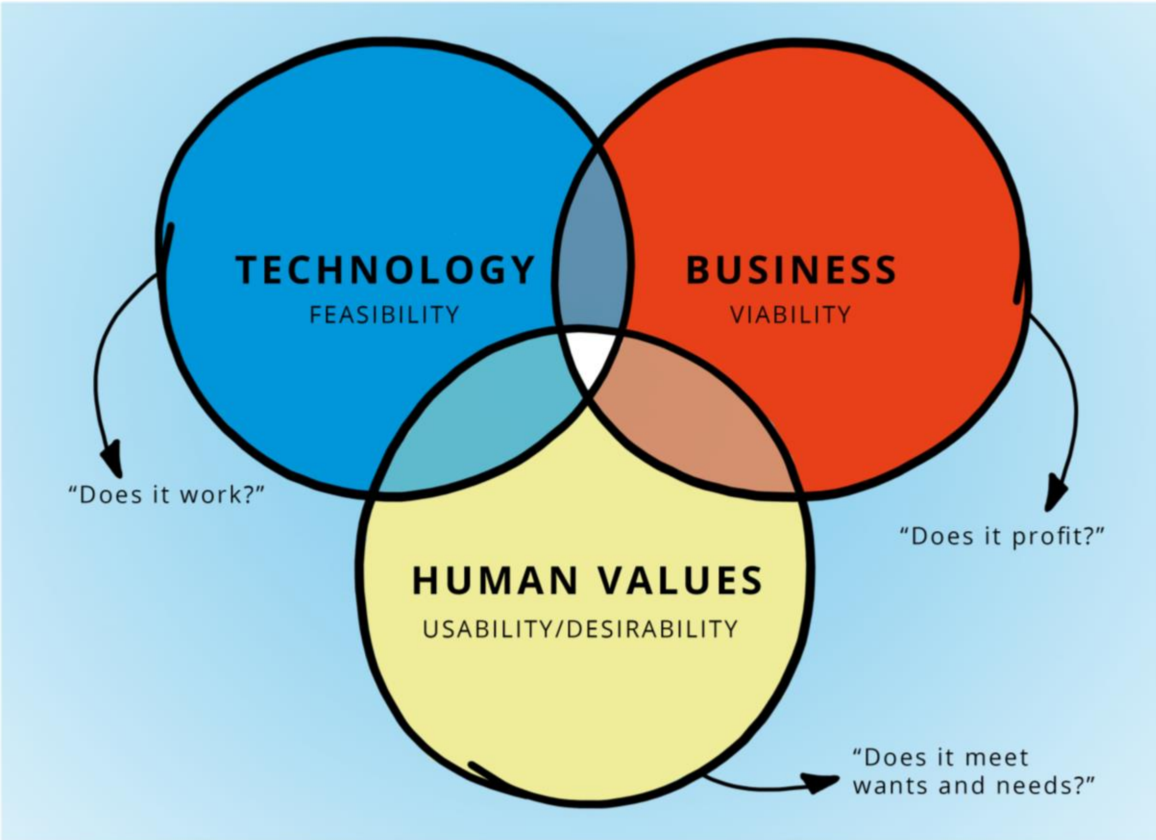


Figure 37: Three aspects of Industrial Design Engineering domain

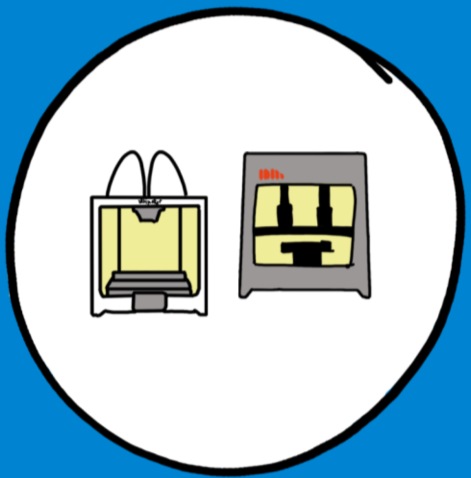
2.2 FEASIBILITY, VIABILITY AND DESIRABILITY

This chapter explains why the proposed solution leads to the preferred situation by assessing the solution according the three aspects of the Industrial Design Engineering domain: Technology, Humans Values and Business (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). These three aspects (Figure 37) show why the presented solution is the most valuable recommendation.

Figure 38: Thialf at Calandkanaal Rotterdam

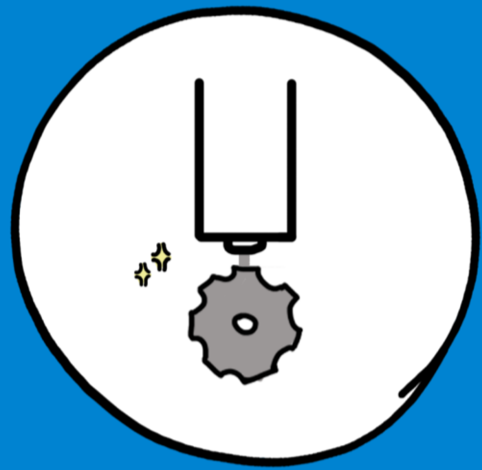
FEASIBILITY

TECHNOLOGY; Does it work?

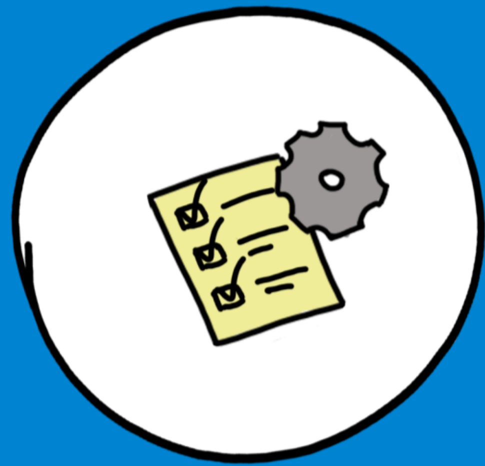


1. HARDWARE WORKS

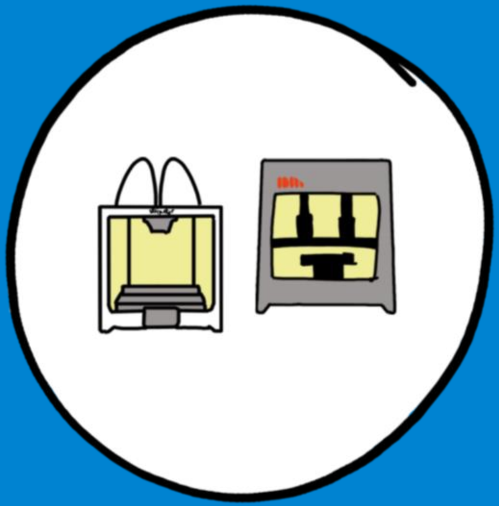
2. PARTS AVAILABLE



3. PRINTABLE PARTS



4. SUFFICIENT QUALITY



1. HARDWARE WORKS

To proof feasibility, it is explained why the Ultimaker S5 and studio system are selected. Additionally, practical examples proof the feasibility of the chosen hardware.

WHY THE ULTIMAKER S5?

The Ultimaker S5 is proposed, because of the following reasons (also see Appendix 21):

- It has a build volume creating the possibility to print parts within the range of 330x240x300 mm.
- It has the possibility to print carbon fibres.
- The print environment can be closed to prevent it from for example, dust and salt.
- Appendix 24 explains why the vessels will not use the same Leapfrog printer as used in the Leiden Office.

WHY BOUND METAL DEPOSITION?

It is decided to focus on metal 3D printing as final goal, the 'next step' once plastic succeeded. The technology and knowledge are less advanced compared to plastic printing, and therefore a bigger challenge to figure out the added value.

With the benefits and limitations provided in Appendix 25, it is decided to use the technique based on material extrusion named **Bound Metal Deposition** for the following reasons (Rejto, 2020):
1. The big advantage of this 3D printing technique is the absence of metal powder. These kinds of powders are highly flammable and require specified staff to clean the machines.
2. Next to that, the materials that can be applied in this printing system are broad and in development.
3. To use this printer, no tooling is involved which saves a lot of time compared to the other printing techniques.

HOW DOES IT WORK?

Bound Metal Deposition, or BMD, is based on the same material extrusion principle as the plastic Fused Deposition Modelling technology used in the Ultimaker. Metal components are constructed by extrusion of a powder-filled thermoplastic media: bound metal rods. These rods are build out of metal powder that is held together by wax and polymer binder. This material is extruded out of the printing heads to form a model layer-by-layer. Next to that, with BMD, the metal material is debinded to remove the polymer binder and then sintered to densify the metal particles. The steps of the BMD process are shown in Figure 39.

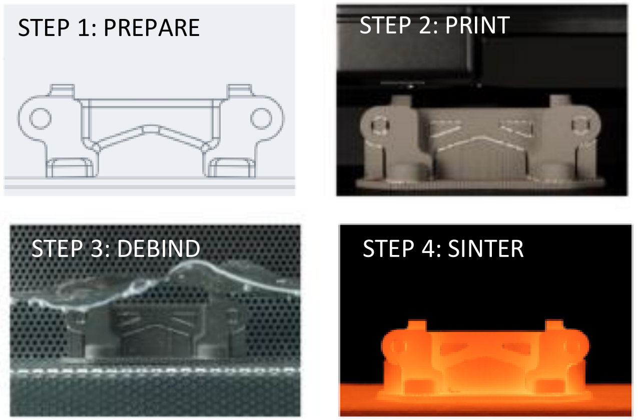


Figure 39: Steps of BMD process (Desktop Metal, n.d.)

This technology uses metallic alloys such as stainless steels, tool steels, but also other metals such as refractory metals, cemented carbides and ceramics (Manufactur3d, 2018).

WHY DESKTOP METAL?

The system that is most suitable for Heerema is the Studio System of Desktop Metal. According to Desktop Metal this system has the following unique selling points (Desktop Metal, n.d.):
Globally available: even located in the Netherlands.
Safe for the office: Studio System can be used in an office like environment because of the elimination of lasers and loose powders.
Easy to use: with the integrated software that automates the process, it is easy to print parts.
Built to scale: the system enables scalable throughput for low volume production.
Other BMD systems are discussed in Appendix 25.

EXAMPLES BMD

There are examples that verify the Bound Metal Deposition printing technique and show that the Desktop Metal Studio System produces sufficient quality.

OKINAWA MARINES

The Okinawa Marines already printed plastic parts on-board for the last five years. In December 2019 they installed the Metal X 3D printer (Burke, 2020). This printer uses the Bound Metal Deposition method (Mark3D, n.d.). The benefits that are expected with the introduction of this printer include increasing number of free man-hours, save money on waste and avoid downtime (Burke, 2020). On-board, the Marines design their own parts by using SolidWorks, a design software. Some parts can be downloaded from the internal Marine Corps System.

Figure 40: Okinawa Marines example BMD (Burke, 2020)

MASTER DRILLING

According to Layertec (Layertec, 2019) the company Master Drilling printed a gear for a soil drilling machine for mining. This gear got hardened afterwards. This part normally had to come all the way from Japan, now they can print it themselves.

Figure 41: Master Drilling example BMD (Layertec, 2019)

UHT ATOMIZER FOR LNG TANKER

One of Desktop Metal clients used the Studio System to print a AHT Atomizer that is used in a marine burner for steam propulsion boilers on LNG tankers. They redesigned the atomizer to improve the performance. (Rejto, 2020).

Figure 42: UHT Atomizer example BMD (Layertec, 2019)

AFTERMARKET ORDER WITHOUT TOOLING

Another example in the marine sector is from an American Navy ship. With the Studio System they printed a yolk and handles for a safety shut off device. Both parts are officially installed at the ship (Rejto, 2020).

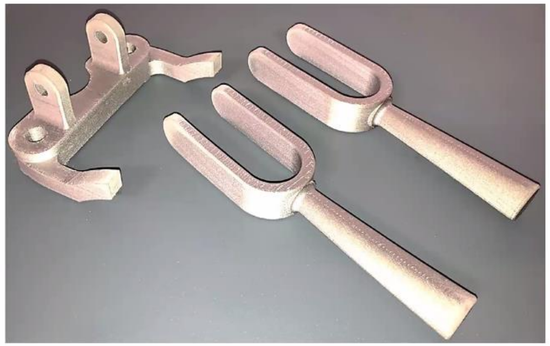


Figure 43: American Navy example BMD (Layertec, 2019)

2. PARTS AVAILABLE

To use a 3D printer, printable parts are needed. To select these parts, a paper and field study are conducted. To quantify ‘printability’, design rules are discovered during a print study.

PART SELECTION

According to the paper and field study conducted in the Discover Phase of the Project (Appendix 26), the vessels of Heerema have parts available that can be produced with 3D printing due to their geometry and application (Appendix 27). The Lever and the Worm Wheel Gear are selected to be used for the design study (Figure 44).

FIELD STUDY

To conduct the field study, a physical visit to the warehouse of the Thialf is executed. For this study the following filters were applied to the parts list:
Filter 1. Geometry study warehouse
Filter 2. Layertec check
Filter 3. Application check
Filter 4. Cost comparison

PAPER STUDY

To substantiate the field study, a paper study is executed. For the paper study, the following filters are applied to the spare parts list:
Filter 1. Thialf
Filter 2. Non printable stores
Filter 3. Non printable parts
Filter 4. Categories warehouse

Some of the filters mentioned are based on the factors that should be considered while selecting an optimal 3D printing process according to Gokuldoss (2017).

NAME	DESCRIPTION HANS HAVERMANS	PRICE	SIZE (cm)	LAYERTEC
Lever and Bush	This is a part of the MAK head engine. With the equipment of which this part is part, you can control an electrical shut down of the Main Engine.	$192,40	3*4*5	Yes, this can be printed. Depending on the dimensions of the part and the build volume of the printer.
Worm Wheel Gear	This part is a gearbox gearbox for a Shimadzu / Rotork Motor Operated Valve that controls the ballast water pump	$1319,69	12*12*12	Yes, this can be printed. Depending on the dimensions of the part and the build volume of the printer.

Figure 44: Lever and Worm wheel gear original part

PRINT STUDY BOUNDARIES

To quantify the 'printability' of parts, a design study is conducted. The goal of this design study was discovering the boundaries of the selected printing system of Desktop Metal, since this printing method is less known then FDM.
In aerospace design, a framework of boundaries is used to select an appropriated design. To discover the boundaries of this design brief, and show the employees of Heerema to what extend metal can be printed, the model of a M56x320 bolt was send to Layertec.

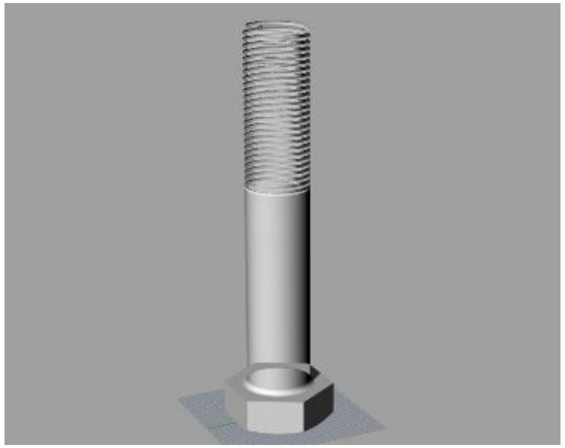


Figure 45: M56x320 Bolt CAD model

Next to the fact that the size of this part will push limits of the Studio System, the decision to choose the bolt is based on two factors: this part will be recognised and impressing. The bolt is big, but on-board it is not. All Heerema employees know this part well since it is so commonly used.

During the design study with the M56x320 bolt, it turned out the design was exceeding the boundaries of the system (Appendix 28). That is why it is not printed. However, the attempt was a great way to discover the following boundaries of the system that quantify printability:

DESIGN RULES

Design Rule 1. Solidness

If the part is completely solid, the time in the debinder increases since the liquid has to get to the centre of the shape.

Design Rule 2. Size

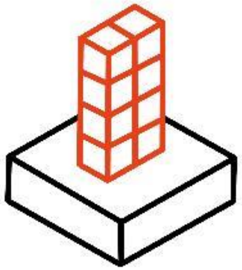
The maximum size of the printed part is 20x30x30 cm because of the size of the printer itself.

Design Rule 3. Materials

The Studio System can print different types of meta: 17-4SS, 316L SS, H13 Tool Steel and 4140. Alloy625 and Copper are still in development.

Design Rule 4. Aspect Ratio

The parts printed by the Studio System have an aspect ratio of 1:8. This means that if the height increases by factor 2, the width has to increase by factor 8. Deviating from this ratio is possible when increasing the about of print support (3D Hubs, n.d.).



Design Rule 5. Time

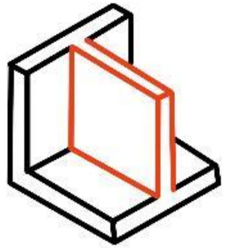
Every part has to be in the debinder 38 hours and be in the furnace for 44 hours. This is a sum of 82 hours, which can be seen as 3,5 days.

Design Rule 6. Costs

The support material has a big impact on the price of printing a part. Support can be easily decreased by using for instance organic shaped structures that support itself.

Design Rule 7. Wall Thickness

The wall thickness of the part has a limit that depends on the printhead. The printheads are available with a standard resolution of 400 micron or a high resolution of 250 micron. In Metal Extrusion, parts should always have a consistent wall thickness (preferably, smaller than 10 mm). If this is not the case, then the time needed to fully de-bind and sinter the parts can increase by several hours (Desktop Metal, n.d.). Especially in the 'Green state', between printing and Debinding, the parts are most fragile. A thicker wall reduces the probability of breaking (3D Hubs, n.d.).



Design Rule 8. Fillets and edges

Another detail is the **fillet** of the sharp edges of the part. To get a nice printing result the fillet should at least be 0.5 mm. Eliminate overhang by adding a 45 degree chamfer (3D Hubs, n.d.).

Design Rule 9. Application
If the application of the part requires a high material density, because of a vacuum application for example, the Studio System printing method is not suitable since the printing pattern gives the solid parts a textured lay-out which makes it brittle.

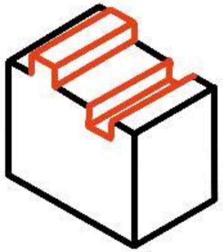
Design Rule 10. Positioning
While the part is in the oven, it will shrink. This means the shape of the part will change. If a cylinder is put in the oven on its side it will become an oval.

Design Rule 10. Weight
The total weight of the parts per print-shift, has a limit of 3 kg. This limit is set by the furnace.

Design Rule 11. Post Process
It is possible to post-process the parts that are printed in the Studio System, possibilities are (see Figure 46):

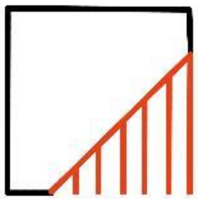
1. Plating
2. REM Super finish, REM is an isotropic finish method
3. REM Surface treatment
4. Welding parts together

Design Rule 13. Details
The minimum detail size depends on the size of the nozzle, which is this case has two options: standard resolution of 400 micron or a high resolution of 250 micron.



Design Rule 14. Support
Support could be needed to support the model, like FDM printing. With BMD, support is also needed for the sintering step. According to 3D Hubs “at these very high temperatures, the metal material becomes soft and pliable and may collapse under its own weight.” (3D Hubs, n.d.)

Design Rule 15. Maximum Overhang
Because of the layer-on-layer building technique, a maximum overhang of 45 degrees is allowed. If the overhang increases, more support might be necessary (3D Hubs, n.d.).



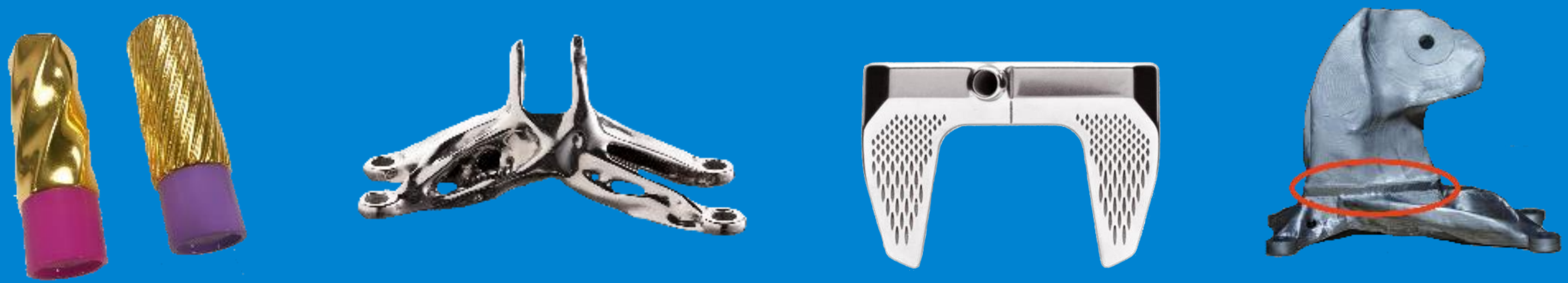
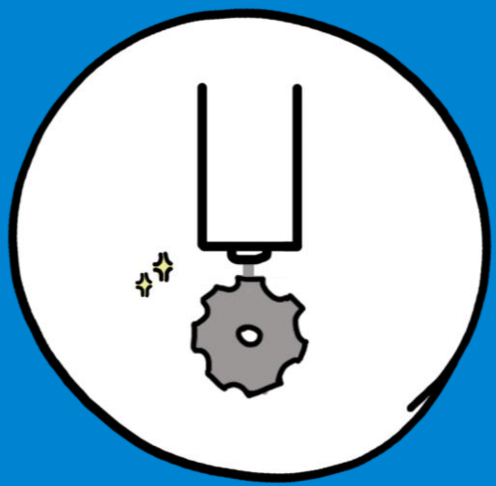


Figure 46: Post-processing options Studio System parts



3. PRINTABLE PARTS

To research the quality of the printed plastic and metal parts, several print studies are conducted with plastic and with metal parts.
The metal printed parts are tested with a tensile and hardness test at the TU Delft.

PRINT STUDIES OVERVIEW

The following print studies are executed:

- **Plastic Printing Phase**
  Plastic print study: the main goal is trying the printability of one of the plastic parts on-board.

- **Metal Printing Phase**
  Plastic print study: the main goal is trying the printability of the selected parts (lever and worm wheel gear).

  Metal print study: the main goal is combining knowledge and experience from all design studies to print a metal proof of concept with selected parts (lever and worm wheel gear).

USED PRINTERS & SOFTWARE

The following printers, modelling software and slicer programs are used for conducting the studies
Printers
Plastic: Leapfrog
Metal: Studio System, Desktop Metal
Modelling Software
Rhinoceros, SolidWorks and 3D Max
Slicer programs
Desktop Metal and Simplify3D

PLASTIC PRINTING PHASE - PLASTIC

To proof the printability of plastic parts, the part as shown in Figure 47 is 3D printed (Appendix 29). As Figure 48 shows, the model is not yet ready for use because of design differences. Also, this part is not tested on mechanical properties. However, the design study shows that a part like this can be printed with a FDM printer.

Figure 47: Plastic Part in Thialf warehouse

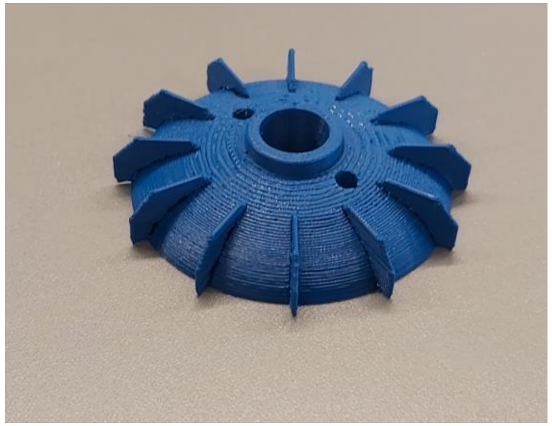


Figure 48: 3D printed plastic part

METAL PRINTING PHASE - PLASTIC

As mentioned in 'Part selection', two parts are selected. To test the printability of both parts, it was decided to print them in plastic at the Leapfrog printer at the Leiden Office. Both parts are modelled in Rhinoceros with the content gathered during the field study on-board of the Thialf. The process of modelling, slicing and printing gave the following useful insights:

Worm Wheel

After modelling the part in Rhinoceros, a first check is done by placing the CAD model in 3D Max. After fixing some 'Open Edges' in de CAD model, it is put into the Slicer program. Half of the size is printed to first validate the CAD model. As can be seen in Figure 49, the first print (on the right) did not turn out well at the bottom surface. The second print is an improved model and modelled with the use of 3D Max. As can be seen, the details of this model are improved compared to the first try. The second print proofs the printability of the CAD model and will therefore be printed in metal.

Lever

The first print is printed half the size with a 3D Max model. As can be seen in Appendix 30, these models contain some failures that were solved in Rhinoceros. The second print is true size and done twice: a print with a 3D Max model and a print with a Rhinoceros model. The difference between those two programs is the way they combine shapes: 3DMax combines the whole shape as a mesh, whereas Rhinoceros combines the shapes with a numerical formula of vectors. The second print proofs the printability of the CAD model and will therefore be printed in metal.

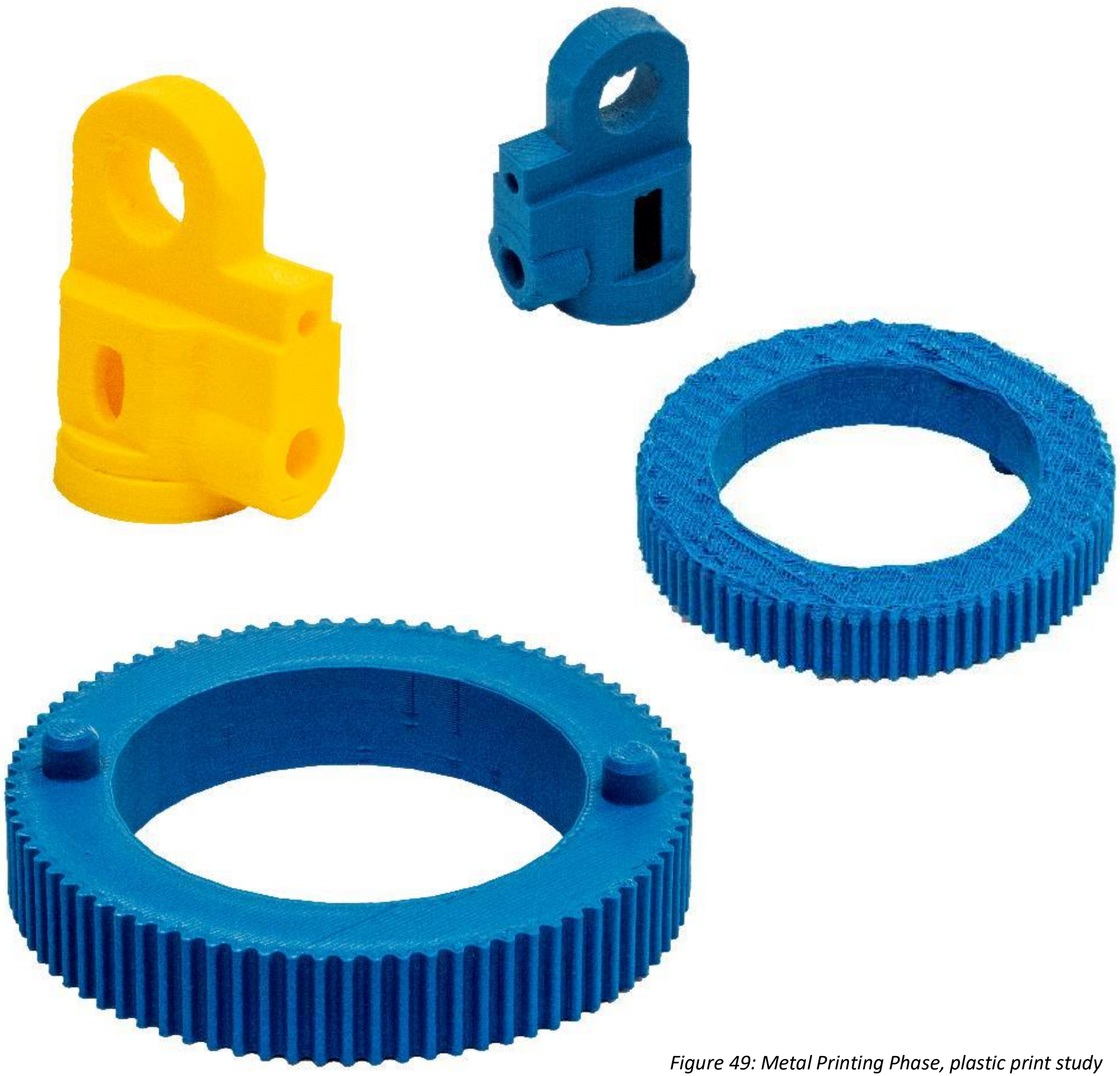


Figure 49: Metal Printing Phase, plastic print study

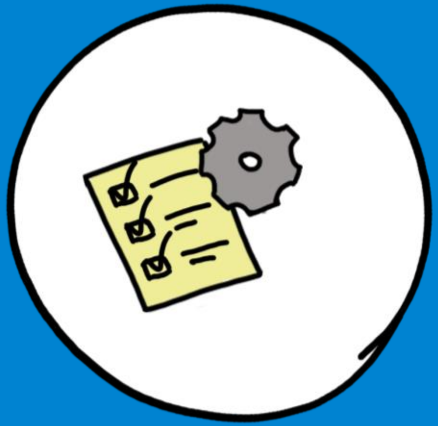
METAL PRINTING PHASE - METAL

As mentioned, both parts are printed in metal to proof the concept of metal 3D printed parts. The Studio System of Desktop Metal can best be used for parts that are hard to manufacture with the traditional techniques like CNC milling and casting, which makes both parts (next to its printability proven in the plastic print) well suited. Together with Layertec both selected parts from the Thialf Stores are printed to proof the printability to Heerema. The print setting of this process can be found in Appendix 31. Pictures of the metal printing process (green parts) can be found in Appendix 32.

As can be seen in the pictures, the gear has 4 cracks. Layertec got in touch with the Engineers of Desktop Metal and they explained this failure as follows: the crack is due to the shrinkage of 20% that happens during the sinter process. The ceramic layer, that prevents the part sticking to the support bed, was too thin. After sticking to the support bed, the part started to shrink. Shrinking put load on the part and because it got stick to the bed, it started to crack.

The lever turned out to be printed very well, to improve it some post-processing could be done.

Figure 50: Metal Printing Phase, metal print study



4. SUFFICIENT QUALITY

To substantiate the Roadmap, the 3D printed parts are reviewed to validate a certain quality. The following types of validation are looked into:

geometry, tensile strength, hardness, literature and expert reviews.

To get an idea of tolerances, the geometry of the original and 3D printed parts is compared. Next to that, the 3D printed metal parts were tested on their tensile strength and hardness. The results of these tests provide a basis for the Roadmap, since it sets a starting point: what is technology capable of now and how to move forward from this point?

To provide additional information, besides testing, results of literature research and expert reviews are mentioned in this chapter too.

GEOMETRY

As can be seen in Figure 51, the printed parts appear to have the geometric basic shape of both original parts. The detailed dimensions of the parts are not equal. During the field study of the part selection in the Discover Phase, the potential printable parts were photographed with measurements. For this method a tolerance of 2cm has to be taken into account.

3D PRINTED GEAR
17-4 PH Stainless Steel

ORIGINAL GEAR
Bronze

3D PRINTED LEVER
17-4 PH Stainless Steel

ORIGINAL LEVER
Bronze

Figure 51: Printed and original Lever and Gear

MECHANICAL PROPERTIES TEST

A hardness and tensile test are conducted to investigate the mechanical properties of the parts. To prepare for these tests, samples were made from the metal printed gear and the original gear. For both tests, sample 3 and 4 of the bronze and 3D printed gear are used. To execute the tensile test, the gear is used. Because of the geometry of the lever, this part was not suitable. The width of the part did not fit in between the clamps of the test equipment and would lose its dimensional stability if the part got sliced. To execute the tensile test, the gear is divided into four pieces (Figure 52). The small and big part are used as the two test samples. For the original, bronze gear, the same division is applied with a tolerance of 0.5 cm.

Figure 52: Original and printed gear sliced into four samples

TENSILE TEST

The tensile tests for this project are executed in collaboration with Mascha Slingerland at the Applied Labs of the Faculty of Industrial Design and Engineering at the TU Delft.

Tensile testing is a fundamental material test where a sample is subjected to a controlled tension until failure. The properties that can be measured with this test are: *tensile strength, breaking strength and maximum elongation and reduction*. Using those properties, the following additional properties can be calculated: *Young's Modulus, Poisson's ratio, Yield strength and strain-hardening characteristics* (Joseph, 2004).

Finally, to calculate the Young's Modulus, the following equation is used, based on Hooke's Law. Which can be used to calculate the stress and strain with the following equations:

$E = \sigma/\varepsilon$

E = Young;s Modulus (MPa)
σ = *stress* (N/m^2)
ε = *strain*

$\sigma = F/A$

σ = *stress* (N/m^2)
F = force (N)
A = intersection (m^2)

$\varepsilon = \Delta L/L0$

ε = *strain*
ΔL = *elongation (m)*
L0 = starting length (m)

Which results in the values presented in Table 1 and Figure 53 (Appendix 33 for more details).

Table 1: Young's Modulus test samples tensile test

Sample	Young's Modulus	Graph Colour
Sample 4 3D	269.28 MPa	Red
Sample 3 3D	883.44 MPa	Green
Sample 4 Bronze	459.97 MPa	Blue
Sample 3 Bronze	921.23 MPa	Orange

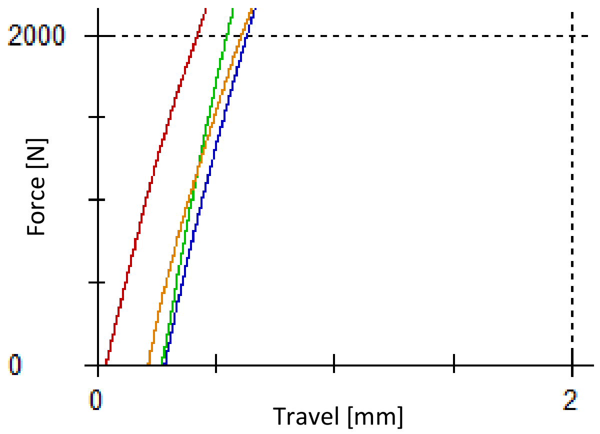


Figure 53: Graph Deformation test samples tensile test

Figure 54: Tensile Test Zwick/Roell Applied Labs

RESULTS TENSILE TEST GEAR

As can be seen in Table 1 and Figure 53, the Young's Modulus per sample differs. The differences between the test samples could be explained by the following factors:

Material difference

Different material types have different mechanical properties. This includes the frictional resistance which influences the needed load to clamp the samples according the formula: $F_w = F_w * \mu$

In which μ is the resistance coefficient, which differ per material. At a certain point, all samples started slipping in the clamp of the test set-up, which influences the test results. Since the moment the slipping started is not determined per sample, it creates an uncertainty in the test results. It has to be mentioned that the test is also influenced by the use of sandpaper, which was positioned between the clamps and parts to delay slipping (Figure 56).

Created moment

Since the samples all have a curved shape, the load of the Tensile Test creates a moment. This moment differs per length of the curvature. This difference in length influences the difference in result per size of the sample (3 or 4), independent of the material (Figure 55).

Positioning clamps

Because of the moment that is created, the positioning in the clamps is important. This position defines the magnitude of the created moment since it is defined as the arm reacting with the test load.

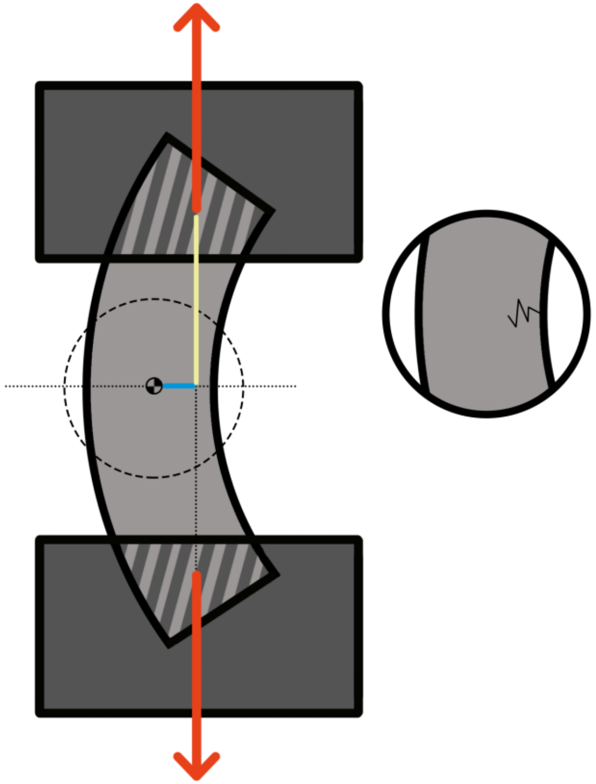


Figure 55: Free body diagram tensile test with sample

Difference in contact surface

Since the surface of the 3D printed and original gear differ, the surface that is in contact with the clamps differs. The size of the contact surface influences the friction resistance, and therefore this factor also influences the results of the test.

Difference in intersection surface

Because of the difference in size, the intersection surface also differs per material sample. This intersection surface has a direct influence on the Young's Modulus.

Post processing

The bronze samples are post processed, while the 3D printed samples are not. Post processing could influence the frictional resistance on the surface and the mechanical properties depending on the type of post processing.

Print settings

The print settings (Appendix 31) determine, amongst other things, the infill. It is important to take the infill of the print into account, since it shows the density of the object. In the printed parts, the infill is 2.8 mm (Figure 56). The change in infill density determines mainly the tensile strength (Fernandez-Vicente, Calle, Ferrandiz, & Conejero, 2016), which determines the Young's Modulus. Next to the infill, the print direction influences the test results.

Additional photos and results can be found in Appendix 33.

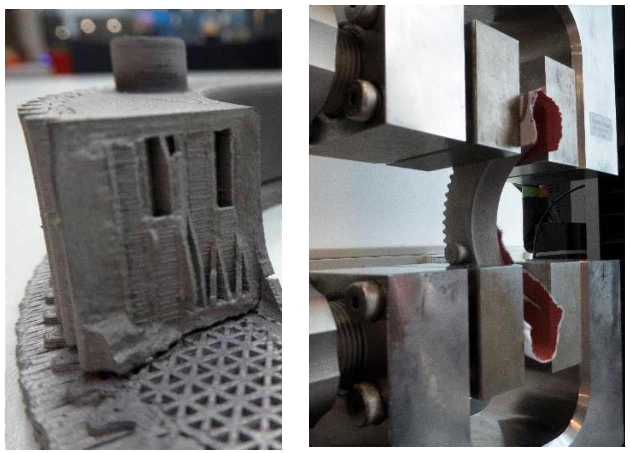


Figure 56: Influencing variables; infill and sandpaper

HARDNESS TEST

The hardness tests for this project are executed in collaboration with Elise Reinton from the Materials Lab of the Faculty of Mechanical, Maritime and Materials Engineering (3ME) at the TU Delft.

Hardness testing is a critical step in qualifying metal parts. 'The test determines various properties of a specific metal, such as resistance to wear, toughness and formability' (Engineering Specialties Inc., 2018).

To test the hardness of metal, the Vickers or Rockwell method can be used in the 3ME Materials Lab. For this project the Rockwell method is used. This testing method is 'less destructive, eliminates errors associated with mechanical imperfections, requires no material preparation and is quicker and cheaper than the Vickers method' (Engineering Specialties Inc., 2018).

The results of the test are presented in Table 2. As can be seen the hardness values of the bronze (original) samples and the hardness values of the Stainless Steel (3D printed) samples, are quite close. The differences in the test results can be explained by the structure of the printed part and the location on the surface of the sample.

Figure 57: Sample 4 Stainless Steel Hardness tested

However, the values between the different materials vary with an approximate factor of 4, which is which can be explained with bronze material being less hard compared to Stainless Steel (CES Edupack). Additional photos and results can be found in Appendix 34.

Table 2: Hardness values test samples

	Bronze (Original)	Bronze (Original)	Stainless Steel (3D print)	Stainless Steel (3D print)
	Sample 3	Sample 4	Sample 3	Sample 4
Mean *usual average*	**3.466666667**	**2.784615385**	**19.12857143**	**16.03571429**
Median	**3.5**	**3.3**	**19.4**	**15.6**
Range	**3.3**	**4.6**	**20**	**17.2**

Figure 58: Hardness test Materials Labs

THEORETICAL COMPARISON

After testing the mechanical properties of the samples of the gear, it is interesting to compare these values with the mechanical properties mentioned in literature. However, it must be said that the comparison of these values is only to indicate a difference range. No conclusions can be drawn since the samples used in the tests of this project are samples of a part. In other words, this would mean comparing material properties with part properties. In such a case, a lot of variables influence the difference, for example: geometry, production method, and post-processing.

YOUNG'S MODULUS

Taking into account Sample 3 of both materials:
Stainless Steel: value out of literature is approximately factor **223** higher than tested value.
Bronze: value out of literature is approximately factor **112** higher than tested value.

HARDNESS

Taking into account Sample 3 of both materials:
Stainless Steel: value out of literature is approximately factor **2,14** higher than the test.

NB: It has to be taken into account that the differences between the Desktop Metal results and the CES Edupack results are influenced by the fact that the CES Edupack material is martensitic and hardened.

Table 3: Results mechanical properties test samples gear

	Bronze (Original)	Bronze (Original)	Stainless Steel (3D print)	Stainless Steel (3D print)
	Sample 3	Sample 4	Sample 3	Sample 4
Young's Modulus [MPa]	921,23	459,97	883,44	269,28
Hardness [HRC]	3.47	2.78	19.13	16.04

Table 4: Mechanical properties material literature

	Studio System sintered 17-4PH (Desktop Metal, n.d.)	**Stainless Steel 17-4PH H900** (CES Edupack)	**Bronze** (CES Edupack)
Young's Modulus [MPa]	195.000	197.000 – 207.000	103.000 – 117.000
Hardness [HRC]	37	41-47	-

	standard	Studio System™ as-sintered
Yield strength (MPa)	ASTM E8M	660
Ultimate tensile strength (MPa)	ASTM E8M	1042
Elongation at break	ASTM E8M	8.5%
Young's modulus (GPa)	ASTM E8M	195
Hardness (HRC)	ASTM E18	37
Density (relative)	ASTM B311	98%

Figure 59: Mechanical properties Desktop Metal print as-sintered

Desktop Metal Tensile Testing

For the mechanical properties of Desktop Metal in Figure 59, T-bone shapes are the regular shape when conducting a test. For printing these T-bones, Desktop Metal recommends to apply the full density in the printer settings. The use of the original shape, with an infill instead of a 100% density, explains part of the difference.

EXPERTS REVIEW

The tests at the TU Delft gave us insights about the parts included in this project. These were compared with the properties given by theoretical references. But what do other companies say about the quality of 3D printer metal parts?

ROYAL NAVY

The Royal Navy is also testing the quality of 3D printed metal parts. At the Expertise Center of Additive Manufacturing (ECAM) they are focusing on the differences between several metal 3D printers

At this moment, they do not yet have results of mechanical properties. The Royal Navy also includes the BASF316 materials, for which they have ordered an industrial furnace

An interesting insight that Sander Wanningen shared is the effect of the slicer software on the quality of the print. According to S. Wanningen the slicer software of Desktop Metal is not ideal.

Frederic Creusen

Frederic Creusen graduated on the quality of 3D printed plastic parts for the Royal Navy. According to Frederic, tensile testing and hardness testing is a first step to determine mechanical properties. The second step is comparing these results to other print methodologies and conventional manufacture methods.

LLOYDS

Lloyds in an independent certification organisation that collaborates with Heerema. At this moment Heerema has three different certification programs at Lloyds:

- For the Business Assurance ISO certificates [ISO 14001, ISO 9001 and ISO 45001];
- For the vessels and equipment classification and certification;
- Marine Assurance certification for ISM, ISPS, MLC e.g.

Casper van Egmond

According to Casper, working at Lloyds, it is important to follow set guidelines to define quality. A first step would be non-destructive testing. Second, the parts should be taken to a mechanic lab. During the second step, it is recommended to determine direction, decide on the radius by bending the sample, conduct a test with a notch, a tensile test, a hardness test and a temperature test. Additionally, it is important to take into account, once a part has to be certified, the used material has to be certified as well. This ensures the parameters of the tested quality.

DNV GL

DNV GL is an independent expert in risk management and quality assurance in the oil, gas and maritime sector. According to them external certification is key to these sectors accepting 3D printing. At the moment, they are working on processes to independently qualify or certify parts made by Aurora Labs, an Australian developer and maker of industrial 3D printing machines, claiming to be able to send Digitally Certified parts (Aurora Labs, n.d.).

"Overcoming challenges in qualification and certification can raise the adoption level of 3D printing in the oil & gas and marine sectors" - Brice Le Gallo, regional manager, South East Asia and Australia, DNV GL - Oil & Gas (DNV GL, n.d.)

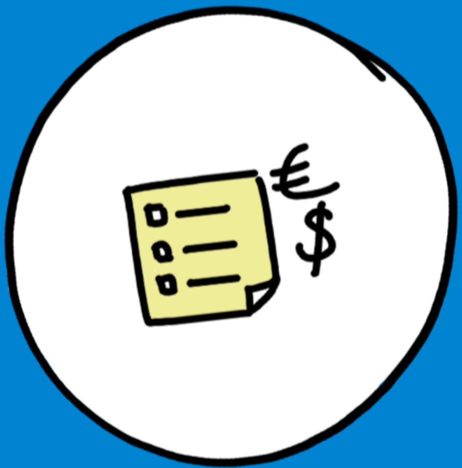
However, DNV GL also mentions that 3D printing should not end up in the Piracy context as the music industry did in the late 1990's. "Digital parts need protection, just like songs in iTunes do" (DNV GL, n.d.).

SHIMADZU

To receive the mechanical properties of the original gear, Shimadzu was contacted. However, the part specifications were not available (Appendix 35).

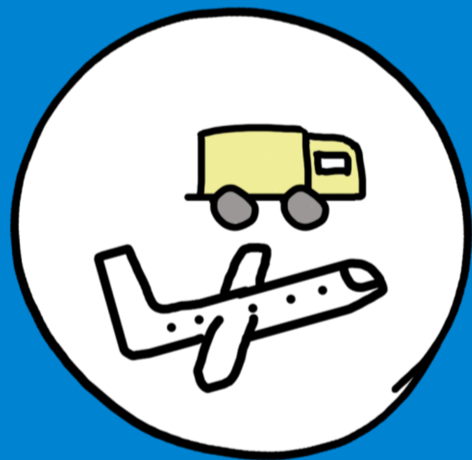
VIABILITY

BUSINESS; Does it profit?

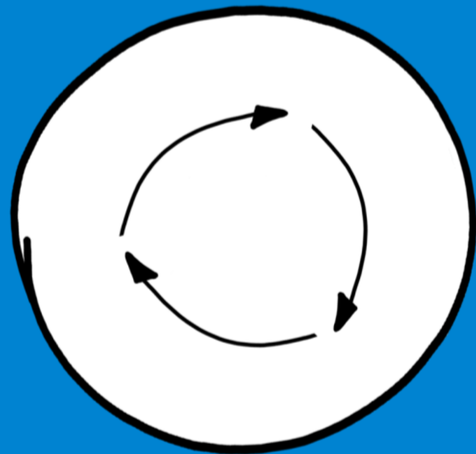


1. LOW INVESTMENT COSTS

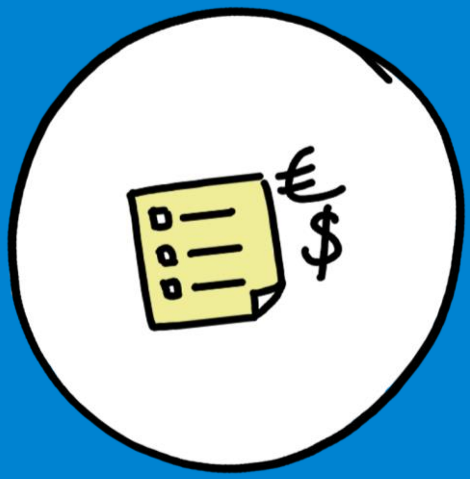
2. SAVING MAN-HOURS



3. DECREASING DELIVERY TIME



4. REDUCING WASTE



1. LOW INVESTMENT COSTS

To start the Roadmap, an investment has to be made. Both printing phases have their own investment costs and additional resources costs.

Next to these man-hours, other spendings can also be reduced: for example, material use during production process, reduction of air freights and reducing the amount of in-stock capital.

INVESTMENT PLASTIC PRINT PHASE

The investment for the Plastic Printing Phase is **€6000**, including:

- The Ultimaker S5
- Education for 2 users
- Support service
- Consumables service
- Installation
- Two spools of material (support and print)

INVESTMENT METAL PRINT PHASE

The investment for the Desktop Metal Studio System is **€220.000**, including:

- The Studio System
  - Printer
  - Debinder
  - Furnace
- Education for 2 users
- Support service
- Consumables service
- Installation
- Starter package resources

RETURN OF INVESTMENT

The total investment for both systems is **€226.00,00** excluding VAT. Taking into account the economic value of the warehouse stock of **$13.000.000**, this investment takes up only 1.74% of it. It is already known that the in-stock value will decrease once 3D printing is implemented. To quantify this: an in-stock reduction of only 5% equals a value of approximately **$650.000.**

Additionally, implementing 3D printing will reduce air freights. Taking the numbers of the Balder into account, additional air freights for transporting parts can take up approximately **$93.240** per year. Knowing the amount of air freights will decrease once 3D printing is implemented, shows the following: a reduction of only 30% of air freights equals a value of approximately **$27.000.** An amount of money equal to more than 10% of the investment for both printing systems.

Appendix 36 shows the complete overview of costs and benefits.

COSTS AFTER INVESTMENT

After installing the hardware, additional costs have to be made during the Roadmap execution. These costs include the following:

- Maintenance
- Man-hours for new production technology: vessel crew, installation, printing
- Resources hardware:
- Metal printer
- Liquid debinder
- Gas furnace
- Power to run processes

It is also possible to lease the printers in case this is preferred by Heerema.

2. SAVING MAN-HOURS

As mentioned by Rene van der Linden, man-hours are very valuable. By printing a part instead of ordering it or producing it in the workshop, a lot of man-hours could be saved.

ADMINISTRATION

As already mentioned by Peter de Bree (Chapter 1.2), the current system is not optimal to use since it costs the Storekeepers a lot of time on administration of ordering parts. When parts do not need to be ordered anymore, these man-hours can be saved. Next to that, hours spend by procurement and logistics in the office can be saved when producing a part on-board.

TRANSPORT

When a part is produced on-board, no more hours are needed to transport the part to the vessel. Since each way of transporting makes use of

COMPARISON 3D PRINT AND MACHINING

An already familiar manufacturing technique is machining. According to 3D Hubs (3D Hubs, n.d.), BMD is excellent for functional prototyping and small productions of metal parts that would otherwise require a 5-axis CNC machining to produce since it saves time.

The following case studies proof the benefits of the Desktop Metal Studio System compared to a CNC milling machine (Layertec, 2019).

LUMENIUM CASE STUDY

For this part the BMD technology is approximately two times faster and six times cheaper. Also, only two third of the CNC material weight is used for printing the part.

SMARTPHONE HOLDER CASE STUDY

For this part the BMD technology is approximately three times cheaper and faster.

Figure 61: Lumenium Case Study (Layertec, 2019)

Table 5: Lumenium Case Study (Layertec, 2019)

	INHOUSE MACHINING	STUDIO SYSTEM FABRICATION
Technology	CNC machining	Bound Metal Deposition
Material	4340 steel	AISI 4140 steel
Weight	1518 gr	933 gr
Lead time	1 week	4 days
Cost/part	$980	$148

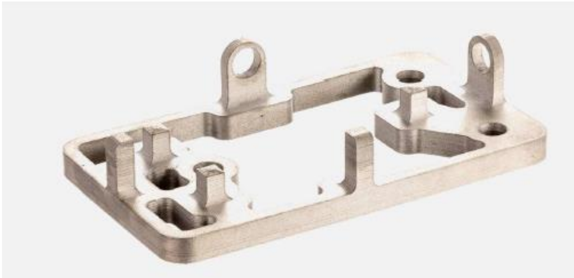


Figure 60: Smartphone Case Study (Layertec, 2019)

Table 6: Smartphone Case Study (Layertec)

	INHOUSE MACHINING	STUDIO SYSTEM FABRICATION
Technology	CNC machining	Bound Metal Deposition
Lead time	2 weeks	5 days
Cost/part	$450	$150

3. DECREASING DELIVERY TIMES

One of the problems mentioned in the analysis is the speed of a part delivery to the vessel. In case a part is printed on-board, the transport can be skipped. By using 3D printing as one of the production methods, parts could be finished faster.

COMPARISON

The comparison as shown in Figure 62 is based on a minimum and maximum time indication of the time needed. Ordering or printing the parts is based on the following situations:

- The part is no longer in-stock, but needed with a high priority.
- The vessel is in a non-beneficial position for receiving parts; a plane would be needed.

It has to be mentioned, that once critical parts will be printed, certification and testing of the parts has to be included in the total amount of hours for printing the part. On the contrary, critical parts that will be ordered at a manufacturer have a high potential of having to be produced, since they are not in-stock because they are rarely ordered. This situation will also increase the amount of hours for ordering the part.

ORDERING VARIABLES

The variables for ordering the part are:

- The **location** of the manufacturer and the location of the vessel.
- The **workload** at the office determines the speed of reaction.
- The **availability** of the part determines whether the manufacturer has to produce a new one.

PRINTING VARIABLES

The variables for printing the part are:

- The **size** of the part; the smaller the parts the less time the production process (print, debind, sinter) takes.
- The **availability** of a CAD model; receiving this straight away or already having the model speeds up the process incredibly.
- The **complexity** of the part; the more complex the part is, the more time it takes to model the part.

PRINT THE PART	MIN	MAX
GET MODEL/MODEL PART	4 HOURS	*5 DAYS* 120 HOURS
PRINT PART	30 HOURS	30 HOURS
DEBIND PART	68 HOURS	68 HOURS
SINTER PART	44 HOURS	44 HOURS
POTENTIALLY POST PROCESS PART	4 HOURS	24 HOURS
	6+ DAYS 150 HOURS	*12 DAYS* 286 HOURS

ORDER THE PART	MIN	MAX
CREATE REQUISITION	4 HOURS	*5 DAYS* 120 HOURS
3 INQUIRIES	4 HOURS	*5 DAYS* 120 HOURS
ORDER	24 HOURS	*8 WEEKS* 1344 HOURS
TRANSPORT TO WAREHOUSE/HARBOR	72 HOURS	*2 WEEKS* 336 HOURS
TRANSPORT TO VESSEL	24 HOURS	*5 DAYS* 120 HOURS
	5+ DAYS 128 HOURS	*85 DAYS* 2040 HOURS

Figure 62: Comparison delivery times

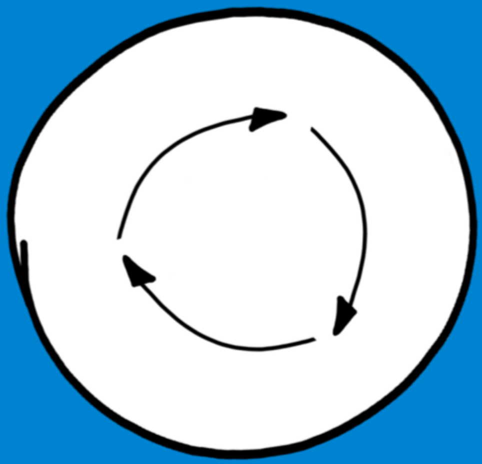


Figure 63: Eight types of waste

4. REDUCING WASTE

The current process creates waste: anything a customer doesn't pay for. In reality, not all waste is avoidable, but reducing it will improve your process. When the 3D print technology will be implemented, all types of waste can potentially be reduced.

1. Inventory: it is not necessary to have them in-stock since they can be printed.

2. Defect: the chances of (human) errors decrease: the amount of proceedings, within the ordering process, decreases which limits risks.

3. Move: the number of administrative tasks decreases: the risk of losing focus disappears.

4. Talent: the use of internal knowledge about manufacturing parts increases: on-board of the vessels there might be a lot of knowledge about manufacturing parts, however this might not be used because of the current established production methods.

5. Transport: the number of unnecessary transports decreases: the number of airfreights and other types of transports that were needed to take parts on-board, will be lowered since part of the order can be produced on-board.

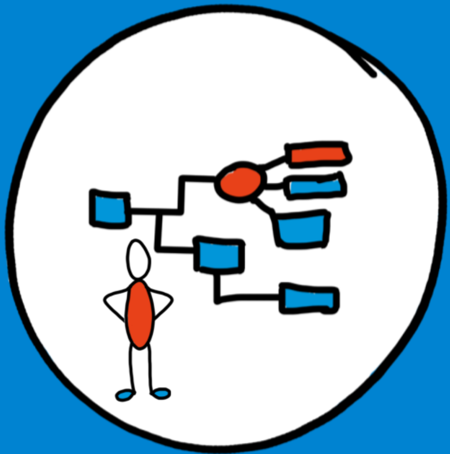
6. Wait: the time of waiting for orders to arrive reduces: the parts can be printed on-board which lowers the delivery time.

7. Overproduction: the amount of produced parts will be in balance with what is needed: there is no more need to order more parts 'just to be sure'. Next to that, parts that normally only could be ordered in batches of e.g. 100 parts, can now be printed one by one.

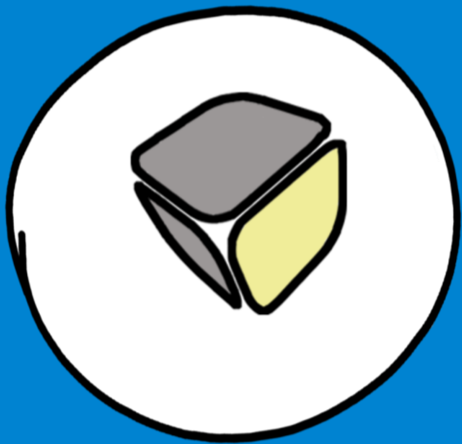
8. Over processing: the procedure of ordering parts will be less complicated: when a part is printed there is no need to get the order through procurement and logistics. The only additional procedure is ordering the resources needed.

DESIRABILITY

HUMAN VALUES; Does it meet wants and needs?



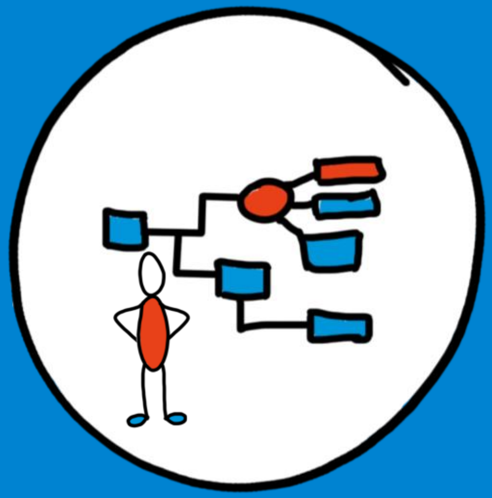
1. FIT CURRENT PROCESS



2. PARTNERSHIP LAYERTEC

3. SAFE TO USE

4. FIT HEEREMA



1. FIT CURRENT PROCESS

The Roadmap is designed for, and in collaboration with, the users. All stakeholders of the ordering and producing process of spare parts are involved, which makes the solution fit with the current process.

USERS

As already mentioned, the 3D printers will be under surveillance of the Engineers of the Thialf. The group of Engineers is organised as shown in Figure 64. Because of the hierarchic level and included delegation potential, the ones responsible for printing parts will be the Engineers 1 and Engineers 2. Next to that, the 3D printing Roadmap is a technical related project and therefore needs technical crew (Rene van der Linde, Appendix 14). All Engineers of Heerema graduated at the Higher Nautical College. This education includes CAD Modelling, which means they are already experienced in creating three-dimensional models digitally. If a part needs post-processing, the Engineers can delegate this to the Mechanics. During a project the Thialf has four Engineers 1 and four Engineers 2 on-board. Taking into account the crew shifts, the total amount of Engineers 1 and 2 doubles: in total the group of users consists of 16 people.

One could argue the Storekeepers as potential users, however they are skilled in the logistics of spare parts instead of the production. Therefore, the Storekeepers are important stakeholders of the Roadmap, but not the ones using the printers.

INCENTIVES USERS

Why would the Engineers 1 and 2 use the 3D printer? General known incentives within Heerema are costs and authority. A project like this however, has to be led by someone with intrinsic motivation. Someone with an intrinsic incentive will continue pushing the use of the new technology on-board.

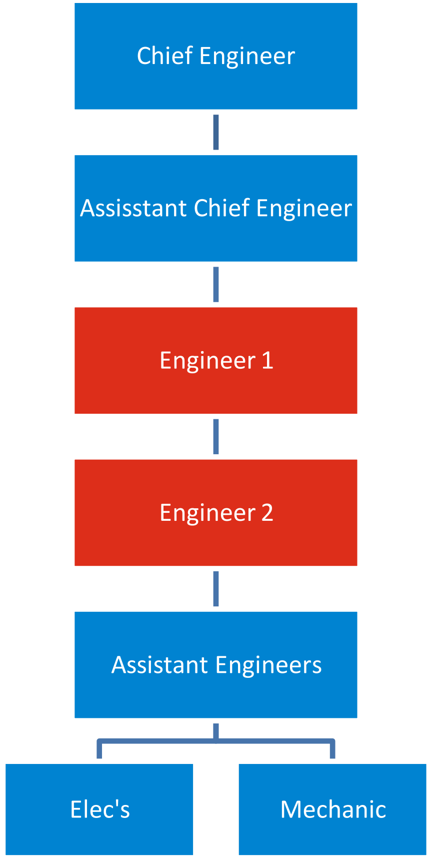


Figure 64: Organizational Breakdown Structure Engineers

Out of the interview with Rene van der Linden (Appendix 14), an interesting insight occurred about one of the Engineers: Rob Beuker used to be Engineer 1 at the Balder and is now working as Engineer 1 at the Thialf. He used to have a 3D printer on-board for his model airplanes.

Next to involving Rob Beuker in the process of starting the Roadmap, it is recommended to make sure the benefits of this new technology are made clear to the other users during the Research Phase.

EDUCATION

To educate the 16 Engineers, a Training Matrix has to be developed. These Training Matrices are the common way of introducing a class on-board (Appendix 14, Harm van der Meulen). The education will be supported by Layertec, since they provide a service including education.

STAKEHOLDERS

The success of the Roadmap does not solely depend on the Engineers. Other stakeholders will be involved externally and internally. Table 7 shows how the different groups of stakeholders influence the project.

Table 7: Stakeholders Roadmap

Core Stakeholders	
Engineers 1 and 2	Using the printers
(Ass.) Chief Engineer	Approving prints
VMT, Rinze Huisman, Jan van Akkeren, Peter de Bree	Network of Support
Chief Storekeeper	Warehouse logistics
Layertec	Service support
Primary Stakeholders	
Heerema procurement	Procurement resources
Storekeepers	Parts in-stock
HR Heerema	Education Matrix
Mechanics	Installing printed parts
Office Leiden	Modelling support
Secondary Stakeholders	
Huisman	Contact AM on-board
Desktop Metal/Ultimaker	Printer manufacturers
Other Vessel crews	Support base

Figure 65: Stakeholders Thialf

2. PARTNERSHIP LAYERTEC

To increase the usability of both printing systems, it is recommended to partner up with Layertec: added service and education are included.

LAYERTEC

Layertec is a company located in Zaltbommel, the Netherlands. They are supplying 3D printers, including complete support and service. One of the 3D printing systems Layertec is selling is Desktop Metal. Because of previous collaboration between Heerema and Layertec, the company was taken into account again. According to Layertec, they distinguish from other companies with the following selling points (Layertec, n.d.):

- **Certified experts,** to help installing and support throughout the use process.
- **Implementation,** installation and configuration on location.
- **Service,** support from CAD modelling to the 3D printing process during use of the printers.
- **Education,** training, seminars and webinars to learn how to work with Desktop Metal systems (including CAD modelling in SolidWorks).
- **Part of Visiativ**, a group that "accelerates corporate innovation and digital transformation via its collaborative and social business platform" (Visiativ, n.d.), a useful connection for the implementation of innovations.

For this project Dennie Rijk and Robert Slegers added a lot of value by sharing their knowledge. Dennie works as Desktop metal Specialist at Layertec, his responsibility is selling the 3D print services of Layertec. Robert is working at Layertec as a Service Engineer.

Figure 66: Logo Layertec (Layertec, n.d.)

STUDIO SYSTEM DESKTOP METAL VIA LAYERTEC

Ordering a Studio System at Layertec costs €300.000 per set (printer, debinder and furnace). When a Desktop Metal Studio System is ordered at Layertec, they will provide the full support on installing the system. Before installing they will support the education of software and hardware skills. To successfully print parts, the Studio System requires several resources that can be ordered at Layertec:

- **Metal rods**, for the printing process.
- **Debinding liquid**, for the debind process.
- **Gas**, for the sinter process in the furnace.

OTHER SYSTEMS DESKTOP METAL

Desktop Metal also has a printer called the Production System. This system is based on the Binder Jetting method and thus a powder based printing technology. This makes the printer unsuitable for on-board applications. However, it is perfect for mass production that needs to be done quickly and cheap (Desktop Metal, n.d.). This system would be very suitable to create consumable parts in warehouses on-shore and is therefore mentioned in the Roadmap.

OTHER COMPANIES OFFERING DESKTOP METAL

The investment of a Studio System can also be done at other companies. An example is **Trideus** (Trideus, n.d.), located in Belgium. This company is also located nearby and offers Desktop Metal systems with service support. However, Robert and Dennie were closely involved in this project. Therefore, Layertec already has a lot of knowledge about Heerema which puts Layertec in a favourable position.

3. SAFE TO USE

As mentioned by Layertec, Ultimaker and Desktop metal, both printers can be used in offices safely.

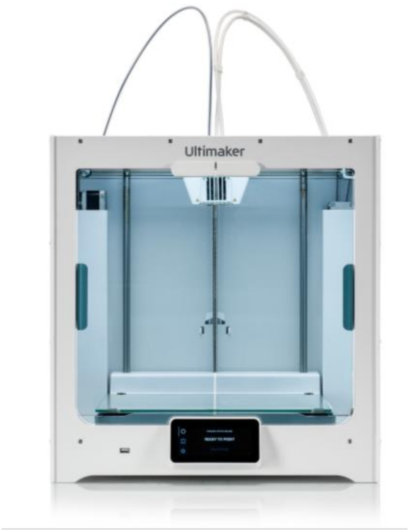


Figure 68: Ultimaker S5 (Ultimaker, n.d.)

Figure 67: Desktop Metal Studio System (Desktop Metal, n.d.)

ULTIMAKER S5

The Ultimaker S5 received a declaration of safe unattended professional use, which states that the printer can even be used overnight (Appendix 21).

To secure the users and the print system, the Ultimaker S5 can be closed.

The spools of material are easily swappable. Combined with the intuitively touchscreen software, the Ultimaker S5 is safe to use regardless of the user's technical abilities (Ultimaker, n.d.).

DESKTOP METAL STUDIO SYSTEM

No metal powder is used, which eliminates the risk of flammability that normally occurs when printing metal.

The furnace is designed to be safe for office environments. It has a peak temperature of 1400 degrees Celsius and automatically detects levels and gas type. If there is an issue, the system sends a notification.

The print material is packed as media cartridges. According to Desktop metal, these cartridges are safe-to-handle.

The canisters that hold the gas for the furnace are easily swappable, which makes it safe to manage the gas of the system.

In addition to these safety specifications, the Studio System has built-in effluent filters, binder cold traps and safety fail safes (Javelin, n.d.).

4. FIT HEEREMA

As mentioned in the sustainability beliefs of Heerema, being sustainable means “to strive for a careful balance between people, planet and profit in everything we do” (Heerema Marine Contractors, n.d.). These desires will be met according the insights gathered in the Discover Phase: recyclable materials, less parts in-stock and being able to print parts whenever needed.

SUSTAINABILITY ROADMAP

At the moment the Roadmap of this project kicks off, one of the ambitions of the Sustainability Roadmap of Heerema is touched upon.

This project is part of the Sustainability theme Offshore Excellence, but the outcome is also in line with the themes:

- Reduce Emissions and Footprint
- Sustainable Supply Chain management

FOUNDER’S MENTALITY

Starting the Roadmap is in line with the Founder’s mentality, that is currently implemented in the organization of Heerema. This mentality focuses on taking ownership, which is reflected by solving the pain points mentioned in the problem definitions.

FUTURE HEEREMA

When the implementation of 3D printing succeeds,

- recyclable plastics can be used on-board;
- less parts are in-stock, which influences the environmental and economical sustainability;
- opportunities open up for the use of high quality plastics, like carbon fibres;
- more space on-board is available for initiatives like Carbon Capture.

Figure 69: Sustainability Roadmap Heerema (Heerema Marine Contractors, n.d.)

3. DISCUSSION

This chapter mentions the research limitations and reflects critically on the taken steps and methodology.

Figure 70: Thialf at Calandkanaal Rotterdam (Heerema, n.d.)

LIMITATIONS

It is important to be transparent about the limitations within the approach and execution of this research, as it influenced decisions made.

AIR FREIGHTS

For this research the data of air freights has been used. However, this data is from 2011 only, which limits the broader view on costs. Additionally, it has to be noted that:

- There are more vessels; they all make use of air freights.
- This is only the Workshop, Stores & Tools unit; a higher percentage of the weight and numbers of airfreights could be printed on-board.
- Also, these numbers are based on 2011 which is already 9 years ago. Numbers of airfreights may already be different.

More data about the additional air freights used to get spare parts on-board would be an addition for the outcome of this project.

TENSILE TESTS AMOUNT OF SAMPLES

During the tensile tests only two samples per part are tested. Also, per sample only one test is conducted because of time. This affects the reliability and validity of the test. Therefore, the tests could be expanded by increasing the number of samples per part.

HARDNESS TEST SURFACE LOCATION

To perform the hardness test, locations on the part surface are randomly selected. Especially in the 3D printed samples, the result of the test depends on the local structure of the sample. Therefore it would have been a valuable addition to have a scan of the structure of the sample, to link this to the outcome of the selected test points on the surface.

STEPWISE IMPLEMENTATION

This research's deliverables are based on the stepwise implementation on the research of Huizingh (2009). As mentioned before, Huizingh implies innovation adoption is not a binary process, and can therefore be adopted stepwise. This research is primarily following Rogers' (1995) innovation adoption model, by investigating the knowledge, perceived potential value, implementation and satisfaction of the users of the innovation. Since the implementation of this innovation effects a large organization, but is used by just a small amount of users, it could be interesting to look at the effect of the factors on the adoption in different levels of the organization.

REFLECTIONS

To deliver honest research results, it is important to critically reflect. Therefore, several aspects are highlighted in this section.

USERS

At first, it should be mentioned that the research among the potential users and stakeholders was qualitative. The consequence of this is results based on solely a small group of respondents. Additionally, being aware of the availability bias is of importance. Despite the open approach of the interviews, possible solutions got presented. Accordingly, it is interesting to expand research to validate the qualitative results.

COMPARISON PARTS/MATERIAL

To research the quality of the prints they are tested on some mechanical properties. However, during the project they are compared to mechanical properties of materials. This comparison has a lot of different variables to get to a conclusion. Therefore this method can only be used to get an indication of the properties.

PART SELECTION MATERIAL

During the part selection process, the only concern within material was the part being made from metal. Afterwards, it would have been a more deliberate decision to choose parts that are made out of Stainless Steel, just like the material they got printed with. For this project it is decided to not reconsider this decision since the metal print study was already executed. Printing additional parts would take up to much time.

TENSILE TEST EXECUTION

During the execution of the tensile tests, the samples' centre point should be in line with the centre points of the tensile loads. At the moment these centre points are not aligned, a moment is created. This moment adds another insecurity in the results of the tensile tests that could easily be eliminated.

REFLECTION PREVIOUS RESEARCH

In the introduction of this report the results of previous 3D print researches were mentioned. For now, it is interesting to reflect on those.

The following was stated in the research in collaboration with the University of Amsterdam:

"For now, Additive Manufacturing is not eligible for actual use since the components do not fulfil the standard minimum requirements of the mechanical properties."

From this research we can see that quality of the prints indeed is one of the bottlenecks. However, stating 3D printing is not eligible for use is too reductive since the student from the UvA did not look into plastic printers. Taking into account the predicted developments within the metal 3D printing technologies, the quality seems promising by the time the vessels of Heerema would want to implement this.

"Heerema should consider investing in prototypes of 3D printed components to fully evaluate the printability."

The printability of two selected parts is proven in this research.

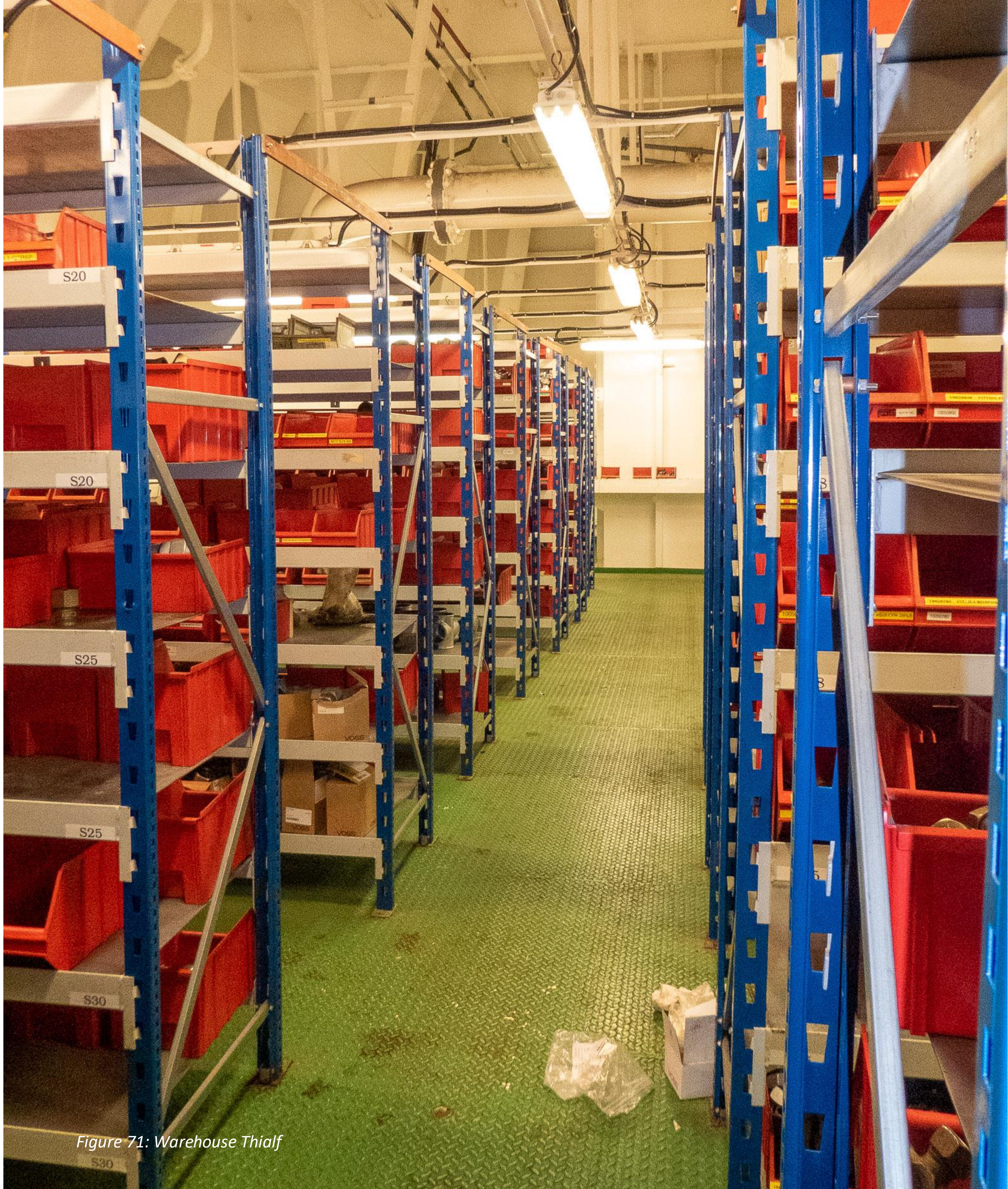


Figure 71: Warehouse Thialf

4. CONCLUSION

Summarizing the project by highlighting the most interesting findings.
This chapter also explains whether the hypothesis is confirmed.

Figure 72: Thialf at Calandkanaal Rotterdam

CONCLUSION

The aim of this Master Thesis is researching the potential of implementing 3D printing on-board vessels of Heerema and recommending the most suitable way of doing so.

The conducted research illustrated the benefits of implementing 3D printing on-board Heerema vessels. Based on the research outcome, several decisions about the implementation are made:

The recommended Roadmap presents a stepwise implementation to avoid risks. The first step of the Roadmap consists of printing the plastic parts with an Ultimaker S5. After completion of this phase, it is recommended to start printing metal parts with the Desktop Metal Studio System. In the 3D printing Roadmap the recommended users are the Engineers 1 and 2, as they are skilled at CAD modelling and have the hierarchic level with the possibility to make decisions and delegate tasks. The first printer will be installed in the Warehouse of the Thialf, since this vessel supported the research conducted during this project. Therefore, the stakeholders and users are already up to date about the developments. It is decided to choose the warehouse as the 3D printing location, since this space can be locked and kept clean.

The Roadmap includes potential exit points once the added value of the execution does not fit the expectations.

By following the recommended Roadmap stepwise, Heerema will benefit from the opportunities 3D printing has to offer.

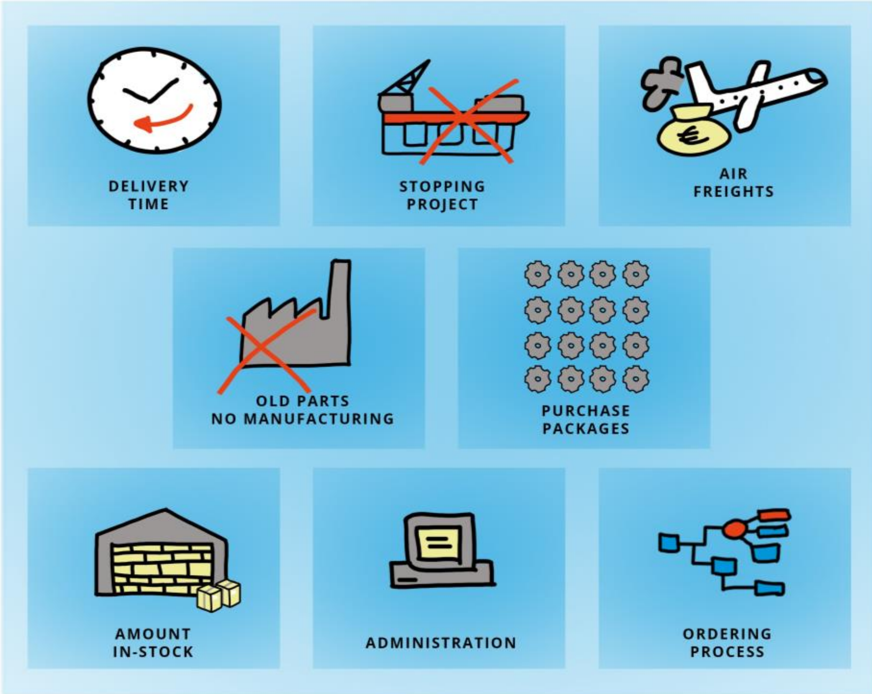


Figure 73: Pain points current situation

PAIN POINTS SOLVED

The substantiations of the feasibility, viability and desirability show how the pain points, mentioned in the problem definition and Figure 73, can possibly be solved.

Delivery time can be decreased by printing the parts on-board, which could potentially prevent **stopping projects**. At the moment parts are printed on-board instead of ordered, transports of the parts can be decreased including **air freights.** In addition, in the event of a desired part is **not manufactured** anymore, 3D printing offers the opportunity of producing it on-board. In the case it is only possible to **purchase packages**, a more sustainable solution is 3D printing the part, which also leads to a decreased **amount in-stock.** Lastly, 3D printing parts instead of ordering them improves the process of **administration** and **ordering**.

KEY CHALLENGES TACKLED

The three Key Challenges as defined in the problem section of this research, are solved by decreasing the delivery time, researching the quality of the printed parts and recommending a stepwise implementation. However, it must be noted that the challenges are solely solved within the recommended Roadmap, and the execution has to proof itself once started.

FEASIBILITY

1. The chosen hardware is proven to function.
2. The warehouse on the Thialf has parts that are suitable for 3D printing.
3. The printing studies show the printability of the selected spare parts.
4. The quality of 3D printed parts of the printing study is promising, based on the mechanical tests.

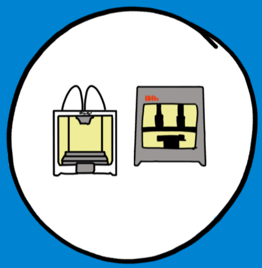
VIABILITY

1. By decreasing the amount in-stock with 1,8%, an equal amount as the needed investment is saved.
2. Man-hours can be reduced in several departments.
3. Delivery time of a part could be decreased by printing it on-board instead of ordering it and transporting it from manufacturer to vessel.
4. Different types of waste are reduced, improving the ordering process.

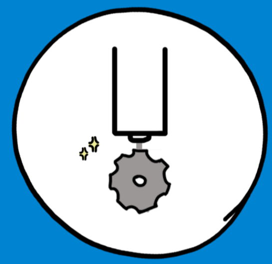
DESIRABILITY

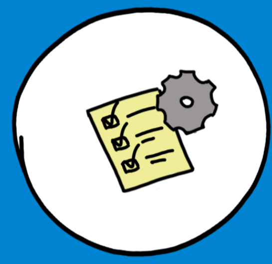
1. The new technology is designed to fit within the current user processes on-board.
2. The partnership with Layertec provides Heerema with hardware, software and service.
3. All phases of the recommended Roadmap are safe for use.
4. The Roadmap fits Heerema's Sustainability Roadmap.

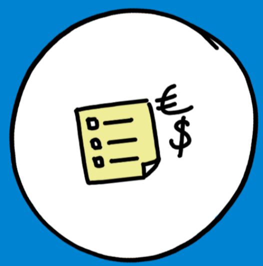
Based on the feasibility, viability and desirability, we can conclude that Heerema will benefit from an investment in 3D printing as recommended in the presented Roadmap.


1. HARDWARE WORKS


2. PARTS AVAILABLE

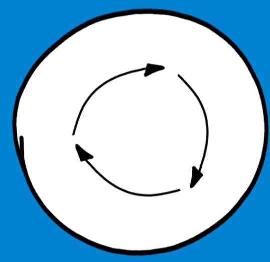

3. PRINTABLE PARTS

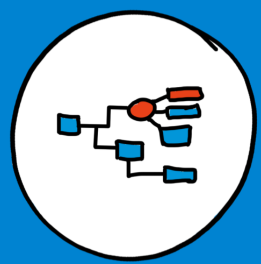

4. SUFFICIENT QUALITY

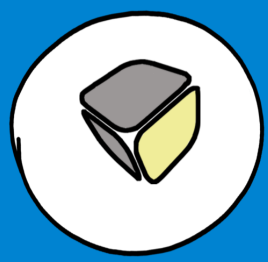

1. LOW INVESTMENT COSTS


2. SAVING MAN-HOURS


3. DECREASING DELIVERY TIME


4. REDUCING WASTE


1. FIT CURRENT PROCESS


2. PARTNERSHIP LAYERTEC


3. SAFE TO USE


4. FIT HEEREMA

HYPOTHESIS CONFIRMED?

As mentioned in the introduction, the motivators of Heerema to execute this project are improving environmental and economic sustainability and using innovation within technology to open up possibilities (Figure 74). In this chapter the motivators are evaluated to conclude whether they can be confirmed as stated hypothesis.

ECONOMIC SUSTAINABILITY

In-stock amount reduction

The amount of parts that is in-stock now, can be reduced by printing the parts only once they are needed. Quantifying this reduction shows that 10% already results in a decrease of 30.000 parts, equivalent to 140.000 kg in weight. A reduction in amount of parts in-stock also results in a decrease of the average economic value of parts in-stock on-board.

Cost reduction

A significant amount of costs can be reduced by implementing 3D printing. The amount of logistic administration will decrease, which means Heerema spends less man-hours. Additionally, costs of transports and in-stock parts reduces.

ENVIRONMENTAL SUSTAINABILITY

Material reduction/recycling

Aforementioned, the amount of parts in-stock can be reduced. Next to that, the amount of used material can be reduced compared to the traditional milling production method. Another important aspect is that the used material in the 3D printing process has a recycling potential.

Transport emissions reduction

The more transports there are, the bigger Heerema's carbon footprint will be. This will consequentially effect the environment negatively. Assuming Heerema can reduce the transports by producing parts on-board, the emission reduction will be beneficial to Heerema's Sustainability goals.

INNOVATION

Opportunities Roadmap

The recommended Roadmap provides options for the long-term possibilities for Heerema.

Smart use of space on-board

Once the amount of parts in-stock is reduced, more space for other initiatives could open up. These initiatives can differ from the carbon capture Heerema is currently working on in the Leiden Office, to initiatives of the vessel crew taken on-board.

Process improvement

Waste, as defined by the Value Stream Mapping method, reduces as a result of implementing 3D printing. As a result, the procurement and logistics process of spare parts improves. This added value is in line with the current Microbattle focusing on the procurement process.

Figure 74: Motivators Heerema

5. RECOMMENDATIONS

The results of this design project lead to several recommendation for Heerema. These recommendations are based on the qualitative and quantitiave research: a combination of the literature research and interviews with vessel crew members. This chapter discusses these recommendations and further research.

Figure 75: Thialf offshore (Heerema, n.d.)

RECOMMENDATIONS

During the validation of implementing 3D printing on-board of the vessels, it became clear that there is interest within Heerema to use this new production technology. However, to increase the success of executing the Roadmap, several recommendations are presented that can be taken into account during the Research Phase.

EXTEND STAKEHOLDER VALIDATION

The first recommendation is extending the validation to the stakeholders of this project. Starting with crew members, including crew of other ships. Secondly, take the stakeholders of different departments into the decision making phase. Examples of these stakeholder are Rinze Huisman, Jan van Akkeren, Peter de Bree and Human resources. It is important to create a stable network of support to execute the recommended Roadmap to absorb setbacks. A network of ambassadors per level within the organisation could positively affect this support.

DISCUSS SUPPORT LAYERTEC

During the Printing Phase of the Roadmap, many tests and experiments using the printers will be conducted. Therefore, it is important to have a steady support base provided by Layertec. Since the printers will go offshore, it will be beneficial to discuss the way of supporting with Layertec beforehand. By doing so, the right way of communication for both parties can be chosen. Additionally, it is recommended to discuss the material purchase for the first Printing Phase with Layertec.

START COLLABORATION WITH LLOYDS & DNV

It is highly advised to start collaborating with Lloyds and DNV, two external certification organizations, from the beginning of the Roadmap. At a certain point, there is a stop on expanding the database of printable parts because of certification. If the external parties responsible for certification are involved in the Roadmap from the start, the possibility of getting a 3D printed part certified increases. Getting this certification increases trust among the stakeholders, which will open up the opportunity of using 3D printed spare parts in critical mechanic systems as well. More information about different types of certification is provided in Appendix 7.

CONTINUE METAL PRINT QUALITY RESEARCH

Based on the reflections mentioned in the discussion, it is recommended to continue researching metal printed parts. This continuation will increase the reliability and validity of the results (Figure 76). It is recommended to increase the number of samples, and to increase the diversity of the tested parts. When selecting additional parts for these tests, it is recommended to also select parts that are made of the same material as the material they will be printed with. Bronze is currently in development and would be interesting to test. Once this is completed and a sufficient quality is shown, it is recommended to conduct a practical test on-board by placing the 3D printed part in the machine where it belongs. It is important to monitor this mechanical system to make sure no critical parts get damaged.

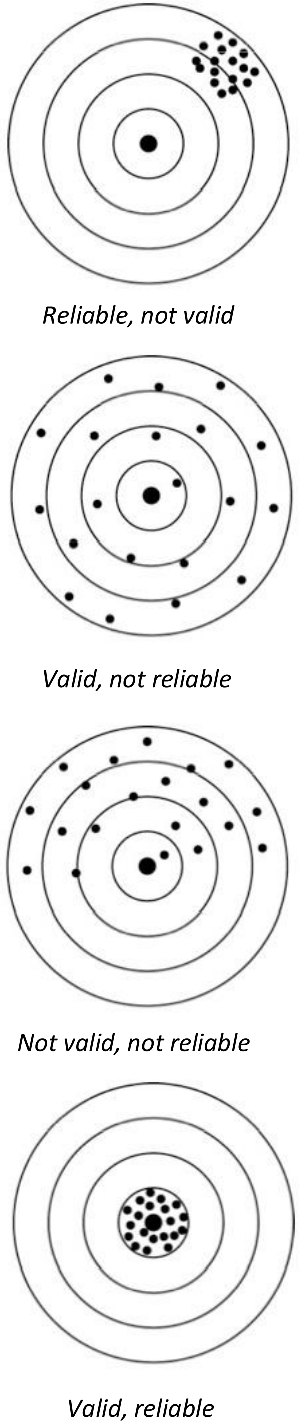


Figure 76: Reliability and validity (Scribbr, n.d.)

Figure 77: Thialf deck

FURTHER RESEARCH

To conduct further research, all opportunities mentioned in the Roadmap could be of interest. Since this research was finalized within a limited amount of time, numerous interesting ideas are not even touched upon in the Roadmap and are therefore mentioned as potential directions for further researched.

MEASURE THE SUSTAINABILITY IMPACT

It is interesting for Heerema to measure the sustainable impact of the Roadmap. Especially since it is questionable in what way 3D printing itself is sustainable. For this research it is recommended to take the research of Faludi (2017) into account that discusses the environmental implications of 3D printing by comparing the environmental impact of today's typical 3D printing with two classic manufacturing methods.

PERFORM A TREND ANALYSIS

Perform a trend analysis within the field of 3D printing to expand the Roadmap with opportunities.

RESEARCH ADDITIONAL PRINT TECHNOLOGIES

For further research, it is interesting to look into other metal print technologies. Two examples of these technologies are casting with the use of plastic prints and printing metal with FDM. The first technology casts the metal in a mould that is formed around a plastic printed part. The second example of printing metal is using BASF316 metal filaments on the Ultimaker, as mentioned in one of the concepts (Appendix 16). Since this option would require an industrial furnace (Appendix 37), it is interesting to stay up to date on the developments, but focus on the Desktop Metal for now.

ADOPTION ORGANISATION

As mentioned in the discussion section of this research, it is interesting to research which factors affect the adoption in different levels of the organization (Wilkinson, 1989). Might there be differences in factors within the different organization levels, it could be beneficial to change the Roadmap accordingly.

STRUCTURE OF 3D PRINTED PARTS

A remarkable research within the quality of the spare parts, is the influence of the structure of the 3D printed part on its mechanical properties. Therefore, it could be interesting to gather more knowledge within Heerema about the influence of the print direction, infill, wall thickness and other structural variables influencing the properties. By doing so, the substantiation of the mechanical test results could improve.

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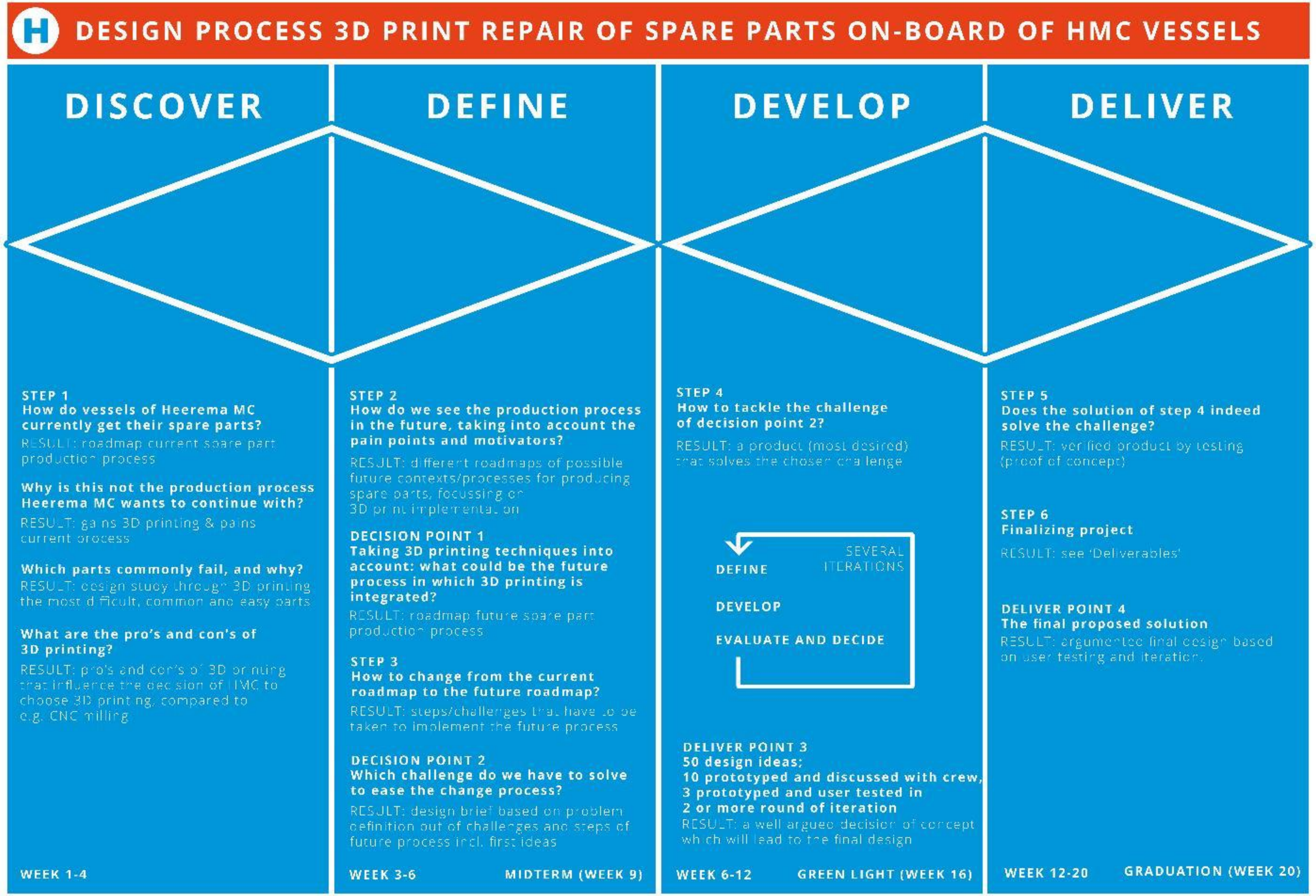
7. APPENDIX

Figure 78: Thialf Offshore (Heerema, n.d.)

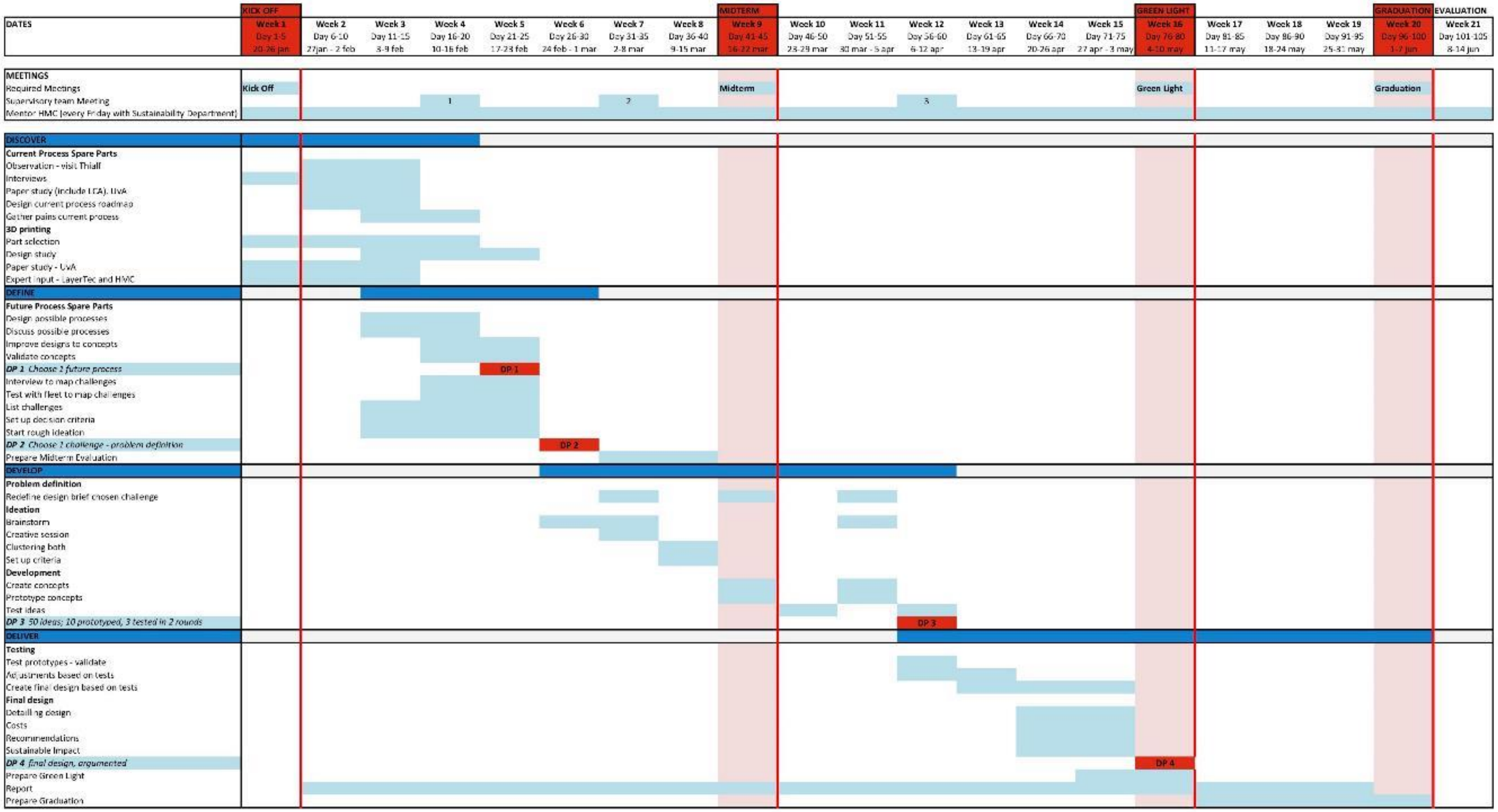
APPENDIX 2

Project Approach



APPENDIX 3

Planning: Gannt Chart Project Approach



MEETINGS

Team Meeting 1

Show conclusions discover phase
Show first ideas future process
Show design study outcomes

Team Meeting 2

Present decision of future process
Show first draft of challenges

APPENDIX 4

Insights experts on-board

HANS HAVERMANS

Hans is Chief Storekeeper, his responsibility is managing the warehouse on-board.

The parts in-store are categorized after the REL project: a project to improve the system (Infor) that is used. Categories: critical, strangers, consumables.

Due to REL most parts have a maximum and minimum quantity. The delivery time influences the minimum quantity.

Why not decide whether to take a 3D printer or not based on the project?

We use the workshop to repair parts or produce them ourselves.

How do we educate the people that have the fix the printer when it breaks down?

STOREKEEPERS

Alain and Arthur are Storekeepers at the Thialf, their responsibility is keeping the quantities of parts in Infor up to date.

Have shifts of 12 hours, then a 12 hour break.

The total storekeeper team consist of 7 employees.

There are two stores: on deck and the general warehouse. The general warehouse consists of different sub-warehouses.

JAN PLUIMGRAAFF

Jan is Superintendent, his responsibility is managing the offshore project on-board.

During my career we had to shut down the whole project once. These kind of activities costs HEEREMA approximately 1 million euros per day.

Parts can be critical or certified. Critical parts are of great importance for the project. Certified parts guarantee a certain quality.

Each project has its own PRL: Procurement Resource List. Sub-contractors and clients add their own stuff in containers.

If we create parts in the workshop, we always test them with specific tests.

RENE VAN DER LINDEN

Rene is Chief Engineer, his responsibility is managing all technical equipment.

The chance a part will fail is based on experience.

The delivery time of a part could possibly be 4-5 months, this is essential for the project.

It also takes a lot of time to change the part: take it out of the crane and putting the new part back.

We want to deliver quality for our client. They choose Heerema since we are the best you can get within offshore construction.

The hours one of my men will work in a post-process are hours they could also be putting into a task on-board.

I do not know what happens with my manufacturer's warranty when I put one of my own parts in this machine.

How do insurance companies react on parts I created myself? These will need tests, which takes time.

Auto motion designer is already on board.

Every check (for example tolerances) takes time, on-board time is money.

ERIK VAN HINTUM

Erik is former Captain of the Thialf, at this moment he is Marine Advisor at the office of HEEREMA.

The Captain is responsible for the vessel and therefore part of the Vessel Management Team (VMT).

Critical parts have a classification: REL classifies it. REL is a project executed a few years ago to research the parts that are in-stock.

It is important to make clear how much this idea will cost and when this money is returned (Return on Investment). This ROI influences the added value.

It should be clear what is needed to start printing; resources, education, etc.

APPENDIX 5

Order types

1. Regular re-order

This type of order is used to order parts that have to be on-board to maintain the vessel. These parts have a maximum and minimum quantity. Once the present amount exceeds the minimal quantity, new parts will be ordered by the storekeepers.

Preferable time to vessel: within calculated range.

3. Project-specific order

This type of order is used to order parts that are not on-board in the standard stock. They are needed to execute the specific project of the client. The Vessel Management Team will add these parts to the Project Resource List.

Preferable time to vessel: before departure.

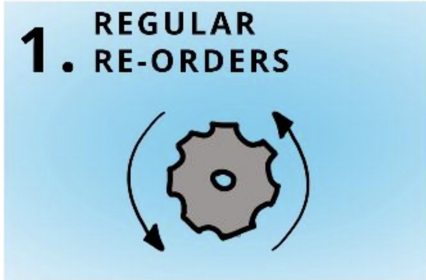
4. Expensive order

The difference between this order type and the regular re-order type, is the price. The parts of this type of order are such a big part of the budget that the VMT needs to approve the order before any further actions can be taken.

Preferable time to vessel: before departure.

VALUE STREAM MAPPING - PROCESS

The **first type** is the most regular process and therefore the most used, which makes it important to look into. It is important to know how parts are ordered regularly. The regularly ordered parts are named as 'Consumables' by the earlier conducted REL research.



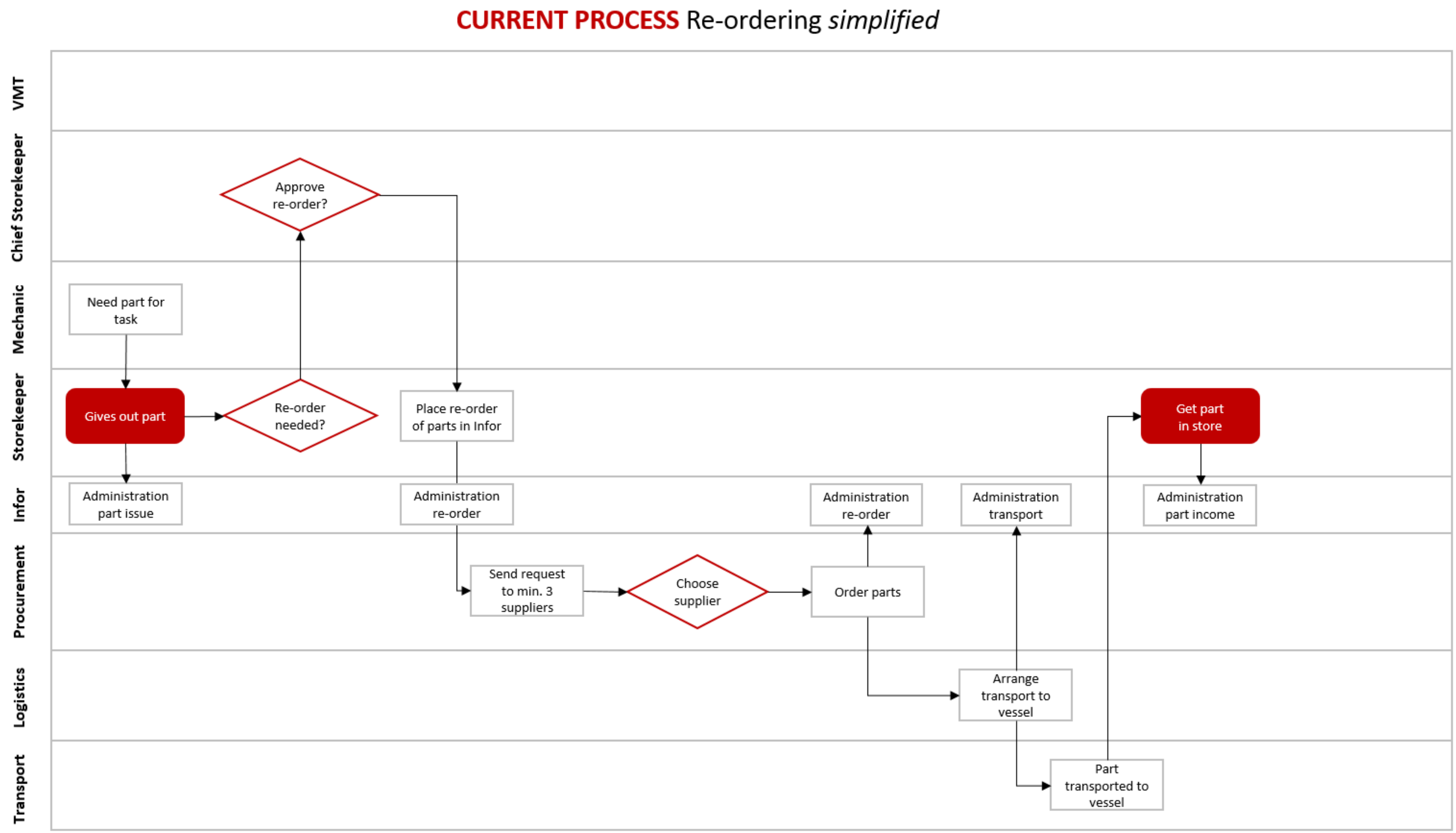
The **second type** is an order with a lot of potential in terms of economic and environmental impact since it is brought to the vessel by an extra transport. The parts that are named as 'Strangers' by the earlier conducted REL research are parts that fit within emergency ordered parts. Strangers are not mass manufactured, and therefore on-board in greater numbers than actually needed. However, they are unique, which makes them more expensive and less available. This type is visualized in figure X.

The **third type** will be interesting to include into further research, but for the first steps towards Additive Manufacturing, the client specific parts are too complex. The suppliers of the parts are unknown, just like the applications and load cases.

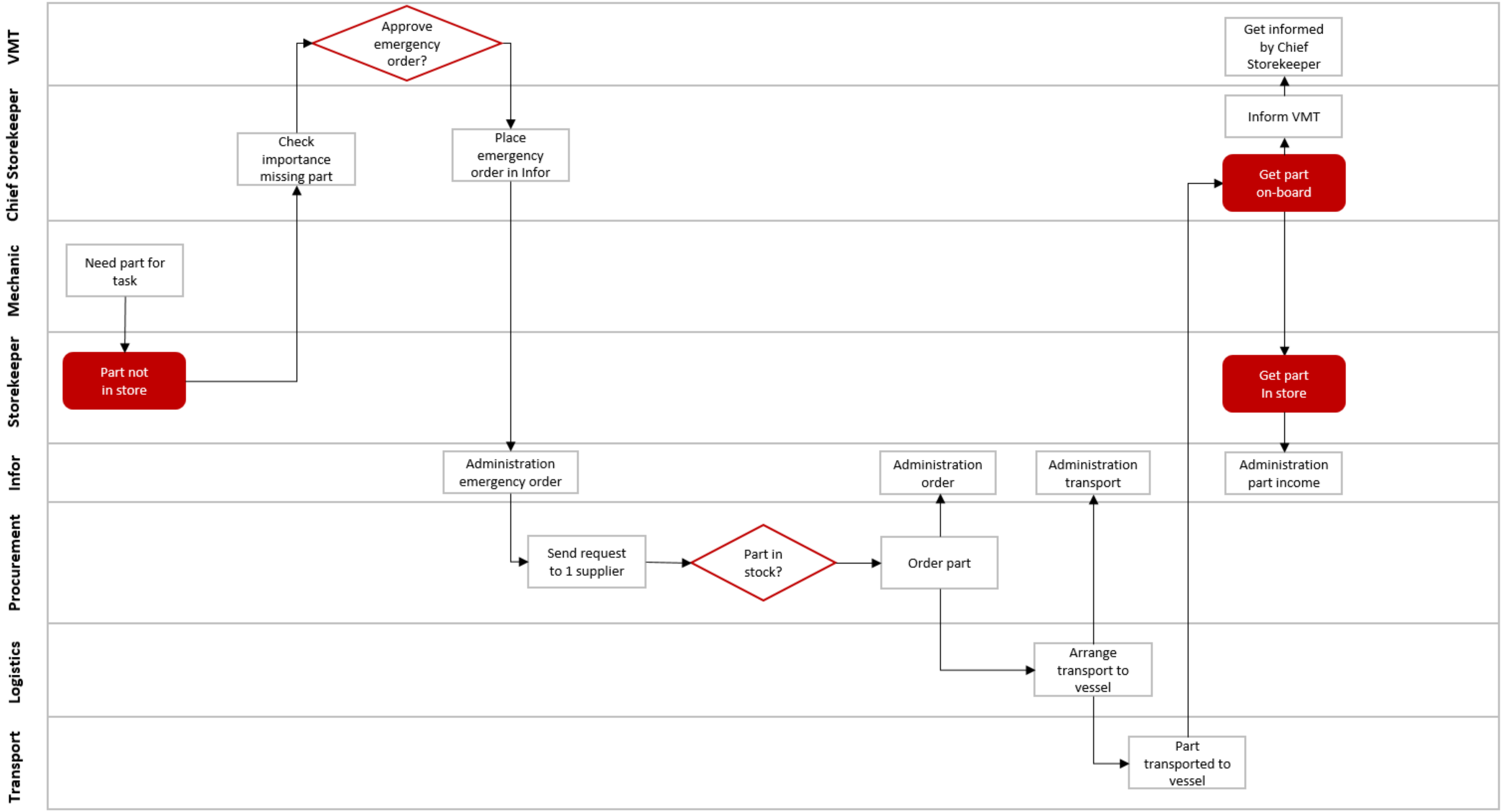
The **fourth type** is an interesting type because of the potential of decreasing costs by printing the parts instead of ordering them. However, the process has only one minor difference with the first type, which is the approval of the Vessel anagement Team.

APPENDIX 6

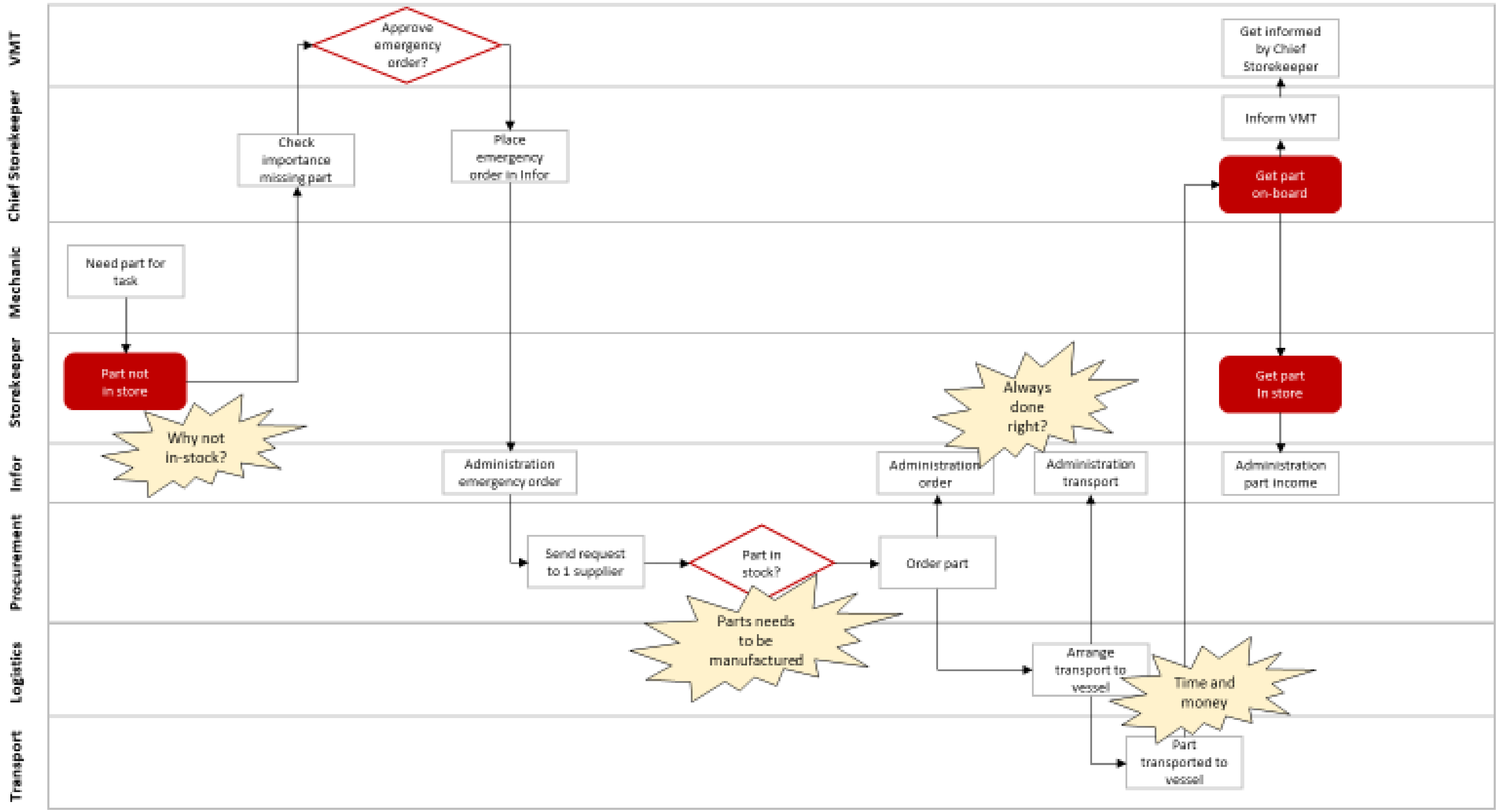
Value Stream Mapping of the 4 processes



CURRENT PROCESS Emergency order *simplified*



CURRENT PROCESS Emergency Order *simplified*



APPENDIX 7

Interviews External 3D printing metal in marine industries; interesting insights detailed

1. Huisman
2. University of Amsterdam
2. Shell Moerdijk
3. Royal Navy

1. HUISMAN – HUGO ROMER

GENERAL

Hugo graduated at the Research and Development department of Huisman. His topic was 3D printing steel. During his studies Hugo also did an internship at Heerema's Production department.

During his graduation he tested if the hook he printed could be trusted: therefore he printed blocks as well that could be used for material tests.

All parts that Huisman orders are made in Czech Republic/China. Hugo worked together with RAMlab in Amsterdam to research the print process called WAAM: wire and arch manufacturing.

According to H. Romer, implementing 3D printing has the following benefits:

- Recycling metal.
- Less shipping.
- Saving delivery time.
- Less carbon dioxide.
- One ship can execute more projects because you print the needed parts on location.
- Your operation is finished much faster.

CERTIFICATION

Within his project at Huisman, Hugo worked a lot on certification. According to Hugo, certification can be done in two ways:

1. One by one

By using this way of certification, all printed parts have to be tested individually. For this method each print has to be combined with a tie rod. This tie rod is used for the tests that have to completed before using the part.
Compared to a bakery: each croissant has to be tested individually before selling it.

2. Certify the 'recipe'

It is also possible to certify the 'recipe' of manufacturing a part. This way of certification is used with most welds in the offshore industry. If a part is manufactured according the certified recipe, the part will be certified as well.
Compared to a bakery: the baker tested different ways of baking croissants, he saved the best recipe. All croissant that are baked with this detailed recipe must be good to sell.

Which of the two ways of certifying a part takes less time?

TESTING

For testing it is useful to test a block of the used material. Hugo recommends to do 3 tests of each research to create a scientific result.
There are two ways of testing:

1. Destructive

Break it and see what happens.

2. Use it

Use it a lot and see what happens.
To check the quality of a parts, Hugo recommends to test the following:

- Yield strength
- Tensile strength
- Prolongation (breuk en trek)
- Hardness
- Wear
- Context: salt water
- Oxidation

Different laboratories help with testing materials:

- Element (NL)
- SGS
- TU Delft, material labs 3ME

Hugo also told me to be aware that not all parts need a certification of Lloyd.

Hugo Romer conducted a study about 3D printing parts for the offshore Industry at Huisman. The result of this study is a 3D printed hook with the Wire & Arc Additive Manufacturing method (figure X). According to Huisman the following benefits characterize the project (Huisman, n.d.):

- High control over process and material quality.
- Layer-by-layer manufacturing, enabling a new range of component shapes.
- Cost and/or lead time reduction for critical components.
- Tailor-made material properties within same product: strength, ductility, wear/corrosion-resistance, etc.
- Huisman welding expertise directly applied.

Huisman summarizes the benefits as follows:

"An important benefit for larger crane hooks is the significant reduction in delivery time at a cost that competes with forgings and castings, and a more consistent level of quality" (Huisman, 2018).

Since the report of Hugo Romer will be published publicly in 2022, detailed information cannot be gathered before. However, for this project I got the opportunity to get in touch with Hugo during a

Figure 79: 3D printed hook during its load test, Huisman

2. HEEREMA, University of Amsterdam

The University of Amsterdam conducted a research for Heerema about the potential of implementing 3D printing in the organisation of Heerema. Students of the University of Amsterdam asked the question: will 3D printed components be able to fully replace conventional produced components?

The reasons to start this research were:

- "Reducing waste by printing only the necessary components could help Heerema achieve intern circularity."
- "3D printing components on board could reduce Heerema's footprint and emission as well as creating a fully self-sustaining supply chain on each Heerema vessel."
- "Some of these parts are never used. Having stock on board is costly, stock limits the space available for other purposes and the extra weight on an offshore vessel increases fuel costs"
- "Resupplying an offshore vessel is also expensive."

Some interesting quotes of their research:
"For now, Additive Manufacturing is not eligible for actual use since the components do not fulfil the standard minimum requirements of the mechanical properties."

"Heerema should consider investing in prototypes of 3D printed components to fully evaluate the printability."

The students of the University of Amsterdam concluded that Selective Laser Melting (SLM) would be the most suitable method of metal additive manufacturing. However, the mechanical properties are not yet up to required standard minimum requirements of the mechanical properties. However, the switch to Additive Manufacturing metal parts would result in the following non-quantified benefits:

3. SHELL MOERDIJK – MARCEL VERCOUTEREN

Rotating workshop Shell Moerdijk started to 3D print metal parts. Their main motivators are the increasing environmental issues and the reduction of resource usage. Other motivators are the increasing prices and delivery time of OEM parts. They see 3D printing metal as full-fledged alternative to casting and forging as well as to mechanical machining (Vercouteren, n.d.).

3D printing at Shell is at a early stage; the picture on the right was their first try. Now Shell Pernis also did two projects with 3D printing metal parts.

Shell mostly works with OEM parts (Original Equipment Parts) (Bulthuis, n.d.), which have high demands and strict certification. The manufacturers do not give information easily and the delivery time is very long. Next to that, some of the parts Shell used to order are now produced by a new Italian company which results in a lower quality.

Shell Amsterdam has done a big investment to purchase a 3D printer. This investment was made to manufacture old parts that are not manufactured anymore. This means there are no consequences on the Intellectual Property Rights (IPR). The parts that are printed are 'simple' parts like a valve of a *water pump.*

Shell tests the parts as follows: Scan with NDO and Rontgen. Place part in mechanism. Monitor the mechanism. Check status of part after 1 year of use.

Marcel Vercouteren • 3de+
Maintenance Team Leader Shell Moerdijk
2 mnd • Bewerkt •

Rotating werkplaats Shell Moerdijk stap in de wereld die 3D printen heet.

De berichtgevingen over 3D printen van metaalonderdelen stapelen zich de laatste tijd steeds verder op. Er gaat haast geen vakbeurs of congres meer voorbij of men kan kennismaken met deze geavanceerde manier van produceren. Was men enige jaren geleden over dit thema nog als een roepende in de woestijn en nauwelijks serieus genomen, tegenwoordig is dat geheel anders omdat de moderne maatschappij daar blijkbaar gewoon aan toe is. De milieuproblematiek en het terugdringen van het grondstofgebruik geven mede een enorme 'boost' om deze technologie serieus te overwegen als volwaardig alternatief voor het gieten en smeden alsmede voor het mechanisch bewerken ook binnen Shell.
Daar OEM parts steeds duurder worden en levertijden soms geen optie zijn besloot Rotating werkplaats Moerdijk in samenwerking met Shell Amsterdam eerste waaier te printen.

Figure 80: Shell Moerdijk, Linkedin (Vercouteren)

4. ROYAL NAVY – JAN, SANDER

Jan Spoelstra
j.spoelstra@vakbladen.com
088-2266625

Jan Spoelstra published an article about printing on board in the magazine 'Maritime Nederland' (see figure X).

In his article he mentions that companies with big vessels should contact the Royal Navy. That is why I tried to get in touch with Jan, so he could help me with getting in touch with them.

Jan Spoelstra separates two ways of implementing 3D printing on-board: as a startup, or through a longer research trajectory. According to Jan the Royal Navy has a computer, scan and printer in one room on-board of their ships.

"Heerema should not worry, just place a 3D printer on board together with two skilled employees and see what happens!"

COPY CAT THE START UP mentality?

Does this mean we have to take it slow? According to Jan Spoelstra, Chief Editor of Maritiem Nederland, there are two ways of implementing a new technology like 3D-printing.
First, the conventional way: doing research, setting up a business case and slowly letting your organisation get along with this new technology. The other way is much faster: implement it like a start-up. **The Royal Navy** of the Netherlands choose for this option: placing a printer on-board and print non-crucial spare parts. Not every company has the privilege to do so, but according to J. Spoelstra companies with big ships with a lot of crew sure do have potential (Spoelstra, 2020).

Redactioneel

3d printen aan boord

Er zijn ruwweg twee manieren om nieuwe technologie in te voeren. Langzaam of snel. De langzame manier, waarbij je start met onderzoek, een business case uitwerkt en de organisatie langzaam laat meebewegen, kent een hamvraag. Kunnen we er geld mee verdienen? Volgens verschillende sprekers op de 3D Print Conference die op 11 februari werd gehouden in de 3D Makers Zone in Haarlem kan dat op twee manieren.

Aan de ene kant doordat 3d Printen en Additive Manufacturing zaken mogelijk maakt die voorheen niet mogelijk waren. Er werd een voorbeeld genoemd van een 3d-geprint onderdeel van de inspuiting van een benzinemotor, die het mogelijk maakt de brandstof fijner te vernevelen in de cilinder, waardoor de motor zuiniger en krachtiger wordt. Het gevolg is dat het bedrijf een 'premium' label op die motor kan plakken en er 20% meer geld voor kan vragen. Daarnaast zou je 3d printen of AM kunnen invoeren om bestaande processen te veranderen of optimaliseren. De stip op de horizon voor de maritieme sector kan een wereldwijd netwerk van printers zijn, waar je onderdelen op aanvraag kunt bestellen, met korte levertijden, waar ook ter wereld, zonder dure warehouses.

Bij het invoeren van 3d Printen en AM moet een hele organisatie meebewegen. Bovenstaande voorbeelden laten zien dat de afdeling logistiek anders moet omgaan met voorraden, dat marketeers een nieuw label op een product kunnen plakken, dat onderhoudstechnici met nieuwe materialen en machines werken, dat ontwerpers er rekening mee moeten houden dat AM-machines producten moeten kunnen maken, dat de financiële afdeling de hogere kosten voor één enkel product afweegt tegen het reduceren van de warehouse capaciteit. Hoofdbrekens voor bedrijfskundigen – ik snap wel dat deze technologie de beloftes van vijftien jaar geleden nog niet heeft waargemaakt.

De Koninklijke Marine koos echter voor de snelle manier van invoeren, als een startup. Personeel aan boord van de schepen kreeg de beschikking over 3d-kunststofprinters om zelf aan de slag te gaan met het fabriceren van niet cruciale reserve-onderdelen. De 3d-printers fabriceerden afdekdopjes die mitrailleurs beschermen tegen zout zeewater, waterfilters, de behuizing van stopcontacten en onderdelen van de HVAC installaties. En wat bleek? Het werkt. Inmiddels staan op alle grote oppervlakteschepen 3d-kunststofprinters, en wil de Marine dit uitbreiden naar metaalprinters.

Dat biedt de nodige uitdagingen, want die zijn gevoeliger voor beweging en variabele weersomstandigheden, maar ik verwacht dat ze deze aan de praat gaan krijgen aan boord. Fascinerend. Niet iedere organisatie kan het zich veroorloven om op deze manier bepaalde processen rigoureus om te gooien. Maar mocht uw bedrijf grote schepen met veel personeel in de vaart hebben – waar aan boord nog wel eens wat gerepareerd moet worden – ga eens praten bij de Marine die het nodige voorwerk inmiddels gedaan heeft.

Jan Spoelstra
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Cover

De 'Lady Christina' van rederij Wijnne Barends maakte in 2019 een anatal testvaarten met twee VentiFoils aan boord, naar een idee van ontwerpbureau Conoship. De foto werd gemaakt door Herman IJsseling in opdracht van Wijnne Barends.
Vanaf pagina 28

ARTIKELEN

RUBRIEKEN

februari 2020 | 3

Sander Wanningen
On the 13th of March a visit to the Royal Navy in Den Helder was planned. Sander Wanningen works at the Expertise Centre of Additive Manufacturing and invited me to visit them. Unfortunately this visit was cancelled due to Covid-19 measures. Therefore the questions were asked by phone.

"You did not choose an easy topic, it is very complex since you are talking about metal, printing on-board and parts with a certain quality."

Royal Navy Netherlands
The Royal Navy already uses Ultimaker printers with the plastic FDM technology on their ships (Snel, Volle kracht innoveren, 2018). Their goal is to use different types of Additive Manufacturing on all their ships. Instead of selecting parts first, the Royal Navy set up rules of what was allowed to print and what not. At the Expertise Centre of Additive Manufacturing, they are researching the possibilities of metal 3D printing. The Desktop Metal printer is one of the technologies they are looking into.

Sander Wanningen is a Marine Officer of the technical service of the Royal Marine. Before joining the marine he studied at the TU Delft. 3,5 years ago he joined the main yard in Den Helder. He started small experiments with plastic 3D printing. At this moment the Royal Navy is professionally printing plastic parts. They aim to go from plastic to metal prints on an iteration base.

To realise this aim they build a network with: Bridelands, TNO, L&R, RAMlab.

Their roadmap contains the goal of printing critical and non-critical parts of all sizes globally, even on the ships. Sander thinks this will be possible with a 3D print container.

Material guarantee and quality of the parts

The Royal Navy came up with this goal because

Figure 81: Sander Wanningen Royal Navy (Snel, Volle kracht innoveren, n.d.)

Figure 82: Sander Wanningen Royal Navy (Snel, Volle kracht innoveren, 2018)

APPENDIX 8

Interviews External 3D printing methods; interesting insights detailed

LAYERTEC FIRST MEETING

Questions

Hoe gaat het eraan toe zodra een onderdeel het begeeft?

- Hoe aan boord?
- Altijd aanwezig?
- Wat als niet?
- Wie installeert de onderdelen?
- Hoe gaat dat?

Answers

LAYERTEC – Combining Ultimaker and Desktop Metal

To discuss the possibility of combining an Ultimaker printer with the Desktop Metal debinder and furnace a call with Dennie Rijk was planned.

According to Dennie it is not possible to place parts that are printed with BASF metal filaments on a Ultimaker in a Desktop Metal furnace: because of the created vacuum **the parts explode**. This has been tested by the engineers of Desktop metal themselves.
Also, during November 2019 one of the clients of Layertec has tested a print with the BASF material in an Ultimaker, but the **shrinkage** was very unpredictable which resulted in endless printing before the right measurements came out of the process.
Next to that, the Ultimaker will not print the **ceramic layer** that the Desktop metal printer does. This layer is needed because of the shrinkage in the furnace.

According to Dennie it is possible to put the BASF metal filaments in a Leapfrog, but it might be needed to change the printhead to a harder one.

Dennie also told me about Markforged (Markforged, n.d.), another company that sells 3D printing systems for metal parts with the Bound Metal Deposition technology. Markforged systems only have their own printer, the debinder and furnace are industrial machines from other companies. Especially the furnace differs a lot since it needs approximately 15.000 liters of Argon, whilst the furnace of Desktop Metal only uses 900 liters of Argon per session.

LAYERTEC SEMINAR

Questions

Hoe gaat het eraan toe zodra een onderdeel het begeeft?

- Hoe aan boord?
- Altijd aanwezig?
- Wat als niet?
- Wie installeert de onderdelen?
- Hoe gaat dat?

Answers

WEBINAR DM

How are DM users currently handling intellectual property (design files), both in terms up "sending these files around the world", and tracking version control / traceability across the different users of a specific file?

The "send files instead of parts" aspect is more related to the supply chain reengineering opportunity for manufacturers, rather than the specifics of Desktop Metal software. (The files are tyopically shared in a variety of secured ways, such as box.com, internal networks, etc.)
As it related to DM's Fabricate software: We use encryption methods similar to other cloud-based secure apps. And of course, a local version of Fabricate is available - so that files can stay within the confines of your local network.

Can you go into detail on that 3 week lead time as fas as how long each step takes?

4-5 days to print (it's a large part!), another several days to debind (thick walls!) and sinter. And a several day turn-around for the case hardening (plasma nitriding) process.
Most parts start-to-finish are completed within 5 days.

Did you discover the possibilities of bronze material already?

This question has been answered live
We have many materials in development including bronze. Would love a chat offline if you have a specific application need.
meghan@desktopmetal.com

What if you have trouble receving the drawings from the former manufacturer?

If you have the part, it can be re-modeled in 3D CAD via reverse engineering (measure and model); or, scanned via a 3D scanner and "clean up" the resulting file before printing.

APPENDIX 9

Interviews Heerema Employees; interesting insights detailed

JAN PLUIMGRAAFF 24/01/2020

Function: Superintendent (VMT)

Questions

What happens if a part fails?

- How does it work on board?
- Is the spare part always there?
- What if the part is not on board?
- Who installs the parts?
- How does that work?

Answers

The process is as follows: Procurement, to Logistics, to Transport, to vessel.

Different scopes are: getting the part on-board, maintain the warehouse and installing the spare parts. According to Jan the focus of this project is most interesting within the scope maintaining the Warehouse.

Sometimes the parts are brought to the vessel by an Junior Engineer by plane.

There is a *Project Resource List (PRL),* this is a list of parts needed specifically for the project. The subcontractors deliver their own containers.

At this moment the vessel is testing with load tests on-board.

Parts can be certified, most certified parts are seen as critical as well.

There are different stores: the consumables with a min/max quantity and the parts downstairs. The parts downstairs are especially important for Heerema since they implicate if Heerema is having its affairs in order.

The Chief Engineer is part of the *Vessel Management Team (VMT)*. He is responsible for the decisions about the parts on-board together with the Captain and the Superintendent. They ask the Chief Storekeeper to get the parts on-board together with his Storekeeper team.

Dave Woessner 27/01/2020

Function: Lead Drawing Team

Questions

- Pros and cons 3D printing
- Design study parts
- Fun print

Answers

CAD Models can be generated with *Nerbs* (mathematical, like SolidWorks), or as a *Tri-mesh* (not clean, risk of flipped surfaces, STL).

Slicer software likes the files as clean as possible.

What if the printer has to work 24/7? How will you solve problems that occur? The crew should understand the 3D printing technique and the printers (software and hardware).

3D Printing is ideal for organic shapes and complicated details.

Look into: The makers: Precious Plastics.

How can I get the most efficiency out of my part? Is it printing apart and then glue together? Print direction also of importance.

Jasper van Driel 27/01/2020

Function: Graphic Designer

Questions

- Pros and cons 3D printing
- Design study parts
- Fun print

Answers

3D printing can be used as a manufacturing tool: create a mould and then cast the part.

Jasper has his own 3D printer (AliExpress.com. He works with Fusion 360 as his slicer program.

It is important to create support base within Heerema.

An idea: set up an mobile 3D printer container. This could make it possible to combine big and small 3D printing techniques. The container can be stacked on the deck instead of taking up permanent space in the workshop.

If post processing is needed you can always ask the guys of the Workshop (as long as you have access to the vessel).

You can also decide to go for the polymers that are mechanical loadable: nylon and polycarbonate.

Catherine Barney 28/01/2020
Function: Process Improvement Manager
Questions
- Kaizen methods
- Microbattles at Heerema: procurement?

Answers
Value Stream Mapping is a useful method to analyse processes and their bottlenecks. *The files that show the Value Stream Map method can be found in the 3D Printing folder on the Technology Management drive.*
Other methods that can be used are Lean and Six Sigma.

One of Heerema's Microbattles will be focussing on the procurement process that could be more efficient. This Microbattle might have overlap with the analysis of my Graduation Project.

A few years ago the REL project got executed. Result was that there are 15.000 online forms per year with 700 suppliers.
Another REL result are the categories: Runners (daily parts), Repeaters (the parts that are ordered with a certain rhythm) and the Strangers (the parts that are ordered incidentally).

Kevin Braber 28/01/2020
Function: Sr. Equipment Resource Coordinator
Questions
- Problems current process parts on-board
- Which part commonly fail and why?
- How do I get an overview in the Excel? What are possible categories?

Answers
Logistics is mostly dragging parts from manufacturers/suppliers to the warehouses or vessels.

Do parts get repaired? I do not know if they leave the ship or if they fix this on board.

Everything is shipped with big containers (5.8 meters – standard size) from steel. The smaller parts get delivered on pallets.

One of the warehouses is in Vlissingen. This is where we send the parts, they send it to the vessels.

We use the system called Infor, in which you can also see if a part is certified.

For some parts we have to pay import costs, these costs are added to the purchase price.

The Project Resource List (PRL) is used as a shopping list, mostly Heerema adds parts to this list.

If your project has the outcome that concludes we should not start 3D printing it is also very valuable.

With the function *Track by Asset* in Infor, you can see which parts are being reused.

It is a good thing to prevent re-orders.

An agent helps with the finances and administration of shipping and containers.

Heerema uses their own containers, but uses ships of other shipping companies.

If there is an emergency (a part is missing) they decide to use a plane to get the part on board. This can be very expensive. An example: 350 kg to Trinidad for 3€/kg, which equals in 1050€ for only transporting a part to the vessel.

Think of: how much time do you need to model the parts on your computer? You can use the following reminder: 1 day of no project execution is approximately 1 million€.

The delivery time is very complex since it depends on a lot of factors:
- Location
- Situation
- Manufacturer
- Supplier
- Availability ships/containers

Hans Havermans 29/01/2020
Function: Chief Storekeeper
Questions
- How do the vessels get their spare parts?
- Procurement process
- Logistics process
- Storing de spare parts
- Using the spare parts
- Workshop: which parts do we create on the vessel already?
- Why is this not the process HMC wants to continue with?
- Which parts commonly fail, and why?
- Excel Visualisation

- Hans his opinion on 3D printing as additional method to produce parts.
- Smaller parts
- Bigger parts
- Certified parts
- Pictures of the environment we are talking about.
- How do they decide what to take on-board and how many to take on-board.
- What is the basic quantity in stock? Is there?

Answers
Hans is Chief Storekeeper and is responsible for the transportation of spare parts, administration of the certifications of parts and all other part related administration. Next to that he advices departments about alternatives (for example in the switch from IS to Infor).

There are two different stores on-board of the Thialf: the general store and the Deck store.

For this project Hans would like to see what time it takes to have the investment back.

About the Service of Layertec: what if a mechanical part in the hardware fails? What is the price of spare parts and do we need to replace this ourselves?

If we have to educate the crew, please do so while they are onboard and not during their leave of absence.

Out of the REL project we have three categories of parts:

- Critical = equipment (crane/head engine) and a long delivery time (long = more than 3 months).
- Strategical = not critical, but long delivery time.
- Consumable = parts like an O-ring, easy accessible.

Most of the time the minimal number of units that can be ordered is 100 parts.

Other categories that are used:
- Runners = parts like an overall.
- Repeaters = strategic: critical with short delivery time.
- Stranger = critical parts, there is not much of it in stock.

The people who work with the parts have to understand the materials, you learn this by experiencing it.

The minimum quantity is based on the time it takes to refill the stock. With this minimum quantity the delivery time of the new parts can be bridged.

Hans thinks the 3D printing decisions have to differ per project.

It is important to know if it works: does the quality meets?

In the workshop they repair parts and create their own parts.

Another idea is creating a small factory where we create our own parts.

Another idea is a situation in which we create a model at the office at print it on the vessel.

The Storekeepers work with Infor to fix the administration of all spare parts in-stock.

Rinze Huisman 29/01/2020
Function: Equipment Manager
Insights
Costs in and out: what does it yield?

What do we pay extra or less and for what?

Make a difference between dynamic and static parts.

According to **Rinze Huisman,** Equipment Manager at the Leiden Office and Technical Superintendent of the Thialf the idea of placing a 3D printer on-board is questionable: “I do not see potential in this application, but nothing ventured nothing gained.”

Rene van der Linden 29/01/2020
Function: Chief Engineer
Questions
- How do the vessels get their spare parts?
- Procurement process
- Logistics process
- Storing de spare parts
- Using the spare parts
- Workshop: which parts do we create on the vessel already?

- Why is this not the process HMC wants to continue with?
- Which parts commonly fail, and why?
- Excel Visualisation
- Hans his opinion on 3D printing as additional method to produce parts.
- Smaller parts
- Bigger parts
- Certified parts
- Pictures of the environment we are talking about.
- How do they decide what to take on-board and how many to take on-board.
- What is the basic quantity in stock? Is there?

Answers
Rene is responsible for the technical maintenance of the vessel.

For some parts the delivery time can be 4-5 months, for these kind of parts this project could be essential.

It takes time to change the parts as well. We have to remove them out of the assembly and place them back.

We have different rolls of materials on board.

Take into account: specifications of the materials; alloys for salt water, bronze, universal materials. Also depends on the application of the part.

Every moment we are not executing a project is costs money.

Take into account that Heerema has a reputation of quality. Collaborating with Heerema is like buying a John Deere: you know it is good. Doe the clients agree with using 3D printed parts?

What is the quality of the printed parts?

What are the costs per unit? Maybe we can fix it ourselves in the workshop already?

Make an overview of hours and costs:

- Self → man hours (could have been used somewhere else as well).
- Ordered

Think of tolerances: do we have time to check this? Also takes time!

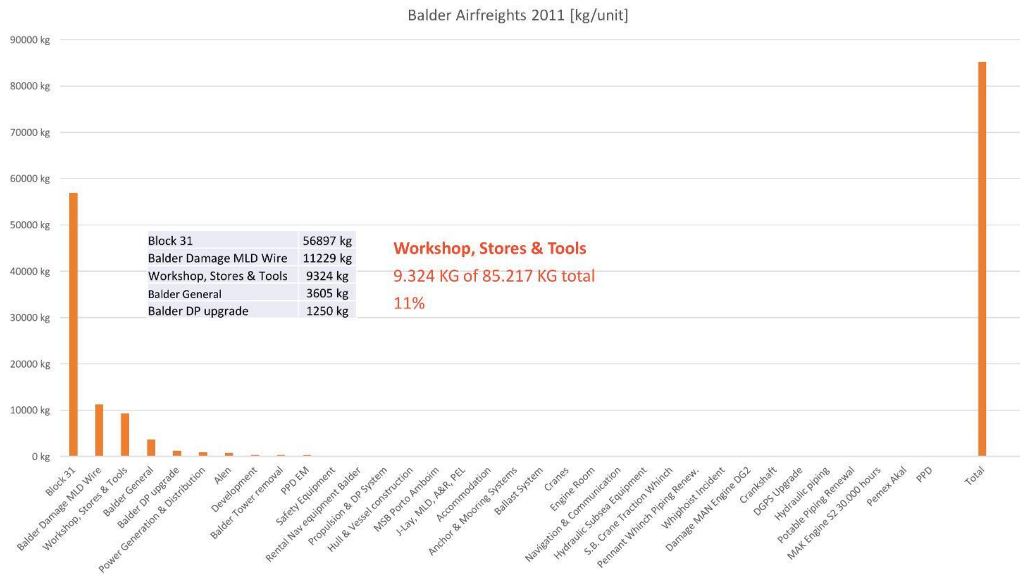
What if we are waiting for a part and it looks like it will not fit in the end?

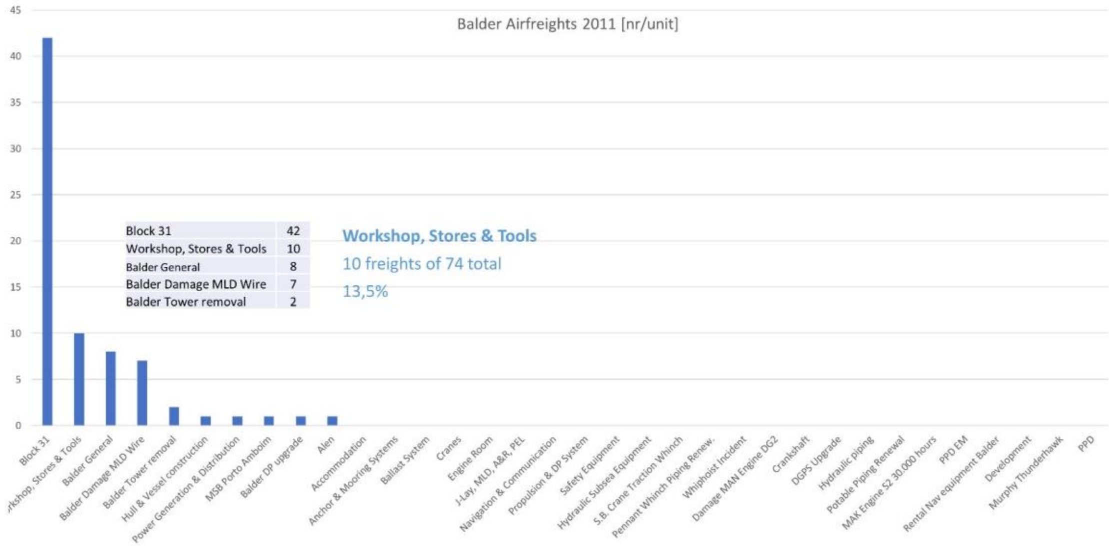
APPENDIX 10

Results Analysis Air Freights Balder 2011

BALDER 2008-2011

	Nr.	KG	Kg/Freight
2008	90	43007 kg	478 kg/airfreight
2009	63	63267 kg	1004 kg/airfreight
2010	64	49205 kg	769 kg/airfreight
2011	74	85217 kg	1152 kg/airfreight





APPENDIX 11

Why not do it?

Being aware of the risks of the implementation of one of the concepts is important since it can be decided to eliminate, avoid or accept them (Tonnquist, 2018). The method to analyse the strategic position of an idea is the SWOT Analysis (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). This method includes the *Strengths*, *Weaknesses*, *Opportunities* and *Threats*. Since the *Strengths* and *Opportunities* of implementing a 3D printer are already discussed and we would like to know why we should **not** do it, the *Weaknesses* and *Threats* are defined in this chapter.

WEAKNESSES

Which internal origins weaken the position of the achievement?

CONSERVATIVE ATTITUDE ON-BOARD

As mentioned in several interviews, it is hard to implement changes on the vessels. The crew is used to their routines and does not like to adapt to continuous changes of this framework.

CAD MODELLING TAKES TOO LONG

When modelling the parts takes too long, the benefits of 3D printing on-board decrease. The amount of man-hours needed for a print increases, which makes it a more expensive way of producing.

FAILING FIRST PRINTS

At the moment a print, or even several prints, do not fulfil the wishes or requirements of the crew, the risk of the 3D printer getting kicked out appears. “You see? I told you this would not work!”.

THREATS

What is threatening the achievement externally?

AVAILABILITY TECHNICAL DRAWINGS OR CAD MODELS

As already mentioned in the weaknesses of the implementation, the CAD models could be a bottleneck. This also is a threat since receiving the models happens from external parties.

CERTIFICATION OF PARTS

As long as 3D printed parts do not get certified externally, it is not advisable to print critical parts. This does not mean parts cannot be printed, but is does stop the initiation phase of a new set of rules, and thus parts later on in the Printing phases.

SERVICE LAYERTEC INSUFFICIENT

The Engineers at the Thialf are already experienced in producing parts, but they do need additional knowledge to adapt to the new production method of 3D printing. If the service of Layertec does not deliver the support needed, this might get the implementation in the way.

APPENDIX 12

Mail contact ordering worm wheel

OVERVIEW

REQUISITION PHASE

- First step is a GL and WBS.
- Next step is: description, vendors, price.Turns out to be an Infor part; contact Kevin Braber.
- Requisition is made in SAP because of Infor.

"Attached the list of G / L codes, you may know better what this falls under. We do not have / use WBS because we book in the budget department 1502404 for Technology and 1502124 for Strategy."

PROCUREMENT PHASE

- More information needed:

"Do you have more information about this request as a quote or else the Vendor?"

- Turns out worm wheel gear factory does not exist anymore.

"I would like to search for the worm gear, but then this will take a while and will probably require a drawing."

- Normally a part has 3 potential vendors to prevent having no vendor (as is happening here). However, according to Nico: *"very specific parts such as worm gear are not made by 3 different manufacturers, it is just the manufacturer itself".*

- Ordering parts normally takes 2 weeks, with Covid-19 not sure.
- Lever was never bought before at selected vendor.
- Lever will arrive 5 weeks later at the Office Leiden.

CONCLUSION

At the 26th of March the first serious steps were taken for ordering the original parts, on the 17th of April the Lever was ordered. The estimated time of arrival is 22nd of May. This means ordering the lever would take **2 months.**
Ordering the worm wheel was an even bigger hurdle since it turned out the factory did not exist anymore. Question arises: what would happen if the last part is used and there are no more spares in-stock? According to Nico, in this situation, the whole motor operated valve has to be replaced. Replacements of whole systems because of missing parts, occur once in every ten year according to Nico. Nico also mentions when a factory closes down, the drawing will not be available anymore.

We can conclude that for both parts there is room for improvement in terms of delivery time and availability of parts.

EMAILS

REQUISISTION PHASE,

Peter

Jessica,
Kun jij een requisitie maken met GL en WBS voor Meike zodat er onderdelen bestelt kunnen worden? Kan op algemeen S&T.
Dank je wel,
Peter

Jessica

Hi Peter, Meike,

Ik zou heel graag een requisitie aan willen maken maar ik heb meer informatie nodig, zodat ik een G/L account kan toepassen.
Een WBS element word alleen gebruikt bij projecten, niet als die op de S&T afdeling geboekt wordt.

Info die ik nodig heb is zoal:
Beschrijving
Vendor
Prijs

Jessica

Ik zou graag willen helpen, alleen op de afdeling werken we niet met Infor. Ik kan je dus hier niet mee helpen, ik heb ook geen access tot Infor. Engineers hebben wel access tot infor.
Infor wordt voornamelijk gebruikt op projecten. Ik zou even contact opnemen met Kevin Braber hoe dit op te lossen.

Peter

Jessica,
Weet je anders een GL en WBS van onze afdeling?

Als dat niet lukt Meike, kan ik het ook kopen met mijn credit kaart

Jessica

Hi Peter,

Bijgevoegd de lijst met G/L codes, wellicht weten jullie beter waar dit onder valt. We hebben/gebruiken geen WBS omdat we op afdeling budget boeken dus 1502404 voor Technology en 1502124 voor Strategy.

Peter
Jessica, Meike,

Probeer maar:

G/L 410110
Afdeling 1502124 ipv WBS want daar ben ik Budgethouder van en kan ik snel goedkeuren.

Jessica
Hi Johan, Kevin,

Even een vraagje; er moet een requisitie komen voor onderstaande INFOR items, alleen moet dit op een afdelings cost center en dus geen wbs element available.
Op afdelingen werken we niet met INFOR.

Kan ik deze requisitie ook in SAP maken???

Jessica
Daan, Peter,

Voor onderstaand heb ik een requisitie aangemaakt zodat deze er maar alsvast is. Ik heb nog geen antwoord van Procurement maar deleten kan altijd.

R404JS1068 – Original parts 3D printing
Please release.
Note; no vendor filled in yet.

PROCUREMENT PHASE

Nico
Hebben jullie meer gegevens over deze requisitie als offerte of anders de Vendor waar we dt vandaan halen kan ik get zsm bestellen

Meike
Zie de screenshots voor meer informatie over beide onderdelen.
Is dit voldoende? Zo niet dan hoor ik het graag, ga ik kijken of ik die informatie kan verkrijgen!

Nico
Dit zijn engine parts en afsluiter onderdelen
Weet je dir zeker sowieso bestaat de afsluiter fabriek niet meer en onderdelen krijgen is erg moeilijk

Meike
Bedankt voor je reactie en fijn dat je zo mee denkt.
Heb je wellicht een tijdsindicatie hoelang het duurt om de onderdelen op kantoor te krijgen?
Misschien zelfs een tijdsindicatie per onderdeel?
Ter controle: het tandwiel (10003865) komt uit de afsluiter fabriek die niet meer bestaat?

Nico
Duurt normaal ongeveer 2 weken maar ni=u met Corona durf ik dat niet te zeggen
Tandwiel komt inderdaad uit fabriek wat mier meer bestaat dus moet uit Azië komen heeft erg lange levertijd

Nico
Heb de lever aangevraagd bij leverancier (was nog nooit ingekocht)

De worm wheel gear moeten we wat anders voor bedenken dat wordt echt niets

Meike
Bedankt voor alle moeite!
Als ik het goed begrijp is de lever nu besteld, klopt dat of is een aanvraag bij leverancier nog een andere stap in het bestel proces?

Wat betreft de worm wheel gear: zelf heb ik 0 ervaring met de inkoop van dit soort onderdelen, heb jij een aanbeveling wat we hieraan zouden kunnen doen? Wat zou het VMT bijvoorbeeld doen in een situatie als deze?

Nico
De lever staat in aanvraag bij de leverancier
Voor de wormgear wil ik best gaan zoeken maar dan duurt dit wel even en waarschijnlijk een tekening nodig.

Meike
Betekent ‘in aanvraag staan’ dat de leverancier een offerte stuurt?

Zoeken naar de wormgear zou fijn zijn met het oog op de gewenste resultaten van mijn project!
Heb je een tijdsindicatie van een zoektocht als deze?

Nico
Ja klopt maar weet niet of lerverancier fully operationeel is

Wormgear ga het proberen maar dit gaat wel een poos duren komt uit Azie en daar is zo’n beetje alles in lockdown

Meike
Oke, ben benieuwd! Hopelijk kan de lever in ieder geval geleverd worden. Ik hoor het graag zodra er reactie is.

Wat betreft de wormgear: klopt het dat er normaliter 3 vendors voor 1 part beschikbaar zijn? En zo ja, zijn deze alle 3 niet meer beschikbaar voor de wormgear?

Stel dat de Thialf dit tandwiel nu zou bestellen, welke stappen zouden er dan genomen worden als er hoge nood is?

Dankjewel! Mocht ik iets kunnen uitzoeken en je daarmee helpen hoor ik het graag.

Nico
Heel specifieke onderdelen als wormgear worden niet door 3 verschillende fabrikanten gemaakt dat is gewoon alleen de fabrikant zelf

LOOKING FOR WORM WHEEL
Nico - Shimadzu
Dear Sir

We are looking for:
1 ea Worm Wheel Gear ratio 1 : 80
    Manufacturer: Shimadzu
    Drawing: RE-02503
    Part no. 21
Please give us price and del. time

Shimadzu – Nico

Beste Meneer de Hoop, sunny greetings,

Hope this find you and your team keeping well.
Well received your enquiry for Shimadzu, however, due to obsolete spares as we had struggled in the past for
their device, would you please provide copy of relevant drawing by return? - And is it for SSCV Thialf?
Please take good care and stay safe.

APPENDIX 13

Key challenges

Challenges have to be overcome to get to the implementation of the Studio System on board the vessels. The challenges that seem to be the biggest hurdle are called the Key Challenges. This chapter introduces them with Figure x showing an overview of the Key Challenges per scope. The position of the challenges within their scopes is based on two axis:

- X-axis: how much is already known about this challenge?
- Y-axis: where is the knowledge about the challenge that is needed to solve it?

Crucial insights about the implementation of the Studio System are gathered during an interview with Hans Havermans, Chief Storekeeper Thialf, about the Desktop Metal Studio System.

For every challenge, the important, already known **variables** are mentioned. These variables give insight in the complexity and the scope of the certain challenge.

For every Key Challenge the **threshold** is also mentioned. The threshold shows the range in which the challenge should be solved.

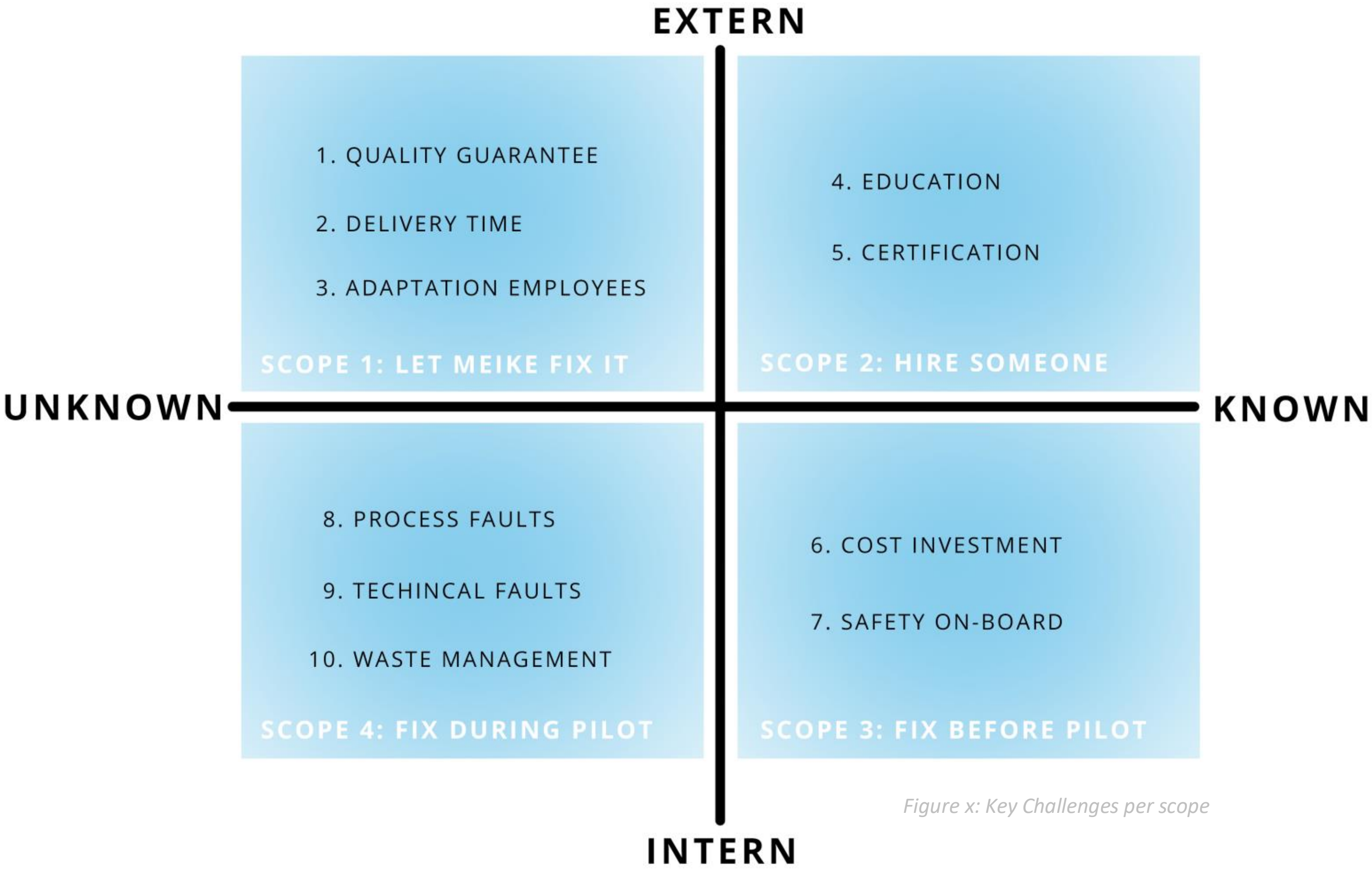


Figure x: Key Challenges per scope

1. DELIVERY TIME
The challenge is to get the spare part on-board of the vessel as soon as possible, without the use of extra transports. This challenges has to take into account: the area of the project offshore, the stock of thee manufacturer, availability of part/drawing, project phase.
Threshold
The threshold for this challenge depends on the order: with an emergency order every hour counts.

2. QUALITY PRINTS
The challenge is to get the right quality with the 3D printed parts. Is the quality of 3D printed parts sufficient? What influences the print quality?
Variables
Tolerances, mechanical properties, density, wear resistant, tilt of vessel.
Threshold
The threshold of this challenge is set by the original part. However, the crew should be aware that some parts might be designed with an over-dimension. Therefor it is important to take the application into account as well when producing a part.

3. ADOPTION BY VESSEL CREW
The challenge is to make sure the crew adopts the 3D printer by experiencing the added value. It is important to get clear the 3D printer supports their job, instead of taking it over. What does the crew need to approve the benefits of the system?
Variables
Man-hours used/left over, added value 3D printer, amount of failures.
Threshold
The threshold of this challenge is specific: the implementation succeeds or it does not. This success depends on several factors, these will be added in the pilot plan (Chapter 4).

SCOPE 2: HIRE SOMEONE

4. EDUCATION
The challenge is to get to the point where the vessel crew can use the 3D printer independently.
Questions
Who should be educated? To which level? Are the skills already in-house?
Variables
Software modelling, software slicer, hardware Studio System, adaptation crew, support Layertec, existing knowledge.
Threshold
This challenge is achieved once the crew does not need external support anymore to fix an error in the system or a fail in a print.

5. CERTIFICATION
The challenge is to get a certification on certain critical parts, so they crew can use the parts in existing critical machines. Once the quality of the prints is proven, an external party has to certificate the part. This certification is needed to ensure safety of use.
Questions
What is needed to get a part certified? How to achieve this?
Variables
Quality of 3D printed parts, warranty of material quality, test possibilities on-board, norms of certification organizations.
Threshold
The threshold of this challenge is set by external certification organisations, for example Lloyds.

SCOPE 3: FIX BEFORE PILOT (ASAP)

6. COST INVESTMENT
The challenge is to get a clear overview of the costs of the system and the money that will be saved because of the investment.
Questions
When do we see the money back?
Variables
Education, man-hours, investment hardware, materials, resources, maintenance, power used, waste.
Threshold
As long as the benefits show an added value that outweighs the costs for the crew and projects offshore, the threshold is reached.

7. SAFETY ON-BOARD
The challenge is to create a safe solution. An example of a safety issue with 3D printing on-board is the inflammation that might occur while cleaning powder machines with magnesium; a little static energy is enough to let it explode.
Questions
How to create a safe solution for an offshore application?
Variables
Use, storage, exhaust, energy use, maintenance.
Threshold
Just like Challenge 3, this threshold is specific: any risk with safety concerns will influence the implementation negatively.

SCOPE 4: FIX DURING PILOT (LATER)

8. PROCESS FAULTS

The challenge is to get the faults that occur in the process of the first pilot fixed. Someone has to put extra time and effort in fixing these bugs.

Questions

What faults will occur in the process? Who will fix these? How would they be fixed? How much time does this take?

Variables

Communication, occurrence of process faults, arrangements, rules, maintenance process, errors that have to be fixed, resources needed (knowledge and tooling).

Threshold

At the moment someone is taking responsibility and acknowledges the needed amount of time to fix the faults, the challenge can be achieved.

9. TECHNICAL FAULTS

The challenge is to get the faults that occur in the process of the first pilot fixed. Someone has to put extra time and effort in fixing these bugs.

Questions

What faults will occur in the process? Who will fix these? How would they be fixed? How much time does this take?

Variables

Support Layertec, communication, occurrence of process faults, arrangements, rules, maintenance of printer(s), errors that have to be fixed, resources needed (knowledge and tooling).

Threshold

At the moment someone is taking responsibility and acknowledges the needed amount of time to fix the faults, the challenge can be achieved.

10. WASTE MANAGEMENT

The challenge is to manage the waste that is produced by the 3D printing process.

Questions

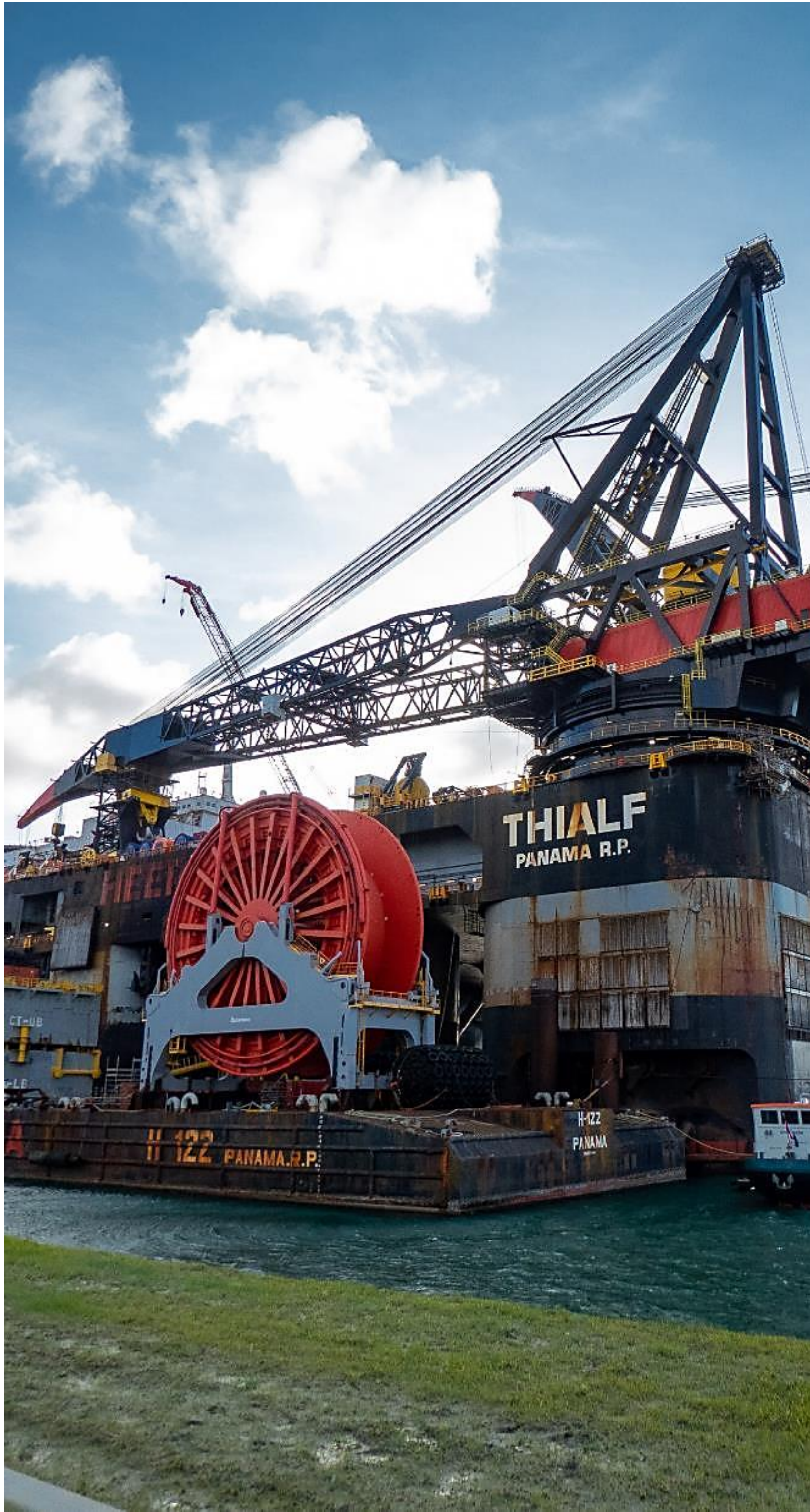
What types of waste does the 3D printing process produce? Can we manage this waste worldwide? Is there a deposit system with the materials/resources?

Variables

Amount of waste, location vessel, system Layertec/Desktop Metal, waste separation facilities on-board.

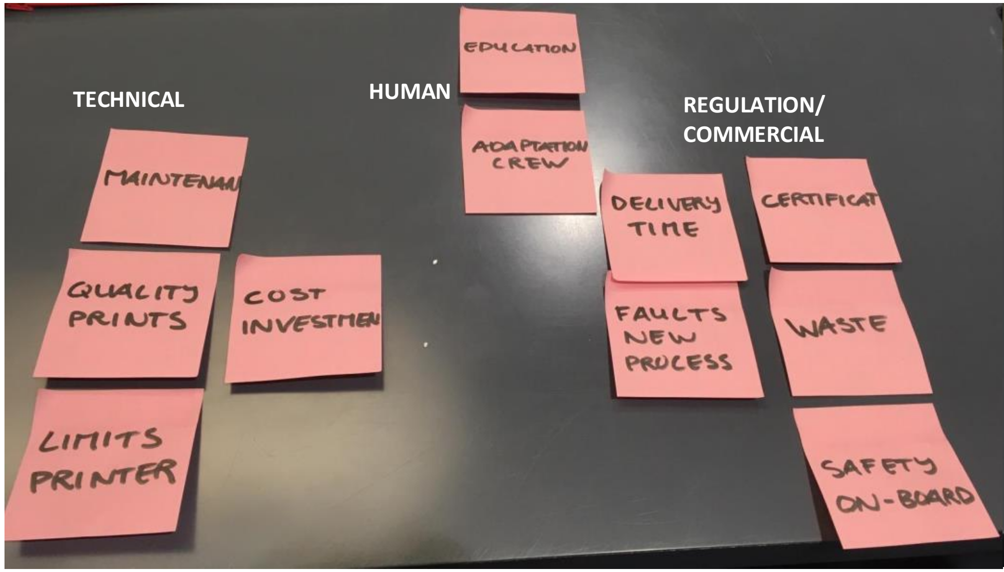
Threshold

The challenge will be achieved once the waste in managed efficient enough to not create extra work or hurdles for the responsible crew members

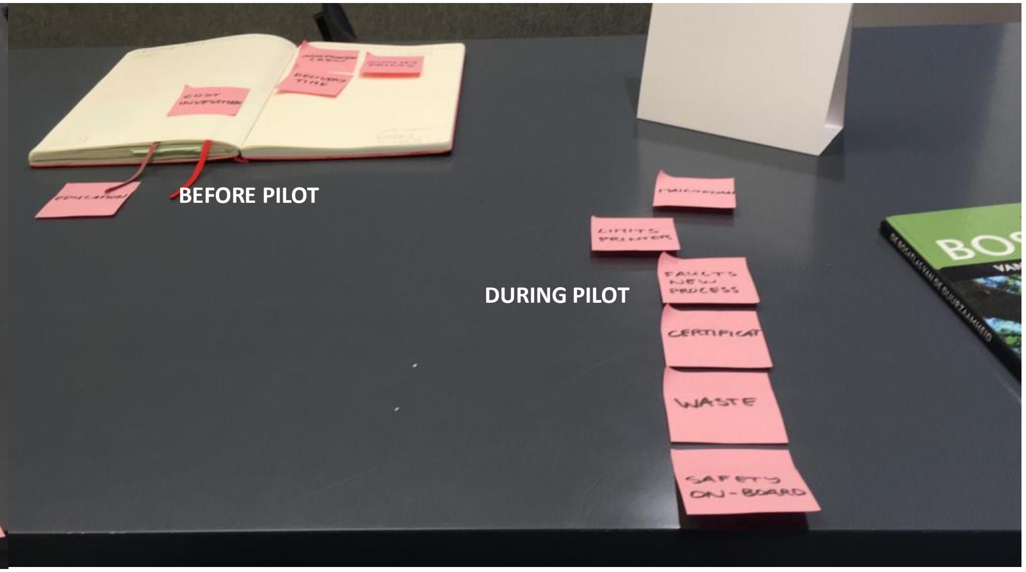


STRUCTURING KEY CHALLENGES

Pictures categorization Challenges
In collaboration with Vincent Doedee



Challenges categorized on topic



Challenges categorized on time frame

APPENDIX 14

Interviews Stakeholders Solution

QUESTIONS

While showing the potential users and stakeholders the Morphological Chart, they were asked to rank the options per category.

- Ranking the options
- Go through options:
- Explain options
- Rank options
- Describe ranking
- Did you miss an option that you would like to rank?

ANSWER OVERVIEW

ERIK VAN HINTUM

07/04/2020

Former captain Thialf

USER

1. Workshop Employees
2. Storekeepers
3. Heerema Employees
4. Subcontractors
5. Vessel Crew
6. Students

PRINTER

LOCATION

1. Warehouse
2. Deck-office
3. Workshop
4. Container

DIGITIZE MODEL

1. Manufacturer
2. Office
3. On-board
4. 3D scan

OTHER

ROB WITKAM

14/04/2020

Former Storekeeper

USER

1. Workshop Employees
2. Storekeepers

All other users do not seem to be the right ones in my opinion.

Students on board means extra crew, ask Chief Engineer about this.

In my opinion the Engine Room Staff is well suited for this project. The engineers department has Engineers 1, Engineers2 and Assistant Engineers. They can read drawings, can use machines and most them speak Dutch.

The extra help of External Experts will be needed, whoever you select as the user of the printer. However, I would choose someone from the vessel from the start.

LOCATION

This will differ per vessel, where is enough space to place the machine(s)?
If you place them in the Workshop you will have the Engineers close.
If you place it in the warehouse or in the office, you will still have the problem of transporting parts. Next to that, only when the part arrives at the vessel there will be a confirmation if it fits.
Container: moving the container it will damage the stuff inside the container.

MATERIAL

By selecting materials you also limit the parts that could be printed. Which parts do you want to start printing?
3000$ for a printer is not a lot of money. Put this printer on-board and then check the need for a printer that can produce metal parts.

DIGITIZE MODEL

I would always go for a mix of all the options. You will never know if you receive a part, if the crew or the office has time to model the part, etc.
The amount of man-hours and knowledge will decide whether it will be modelled on the vessel or in the office.

In my opinion this category could be the bottleneck of your project: something has to be made with a certain time pressure. If it is easier to ‘just order’ the part for 5 situations in a row, it will damage the success of your project.

OTHER

Please put your parts in the machines where they belong and see what happens. This practical test will definitely prove the quality to the crew. For me this test would be one of the decision factors.

Make sure the project will not become a ‘hobby’ project where everyone just prints stuff for themselves.

BART LABLANS
16/04/2020
Chief mate Aegir

USERS
1. Storekeepers
2. Workshop employees
3. Vessel crew members
4. External Experts
5. Students
6. Subcontractors

The storekeepers are the ones who have overview and normally issue the spare parts.
The Workshop employees already produce parts.
Vessel crew members like machinists and elec’s are potential users.
Students are not the ones that are on-board regularly. They would only use the machine with supervision because they are working on their education.
Subcontractors should not be touching the machines from Heerema. This is legally complicated when something breaks.

Once the part is produced, the part has to be installed. This will be done by an machinist, elec or mechanic.

LOCATION
1. The location should be close to the warehouse since this is where the parts normally will be.
2. If the warehouse is not possible, then the Workshop is the place where the parts will be made.
3. A container could be an option, but I would keep it below the deck.
4. The Leiden office or Warehouse Vlissingen would be options if the printer cannot be on-board.
5. The deck office does not seem the be an option since it is no place to work.

MATERIAL
For the metal: how well suited is the 3D print technique for bearings and rotating parts?
How strong is the printed metal? We use the parts in machines.

The parts that will be used: how many times do we have to replace them? Is it due to wear or use?

Be aware: for some parts it might work much better to just use the cast iron or milling production method since it will be produced out of one big block of metal. Compared to those methods 3D printing is quite a challenge. How far away is this level of ‘easy production’ for the 3D print method?

It might be possible to replace the metal parts for plastic parts since the technologies of carbon printing arise.

It might be interesting to only print with bio-based plastics, sustainable solutions!

DIGITIZE MODEL
Getting the model from the manufacturer is the best, ideal way. This could be included in a future vision but does not sound realistic for now.

On-board there are the following people that are able to create CAD-Models: the field-engineer and the drawing team of the specific project.

If you want to print parts that are already on-board you can use a 3D scan or photogrammetry software.

You might get in trouble when you copy parts that you would normally pay for.

OTHER
You choose for a difficult subject! Why wouldn’t we use a 3D milling machine? Look into Haas machines.

On-board we would only decide to print is once it is critical, otherwise we just order it since we can wait for the part to arrive.

How fast can the external services help/reply?

It is essential to mention that this manufacturing method is there to add extra value, not to replace the existing ways of manufacturing parts – e.g. in the Workshop.

Is the part critically needed? Only then we would 3D print it, otherwise it would be fine to just order it.

Potential printable parts: valves piping. These are made of cast iron and do not have to handle any load.

What are the available test facilities on board?
NDT
AUT
The parts we produce in the workshop are not that critical that they have to be tested with, for example, a tensile test or hardness test.

Non-destructive testing does happen with, for example, welding. This non-destructive testing happens with X-Ray or spray to look for cracks.

HARM VAN DER MEULEN

20/04/2020
Chief Mate Thialf

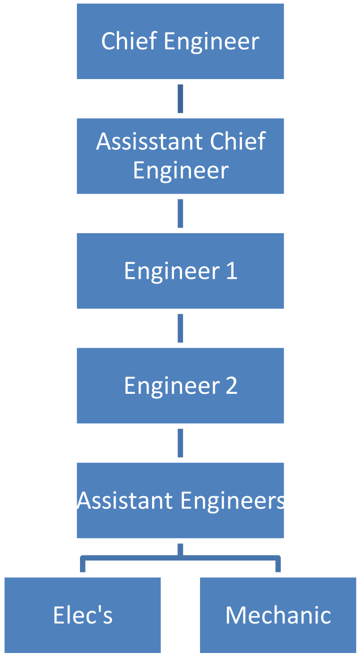
USER
Question is: how hufter proof is the printer?

Workshop Employees are the ones that produce/create something. We ask them to fix this, their skills are called upon. However; these skills have developed within a long period of time since the milling machine already exists quite long. A new technology takes time and a lot of explanation.

Storekeepers do not produce stuff, they fix the logistics and procurement. Therefore this option does not seem to be the best.

Students is not an option on-board. A student Engineering might help the Engineer, but this would be an exception.

Subcontractors could be potential users, but in practice and not on paper. It could be possible the guys from the bubble robot know how to use a 3D printer and therefore use the printer



independently, but this would only be happening if the responsible person approves it.

The **vessel crew members** would be a too broad group of users. If you get more specific I think from the whole crew, the **Engineers** could be the right users. They have a structure as mentioned in figure X. They all work in the Engineering Room (machine kamer).

The mechanics can also work in the workshop.

If the Engineers would be the ones to use the 3D printer, they have to be educated. Harm thinks it would be the Engineers 1 and 2 that get the education about the software and hardware involved. They can teach the assistant Engineers.

Next to that, all engineers graduated at the Higher Nautical College. This education includes CAD Modelling, which means all engineers have experience in doing so.

On-board there are four Engineers 1 and four Engineers 2. Since Heerema works with two different shifts, this means the amount of people doubles. For the Thialf a total amount of 16 Engineers has to be educated.

Assistant Chief Engineers are: Martijn Bouwman and John Boersma.

LOCATION
Only if you would have 1 printer for all vessels it would be a logical decision to place the printer in the Vlissingen warehouse or the office in Leiden. This is the logistics question of your thesis.

The location for the printer on-board will differ per vessel. This is best to ask the Chief Engineer.

A **container on-deck** is not a good idea. This container will be moved constantly, some vessels do not have enough space for it, some have to be warmed or cooled depending on the location of the project.

The deck-office is close to the storekeepers, but is not ideal since the Project Engineers will be present in this location. The Engineers are in the Engineering Room (Machinekamer). If the Project Engineers need something to be produced, they will have to ask the Engineers.

Harm: "In my opinion the Workshop is the best location, but Rene might say that this location is to 'rough' for this more fragile technology. I think the Chief Engineers have the best idea for a location per vessel."

MATERIALS
Harm: "You are the expert, what did you decide?"
Most parts on-board are made of metal, which gives the first impression of choosing the metal materials.

Be aware of the mentality on-board, it is quite conservative. This means anything 'new' is not received positively in general.
Therefore it is great to first implement the plastic printers and then go for the metal printers.
Especially the plastic pilot telling you how high the chances of succeeding with metal are, is a great way of implementing it on-board.
Also, take in to account Rinze Huisman, he is the Technical Superintendant of the Thialf.

After implementing it on the Thialf, can it be expanded to all the vessels? Can the other vessels immediately go for metal if the plastic pilot is successful? Do we keep the plastic printers?

DIGITIZE
Again, Rene can advice you about the option of getting parts from manufacturers. I believe this will be harder for a student than a Chief Engineer.
Engineers already make the drawings for the Workshop guys in CAD. They could create the models, however it should not take too much time.
The Chief Engineer has the amount of man on-board that covers the needed man-hour to complete a job. If a few engineers would have the time to model difficult parts, this balance would be gone. In these kind of situations it would be great to ask the office to help modeling the part.

RENE VAN DER LINDEN
21/04/2020
Chief Engineer Thialf

USERS
Number one of the ranking will be the vessel crew if the crew is interpreted as the technical crew: all Engineers. This project is technical and therefore I would like to have the technical people as the users.

The Storekeepers are on number 2, since I would only place them on place 1 in the ideal situation where we have a digital catalogue with all the printable parts. As long as we have to model the parts, the Engineers stay on number 1.

External experts are not on-board of the vessel.

Office could also use the printer digitally, but I do not see them as users. They are stakeholders.
A good example could be Rinze, the Technical Superintendent that prints project equipment from the office on the Thialf.

Students in the direction of a function we have on board could be possible, however that means we would have more people. This has to be discussed with Jan van Akkeren. This extra employment has to be earned back by the printer.

Subcontractors will absolutely not be the users. They have to work with their own equipment, like they always do.

The guys in the Workshop mostly are mechanics. Most of them do not speak English properly enough to discuss technical solutions.

LOCATION
If we assume the printer is 1m2 I would say place it in the Warehouse. This location is clean and you can close it. Next to that, the printer needs resources that will be stored in the warehouse.

If the printer takes up more space than 1m2, the warehouse will still be a potential location. The Thialf has enough space to create a room for the 3D printing stuff once the project is getting real. This could be a room like the tool room in the warehouse is nowadays. It could be possible to create a room like this between the warehouse and the workshop.

The workshop is pretty clean since the welding and grinding is done in a dedicated area. However, the printer equipment is valuable and you do not want everyone to touch it. Therefore the Warehouse seems to be a better option.

A container could be a option, but the Thialf has enough space to place it underneath the deck.

The Deck-office would be confusing because the Field and Project engineers work at this location. If they need anything they ask the Engine Room.

Asking someone in the office to print the part might take more time than asking the manufacturer to send it to the vessel.

MATERIALS
If I want to place a new ring in a machine, I would want to place one of the same quality. Is that possible? This will be the skeptical mindset on-board.

If you go for plastic, limit the amount of plastic types to make it as simple as possible.

PRINTER
For introducing a new technology on-board, you have to be sure it is working. Therefore I would not go for the metal printer that might not produce the right quality. After a few low quality prints you will hear them saying: "I told you this would not work!"

First create a support base with the guarantee of a good product, then do not ruin this with a cheaper shortcut.

DIGITIZE
It would be ideal if we get the models from the manufacturer, but I do not see this happening. The manufacturers see money when Heerema vessels are in urgent need of a part. If we talk about modelling the parts ourselves, I am worried about the tolerances. In the mechanical systems this is really important, otherwise it will get rattling.

If you can model the parts yourself with the right tolerances, you are fine.

3D scanning sounds great as long as the costs and the technique are oke.

OTHER
You should really create a support base for this project, the crew can be very conservative. This is the maritime sector in general: we lag behind approximately 30 years.

Engineer 1 and 2 are the right ones to educate for the use of a 3D printer. Especially the younger generation is absolutely into this if you do it well. There will even be some 'older dinosaurs' that you will get interested. To get them on-board: convincing is the best method.

Rob Beuker used to be Engineer 1 at the Balder and now is Engineer 1 at the Thialf. He used to have a 3D printer on-board. He placed it in his bathroom because of the noise it made. He used the printer to print parts for his model airplanes.

Rob had made a machine that could cut tools automatically after uploading the drawings in the control room. However, this project did not succeed since it had troubles appearing while introducing it. He did not have enough support base. If you want your project to succeed you should have perseverance.

I would not use 3D printed parts in my thrusters, motors and crane for now. What I need to know for doing so? The manufacturer has to approve that I am using a part I produced myself. Only than Lloyds will certificate it and I can be in DP3 while being certified. Otherwise I can not justify the use of a 3D printed part in one of my machines. My biggest concern in this approval is the tolerances.

APPENDIX 15

Why working towards metal printing?

As explained, there are different 3D printing methods. All those methods have their own set of materials. Since the Thialf warehouse has plastic as well as metal parts in-stock, the question arises: should we print in metal or plastic? Is it needed to print the parts out of metal? Or does plastic fulfil the requirements to solve the stated problem?

QUANTITATIVE

1. Plastic/metal rate in-store

The spreadsheet consisting of all parts present in-store of the Thialf is used to get an overview of the ratio plastic/metal on-board.

2. Metal air freights

According to the documentation of Mike van der Plas, we cannot conclude the exact amount of metal and plastic since the units are too broad and both contain plastic and metal parts. However, according to the Spare parts list of the Thialf, all units on the list of airfreights do contain metal parts that otherwise could have been printed instead of flown over.

3. Development plastic printing

According to 3D Hubs, SLA is famous for being the first 3D Printing technology based on plastic (3D Hubs, n.d.). Charles W. Hull patented the technology back in 1984 (Justia Patents, n.d.). In 1997 the first Metal 3D Printer was produced by AeroMat (Hoskins & Palsenbarg, n.d.). This means we can conclude commercial metal printing appeared just recently, which makes it a less developed technology compared to plastic printing (Thomas, n.d.). Based on this difference it is decided that metal printing is a bigger challenge and therefor more interesting for this project.

4. Recyclability plastic/metal

A lot of initiatives arise for recycling plastic and metal. However, some plastic materials are already bio-based and therefore use less scarce raw materials. Next to that, some bio-based plastics are bio-degradable, like PLA.

QUALITATIVE

1. Advise Heerema

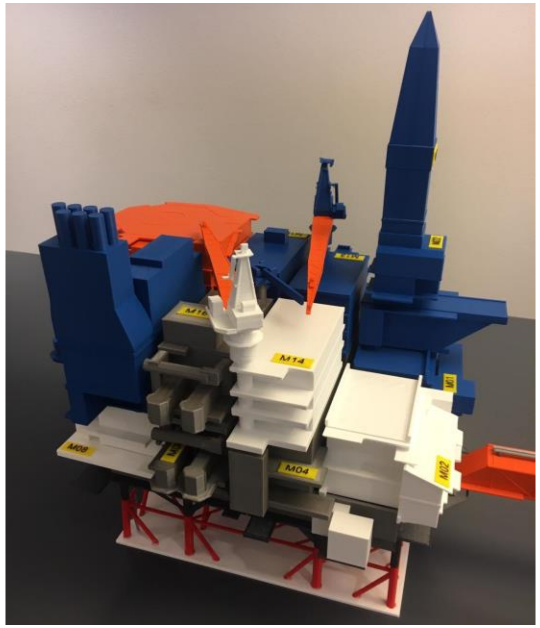
Since one year Heerema owns its own 3D printer: a Leapfrog with 12 types of plastics. As can be seen in figure X, Heerema already uses plastic 3D printing to discuss decommissioning projects. Vincent Doedee: *´Plastic can be done by Heerema since we have experts on this type of Additive Manufacturing. For your project I would like to have a special focus on metal: we have no one internally who could be expert on this topic.”* Marco Huisman, Technology Advisor, has used metal 3D printed parts for project discussions. These parts were produced at a company named Materialze in Belgium (figure X).

2. Offshore forces - durability

With cranes that are able to lift 300 NS Sprinter trains, one can imagine that the parts on the vessels have to endure high forces and thereby benefit from a robust and durable material choice.

3. Metal knowledge on-board

On-board of the vessels there is a lot of knowledge about processing metal: workshop employees, welding experts and engineers all work with metal on a daily base. It is beneficial to have this knowledge when
introducing a new manufacturing technique on-board. Because of the above reasons out of quantitative and qualitative research, this project will focus on metal 3D printing.



APPENDIX 16

Conceptualisation with Morphological Chart

MORPHOLOGICAL CHART

According to the Delft Design Guide, a Morphological Chart helps to "generate principal solutions in an analytical and systematic way" (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). By using this method all options will be extensively considered, focusing on the combinations. To create options per subfunction, an ideation session was held.

The Morphological Chart with the subfunctions and options described as above, is used as the basis for creating different compositions of the possible options, which are named the Concepts. These concepts act as the base of the final result.

FUNCTIONS

According the Delft Design Guide the main function and sub functions of the product have to be defined before setting up a morphological chart.

MAIN FUNCTION

Instructing Heerema about the implementation of 3D printing on-board of their vessels with a detailed plan of action for the pilot.

SUBFUNCTIONS

- User: knowledge, act
- Hardware: printer, debinder, furnace, computer
- Software: slicer, modelling
- Location
- Resources: material, printer needs (liquid, gas, electricity)
- Installation
- Database/storage
- Time indication: planning
- Cost indication: ROI
- Parts
- Rules: responsibility, certification
- Partnerships: maintenance, service, education
- Safety: on-board, warranty

Some of the subfunctions are implemented in the Morphological Chart since they represent different options to create concepts. Other subfunctions are used as Roadmap content. The selected sub-functions are:

Users

The users are the ones using the 3D printer.

Location on-board

The location on-board is the room or space where the 3D printer will be placed.

Materials

The materials describe the materials that will be used to print the parts.

Printers

The printers describe the options that could be used to print the parts.

Debinder/furnace

Next to the printer, a debinder and a furnace are needed for printing metal with the BMD technique.

Digitize models

To print parts a CAD model is needed.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			

CONCEPT 1 – STORKEEPERS DESKTOP METAL

Within this concept the storekeepers use the Desktop Metal Studio System in the deck office on-board. The models they print will be received from the manufacturer.

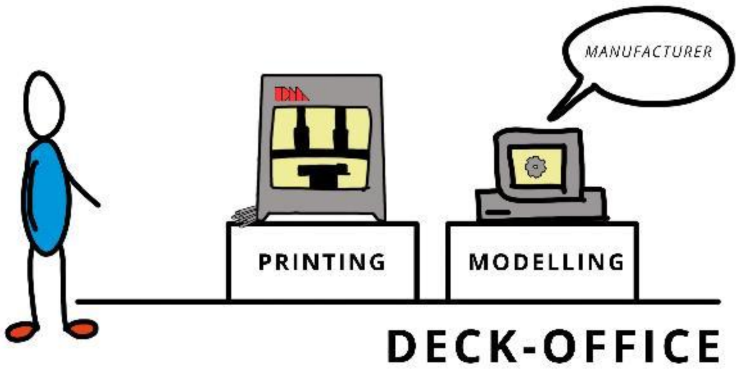
BENEFITS

- Storekeepers know a lot about the existing parts.
- The deck-office is a room with Engineers, who have knowledge about the mechanic installation.
- The Storekeepers are already working on the vessel and therefore this solution does not add people to the current vessel crew.

DISADVANTAGES

- There is no possibility to try a model with plastic prints, since this concept immediately starts printing metal.
- If the Storekeepers are busy printing, who can issue spare parts?
- If the manufacturer or supplier does not want to send the model, the Storekeepers have to find another way of modelling the parts.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			



CONCEPT 2 – WORKSHOP DESKTOP METAL

Within this concept the Vessel Crew Members use the Desktop Metal Studio System in the warehouse on-board. The models they print will be received from the manufacturer.

BENEFITS

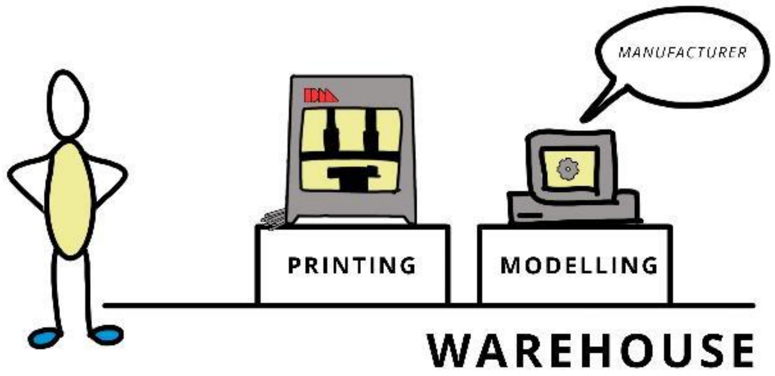
- Vessel Crew Members already have a lot of experience with producing parts that will be used on-board.
- The warehouse is a closed area where not all crew members can join.
- The Vessel Crew Members are already working on the vessel and therefore this solution does not add people to the current vessel crew.

DISADVANTAGES

- There is no possibility to try a model with plastic prints first, since this concept immediately starts printing metal.
- Not all Workshop Employees speak Dutch or English well.

If the manufacturer or supplier does not want to send the model, the Storekeepers have to find another way of modelling the parts.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			



CONCEPT 4 – WAREHOUSE ULTIMAKER PLASTIC

Within this concept the Workshop Employees use an Ultimaker printer to print plastic in the workshop on-board. The models they print will be modelled on-board by the Engineers.

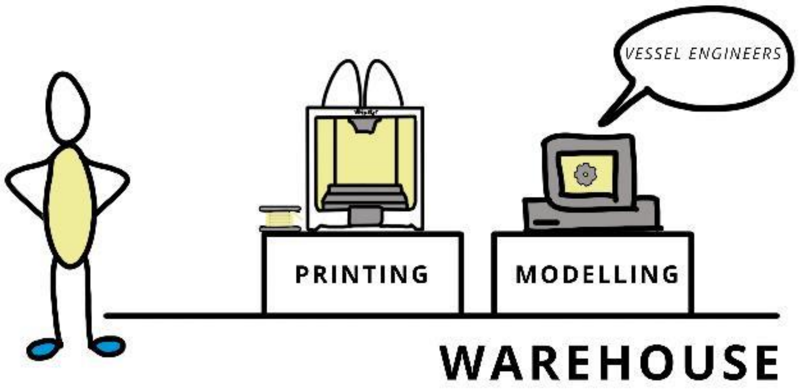
BENEFITS

- Workshop employees know a lot about the existing parts.
- Starting with plastic prints is a small first step towards metal printing.
- The Workshop Employees are already working on the vessel and therefore this solution does not add people to the current vessel crew.
- Potential of metal prints will be shown by the use of the plastic printer

DISADVANTAGES

- The Engineers already have their tasks on the vessel, modelling the parts will cost man-hours.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			



CONCEPT 3 – OFFICE LEAPFROG

Within this concept the employees at the Leiden office use the existing Leapfrog. The models they print will be modelled by the engineers in the office and then send to the vessel.

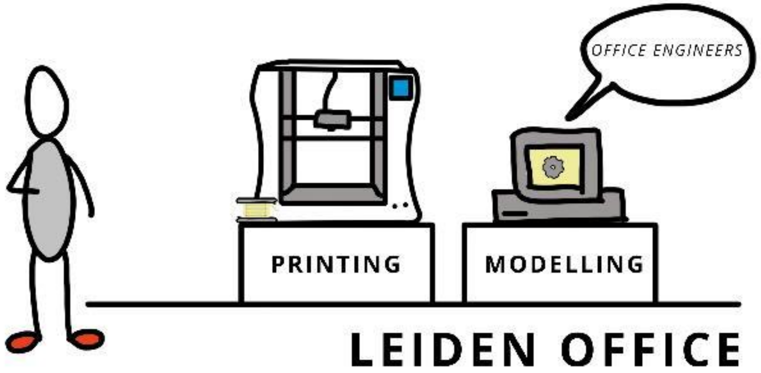
BENEFITS

- The printer is already known and used.
- No investment since the printer is already purchased.
- The Drawing Team of the Leiden Office is experienced in CAD Modelling.

DISADVANTAGES

- The parts still need to be transported to the vessel.
- The parts have to be modelled and printed at the office, if the part does not fit the print has to be done repeated, including the transport.
- The success of this solution depends on the communication between the vessel and the Employees of the Leiden Office.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			



CONCEPT 5 – WORKSHOP ULTIMAKER METAL

Within this concept External Experts use an Ultimaker printer to print metal parts with the BASF filaments in the warehouse on-board. The models they print will be modelled on-board by the experts.

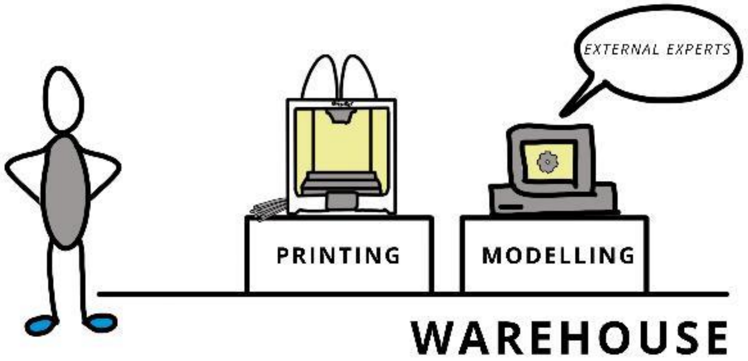
BENEFITS

- Experts are familiar with the errors that potentially might occur.
- Experts are experienced in CAD Modelling, which will save time.

DISADVANTAGES

- The industrial set (debinder and furnace) is not suitable for offices, thereby it is assumed this would not be safe to use at the vessel.
- Costs of industrial set are uncertain.
- External experts have to be added to the current crew vessel, which increases the number of people on-board.
- External Experts are expensive to hire compared to crew members already on-board.

	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			

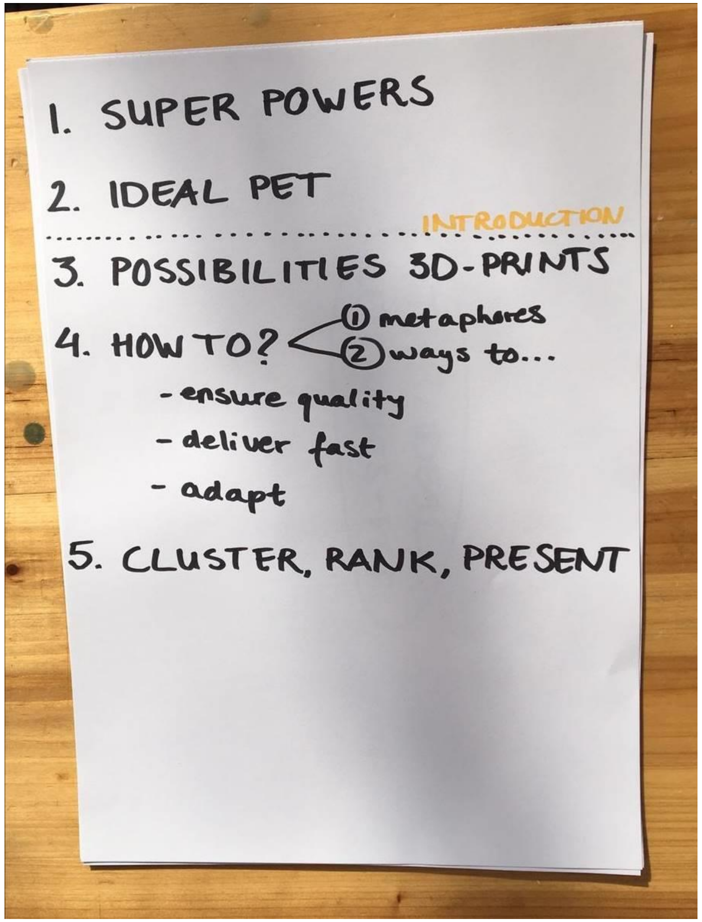


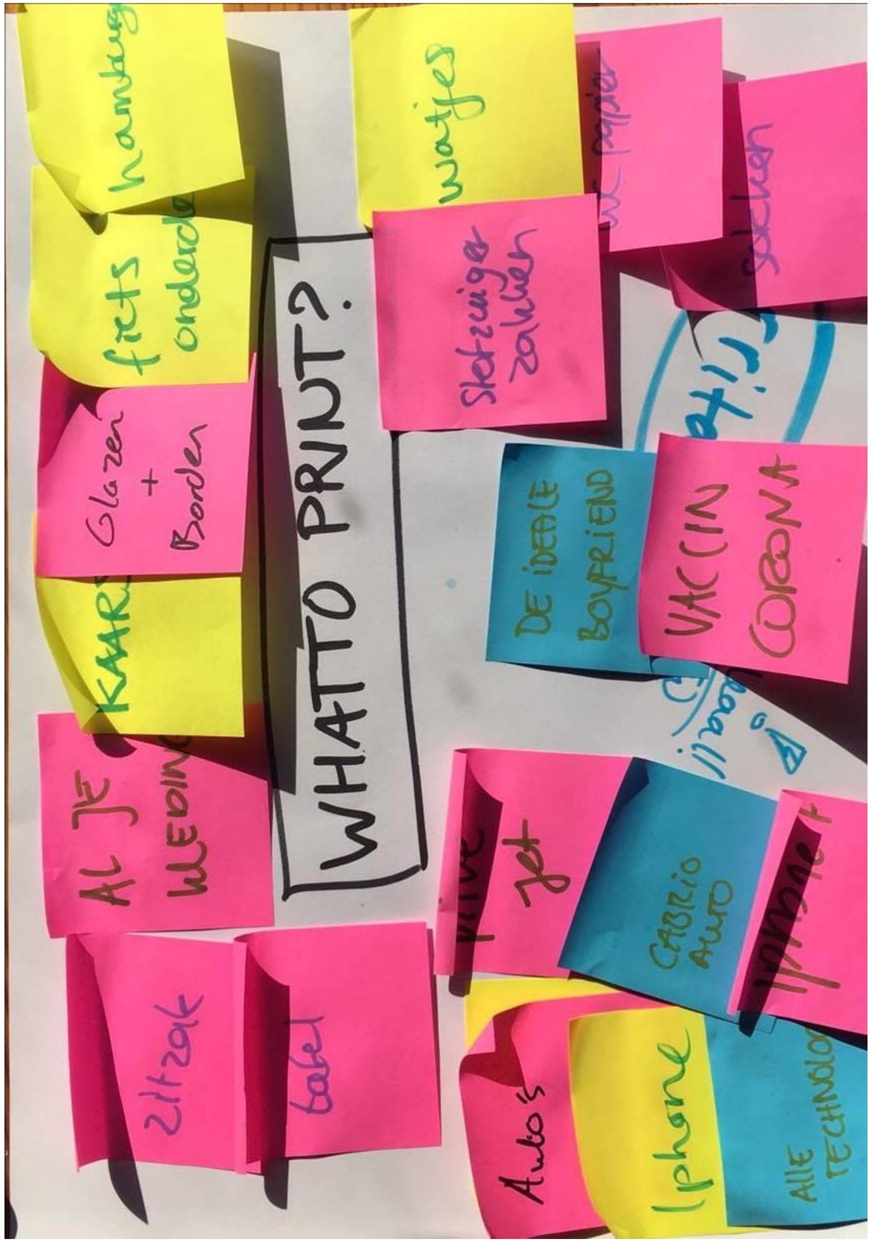
APPENDIX 17
Ideation Sessions

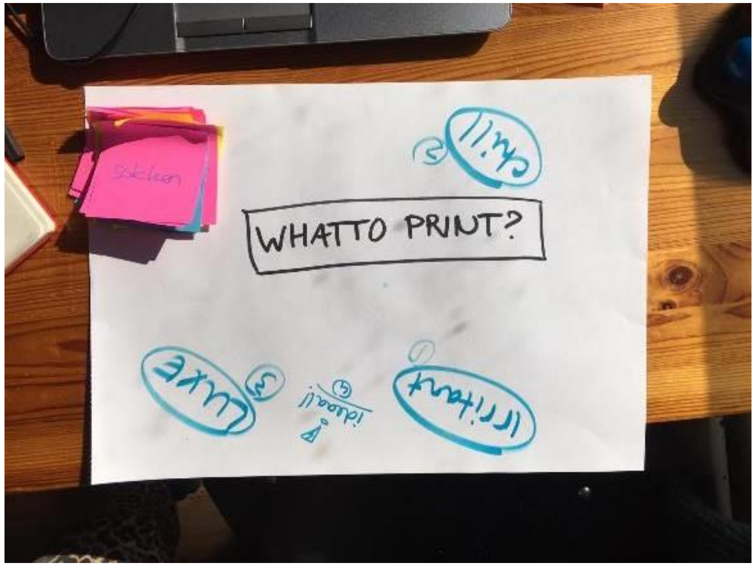
https://business.tutsplus.com/tutorials/how-to-run-an-effective-brainstorming-session--cms-27145

Together with 6 other students form the TU Delft a brainstorm session was held. The brainstorm agenda:

1. To loosen up:
- What would be your super power?
- What characterises the ideal pet for our home?
- Project related:
- What would you 3D print if everything was possible?
- Metaphors:
- Ensuring quality
- Delivering fast
- Adapting
- How to..
- Ensure quality?
- Deliver fast?
- Adapt?
- Cluster, rank and present







Results of the ‘What to print?’ question resulted in the following clusters:

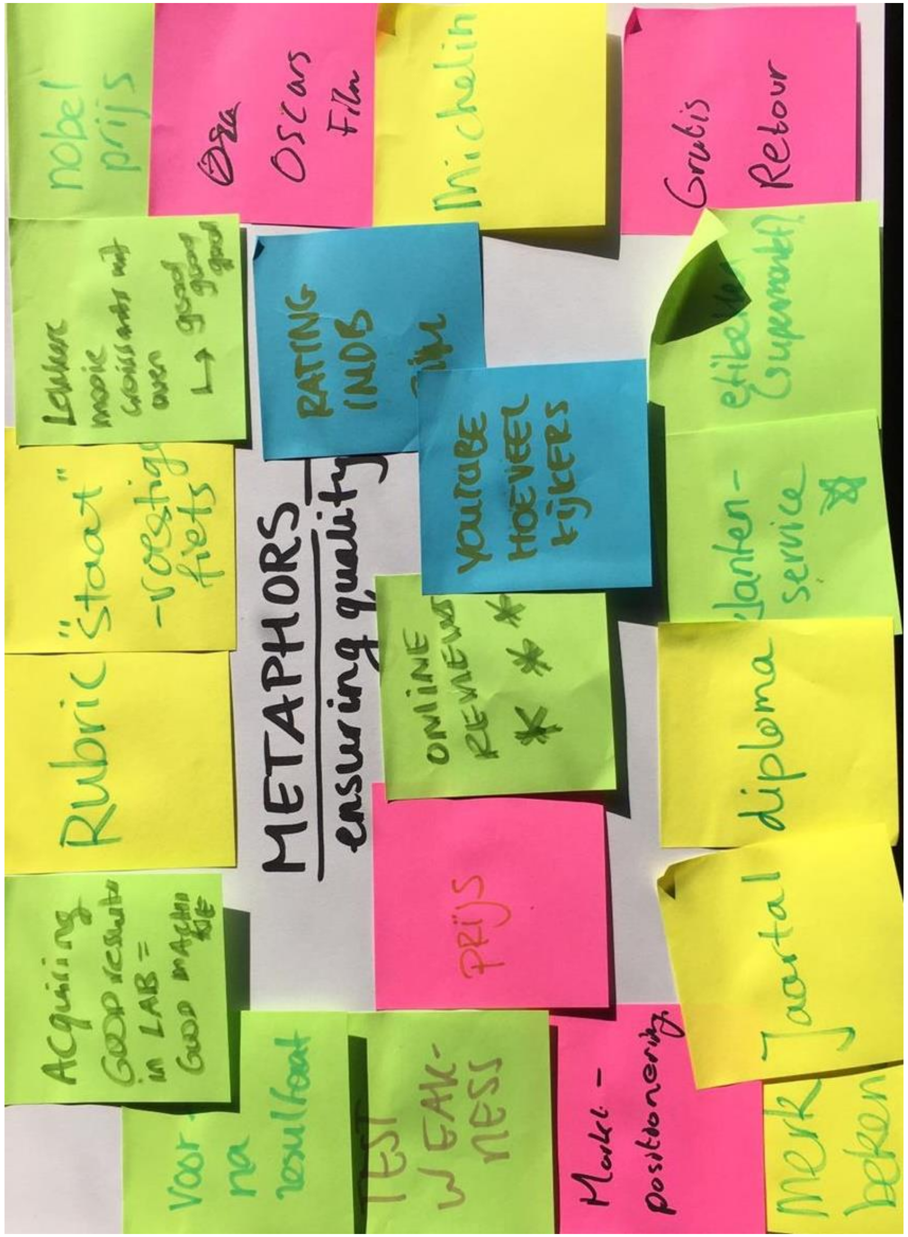
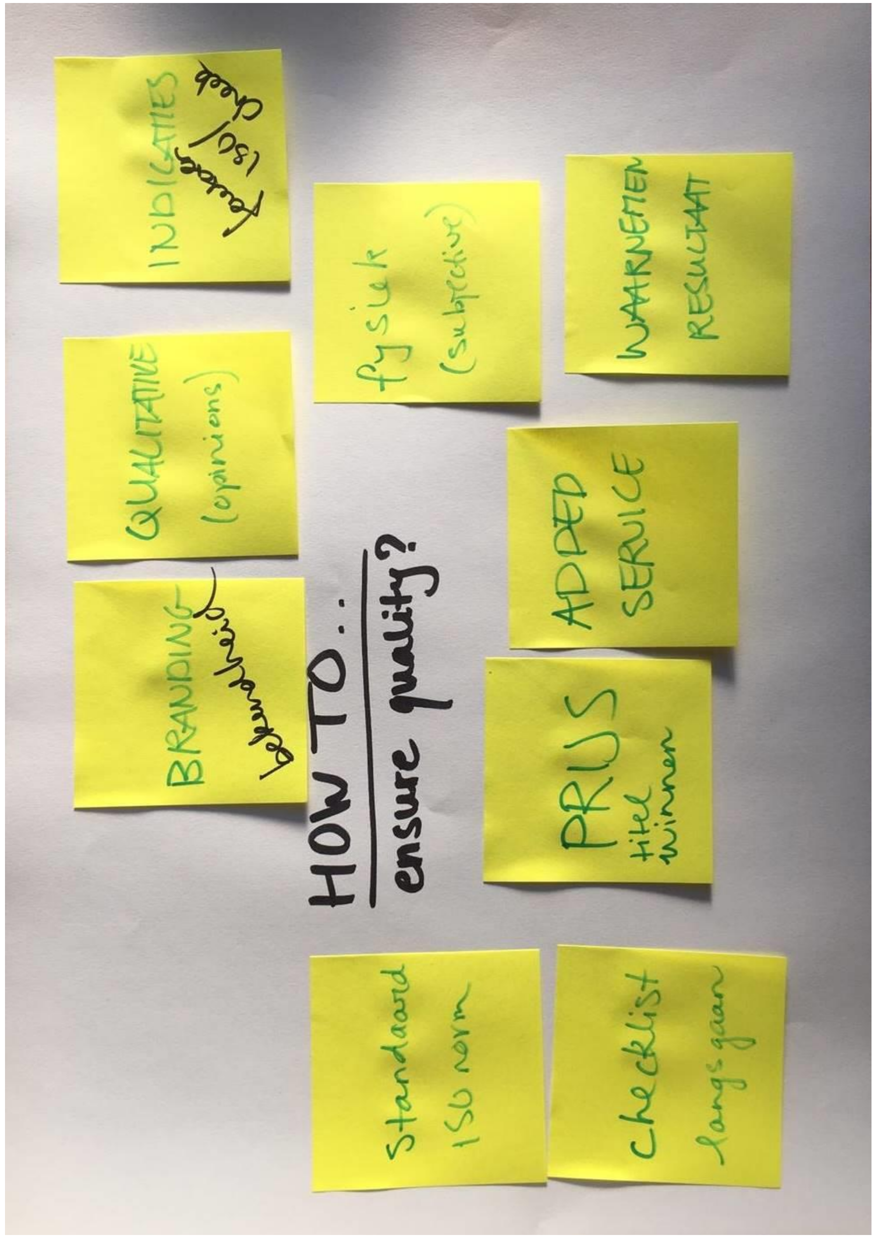
1. Annoying stuff
The products that are annoying to purchase over and over again. The group would love it if you could just print it whenever you are out of stock again.

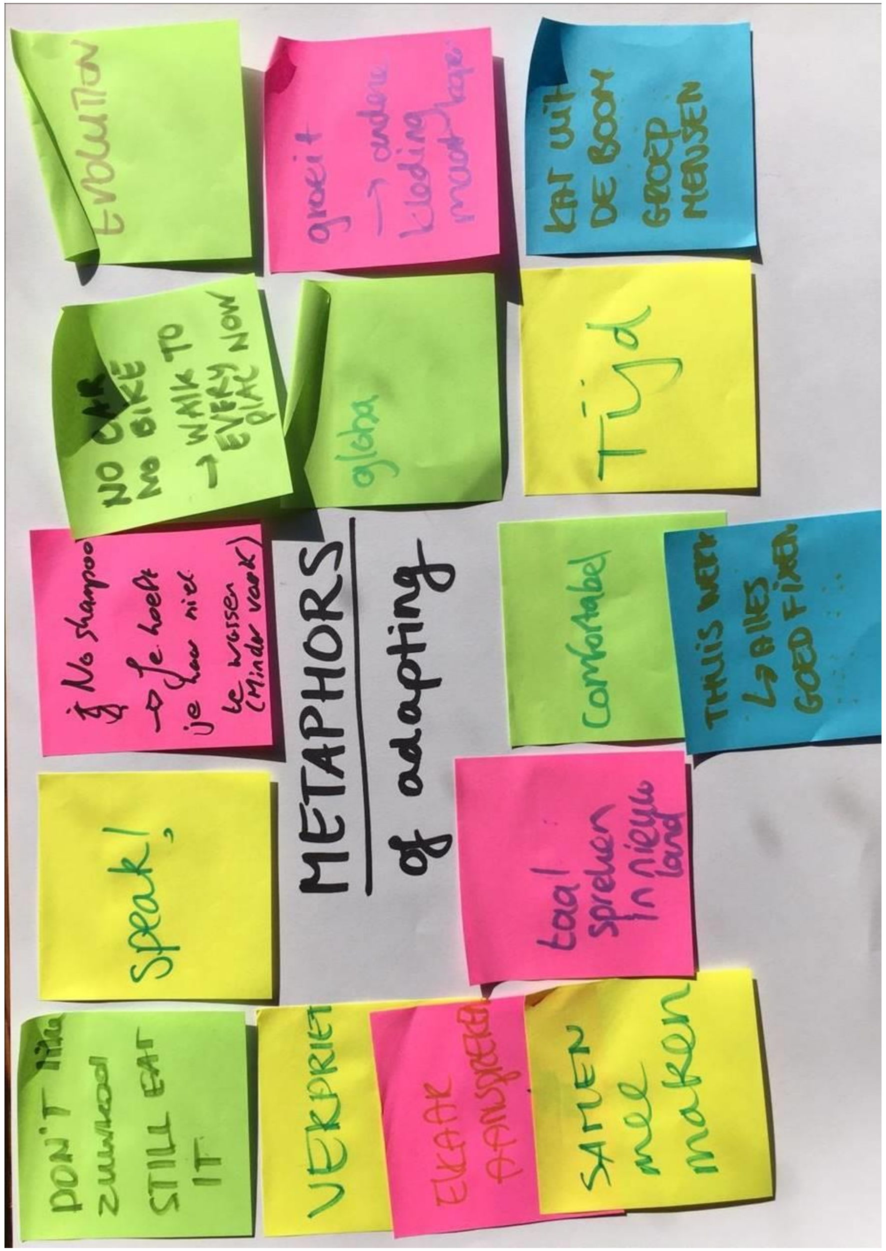
2. Chill stuff
The products that would be chill to print since you would like to have them at specific moments.

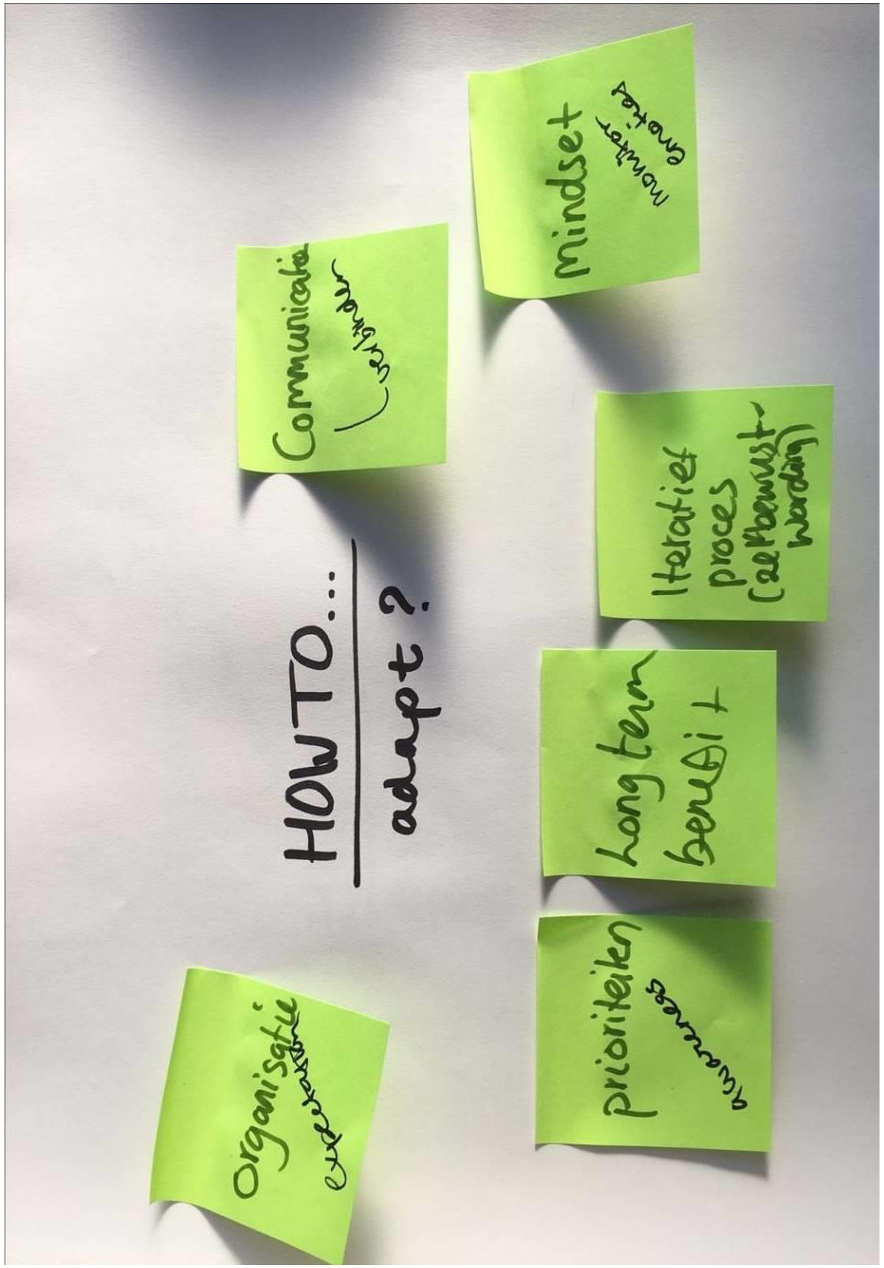
3. Luxury stuff
Cheaper, easier accessible luxury goods. Dreaming!

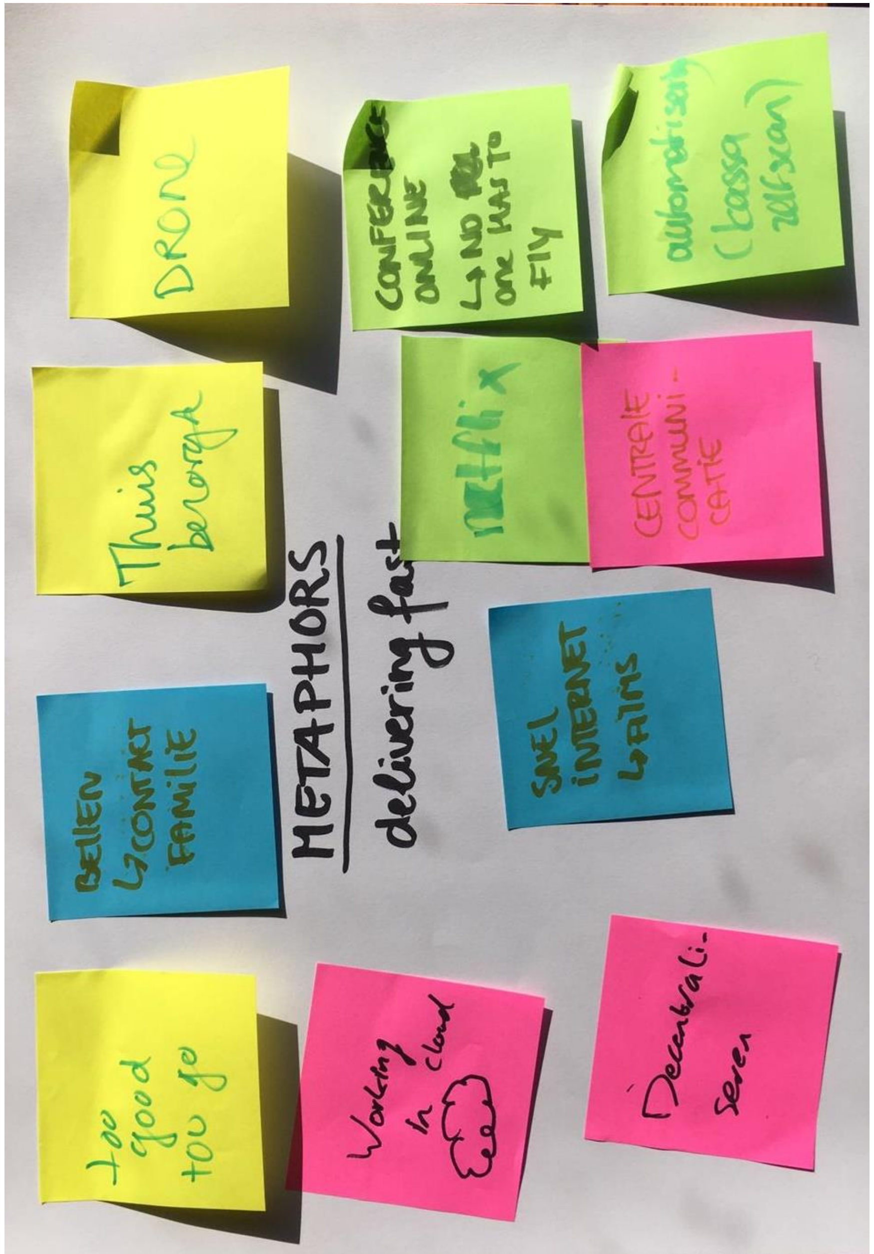
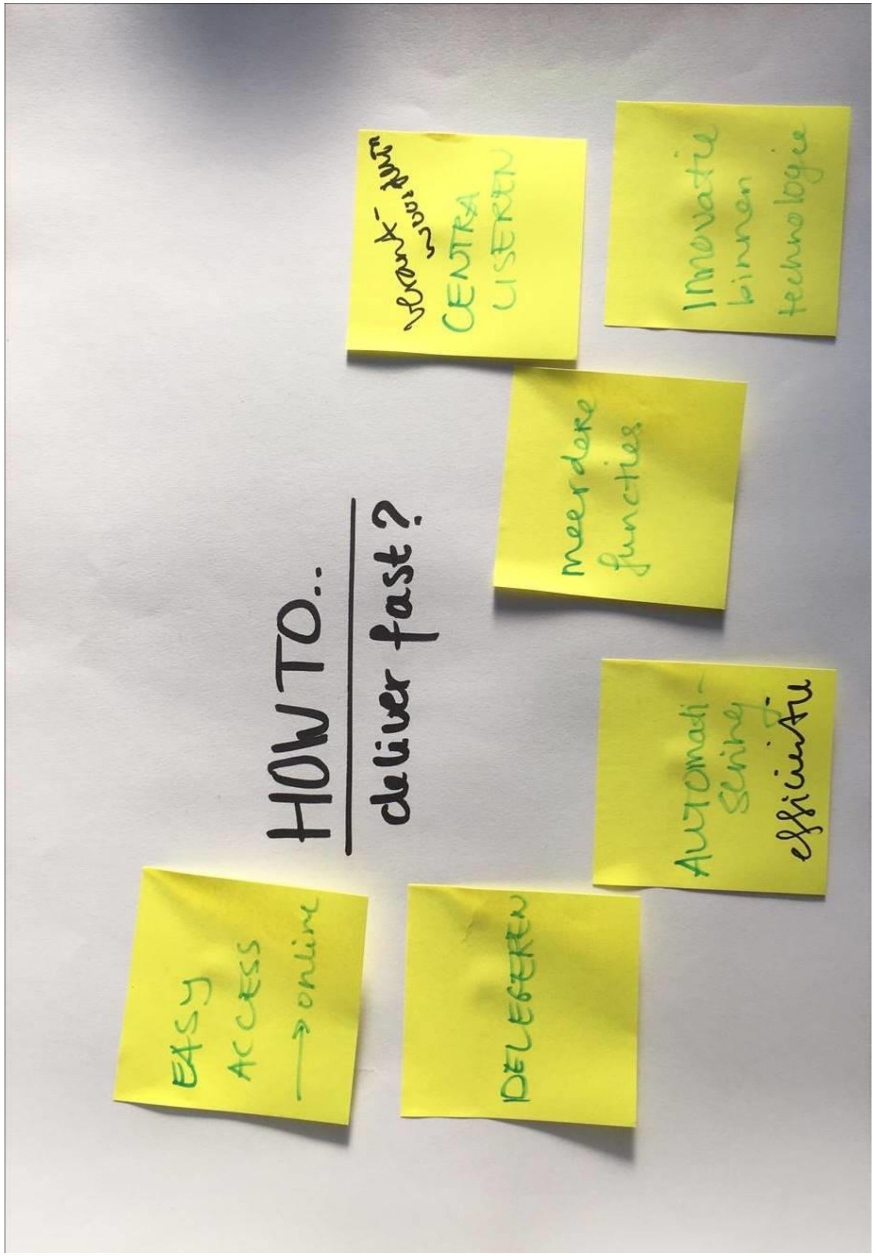
4. Ideal!
The crazy future: printing boyfriends and Covid vaccins.


16 01


METAPHORS
ensuring quality
nobel prijs
Oscars Film
Michelin
Gratis Retour
RATING IMDB
YOUTUBE HOEVEEL KIJKERS
Rubric
ONLINE REVIEWS
PRIJS
diploma
Jaartal
service
TEST WEAKNESS
Voor na resultaat

HOW TO..
ensure quality?
INDICATIES
QUALITATIVE (opinions)
BRANDING
fysiek (subjective)
WAARNEMEN RESULTAAT
ADDED SERVICE
PRIJS titel winnen
Standaard ISO norm
Checklist langs gaan


METAPHORS of adapting
EVOLUTION
groeit
Tijd
Speak!
Comfortabel
taal spreken in nieuw land
SAMEN mee maken
KAT UIT DE BOOM GROEP MENSEN
NO CAR NO BIKE
→ WALK TO EVERY PLACE NOW


HOW TO... adapt?
Communicatie
Mindset
Iteratief proces
Long term benefit
prioriteiten
Organisatie


METAPHORS
delivering fast
DRONE
CONFERENCE ONLINE
automatisering
Thuis bezorgd
netflix
CENTRALE COMMUNICATIE
BELLEN
SNEL INTERNET
Working in cloud
Decentraliseren

HOW TO..
deliver fast?
CENTRALISEREN
Innovatie binnen technologie
meerdere functies
EASY ACCESS
→ online
DELEGEREN

PRINTING CATEGORIES

Results of the 'What to print?' question resulted in the following clusters:

1. Annoying stuff

The products that are annoying to purchase over and over again. The group would love it if you could just print it whenever you are out of stock again.

2. Chill stuff

The products that would be chill to print since you would like to have them at specific moments.

3. Luxury stuff

Cheaper, easier accessible luxury goods. Dreaming!

4. Ideal!

The crazy future: printing boyfriends and Covid vaccins.

The goal of the ideation phase is creating concepts. To get to these concepts, two methods are used. First, an ideation session is held to get ideas on an abstract level about the topics mentioned in the Key Challenges (see figure X). The input gathered in

this session is used in the second method: a Morphological Chart. This method consists of setting up a function and sub-functions that can be connected for creating different combinations.

The following figures show an overview of the insights gathered during one of the ideation sessions with TU Delft students

HOW TO DELIVER FAST?

EASY ACCESS

DELEGATING

AUTOMATIZATION

EXPAND FUNCTIONALITIES

TECHNOLOGY INNOVATIONS

HOW TO ENSURE QUALITY?

STANDARD NORM

CHECKLIST

BRANDING

QUALITATIVE REVIEWS

PHYSIC STATE

RESULT BASED

ADDED SERVICE

ACKNOWLEDGEMENT

HOW TO ADAPT?

ORGANISATION

COMMUNICATION

PRIORITIES

LONG-TERM BENEFIT

ITERATIVE PROCESS

HOW TO ENSURE QUALITY?

Standard norm
Most products with an expected quality are tested according a set norm. If a product fits this norm a specific class of quality is guaranteed.

Checklist
It is also possible to test the quality a product yourself. This can be done as long as you have a checklist with all expectations of the part. This checklist can be objective and based on quantified specifications. It can also be based on indications that create a certain value: e.g. price, year.

Branding
Quality can also be defined by the brand that is selling the product: the publicity or way of marketing.

Qualitative reviews
At this moment most products get reviewed. Users give their opinion about the product online or through other media.

Physic
The physical appearance of a product already tells a lot about the quality of the part. This is a subjective assessment but an important one to take in mind.

Result based
Quality can also be measured. Tests can tell if a part meets the required specifications or not. This way of measuring quality is currently most used on-board of the vessels.

Added service
An added service could increase the value of the product. This increased value can be seen as increased quality. That simple bike might seem of higher quality since the added service fixes your flat tire.

Acknowledgement
Some products have won a title and are therefore recognized as high quality. Think of the '*Nobel Price'* films or the '*Beter Leven'* chicken.

HOW TO DELIVER FAST?

Easy access
To deliver fast, it is important to have easy access to your resources. Online meetings or databases are a good example. It creates an centralized medium. Another example is *Netflix* or *Thuisbezorgd*.

Delegate
To deliver result quickly try to delegate tasks and responsibilities, this prevents delays.

Automatization
Efficiency of processes increases by automatization since repetitive tasks can be done by robots or processes can be monitored with digital systems.

Expand functionalities
If a restaurant not only serves their customers on a table, but also lets them pick up the food, they deliver more units per time.

Technology innovations
Innovations within technology open up interesting directions. Most of these are disruptive and therefore harder to implement.

HOW TO ADAPT?

Organisation
The right way of managing is important to make the organisation adapt to a change. Expectations have to be measured and communicated.

Communication
By communicating, people will feel connected. Connecting is important to share experiences within the period of change towards the adaption.

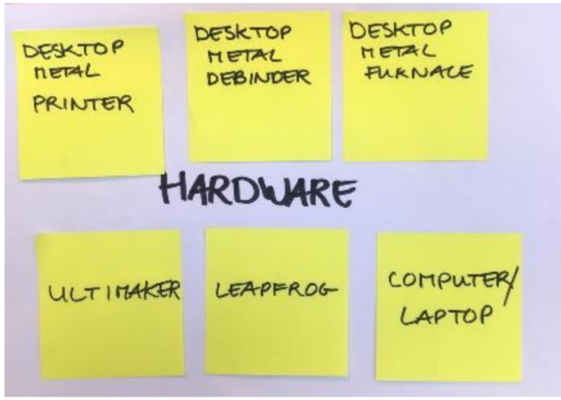
Priorities
While implementing a change, it is important to be clear about the priorities that were set. Awareness about this decision influences the degree of adapting to the change.

Long-term benefit
Making people aware of the long-term benefits of the change makes it easier for them to adapt: they know why they have to adapt. It is important to keep the personal incentives in mind per user.

Iterative process
It is recommended to adapt to changes step by step. This iterative process gives the users trust in the change that occurs.

SECOND IDEATION SESSIONS BASED ON MORPHOLOGICAL CHART

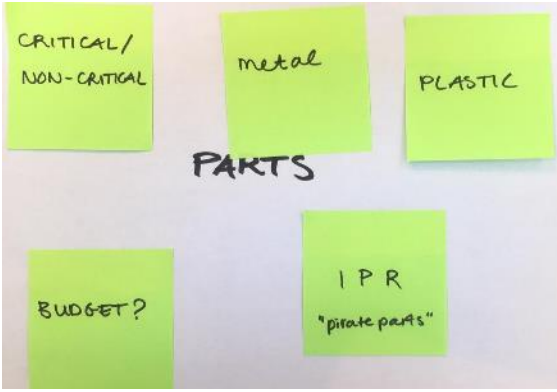
Hardware



Location

Materials

Parts



Safety

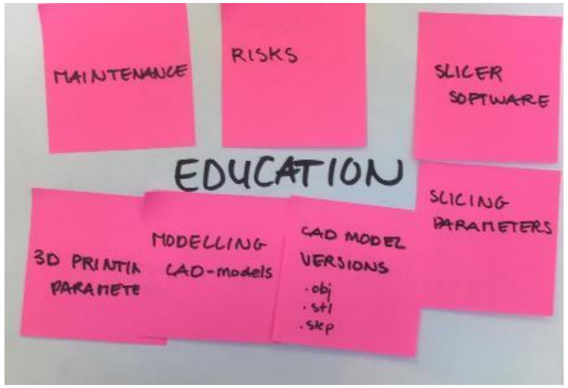
Rules

Software

Users

Storage

Education

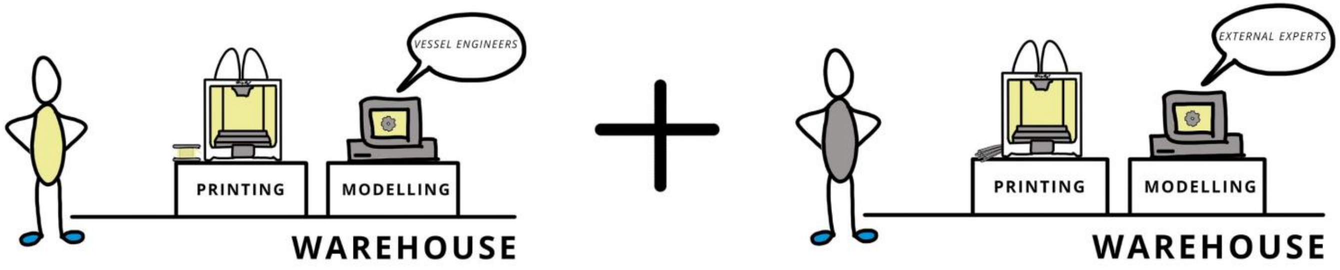


APPENDIX 18
Combined concepts

COMBINATION A
Combination A is based on concept 4 and 5. It implies a stepwise implementation with a shift from plastic to metal, supported by the Ultimaker printer that shifts in material use.

BENEFITS
- Less investment (?)
- Only 1 printer = less learning (?)

DISADVANTAGES
- Not recommended by Layertec – explode?
- BASF not tested in my project – Ultimaker did test it? Johan



	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			

COMBINATION B

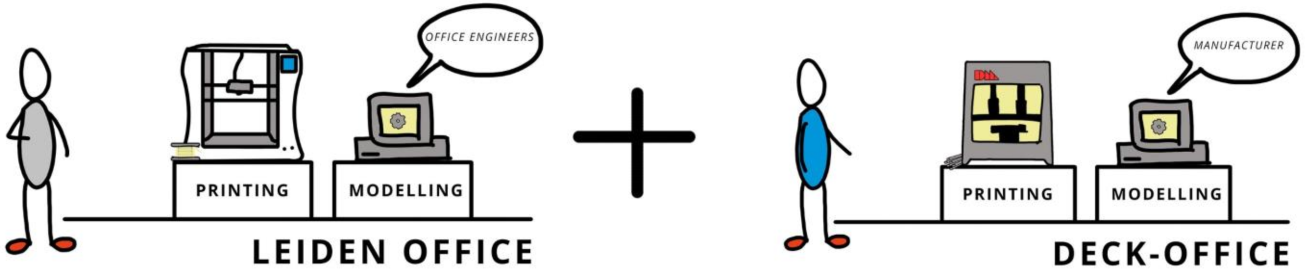
Combination B is based on concept 1 and 3. It implies a stepwise implementation with a shift from plastic to metal, supported by the Leapfrog and Studio System printers.

BENEFITS

- Potential exit/adjust point to C3
- Known technology gets to vessel
- Investment after pilot plastic

DISADVANTAGES

- Higher investment
- Sinter learning starts late



	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			

COMBINATION C

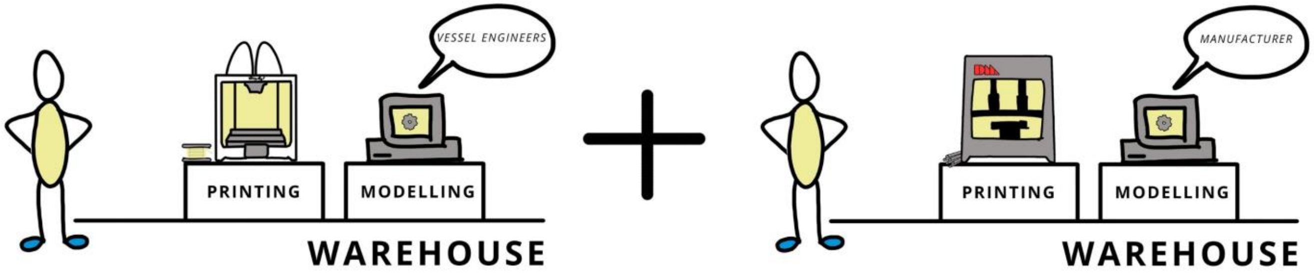
Combination C is based on concept 2 and 4. It implies a stepwise implementation with a shift from plastic to metal, supported by the Ultimaker and Studio System printers.

BENEFITS

- Potential exit/adjust point to C3
- Known technology gets to vessel
- Investment after pilot plastic

DISADVANTAGES

- Higher investment
- Sinter learning starts late



	1	2	3	4	5	6	7
USERS	Storekeepers	Heerema Employees	External Experts	Workshop Employees	Vessel Crew Members	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board	Warehouse on-board	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments	Metal rods Desktop Metal	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System	Ultimaker	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System	Industrial set					
DIGITIZE MODELS	3D scanner	Measure and model on-board	Measure and model in office	Get model from manufacturer			

APPENDIX 19

Harris Profile

To assess the combinations created, criteria are set up for a fact-based and deliberately decision. These criteria are placed in a Harris Profile : "a graphic representation of the strengths and weaknesses of a design concepts with respect to predefined design requirements" (van Boeijen, Daalhuizen, Zijlstra, & van der Schoor, 2016). Next to that, several interviews are conducted with potential users and stakeholders to use their input in the decision making process.

CRITERIA

1. ***Execution***

Is the execution of this solution realistic? Is the quality of the printed parts sufficient?

2. ***Safety***

Is the solution safe to use? What is the biggest risk?

3. ***Usability***

Is the solution usable for the appointed users?

4. ***Costs***

How much does the solution cost? What is the return of investment (ROI)?

5. ***Sustainability***

Is the solution in line with the sustainability beliefs of Heerema?

6. ***Planning***

Is this solution feasible within the time slot of the Sustainability Roadmap of Heerema?

HARRIS PROFILE

For each design concept, a Harris Profile is created to see how they meet each listed design requirement (figure X).

1. EXECUTION

Combination A requires a lot of research with the BASF316L filament. Therefore, the execution of this solution is not realistic yet. Once more is known about this way of production, the execution score increases. **Combination B** includes the plastic Leapfrog printer, a printer that Layertec does not support. This would influence the education phase since the hardware is not in line with the hardware discussed during trainings. Next to that, the Storekeepers have less knowledge about CAD modelling, which will extend the education phase. The Desktop Metal printer has a promising quality. **Combination C** is the most executable because all hardware is supplied by Layertec, which increases the value of the education prior to using the printer. Also, the users of Combination C will be the Engineers already have knowledge about CAD Modeling, which works in favor for the execution of this concept.

2. SAFETY

Because of the industrial furnace that is part of **Combination A**, the safety on-board of the vessel cannot be guaranteed as it can be with the Desktop Metal Studio System. **Combination B** and **Combination C** both work with the Desktop Metal Studio System, which is proven to be safe enough for an office. The safety level of the Ultimaker or Leapfrog is assumed equally.

3. USABILITY

Combination A needs an industrial furnace, which has to be used by experienced staff. This decreases the usability, since this concept is restricted to external experts. The usability of **Combination B** is sufficient since the plastic pilot does not include the service Layertec has to offer, but both system are user friendly.

4. COSTS

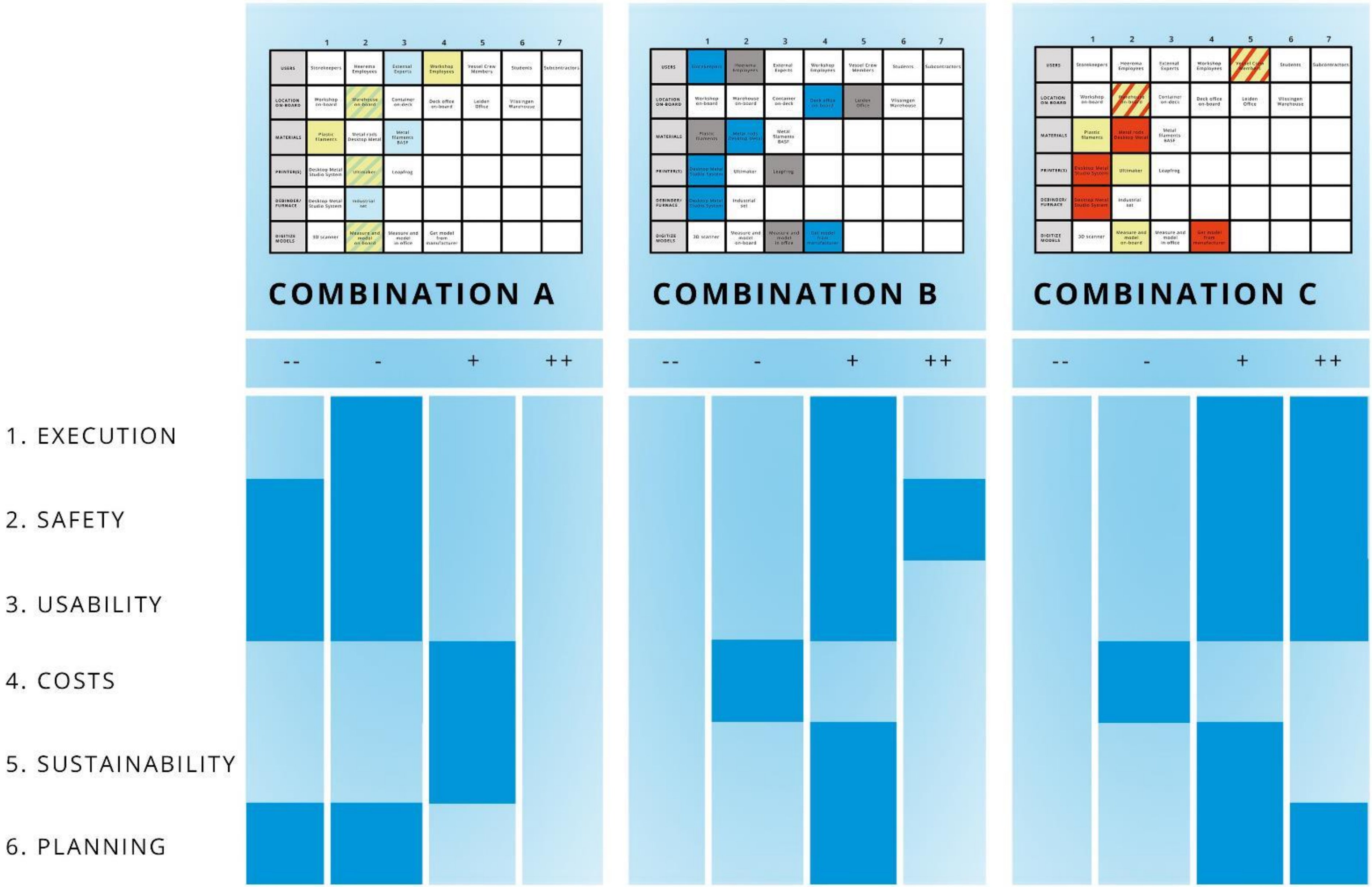
The investment of **Combination A** is relatively low compared to the other combinations, since only one printer has to be purchased per vessel. For both **Combination B** and **Combination C** two types of printers have to be invested in, which makes the costs of the combination less attractive.

5. SUSTAINABILITY

Combination A, Combination B and **Combination C** al received the same score for sustainability since the sustainable impact depends on the printer use.

6. PLANNING

Combination A is not ranked high: it takes extra time before the plan can be implemented. **Combination B** is feasible within the time slot of the Sustainability Roadmap, but does take extra communication channels since the Leapfrog is not part of the Layertec offer. Compared to the other combinations, **Combination C** is most realistic to be implemented within the set time frame since all hardware, software and education can be fixed with one stakeholder. This advantage will smoothen the process since all lessons learned with the plastic printer can be used in the metal pilot phase.


COMBINATION A
COMBINATION B
COMBINATION C
--
-
+
++
1. EXECUTION
2. SAFETY
3. USABILITY
4. COSTS
5. SUSTAINABILITY
6. PLANNING

APPENDIX 20

Interviews potential users and stakeholders

To get insights about the reaction of users and stakeholders on the concepts, interviews are conducted with the following people:

- Erik van Hintum, former captain Thialf
- Rob Witkam, former Storekeeper
- Bart Lablans, Chief Mate Aegir
- Harm van der Meulen, Chief Mate Thialf
- Rene van der Linden, Chief Engineer Thialf

Out of the answers, the overview with preferences is created.
As can be seen the Workshop Employees and Vessel Crew Members are preferred users. Harm and Rene both mentioned the Engineers as the ideal Vessel Crew Members. The preferred location is the Workshop or Warehouse, depending on the space needed. All interviewees agreed to using a system that is already well developed so the quality of the prints would increase the adaptation of the crew. Most of the interviewees agreed with starting the implementation of 3D printing with a plastic printer. Based on the possible limitations of modelling a certain part, all interviewees would keep most options open.

	1	2	3	4	5	6	7
USERS	Storekeepers [Bart]	Heerema Employees	External Experts	Workshop Employees [Erik, Rob]	Vessel Crew Members [Harm, Rene]	Students	Subcontractors
LOCATION ON-BOARD	Workshop on-board [Rob, Harm]	Warehouse on-board [Erik, Bart, Rene]	Container on-deck	Deck office on-board	Leiden Office	Vlissingen Warehouse	
MATERIALS	Plastic filaments [Erik, Rob, Bart, Rene]	Metal rods Desktop Metal [Erik, Rob, Bart, Harm, Rene]	Metal filaments BASF				
PRINTER(S)	Desktop Metal Studio System [Erik, Rob, Bart, Harm, Rene]	Ultimaker [Erik, Rob, Bart, Rene]	Leapfrog				
DEBINDER/ FURNACE	Desktop Metal Studio System [Erik, Rob, Bart, Harm, Rene]	Industrial set					
DIGITIZE MODELS	3D scanner [Rob, Bart, Rene]	Measure and model on-board [Rob, Bart, Harm]	Measure and model in office [Rob, Harm]	Get model from manufacturer [Erik, Rob, Bart]			

ERIK
ROB
BART
HARM
RENE

APPENDIX 21

Specifications Hardware

ULTIMAKER S3/S5

1. Larger build volume

Double nozzle makes the print bed of S3 a 197 width.

Bouwvolume S5

330 x 240 x 300 mm

Bouwvolume S3

230 x 190 x 200 mm

2. Possibility to print carbon fibres

3. Possibility to close the print environment

De Ultimaker S5 Pro Bundle is vanaf 18 oktober verkrijgbaar voor een adviesprijs van **8685** euro, terwijl de Ultimaker S3 per direct beschikbaar is voor een adviesprijs van **3995** eur

Declaration of safe unattended professional use

For the following:

Product:	3D printer
Models:	Ultimaker S5
Manufacturer:	Ultimaker B.V. Watermolenweg 2 4191 PN Geldermalsen The Netherlands +31 (0)345 712 017 info@ultimaker.com

To assure safe use, our printers are subject to the following tests and data analysis:

- Tests according to IEC 60950-1, am1, am2 and UL60950-1:NL52073
- Design risk assessment:
  - FMEA XL 20170119
- Collected meta data related to prolonged use:
  - FFS endurance document. Which shows no safety problems during failure of prints.

Taking into account:

- The above mentioned tests and data analysis
- All prescription from the latest versions of our manuals (www.ultimaker.com) for installation, operation and maintenance
- The usage of UM branded filament

We hereby declare that the Ultimaker printers specified are safe for unattended (overnight) use.

The technical documentation is kept at the Manufacturer's address.

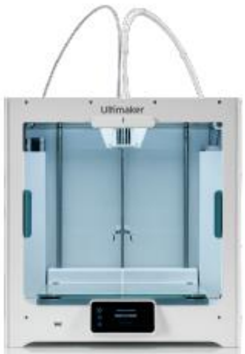
Marcel Buter, Manager Quality and compliance

Date of issue: 17 May 2018

Place of issue: Geldermalsen

Ultimaker

Please note that Ultimaker does not accept any liability for product defect or failure as a result of misuse or abuse of our product. Ultimaker does not accept any liability or damages arising out of death or personal injury resulting from assembly or operation of our products or for indirect, punitive or consequential damages (including loss of profits or business interruption). The laws of the Netherlands apply and the courts of the Netherlands will have sole jurisdiction to resolve conflicts relating to our product or this declaration.



Ultimaker S5

Product data sheet

Reliability at scale

The Ultimaker S5 is built to maximize uptime with great print results and a large build volume. It delivers best-in-class technical specifications for a desktop 3D printer, plus the performance and peace of mind that comes with using our complete 3D printing solution – one trusted by hundreds of thousands of professionals worldwide.

Open and connected system

With the Ultimaker S5, you are not only getting a market-leading 3D printer. Our open filament system ensures you are never locked in. Our online Ultimaker Marketplace gives you free access to material profiles from leading brands. And our software simplifies the 3D printing workflow, from integration with leading CAD platforms to managing your printers via your network or the cloud.

Key features

- ✓ **Larger build volume:** Scale up with bigger parts or batch production
- ✓ **Network connectivity:** Print via Wi-Fi, LAN, cloud, or with USB
- ✓ **Touch screen:** Effortless operation via an award-winning user interface
- ✓ **Advanced active leveling:** Reliable first-layer adhesion, enables unattended use
- ✓ **Front enclosure:** Improved printing environment for better print results
- ✓ **Flow sensor:** Stay informed when filament runs out to increase print success
- ✓ **Easy setup and monitoring:** With NFC material recognition and internal camera
- ✓ **Composite materials compatible:** Print parts with high strength and unique properties

Why choose Ultimaker

3D printers that simply work
Our award-winning 3D printers are robust, reliable, and easy to use. They deliver quality parts time and again. Certified to run 24/7, they allow you to achieve the results you need more quickly and easily.

Software ready for Industry 4.0
Trusted by millions of users across 14 languages, Ultimaker Cura integrates with any workflow through Ultimaker Marketplace plugins. Then scale production and digital distribution with Ultimaker Cloud.

Material choice like never before
Ultimaker offers the widest material choice on the market. Through our Material Alliance, choose the perfect filament for your application – from advanced polymers to carbon fiber composites.

Support dedicated to your success
Wherever you are in the world, Ultimaker support is close by. Our global network of service partners offer professional installation, training, and maintenance in your language and time zone.

Request a quote today at ultimaker.com/quote/request

Ultimaker

Ultimaker S5 specifications

Printer and printing properties	Technology	Fused filament fabrication (FFF)
	Print head	Dual extrusion print head with a unique auto-nozzle lifting system and swappable print cores
	Build volume (XYZ)	330 x 240 x 300 mm (13 x 9.4 x 11.8 in)
	Layer resolution	0.25 mm nozzle: 150 - 60 micron 0.4 mm nozzle: 200 - 20 micron 0.6 mm nozzle: 300 - 20 micron 0.8 mm nozzle: 600 - 20 micron
	XYZ resolution	6.9, 6.9, 2.5 micron
	Build speed	< 24 mm³/s
	Build plate	Heated glass build plate (20 - 140 °C)
	Nozzle diameter	0.4 mm (included) 0.25 mm, 0.6 mm, 0.8 mm (sold separately)
	Operating sound	< 50 dBA
	Connectivity	Wi-Fi, LAN, USB port
Physical dimensions	Dimensions (with Bowden tubes and spool holder)	495 x 585 x 780 mm (19.5 x 23 x 30.7 in)
	Net weight	20.6 kg (45.4 lbs)
Software	Supplied software	Ultimaker Cura, our free print preparation software Ultimaker Connect, our free printer management solution Ultimaker Cloud, enables remote printing
	Supported OS	MacOS, Windows, and Linux
Warranty	Warranty period	12 months

Compatible accessories

Air Manager
EPA filter removes up to 95% of UFPs

Material Station
Simplify and automate material handling

Print cores AA and BB
Quick-swap nozzles for build and water-soluble support materials

Print core CC
Ruby-tipped for printing abrasive composites

Compatible materials

Unlock a wide range of applications with complete material choice. Use Ultimaker materials, any third-party filament, or access material profiles from leading brands. Choose from these materials and more.

Easy to print and visual quality
- Ultimaker PLA
- Ultimaker Tough PLA

Mechanical strength
- Ultimaker ABS
- Ultimaker PC
- Ultimaker CPE

Wear resistance
- Ultimaker Nylon
- Ultimaker PP
- Igus Iglidur I180-PF

Heat resistance
- Ultimaker CPE+
- DSM Arnitel ID 2060 HT

Flexibility
- Ultimaker TPU 95A
- DuPont™ Hytrel® 3D4100FL

Reinforced composites
- Owens Corning XSTRAND™ GF30-PA6
- DSM Novamid® ID1030 CF10

Support
- Ultimaker PVA
- Ultimaker Breakaway

Ultimaker

DESKTOP METAL STUDIO SYSTEM

STUDIO SYSTEM

Printer specifications

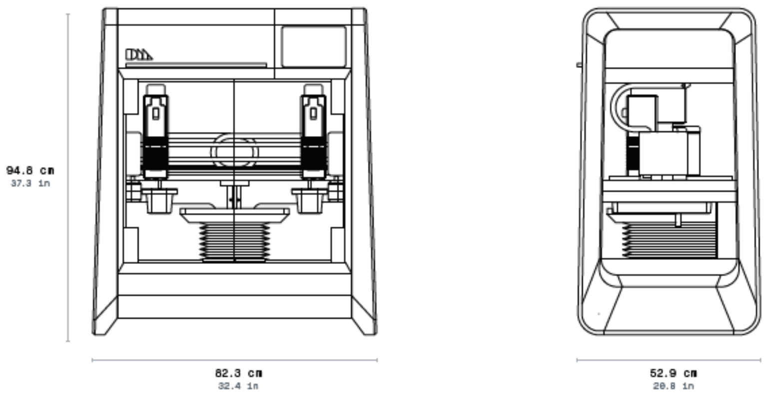
The printer was designed from the ground-up for simple installation and use. Its process is similar to the safest, most widely used 3D printing process—Fused Filament Fabrication (FFF). Unlike laser-based systems that selectively melt metal powder, the Studio System™ printer extrudes bound metal rods, eliminating the safety requirements associated with metal 3D printing and enabling new features like closed-cell infill for lightweight strength. New features introduced with Studio System+ include high-resolution printing and an in-chamber camera for live viewing of the part as it prints.

TECHNOLOGY	Print technology	Bound Metal Deposition™
	Support technology	Separable Supports™
	Interface technology	Ceramic Release Layer™
PERFORMANCE	Max build rate	16 cm³/hr 1 in³/hr
	Layer height	• 50 μm high resolution printhead • 100-220 μm standard resolution printhead
	Max build weight for all parts in job	6.5 kg 14.3 lbs in green state
	Safety features	Over-temperature protection
PHYSICAL	External dimensions	94.8 x 82.3 x 52.9 cm 37.3 x 32.4 x 20.8 in
	Weight	97 kg 214 lbs
	Build chamber	Heated up to 50 °C 122 °F
	Extruder assembly	Dual quick-release print heads
	Build envelope*	30 x 20 x 20 cm 12 x 8 x 8 in
	Build plate	• Heated, up to 70 °C 158 °F • Vacuum-enabled print bed
	Print sheets	Polypropylene, peel-away
	Nozzle diameter build media	• 0.40 mm standard resolution • 0.25 mm high resolution
	Nozzle diameter interface media	0.40 mm
	Power requirements	100-130 VAC, 50/60Hz, 15 A, 1-phase 220-240 VAC, 50/60Hz, 10 A, 1-phase
	Onboard control	7-inch touchscreen display
	Chamber view	• Glass doors and clear polycarbonate siding for 360° view • In-chamber build plate camera
MEDIA	Media holding	RFID-enabled, hot-swappable cartridges
	Media loading	Push-to-release
	Build media	Bound metal rods (metal powder + wax and polymer binder)
	Interface media	Bound ceramic rods

*build volume applies to printers with part number BMD-PP0003

PLATFORM	Network connectivity	Wireless and Ethernet
	Software	Fabricate™ software
	Browser requirements	Accessible via any web browser
	Supported file types	STL, IGES, JT, STEP, VDA-FS, U3D, VRML and native file types (SolidWorks, ProE, etc)
	Automation	• Auto-generated build plans based on geometry and material • RFID-enabled supply monitoring • Live job progress tracking

DIMENSIONS



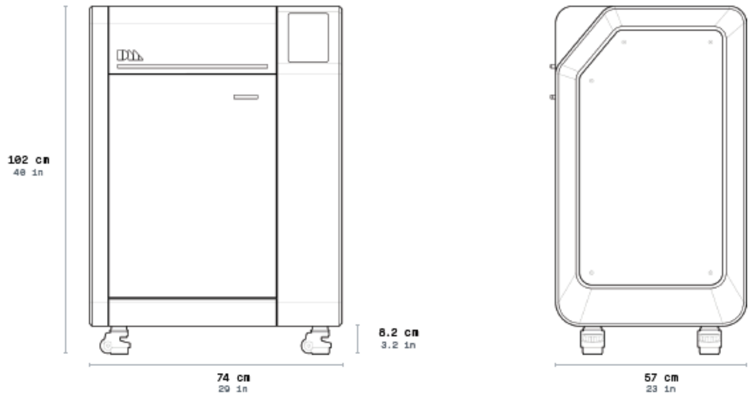
STUDIO SYSTEM

Debinder specifications

The Studio System™ debinder immerses green parts in proprietary debind fluid, dissolving primary binder and creating open-pore channels throughout the part in preparation for sintering. With a low emission design, the debinder is safe for use in an office environment. Automatic fluid distillation and recycling means there is no need to refill between each cycle. New features introduced with Studio System+ include adjustable shelving optimized for batch processing.

PHYSICAL	External dimensions	102 x 74 x 57 cm 40 x 29 x 23 in
	Height in open position	160 cm 62 in
	Weight	150 kg 330 lbs without fluid
	Max fluid volume processing tank	17.4 L 4.6 gal
	Max fluid volume storage tank	22.5 L 5.9 gal
	Workload envelope	30 x 20 x 20 cm 12 x 8 x 8 in
	Workholding	Stainless steel basket with adjustable trays (3 levels)
	Vapor management	• Low emission design • Vapor-tight tank lid
	Binder management	Disposable binder waste canister
	Fail safes	• Over-temperature shutoff control • High vapor pressure shutoff control
	Power requirements	• 100-130 VAC, 50/60Hz, 20 A, 1-phase • 220-240 VAC, 50/60Hz, 10 A, 1-phase
	Onboard control	7-inch touchscreen display
	Mobility	Swivel casters with adjustable leveling locks
SOLVENT	Solvent	Desktop Metal's proprietary debind fluid
	Chemical properties	Refer to SDS
	Fluid management	Automatic distillation and recyling
PLATFORM	Network connectivity	Wireless and Ethernet
	Software	Fabricate™ software
	Browser requirements	Accessible via any web browser
	Automation	• Auto-generated custom debind cycle • Fluid level monitoring • Live job progress tracking

DIMENSIONS



STUDIO SYSTEM

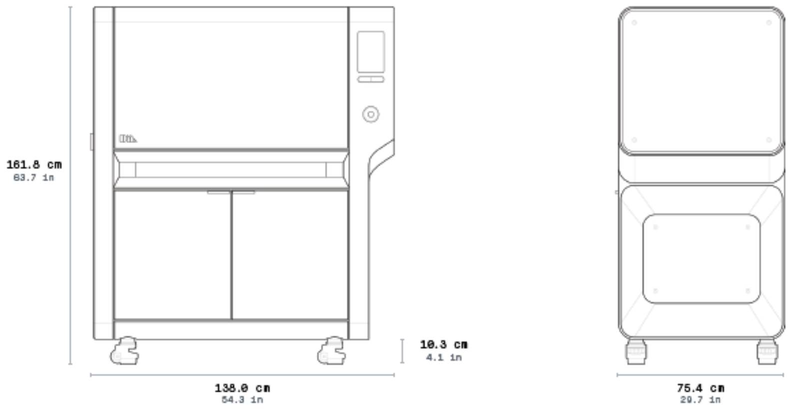
Furnace specifications

Fully-automated and sized to fit through a doorway, the furnace delivers industrial-strength sintering in an office-friendly package. The furnace uniformly heats parts to just below their melting point to remove secondary binder, causing the metal particles to fuse together and the part to densify up to 96 to 99.8%—without residual stresses introduced in laser-based systems. New features introduced with Studio System+ include a newly designed retort box with adjustable shelving designed for batch processing.

PERFORMANCE	Atmosphere	Partial-pressure sintering (vacuum-enabled)
	Heating	SiC heating elements (4 sides)
	Max temperature	1400 °C 2552 °F
	Average heat load	8,100 BTU/hr
	Max heat load	15,600 BTU/hr for 2 hours
	Thermal uniformity	±5 °C at sintering temperatures
PHYSICAL	External dimensions	161.8 x 138.0 x 75.4 cm 63.7 x 54.3 x 29.7 in
	Height in open position	216 cm 85 in
	Weight	798 kg 1,760 lbs
	Workload envelope	30 x 20 x 20 cm 11.8 x 7.9 x 7.9 in
	Workholding	Adjustable multi-level trays with ceramic setters (6-position)
	Retort	Stacking graphite rings
	Ventilation	• Effluent air exhaust line (0.5 in, push-to-connect) • Liquid drain line (0.5 in, push-to-connect)
	Binder management	Removable binder cold trap liner
	Fail safes	• Thermal interlocks • Front-mounted E-stop • Over-temperature protection
	Power requirements	• 208 VAC, 60 Hz, 30 A, 3-phase dedicated circuit
	Onboard control	7-inch touchscreen display
GAS	Gas types	Forming gas, Argon (material dependent)
	Gas connection	• RFID-enabled, 900 L onboard canisters (x2) • External gas connection
PLATFORM	Network connectivity	Wireless and Ethernet
	Software	Fabricate™ software
	Browser requirements	Accessible via any web browser
	Automation	• Auto-generated temperature profiles • RFID-enabled gas supply monitoring (onboard canisters) • Live job progress tracking

Desktop Metal
Studio System™ Office-friendly metal 3D printing

DIMENSIONS



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www.desktopmetal.com

APPENDIX 22

Reacting on exit points

Plastic parts are not being used.
Discuss the parts that are being printed, why these? Who are the users of these parts? What is their reason not the use the parts? What is their alternative?

There is no need to prints parts in metal.
Who is stating there is no need? When does the crew think there might be a need? Can we organise this situation?

Client refuses to use machines/assemblies with printed parts.
What is the reason of refuse? How do we proof the opposite? Do we have to show certification? Than include Lloyds.

Warranty related problems occur.
Include Lloyds and DNV. Also discuss with Layertec and Desktop metal.

Safety or health related problems occur.
What are the problems? Can we create a safe environment? Do the users still trust the Roadmap?

APPENDIX 23

Roadmap concepts and ideation

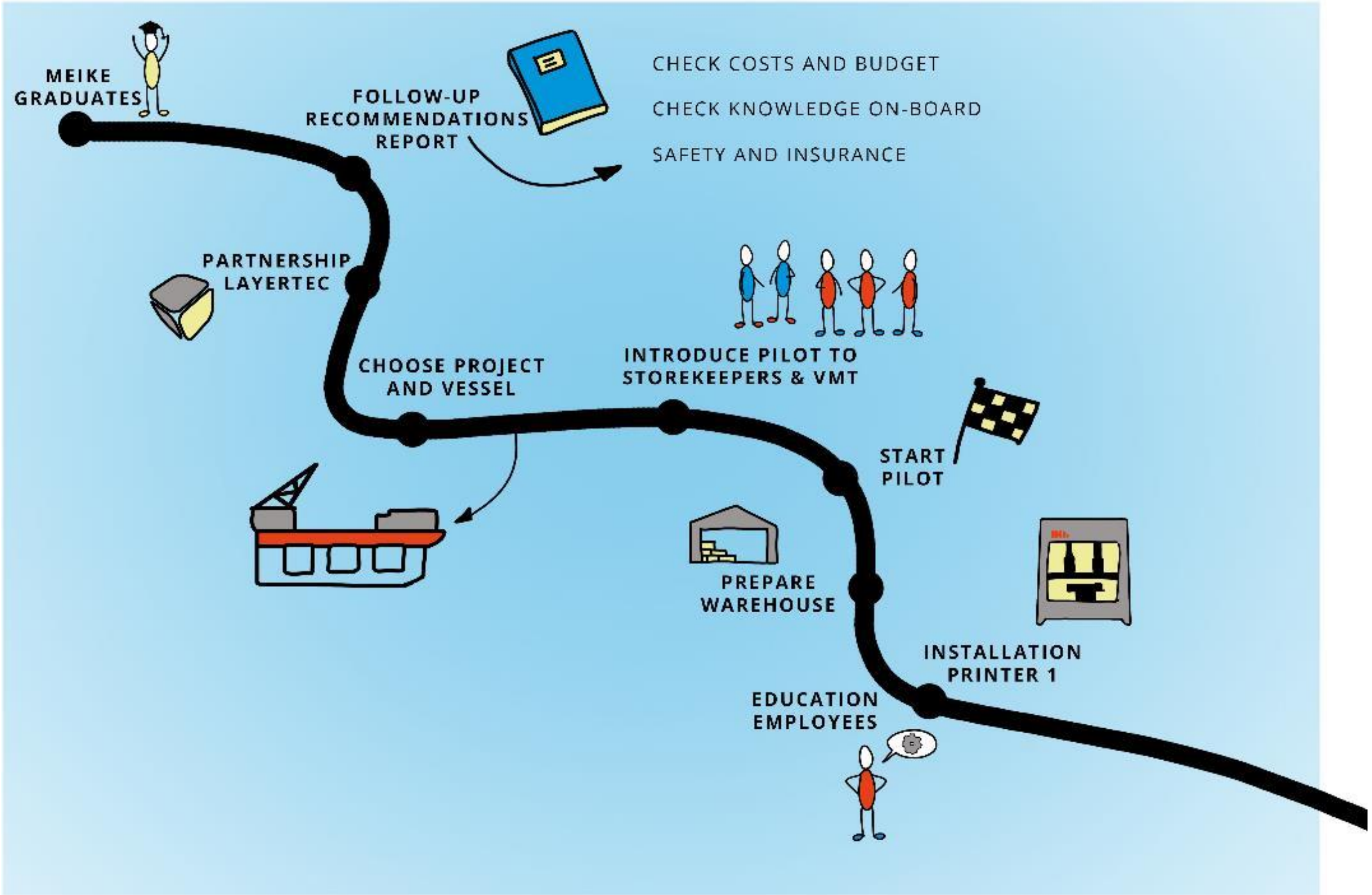
To create an overview of the future process a roadmap is created.

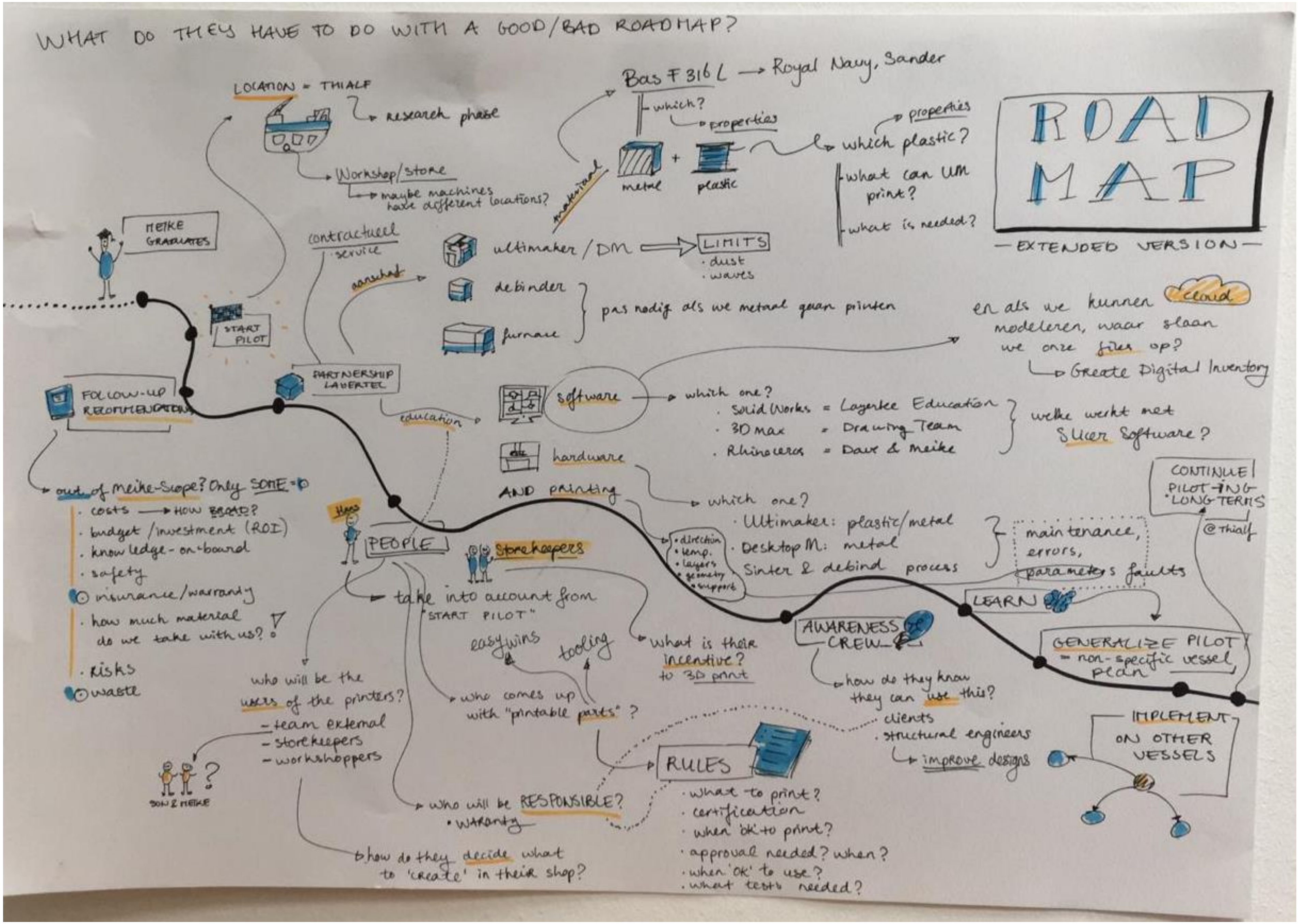
After the graduation and thereby publication of this report, the recommendations regarding the metal printing on-board should be followed-up.

Once these are clear and the idea still is feasible, viable and desirable, the Partnership with Layertec can be set up.

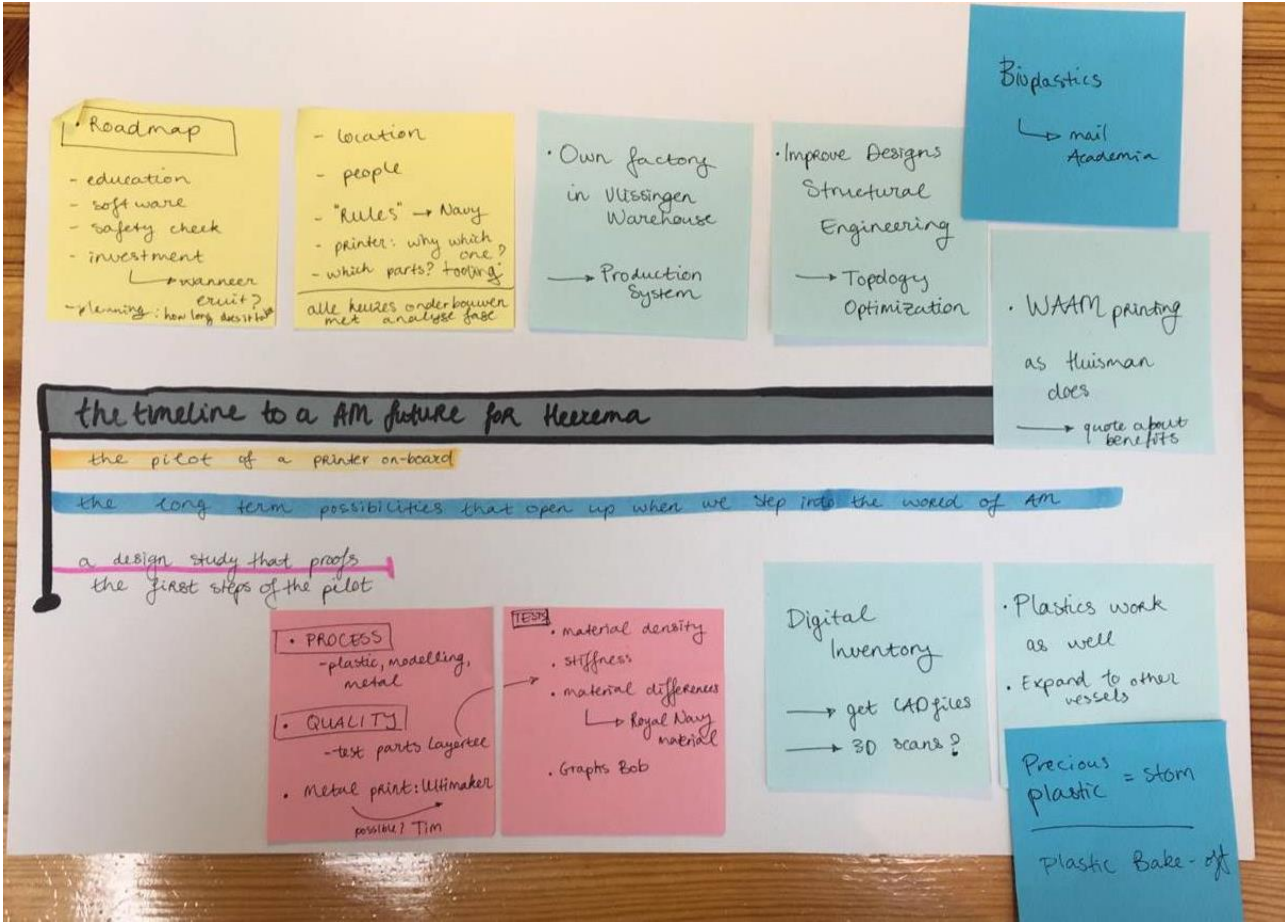
Together with Layertec Heerema has to decide which vessel and project seem to be most suitable to start the pilot of 3D printing on-board.

Once the decision is made, the pilot has to be discussed with Storekeepers and VMT of the particular vessel. All strengths, weaknesses, opportunities and threats of the system should be included.





WHAT DO THEY HAVE TO DO WITH A GOOD/BAD ROADMAP?
ROAD MAP
— EXTENDED VERSION —
LOCATION = THIALF
research phase
Workshop/store
maybe machines have different locations?
Bas F 316 L → Royal Navy, Sander
which?
properties
material
metal
plastic
properties
which plastic?
what can UM print?
what is needed?
MEIKE GRADUATES
contractueel service
aanschaf
ultimaker / DM
LIMITS
· dust
· waves
debinder
furnace
pas nodig als we metaal gaan printen
en als we kunnen cloud modeleren, waar slaan we onze files op?
Create Digital Inventory
START PILOT
PARTNERSHIP LAVERTEC
FOLLOW-UP RECOMMENDATIONS
education
software
which one?
. Solid Works = Layertec Education
. 3D max = Drawing Team
. Rhinoceros = Dave & Meike
welke werkt met Slicer Software?
hardware
AND printing
which one?
· Ultimaker: plastic/metal
· Desktop M: metal
Sinter & debind process
· direction
· temp.
· layers
· geometry
· support
maintenance, errors, parameters faults
CONTINUE PILOT-ING "LONG-TERMS"
@ Thialf
out of meike-scope? Only SOME = ●
. costs → HOW BROAD?
. budget / investment (ROI)
. knowledge - on-board
. safety
● insurance / warranty
. how much material do we take with us?
. Risks
● waste
Hans
PEOPLE
Storekeepers
take into account from "START PILOT"
easy wins
tooling
what is their incentive? to 3D print
LEARN
AWARENESS CREW
GENERALIZE PILOT = non-specific vessel plan
who will be the users of the printers?
- team external
- storekeepers
- workshoppers
who comes up with "printable parts"?
how do they know they can use this?
· clients
· structural engineers
improve designs
IMPLEMENT ON OTHER VESSELS
SON & MEIKE
RULES
· what to print?
· certification
· when 'ok' to print?
· approval needed? when?
· when 'ok' to use?
· what tests needed?
who will be RESPONSIBLE?
· warranty
how do they decide what to 'create' in their shop?


the timeline to a AM future for Heerema
the pilot of a printer on-board
the long term possibilities that open up when we step into the world of AM
a design study that proofs the first steps of the pilot
· Roadmap
- education
- software
- safety check
- investment
→ wanneer eruit?
- planning: how long does it take
- location
- people
- "Rules" → Navy
- printer: why which one?
- which parts? tooling
alle keuzes onderbouwen met analyse fase
· Own factory in Vlissingen Warehouse
→ Production System
· Improve Designs Structural Engineering
→ Topology Optimization
Bioplastics
→ mail Academia
· WAAM printing as Huisman does
→ quote about benefits
· PROCESS
- plastic, modelling, metal
· QUALITY
- test parts Layertec
· Metal print: Ultimaker
possible? Tim
TESTS
· material density
· stiffness
· material differences
→ Royal Navy material
· Graphs Bob
Digital Inventory
→ get CAD files
→ 3D scans?
· Plastics work as well
· Expand to other vessels
Precious plastic = storm
Plastic Bake-off

APPENDIX 24

Leapfrog printers Heerema

At the moment Heerema and HES are using Leapfrog printers, why not choose this on-board of the vessels as well?

- For this project Heerema will collaborate with Layertec. This company sells Ultimakers and Desktop Metal systems. To make use of their service and education the printers have to be bought there as well.

- It seems logical to use the same printer as already been used in the office. Howevere if we, again, look at the main goal of the pilot, we want the crew to adapt. In other words, we do not want them to be depending on the knowledge in the office. Therefore, using other hardware will encourage the users to try out the service of Layertec. Potential bugs that we discover for using the service offshore could possibly be fixed before implementing the more advanced metal technologies.

- Finally, diversifying and gaining new knowledge on other printing systems fits the Founder's Mentality within Heerema.

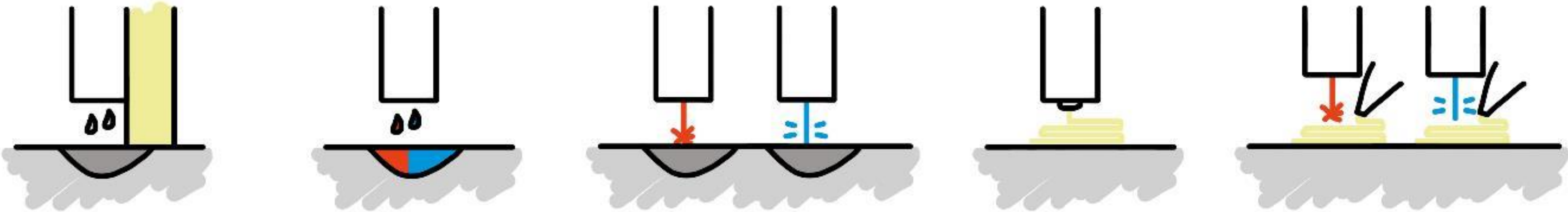
Figure 83: Leapfrog Bolt (Leapfrog)

APPENDIX 25

Benefits and limitations printing techniques metal

There are different techniques within the Additive Manufacturing technology for printing metal materials (Doubrovski), the benefits and advantages per technology are shown in the following figure:

MATERIAL JETTING	BINDER JETTING	POWDER BED FUSION	MATERIAL EXTRUSION	DIRECT ENERGY DEPOSITION
NPJ NANOPARTICLE JETTING	**BJ** BINDER JETTING	**DMLS/SLM** DIRECT METAL LASER SINDERING/ SELECTIVE LASER MELTING **EBM** ELECTRON BEAM MELTING	**BMD** BOUND METAL DEPOSITION	**LENS** LASER ENGINEERING NET SHAPE **EBAM** ELECTRON BEAM ADDITIVE MANUFACTURING



MATERIAL JETTING	BINDER JETTING	POWDER BED FUSION	MATERIAL EXTRUSION	DIRECT ENERGY DEPOSITION
BENEFITS (XJet, 2019) • *Smooth surfaces and fine details.* • *No powder bed.* **DISADVANTAGES** (XJet, 2019) • *Layer thickness of microns causes long print times* • *Support material.* • *Inkjet technology.*	**BENEFITS** (ExOne, n.d.) • *Does not employ heat* • *Fine details.* **DISADVANTAGES** • *Metal powder is highly flammable and thereby dangerous on-board.*	**BENEFITS** *(UVA)* • *Possibility to print in small details.* **DISADVANTAGES** • *Metal powder is highly flammable and thereby dangerous on-board.* • *Because of the lasers the balance of the vessel offshore might be problematic.*	**BENEFITS** (3D Hubs, n.d.) • *Safe to print on-board.* • *Broad material range.* • *Easy to use.* **DISAVANTAGES** • *Limitations in size (30x20x20 cm).*	**BENEFITS** *(Hugo Romer, Huisman)* • *Already proven to work for bigger offshore spare parts.* **DISADVANTAGES** • *Used for parts of a larger size than the spare parts of the project context.*

BMD SYTEMS

There are various BMD systems on the market:

- **Markforged,** offering a system called the Metal X System (Markforged, n.d.).
- **BASF Ultrafuse 316L,** a material produced by BASF that can be placed in a traditional FDM printer. An industrial debinder and furnace have to be purchased separately (BASF, n.d.).
- **Rapidia**, a company based in Canada. They are quite new and therefore only deliver in the North of America at the moment.
- **Desktop Metal**, a company based in the United States that is located quite globally (figure X, (Rejto, 2020)).

BENEFITS AND LIMITATIONS BMD

Desktop Metal:

- Safe to print on-board.
- Broad material range.
- Easy to use.

According 3D Hubs, the benefits of the BMD technique are (3D Hubs, n.d.):

- Low-cost metal 3D printing.
- Functional metal prototypes.
- Easy-to-use systems.

These benefits prove the fit of the chosen technique with the problems mentioned in the previous chapter.

The limitations are described as (3D Hubs, n.d.):

- Higher cost than CNC for simple parts.
- Lengthy post-processing.
- 33% lower strength than wrought.

Because of these limitations it is important to choose the right BMD system to reduce the limitations were possible. Also, the limitation based on costs does not bother the solution since the delivery time of the part is a bigger bottleneck. Also, the size is limited (30x20x20 cm).

APPENDIX 26

Paper and Field study Part Selection

Because of the limitations of 3D printing technologies, not all parts on-board are suitable. This chapter will focus on selecting part to explore whether there are parts on-board that are suitable for 3D printing. Also, selection will take place to choose parts to conduct the design study with.

INPUT HEEREMA

According to Vincent Doedée, the parts selected should be the easy wins. This means the vessel crew should see a ‘clear beneficial improvement’. For them, it has to make sense to produce these parts with this new machine.

To select the parts that will be printed, two studies are conducted: a study data assessing parts on-board in collaboration with Layertec and a study analysing existing parts.

STUDY 1: FIELD STUDY

To analyse the parts present at the Thialf warehouse they were all individually looked at.

FILTER 1. GEOMETRY STUDY WAREHOUSE

The first step was selecting parts based on the knowledge gathered about the BMD technique. A picture with measurements was taken of all parts that seemed geometrically suitable. These pictures were combined with information from Infor to create a spreadsheet consisting of 45 parts that could potentially be printed, based on geometry and gathered knowledge.

FILTER 2. LAYERTEC CHECK

The spreadsheet with all information was sent to Robert Slegers of Layertec, to let them check the compatibility of the 45 parts. Four parts were selected to show Heerema what is possible with the Desktop Metal printers.

FILTER 3. APPLICATION CHECK

To choose one of the 4 selected parts the application was analysed in collaboration with Hans Havermans, Chief Storekeeper. Based on the applications the following insights were created:

Nozzle, 10040080: suitable, but modelling the part will take time because of the organic shapes.
Lever 10001942: suitable, modelling needed to estimate costs and printing time.
Cover suction filter 10115023: suitable to print, but application has vacuum function: 3D printed materials are brittle.
Worm Wheel 10003865: suitable, especially the price makes this part interesting since it will be much cheaper to 3D print it.

FILTER 4. COSTS COMPARISON

As can be seen in figure X, the Worm Wheel Gear, part of a Shimadzu/Rotork Motor Operated Valve is 1319,69$ per unit. According to Rob Witkam, 3 units were purchased in July 2017. During the period 2005 – 2007 14 units were used.
The Lever is 192,40$ per unit and located in the head engine of the Thialf as part of the switch.

PICTURE	NR	NAME	DESCRIPTION HANS HAVERMANS	PRICE	SIZE (cm)	LAYERTEC
	10040080	Nozzle 1.1/2" BSP, 60 Degr Stainless Steel 316 f/Coolingwater Spray Exhaust Sys	Used in the Balder at the exhaust of the main engine. By pushing water through the nozzle a spray is create which causes the heavy parts of the exhaust gases to descend	$145,49	5*5*17	Probably yes, depending on the geometry, dimensions in height, aspect ratioand the build volume of the printer.
	10001942	Lever and Bush	This is a part of the MAK head engine. With the equipment of which this part is part, you can control an electrical shut down of the Main Engine.	$192,40	3*4*5	Yes, this can be printed. Depending on the dimensions of the part and the build volume of the printer.
	10115023	Cover Suction Filter	This is a cover plate of a suction filter from the smaller crane on-deck.	$223,09	16*10*11	Yes, this can be printed. Depending on the dimensions of the part and the build volume of the printer.
	10003865	Worm Wheel Gear	This part is a gearbox gearbox for a Shimadzu / Rotork Motor Operated Valve that controls the ballast water pump	$1319,69	12*12*12	Yes, this can be printed. Depending on the dimensions of the part and the build volume of the printer.

CONCLUSION STUDY 1: FIELD STUDY

Based on previous mentioned insights the Lever (10001942) and the Worm Wheel Gear (10003865) are selected to be used for the design study.

STUDY 2: PAPER STUDY

To substantiate the first study conducted in the field, a paper study is executed. For the paper study, various filters are applied to the current spare parts. Some of the filters mentioned in figure x are based on the factors that should be considered while selecting an optimal additive manufacturing process according to Gokuldoss (2017).

FILTER 1 THIALF

FILTER 2 NON PRINTABLE STORES

FILTER 3 NON PRINTABLE PARTS

FILTER 4 CONSUMABLES, STRANGERS, REPEATERS

FILTER 1. THIALF

The excel with spare parts is narrowed down to the parts that are present in the Thialf store. This selection is used for the analysis to create focus. Later on in the process, the solution will be made applicable for the other stores/vessels as well. The following categories are made within the Thialf store selection.

Further filters are applied to minimize the Excel with 28.124 parts.

FILTER 2. PRINTABLE STORES

The second selection is based on stores that contain parts that are not interesting for 3D print applications for now. These stores include medicines and food.

It is also decided to not look into the Project Store since this store varies per project. The client is involved in creating this list and thus printing parts might be possible, but this store is not used as starting point.

That is why after applying filter 2, the Investment store, MRO store, NFE store and OPS store remain.

Store Nr.	Store Name
333-INV	Thialf Investment Store
333-MED	Thialf Medical Store
333-MRO	Thialf MRO Store
333-NFE	Thialf NFE Store
333-OPS	Thialf Operations Store
333-PROJ	Thialf Project Store
333-UTIL	Thialf Ultility Store

If any item within the non-printable stores seem to be printable, but are within the deselected stores, those items will be taken into account as a recommendation.
It must be said that food and medicines do have a future in which it seems possible to be printed (Tran, J. 2016 and Awad, A. et all, 20..). However, this will be recommended to look at when the technology is more adapted to daily use before taking it on-board.

FILTER 3. PRINTABLE PARTS

The parts that are present in the selected stores, but for sure not printable are deselected as well. Those parts include:

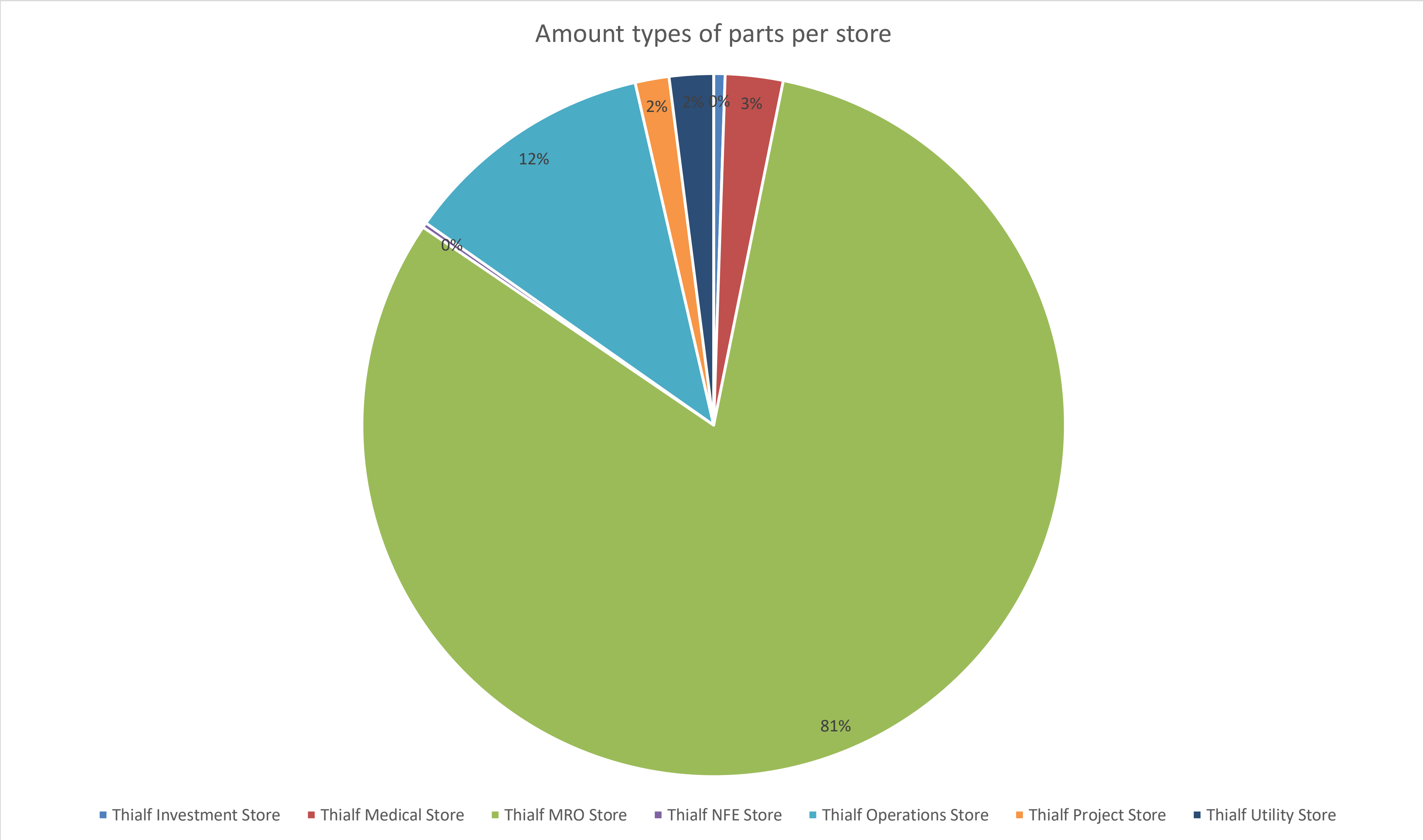
- *Electrical parts*
- *Too big/heavy/mechanic*
- *Printable, but not with BMD*
    - *Plastic*
    - *Rubber*
    - *Too big for BMD*
- *Non-printable materials (schuurpapier)*
- *Safety parts/PPE*

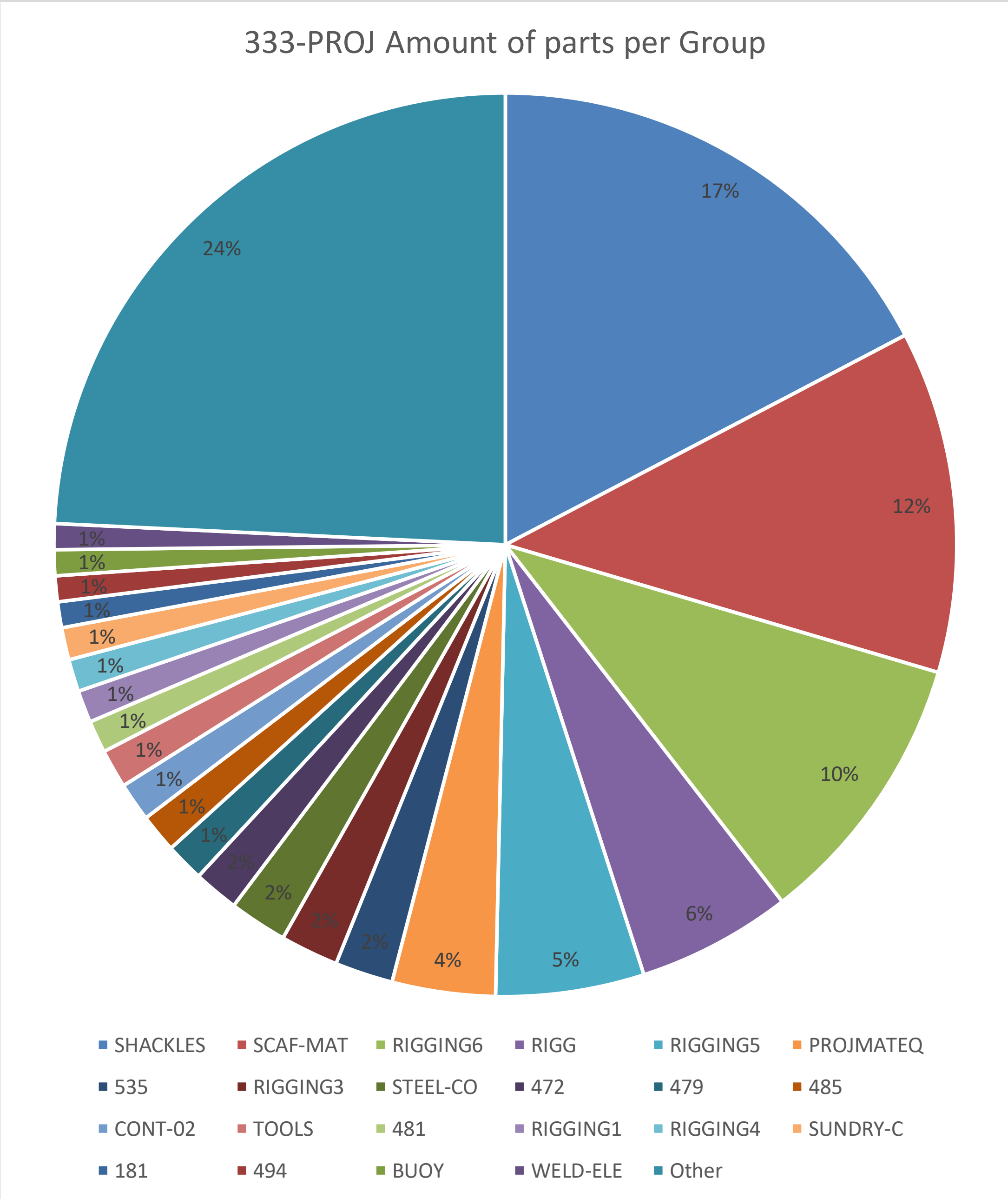
Electrical parts can be printed as well (Flower, P. F. 2017), however as Flower states this technology is too advanced to implement in a rough environment.

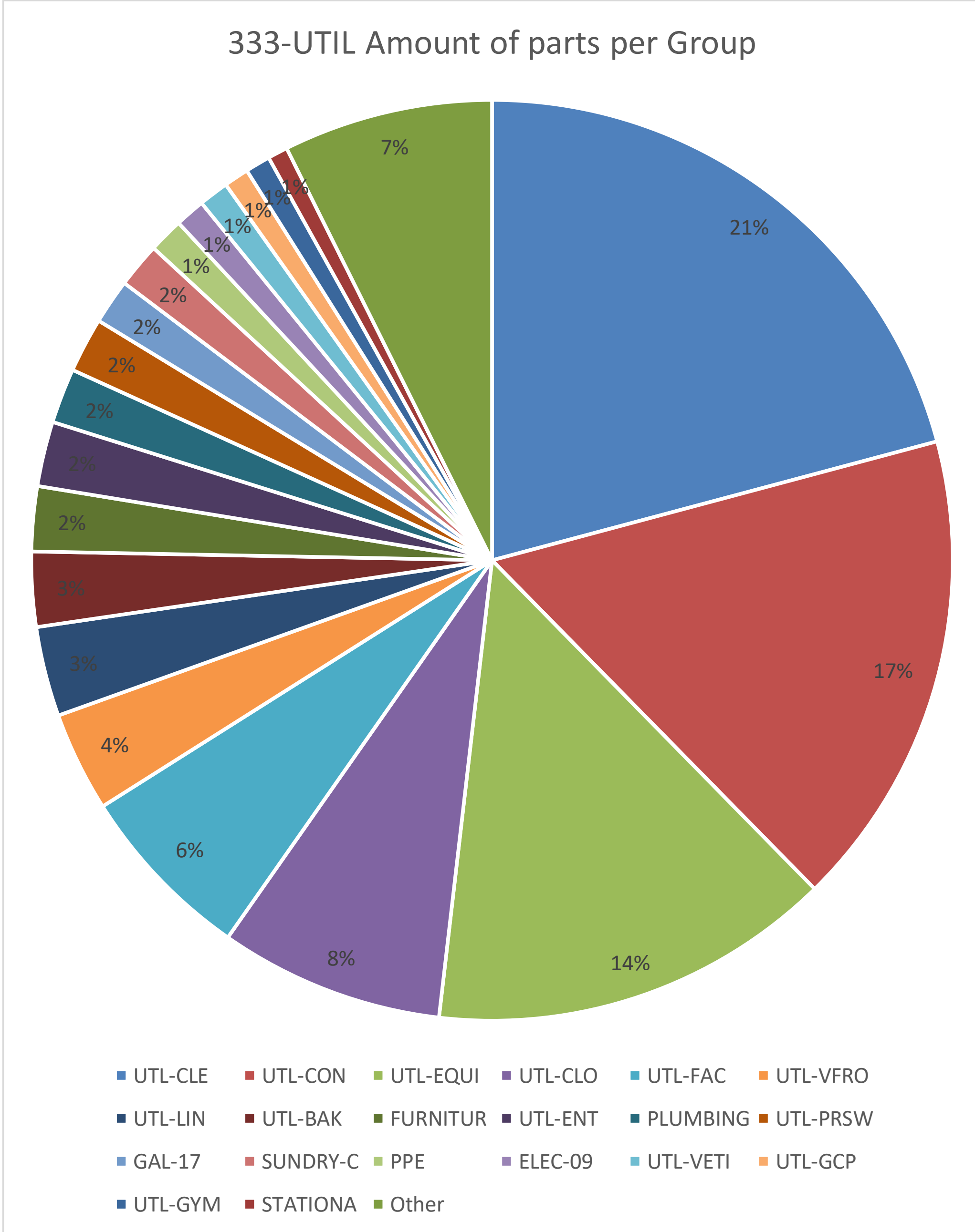
FILTER 4. CONSUMABLES, STRANGERS, REPEATERS

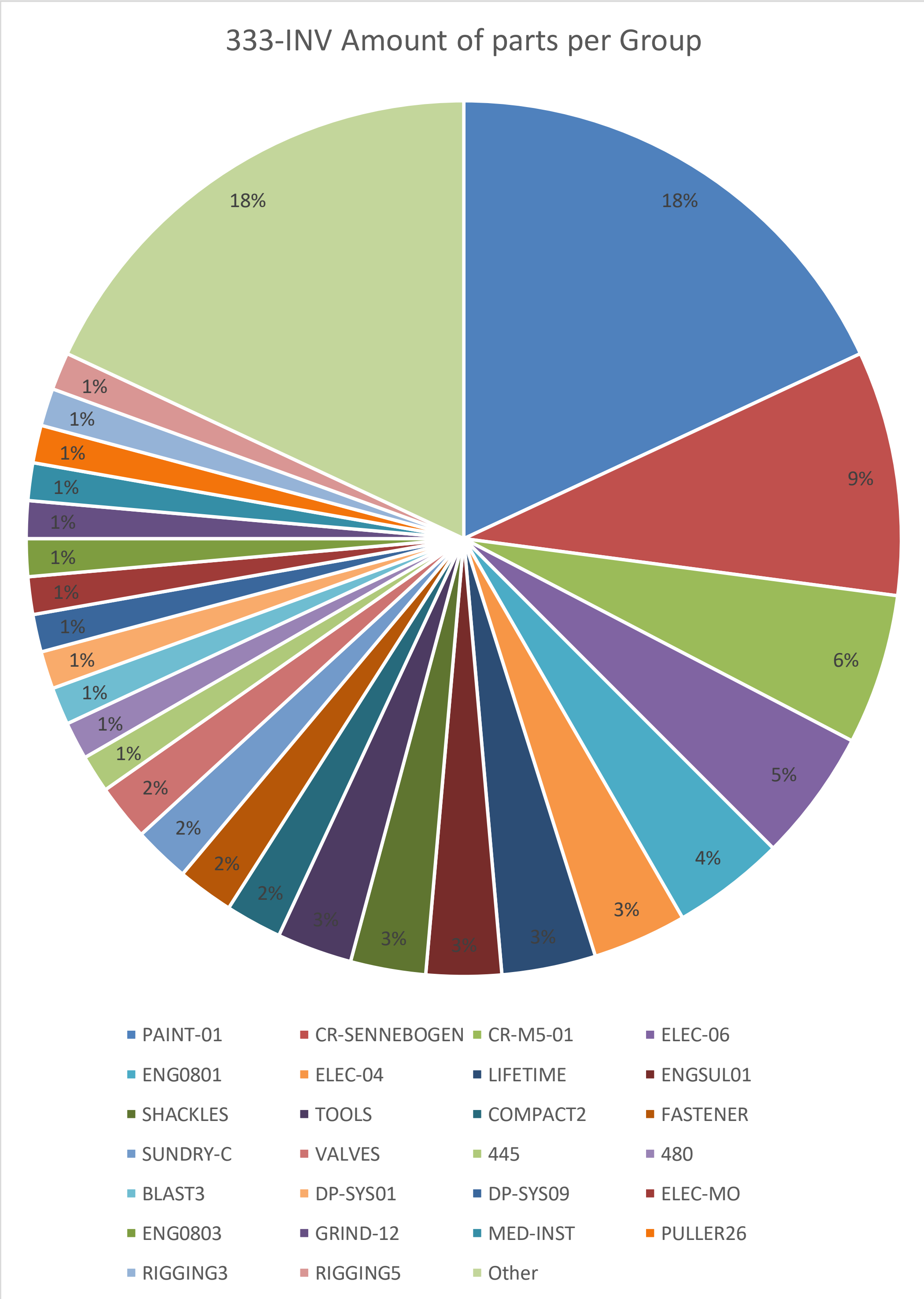
To decide whether a part belongs to the consumables, strangers or repeaters group the criticality and need to certify are determinative. However, this is not stated in Infor.

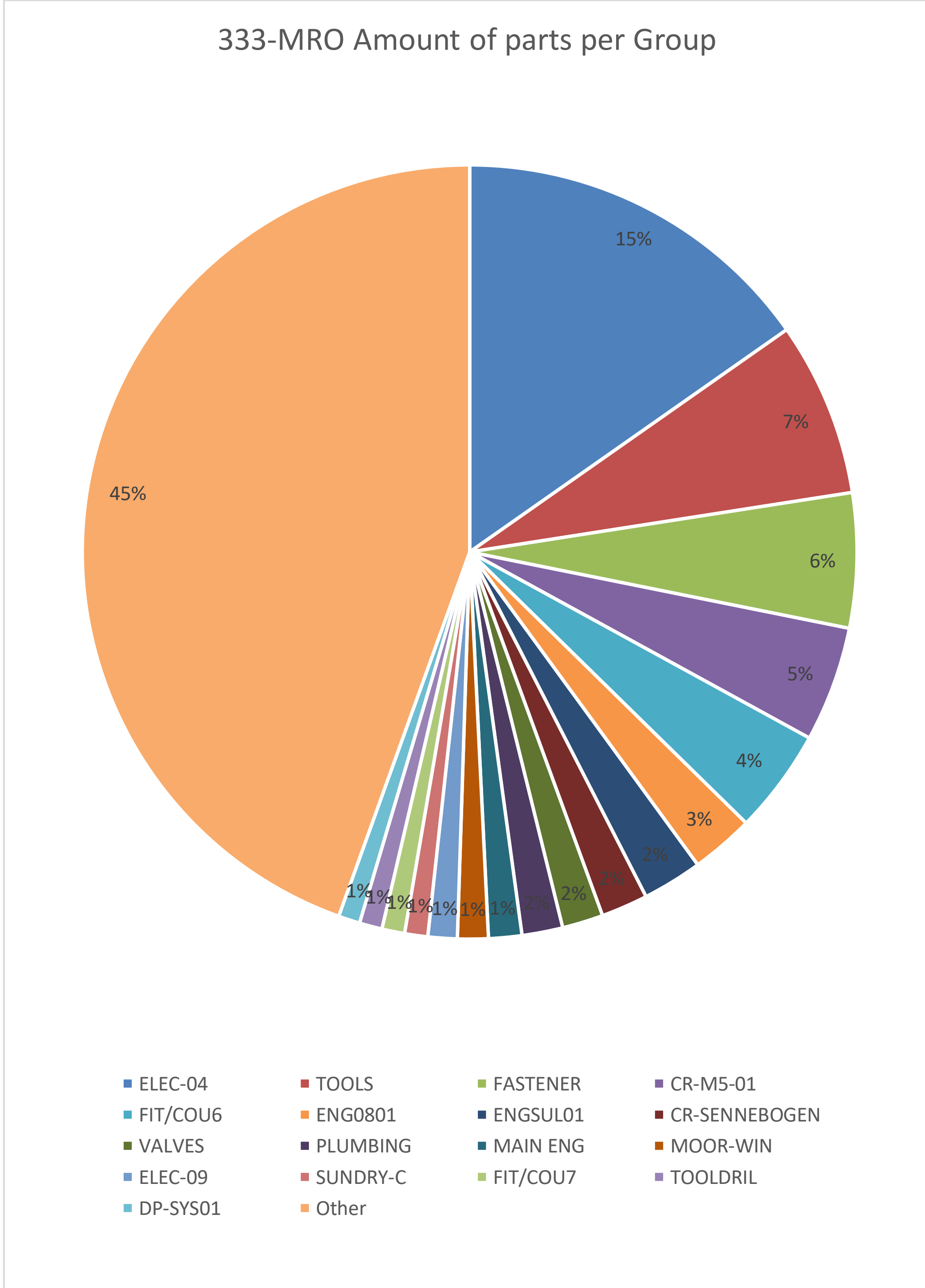
Division of parts per store at Thialf

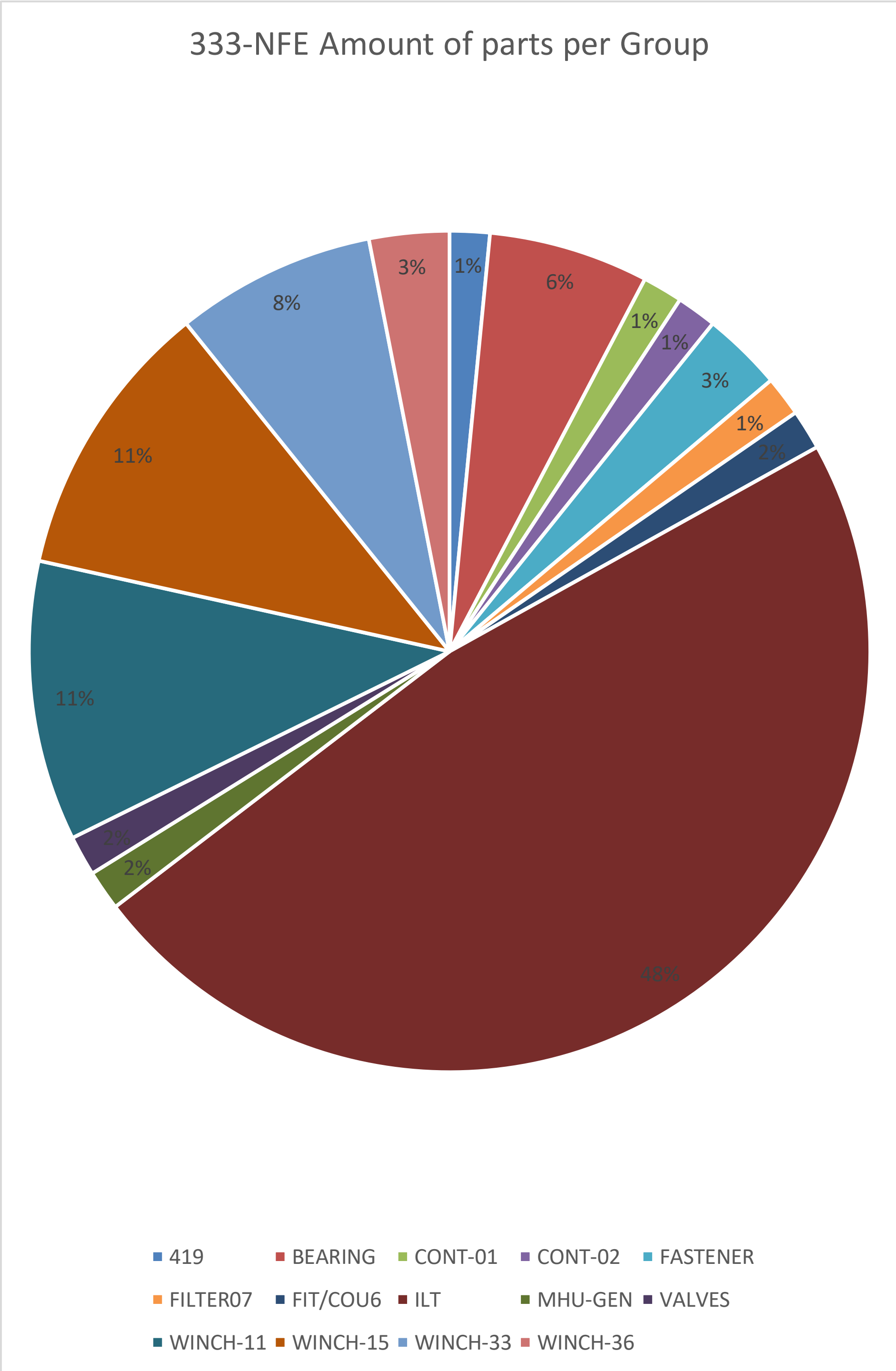


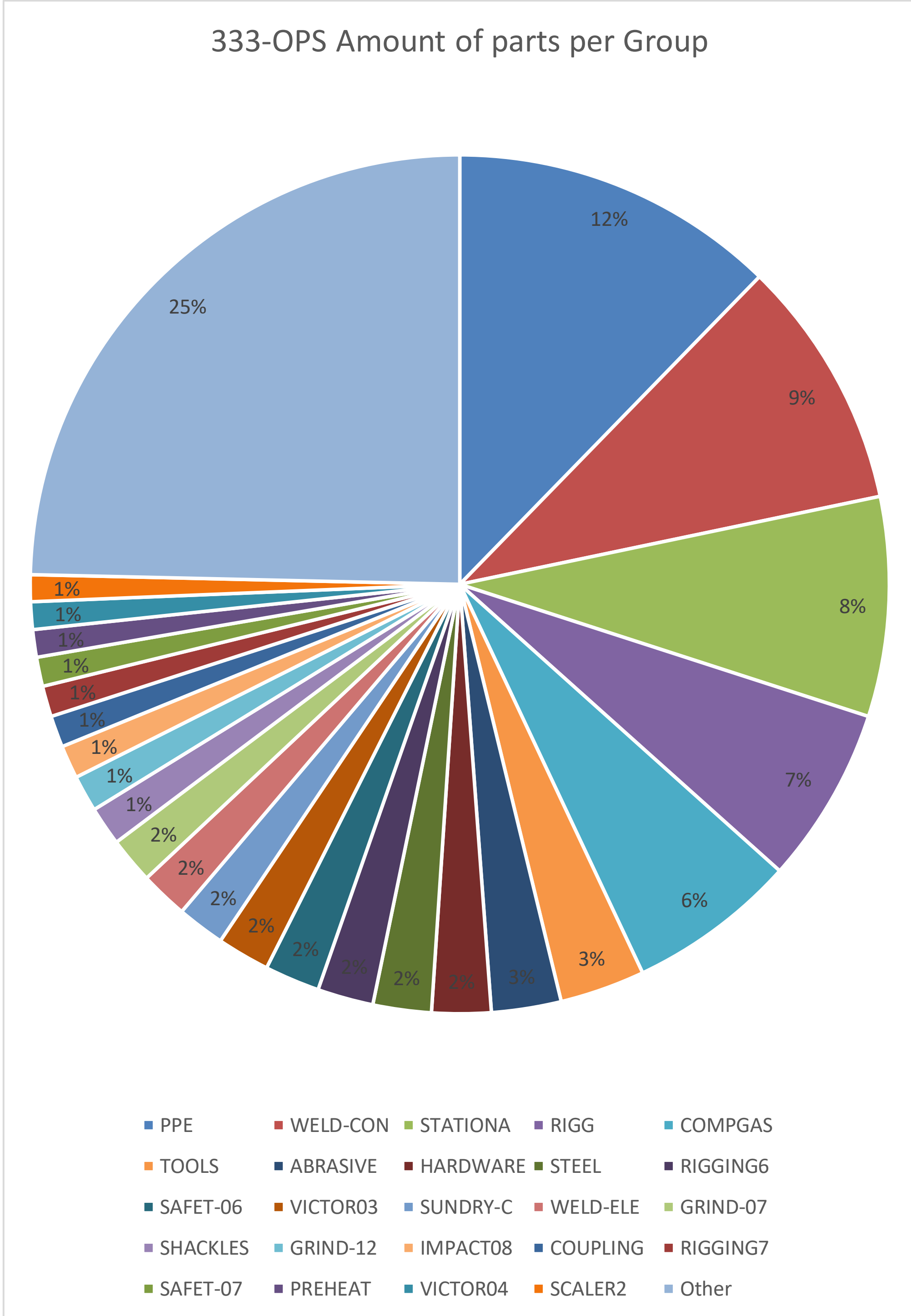

333-PROJ Amount of parts per Group
SHACKLES
SCAF-MAT
RIGGING6
RIGG
RIGGING5
PROJMATEQ
535
RIGGING3
STEEL-CO
472
479
485
CONT-02
TOOLS
481
RIGGING1
RIGGING4
SUNDRY-C
181
494
BUOY
WELD-ELE
Other


333-UTIL Amount of parts per Group
UTL-CLE
UTL-CON
UTL-EQUI
UTL-CLO
UTL-FAC
UTL-VFRO
UTL-LIN
UTL-BAK
FURNITUR
UTL-ENT
PLUMBING
UTL-PRSW
GAL-17
SUNDRY-C
PPE
ELEC-09
UTL-VETI
UTL-GCP
UTL-GYM
STATIONA
Other


333-INV Amount of parts per Group
18%
9%
6%
5%
4%
3%
3%
3%
3%
2%
2%
2%
2%
1%
1%
1%
1%
1%
1%
1%
1%
1%
1%
1%
1%
18%
PAINT-01
CR-SENNEBOGEN
CR-M5-01
ELEC-06
ENG0801
ELEC-04
LIFETIME
ENGSUL01
SHACKLES
TOOLS
COMPACT2
FASTENER
SUNDRY-C
VALVES
445
480
BLAST3
DP-SYS01
DP-SYS09
ELEC-MO
ENG0803
GRIND-12
MED-INST
PULLER26
RIGGING3
RIGGING5
Other


333-MRO Amount of parts per Group
15%
7%
6%
5%
4%
3%
2%
2%
2%
1%
1%
1%
1%
1%
1%
1%
45%
ELEC-04
TOOLS
FASTENER
CR-M5-01
FIT/COU6
ENG0801
ENGSUL01
CR-SENNEBOGEN
VALVES
PLUMBING
MAIN ENG
MOOR-WIN
ELEC-09
SUNDRY-C
FIT/COU7
TOOLDRIL
DP-SYS01
Other


333-NFE Amount of parts per Group
1%
6%
1%
1%
3%
1%
2%
48%
2%
2%
11%
11%
8%
3%
419
BEARING
CONT-01
CONT-02
FASTENER
FILTER07
FIT/COU6
ILT
MHU-GEN
VALVES
WINCH-11
WINCH-15
WINCH-33
WINCH-36


333-OPS Amount of parts per Group
12%
9%
8%
7%
6%
3%
3%
2%
2%
2%
2%
2%
2%
2%
2%
1%
1%
1%
1%
1%
1%
1%
1%
1%
1%
25%
PPE
WELD-CON
STATIONA
RIGG
COMPGAS
TOOLS
ABRASIVE
HARDWARE
STEEL
RIGGING6
SAFET-06
VICTOR03
SUNDRY-C
WELD-ELE
GRIND-07
SHACKLES
GRIND-12
IMPACT08
COUPLING
RIGGING7
SAFET-07
PREHEAT
VICTOR04
SCALER2
Other

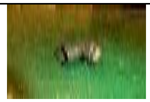
APPENDIX 27

Selected parts (45x)

PARTS										
PRINTABLE Y/N - Layertec		**NR.**	**NAME**	**DESCRIPTION**	**PRICE [US$]**	**SIZE *(l*w*h)***		**MANUF.**	**DRAWING NR.**	**Thialf PART**
Probaly yes, depending on the Geometry, dimensions in height, aspect ratio of the part and the build volume of the printer.		10040080	Nozzle 1.1/2" BSP, 60 Degr. Stainless Steel 316 f/Coolingwater Spray Exhaust Sys	**Hans Havermans:** Wordt gebruikt bij de Balder onder de “koekdoos” bij de exhaust van de main engines. Door water door deze Nozzle sturen creëer je een spray waarmee de zware delen in uitlaatgassen neervallen	**$145.49**	5*5*17	**SS 316 f**	BETE-FOG	-	-
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001942	Lever and Bush	**Hans Havermans:** Is een onderdeel van de MAK hoofdmotor. Met het equipment waar dit onderdeel deel van uit maakt kan je een electrical shut	**$192.40**	3*4*5		MAK	1.4677B	ENG-MAIN.1080

				down van de Main engine aansturen						
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10115023	Cover Suction Filter	**Hans Havermans:** Dit is een afdek plaat voor een zuig filter van de Maeda (calimero) kraan aan dek	**$223.09**	16*10*11		MAEDA	-	-
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10003865	Worm Wheen Gear Ration	Gear ratio 1:80	**$1,319.69**	12*12*2		SHIMADZU	RE-02503	MOV-309
Need more info on this one. Can't see what's inside		10140465	Bottom Bearing Holder	-	**$1,777.98**	6*6*17		ALFALAVAL	-	-

What kind of material? yes, this can be printed. depending on the dimensions of the part and the build volume of the printer. Need more info		10073847	Impeller for Pump Type CA 50/3A	Watermaker Demitec SW 8040/10	**$626.28**	16*16*3		AZCUE	-	RO-0050
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer. Having doubts about achieving the material properties.		10030972	Die Plate M90x4	-	**$341.85**	14*14*3		VAN-EYLE&	-	DIE-194
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10071575	Wedge Socket Steelrope Suspension	-	**$78.90**	24*6*4		REUS	-	ELEV-ACCOM.0196

Need more info										
Easy to have on stock.		10034690	Coupling Clamp VSH 28mm - OT1"	-	**$4.46**	6*5*3		TECH-UNIE	-	PLUMB-355
No, Wallthickness and aspect ratio could be a problem		10053246	Vessel De-Airation	-	**$2,189.90**	33*26*9		BAKKER-SL	-	PROPUL-0504
No, Wallthickness and aspect ratio could be a problem		10054316	Cock Drain 3/4" - Fig. 713 - Bronze Brent - Nose Loackable	-	**$65.02**	9*10*4		ECONOSTO	-	VALVE-002
Wall thickness could be a problem		10130470	Cap	-	**$32.20**	17*15*6		MAK	7.1633A	-
Wallthickness and aspect ratio could be a problem		10050467	Coup. Swaged Hose 1" Hose 0 28 mm. Pipe-Straight	-	**$19.79**	4*4*9		FLEXION	ES16A28RZ	COUPLING-1062
Wallthickness and aspect ratio could be a problem		10052976	Filter Housing (Suction) 1" (Stainless)	-	**$70.00**	4*9*12		WARTSILA	W084832400/POS.11	PROPUL-0109
Wallthickness and aspect ratio could be a problem		10075939	Impellor for Sewage Plant type SK-SUPER-	ST-20-PART NO 26-S NO. 1512	**$33.98**	8*8*13		SASAKURA	PS NR.26	-

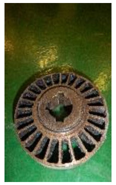
			TRIDENT Model ST-20							
Depending of the material.yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10052059	Retainer Water Impeller	-	**$459.37**	12*12*5		SUCTION GA	3024020	EQUIP-AUX.0221
Yes, this can be printed **but not in Brass**		10039364	Plug Complete (brass) - set	-	**$9.79**	5*5*5		BLOKSMA	-	FOC-0020
yes, this can be printed. depending on the dimensions adn wall thickness of the part and the build volume of the printer.		10040797	Impeller P/N 230	-	**$200.00**	14*14*12		VATEC-MACH	-	PUMP-0562

yes, this can be printed. depending on the dimensions of the part ,Aspectratio of the Wall thickness and the build volume of the printer.		10001120	Bearing Collar	Fire Pump EB2H-100S	**$3.20**	10*10*9		Naniwa-Pum	DS-1955AM	PUMP-0103
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001032	Stage Ring	FW Pressure and SW Pressure Pump EB2H-65	**$333.04**	15*15*4		Naniwa-Pum	DS-1426M	PUMP-0002
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001056	Nut Bearing	Main SW Cool pump FBWV-450	**$16.40**	10*10*2		Naniwa-Pum	DS-1962AM	PUMP-0028
yes, this can be printed. depending on the dimensions of the part		10001330	Seal Cover	Fire Pump EB2H-100S	**$219.78**	12*16*4		Naniwa-Pum	DS-1955AM	PUMP-0420

and the build volume of the printer.										
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001388	Flinger	FW Pressure and SW Pressure Pump EB2H-65	**$134.55**	8*8*3		Naniwa-Pum	DS-1426M	PUMP-0526
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001524	Plate Valve	-	**$40.00**	12*12*3		MAK	7.1633A	ENG-MAIN.0115
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001597	Lever and Bush	-	**$200.00**	21*10*4		MAK	7.4215C	ENG-MAIN.0223

yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10001728	Flange	-	**$135.85**	16*9*3		MAK	1.4677B	ENG-MAIN.0559
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10003861	Limit Switch Worm Wheel	Gear ratio 1:80	**$492.43**	9*9*2		SHIMADZU	RE-02503	MOV-304
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10003866	Thrust Pad	-	**$10.00**	16*10*5		SHIMADZU	RE-02503	MOV-310
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10005353	Nut Eye	Din 582/Grade C15	**$7.18**	11*13*5		-	-	FASTENER-0908

yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10006878	Valve Seat Exhaust	-	**$66.85**	14*14*8		SULZER	2701-1/A1&2754-1/A2	SULZ-0461
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10010001	Tee 2" Galvanised Malleable	Acc. EN 10242-Material W-400-05	**$10.03**	10*10*12		V-LEEUW	-	-
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10023971	Rod LP Connecting R22594	-	**$218.18**	37*9*2		INGERSOLL	-	COMPRS-ING.079
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10024176	Valve with Concentric Ring	-	**$1,069.58**	13*13*12		INGERSOLL	-	CRANE-WINCH0228

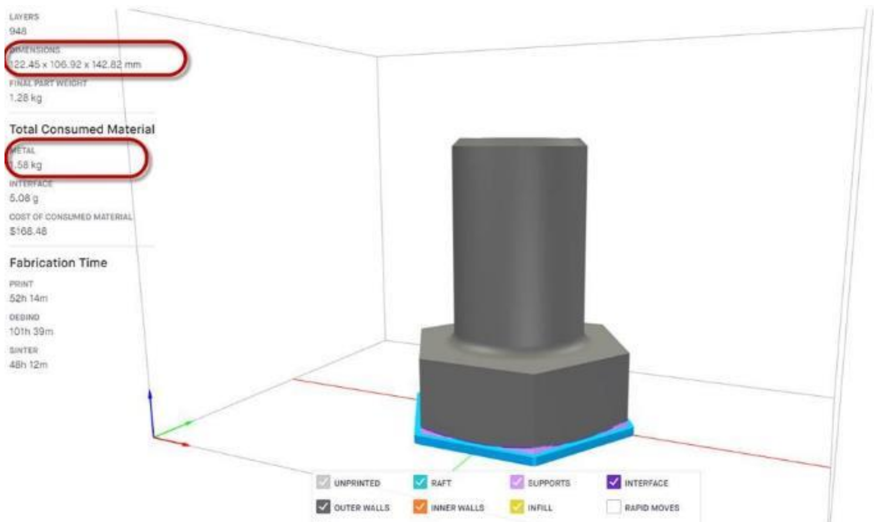
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10040790	Coupling Deliver Bore 32	M/G F.O. Supply Pump ALG-32	**$168.59**	13*13*5		Naniwa-Pum	DS-1363PM	PUMP-0090
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10040814	Wheel Air Item No. 1500	-	**$60.00**	11*11*3		STORK	-	PUMP-0700
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10044481	Bush Sealing Turbine End (51014)	Turbo Type VTR454-11 and VTR454-21 (Main Eng 1 thru 8)	**$191.39**	10*10*5		ABB	411817A	ENG-MAIN.0204
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10044523	Candle Support	-	**$4.22**	10*10*2		MISUZU-MAC	G2-01011	ENG-MAIN.0313

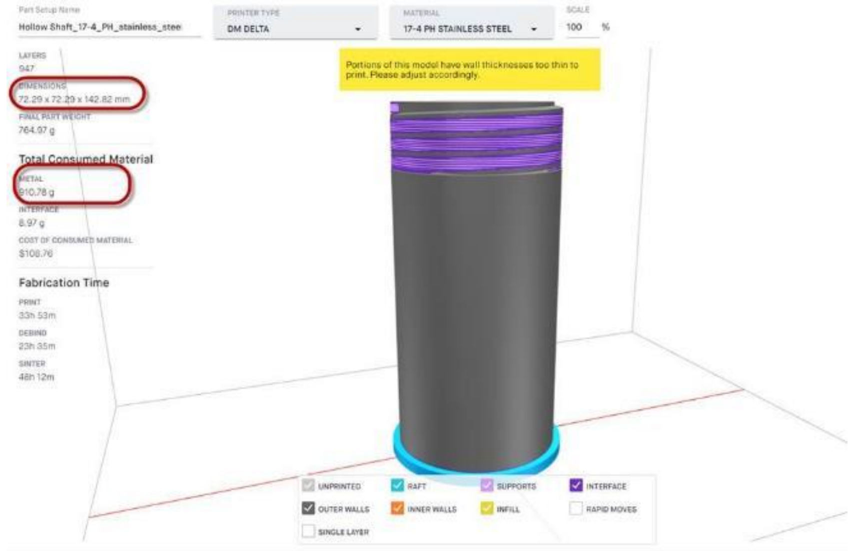
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10053341	Couplet Eritite ETD 1" SS F BSP 1"	-	**$32.00**	4*4*5		ERIKS	-	PROPUL-0635
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10057968	Snaplock Adaptor 1.1/2" Outside Thread Stainless Steel Type F	-	**$32.81**	6*6*8		SNAPLOCK	-	COUPLING-0266
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10120595	Gasket Victaulic Style 77 - 10" /273	-	**$50.25**	8*10*3		VICTAULIC	-	-
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10125549	Palm Grip	Cylinder Head Cap B1.05.01.9.2190 DD	**$22.22**	7*7*6		MAK	-	-

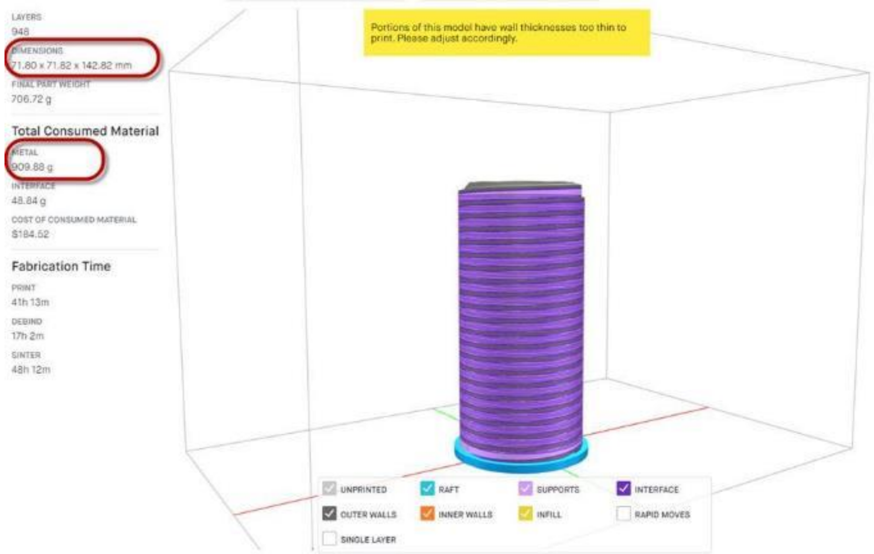
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10145595	Coupling Part	Hub 1.0 38H7 Key Din 6885/1-JS9 For lub oil priming pump sulzer	**$41.68**	8*8*7		ROTEX	-	-
yes, this can be printed. depending on the dimensions of the part and the build volume of the printer.		10193253	Bearing Cover	No. 1-3 F.W. Pressure Pump EB2H-65	-	16*16*4		Naniwa-Pum	209	-
yes, this can be printed. depending on the dimensions of the part, wall thickeness and the build volume of the printer.		10001329	Clutch	Vacuum Pump	-	18*18*8		Naniwa-Pum	DS-1121	PUMP-0419
		10001182	Rotor	Vacuum Pump	**$40.08**	10*10*10		Naniwa-Pum	DS-1121	PUMP-0187

APPENDIX 28

Snapshots of errors printing Bolt at Layertec

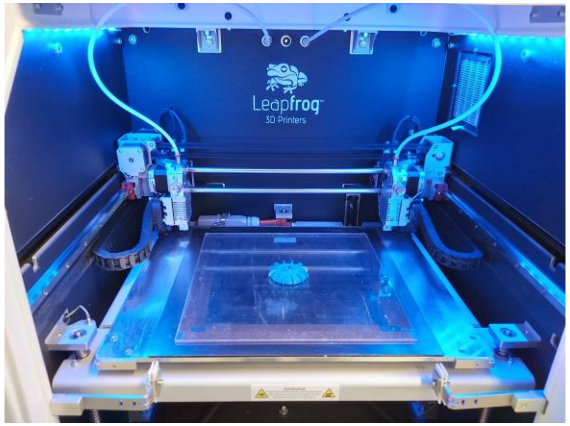


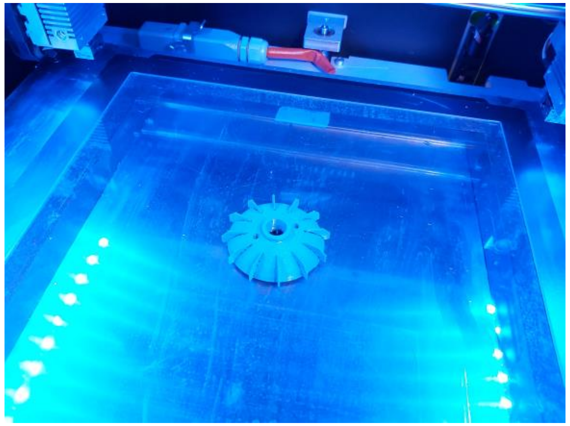




APPENDIX 29

Print study plastic part





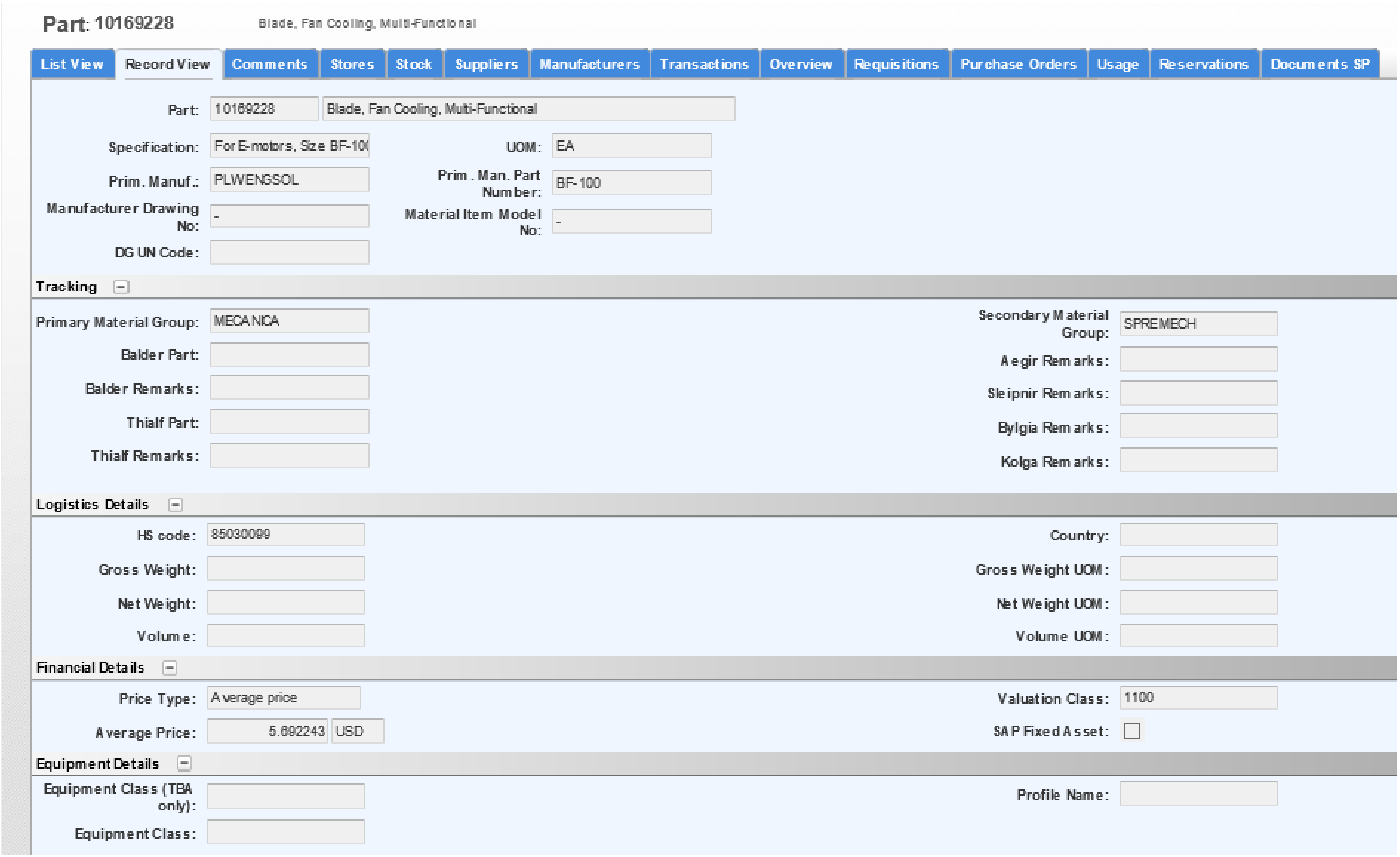


Figure 84: Infor screen part 10169228

APPENDIX 30

Plastic print study

PLASTIC PRINT – practising

3D PRINT PROCESS

For the design study with plastic 3D printing I started a design project of a Heerema coffee cup. The cup is modelled in Rhinoceros and printed with the Leapfrog 3D printer at the Heerema Office with PLA.

This process gave the following general insights:

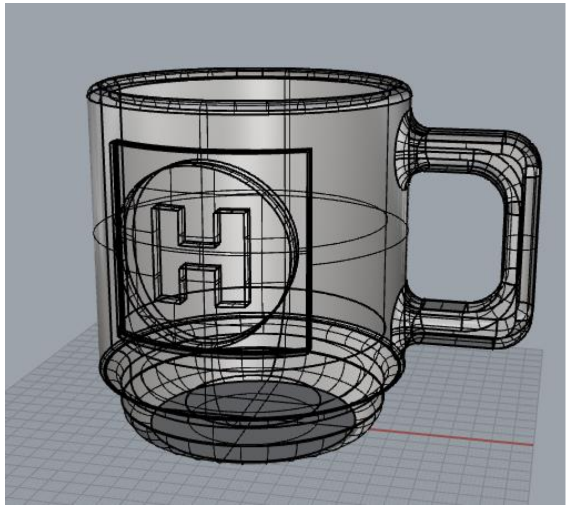
Rhinoceros
Tolerances details
Material knowledge
Waiting time

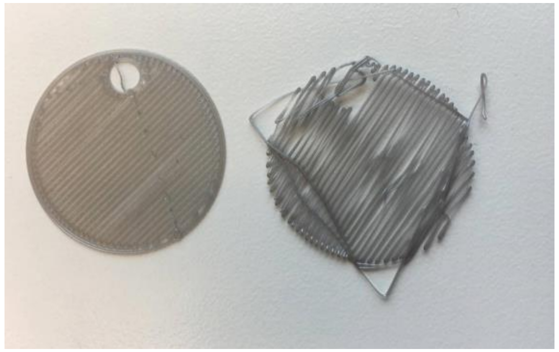
What did we learn from the first print?

OBJ/SLT difference in quality: mesh language or logarithm language.
Small details not possible – logo letters.
Difference per colour in finishing the surface.
Knowledge of software big influence on the possibilities.

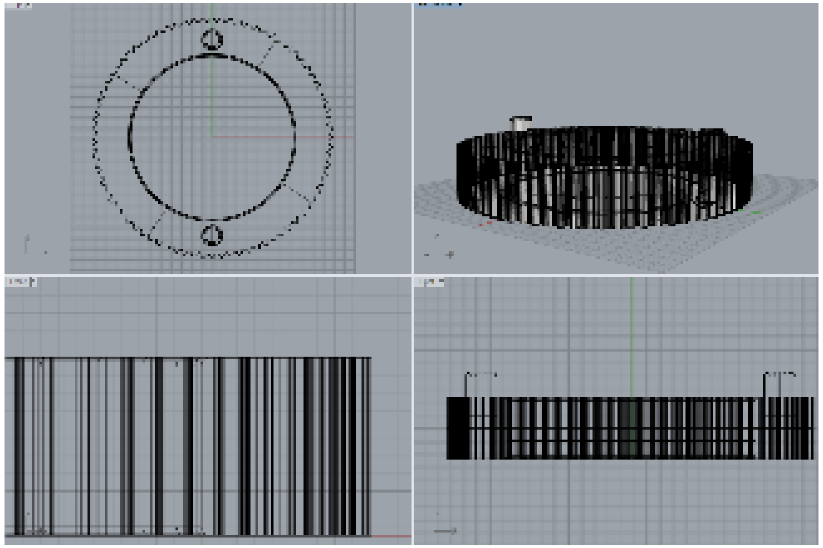
Keychains Midterm

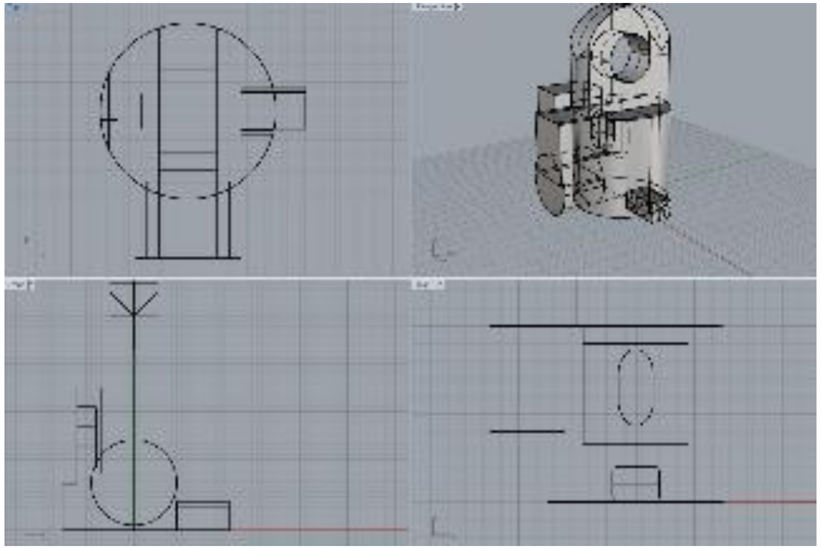
For the midterm presentation at HCM, Sustainability keychains got printed. This process also gave interesting insights. Before the printer starts printing the keychains, it creates a 'scope' of plastic around the area where the part will be printed. If this first layer of plastic fails, you have to stop the print because something obviously is wrong. This was the case with the keychains as well (figure X). We did not add enough spray to the printing bed and the nozzle speed was too high, so the plastic had no time to 'bind' to the bed. We also increased the temperature a bit so the plastic would melt a bit more to the bed.

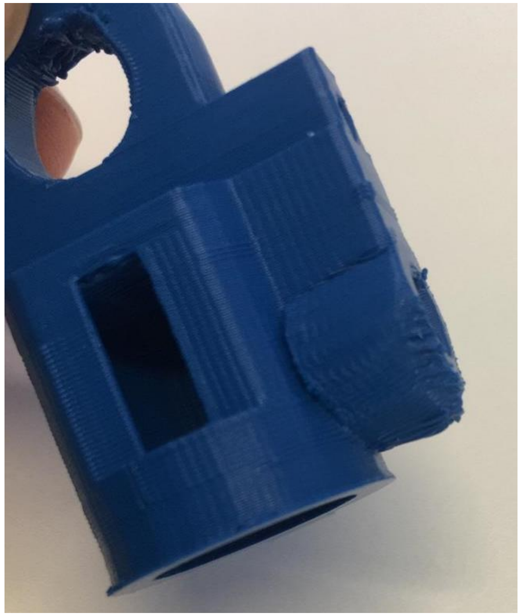


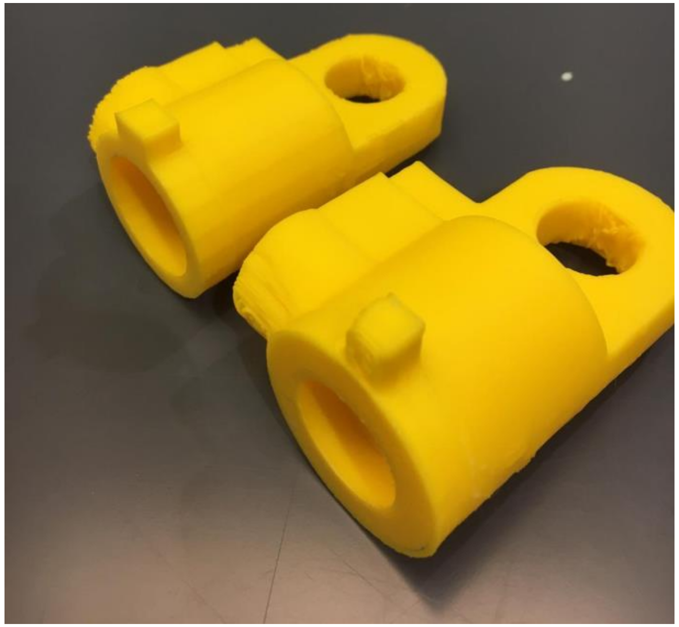


PLASTIC PRINT – metal parts try-out





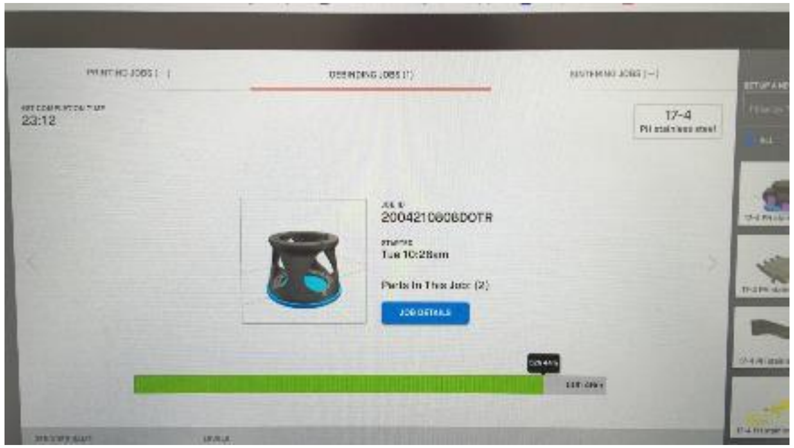


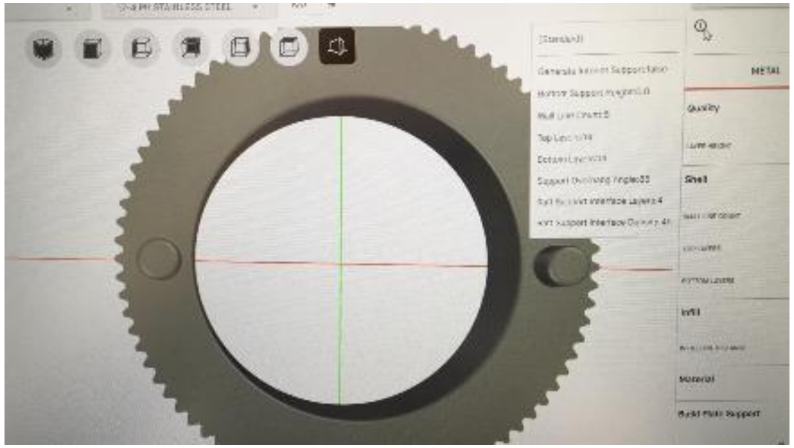


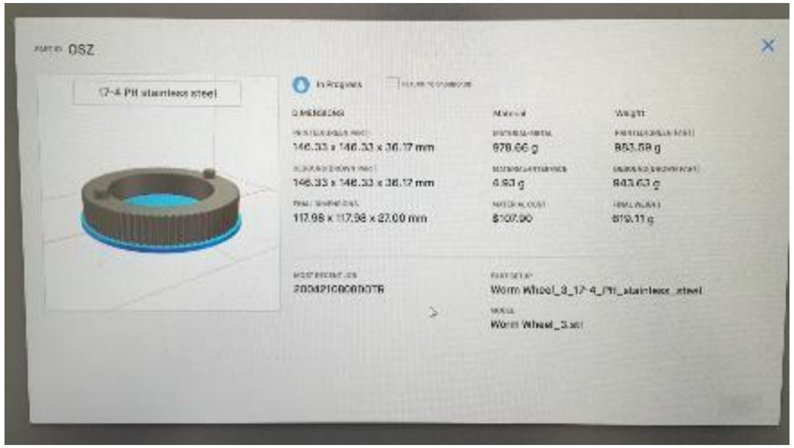
APPENDIX 31

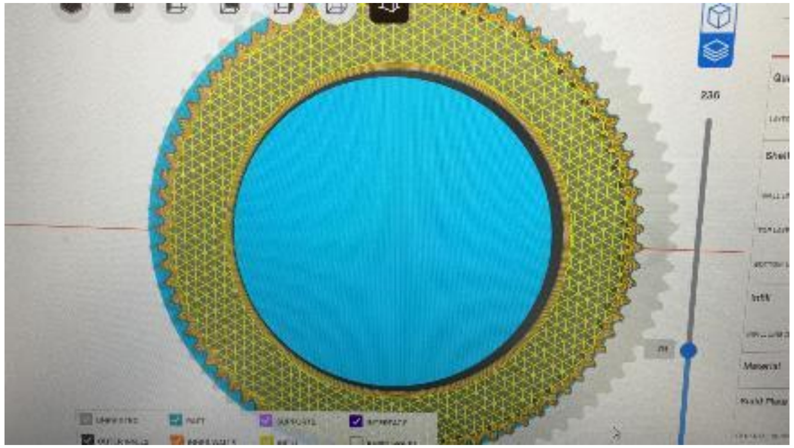
Print settings metal prints

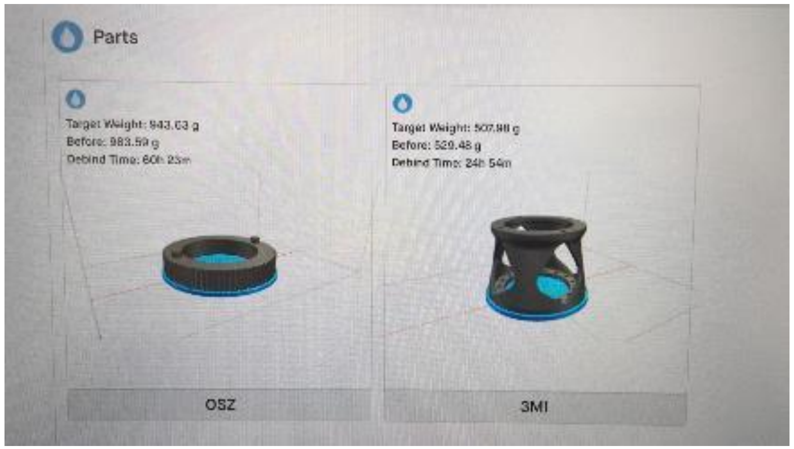
The print settings used by Layertec for both parts are shown in this chapter.

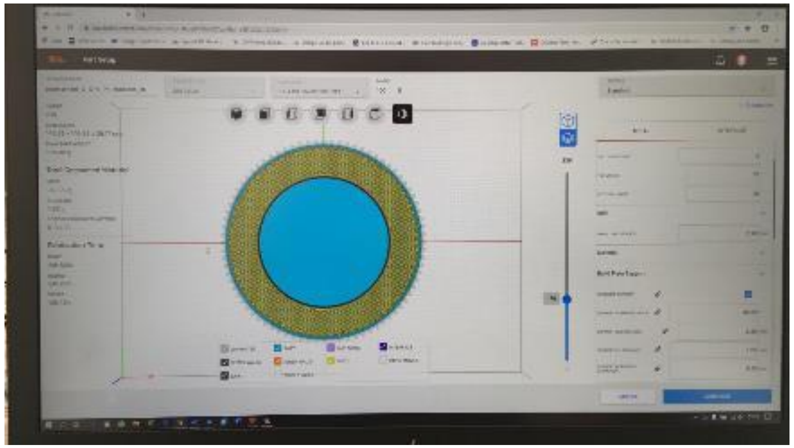




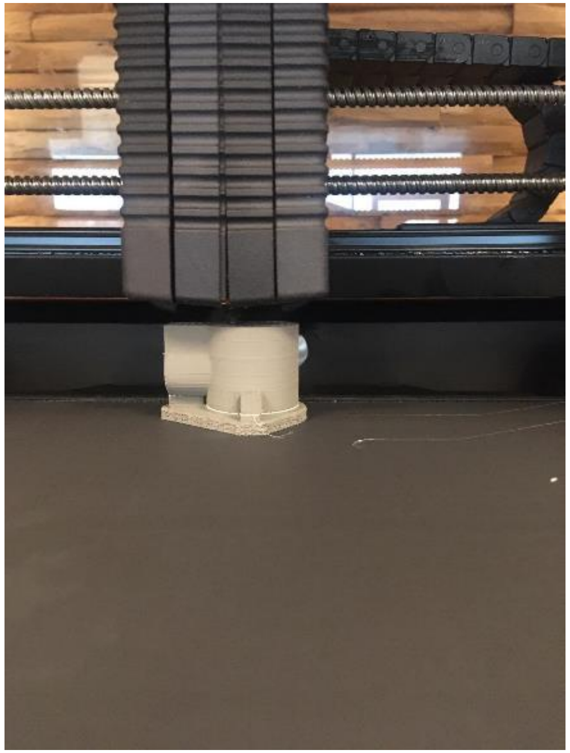








APPENDIX 32 Print process metal

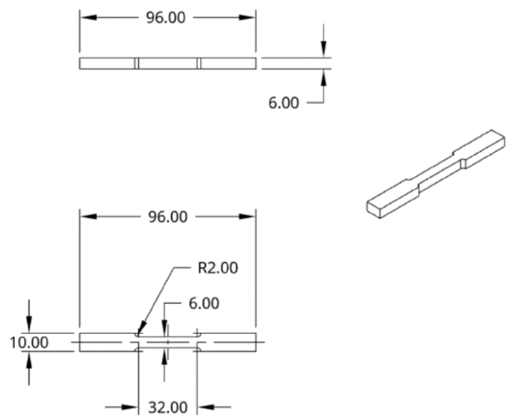


APPENDIX 33

Tensile testing

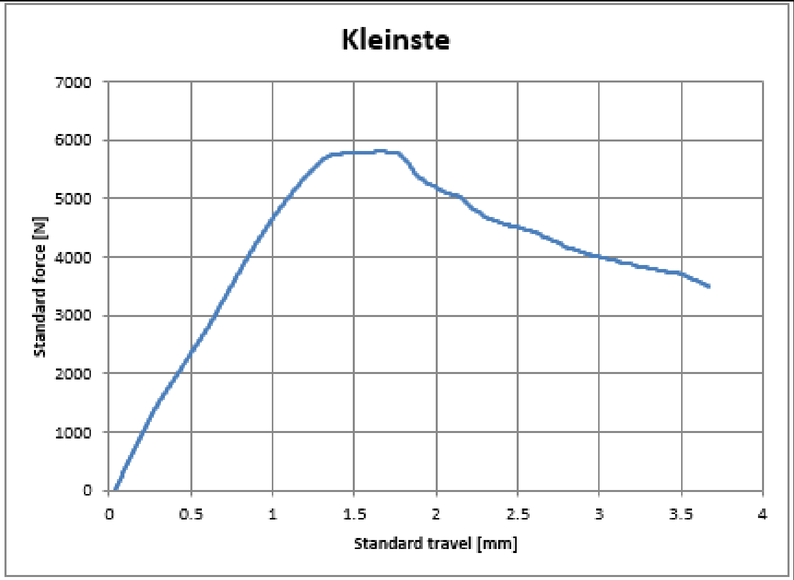
	Maximum extension	Test speed	Pre-load	Specimen no.	h	b	A_0	Peak detection	Date/Clock time	$L_{0\ CH}$
	mm	mm/min	N		mm	mm	mm^2	N		mm
kleinste	3	1	0.1	1	20	19	384	5797.04883	43927.59309	20.98437
grootste	3	1	0.1	2	20	19	384	4282.01758	43927.60157	47.17474
brons groot	3	1	0.1	3	22	15	323.85	3329.83594	43949.59678	47.25932
brons klein	3	1	0.1	4	22	15	323.85	4568.71045	43949.60237	25.1743

Series	Maximum extension	Test speed	Pre-load	Specimen no.	h	b	A_0	Peak detection	Date/Clock time	$L_{0\ CH}$
n = 4	mm	mm/min	N		mm	mm	mm^2	N		mm
x	3	1	0.1	2.5	20.86	17.055	353.9226	4494.4032	43938.59845	35.14818
s	0	0	0	1.2909944	0.993042	2.476833	34.73039	1017.14171	12.70300299	14.04053
ν} [%]	0	0	0	51.639778	4.76051	14.52262	9.81299	22.6312964	0.028910806	39.94668

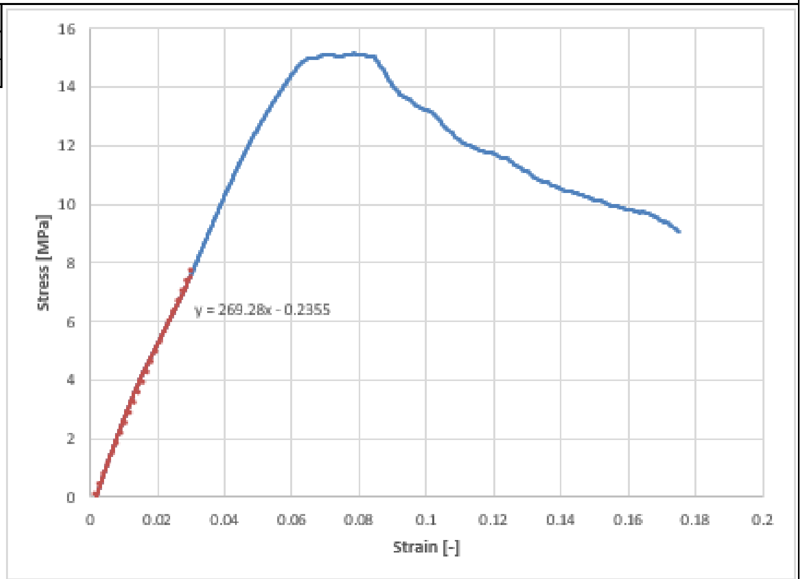


InfoGraphics

Title	Short Part 3D
Y-Axis	Standard Force [N]
X-Axis	Standard Travel [mm]

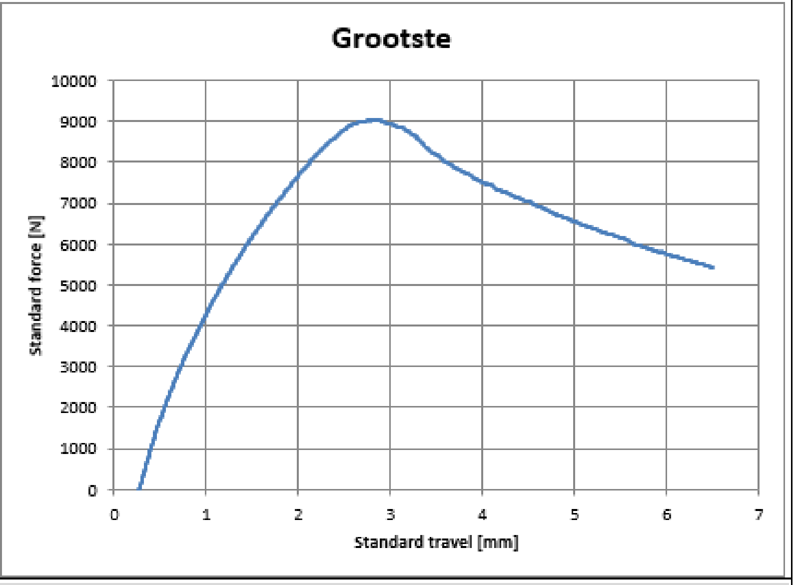


Title	Short Part 3D
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]

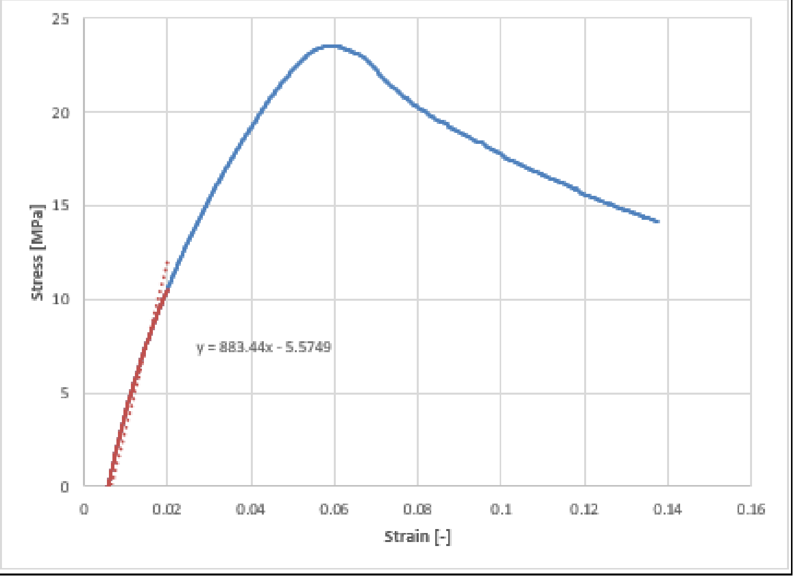


InfoGraphics

Title	Short Part 3D
Y-Axis	Standard Force [N]
X-Axis	Standard Travel [mm]

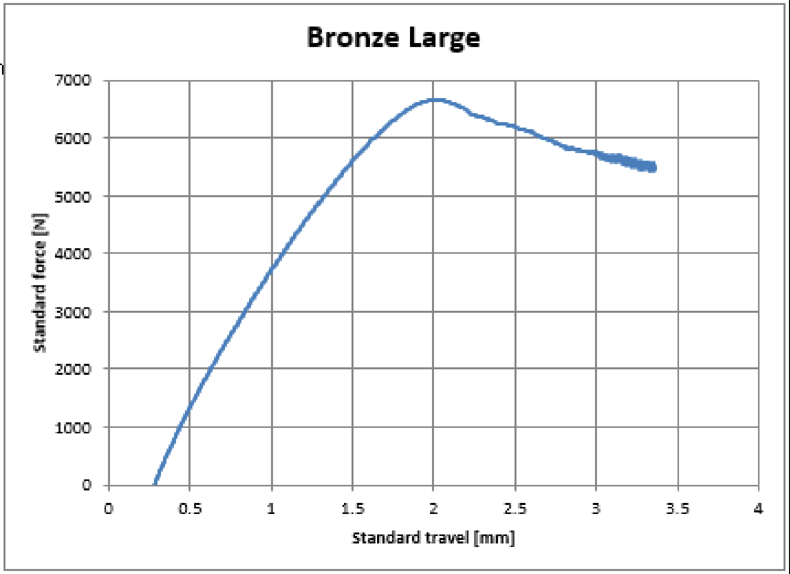


Title	Large Part 3D
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]

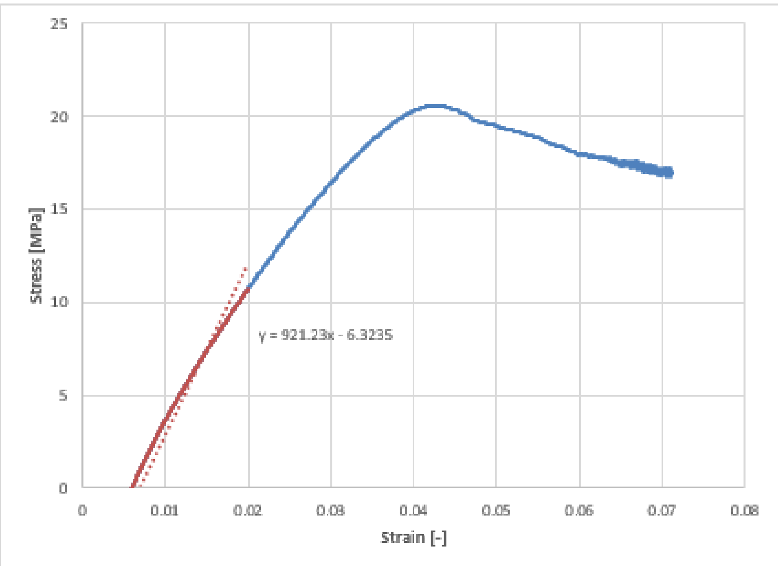


InfoGraphics

Title	Large Part Bronze
Y-Axis	Standard Force [N]
X-Axis	Standard Travel [mm

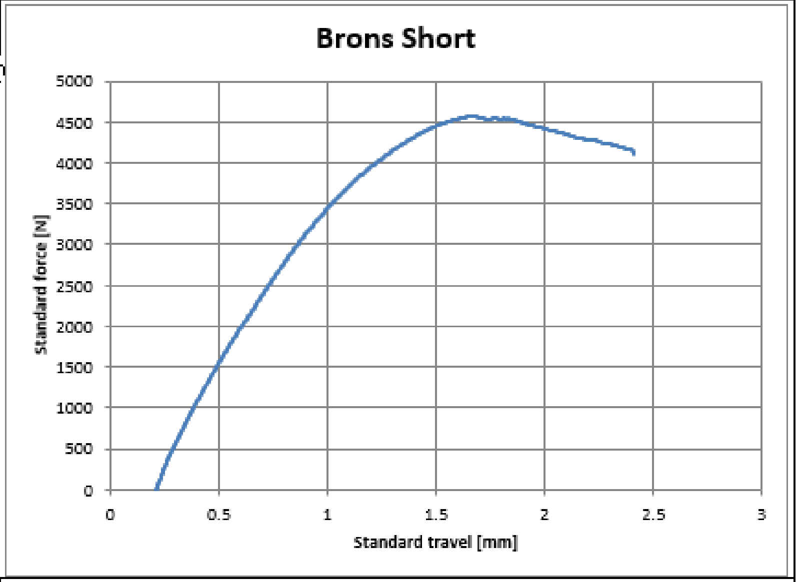


Title	Large Part Bronze
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]

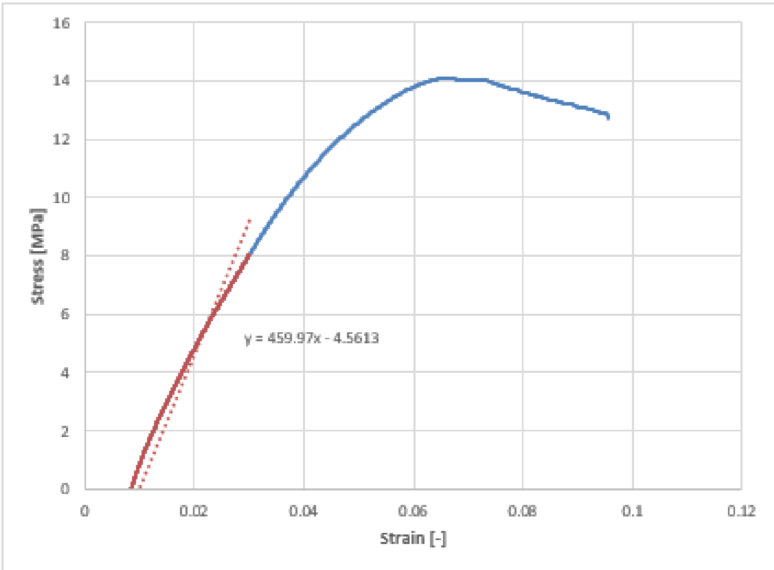


InfoGraphics

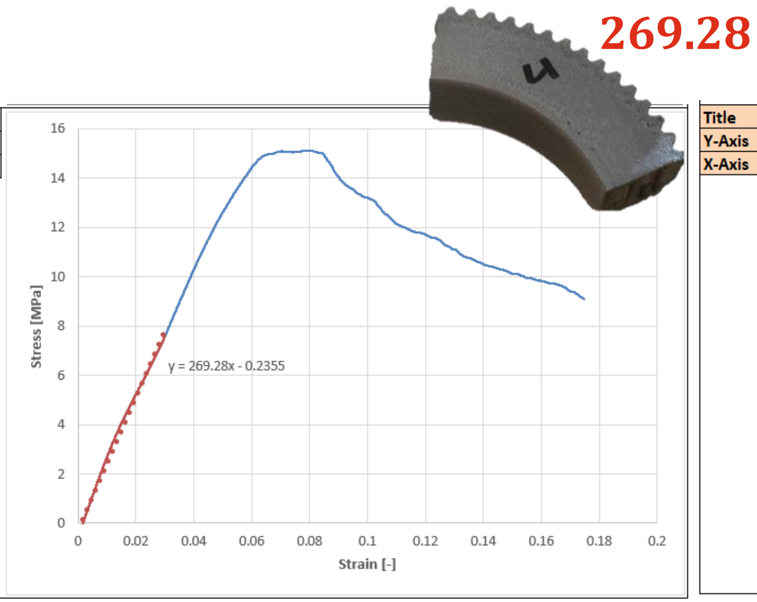
Title	Short Part Bronze
Y-Axis	Standard Force [N]
X-Axis	Standard Travel [mm



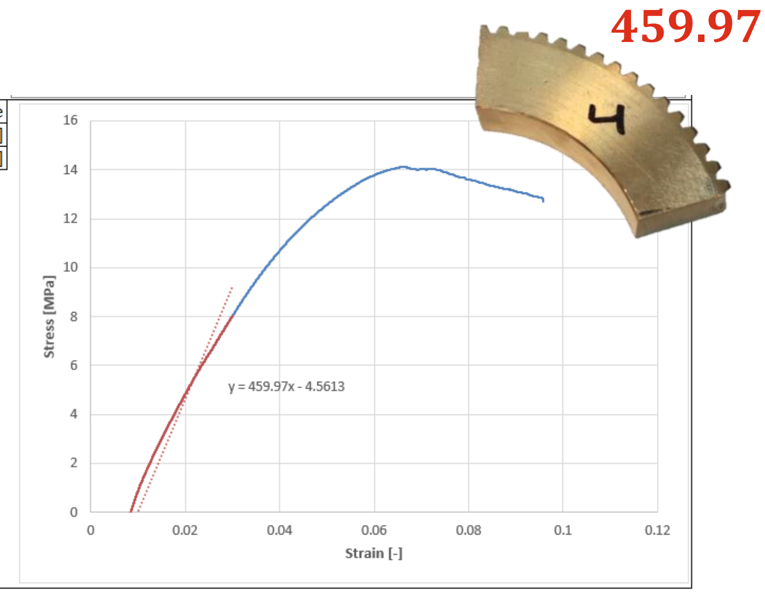
Title	Short Part Bronze
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]



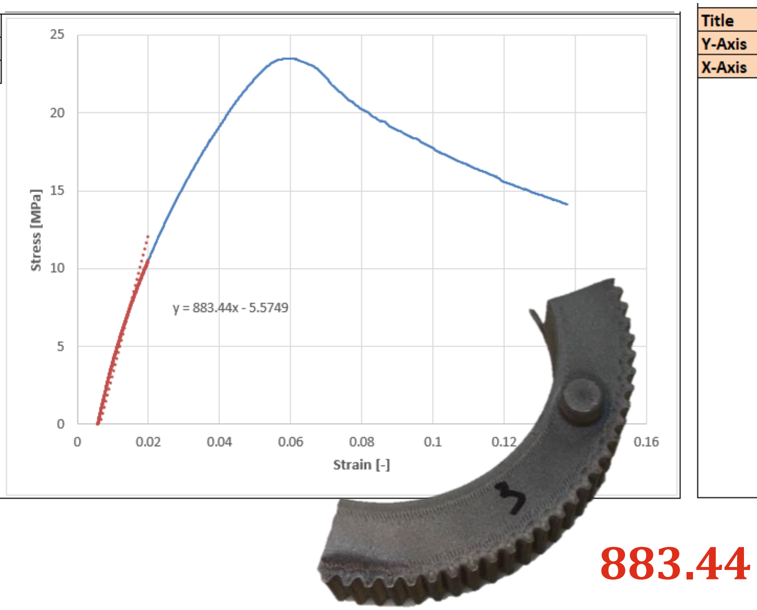
Title	Short Part 3D
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]



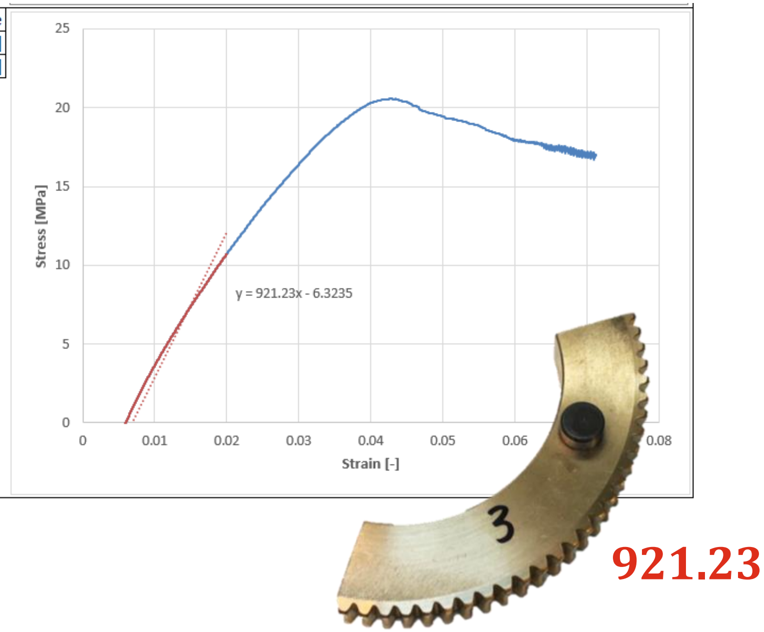
Title	Short Part Bronze
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]

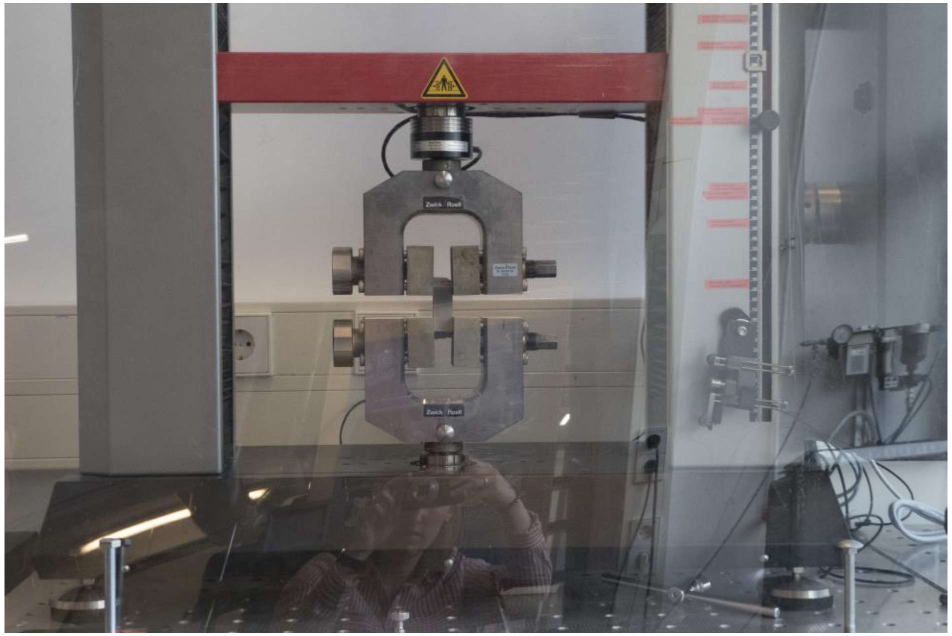


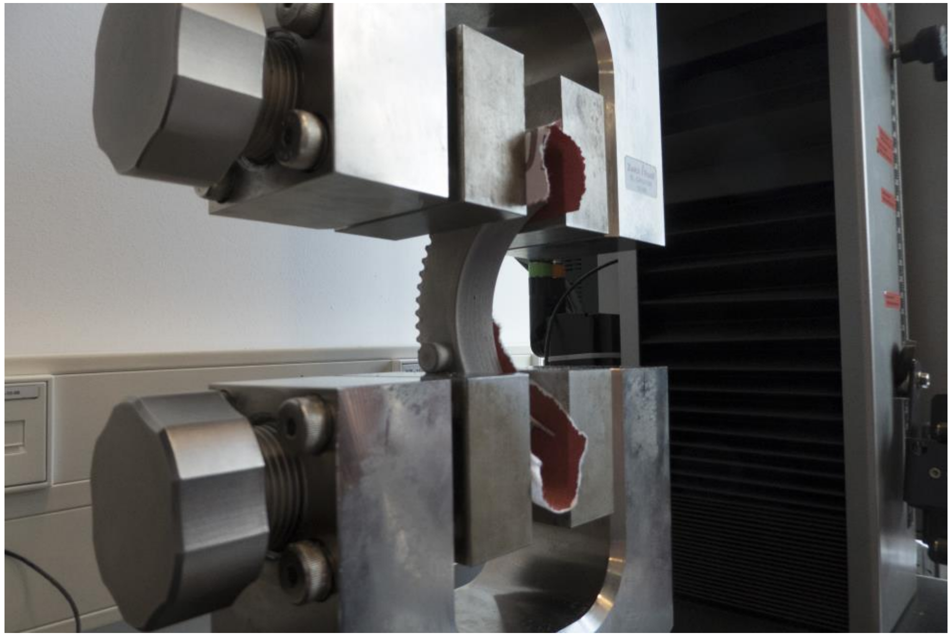
Title	Large Part 3D
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]



Title	Large Part Bronze
Y-Axis	Stress [Mpa]
X-Axis	Strain [-]







APPENDIX 34

Hardness testing

Test nr.	Bronze 3	Bronze 4	SS 3	SS 4
1	-	-	-	-
2	2.2	0.2	-	6.5
3	4.4	3.3	5.6	-
4	2.3	3.2	11.7	6.8
5	3.3	-	14.1	20.3
6	2.9	0.1	22.8	13.3
7	2.9	3.7	25.6	10.9
8	3.5	2.6	21.4	10
9	3	-	18	18.9
10	1.8	2.9	23.6	21.8
11	4.3	4.4	23.2	19.2
12	3.5	3.6	25.1	23.7
13	5.1	0	19.4	22
14	3.9	4.2	15.1	13.9
15	4.5	3.4	19	15.6
16	4.4	4.6	23.2	21.6
total	*52*	*36.2*	*267.8*	*224.5*
Mean *usual average*	**3.4666667**	**2.784615**	**19.12857**	**16.03571**
Median	**3.5**	**3.3**	**19.4**	**15.6**
Range	**3.3**	**4.6**	**20**	**17.2**

APPENDIX 35

Mail contact Shimadzu

Dear Meike,

unfortunately we could not help.

We checked the number RE-02503, but it is unkown in our system.

Also our colleagues in Japan can`t identify the photo you sent us.

I`m sorry that we can`t help you.

Enjoy your weekend and stay healthy.

Mit freundlichen Grüßen
with best regards

SHIMADZU
Excellence in Science

Daniela Reichert | Inside Sales
Sales Europe | Fluidics Systems Division (Hydraulics)
Shimadzu Europa GmbH
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Tel: +49(0)203/7687-442 | E-Mail: reichert.d@shimadzu.eu |
Website: www.shimadzu.eu
Follow us
www.shimadzu.eu/fluidics

APPENDIX 36

Costs overview

Gas Consumption

A sinter run uses:

- approximately 750L of gas (each gas tank on board contains 900L of gas).
- 1 Desktop Metal gas bottle

When the Furnace is started, there must always be 2 gas bottles in the machine because of any problems with one of the gas bottles, the machine automatically switches to the other.

The costs of a Desktop Metal gas bottle: € 200.
The costs of a House Gas bottle: € 20 per run.

Power Consumption

The power consumption of the Studio System Furnace varies depending on the phase of the sintering cycle in which it is located:

- Preheating: about 0.5 kW
- Active heating: ranges range from 1 kW and 7 kW
- Cooling: about 0.5 kW

Due to the different power levels during the sintering cycle, the calculation of the energy consumption is more complex than with the Debinder and the printer. However, for a typical sintering cycle, energy consumption is estimated to be approximately 65 kW-hour.

If we assume electricity costs of € 0.17 / kWh, the energy costs of this sintering cycle would be: 65 kWh x € 0.17 / kWh = € 11.05.

Investment Cost	
Internal	
Resources	
Education = man hours	
Man-hours use of printer	
Project team managing pilot	
Vessel crew installation team	
External	
Hardware	
Ultimaker S5	$ 6,000.00
Desktop Metal Studio System	$ 220,000.00
Software	
SolidWorks	included
Cura	included
Desktop Metal	included
Resources	
Plastic fillaments	
Tooling Ultimaker	included
Metal rods	
Debinder Liquid	
Sinter Gas	20 per run
Tooling Maintenance Studio System	included
Process	
Education	included
Installation	included
Maintenance	included
Certificaiton and approvals (Lloyds)	
Testing	
Other	
Waste	
Energy	0,17 per kWh
TOTAL	$ 226,000.00

Yearly Benefits	
Transport	
Air freight reduction	$ 90,000.00
Other transports reduction	Estimate
Material reduction	
In-stock reduction of 10%	$ 130,000.00
Material use reduction compared to CNC	Opportunity
Emission reduction (green image)	
CO2 reduction	Opportunity
NOx reduction	Opportunity
Subsidy	Opportunity
TOTAL	$ 220,000.00

APPENDIX 37

Furnace and debinder requirements basf316l

Product Description

1.75mm and 2.85mm filament for the manufacture of full metal, 316L stainless steel 3D printed parts on most Bowden and direct drive Fused Filament Fabrication (FFF) 3D printers.

Product Owner

BASF 3D Printing Solutions GmbH
Speyerer Straße 4
69115 Heidelberg
Germany
E-Mail: metals@basf-3dps.com

Part Design

Parts designed in accordance with the Ultrafuse 316L User Guidelines have been shown to possess improved stability and overall quality. Part features achievable with FFF 3D printers typically require support material for any overhang less than 45° from the horizontal.
Shrinkage resultant from debinding and sintering must be accounted for in print preparation. Standard oversi-zing factors are provided within in the Ultrafuse 316L User Guidelines. Whenever possible, parts should be debound and sintered in the orientation that they were printed.

Debinding

Debinding according to the BASF process at 120 °C with HNO_3 > 98 %. Formaldehyde evolving from the parts during debinding can react with oxidizing agents. Explosion limit of formaldehyde with oxygen is 4.5 % by volume. There is some indication that a slow reaction between formaldehyde and nitric acid exists. Therefore, any unintended high dose of nitric acid must be avoided.

Refer to the oven manufacturer's instructions to avoid leakage and therefore hazardous condtions for both personnel and oven parts. We highly recommend keeping the maintenance intervals for the door seals and bearings of the circulation fan. Based on a 50 liter debinding furnace (e.g. Nabertherm NRA 40/02-CDB) a nitric acid feed of typically 30 l/h and a purging gas (nitrogen) with a throughput of 500 l/h proves to lead to safe processing. At this gas throughput, the acid feed may not be increased to more than 38 l/h. The debinding process is finished when a minimal debinding loss of 10.5% is reached.

Sintering

Sintering should be done in an atmosphere with 100% clean and dry hydrogen (dewpoint < – 40 °C) or argon (dewpoint < – 40 °C). Al_2O_3 sintering supports of 99.6% purity are recommended.

A typical sintering cycle consists of a ramp from:

1. room temperature – 5 K/min – 600 °C, hold 1h
2. 600 °C – 5 K/min – 1380 °C, hold 3h
3. Furnace cooling

In the early stage of the sintering process, remaining binder constituents are burnt off and the pyrolysis products should be removed by a suction fan. Removal of condensed pyrolysis products from the wall of the sintering furnace should be done wearing laboratory gloves or, in extreme cases, gloves made of nitrile rubber. Under certain circumstances, deposits can be formed in the sintering furnace containing MnO, manganosite. This compound may also exhibit a fiberlike morphology which may pose a health hazard requiring special care during clean-ing of the furnace. It is highly recommended to avoid dust formation and the use of disposable masks with particle filters type FFP3 (DIN EN 149).

APPENDIX 38

Midterm presentation/brainstorm Heerema

At the 12th of March I organized a Midterm presentation at the Heerema office in Leiden. Various employees got invited to discuss decisions and assumptions. The people who participated came up with the following feedback:

- Direction: structural strength, metal matrix
- Improve design; possible if you 3D print parts → unique selling point
- Client could also be the one who decides whether we use the 3D printed parts for a project.
- How does the warranty work if we implement a part that we created ourselves?
- Assembly – can we add our own parts? Manufacturer might not accept this.
- There is a link between 'Certification' and 'Adaptation' since the crew would more easily accept it once they know they create something that is safe/strong enough for use.
- What is the incentive for the storekeeper to start a 3D print instead of ordering it in Infor?
- Adaptation not only Storekeepers – also workshop crew.
- Look at the machining options of workshop and Studio System.
- What is the scope of the costs? How broad do we look at this? Transport/man-hours/etc?
- Limits printing system: dust, waves
- What type of parts does the Royal Navy decided to print?
- Does your lifecycle decreases if your density is 98% instead of 100%?
- What are the statistics of the materials that will be used?
- How do we know how many materials we have to buy? Would be weird to get print material on board with an airfreight.