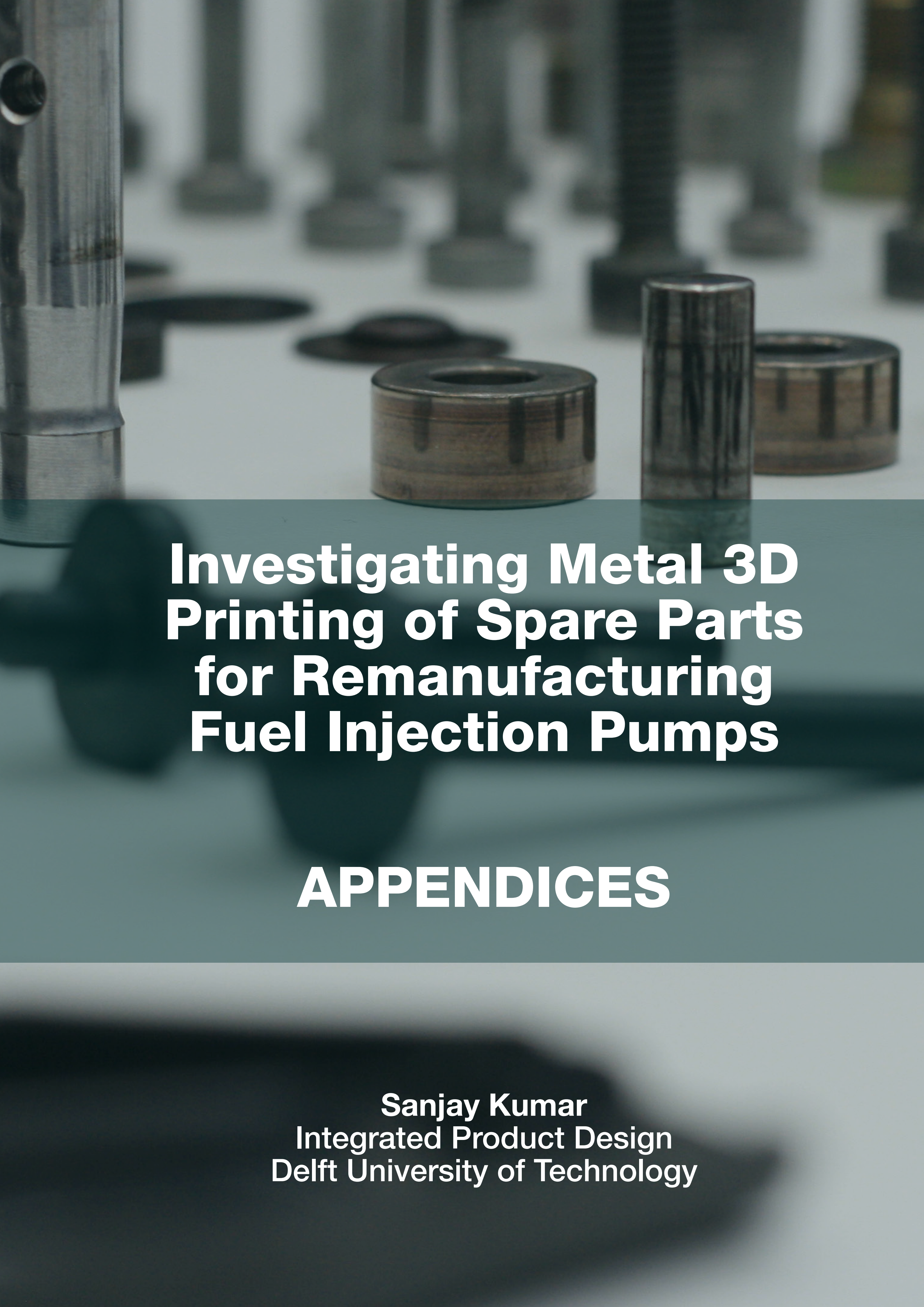

Investigating Metal 3D Printing of Spare Parts for Remanufacturing Fuel Injection Pumps

APPENDICES

Sanjay Kumar
Integrated Product Design
Delft University of Technology

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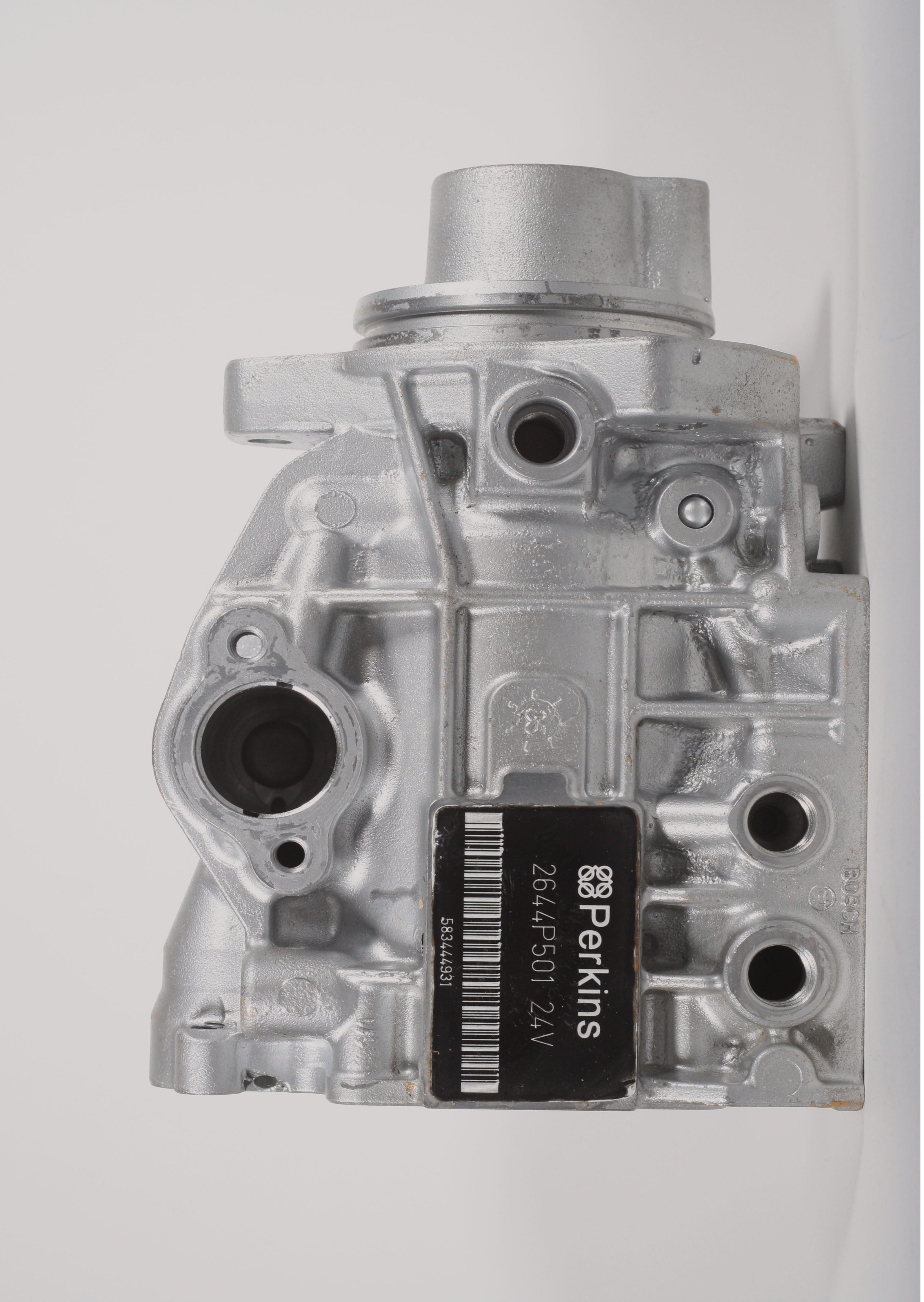


Appendix 1: Final Project Brief

LINK: CLICK HERE

TU Delft

Personal Project Brief - IDE Master Graduation

3D Printing for Re-manufacturing of a Diesel Pump — project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 22 - 02 - 2022 — 15 - 07 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

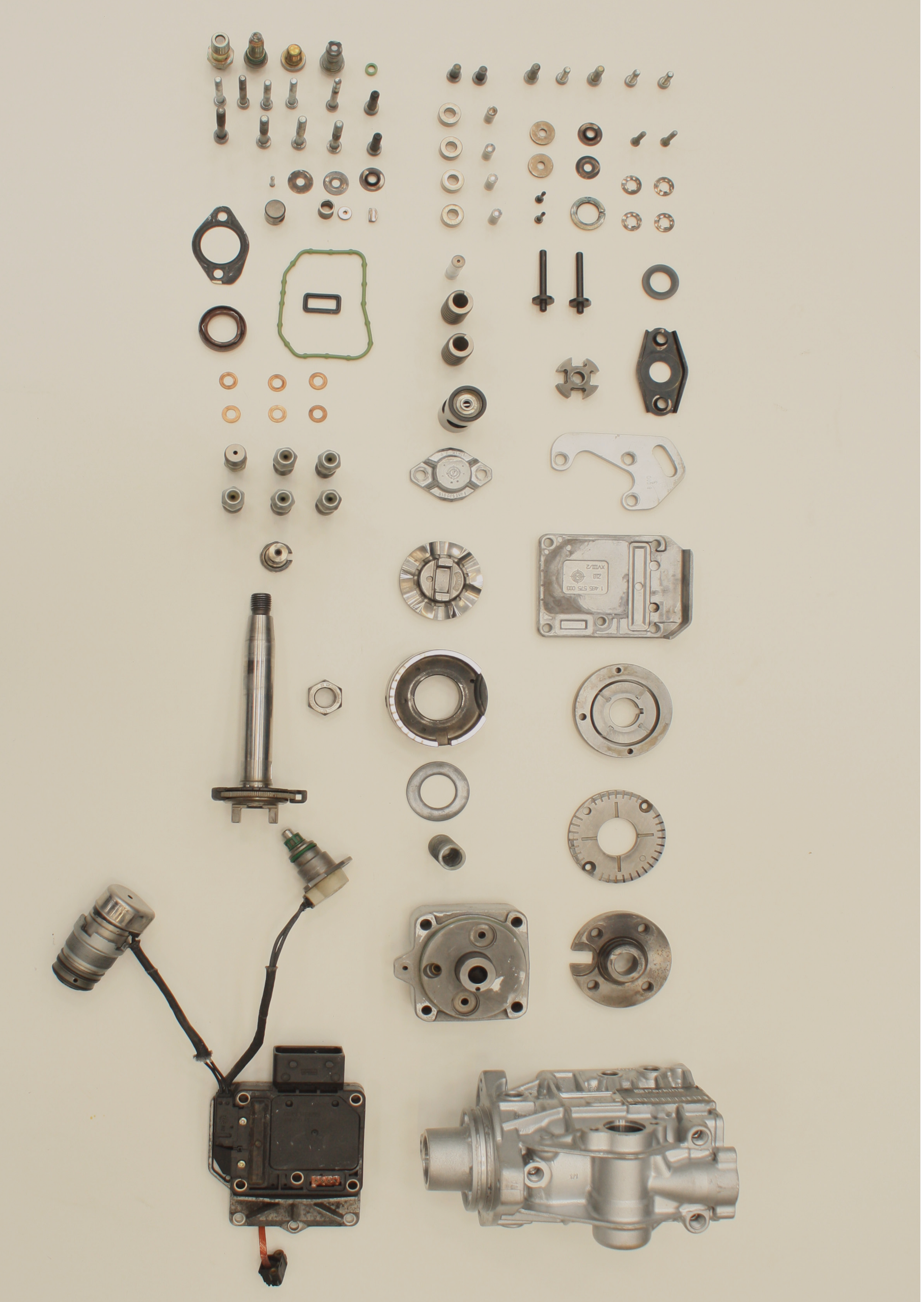
Today, society is reliant on diesel powered engines for purposes ranging from mobility and industrial applications to emergency response. Though mobility might evolve to become more electrified in the future, the needs of developing countries and other industrial applications will still need diesel power before they make the transition to fully sustainable power. These diesel power units can have a long life and thus, keeping them well-maintained and efficient goes a long way in ensuring their environmental impact is reduced. This can be achieved through the re-manufacturing of spare parts needed for their upkeep. Re-manufacturing is one of the product life extension strategies of the circular economy where used products are restored to as-new product quality. However, every spare part needs tooling and a considerable inventory to be maintained to allow for a smooth supply to meet the demand. Keeping the tooling and inventory live for these spare parts increases the costs, leading to higher part prices. On the other hand, not keeping them live would mean a supply crunch unable to meet the demand for the parts. This leads to a reduced reliability view of the industry and thus, in consequence, a hindrance to the movement toward the circular economy for the automotive industry.

By utilizing new and advanced manufacturing methods that can scale better with the demand projections and allow for just-in-time production, the tooling and inventory costs can be reduced. To this effect, advanced manufacturing techniques such as 3D printing can be used to achieve the desired results without the associated environmental impact of traditional manufacturing depending on variables like part geometry (Khosravani & Reinicke, 2020) (AMGTA, 2020). Thus, Robert Bosch GmbH, one of the world's largest producers of aftermarket components as part of the EU ReCiPSS project in collaboration with the TU Delft sought to introduce this line of thinking into their diesel pump line. Currently, Bosch has manufacturing facilities across the world, primarily in Germany and India where components are manufactured and shipped worldwide. The main desired outcome for Bosch is to produce spare parts for the diesel pump on demand with better sustainability metrics while still reaching a necessary cost and quality base.

The primary opportunity presented in this project is the kick-starting of the re-manufacturing industry as a reliable industry which can provide quality parts reliably at a competitive price. In addition, successful 3D printing of spare parts can help reduce the need for expensive tooling setups. Additionally, this can also help democratize production Today, re-manufacturing is widely performed (in automotive and other industries) as a means of prolonging life of manufactured components and evidence shows this meets both environmental and financial bottom lines for organizations (Ahuja & Terkar, 2020) (Liu et al., 2016). However, there is room for innovation in both the re-manufacturing process as well as in 'design for remanufacturing' i.e. designing parts such that they are suitable for re-manufacturing.

The challenges of this project arise in the study of feasibility of advanced manufacturing (especially 3D Printing) to become an economically feasible and environmentally sustainable process to replace traditional manufacturing while ensuring intended production volumes can be produced. With current technology, not all the parts of the pump can be manufactured through additive manufacturing reliably. Additionally, depending on the production volumes, current 3D printing technology might be more expensive per part compared to traditional manufacturing.

However, recent developments in metal 3D printing and better product design suited for remanufacturing could allow for robust and cost-effective production of spare parts and this is what I hope to achieve.



Appendix 2: Disassembly Map

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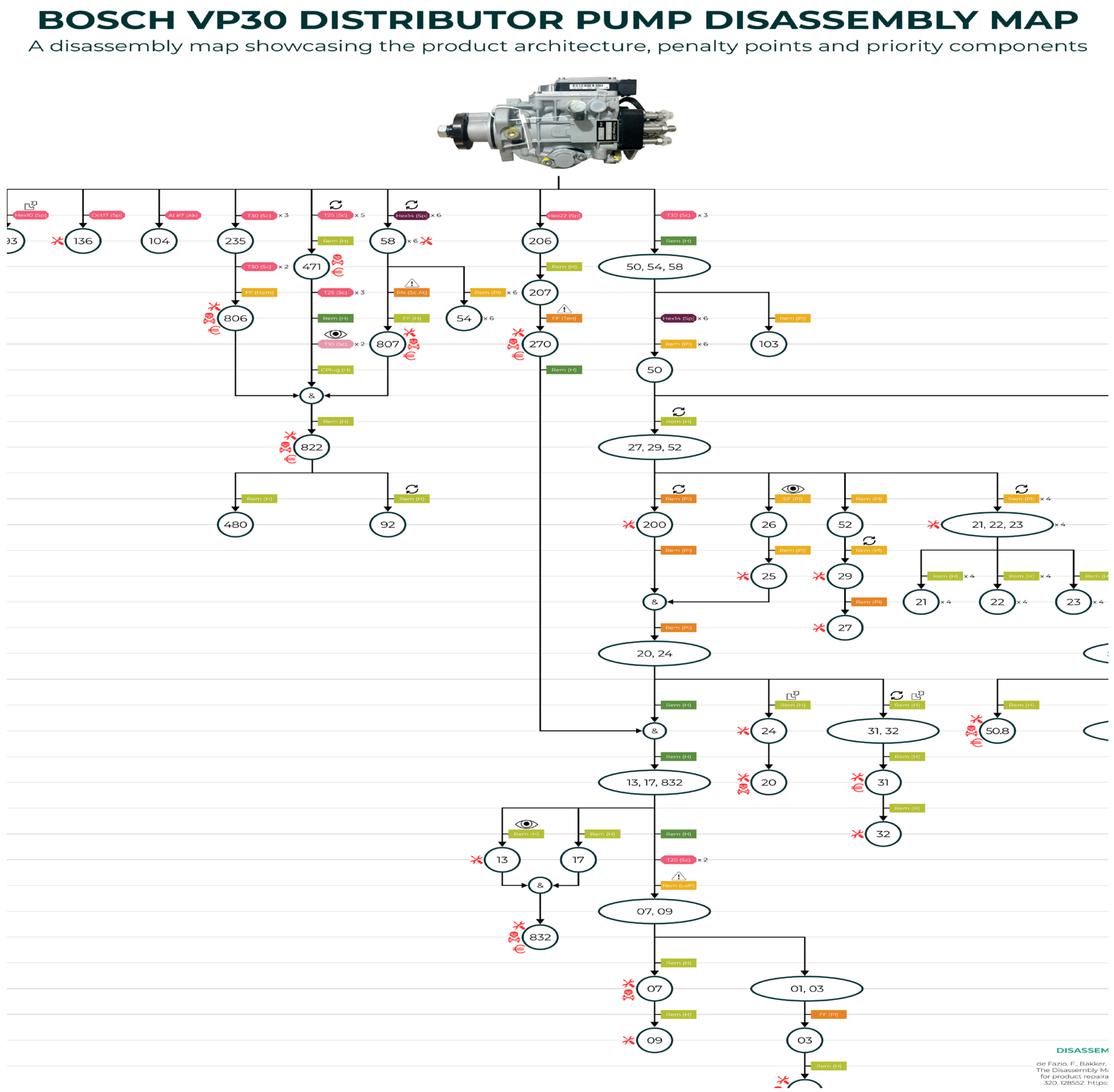

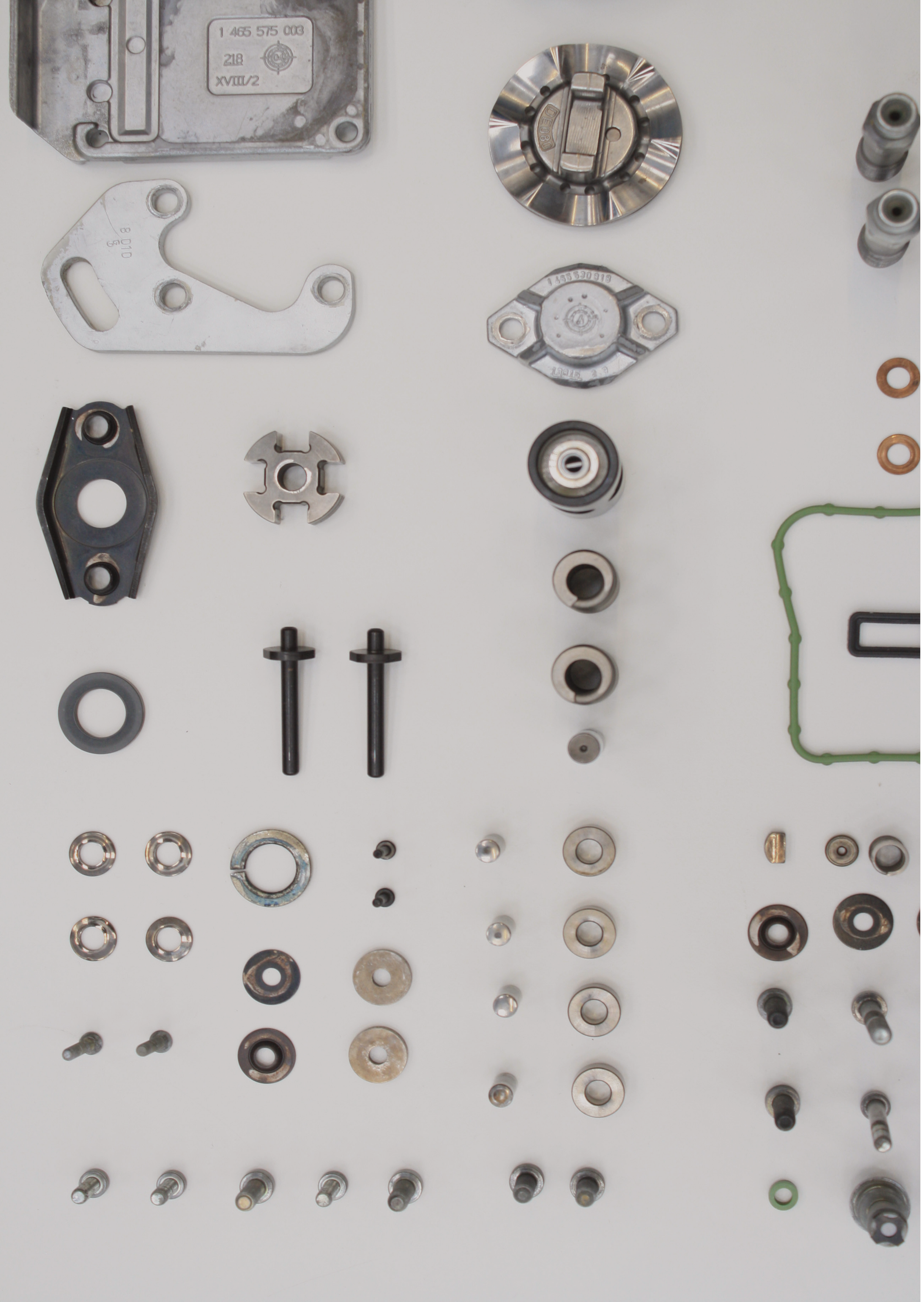

Appendix 3: Hotspot Mapping Manual

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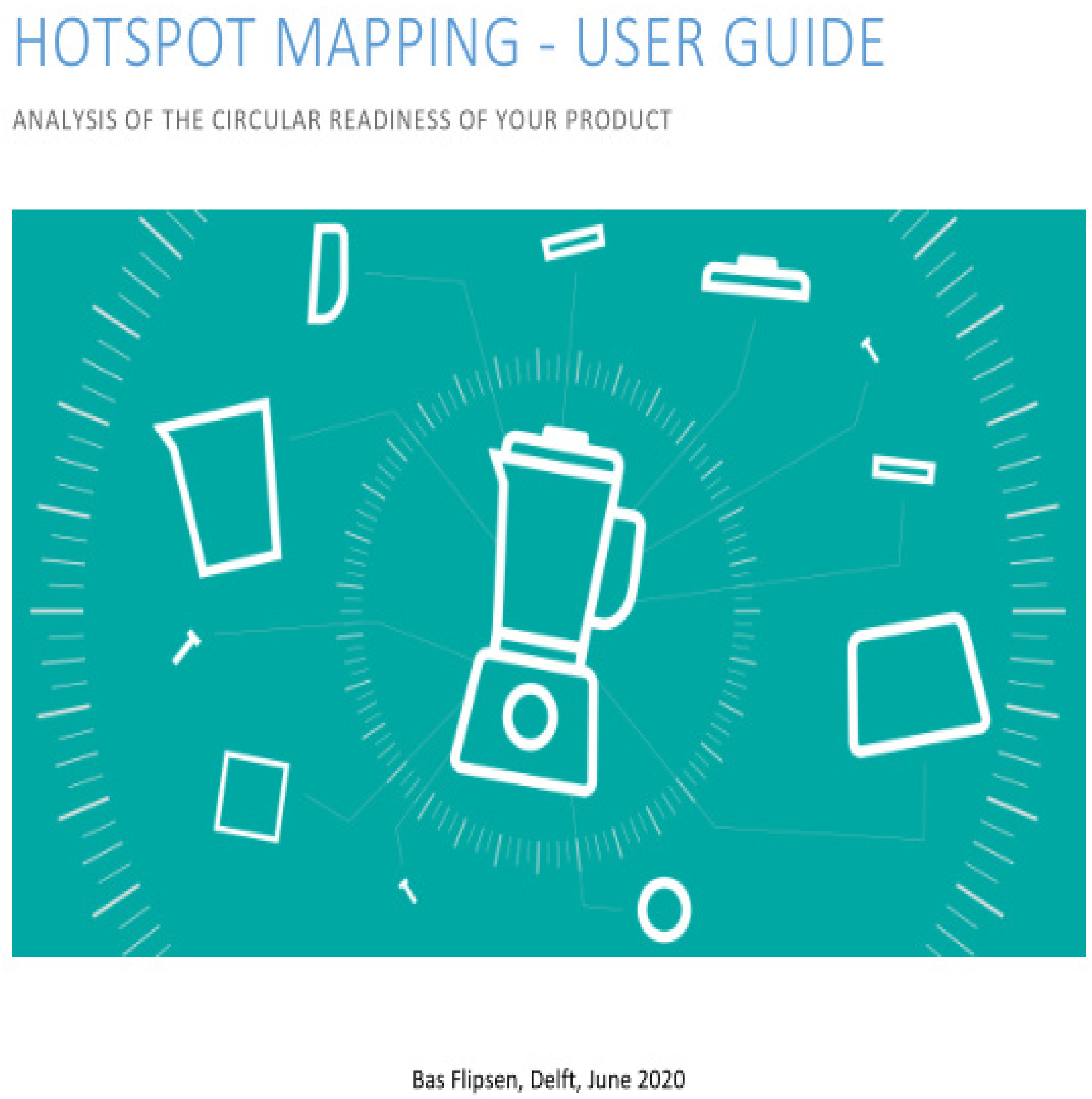
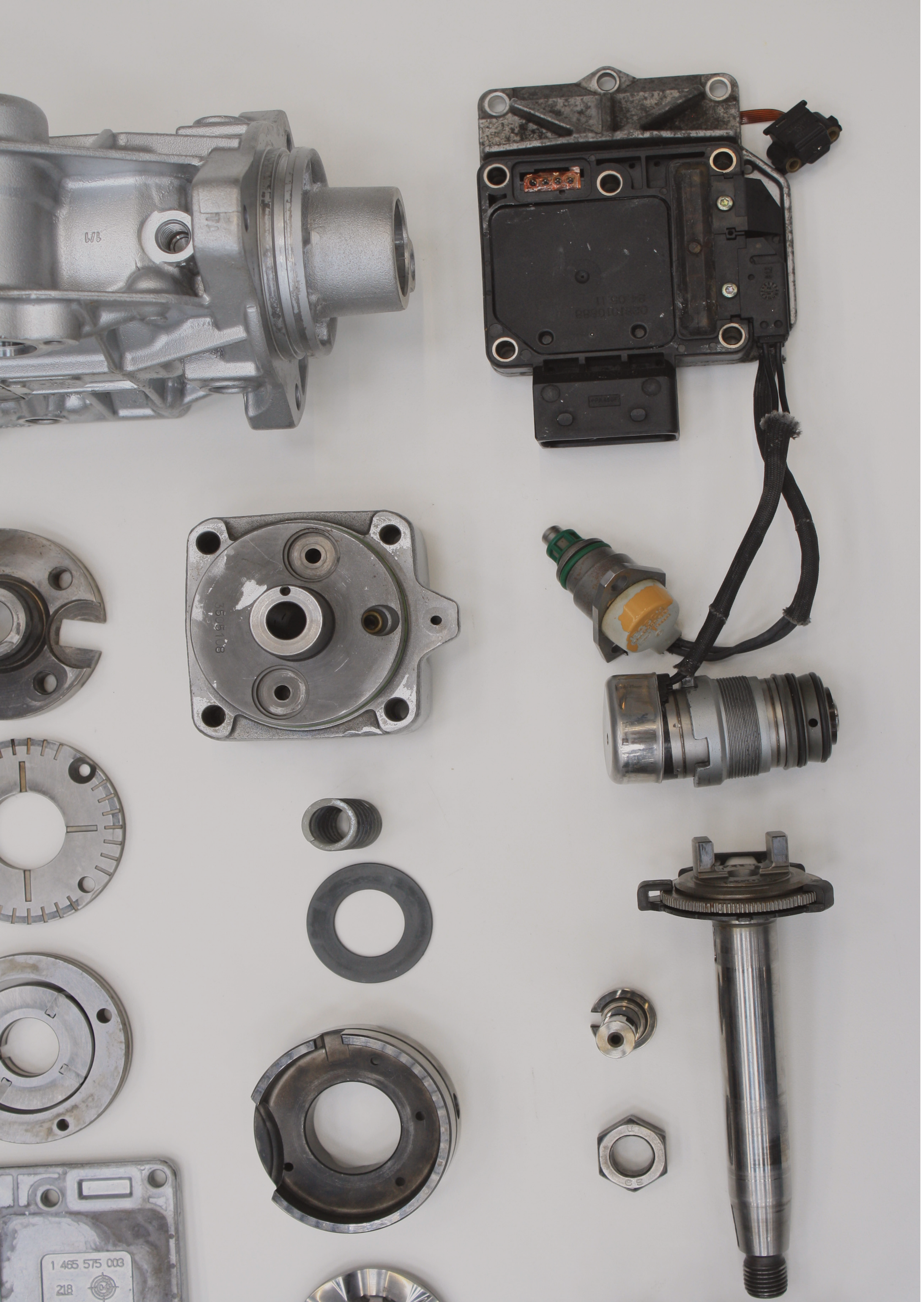

HOTSPOT MAPPING - USER GUIDE

ANALYSIS OF THE CIRCULAR READINESS OF YOUR PRODUCT

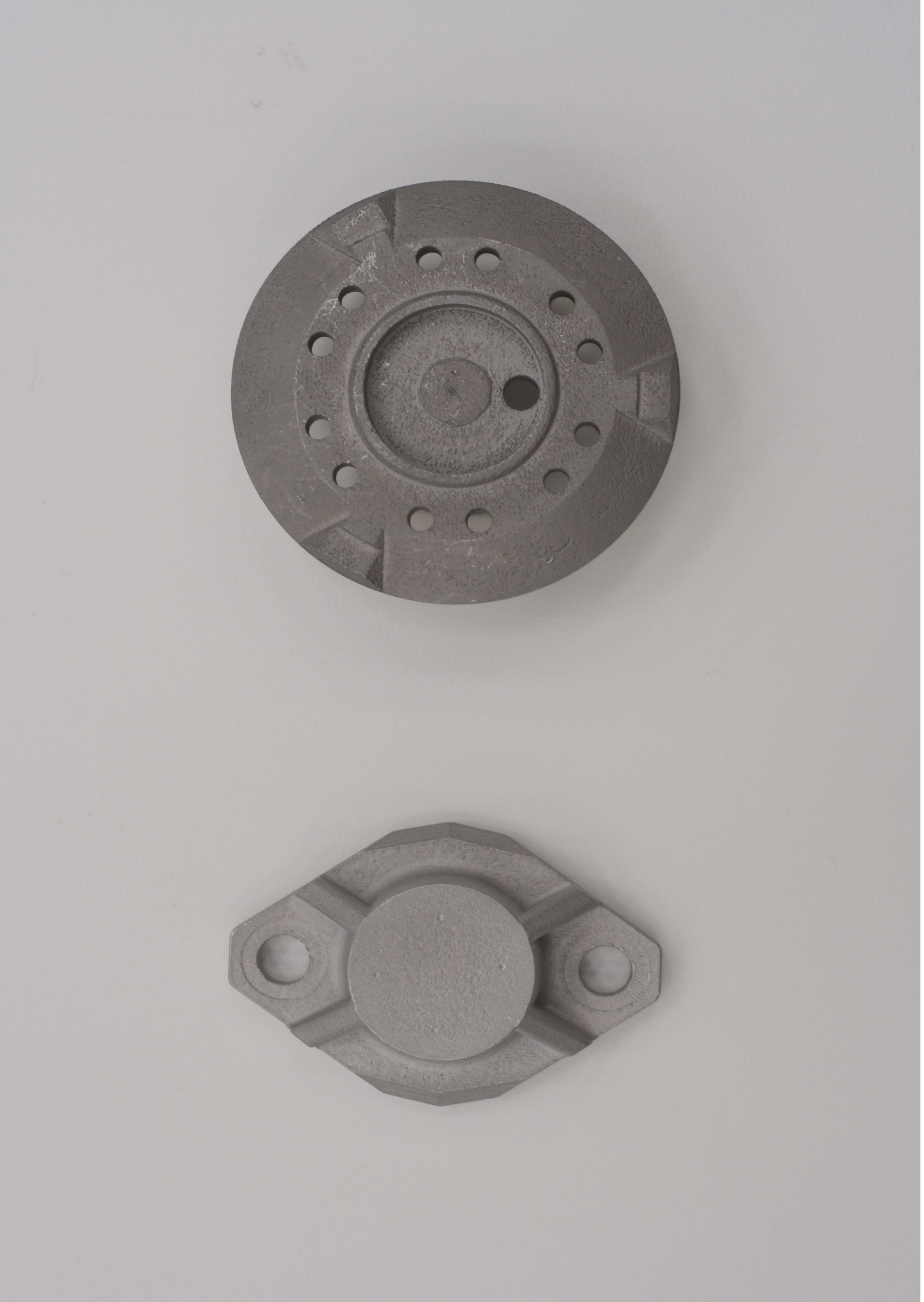
Bas Flipsen, Delft, June 2020



Appendix 4: Hotspot Mapping Spreadsheet

LINK: CLICK HERE

Extra requirement	Material group	Weigth (g)	Time	Activity	Priority part	Environmental	Eco
		Material properties			HotSpot		
level 0 - Not important	Steel	89.8	🚩				
			🚩				
			🚩				
level 2 - Very important	Other Electronics	98.46			🚩	⚐	🚩
level 1 - Moderate	Aluminium	21.5	🚩		⚐		
level 0 - Not important	Steel	13.6					
level 0 - Not important	Steel	4.68					
	Thermoplastic	2.13					
level 0 - Not important	Steel	31.08	🚩				
level 1 - Moderate	Steel	32.09	🚩		⚐		
level 0 - Not important	Steel	15.62					
level 0 - Not important	Steel	22					
level 0 - Not important	Steel	4.75					
level 2 - Very important	Steel	259.6		⚐	🚩	⚐	⚐
level 1 - Moderate	Aluminium	134.7	🚩			⚐	⚐
level 1 - Moderate	Steel	21.13		🚩	⚐		
			🚩				



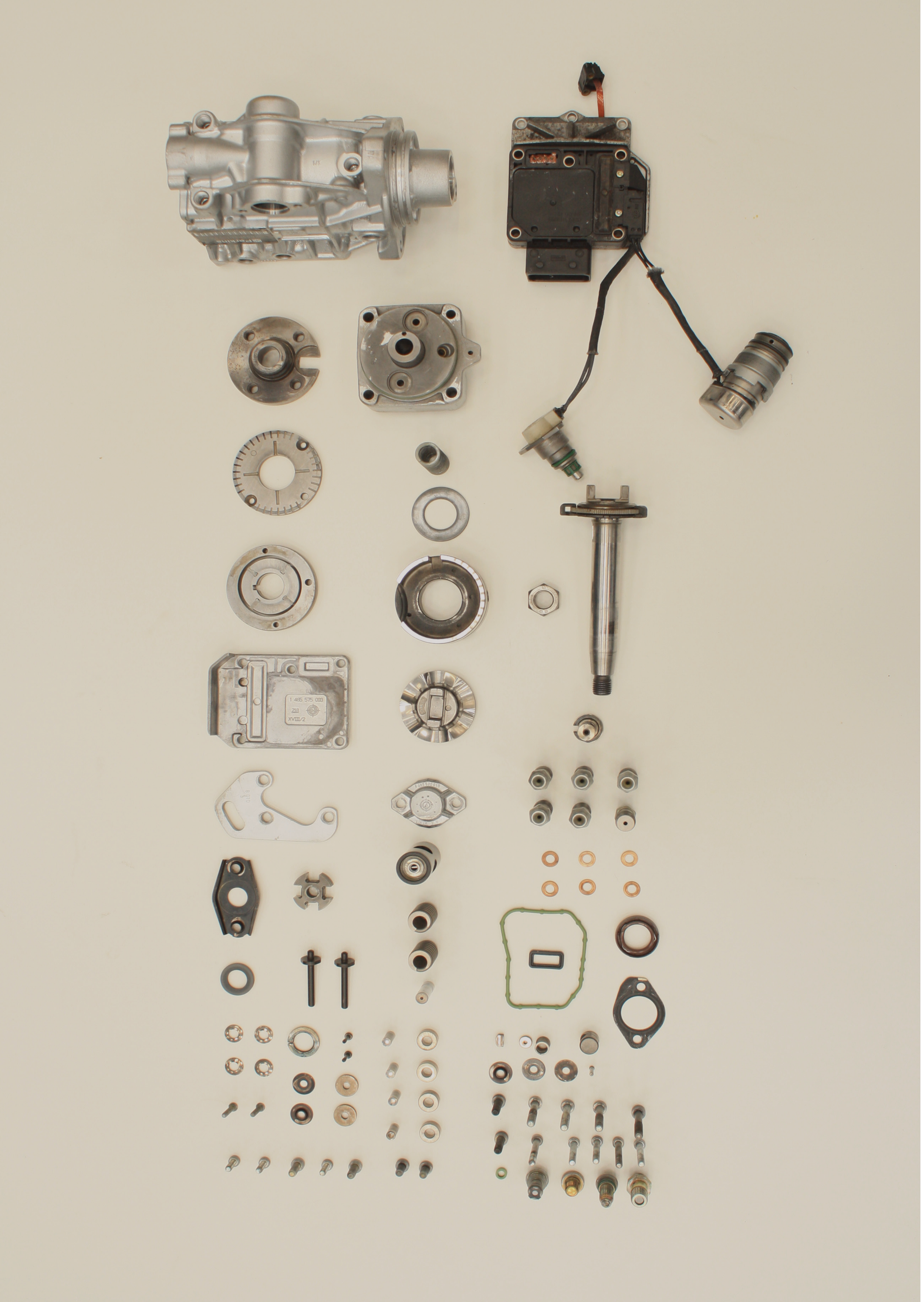
Appendix 5: Metal 3D Printing Guides

LINK: CLICK HERE

Appendix 6: Preliminary Part Proposal

LINK: CLICK HERE

Geometry	3D Modelling	Value	Score	Preliminary Selection
Green	Green	Green	8	Green
Yellow	Green	Red	0	Red
Green	Green	Yellow	4	Yellow
Red	Yellow	Yellow	0	Red
Green	Yellow	Green	4	Green
Yellow	Green	Yellow	2	Yellow
Red	Green	Red	0	Red
Yellow	Green	Green	4	Yellow
Yellow	Green	Yellow	2	Yellow
Red	Red	Green	0	Red
Yellow	Green	Yellow	2	Green
Red	Yellow	Red	0	Red



Appendix 7: Bill of Materials Exploded View

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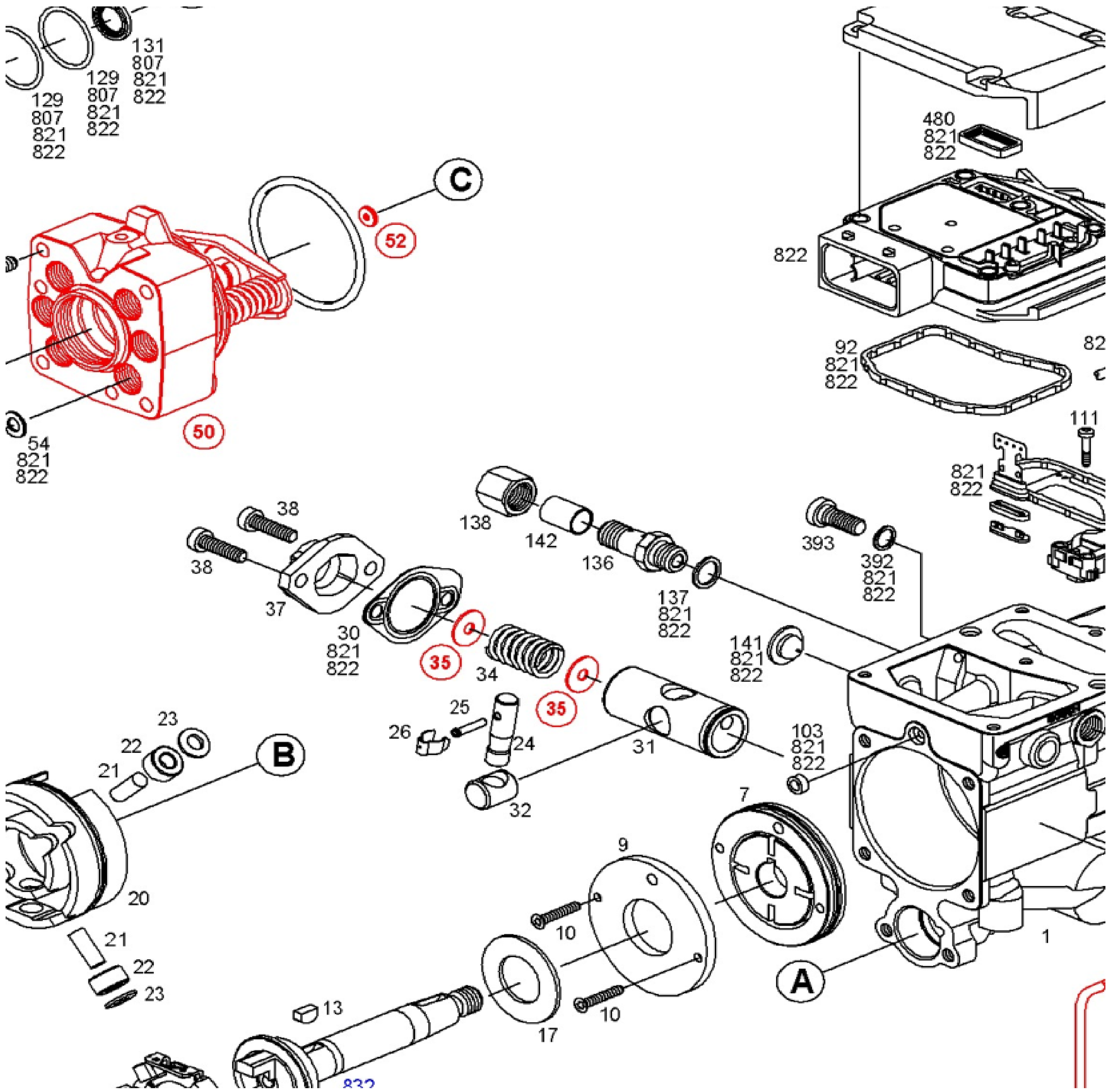

Appendix 8: Locking Cover 3D Models

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Appendix 9: Cam Plate 3D Models

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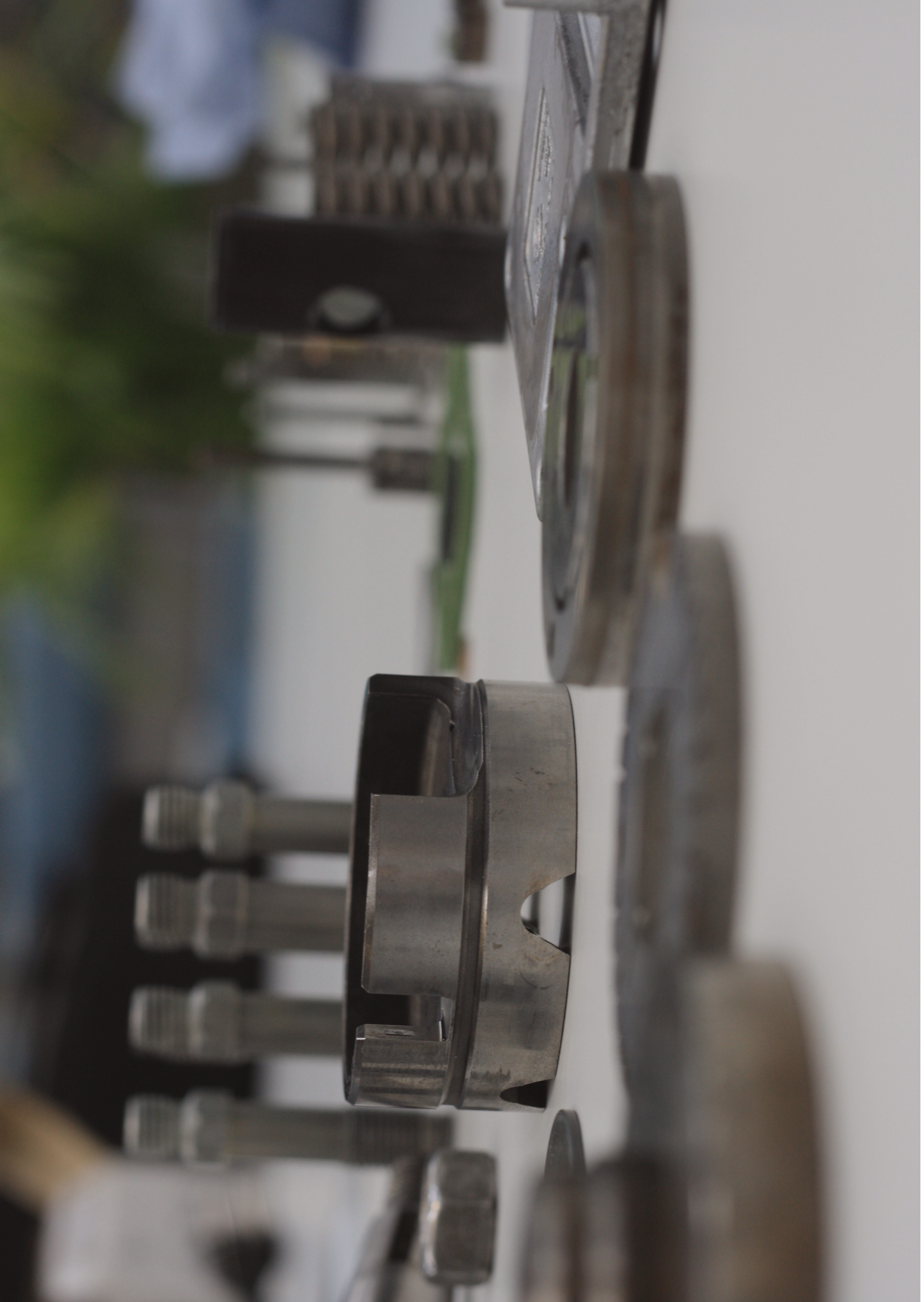

Appendix 10: Product Journey Map Reflection

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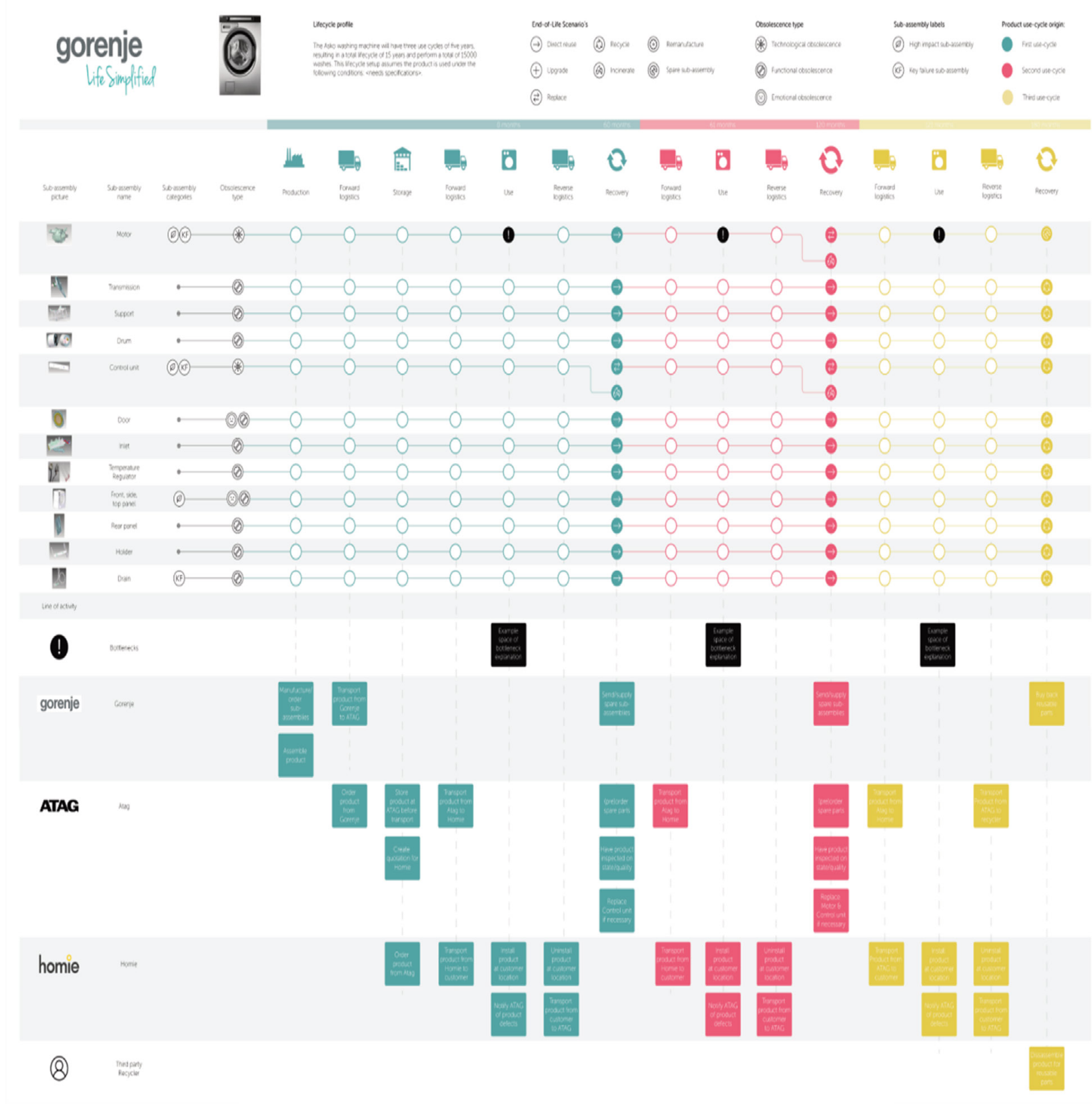

Product Journey Map Reflection

The Product Journey Map (PJM) is a tool developed by Kooijman (2022). It provides a visual understanding of how the various sub-assemblies within a product undergo their lifecycles and where opportunities exist to make these cycles more circular. Thus, it serves as both a tool of information as well as a tool for discovery. An attempt was made to incorporate the thinking of the Product Journey Map in this project. An example of a Product Journey Map for a Gorenje Washing Machine can be seen in *Figure 53.* This section outlines a reflection of the possibility of using this tool in the context of a diesel fuel injection pump and its sub-assembly lifecycles. This reflection reflects on the 5 stages coined by Daalhuizen as outlined in the Product Journey Map Playbook (Kooijman, 2022).

Rationale

For the diesel pump, it is quite important to map the lifecycle of the sub-assemblies so that appropriate End of Lofe (EoL) strategies can be implemented and parts that offer similar functionality / EoL strategies can be combined to reduce environmental impact. However, most functionalities in the pump are served by individual parts rather than subassemblies, it might be more useful to map the life cycles of the priority parts (as flagged by the HotSpot Mapping tool) to truly maximise the potential for discovering better circular strategies.

Framing

To create the PJM, voluminous data is necessary to accurately map the system and the lifecycle of individual components/sub-assemblies. The data for each individual pump is dependent on many extraneous variables such as quality of fuel used, type of environment (passenger, agriculture, commercial vehicles), number of kilometres run etc. Thus, one of the most important data points needed for the PJM i.e. failure rates, are not reliable since this does not accurately portray the lifecycle of the specific part. Moreover, the automotive aftermarket industry is 'data poor' (depending on who collects data and how it is can be used permissibly) and accurate information about these extraneous variables are not easily available thus, presenting a barrier for accurate inclusion. Nevertheless, with a specific scenario set (eg: a passenger car running on paved concrete roads for 200,000 km on Diesel 1 in Munich), accurate data can be extracted and the potential EoL scenarios can be precisely selected.

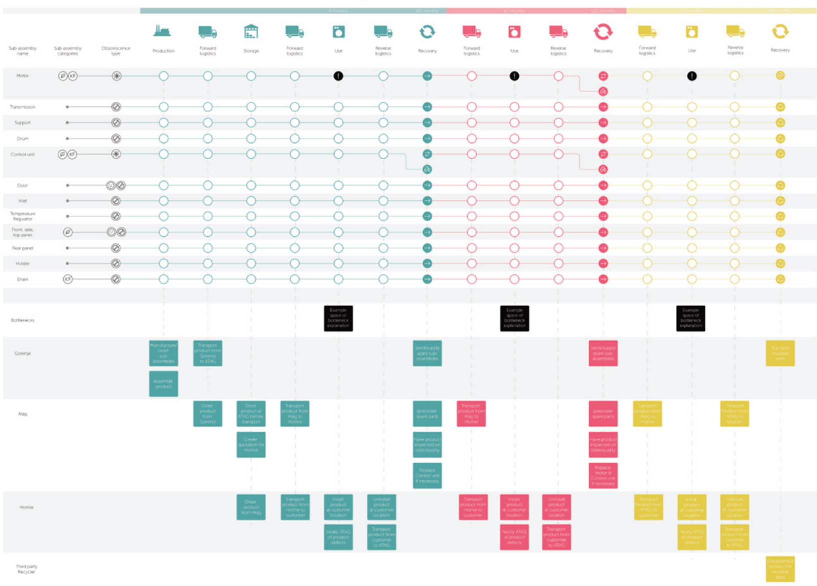

Figure 53: PJM Washing Machine (Kooijman, 2022)

Goal

The goal of the PJM is to provide an insight on opportunities to make a system more circular through stakeholder actions and scenario mapping. Given the wide variety of scenarios for the fuel pump, this becomes a more difficult task. However, the stakeholder action is an interesting data point since there are limited stakeholders in this business, mainly the manufacturer, repair/maintenance organisation and supplier (sometimes all functions provided by the same entity) and the end customer. This could make achieving the desired strategies more straightforward.

Procedure

The procedure defined by the PJM consists of 13 steps. Creating the lifecycle profile narrows down the scope of the PJM for a product such as the VP30 pump which has many different scenarios. The most common scenario could be used, but a lot of data points are needed to determine the most common scenario. The category of obsolescence types makes less sense for this product as it is a purely functional product with the main possibilities for functional obsolescence. Since the project focusses on remanufacturing these pumps, life extension is the desired goal, and this stage does not add any value to the PJM. The EoL scenario also depends on a case-to-case basis due to the nature of functionality and thus, an all-encompassing EoL cannot be made. However, different versions with different EoL scenarios can be made for the same part/sub-assembly. The life of (reused) products can also not be predicted due to the aforementioned extraneous variables. The EoL checklist is confusing since for the pump, all manners of EoL strategies are applicable for different parts in different scenarios. Remanufacturing is an especially complex one since that involves a combination of replacing and reusing, so such a choice in unclear in this case at a part level. The visual template conveys a lot of information and is very well laid out. However, it presents a very simplified image of the journey, thereby lacking the complex reality of the various scenarios (such as the logistics and recycling), the product life (in years) and the paucity of data for fields such as obsolescence.

Mindset

There are no reflections about the mindset needed as such a mindset is absolutely necessary to imbibe a long term, circular design focussed world view. The only point of note is that the PJM is a very data driven design tool and lack of accurate data could produce completely unreliable maps which have limited real world value.

Value

The last reflection lies in the value of the PJM for the case of the fuel injection pump. Recommendations have been given in each section for how it could be more relevant for the diesel pump. The pump is a ~25-year-old product at the end of its life and life extension strategies (specially remanufacturing) are applied to it. The life of each of the parts depends on extraneous variables and needs data to arrive at a median result. The EoL scenarios for the sub-assemblies are already fixed in place due to the rigorous nature of compliance in the automotive industry. Thus, looking for new opportunities is a task that does not have to be performed. The value of the PJM in the case of the pump is to visualise this journey for the sake of information. By adding stacked uncertainty swim lanes instead of one straight swim lane for each part/component, a wider variety of scenarios can be visualised and make the map more useful. From the operator standpoint, if the operator has data on a particular p art, they can refer to the PJM to decide what EoL strategy to use based on its scenario, thus serving as a remanufacturing guide for the pump. In my opinion, this is where the greatest value of the PJM lies for the VP30 pump.

A sketch which showcases the aforementioned reflections incorporated into the PJM template is shown in *Figure 54*.

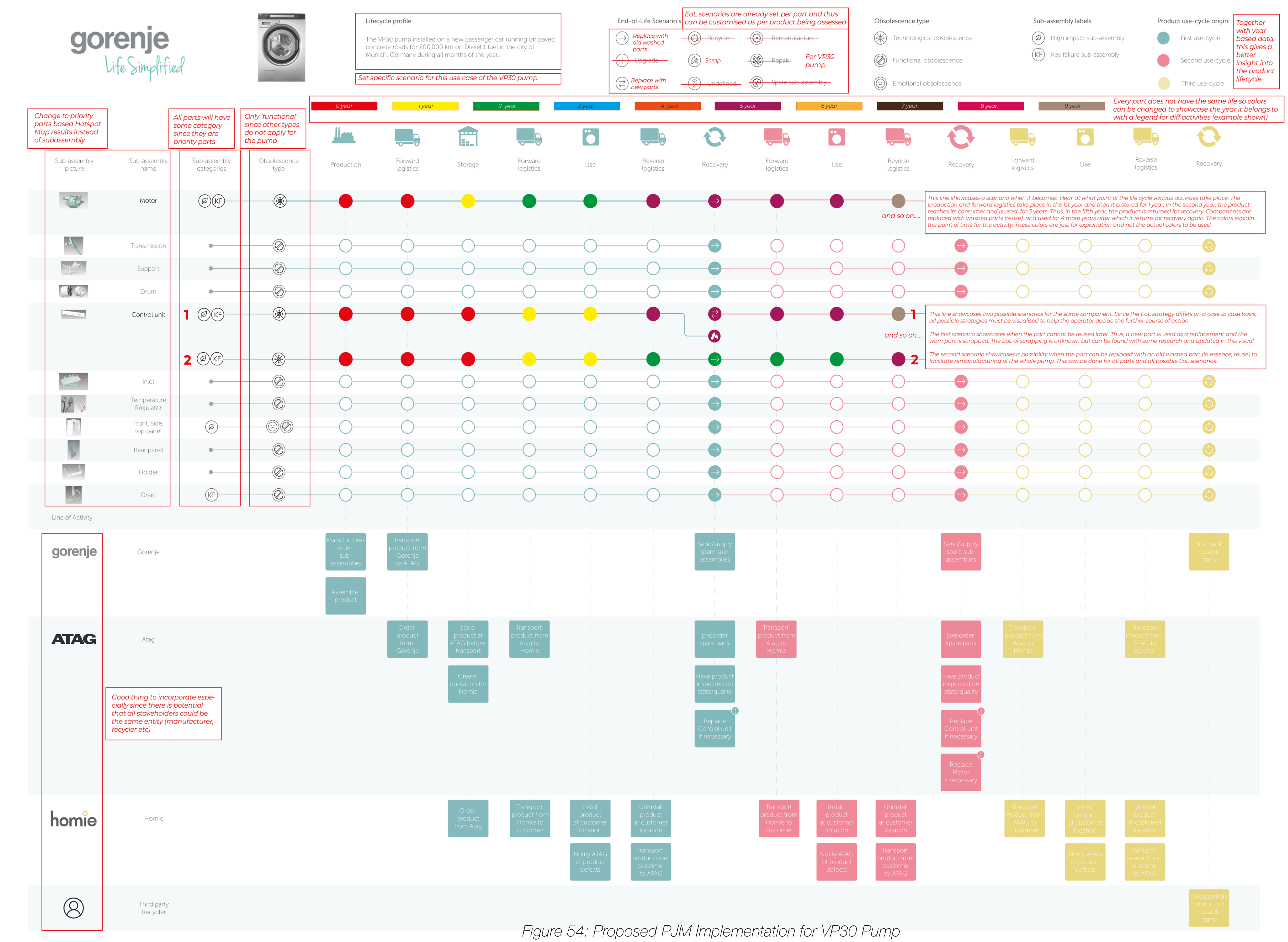

Figure 54: Proposed PJM Implementation for VP30 Pump

Appendix 11: Material Data Sheets

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LaserForm AlSi10Mg (A)

AlSi10Mg fine-tuned for use with ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 printers producing industrial parts with a combination of good mechanical properties and good thermal conductivity.

LaserForm AlSi10Mg (A) is formulated and fine-tuned specifically for 3D Systems ProX® DMP 320, DMP Flex 350, DMP Factory 350 and DMP Factory 500 metal 3D printers to deliver high part quality and consistent part properties. The print parameter database that 3D Systems provides together with the material has been extensively developed, tested and optimized in 3D Systems' part production facilities that hold the unique expertise of printing more than 1,000,000 challenging metal production parts in various materials year over year. Based on a multitude of test samples, the properties listed below provide high confidence to the user in terms of job-to-job and machine-to-machine repeatability. Using the LaserForm material enables the user to experience consistent and reliable part quality.

Material Descriptio

AlSi10Mg combines silic
which results in a signifi
compared to other alum
and solidification during
in as-printed condition s

In the aerospace and au
(A) is used for its light w
design and specific heat
thermal conductivity of t

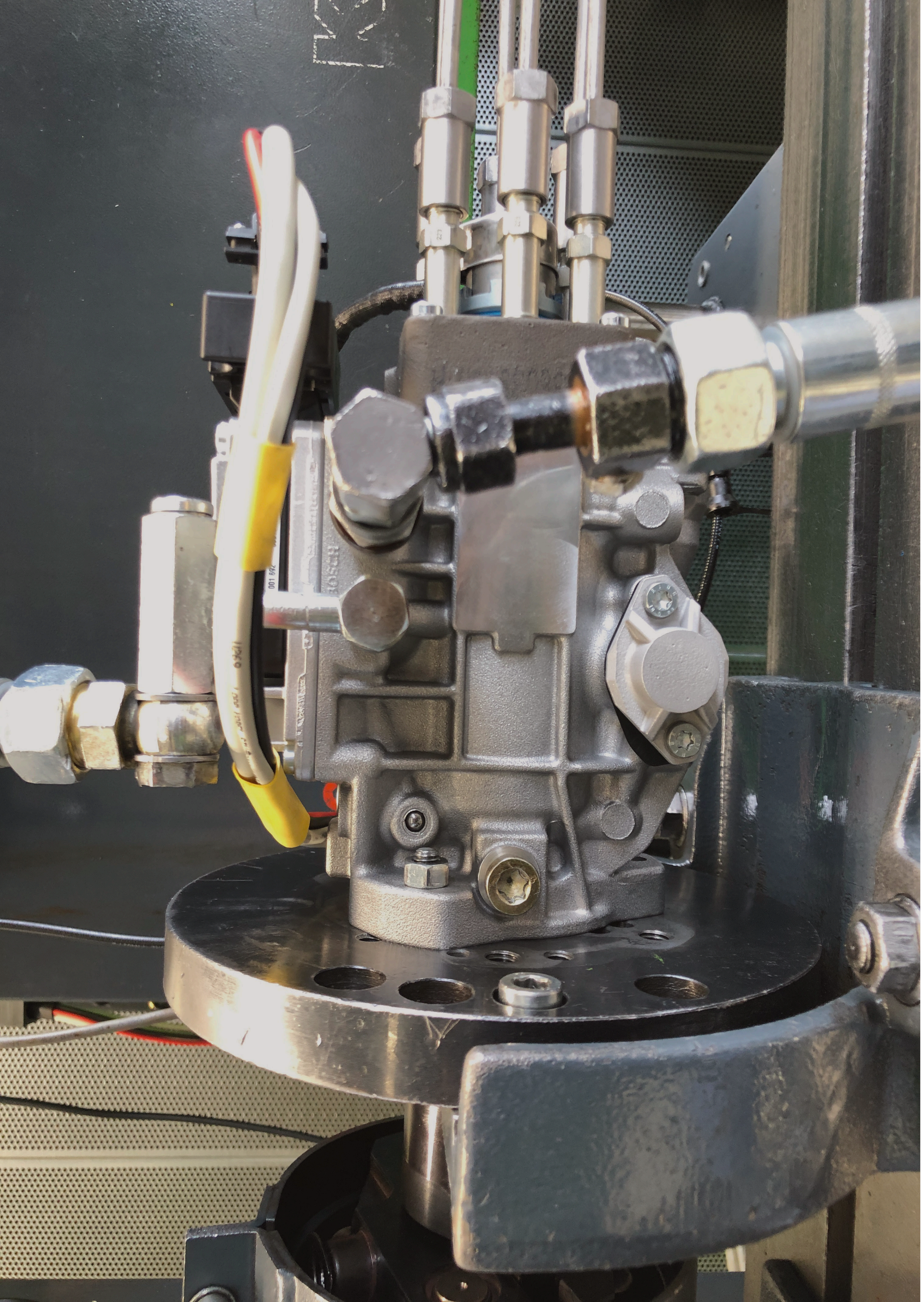
CLASSIFICATION:

Parts built with LaserFor
that complies with EN A(

Mechanical Properties

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 - LT 30[1, 4, 5]	TEST METHOD	METRIC			
		NHT	SR1	SR2	NH
Ultimate tensile strength (MPa | ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	470 ± 10 460 ± 25	300 ± 20 300 ± 20	400 ± 15 430 ± 15	68 ± 67 ±
Yield strength Rp0.2% (MPa | ksi) Horizontal direction - XY Vertical direction - Z		280 ± 10 240 ± 10	190 ± 20 180 ± 20	270 ± 10 250 ± 10	41 ± 35 ±
Plastic elongation (%) Horizontal direction - XY Vertical direction - Z		13.2 ± 4.8 8.3 ± 4.0	15.6 ± 3.6 15.8 ± 2.7	9.2 ± 3.8 5.2 +3.7/-2.6	13.2 ± 8.3 ±

PROX DMP 320, DMP FLEX 350, DMP FACTORY 350 – LT 60[2, 4, 5]	TEST METHOD	METRIC			
		NHT	SR1	SR2	NH
Ultimate tensile strength (MPa | ksi) Horizontal direction - XY Vertical direction - Z	ASTM E8	440 ± 30 425 ± 50	290 ± 20 290 ± 20	390 ± 20 400 ± 40	64 ± 62 ±
Yield strength Rp0.2% (MPa | ksi) Horizontal direction - XY Vertical direction - Z		260 ± 15 225 ± 10	170 ± 20 170 ± 20	255 ± 10 230 ± 10	38 ± 33 ±



Appendix 12: Test Bench Results

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PSG-Datum	PSG-Inhalt
TTNR Pumpe	0470006010
Fertigungsdatum	275
Seriennummer	512001
Fertigungswerk	999
Kundennummer	2644P501
Kundenänderungsindex	001
WID	---
Steuergerät	0281001692
PSG Fertigungsdatum	855
PSG Chargen-Nr.	
Fahrsoftware	2469946010
Version Fahrsoftware	P071_1.V71
Datensatz	2469947036
Referenz-Kennfeld	2469948021
Änderungsindex PV	---
FB-Mass	0.000000
dPhi1	0.761719
MVT-Abgleich	0.000000
DeltaPhi-AD	ffc8 ffb2 ffd8 ffcc 0011 8000
DeltaPhi-AD	8000 8000 8000 8000 8000 8000
DeltaPhi-AD	8000 8000 8000 8000 8000 8000
DeltaBlockierwinkel	0.000000
DeltaPhi-Offset	0.000000
DynFDKorrektur	0.000000
dT-Hybrid	-2.000000
Selbsttest	00 (Hex)
CAN-Status	000ch / 00000000 00001100b
Fehlerspeicher	

Appendix 13: Life Cycle Assessment

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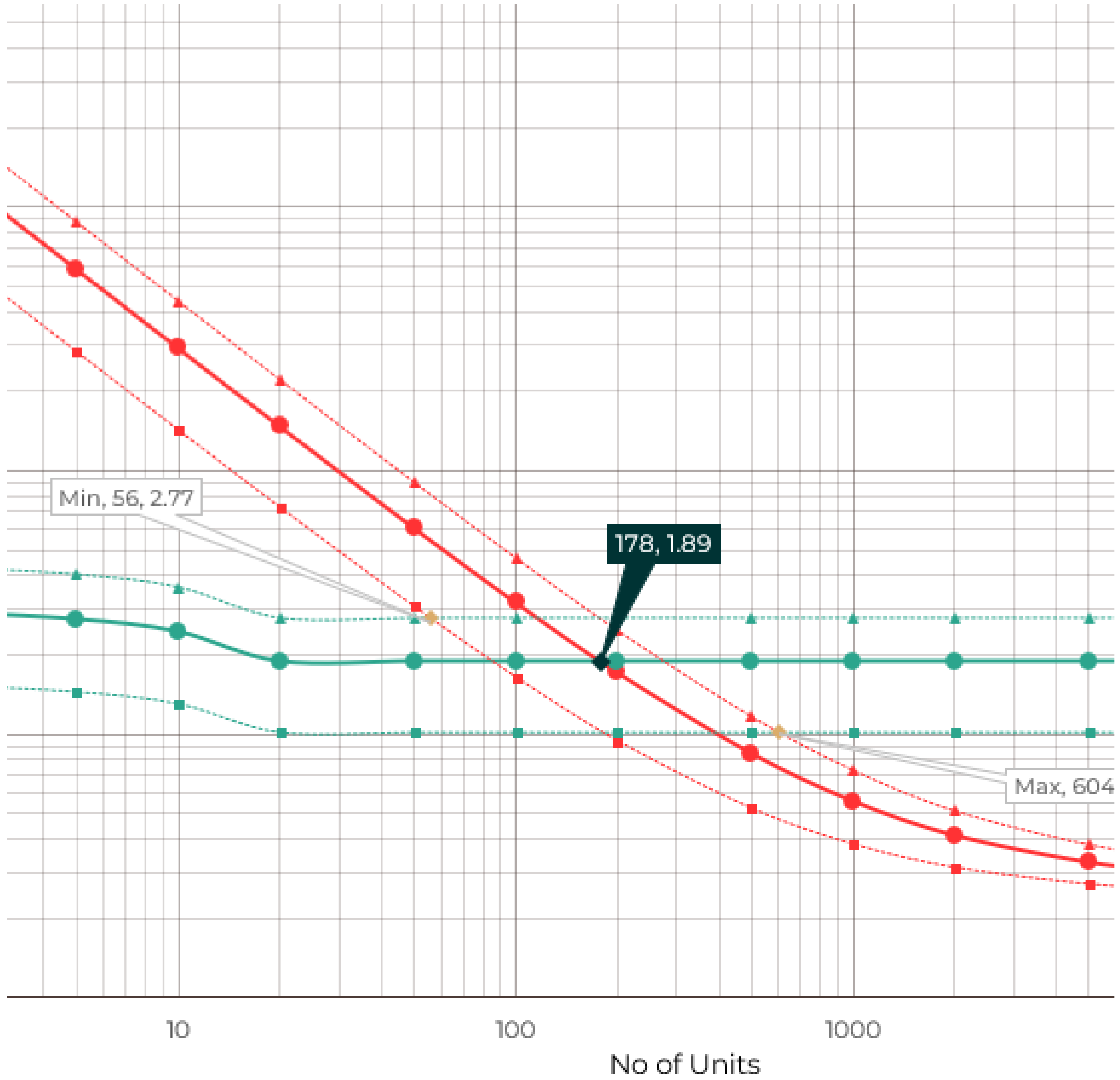

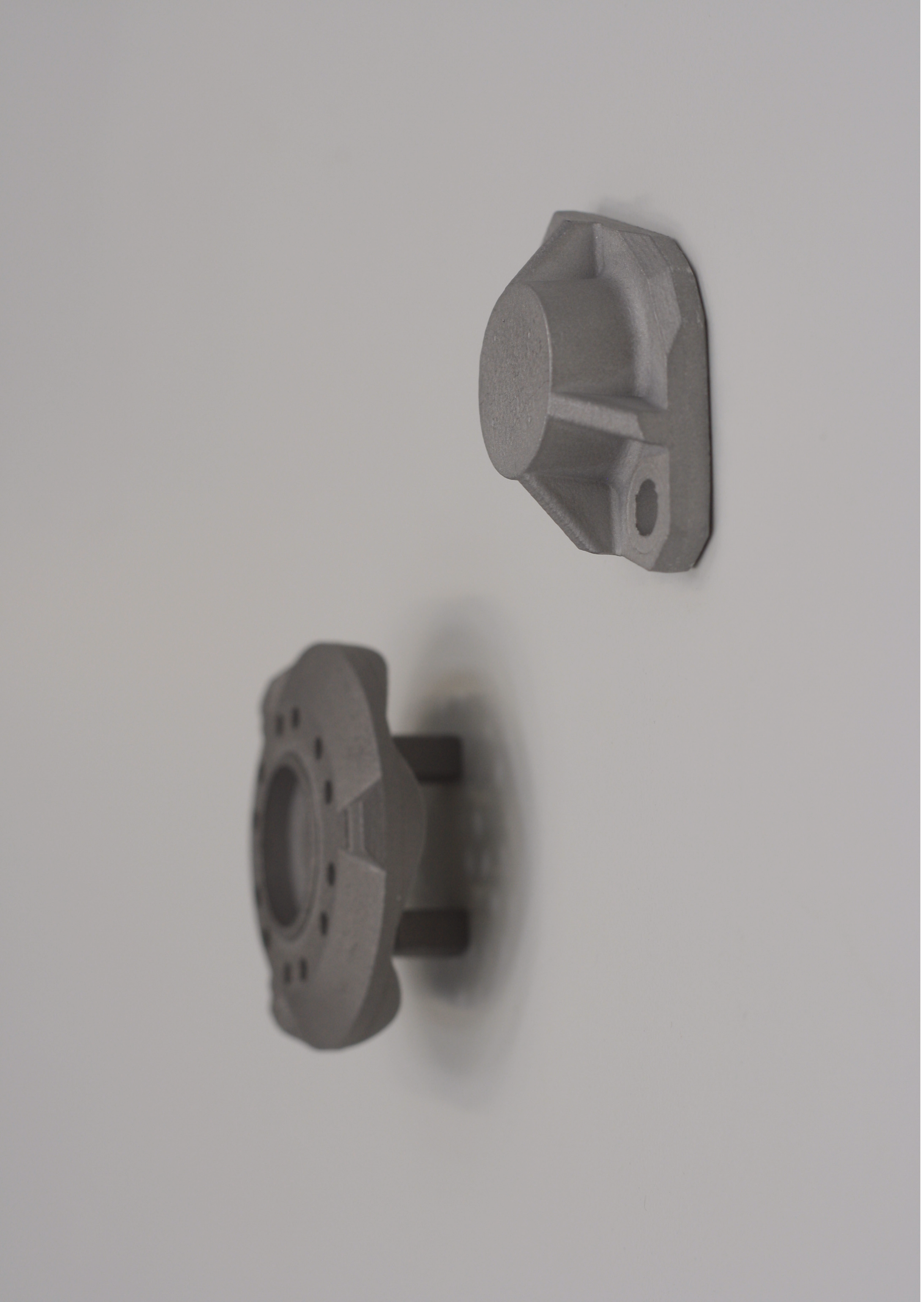

Appendix 14: 3D Print Investigation Flowchart

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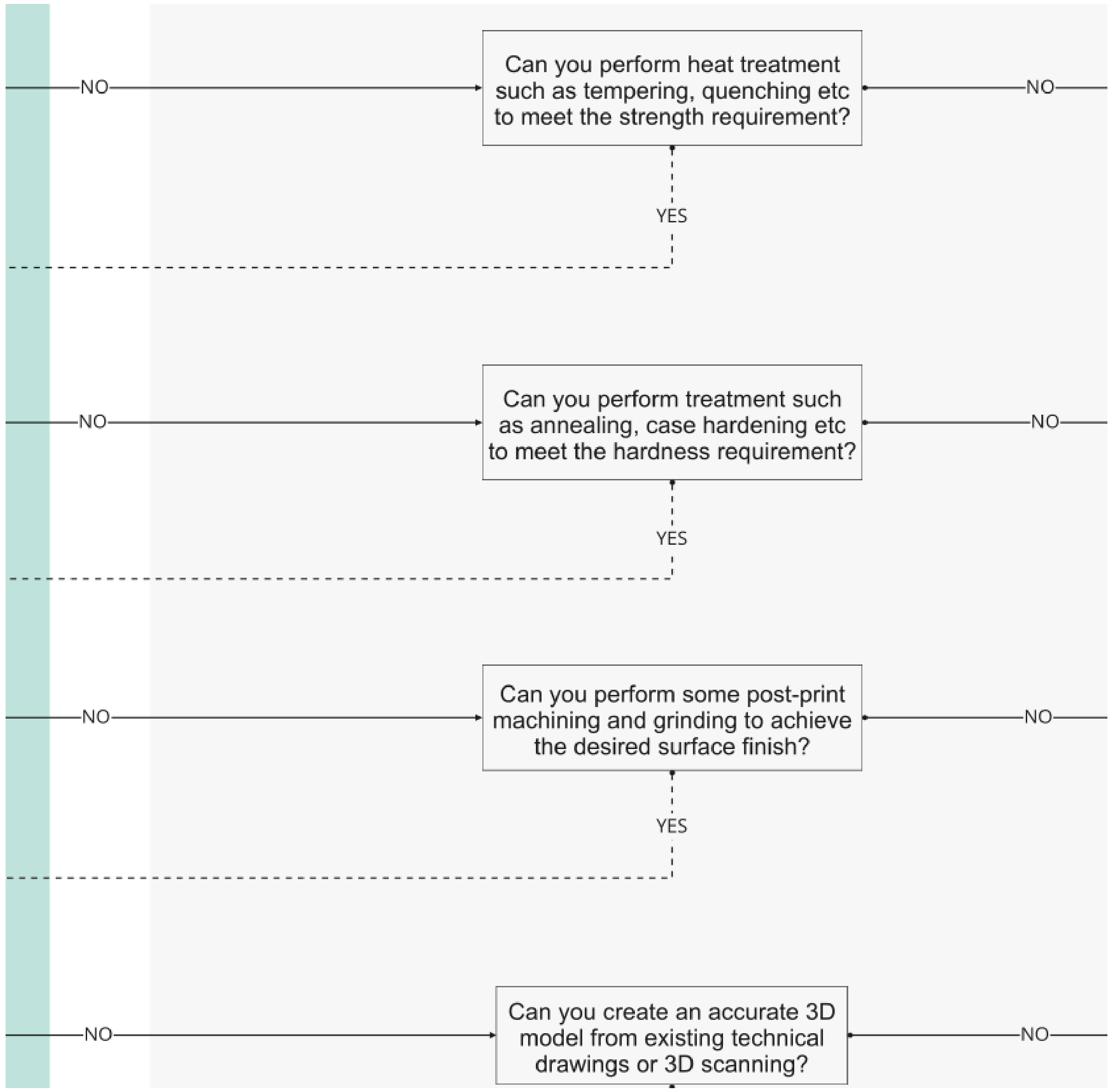

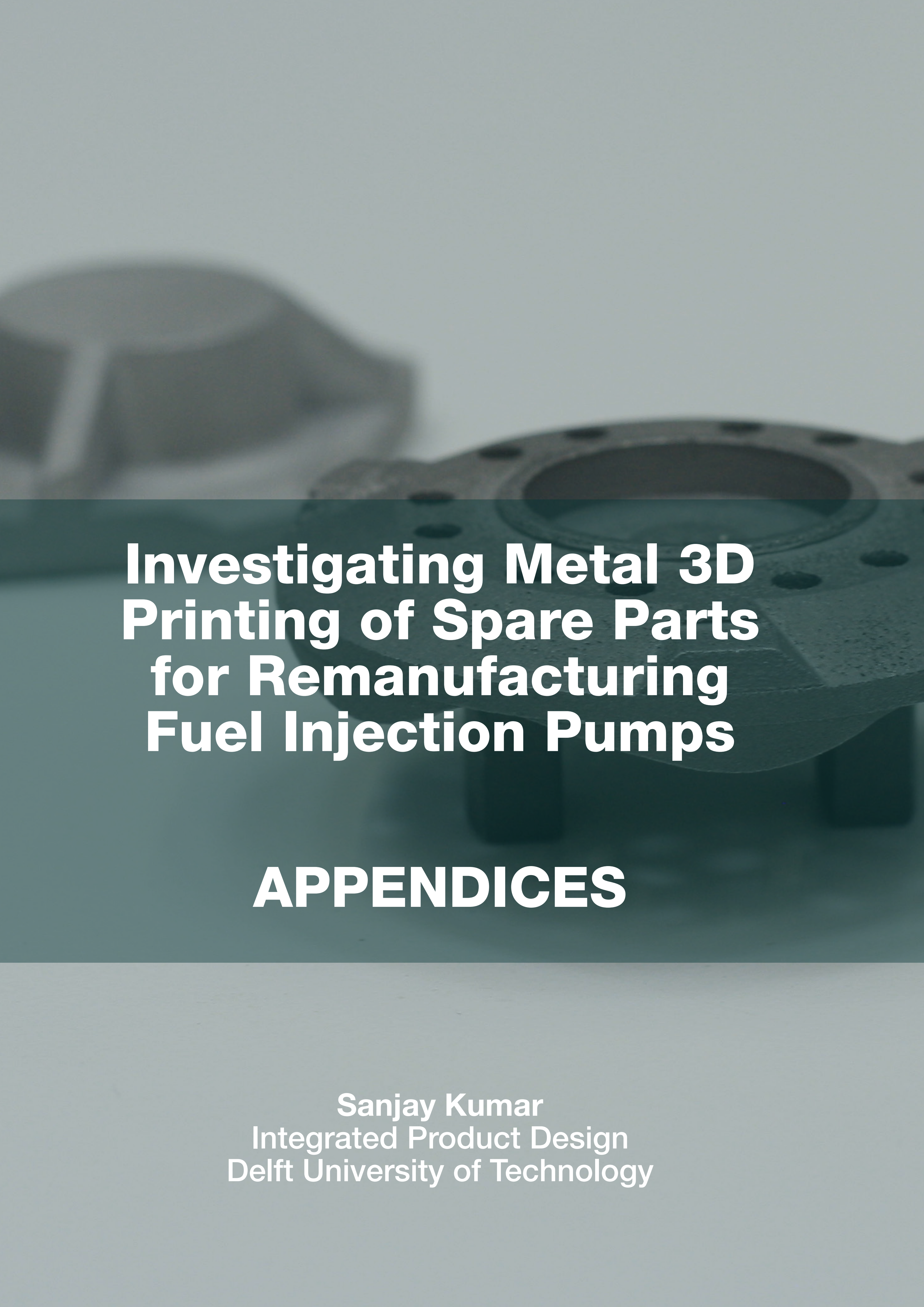

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