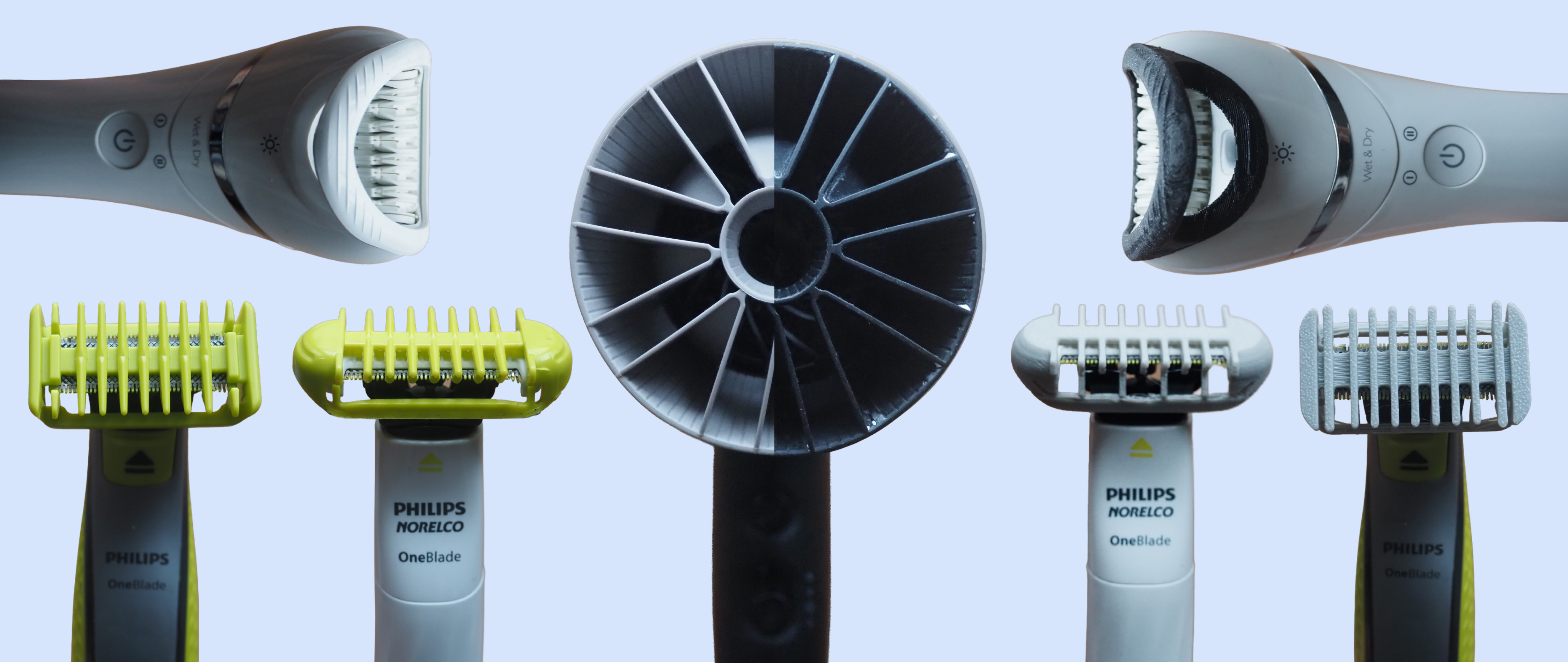

Philips printable spare parts

Evaluating the Feasibility of Additive Manufacturing for Spare Parts in the Philips Personal Health Portfolio

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MSc Thesis Integrated Product Design
Delft University of Technology l February 2026

TU Delft PHILIPS

Philips printable spare parts:
Evaluating the Feasibility of Additive Manufacturing for Spare Parts in the Philips Personal Health Portfolio

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Preface

I am proud to present my master's thesis, the result of six months of hard work. This project is a good reflection of me as a designer, someone who enjoys working at the intersection of disciplines, and who is fascinated by how design can contribute to product durability.

As will become evident throughout this report, I have 3D printed more in the past months than ever before. What I knew as a familiar prototyping technique evolved into a deeper understanding of 3D printing as a manufacturing method for end-use components.

I hope this thesis inspires you to think about repairability and to consider yourself as a potential user of a 3D printed spare part. Would you accept an additively manufactured replacement part in the future? Although this report is not tangible, the work behind it certainly is. If reading this sparks curiosity and you ever feel the urge to hold, compare or examine any of the prototypes I created, please feel free to reach out. I now own far more printed parts than I ever expected to.

I would like to express my gratitude to everyone who supported me throughout this project. First, I want to thank Bas and Ruud for their guidance, and for keeping me sharp. I also want to thank Daniela and Leendert Jan for giving me this opportunity, and for your endless enthusiasm. Thank you as well for always being able to connect me to the right people, it made all the difference. My gratitude extends to the many people at Philips who took the time to share their expertise, provide input, and for the coffee breaks. I have learned so much from all of you, and I deeply appreciate your openness and willingness to help. A very special thanks goes to all my friends in Delft, who carried me through this project with discussions, distractions, and constant encouragement. This would have been far less fun without you all. Finally, to everyone else who took the time to give feedback, listen to my ideas, or simply hear me out along the way, your support meant a lot.

Enjoy reading!

Rachel Prud'homme van Reine

Executive summary

This thesis investigates how additive manufacturing (AM) can be meaningfully integrated into the Philips Personal Health (PH) spare-parts ecosystem, with the aim of enabling more repair, supporting circularity ambitions, and preparing for future service and fulfilment models. At the core of the project are three deliverables: a strategic future vision roadmap for AM integration, a part selection framework, and a redesign framework supported by a prototype display. Together, these provide a structured understanding of what is feasible now, what could be feasible next, and what Philips could do to scale AM as a credible complementary spare parts route.

The future vision roadmap outlines four horizons, from today's consumer home-printing model through Philips Fixables to long-term hybrid fulfilment systems, and identifies the technological, regulatory, market and business model developments required along the way. Findings show that consumer FDM (Fused Deposition Modelling) printing can support only a limited subset of grooming and beauty parts, and that meaningful expansion will depend on the emergence of professional printing environments with certified materials and predictable quality. Ultimately, AM could enable Philips to offer "spare parts on demand", supporting repair and refurbishment far beyond the lifespan of traditional sourcing.

A part selection framework was developed and applied to the full PH consumer replaceable parts (CRP) portfolio. Out of 492 parts, 133 were considered eligible for AM, from which 104 as suitable for consumer FDM printing. Eligibility was strongly constrained by regulatory classification and material limitations, confirming that near-term AM opportunities lie primarily within the grooming and beauty category. The analysis also highlighted organisational gaps in data consolidation, reinforcing the need for Philips to streamline part data to scale AM decision-making.

To enable scalable redesign capability, a redesign framework and prototype display were created based on the insights from the succesful redesign of four parts from the grooming and beauty portfolio. These tools help designers structure early-stage AM decision-making and promote a shared way of thinking. User testing showed that the content is clear and valuable for onboarding less experienced designers, though further refinement and broader stakeholder testing are needed.

The project concludes that AM is not a replacement for injection moulding but a complementary capability that excels in low-volume, on-demand, long-tail spare parts, especially when traditional sourcing is costly, slow or unavailable. AM's value lies in enabling repairs that would otherwise not occur and, in the longer term, supporting refurbishment and extended product lifetimes. For Philips, the key implications include clarifying future user groups, consolidating relevant part data, reconsidering the structure of the spare-parts portfolio, and deciding how AM redesign responsibilities should be organised.

Overall, this project provides Philips with a strategic direction, practical tools and concrete insights needed to position AM as a scalable and service-oriented spare parts solution for the future.

Abbreviations

- 3DP – 3D Printing
- ABS - Acrylonitrile Butadiene Styrene
- AI - Artificial Intelligence
- AM – Additive Manufacturing
- BJ – Binder Jetting
- CAD - Computer Aided Design
- CRP – Consumer Replaceable Parts
- D2C – Direct to Consumer
- DED – Directed Energy Deposition
- DfAM - Design for Additive Manufacturing
- DLP - Digital Light Processing
- FBD - Free Body Diagram
- FDM - Fused Deposition Modelling
- GnB – Grooming and Beauty
- IM - Injection Moulding
- IoT - Internet of Things
- IP - Intellectual Property
- MEX – Material Extrusion
- MJ – Material Jetting
- MJF - Multi Jet Fusion
- MCC – Mother and Child Care
- OEM – Original Equipment Manufacturer
- OHC – Oral Health Care
- PBF – Powder Bed Fusion
- PC - Polycarbonate
- PEEK - Polyether Ether Ketone
- PEI - Polyetherimide
- PEST - Political, Economic, Social and Technological factors
- PETG - Polyethylene Terephthalate Glycol
- PH – Personal Health
- PLA - Polylactic Acid
- SLA - Stereolithography
- SLS - Selective Laser Sintering
- SPM – Spare Parts Management
- STL - Standard format for 3D printing
- VPP – Vat Photopolymerization

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1. Introduction

We are dealing with an ever-increasing amount of waste from consumer products. To combat this, it is necessary to slow down the flow of resources. Once a product is obtained, the most effective strategy to achieve this is to prioritize repair, maintaining the product at its highest possible level in the value chain for as long as possible (Ellen Macarthur Foundation, 2021).

To facilitate easy repair for consumers, the EU has introduced the "right to repair" as part of a broader set of Ecodesign measures aimed at promoting product repairability (European Commision, 2025b). Effective since March 1, 2021, these regulations mandate that manufacturers design products to be more repairable and ensure long-term availability of spare parts. These regulations apply to new models of home appliances and require that spare parts must be available for a period ranging from 7-10 years after the product is placed on the market. During that period, manufacturers are required to deliver spare parts within 15 working days of ordering (European Commission, 2019).

While the scope of products these regulations apply to is still limited, it is expected to expand in the future to include more consumer electronic appliances. Philips, aiming to stay ahead of these regulations and increasing their circular revenues (Philips, 2025b), wants to investigate new ways of delivering spare parts in their consumer product portfolio, especially those components that are designed to be replaced by consumers without technical assistance.

The traditional way of ensuring spare part availability would be to keep them in stock. It is, however, difficult to predict demand, and warehousing unused parts is costly and can generate additional waste (Turrini & Meissner, 2019). Thus, to effectively comply with the upcoming regulations mandating long-term spare part availability as well as timely delivery, companies need to investigate more efficient ways of spare part delivery.

One promising solution could be additive manufacturing (AM), also known as 3D printing (3DP) to produce spare parts on demand (van Oudheusden et al., 2023b). Instead of maintaining a physical inventory, digital files of parts can be stored, reducing delivery time, costs, emissions, and material waste (Alzahmi et al., 2025), so potentially a manufacturer could support products indefinitely.

1.1 Research gap

Previous studies, such as those by Alma van Oudheusden et al. (2023b) have shown that even when expanding the scope of AM technologies, some parts may never be suitable for additive manufacturing due to functional requirements or technological limitations. The suitability of a part is determined by a combination of factors, including its design, overall functionality, the original material and manufacturing method, and the capabilities of the additive manufacturing technology (van Oudheusden et al., 2024). In this research, this concept is referred to as technical eligibility. While this literature provides tools to aid in the redesign of parts for AM, they are often based on the design of non-aesthetic functional components which differs significantly from the context of Philips Personal Health parts.

Beyond technical eligibility, for parts intended for end-use applications, economic and environmental viability must also be considered, meaning it must be economically and environmentally equal to or better than its traditionally manufactured counterpart (Jung et al., 2023). Current research often focusses on quantifying economic and environmental differences between additively manufactured and conventionally sourced parts. The broader contextual impact of extending product lifecycles through additively manufactured replacements that would otherwise be unavailable or unattractive to consumers is often ignored.

Furthermore, challenges related to certification, quality assurance, and intellectual property for 3D-printed spare parts in consumer electronics remain under-addressed, creating barriers to implementation at scale. Existing studies tend to emphasize what is currently possible with available technologies and regulations and do not take into account future developments which is a necessary consideration for future-proof solutions (Jiang et al., 2017).

Moreover, there is a lack of a comprehensive and scalable framework that integrates these eligibility and viability criteria to guide the selection and redesign of spare parts for additive manufacturing, particularly within the consumer electronics domain. Existing research tends to focus on isolated case studies, general approaches, or other industries such as aerospace and automotive. This research addresses that primary gap by developing an integrated framework and redesign method tailored to the Philips Personal Health portfolio.

1.2 Design challenge and deliverables

This study aims to: *Develop a framework for assessing technical eligibility and guiding decisions on redesign and manufacturing of consumer replaceable 3D printed spare parts for the Philips Personal Health portfolio, focusing on the immediate implementation of redesigning parts at scale for consumer printing, while also covering long term adaptability to evolving technical and regulatory contexts.*

The deliverables will be threefold:

- Future vision roadmap: A recommendation for a forward-looking vision for leveraging AM in spare parts beyond the current state, coupled with a roadmap outlining the current situation and projected horizons for AM adoption in spare parts.

- Part selection and redesign framework: A structured workflow outlining steps and criteria for part selection that addresses both technical eligibility and economic and environmental viability. This is coupled with a redesign framework focused on guiding Philips designers in the process of designing parts for reliable consumer 3D printing. The insights are based on the explorative redesign process of a selection of parts, validated on common consumer printers and feedstocks.

- Prototype demonstration: A curated set of Consumer Replaceable Parts (CRPs) from the Personal Health portfolio, redesigned and printed using various materials and processes, showcasing current and near-future possibilities.

1.3 Research questions and approach

The project will follow a double diamond approach structured in two phases: strategic exploration and building (figure 1). The strategic exploration focuses on defining the scope of the project based on Philips' goals and future horizons, and exploring current and near future possibilities through case-based redesign. The building phase translates these insights into a redesign framework tailored to the Philips Personal Health (PH) portfolio.

Exploration: Conduct background research on Philips, spare parts management, and additive manufacturing. Use PEST (Political, Economic, Social, and Technological factors) analysis to identify external enablers shaping future scenarios and contextualize them through backcasting from Philips' vision. The outcome is a set of future horizons in the form of a roadmap that guide what to prioritize now.
Synthesis: Derive criteria for part selection through literature review and expert input from Philips employees. Map the decision-making process and apply the framework to the full list of CRPs in the PH portfolio. Classify parts as feasible now or in future scenarios, then redesign selected cases using Design for Additive Manufacturing (DfAM) principles from literature and insights from previous AM projects at Philips. This phase concludes with a decision-making framework, list of eligible parts, prototypes and process learnings.
Ideation: Define the design vision and requirements based on insights from redesign cases, followed by concept generation for the framework.
Creation and validation: Develop the design framework that captures all the insights from the previous phases and validate it with Philips designers. Finalize recommendations and deliverables into actionable outputs.

This research aims to answer the following questions:

- **RQ1:** What key developments shape the future of additive manufacturing in spare parts management?
- **RQ2:** What enablers and constraints shape the evolution of the current Fixables initiative into a scalable AM-driven spare parts strategy that moves beyond consumer printing?
- **RQ3:** What systemic criteria can be used to assess the viability of a part for 3D printing across functional, economic and environmental dimensions?
- **RQ4:** What technical criteria determine whether a part is printable, and how do they inform AM technology and post-processing choices?
- **RQ5:** What design modifications are necessary to ensure that 3D-printed spare parts meet functional and aesthetic expectations compared to traditionally manufactured parts?
- **RQ6:** What process gaps and constraints currently hinder the application of design for additive manufacturing (DfAM) during part redesign?

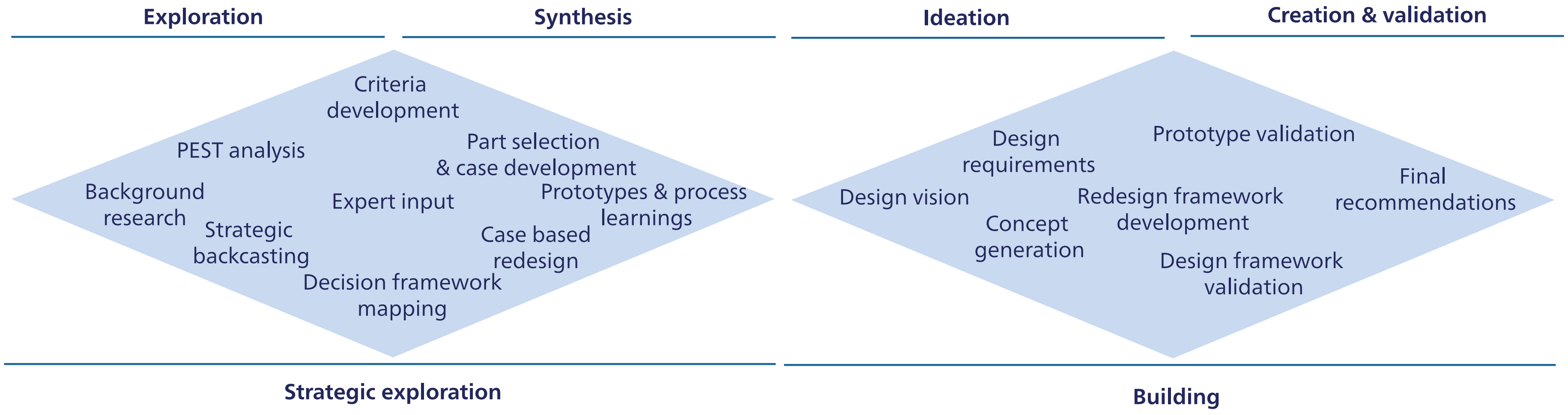


Figure 1: Project approach overview

2.

Background and context

This chapter provides the foundational knowledge required to understand the context of this thesis and to frame the methods, analysis, and design decisions that follow. It equips the reader with the necessary background information in three core areas: the commissioning company, Philips, the manufacturing technology at the centre of the project, additive manufacturing (AM), and the operational domain in focus, spare parts management (SPM).

2.1 Philips

To understand the implications of applying AM in spare parts delivery, it is essential to first understand the organizational context of Philips, particularly the structure and services related to its Personal Health (PH) division, for which this project is carried out. Appendix A1 shows a brief overview of the PH product portfolio. Specific attention is given to Philips Fixables, a trial for consumer printable AM spare parts, which is where the need for this project emerged from. Furthermore, Philips' current spare parts management (SPM) model is detailed. This will help contextualize how AM can realistically be integrated and scaled within the company.

Figure 2: Overview of Philips company structure and business units (Service Parts Manager, 2025)

ABOUT PHILIPS

Philips is a global health technology company. The company is structured into three key divisions (see figure 2): Diagnosis & Treatment, Connected Care, and Personal Health (Philips, 2019). This project is for the Personal Health division.
The PH division focuses on healthy living and preventative care, and comprises the Grooming and Beauty (GnB), Oral Healthcare (OHC) and Mother & Child Care (MCC) business units (Philips, 2019).

AFTER SALES AND SERVICE OFFERINGS

Given that the results of this project will enhance Philips' after-sales and service offerings, it is necessary to identify and understand the company's current initiatives focused on extending product lifecycles.

Service parts

Consumers can order genuine Philips spare parts through Philips' official website or via authorized retailers. This selection of parts does not comprise the whole spare part portfolio but only includes the 'Consumer Replaceable Parts' (CRPs), which are defined as components that can be accessed and replaced without the need for any tools. Typical examples include detachable covers or accessories. Excluded from this selection are consumables, which are parts such as brush heads and shaver heads which require regular replacement due to wear.

Service centres

Philips maintains a global network of authorized service centres that handle repair and maintenance activities. These centres use genuine Philips spare parts and are staffed by trained technicians. Products within the warranty period are repaired free of charge. Out-of-warranty products can also be serviced at a cost to the consumer. This system ensures professional, reliable repairs and helps maintain product quality standards across regions.

Refurbishment

Philips has a refurbishment program where pre-owned and returned products are restored to like-new condition. Refurbishment activities are carried out at larger service facilities using certified parts and standardized procedures to guarantee performance and safety. Refurbished products are then resold through Philips direct to consumer (D2C) channels.

Philips Fixables

In 2025 Philips launched the "Fixables" initiative in collaboration with Prusa Research (Philips, 2025a). Fixables is a platform that provides public access to 3D files, with accompanying manufacturing instructions, for a selection of spare parts for Philips products, allowing consumers to print these parts at home. Figure 3 on the next page shows an overview of the current assortment of parts on Fixables.

The purpose of the trial is to extend product lifespans by facilitating the replacement of essential, non-critical components. Though the 3D files are tested and verified by Philips, the responsibility of the manufacturing of the part lies with the user, relying on them to follow the provided instructions.

Although the initiative aligns with circular economy principles, its impact is constrained by the limitations of home-based manufacturing (Fused Deposition Modelling (FDM) printing with PLA (Polylactic Acid) (Philips Fixables, 2025)), resulting in a narrow range of eligible parts. In addition, the current line of Philips PH products is not designed for repair, so the pool of spare parts, including both CRPs and professional repair parts, remains small until future design revisions prioritise repairability. Product specific requirements for PH devices, notably waterproofing, hygiene standards and other regulatory constraints, further restrict safe home repair and home printing, because water ingress cannot reliably be prevented and not all service grade specifications can be met. Furthermore, the technical knowledge required as well as accessibility to a 3D printer excludes a significant portion of potential users. Thus, expanding this model to include "printing as a service", where certified manufacturers handle the production, could increase accessibility and broaden the range of eligible parts (Pourhejazy et al., 2025). This is where the need for this project emerged from.

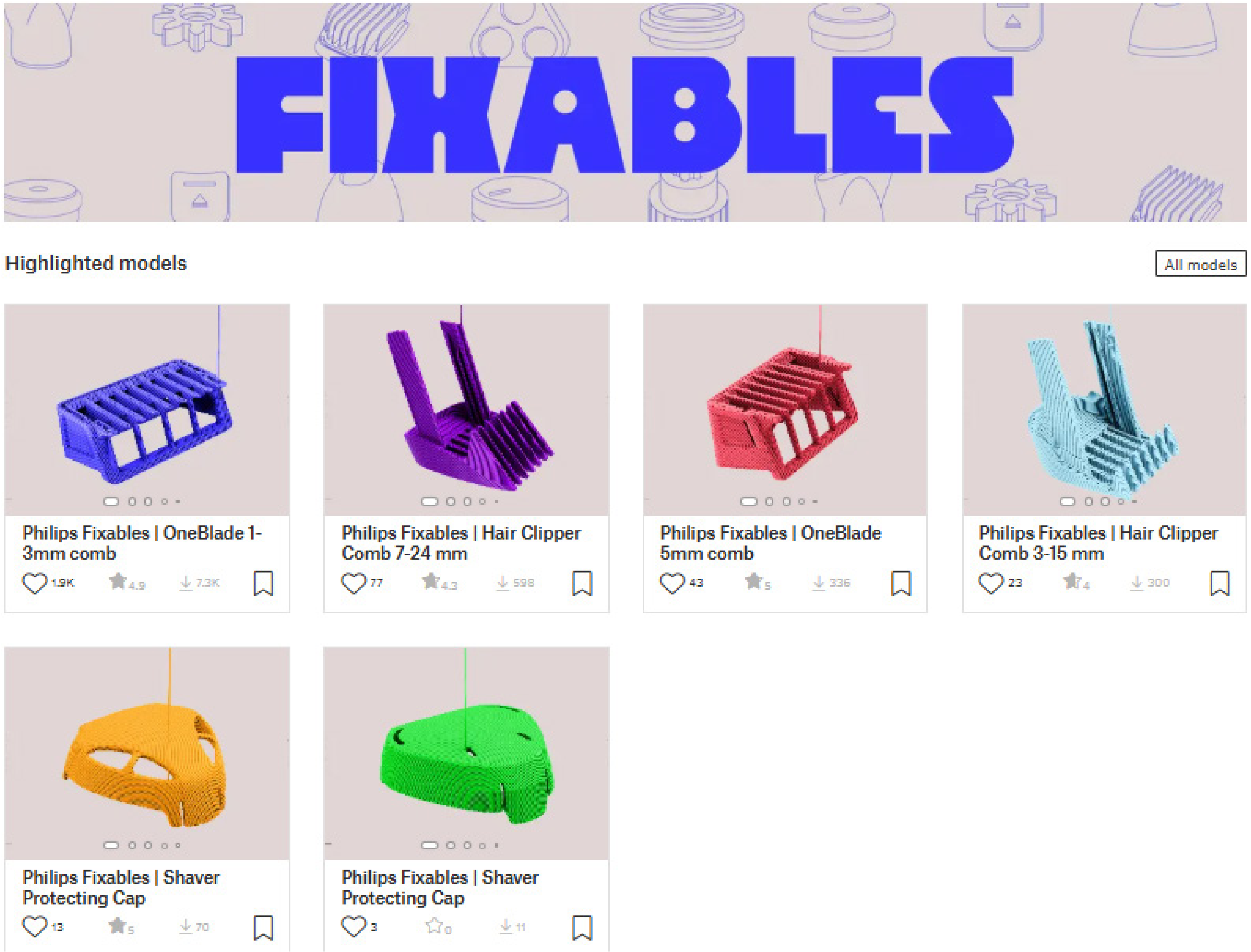


Figure 3: Philips Fixables (Philips Fixables, 2025)

SPARE PARTS MANAGEMENT AT PHILIPS

This section explains Philips' current spare parts management (SPM) model, as well as highlights the structural challenges of traditional approaches. Furthermore, Philips' future vision for their refurbishment and service parts is introduced, providing the context needed to align an AM-driven strategy with broader organizational goals.

Current spare parts and repair service model

The spare parts supply chain includes all stages that a part passes from the extraction of raw materials until its provision to the consumer (Mindt et al., 2022). Within this, SPM is defined as planning, monitoring and control of man, material, processes, spare parts, and information flows, in support of repair and maintenance activities (Kulshrestha et al., 2024).

At Philips this is translated into a repair service model tailored to regional needs, based on cultural preferences regarding repair, as can be seen by the distribution of service centres in figure 4. For this project the focus will be on Central Europe as the demand for product repair is high in this area. In countries like Benelux, UK and Germany a regional approach is used because consumers here are used to shipping their products for repair. Conversely, in Spain and Italy a local model is used because there is a culture of going to small repair shops. All service centres are certified which means that they have an agreement with Philips about using official parts, repair times and price etc. For the Central Europe region, all parts are stored in a central warehouse in Lodz (figure 5).

The repair process is managed by E-care, a third-

Figure 4: Distribution of Philips certified service centres in central Europe (Network and Refurbishment Vendors Manager, personal communication, 20 October 2025)

Figure 5: Overview of warehouses and Philips factories around the world (Network and Refurbishment Vendors Manager, personal communication, 20 October 2025)

party provider that exclusively serves Philips. E-care oversees the entire repair operation and invoices Philips for warranty-covered repairs. Consumers access E-care's services via Philips. Figure 6 shows the flowchart of the flow of products, parts and cash in the Philips repair service chain.

Spare parts management is handled by Flex (previously Flextronics), a company responsible for managing inventory. Flex procures spare parts directly from Original Equipment Manufacturers (OEMs). E-care, in turn, procures spare parts from Flex. Flex also ensures availability of service components offered by Philips. Thus, any modifications to the spare parts system will directly affect Flex's operations. Figure 7 shows the end-to-end spare parts management process, showing the flow of inputs and outputs from business units to service parts teams, and operations that lead to the service parts output.

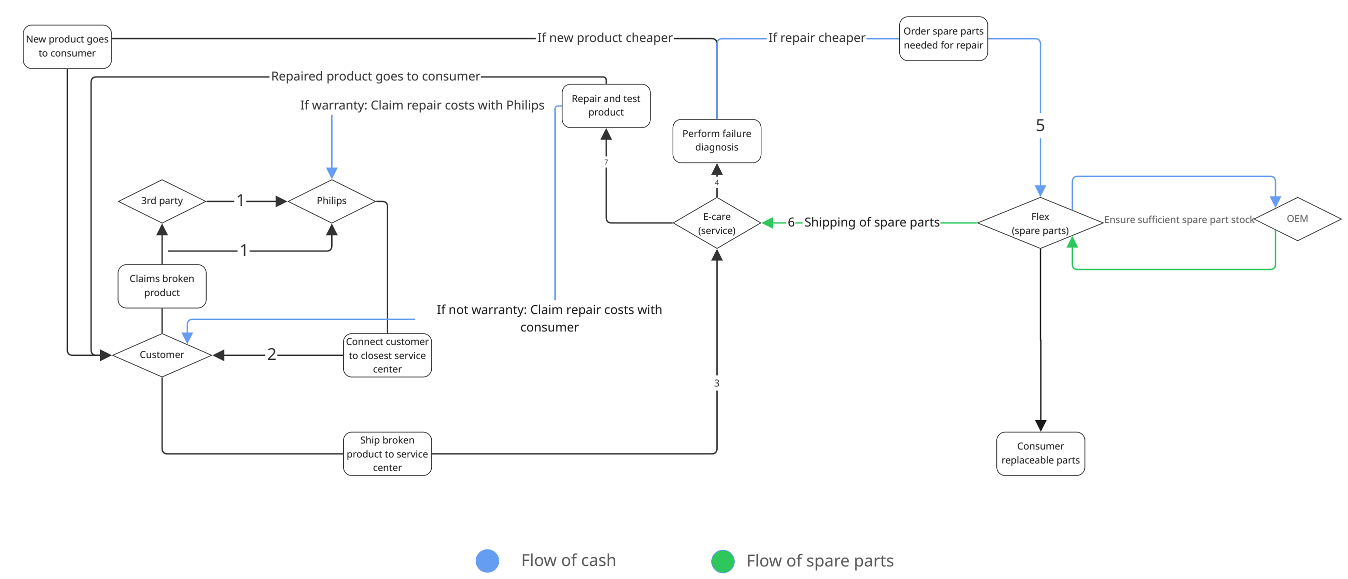


Figure 6: Flowchart of the flow of products, parts and cash in the Philips repair service chain (Network and Refurbishment Vendors Manager, personal communication, 20 October 2025)

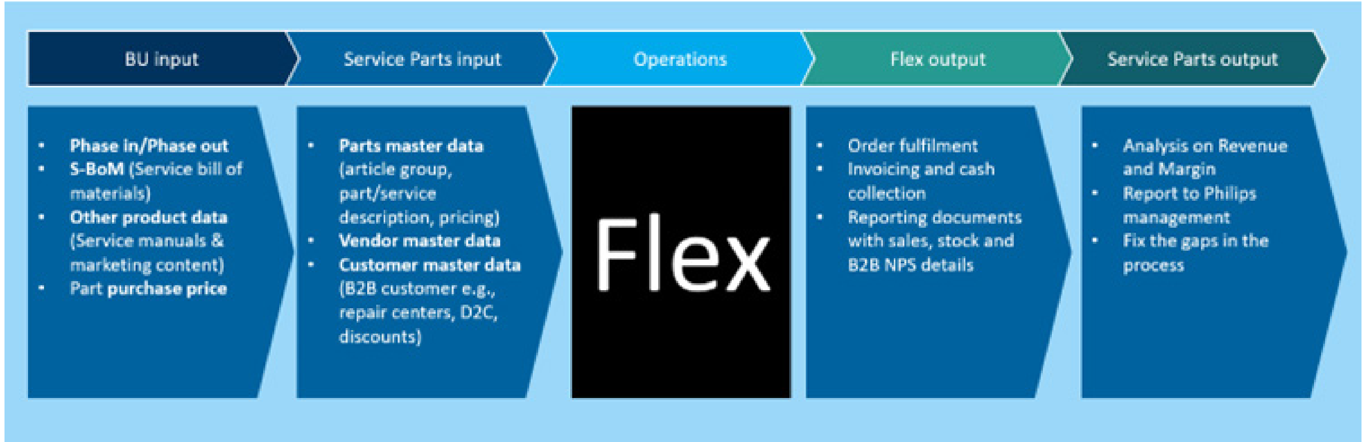


Figure 7: Overview of the process of managing service parts (Service Parts Manager, 2025)

PHILIPS 2035 SERVICE PARTS VISION

Philips has recognized that the current design of the service parts and repair system is not fully in line with circular economy principles, thus they derived a vision by which to redesign this system (Service Parts Manager, personal communication, 23 September 2025).

The vision prioritizes self repair as the highest value end of use option. To enable this, next generation products will be designed for repairability, and all service parts will be made easy to find, access, and order, by both consumers and professional repair shops.

Where self repair is not feasible, returned products follow a staged recovery pathway:

1. Inspect and repair for return to the original user whenever possible.
2. If return to the original user is not possible, refurbish the product and resell it through the designated refurbishment channel.
3. If refurbishment is not viable, perform parts harvesting: recover reusable components for spare parts inventory to reduce waste and demand for new production.
4. Any remaining materials will be recycled.

CHALLENGES IN SPARE PARTS MANAGEMENT

While Philips' service parts vision outlines a future-oriented approach, its current spare parts management still follows a traditional model, which brings several operational challenges. The key questions in SPM are to decide which items are to be stocked as spare parts, when to (re) order them and how many items to (re)order, dominated by two objectives: maximizing spare part availability and minimizing the economic costs (Hu et al., 2018). This section will describe the main challenges faced in traditional SPM and what they mean within Philips PH.

Two primary categories are distinguished: wear parts, which have predictable replacement intervals, and defective parts, which fail unexpectedly, creating sudden demand surges (Mindt et al., 2022) The spare parts assortment consists of a large, extensive and inhomogeneous range of parts (Mindt et al., 2022). Due to legal delivery obligations the permanent availability of spare parts is required for several years up to decades (Mindt et al., 2022).

However, due to the nature of spare parts, demand is intermittent, with many time periods showing no demand at all, making it difficult to determine the proper balance between availability and stocking costs (Peron et al., 2025; Turrini & Meissner, 2019). While demand uncertainty is a common supply chain issue, it is amplified in SPM due to the infrequent and irregular use of spare parts and their long replacement cycles. (Alzahmi et al., 2025). Spare parts have a derivative, unexpected and sporadic demand structure resulting in low individual quantities with poor predictability (Mindt et al., 2022). Furthermore, for legacy parts, tooling and supplier networks may disappear, forcing companies to remanufacture unavailable parts at high cost and long lead times (Foshammer et al., 2022).

This leads to the following challenges:

- **Long and uncertain lead times:** Procuring or replacing certain parts can take considerable time (Peron et al., 2025). For Philips this may become an issue as upcoming regulations may enforce strict delivery times.
- **Dependence on external suppliers and supply chain vulnerability:** Heavy reliance on an external network of suppliers for the timely provision of spare parts means disruptions in the supply chain can significantly affect production systems (Peron et al., 2025). Philips depends on multiple global factories for their production. In Europe, Flex procures spare parts from these factories and operates as the sole regional warehouse, which creates a single point of supply vulnerability.
- **High cost of unavailability and downtime:** The absence of critical parts can cause high downtime costs, driving the need for rapid restoration of function (Mindt et al., 2022; Peron et al., 2025). For Philips this cost is not monetary as it relates to the consumer experience and subsequent consumer decision-making. Since PH products are used daily, fast turnaround for repairs is required (Network and Refurbishment Vendors Manager, personal communication, 20 October 2025). Within consumer self repair this means that unavailability or long lead times of a part may lead to purchasing of a new product.
- **High inventory and holding costs:** Maintaining large inventories to ensure availability leads to high capital tie-up, storage costs, and obsolescence risks (Farghali et al., 2025; Kulshrestha et al., 2024; Peron et al., 2025). The Philips spare parts portfolio for a large part consists of low-cost plastic components, making inventory costs disproportionately high. Often, parts are sold at break-even (Service Parts Manager, personal communication, 23 September 2025).
- **Logistical and operational inefficiencies:** Managing a large, diverse, and inhomogeneous assortment of parts creates complexity and inefficiencies in planning, storage, and distribution (Mindt et al., 2022). The Philips spare part portfolio is highly diverse, further complicated by components that are highly similar but not exactly the same which still need to be handled separately (Service Parts Manager, personal communication, 23 September 2025)

2.2 Additive manufacturing

Since this thesis investigates how to leverage AM for spare parts, a solid understanding of AM's technical landscape and industry precedent is needed to assess what is feasible, desirable, and scalable. This section introduces AM as a technology and explores its capabilities, limitations, and current role in industry. Furthermore, the scope of applicable AM technologies for this research will be defined. All of this will be contextualized for Philips PH, identifying what is feasible now and scalable, with consumer accessibility in mind.

AM PROCESS WORKFLOW

AM is defined as the process of joining materials to make parts from 3D model data, usually layer upon layer (ISO/ASTM International, 2021), and is also commonly referred to as 3D printing (3DP). This section gives a high level overview of the AM workflow, outlining the key stages from design to finished part and the principal considerations at each step to provide the reader with the necessary background on how the technology works, which is essential for understanding its possibilities and applications.

The workflow consists of six main stages (adapted from Zhou et al., 2024):

Design & Modelling: Using Computer-Aided Design (CAD) software to create 3D digital representations of the desired object.

Considerations:

- Choice of material: different materials offer varying properties, design adjustments should cater to the chosen materials properties.
- Printing technology: different technologies have different specifications regarding resolution, accuracy and achievable geometry complexity. The size of the print bed also limits the dimensions of the object. The orientation of the model during printing should also be considered as this can be used to optimize the print's quality, strength and necessity for support structures.
- Practical applications of the final product

Conversion and Slicing: Convert CAD model to an STL file, a standard format for 3D printing, and use slicer software to transform the file into printable layers. This is the translation of the digital design into a printable object.

Considerations:

- Customization of print parameters: Slicing software allows users to customize print parameters, such as layer height, fill density and support structures. These parameters can impact the quality, strength and appearance of the final print.
- Optimization for material and printer: Printer settings can be changed to accommodate to characteristics of material and printer specifications.

Printer setup: Load material, configure the printer and prepare the build platform.

Printing/build process: Printer deposits material layer by layer to build the part

Post-processing: Remove the part from the build platform, remove supports, and finish the part as needed.

Inspection and End-Use Application: Inspect the final part to ensure it meets requirements; deploy for intended use.

ADOPTION OF AM ACROSS INDUSTRIES

The following section benchmarks how industries such as aerospace, automotive, and healthcare are currently leveraging AM. While this information is not the primary focus of this project, from an organization's point of view this is essential information, as it provides context for decision makers unfamiliar with AM's strategic value and underscores the urgency of integrating this technology into organizational processes.

In Wohlers report 2025 (ASTM international, 2025) is reported that the AM industry grew by 9.1% overall. Most of this growth is driven by the service provider, software and material sectors, as well as regional markets in Asia, despite a decline in the system manufacturing sector, as can be seen in figure 8.

The largest applications of AM are in end-use parts and functional prototypes (Wohlers Associates, 2022), as can be seen in figure 9. Prototyping was one of the initial AM applications, providing an easy visual reference for Form, fit and function information of engineering components (Srivastava & Rathee, 2022). The technology has since improved, now capable of producing complex, high-performance parts suitable for end-use parts in several different businesses. This is even argued to be the application with the greatest long-term potential (Wohlers Associates, 2022).

AM has evolved from a prototyping technology into a transformative technology across multiple industries (figure 10). Starting as a low-cost prototyping tool, it was initially ignored by mainstream manufacturers (Steenhuis & Pretorius, 2017). As the technology matured, it created both incremental improvements, enhancing efficiency, reducing costs, and streamlining production, and more radical improvements that redefined how products are designed, manufactured, and delivered (Cotteleer and Joyce, 2014).

For Philips, AM is already an integral part of the product development process. Designers use consumer grade FDM printers for rapid iteration and a dedicated rapid prototyping department runs a model make workshop that specializes in more advanced 3D printing. Leveraging additional post-processing they can achieve like injection moulded quality, though not economically viable for mass manufacturing. Ongoing trials have proven use cases for 3D printing parts for internal applications, such as factory machine components, but use cases for end use parts have not yet gained traction.

Beyond its technical advancements, AM also has an organizational and societal impact. It democratized production by enabling individuals and smaller firms to participate in manufacturing ecosystems (Pazaitis et al., 2025), creating new market structures, job roles, and educational needs, as well as business models centred on customization, digital production, and distributed supply chains (Gao et al., 2015). Philips has also seen a rise in community created designs for Philips products and accessories on maker platforms like Thingiverse.

This demonstrates that the adoption of AM across industries is growing in strategic importance. This project makes use of the derived opportunities as it operates at the intersection of community involvement, by opening the door to user-driven manufacturing, and a technological opportunity,

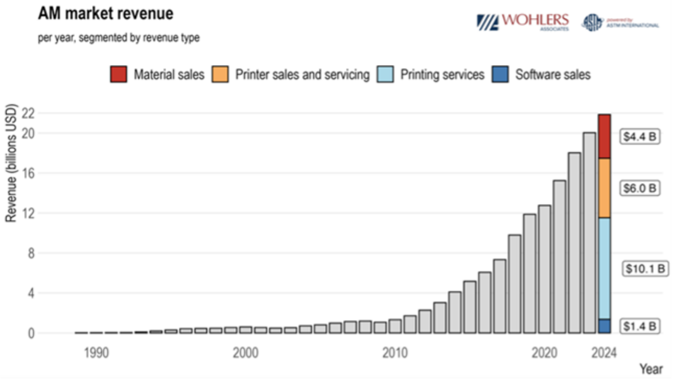


Figure 8: AM market revenue (ASTM international, 2025)

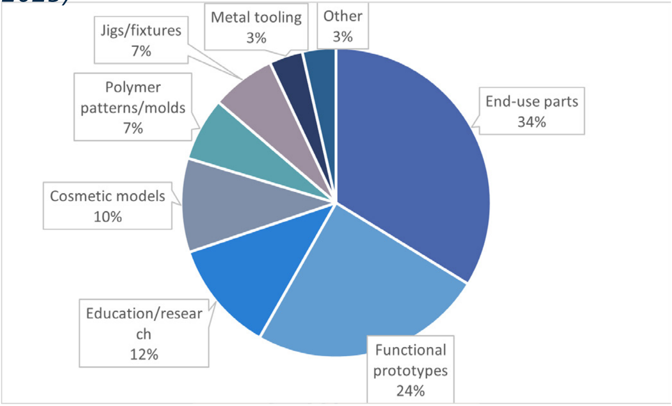


Figure 9: Overview of AM applications based on (Wohlers Associates, 2022)

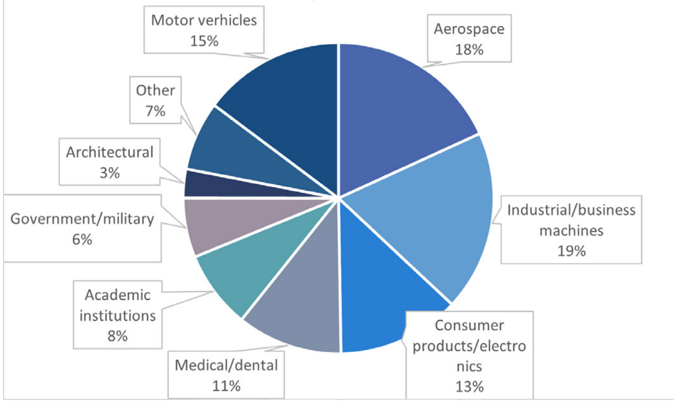


Figure 10: Overview of market share of different industries for AM applications based on (Srivastava & Rathee, 2022)

which can transform spare parts management and create broader organizational impact beyond this domain. Furthermore, it is argued that producing end-use parts represents the greatest long-term potential for AM, making spare parts a suitable starting point for Philips to scale its capabilities. With consumer electronics holding a 12.8% share of the AM market, there is opportunity to act early and establish leadership.

SCOPE OF APPLICABLE AM TECHNOLOGIES

To identify the most suitable AM processes for further consideration, it is necessary to compare them based on the maturity of both the technologies and the providers, as choosing processes that are already used in real-world scenarios provides a foundation of practical insights and validated methodologies upon which design guidelines can be established. This evaluation must be framed within the specific context of end-use parts, polymer-based printing, and applications within the consumer product sector. Equally important is the availability of the technology with regards to consumer accessibility, both now and in the future, so that selected processes support the current consumer printing model and remain viable as consumer adoption and distributed production models evolve. Furthermore, documentation in literature is also important, as selecting technologies that are extensively studied offers a distinct advantage, as a larger and more reliable body of existing knowledge can inform the design process.
Mika & Pei (2023) conducted a comprehensive literature review examining AM processes and materials used for spare parts across a broad range of industrial sectors, focusing on publications from 2019 to 2022. This study is used as the basis for the choice of technology for this study. The study found that the most commonly utilized AM processes for producing spare parts and end-use components are Powder Bed Fusion (PBF), Material Extrusion (MEX), and Vat Photopolymerization (VP), with PBF and MEX in particular noted as prevalent across a wide range of industrial applications. These technologies are widely adopted due to their respective strengths:

- PBF offers high-quality mechanical properties and design flexibility. This category has Selective Laser Sintering (SLS) as most established derivative technology;
- MEX is broadly accessible and cost-effective, with Fused Deposition Modeling (FDM) as most established derivative technology;
- VP delivers superior surface finish and dimensional accuracy and has Stereolithography (SLA) as most established derivative technology.

The in-depth rationale can be found in Appendix A2. The following section will briefly describe the chosen technologies. Table 1 on the next page shows a detailed comparison of properties for each technology.

FDM

FDM builds parts by extruding a thermoplastic filament through a heated nozzle onto a build platform layer by layer. The new molten material fuses to the previous layer via heat and pressure, solidifying almost immediately.
FDM is highly accessible and cost-effective, making it the foundation for consumer-facing models such as Fixables, where it has already proven viable for several CRPs. Its broad user base and well-documented design rules make it ideal for home printing and rapid prototyping. However, it is technically the weakest in terms of accuracy and mechanical strength, requiring careful orientation and reinforcement strategies.

SLA

SLA is the oldest AM method, building parts from a vat of liquid photopolymer resin. A focused UV laser selectively scans and cures the resin layer-by-layer, solidifying the liquid via photopolymerization.SLA offers superior surface finish and high dimensional accuracy, making it well-suited for skin-contact parts and attachments that require precise fit. This aligns closely with requirements related to the PH spare parts portfolio, particularly for shaver and epilator attachments. While SLA is available to some advanced home users, it remains more niche compared to FDM.

SLS

SLS uses a high-power laser to selectively sinter (fuse) small particles of polymer powder into a solid structure. A roller spreads a thin powder layer over the build area, and the laser traces the part cross-section. The unfused powder remains in place, acting as an integrated support structure. SLS provides robust mechanical properties, making it ideal for functional parts requiring strength and durability, such as P-caps (protective covers). While this may not apply to most CRPs today, it becomes highly relevant in a future where Philips products are designed for repairability, and internal components become available as spare parts. Surface porosity and finishing requirements limit its use for skin-contact parts but are manageable for internal components.

Refer to Appendix B1 for a visual overview of PH parts identified as suitable for each technology.

Table 1: Overview of FDM, SLA and SLS properties

Technology	FDM	SLA	SLS
Feedstock	Thermoplastic filament	Photopolymer resin	Polymer powders
Common materials	Thermoplastic polymers (ABS (Acrylonitrite Butadiene Styrene), PLA); Specific high performance materials such as ULTEM and PEEK (polyether ether ketone) exist for industrial applications	Epoxy, polyurethane, polyester, and acrylic resin.	Polyamide powders (mainly PA12 and to a lesser extent PA11), polystyrene (PS) powders, thermoplastic elastomers (TPEs), and polyaryletherketones (PAEKs)
Layer thickness	0.18 – 0.5 mm (Industrial) or 0.10-0.25 mm (Desktop)	0.025 - 0.5 mm	0.08 – 0.2 mm
Key advantage	Broad accessibility and low cost	High level of accuracy and superior surface finish	No need for dedicated support structures, allowing for complex, nested geometries and use for functional parts.
Key limitation	Lower accuracy and speed compared to other processes, and resultant parts are often anisotropic (weaker perpendicular to the layers).	Requires support structures and post-curing for final strength. Materials are thermosets, prone to degradation over time.	Parts are naturally porous (requiring sealing) and have a grainy surface finish. The process requires careful temperature control.

2.3 Strategic role and value of AM in spare parts management

The aim of this section is to connect the dots between the technology (AM) and the business problem (spare parts delivery). It helps justify why the application of AM in this domain is both timely and valuable. The following subsections summarize the practical roles AM can play in SPM and the specific value it can deliver. These insights form the foundation for framing the strategic and design opportunities later in the report. This rationale is based on the results of the literature review on the benefits and limitations of additive manufacturing, the full results of which can be found in Appendix A3.

POTENTIAL ROLE OF AM IN SPARE PARTS MANAGEMENT

As discussed in Section 2.1, traditional spare parts management faces structural challenges such as unpredictable demand, high inventory costs, and long lead times. AM directly addresses these issues by enabling rapid, on-demand production (Butturi et al., 2022; Farghali et al., 2025; Naghshineh et al., 2023; Peron et al., 2025). This capability enables lowering inventory holding, since parts can be produced as needed, thereby eliminating the need for large physical inventories, reducing warehouse costs, while also minimizing the risk of part obsolescence.

Furthermore, AM also serves as a strategic tool for enhancing operational efficiency, specifically by reducing production lead time and minimizing the impact of supply chain disruptions through its adaptability (Peron et al., 2025), in line with the needs of the PH category. It also enhances supply chain flexibility by allowing parts to be produced on-demand at or near the point of use, reducing dependency on complex logistics networks (Farghali et al., 2025), addressing another key challenge identified in Section 2.1.

AM is particularly promising for parts with rare or highly uncertain demand (Mindt et al., 2022), and is considered cost effective for small production batches (Butturi et al., 2022). It has the potential to improve service levels by enhancing the availability of parts, particularly for legacy systems where conventional manufacturing would be uneconomical, addressing challenges related to the discontinuation of parts for older models (Foshammer et al., 2022; Mindt et al., 2022), which directly contributes to the service parts vision as stated in Section 2.1.

AM as a manufacturing technique affects the production stage, enabling three options (Butturi et al., 2022):

1. Centralized: parts are produced in sufficient quantity and stored by a service location company
2. Decentralized: parts are produced by a specific manufacturer on-demand
3. Autonomous: parts are produced directly on site by the user.

Looking at the current benefits and limitations of AM, supported by the benchmark of current industry adoption, generally, it is recommended to opt for a hybrid strategy, utilizing dual sourcing of AM offering (whether it is a printed part or a printable file) and conventionally manufactured parts, as with the current state of the technology, AM is more likely to complement conventional manufacturing than fully replace it (Mindt et al., 2022). In practice this means AM can supplement the offering but cannot on its own meet Philips' spare parts obligations, as offering only a printable alternative is not yet officially recognized as a way of fulfilling spare part obligations.

VALUE PROPOSITION

AM has the potential to directly address the structural inefficiencies and uncertainties inherent to traditional SPM by introducing flexibility and responsiveness into the supply chain. Its strategic value lies in bridging the gap between high availability requirements and costly inventory practices, offering a scalable pathway toward more resilient and sustainable operations.

Key value propositions include:

- **Hybrid sourcing strategy:** Combining AM with conventional manufacturing allows organizations to balance cost efficiency and responsiveness. AM can serve as a complementary production route for parts characterized by low, unpredictable, or end-of-life demand, while conventional manufacturing remains suited for high-volume or standardized items.
- **Cost efficiency for low-demand, legacy, and critical parts:** AM eliminates the need for tooling and reduces dependence on external suppliers, enabling economical production of obsolete or low-volume components where traditional sourcing is uneconomical.
- **Reduced lead times and logistics complexity:** Local or on-site AM production shortens production and transportation times, mitigating the risks of supply chain disruptions and ensuring faster restoration of critical assets.

- **Lower inventory and obsolescence risks:** By shifting from make-to-stock to make-on-demand, AM reduces the need for large safety stocks, thereby decreasing inventory holding costs and the risk of obsolescence.
- **Enhanced supply chain resilience and sustainability:** Decentralized AM networks enable localized production, reducing transportation emissions and increasing adaptability to fluctuating market and operational conditions.

Implementing AM within SPM requires a holistic approach. Pourhejazy et al (2025) propose that several interdependent supply chain decisions must be addressed: selecting parts from the company portfolio for AM production, deciding the best AM technology considering the product and the machine's technical features, and choosing the best material. In addition, a production strategy, whether centralized, decentralized, or hybrid (Butturi et al., 2022) must be defined to align with organizational goals and resource availability. All of these decisions are interrelated (Pourhejazy et al., 2025)), and each involves trade-offs in terms of cost, lead time, flexibility and sustainability (Peron et al., 2025).

What this means for the project is that the to be proposed AM roadmap should support a hybrid strategy, and that the framework that guides part selection, redesign and production strategy decisions should explicitly capture the trade offs between cost, lead time, quality and sustainability.

2.4 Concluding chapter insights

This chapter established the foundational context for this thesis by analysing Philips' organizational structure, its current spare parts management model, and the technical and industry landscape of AM. These insights define the problem space and the boundary conditions for the assignment. The Personal Health division and its after-sales ecosystem set the scope in which the AM-driven solution will operate. By linking Philips' business needs with AM's technical potential, this chapter confirms that AM is not just a technological option but a strategic lever for circularity and operational resilience.

The Fixables initiative demonstrates early adoption potential but also exposes limitations in home printing, such as material constraints and user accessibility. This project will therefore envision how this can evolve beyond consumer printing toward a scalable model that also considers other accessible print technologies such as SLA and SLS and other AM production models beyond autonomous home printing, such as manufacturer driven centralized and decentralized production. Furthermore this research will focus on consumer replaceable parts from the PH portfolio (see Appendix A1 for an overview of the portfolio), which have skin contact, hygiene and waterproofing as challenging requirements, while also considering the possibility of "repair parts" for future consideration. In line with the service-parts vision the proposed AM driven spare parts solution should focus on enabling self-repair and consider contributions to refurbishment.

Traditional spare parts systems struggle with unpredictable demand, high inventory costs, and long lead times. AM offers unique advantages, such as on-demand production, low start-up costs, and decentralized manufacturing, that directly address these pain points. Especially in PH, where daily use requires fast turnaround for repairs, and low-cost plastic parts are disproportionately affected by storage costs, on demand AM spare parts can improve service and value. However, current limitations in material performance and process consistency mean AM cannot fully replace conventional manufacturing today. For the project, this means the to be proposed AM roadmap must support a hybrid sourcing strategy and identify parts where AM already adds clear value. This defines the core goal of the project: creating a hybrid AM-driven solution that reduces inventory dependency, improves service levels, and prepares Philips for regulatory obligations under Right to Repair.

These decisions cannot be made independently. Thus, the to be developed decision-making framework must integrate multiple criteria and explicitly capture trade-offs between cost, lead time, quality, and sustainability, while also defining the most suitable production model (centralized, decentralized, or autonomous).

3.

Future vision and strategy

This chapter establishes the strategic foundation for the design assignment by exploring how AM could shape the future spare parts ecosystem and how Philips can evolve its current initiatives into a scalable AM-driven strategy. It addresses two key research questions:

- RQ1: What key developments shape the future of additive manufacturing in spare parts management?
- RQ2: How can Philips evolve its current Fixables initiative into a scalable AM-driven spare parts strategy?

To answer these questions, a backcasting approach was applied where the end point is Philips' long term vision for AM integration, working backward to the current state (Philips Fixables) and identifying the steps required to achieve the final goal. To inform these steps a PEST analysis was conducted to identify external determinants on a political, economic, socio-cultural, and technological level that could impact AM adoption. These insights are then used to evaluate the feasibility of different production models across short-, mid-, and long-term horizons. This evaluation clarifies how and when the future horizons outlined in the vision roadmap may become achievable.

The chapter then explores opportunities to expand the Fixables concept as well as assesses the feasibility of product groups in the PH portfolio based on their part specific requirements. These insights guide the selection of parts that subsequent redesign phases will focus on.

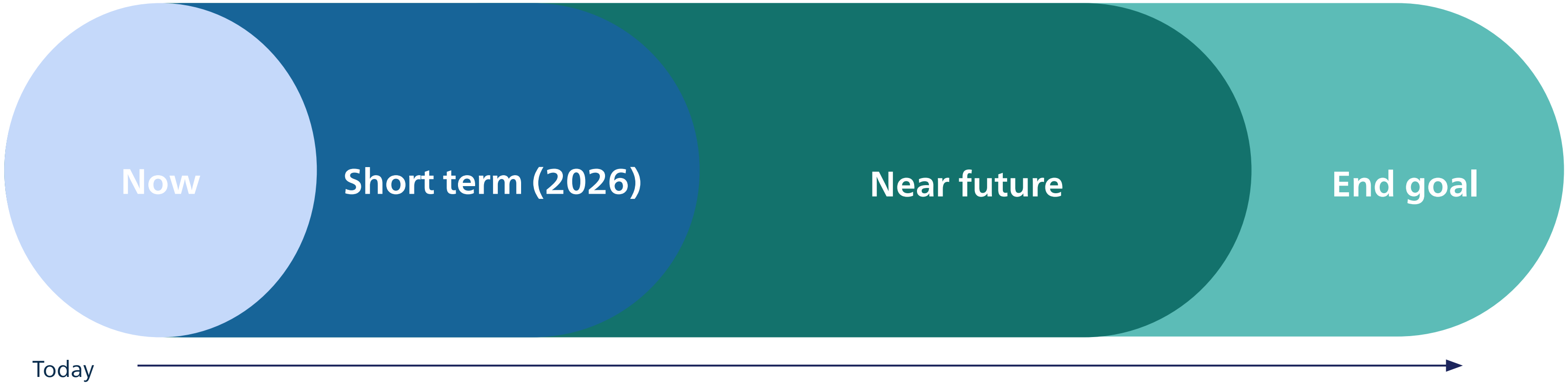
3.1 Vision

Philips aims to establish a reliable alternative to traditional spare parts management, aligned with Right to Repair regulations and contributing to their broader service vision to expand repair and refurbishment operations. The following vision reflects a proposed roadmap and outlines a trajectory across near, mid and long term horizons, based on the wants from Philips and the predicted feasibility of production models. Please refer to figure 11 on the next page for the visualized roadmap.

The ultimate goal of the AM-driven spare parts strategy is to create a system that reduces dependency on physical inventory for all parts that are technically and economically feasible for AM. Beyond inventory reduction, this strategy should also enable Philips to leverage 3D printing in refurbishment and repair processes, supporting a more circular and resilient service model.

However, this vision cannot be realized immediately. While the ultimate aim is to reduce spare part inventory and integrate AM into repair and refurbishment processes, the primary driver for pursuing this strategy is compliance with Right to Repair regulations. These regulations require that repair options are practical and accessible. Thus, for AM to serve as a primary fulfillment route for these regulations it needs to be a viable alternative with respect to quality, cost, and user experience. At present, this is not the case, which is why AM must complement traditional manufacturing within a hybrid sourcing model. Success can be signalled when Philips observes a decline in demand for conventionally stocked parts as consumers increasingly choose AM-produced alternatives, or when professional printing options enable the delivery of certified end-use components rather than just printable files. Achieving this outcome depends on both the maturity of AM technology and its ability to consistently deliver high-quality parts.

In short, the vision is ambitious but phased: start by scaling AM for low-risk Consumer Replaceable Parts, then expand toward professional printing with integration into refurbishment workflows as technology and standards mature. This roadmap ensures that Philips moves toward a future-proof spare parts system while maintaining alignment with regulatory obligations and sustainability goals. This research focuses on the near- and mid-term horizons where Fixables is scaled to include more parts. Thus, the design framework should prioritize efficiently redesigning parts expected to become eligible in the mid-term. To avoid lock into a home printing only model, the redesign framework should be adaptable and encourage consideration of future pathways , for example professional printing options and by promoting ways to increase part eligibility (e.g., through DfAM and designing more repairable products).



	Fixables	+ Adding more parts	+ Integration with traditional offering	+ Dynamic routing and integration with refurbishment
Goal	Validate Fixables concept	Scale Fixables to 50+ parts and demonstrate consistent delivery	Integrate Fixables with official spare parts offering, the goal is to be able to lower spare part stock without forcing people to opt for the AM option	Establish a fully hybrid spare parts system
Integration	Operates as a standalone platform managed by a small internal team	Still separate from official service chain but with expanded contributor capacity	Side-by-side display of printable versions alongside conventional spares in Philips' official channels	Full integration into Philips' service ecosystem, with dynamic routing between AM and traditional production
Service model	Free downloadable files under Creative Commons; consumers print at home	Free downloadable files; usage analytics inform design priorities	Hybrid visibility: home printing remains core, but professional printing options begin to emerge	Monetized AM options: home printing, licensed local hubs, and OEM-controlled professional printing leveraged for repair and refurbishment
Scope	Limited set of low-risk CRPs suitable for FDM/PLA	Broader CRP portfolio, still limited to home printing	CRPs plus selected internal and other repair components as products are designed for repairability	All parts that are technically and economically viable for AM

Figure 11: Vision roadmap

ROADMAP JUSTIFICATION

The roadmap presented in Figure 11 is not intended as the only possible future pathway for AM-driven spare parts, but as one strategically justified trajectory derived through a backcasting process. Backcasting begins by defining a desired long-term end state and then reasoning backward to identify the conditions and intermediate steps required to reach it. The background research used to derive the steps is described in subsequent sections, this section will only describe the justification behind the roadmap.

For this research, the end state is defined by Philips' strategic ambition to:

1. Aid in compliance with emerging Right to Repair regulations.
2. Leverage AM for repair and refurbishment processes.

Starting from this desired future, backcasting shows that full compliance with Right to Repair cannot rely on consumer home printing alone. While home printing provides accessibility for a subset of users, it inherently excludes consumers without equipment or technical ability. Furthermore, regulatory compliance requires validated materials, controlled processes, and certified workflows, which are only achievable through AM in a professional printing context. Therefore, the long-term horizon necessarily includes OEM-controlled or certified professional AM production, either internally or through licensed local hubs.

At the same time, Philips' sustainability ambitions and service-model objectives call for both centralized quality control and decentralized accessibility. OEM-controlled production supports quality, warranty, and integration with refurbishment, while licensed local hubs offer geographic access and lower investment risk. These complementary considerations shape the long-term vision combining home printing, certified hubs, and OEM production.

Working backward from this end state, backcasting identifies Fixables, Philips' existing DIY home-printing initiative, as the logical starting point. Fixables already builds user awareness, and internal experience, making it a natural foundation for AM capability development. The short-term horizon therefore focuses on scaling Fixables to the full set of CRPs that are technically feasible for home printing.

To bridge from the current state to the long-term vision, a near-term transitional step is identified: integrating Fixables with Philips' official spare parts offering. This integration increases visibility to consumers while avoiding forcing users into home-printing, and aligns the initiative with regulatory expectations for practical repair options. Once Fixables is embedded within the official ecosystem, the only viable pathway to further increase accessibility and part coverage is to introduce professional printing options, first through licensed local hubs and later through OEM-controlled workflows.

This sequence, from home printing, to integration, to professional printing, and eventually to hybrid AM-driven fulfillment, reflects a logical progression based on regulatory constraints, technological feasibility, consumer accessibility, Philips' strategic goals, and the enablers identified in the PEST analysis. Though this is not the only possible pathway, this roadmap vision will serve as the framing of the scope of this project.

3.2 PEST analysis: External drivers

As advancements in AM and its implementations are changing fast, it is essential to anticipate future scenarios for AM to help strategically guide its adoption in business (Khorram Niaki & Nonino, 2017). It is important to not only consider likely future scenarios, but also the conditions under which they may or may not materialize. To do this, a PEST analysis is used to anticipate the external drivers that could shape AM adoption. This framework helps explore Political, Legal, Economic, Social, Technological and Environmental influences associated with AM. The full results of this PEST analysis can be found in Appendix A4. This section will focus on the core identified drivers.

Political & Legal

Similar to the past, future patent expirations may democratize access to AM and reduce monopolization (Chua & Leong, 2017). However, in combination with increasingly easier replication of digital files via 3D modelling/scanners (Ben Said et al., 2025) and the rise of open source 3D printing platforms and online design marketplaces (Gao et al., 2015), this may raise new concerns regarding legal and ethical liability due to unauthorized reproductions and patent infringements (Ben Said et al., 2025; Jiang et al., 2017). This could challenge traditional IP (Intellectual Property) frameworks, prompting industries to reconsider how design patents and digital assets are defined and protected (Gao et al., 2015), such as through creative commons licenses (Jiang et al., 2017), encryption and hidden structural signatures (Gao et al., 2015).

At the same time, there is also an urgent need for harmonized standards to ensure safety, quality and interoperability (Chua & Leong, 2017). Despite progress, the rapid diversification of technologies and proprietary systems continues to hinder unified global standards (Gao et al., 2015; Khorram Niaki & Nonino, 2017).

Economic

AM has potential to reshape supply chains toward localized, digital networks close to consumers, cutting transport, inventory and lead times while enabling on demand customization and lower waste (Ben Said et al., 2025; Khorram Niaki & Nonino, 2017). Competitive advantage may then shift to ownership of design data, digital access and rapid prototyping rather than scale or location (Jiang et al., 2017).

Industry standards and certification frameworks regarding quality assurance and warranty management for 3D printable files and parts, as well as advances in real time monitoring and closed-loop control, could improve the consistency, quality and reliability of printed parts, which is crucial for dependable AM parts (Ben Said et al., 2025). Reliable cost modelling could then be central to AM's broader adoption (Khorram Niaki & Nonino, 2017).

Socio–Cultural

AM is driving a cultural shift toward personalization and co-creation (Gao et al., 2015), enabling mass customization at scale (Jiang et al., 2017). This shift may also represent a strategic adaptation to evolving IP conditions, as personalization becomes a key differentiator in markets where replication and imitation are more difficult to control (Jiang et al., 2017). At a societal level, democratization of tools and falling hardware costs has given rise to the DIY/Maker movement and platforms like Shapeways/Sculpteo, fostering innovation from the ground up (Gao et al., 2015). Affordable desktop printers in education are building a future generation fluent in digital manufacturing skills (Chua & Leong, 2017; Gao et al., 2015).

Technological

Technological advances in additive manufacturing are driving rapid improvements in precision, material diversity, and production speed (Chua & Leong, 2017; Diegel et al., 2019). As quality and scalability increase, limitations that once constrained AM may diminish, which could position it as a viable alternative to traditional manufacturing (Gao et al., 2015). This evolution could be accompanied by the widespread integration of DfAM principles, enabling products to be conceived and optimized specifically for AM processes, leveraging geometric freedom, lightweight structures, and functional integration which could deliver new levels of performance and efficiency (Egan, 2023).

The future of AM is often considered to be closely linked to its integration with AI (Artificial Intelligence), machine learning, IoT (Internet of Things) and digital twins, to create smart, sensor rich systems that optimize build parameters, reduce defects and enable real time monitoring and predictive maintenance (Mohammadkamal et al., 2025). These capabilities could support hybrid and autonomous AM setups, combining additive and conventional machining and moving toward more flexible, on demand, and data driven production within Industry 4.0/5.0. At the same time, full realization depends on overcoming constraints around data availability, quality and standardization. Computational cost, and trust in AI models, may shape the pace and feasibility of these technological developments.

The PEST analysis highlights four external drivers that could shape the feasibility of AM-driven spare parts strategies:

- Political & Legal: Lack of harmonized standards and unresolved IP frameworks hinder OEM-controlled production models. Open-source and DIY approaches face fewer regulatory barriers but carry liability risks.
- Economic: Reliable cost modelling and quality assurance systems are essential for scaling. Until these mature, professional printing remains costly and uncertain.
- Socio-Cultural: Growing consumer interest in personalization and repair, combined with the DIY/Maker movement, supports early adoption of home printing and open platforms.
- Technological: Advances in precision, material diversity, and integration with smart systems will enable higher-quality, certified production in the mid- to long-term.

These drivers highlight a range of possible futures rather than a predetermined trajectory. They form the contextual basis for evaluating which AM production models are likely to become viable in the short, mid, and long term, and under which conditions.

PRODUCTION MODEL EVALUATION

For the purpose of this study, a recommendation regarding the preferred production model for a scalable future proof AM driven spare parts system was made in the form of a roadmap.

This AM driven initiative is seen as separate from Philips traditional service parts model and is thus per definition a hybrid approach. The starting point is “Fixables,” which sits in the DIY / prosumer printing category. The roadmap’s objective is to identify pathways from Fixables toward alternative models and to define measurable markers that indicate when a target model becomes viable.

Production models are evaluated along two axes based on Jiang et al., 2017; Steenhuis & Pretorius, 2017: design/IP control (open ↔ closed) and production model (centralized ↔ decentralized), as can be seen in figure 12.

Design/IP control ranges from open, where the OEM exerts limited control and files may be publicly shared or loosely governed (e.g. Creative Commons), to closed, where the OEM retains strict control and files are protected, licensed or available only through official channels. Production model ranges from centralized, in which OEMs or approved partners manufacture parts in regional or centralized facilities, to decentralized, where production takes place closer to the end user at local service providers or by consumers themselves.

Based on the results from the PEST analysis, the feasibility of AM-driven production models can be summarized with markers that signal near-term feasibility and enablers that are required for implementation from the perspective of a company, see next page.

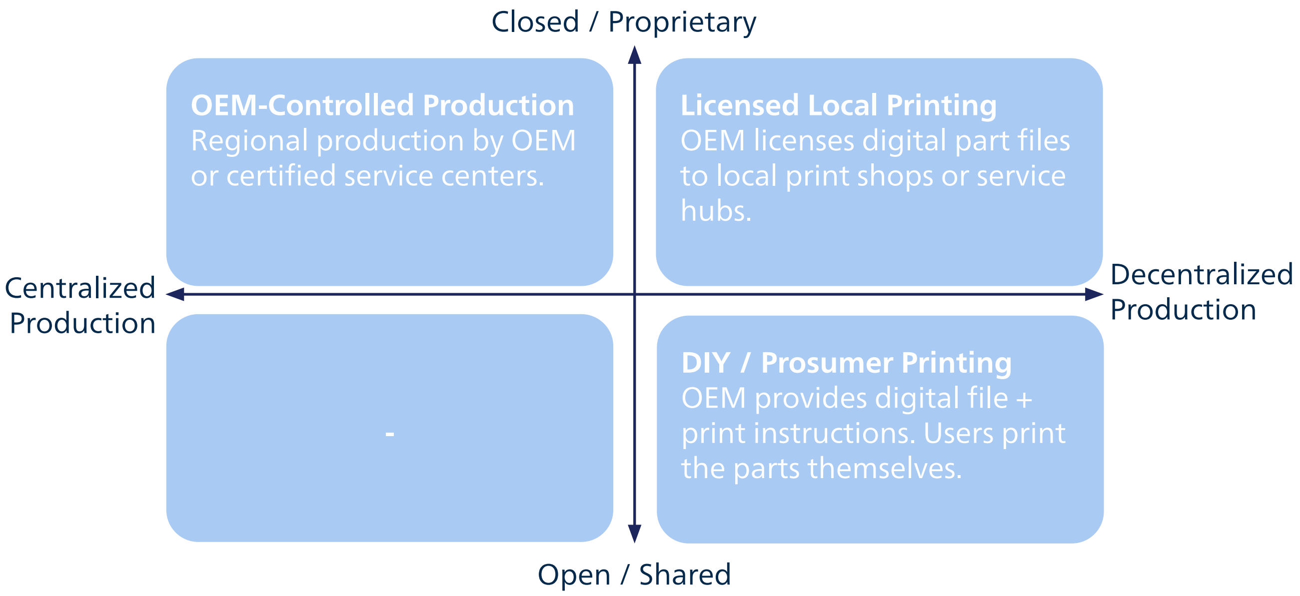


Figure 12: AM driven production models Based on (Jiang et al., 2017; Steenhuis & Pretorius, 2017)

DIY / Prosumer Printing

Feasibility Markers:

- Widespread availability of low-cost desktop FDM printers.
- Basic user-friendly slicer software and open repositories with validated designs.
- Adequate dimensional accuracy and mechanical performance for non-critical parts (e.g., combs, caps) using PLA/ABS.

Required Enablers:

- Standardized slicer settings and calibration guides for consistent results across consumer-grade printers.
- Clear user-oriented design rules for AM spares (e.g., redesign for printability and fit).
- Educational resources for safe handling and basic post-processing.

The main disadvantage of the DIY model is limited accessibility, as it excludes users without suitable equipment or the technical skill to print reliably. Additionally, the high variability in print outcomes may lead to consumer dissatisfaction, which, although not officially a liability for Philips, can still negatively affect brand perception. Beyond setting clear expectations and providing basic guidance, the only meaningful mitigation is to expand to additional production models where print quality and accessibility do not depend on the consumer.

Licensed Local Printing

Feasibility Markers:

- Emergence of local 3D printing hubs with documented, repeatable processes.
- Initial certification schemes for printing hubs and materials.
- Emerging demand for professionalized AM services.

Required Enablers:

- IP protection and licensing frameworks for distributing digital part files.
- Liability agreements defining responsibility between OEM and local producers.
- Industry standards for process qualification, part quality, and warranty management.
- Reliable cost modelling for predictable pricing.

The main disadvantage of licensed local printing is dependence on external parties, limiting control over quality. Accessibility may also remain uneven because availability may differ by region. Moreover, warranty and liability responsibilities become more complex and must be negotiated between parties. While formal agreements and IP and licensing frameworks mitigate risks, the most direct mitigation is to increase direct coordination or gradually internalize hubs, e.g. through the regional service centers, effectively moving closer to a distributed OEM-controlled model.

OEM-Controlled Production

Feasibility Markers:

- Harmonized international standards for AM processes and part certification.
- Demonstrated repeatable AM workflows with certified materials and in-process monitoring.
- Closed-loop control systems ensuring “first-time-right” production.

Required Enablers:

- Regulatory alignment across regions for AM-produced spares.
- Certified materials with full traceability and batch consistency.
- Advanced quality assurance systems with real-time monitoring and predictive maintenance.
- Scalable cost models for high-volume or safety-critical parts.

The main disadvantage of OEM-controlled production is the high investment and associated risk required to build and maintain certified, fully validated AM workflows. However, this model provides full control over quality, compliance, and liability. The only realistic mitigation strategy here is a phased and committed adoption, in which Philips develops internal capability gradually and only when technological maturity, regulatory clarity, and projected demand justify the investment.

The three production models evaluated form the structural basis of the roadmap presented in figure 11. In the current state, Fixables reflects the DIY/prosumer production model: open files, consumer printing, and minimal OEM control. In the short-term horizon, Fixables is scaled within this same model by expanding the number of consumer-printable parts. As the roadmap transitions into the near-future horizon, the limitations of DIY printing necessitate the introduction of licensed local printing hubs, which offer higher-quality materials and professional workflows without fully being controlled by Philips. Finally, the long-term horizon reflects the conditions under which OEM-controlled production becomes feasible: harmonized standards, certified materials, and robust AM quality-assurance systems. At this stage, the AM strategy evolves into a hybrid AM system, dynamically routing demand between home printing, licensed hubs, and OEM production depending on part requirements.

3.3 Expanding Fixables

Thus, the focus is on creating an AM-driven spare parts strategy by building forward on Fixables. To achieve this, it is necessary to understand how to scale Fixables effectively. Two immediate pathways can be pursued:

1. Broaden the Definition of Home Printing
The current limitation to FDM with PLA underestimates the capabilities of hobbyists and prosumers. Expanding to include materials such as PETG and techniques like SLA, combined with basic post-processing guidance (e.g., sanding, polishing, sealing), could increase the number of eligible parts and improve the quality of printed components.

2. Expand Part Scope Beyond CRPs
Restricting Fixables to CRPs is conservative. Many motivated users are willing to perform more complex repairs. Opening the catalogue to internal components and professional repair parts, supported by clear safety and warranty guidance, would better leverage user capability and meet repair needs beyond basic swaps.

The adoption of these two pathways should depend on the needs of the target user segment and their motivations. While the potential audience includes anyone needing a spare part, adoption will likely be driven by specific behaviours, such as willingness to repair, or urgency of replacement. Identifying these drivers is essential for determining which expansion route offers the greatest impact. This analysis, however, falls outside the scope of this project. Therefore, a key recommendation is to explore this white spot through user research to define target groups, their needs, and the conditions under which they would choose AM-enabled repair solutions.

3.4 Product-level requirements and constraints

While Section 3.2 examined external, macro-level drivers influencing AM adoption, this section focuses on product-level feasibility within the Personal Health portfolio. Product groups within the portfolio differ in regulatory requirements they need to adhere to, which directly affect if and when they can be included in the AM roadmap. Some categories face regulatory constraints that influence whether AM can deliver functional, safe, and compliant spare parts, while other product groups face no such specific regulatory requirements and are therefore already considered suitable for AM.

The purpose of this section is to explore how the AM offering can expand by outlining these specialized requirements and evaluating their current and future viability with AM. This analysis supports strategic decisions about if and when each product group can realistically enter the roadmap. The detailed requirements assessment can be found in Appendix A5.

1. Children's products & food-contact items, relating to the mother and childcare category, require the highest mechanical and substance safety standards. Compliance demands validated end to end workflows (certified feedstocks, controlled post processing, full traceability) and non porous finished surfaces, typically achieved through smoothing and food safe coatings. Coatings can mitigate but not guarantee safety and introduce their own compatibility and longevity risks. Given the current lack of AM specific regulatory frameworks for childcare/food applications, liability remains a key barrier. Feasibility therefore depends on clear regulation, certified materials/coatings at viable cost, and sufficient demand to justify compliant production lines.

2. Medical grade external parts, relating to both mother and childcare products as well as oral healthcare appliances, have to comply with the same stringent regulations as more critical internal use medical grade parts. Although AM is established in clinical contexts, treating 3D printing as a regulated manufacturing method excludes home printing. Certified materials and rigorous quality systems are required, making dedicated, validated production lines necessary. The main feasibility question is economic access to certified feedstocks at scale and sufficient demand to justify compliant infrastructure.

3. Heat resistant parts, relating to the haircare portfolio, were found to be technically feasible today using high performance polymers (PC (Polycarbonate), Nylon 12, ULTEM, PEEK) and professional SLA/SLS options. However, these materials often require industrial grade equipment, controlled build environments and higher costs. In this case, AM is promising but will need further validation for safety margins and manufacturability at scale.

It was found that across all requirements, a critical enabler for feasibility is access to affordable, certified materials. This can be achieved either through internal certification investment or by leveraging industry developments as competitors make the investment. Even still, as materials may become more accessible, consumers cannot realistically be expected to invest in these materials themselves, thus parts that require the use of specialized materials are unlikely to be realistic for home printing. This further underscores the need for professional printing environments where Philips or licensed partners can guarantee access to materials, validated workflows and further compliance with regulatory standards. Monitoring market activity and engaging with regulatory bodies is essential, not only for timing feasibility decisions but also as a strategic opportunity for Philips to influence emerging frameworks that enable this.

Even still, independent of the chosen production model, feasibility varies by product group. Food-contact and children's products remain constrained primarily by regulatory requirements and, to a lesser extent, technical limitations around material safety. Medical-grade parts face similar regulatory constraints, coupled by the high cost of certified feedstocks. Heat-resistant components, by contrast, are technically achievable today and therefore included for further exploration within this research scope, though safety considerations and workflow implications require deeper investigation.

3.5 Concluding chapter insights

This chapter scoped the assignment by analysing external drivers (political, economic, socio-cultural, technological) and product-level constraints that influence AM adoption and feasibility. Based on these insights the Philips' strategic roadmap for integrating AM into its spare parts ecosystem is outlined, from the current DIY printing model to a fully hybrid system combining home printing, licensed local hubs, and OEM-controlled production. These insights form the answer to Research Question 1 about what key developments shape the future of AM in spare parts management.

The roadmap developed in this chapter provides a structured approach to expanding the current DIY home-printing Fixables initiative on the short/mid-term horizon by scaling Fixables to the full set of consumer replaceable parts that are technically feasible for home printing, and on the long term by integrating Fixables with Philips' official spare parts offering, thereby answering Research Question 2 about how Philips can evolve the current Fixables initiative into a scalable AM-driven spare parts strategy.

The chapter also defined boundary conditions for the design assignment: what is feasible now (home printing with potential to expand the definition), what requires preparation for mid-term integration (expansion of the range of available materials, professional printing), and what long-term enablers must be anticipated (harmonized standards, certified workflows). Based on these boundary conditions, consumer 3D printing is the only AM production model that is technically and organizationally feasible for the near-term horizon, forming the starting point for the redesign framework developed in later chapters. These findings indicate that, for Philips PH spare parts, the primary barrier to adopting AM is not technical maturity but legal and regulatory constraints; from the consumer side, limitations stem mainly from the availability and affordability of suitable materials and equipment.

This strategic foundation ensures that the redesign framework developed in the following chapter is not only relevant for today's constraints but adaptable to future horizons. It provides clear priorities for the case-based redesigns: parts from the grooming and beauty portfolio, where attachments for hair removal devices are eligible now and near-future potential is signalled for attachments for haircare devices. It fills the research gap by linking AM adoption to strategic foresight in the consumer electronics domain.

4.

Part selection and design workflow

This chapter operationalizes the strategic insights defined in Chapter 3 into a practical decision-making framework for Philips, defining under what conditions AM is preferable to Injection Moulding (IM) for Philips consumer replaceable parts (CRPs). This decision-making framework is needed to realise the vision of scaling Fixables because it identifies which existing parts are eligible for AM today. While Chapter 3 scoped the assignment by outlining external and product-level determinants and defining boundary conditions, this chapter focuses on how to act within those boundaries by answering the following research questions:

- RQ3: What systemic criteria can be used to assess the viability of a part for 3D printing across functional, economic and environmental dimensions?
- RQ4: What technical criteria determine whether a part is printable, and how do they inform AM technology and post-processing choices?

To answer these questions, a multi-criteria, top-down framework was developed. The approach focuses on part selection by moving sequentially through two layers:
1. Techno-economic and environmental viability: assessed with readily available data to filter and prioritize the full part assortment.
2. Technical eligibility: where engineering teams evaluate the feasibility of producing a part through AM.

The resulting workflow enables Philips to consistently identify where AM provides functional, economic, and sustainability benefits.

The chapter concludes by introducing a redesign workflow for AM. This workflow will be applied in the case-based redesigns of Chapter 5.

This framework is one of the core deliverables of this thesis. It translates strategic vision into actionable steps, enabling Philips to move to a systematic, scalable approach for part selection and redesign. It provides the tools to determine the list of current eligible parts in subsequent chapters.

4.1 Decision making approach

To realise the vision of scaling Fixables, an approach is needed to systematically identify which existing spare parts are currently eligible for AM. This puts the focus on the near term, as in the long term AM could also be considered during original product development, following the "equivalent design" approach by van Oudheusden et al. (2025). This approach would diminish the need for a technical eligibility component of the decision-making framework as parts would be designed to be eligible for AM from the outset. The feasibility of this approach will be revisited in Chapter 10 when discussing future pathways for AM integration.

Top-down versus bottom-up approaches

Two decision making approaches are suggested in literature: top-down and bottom-up. Chaudhuri et al. (2021) describe them as following. The top-down approach is data-driven, starting from the entire spare part assortment and evaluating parts on potential economic benefits. The bottom-up approach is expert-driven, where the assessment of the benefits and feasibility of a part is based on its characteristics, considering only a limited number of parts.

The bottom-up approach is suitable when data is limited or when initiating a trial. The top-down approach is the logical choice for when the goal is to find as many eligible parts as possible, as it minimizes the risk of overlooking promising parts and reduces dependence on expert judgment.

Given that Philips has an established spare parts assortment and access to internal data, and because the goal is to identify as many eligible parts as possible, a top-down approach is the only viable option.

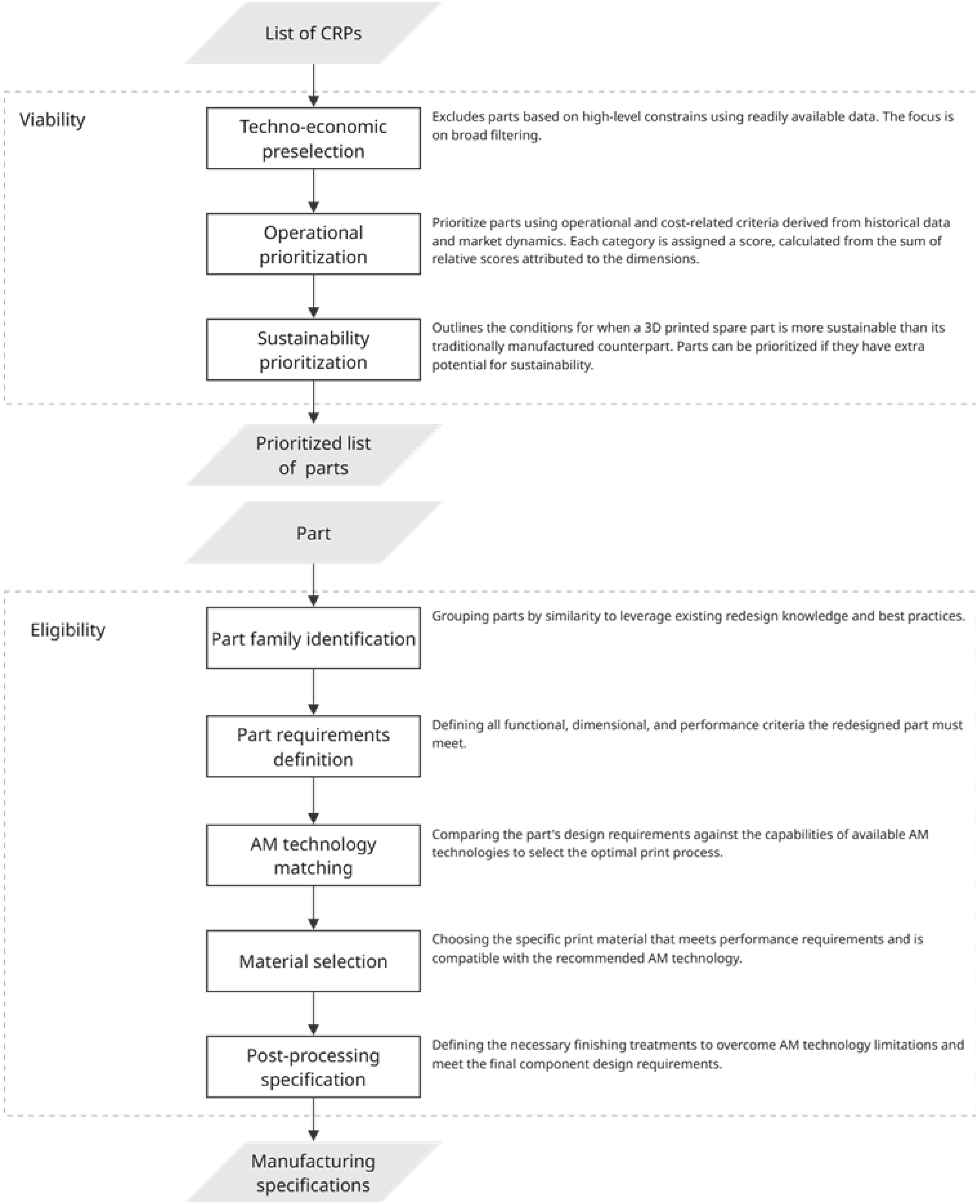
Following Cardeal et al. (2023), the proposed approach folows a sequential exclusion process, starting with broad data-based filtering and progressing toward detailed technical assessment when fewer parts are considered. Early stages rely on readily available system data, enabling operations and procurement teams to take the lead for intial screening, with a handover to engineering teams with AM expertise for detailed part analysis in subsequent stages.

Framework overview

Figure 13 shows an overview of the adapted framework used in this research. The model is divided into two phases. The first filters and prioritizes parts using commonly available data such as warehouse movements, purchasing history, criticality, and cost, to identify a manageable sample, in this research referred to as viability divided in a techno-economical, operational and sustainability component. It takes the full list of parts as input and begins with exclusion of parts in the techno-economic preselection, and then ranks the remaining parts based on operational and sustainability criteria. The output is a prioritized list of parts, ensuring that parts with the highest potential or need are carried into the second phase first.

The second phase applies detailed analysis to this sample. Engineering teams with AM expertise evaluate technical eligibility through defining functional requirements, selecting an appropriate AM technology and material, and specifying post-processing steps. These elements are compiled into a manufacturing specification and handed to the final designer for part redesign.

The following sections move sequentially through each framework layer, describing activities, stakeholders and decision criteria at every step.



Excludes parts based on high-level constrains using readily available data. The focus is on broad filtering.

Prioritize parts using operational and cost-related criteria derived from historical data and market dynamics. Each category is assigned a score, calculated from the sum of relative scores attributed to the dimensions.

Outlines the conditions for when a 3D printed spare part is more sustainable than its traditionally manufactured counterpart. Parts can be prioritized if they have extra potential for sustainability.

Grouping parts by similarity to leverage existing redesign knowledge and best practices.

Defining all functional, dimensional, and performance criteria the redesigned part must meet.

Comparing the part's design requirements against the capabilities of available AM technologies to select the optimal print process.

Choosing the specific print material that meets performance requirements and is compatible with the recommended AM technology.

Defining the necessary finishing treatments to overcome AM technology limitations and meet the final component design requirements.

Figure 13: Overview of the top-down decision making framework, based on (Cardeal et al., 2023)

4.2 Viability

The viability stage narrows the complete Philips CRP assortment into a manageable set of candidates suitable for technical evaluation. It operates as a three-stage funnel, as was shown in figure 13.

Each stage uses readily available data and does not require redesign work. The criteria were developed through insights from the literature summarized in table 2, and are formulated from the perspective of an OEM.

This OEM-perspective reflects only one side of viability. Consumers may evaluate viability differently, through for example prioritising factors related to the decision-making process behind self-repair or their acceptance of a 3D printed part. These aspects fall outside the scope of the current framework but are highlighted in the discussion and recommendations as essential areas for future exploration.

Table 2:Overview of literature used for the viability assessment

Citation	Primary contribution to the framework
(Cardeal et al., 2023)	Provides the structural foundation and specific operational criteria and their scoring rationale for selecting parts for AM, used for the the initial characterization and operational preselection tables.
(Frandsen et al., 2020)	A comprehensive literature review that validates the list of core operational and technical criteria. It ensures criteria alignment with scientific consensus on AM suitability factors.
(Cantini et al., 2025)	Integrates previously neglected qualification costs and safety-criticality as crucial factors for AM decision-making.
(Naghshineh et al., 2023)	Provides validation and context, of operational criteria formulated from both the consumer and company perspective for AM spare parts. It introduces the non-economic consideration of complying with health and safety protocols in AM decision-making.
(Hinze, 2025)	Provide the background by which to compare an AM process to IM on environmental sustainability in the context of spare parts for consumer products.

TECHNO-ECONOMIC PRESELECTION

The first stage applies exclusion criteria to eliminate parts that are fundamentally unsuitable for AM under current conditions. Criteria focus first on product characteristics (e.g., material type, multi-material designs), then on business and legal considerations (e.g., IP restrictions, maintenance contracts), and finally on regulatory concerns (e.g., safety-critical parts), as can be seen in table 3.

Only attributes that are mandatory should lead to exclusion, optional features (e.g. overmoulding that could be avoided) do not automatically disqualify a part, this is included in the justification column. Every excluded part should be documented for reconsideration in the future.

This stage is led by service parts and operations teams, with input from legal teams where needed. The output is a narrowed, but still broad, shortlist.

Table 3: List of techno-economic exclusion criteria

Criterion	Definition	Justification	Sources
Assemblies	Stock Keeping Units (SKUs) representing entire assemblies (e.g., pumps, actuators).	Assemblies are excluded, but individual parts within them are considered if the company replaces them	(Cardeal et al., 2023)
Overmoulded/ multi-material parts	Parts requiring multiple materials or parts that require overmoulding.	Only single material printing is in scope	See appendix A2
Non-polymer parts	Parts made out of non-polymeric materials (e.g., specific metal alloys, ceramics).	Only polymer parts are in scope	See appendix A2
Non-injection moulded parts	Parts produced by conventional methods other than injection moulding	Only IM is in scope.	See appendix A2
Standardized parts	Parts readily available as Commercial Off-The-Shelf (COTS) items.	Not viable due to availability from conventional suppliers	(Cardeal et al., 2023; Frandsen et al., 2020)
Parts that are safety critical or subject to strict regulatory requirements	Applications where part failure poses safety or mandatory regulatory concerns, and where current AM is not certified.	AM is currently not used for safety-critical parts due to uncertainties in failure rates and high qualification costs.	(Cantini et al., 2025; Naghshineh et al., 2023)

OPERATIONAL PRIORITIZATION

This stage focuses on ranking all remaining parts, rather than excluding them. Procurement teams prioritize parts based on operational and cost related criteria derived from historical demand patterns and market dynamics, as can be seen in table 4. Using a scoring approach adapted from Cardeal et al. (2023), each part receives a cumulative score. Parts with higher scores become higher-priority candidates for AM. At this point, the focus is strictly on prioritization, ensuring that all parts remain in scope while directing attention to those where AM can provide the greatest operational value.

Table 4: List of operational prioritization criteria

Criterion	Definition	Justification	Scoring	Sources
Maturity	Spare part's lifecycle phase.	AM is highly valuable for legacy parts by extending the products lifetime and enabling production without moulds.	New = -1 In-use = 0 Obsolete = +1	(Cardeal et al., 2023; Frandsen et al., 2020)
Demand pattern	Frequency and variability of demand.	AM reduces high safety stock levels and obsolescence risks associated with unpredictable or intermittent demand.	Smooth = -1 Intermittent/ Erratic/Lumpy = +1	(Cantini et al., 2025; Cardeal et al., 2023; Naghshineh et al., 2023)
Lead-time uncertainty	Standard deviation of lead time, often influenced by the number and reliability of suppliers.	Lower uncertainty from AM's local, on-demand production is critical to optimizing safety stock and reducing backorder costs.	Low = -1 High = +1	(Cardeal et al., 2023; Farghali et al., 2025; Naghshineh et al., 2023)
Criticality	Impact from stock shortage (e.g., downtime cost/ lost sales). For consumer products, this also includes experiential criticality (consumer satisfaction/ brand loyalty) as well as consumer intention to replace a part.	High criticality requires high service levels. AM's faster delivery lead time improves responsiveness and reduces costly downtime.	Low = -1 High = +1	(Cardeal et al., 2023; Farghali et al., 2025; Frandsen et al., 2020; Naghshineh et al., 2023)
Part value	The acquisition cost of the spare part. High value contributes to high holding costs.	High value parts incur higher holding and tied-up capital costs. AM is preferred when high cost is coupled with low demand and inventory reduction potential is high.	Low = -1 High = +1	(Cantini et al., 2025; Cardeal et al., 2023; Frandsen et al., 2020; Naghshineh et al., 2023)
Lead time (monetized)	The duration from order to delivery. Converted to a cost using the value of one unit of time.	AM offers reduced production lead times decreasing the effective total cost when lead time is monetized.	Low = -1 High = +1	(Farghali et al., 2025; Naghshineh et al., 2023)

SUSTAINABILITY PRIORITIZATION

For the use case of AM within spare parts, the primary sustainability benefit is contextual rather than production based. The largest environmental gain comes not from how the part is manufactured, but from the idea that AM can increase the likelihood that a repair actually happens. By restoring or prolonging part availability, eliminating long lead times, or reducing the cost and effort of replacement, AM can shift consumer behaviour from replacement to repair. In other words, AM's sustainability value arises when it enables repairs that would otherwise not occur, especially for low volume, legacy, or legacy components.

Hinze (2025), compared SLA and IM in the context of spare parts by the example of an ABS pump housing. His findings show that IM is environmentally preferable for high volume spare parts, both today and in most future scenarios. In contrast, SLA becomes more sustainable than IM at low production volumes, with a crossover at roughly 250–350 units and SLA showing a significantly lower impact at very small volumes (e.g., one-fourth the impact of IM at 50 parts). This aligns with the common observation that AM only becomes advantageous when production volumes are limited, reflecting the same economic logic captured in the techno-economic stage of this framework.

Hinze also demonstrated that long-term storage and overproduction are major contributors to IM's footprint. While IM including emissions from storage still remains environmentally preferable in current and near future scenarios, it was found that, under certain future technological trajectories, SLA could surpass IM for spare parts requiring storage beyond eight years depending on relative rates of technological improvement. Thus, the sustainability value of AM is highest where conventional forecasting is most uncertain, but it does, however, not outperform IM. However, as was found in Chapter 2, for Philips, long-term storage also significantly increases part cost and thus affects consumer value. Here AM can improve the likelihood that a repair occurs by ensuring availability of a legacy part, or by shortening delivery time, and in the context of home printing, can even offer a cheaper alternative (since labour costs are then not included).

Decentralised production, another commonly cited advantage of AM, was also evaluated. As expected, shorter transport distances through AM production closer to the end-use location reduces emissions, but Hinze concludes that this effect is small compared with the impacts of material production and energy intensity of AM processes. However, as noted in Chapter 2, Philips operates a global manufacturing network with most major suppliers distant from the Central European warehouse in Łódź, from which parts then need to be redistributed to the rest of Europe. These two long-haul transport movements could make transport impacts more significant in this context. However, as the parts from the PH portfolio are relatively small and lightweight, the per-part transport footprint may still remain limited.

Taken together, these findings reinforce that AM's sustainability advantage is strongest when it enables a repair that otherwise would not happen, or avoids long-term inventory waste. This makes AM most suitable for low volume, or unpredictable parts to avoid inventory waste, or obsolete parts that would otherwise not be available. This aligns with the criteria in the operational prioritization. Further sustainability prioritization should focus on identifying parts where AM meaningfully increases repair likelihood and avoids new product manufacturing. As this is beyond the scope of this project, this will be further addressed in the discussion in Chapter 10.

4.3 Eligibility: Technological perspective

Once viability is established, a detailed engineering evaluation determines whether a part is technically feasible to print. This stage outputs a complete manufacturing specification to be handed over to the person who will work on the redesign.

The eligibility workflow evaluates each part individually. It begins with part family identification, which enables the reuse of existing redesign knowledge. This is followed by part requirements definition and AM technology matching, supported by tools introduced in this section. Based on the requirements established, the technology-matching step determines the most appropriate printing process. This choice sets the boundaries for material selection, after which post processing specifications are defined to ensure that the part meets its final performance requirements.

PART FAMILY IDENTIFICATION

The first step before the detailed analysis is to cluster parts based on commonalities. When examining the Philips spare part portfolio, parts can be classified into groups, as can be seen in figure 14.

For each identified family or category, consider the following actions:

- Check whether an AM design or redesign already exists for identical or similar parts; if so, further investigation is not needed.
- If one variant has been redesigned for AM, obtain the documentation and apply the same redesign approach to other family members where appropriate.
- Capture lessons from parts that share interfaces or functional requirements to inform future redesigns.

This step requires Philips to record and maintain AM design knowledge in a searchable, structured way. While establishing such a repository is outside the scope of this research, it is left as a recommendation for scalable, systematic AM adoption for spare parts.

1. Identical parts: Parts that are identical but vary only by colour. These require only a single redesign effort.

2. Product family variations: Parts from different models within a product range that share the same core function but have slightly different executions. These components are likely to share similarities in the redesign approach.

3. Shared interface components: Parts that are attachments to the same base product. They are functionally different and require unique redesigns, but share a common interface or mounting mechanism with the base product. Learnings can be shared regarding the design of this attachment interface.

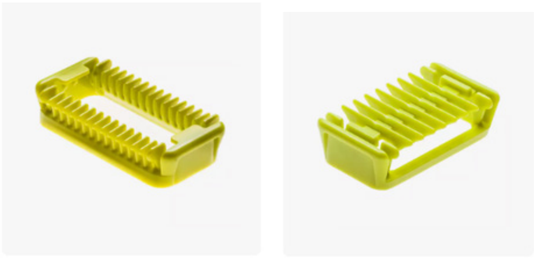


Figure 14: Examples of part families; images from (Philips Nederland, 2025)

PART REQUIREMENTS DEFINITION AND TECHNOLOGY MATCHING

To ensure the redesign process is driven by objective performance needs, the parts' design requirements need to be defined and matched to the right AM technology to define what "printable" means in practice. This process consists of two steps:

1. Defining the part's functional and performance requirements
2. Matching these requirements to the most suitable AM technology

To support this process, two tools from literature are introduced: the Function identification tool by van Oudheusden et al. (2025), and a list of IM vs AM design requirements by van Oudheusden et al. (2024). Both tools are provided in Appendix A6.

Defining part requirements

Start by creating a clear and objective description of what the part must achieve. Available CAD models , simulation and stress analysis can be leveraged to precisely define critical areas and performance criteria. Furthermore, as Philips is the OEM, supplementary information such as annotated drawings, free body diagrams, or existing technical documentation is likely available to streamline requirement definition. Though this provides a starting point, it does not not fully explain why the part is shaped the way it is, nor what performance margins are essential. Therefore, requirements must be derived from the part's intended functions, interfaces, and loading conditions.

The Function identification tool by van Oudheusden et al. (2025) systematically translates a part's primary and secondary functional roles (e.g., Connect, Seal, Resist) into a comprehensive checklist of measurable Expected Design Requirements (e.g., Accuracy, Water/airtightness, Tensile Strength). Utilizing this framework ensures that the required performance criteria are all considered before any manufacturing technology is selected. These design requirements provide the foundation for evaluating technical feasibility and informs redesign decisions later. It also makes the redesign process traceable, as every geometric change can be linked back to the functional requirement it supports.

Accurately defining design requirements is fundamentally a question of experience and 'know-how', underscoring the necessity of engaging experts in this process.

Matching Requirements to AM Technology

The technical feasibility of a part to be produced by AM is determined by a combination of part requirements and the capabilities of the manufacturing technology. To objectively match a new manufacturing technology to a part, a set of objective guidelines to compare the original manufacturing technology to the capabilities of the new technology is needed. Van Oudheusden et al. (2024) developed a comprehensive set of requirements comparing IM to FDM, SLA and SLS, based on the relationship between design requirements and manufacturing capabilities. The framework is structured to evaluate the technologies across three major categories: geometry, configuration, mechanical requirements, and thermal requirements. These established requirements are directly applied in this study to inform the choice of technology when substituting IM with AM. By systematically comparing the original part's design requirements against the documented limitations and capabilities of SLA, SLS, and FDM, this framework allows for the objective selection of the most suitable AM technology.

This results in one of three outcomes:

- A single AM technology is clearly suitable.
- Several technologies are possible: the final choice is determined by the design goal (e.g. designing for home printing requires FDM, but designing for the best possible quality may favor SLA)
- No current AM technology can meet requirements: the part is technically ineligible and removed from further consideration.

The outcome of this step defines the technological boundaries for redesign.
It sets expectations for material choices and post-processing, and it signals where compensatory redesign strategies may be necessary.

MATERIAL SELECTION AND POST PROCESSING

As defined in Chapter 3, for the current scenario, material and post processing are not decision variables; they are fixed parameters. Eligibility is constrained by FDM as the chosen technology and PLA as the material, with no post processing considered. However, the model will be expanded in the future, so to future proof the framework these stages should be included. This section gives a high level overview of the factors relevant to material selection and post processing and outlines a near term approach which will guide the case based redesigns.

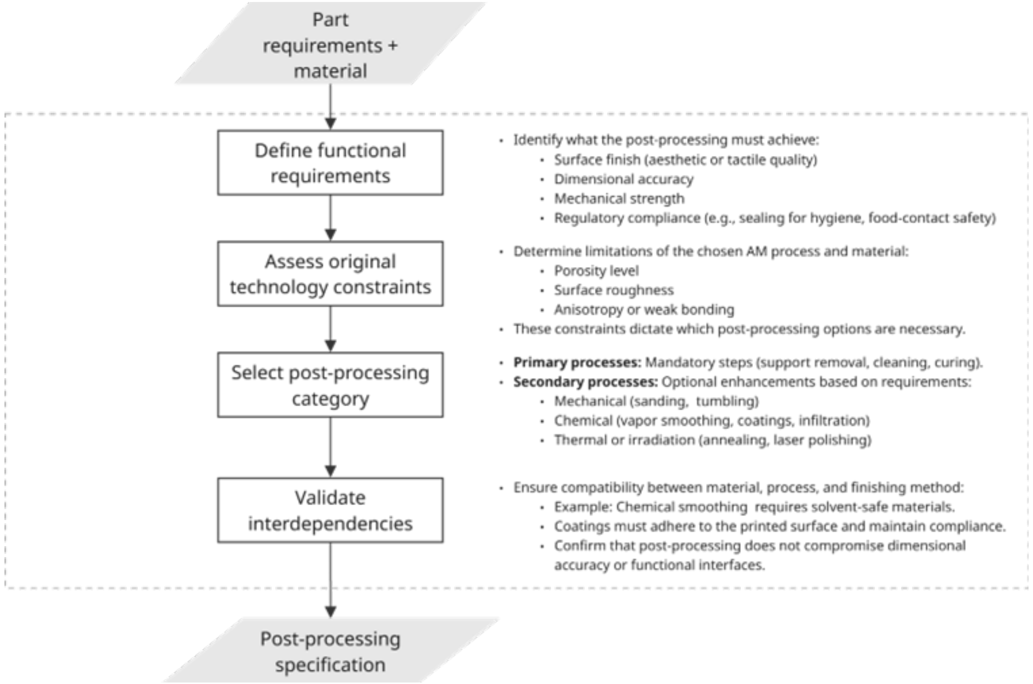
Material selection

Following the top-down approach, first identify any non-negotiable specialized requirements, such as food safety or heat resistance, as these limit the decision space. Then define other essential functional requirements that are materially dependent, and acknowledge trade-offs, such as selecting a clear SLA resin for transparency while acknowledging its lower impact resistance.

For the final material selection two approaches can be used, either prioritize functional equivalence or utilize the upgrade strategy. Functional equivalence aims to select a material that is functionally comparable to the original material. The datasheets of printing materials often give an indication of what injection-moulded materials are similar to the printing material, based on the intended application, which can be used as indications as a starting point for material selection (van Oudheusden et al., 2025). The upgrade strategy suggests using a higher performance AM material to replace a commodity IM plastic if the required functionality is difficult to meet with AM / standard material capabilities, such as filled materials or specialized blends.

Post-Processing Decision Workflow

Post processing decisions should follow a structured sequence to secure functional performance, regulatory compliance, and the desired aesthetic. Post processing is not isolated; it is interdependent with material selection and the chosen AM technology. Make these decisions concurrently with material selection to prevent conflicts and ensure performance targets are achievable. At a high level, the workflow comprises four steps, a can be seen in figure 15.



- Identify what the post-processing must achieve:
    - Surface finish (aesthetic or tactile quality)
    - Dimensional accuracy
    - Mechanical strength
    - Regulatory compliance (e.g., sealing for hygiene, food-contact safety)

- Determine limitations of the chosen AM process and material:
    - Porosity level
    - Surface roughness
    - Anisotropy or weak bonding
- These constraints dictate which post-processing options are necessary.

- **Primary processes:** Mandatory steps (support removal, cleaning, curing).
- **Secondary processes:** Optional enhancements based on requirements:
    - Mechanical (sanding, tumbling)
    - Chemical (vapor smoothing, coatings, infiltration)
    - Thermal or irradiation (annealing, laser polishing)

- Ensure compatibility between material, process, and finishing method:
    - Example: Chemical smoothing requires solvent-safe materials.
    - Coatings must adhere to the printed surface and maintain compliance.
    - Confirm that post-processing does not compromise dimensional accuracy or functional interfaces.

Figure 15: Post-processing decision making workflow based on (Tamburrino et al., 2021)

4.4 Redesign for additive manufacturing

Once a part has been confirmed eligible for AM, the next step is to translate that into a redesign. This section focuses on the workflow for redesigning parts for AM using DfAM principles. While previous sections established eligibility and material considerations, redesign is where these insights are translated into practical geometry and process decisions. The goal is to ensure that parts meet functional and aesthetic requirements while remaining printable.

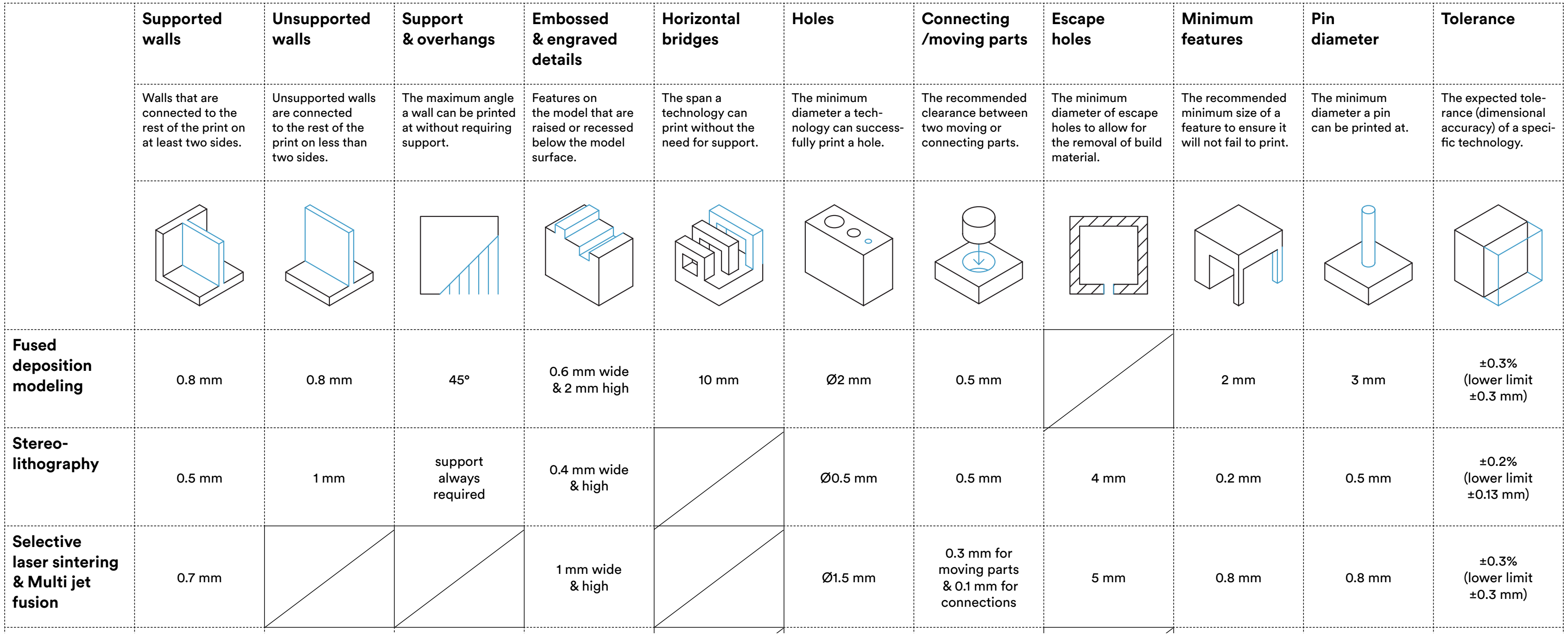
REDESIGN GUIDELINES

Basic DfAM rules, such as the overview by Protolabs (n.d.-b) as can be seen in figure 16, are widely known. Comparing the original against these guidelines will immediately identify necessary modifications.

However, successful redesign requires moving beyond these generalized guidelines to incorporate information about the specific printer's capabilities (Project Leader GnB R&D, personal communication, 11 October 2025). Machine-specific constraints, such as nozzle size, should inform dimensional decisions (e.g., shaping features to allow complete print passes). Furthermore, overcoming print artifacts, such as burring, by avoiding perfectly level surfaces, and stringing, by ensuring sufficient element distance, is achieved through continuous optimization and practical learning by printing.

For Philips, these guidelines should not remain generic. They need to be standardized into an internal rulebook that defines acceptable ranges for critical parameters (e.g., minimum wall thickness, tolerances for snap-fit features) rather than relying on external sources with conflicting recommendations. This standardization should:

- Ensure consistency across the portfolio, reducing redesign complexity.
- Provide a clear reference for engineers and designers, minimizing ambiguity.
- Integrate visual design rules (e.g., patterns) so that printed parts maintain brand identity while meeting functional requirements.



	Supported walls	Unsupported walls	Support & overhangs	Embossed & engraved details	Horizontal bridges	Holes	Connecting /moving parts	Escape holes	Minimum features	Pin diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused deposition modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.3% (lower limit ±0.3 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.2% (lower limit ±0.13 mm)
Selective laser sintering & Multi jet fusion	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)

Figure 16: Design for AM rules (Protolabs, n.d.)

REDESIGN WORKFLOW

(van Oudheusden et al., 2023a) proposed the 3DP4R framework to help people redesign parts for AM from scratch. This setup is used as the basis for the newly proposed framework tailored to the use case of DfAM for an end-use product by an OEM, as can be seen in figure 17. Since the input already includes the original CAD model, manufacturing specifications, and design requirements, the fault diagnosis and initial analysis phases are replaced by focused, iterative stages as well as testing to ensure quality and repeatability of not only the part itself but also the process.

Phase 1: Define

This phase narrows the design space by translating high-level requirements into concrete geometric and functional constraints (e.g., maximum envelope, critical interfaces). A brief Pre-Slicer Analysis then checks the original CAD for obvious printability issues, highlighting features that will need modification.

Phase 2: Redesign

This is the core design loop. Designers develop and refine concepts, applying DfAM principles within the boundaries set in Phase 1. The resulting geometry is passed directly to the Printing phase for rapid testing.

Phase 3: Printing

Here, design and print parameters are iteratively optimized. The printed trials validate whether functional changes work as intended.

- Internal loop: If Redesign Impact Verification fails, the process returns immediately to Redesign for further refinement.

Phase 4: Build Process Validation

With the architecture proven, the focus shifts to validating print stability. This includes print quality (e.g., dimensional accuracy) and repeatability checks to confirm the process produces consistent results.

- Internal loop: If either check fails, the workflow returns to Redesign to adjust geometry or process settings.

Phase 5: Finalization

Post-processing is introduced, and the fully finished part is tested for functional and performance requirements.

- External loop: If the part fails any test, the workflow loops back to Redesign, as the issue likely lies in core design or process decisions.

Phase 6: Final Part Qualification

This final gate confirms that part quality, documentation and process records meet all release standards.

- Final loop: Minor issues found during review may loop the process back to Finalization for adjustments or documentation updates.

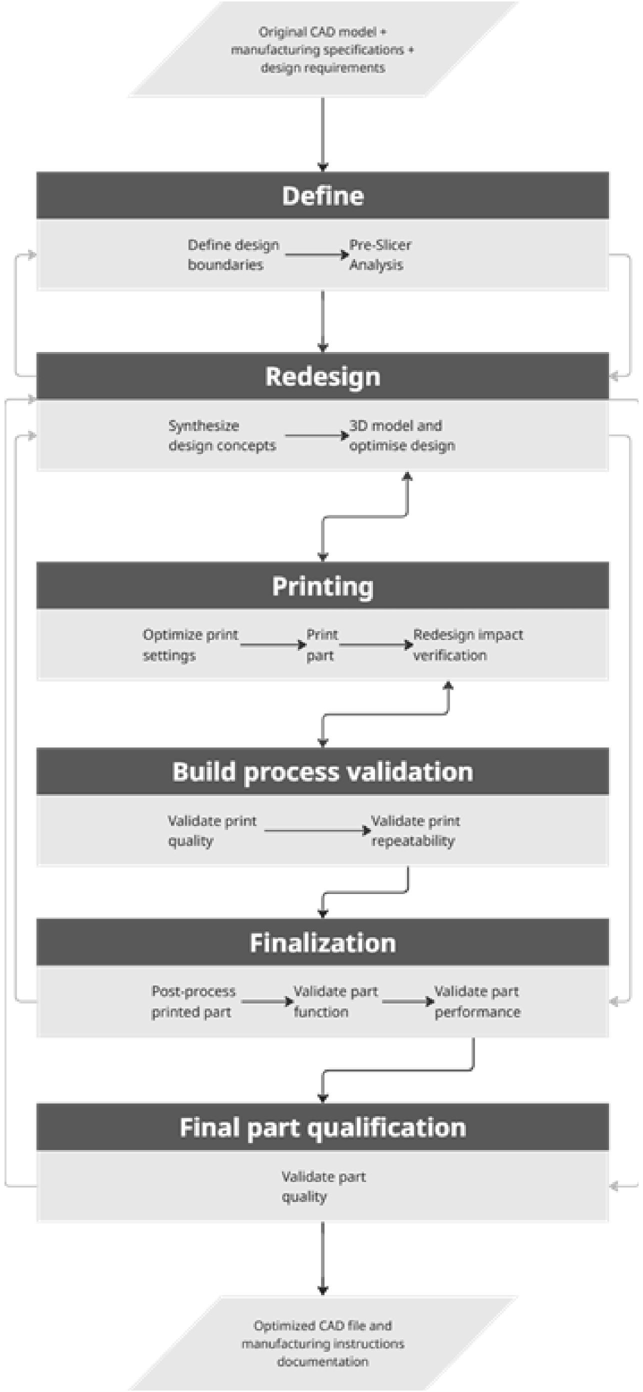


Figure 17: Redesign workflow based on (van Oudheusden, et al., 2023a)

4.5 Concluding chapter insights

This chapter translated the strategic considerations from Chapter 3 into a practical, multi-layered framework for identifying and redesigning parts for AM within Philips. It introduced:

- A viability assessment integrating techno-economic, operational, and sustainability criteria
- An eligibility assessment covering technical feasibility, requirements definition, technology selection, material choice and post-processing
- A structured redesign workflow grounded in DfAM principles and iterative validation steps

The viability assessment answers Research Question 3 about which systemic criteria can be used to assess the viability of a part for 3D printing across functional, economic and environmental dimensions. The eligibility assessment answers Research Question 4 about what technical criteria determine whether a part is printable, and how these inform AM technology and post-processing choices. Together, these elements create a scalable, systematic approach for identifying eligible parts for AM. The framework supports Philips' shift from ad-hoc experimentation toward long-term strategic adoption. It provides the tools and workflows needed for the case-based redesigns in Chapter 5.

Applying the full viability and eligibility framework to the full CRP portfolio resulted in a list of current eligible parts (Appendix B1). Of the 492 CRPs, 332 belonged to the Grooming & Beauty category, which is the only portfolio currently in scope due to regulatory constraints. From these, 133 parts were identified as eligible for AM, and 104 of these as suitable for consumer FDM printing. Most exclusions stemmed from regulatory constraints in the MCC and OHC categories, followed by parts that were inherently unsuitable due to multi-material or overmoulded constructions. Among the parts that remained in scope, the primary barrier to exclusion from the consumer home printing model was the constraint of availability of suitable materials within the consumer printing context, which prevented several otherwise feasible geometries from meeting required performance or safety margins.

While the current framework reflects today's capabilities and constraints, it is intentionally modular. As AM technologies mature and regulatory standards evolve, currently excluded categories (e.g., safety-critical parts) may become viable. Likewise, demand-driven prioritization may become less important if AM transitions into a mainstream production route for spare parts.

In future scenarios, the framework could split into specialised pathways, such as:

- Legacy-driven pathway (end-of-life parts)
- Availability-driven pathway (urgent or unavailable parts)

This adaptability ensures relevance across the technological and organisational horizons introduced in Chapter 3.

5. Case-based redesign

This chapter translates the learnings from literature into practice by redesigning a selection of parts from the Philips PH portfolio. This chapter addresses the following research questions:

- RQ5: What design modifications are necessary to ensure that 3D-printed spare parts meet functional and aesthetic expectations compared to traditionally manufactured parts?
- RQ6: What process gaps and constraints currently hinder the application of design for additive manufacturing (DfAM) during part redesign?

To answer these questions, a case-based redesign approach was applied. Four representative parts were selected from the Grooming and Beauty category, based on the identified list of eligible parts, which can be found in Appendix B1. Each case was designed with a specific research aim in mind:

- Cases 1 & 2: Two OneBlade attachment combs were selected to build on learnings from previous Fixables redesigns. These cases aim to capture undocumented insights from earlier efforts and test whether those learnings are generalizable.
- Case 3: A stretcher attachment for the Satinelle epilator was chosen for its distinct geometry and lower dimensional accuracy requirements. The goal was to explore minimal adjustments to the original geometry rather than a full redesign.
- Case 4: A diffuser attachment for a hair dryer was included to anticipate future eligibility of heat-resistant haircare parts. Here, the focus was on experimenting with different materials and printing techniques rather than geometry adaptation.

Each part was analysed to identify high-level requirements and expected design adaptations. The redesign process followed the workflow detailed in Section 4.4. This chapter shows only high-level insights and process challenges relevant to the project. Detailed case results are provided in Appendix A7.

The outcomes of this chapter serve three purposes:

1. **Validate eligibility of selected parts for AM** through practical redesign exercises.
2. **Provide input for the redesign framework**, which will guide future DfAM efforts.
3. **Determine process gaps and opportunities**, clarifying what Philips already supports well and where improvements are needed to integrate DfAM effectively.

By combining case-specific learnings with broader workflow observations, this chapter builds the foundation for the design vision and requirements presented in subsequent chapters.

5.1 Case selection rationale

Parts were selected from the list of eligible parts derived using the decision-making framework from Chapter 4, the full overview of which can be found in Appendix B1. As outlined in Chapter 3, the vision is to scale Fixables into a future-proof solution. This requires starting from what already exists and progressively expanding. The overview of the cases is summarized in table 5. The case selection reflects this logic:

1. **Apply and validate learnings from the current Fixabels trial and test generalizability:** Two parts similar to existing Fixables designs were chosen. There are two more Oneblade comb attachments beyond the four combs that are already on Fixables, CP0941/01 and CP2193/01. These are picked as candidates for this case as they share interface mechanisms and geometry characteristics with the already existing printable Oneblade combs, allowing for comparison and validation of the design rules for printability already derived.
2. **Explore portfolio expansion:** To move beyond combs and caps, a part with a different function, but still eligible for home printing was selected. Looking at the eligible parts that leaves the Satinelle epilator skin stretchers. Between the three skin stretchers the CP1499 was chosen. This part has a distinct shape and lower dimensional accuracy requirements, making it suitable for testing minimal geometry adjustments rather than a full redesign.
3. **Anticipate near-future eligibility for heat-resistant haircare parts:** As derived in Chapter 3, heat-resistant parts have potential to become eligible for home printing in the near future. Given that this future is dependent on the availability of materials and processes supporting those materials the focus here will be on material experimentation rather than geometry adaptation, thus a part is chosen that is expected to have good printability due to its geometry. Looking at the eligible parts (Appendix B1) the logical choice is a nozzle attachment for the hair dryer, specifically the CP1700/01, as it has simple geometry, and minimal overhangs.

5.2 Overview of results

The following sections describe the high level results of the redesign process for the four cases. Refer to Appendix A7 for the detailed process overview and images of the different protoypes.

Table 5: Overview of cases; images from (Philips Nederland, 2025)

	Part	CRP number	Attachment to	Case objective
	Body Comb intimate	CP2193/01	Oneblade (intimate)	Validate learnings from Fixables designs and test generalizability of design rules for printability.
		CP0941/01	Oneblade	Confirm interface and geometry adaptation principles for similar parts.
	Body Comb Skin Stretcher	CP1499	Satinelle series 8000	Explore minimal geometry adjustments for a part with a distinct shape and lower accuracy requirements.
	TP nozzle	CP1700/01	Hairdryer 3000 series	Investigate material and print process options for heat-resistant parts.

Case 1: Body comb intimate

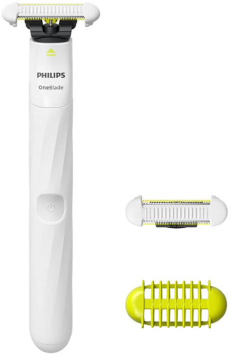


Figure 18:Original part and product (Philips Nederland, 2025)

Figure 19: Final prototypes in PETG (left) and PLA (right)

This case focused on redesigning a OneBlade attachment comb (figure 18) to validate learnings from previous Fixables trials and test their generalizability. The part was redesigned for FDM printing without supports and optimized for both PLA and PETG. The process consisted of seven overarching iterations comprising multiple prints.

Key Challenges were:

- Achieving smooth skin-contact surfaces without post-processing.
- Reinforcing click hooks for strength while preserving flexibility.
- Managing unsupported overhangs to enable support-free printing.

Redesign Approach

The process began by reusing insights from Fixables combs and applying parametric modeling to optimize geometry for FDM printing (figure 20). Teeth were reused from another model (figure 21), and alternating extrusion patterns were introduced to support overhangs (figure 22). Wall thickness was progressively refined to balance strength and printability for both PLA and PETG.

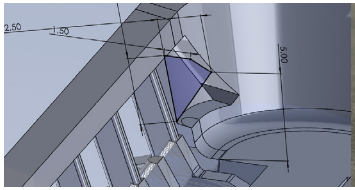


Figure 20: Parametric setup

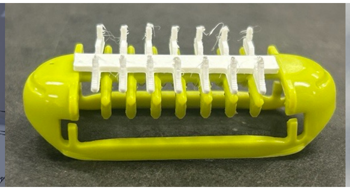


Figure 21: Teeth modelling

Figure 22: Concept explorations

Outcome and key learnings

It was found that a 2 mm wall thickness for the body provided sufficient strength, in line with the findings from the other Oneblade combs (Appendix A7). For the click hooks it was found that a thicker wall thickness was needed than the Fixables examples. It was found that more strength was needed in this area because the click hooks engage from four sides. In the PETG prototypes any wall thickness between 1 and 2 mm was found to be functional. The PLA prototype however, required a minimum wall thickness of 2 mm here. Furthermore, optimizations were needed in the profile of the body as the click hooks required a straight wall to be positioned on, requiring careful consideration of the design of the curves of the body compared to the original design. The approach with reusing a shaver comb teeth from the Fixables design was succesful. However, the main reason for doing this was that the design rules regarding the redesign of the teeth were not well documented, making this an easier approach than rebuilding from scratch. Optimizing the printability of the part required optimization of the extrusions supporting the overhang. It was found that unsupported overhangs between 10-15 mm are acceptable. An alternating pattern with a total of 4 extrusions was chosen for the final concept for aesthetic reasons (see figure 22). Final optimizations made use of parametric modelling of distances between the shaver blade and the part, as can be seen in figure 20. The final prototypes are shown in figure 19.

TAKEAWAYS

- PETG is the preferred material for flexible parts.
- PETG is more forgiving than PLA for thin features. Thus, when optimizing a design for both, prioritize PLA's stricter limits to ensure compatibility with both.
- The reuse of features from a previous CAD model and building the rest of the body around it accelerated redesign compared to full rebuilds, but this more so reflects a need for properly documented design rules than it does for enhanced efficiency.
- Applying best practices derived from previously redesigned combs requires careful consideration of the slight functional differences of the new part.

Case 2: Body comb

Figure 23: Original part and product (Philips Nederland, 2025)

Figure 24: Final prototypes in PETG (left) and PLA (right)

This case extended the learnings from Case 1 to a OneBlade comb that attaches directly to the blade (figure 23), introducing higher risk of blade damage. The redesign aimed to further validate general design rules while addressing new attachment constraints. This part was also redesigned for FDM printing without supports and optimized for both PLA and PETG. The process consisted of four overarching iterations comprising multiple prints.

Key Challenges were:

- Ensuring secure fit without damaging the blade.
- Balancing strength and flexibility in click hooks.

Redesign Approach

The process leveraged symmetry by splitting the original model and rebuilding around it as reference geometry. Iterations focused on optimizing click-hook configuration and wall thickness to achieve stability and prevent blade damage.

Figure 25: First iteration

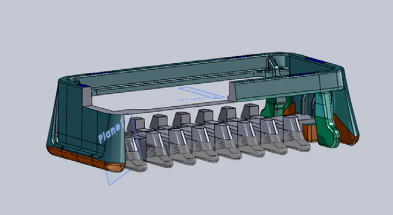


Figure 26: Modelling in original geometry

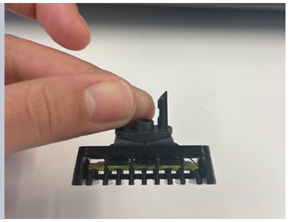


Figure 27: Horizontal blade movement

Outcome and key learnings

Through the learnings and experience from the previous case, the first iteration immediately achieved a properly printed part (figure 25), reinforcing the advantage of known best practices from similar, previously redesigned parts. Furthermore, modeling the new design in the same file as the original geometry (figure 26) made it easier to achieve the correct dimensions. Because of the different shape of the body of this part compared to the previous case, the first iteration experimented with two click hooks instead of four, clamping the blade in the middle of the short walls instead of on the four corners. It was found that this approach damaged the blade by allowing for too much horizontal movement during use (see figure 27). Four hooks positioned at blade corners are essential for stability, highlighting the need to explicitly consider part requirements from the outset. Subsequent iterations focussed on modelling four click hooks where the click hook was positioned as closely to the original position as possible while still positioned on the short wall of the part, as this was identified as the easiest space for redesign while still adhering to the requirement. This led to a functional design. This highlighted the need to consider all the spaces that have potential for redesign. It was also found that direct blade attachment required less clamping force than with the protective guard in the previous case. In this case a wall thickness of 1 mm for the click hooks provided adequate strength for PLA and PETG. All in all, it was found that all other learnings from the previous case applied which significantly sped up the redesign process. The final prototypes are shown in figure 24.

TAKEAWAYS

- Leverage symmetry by splitting and mirroring the model and use the original geometry as a reference during redesign for faster and more accurate dimensioning.
- This case further reinforced the advantage of best practices from similar, previously redesigned parts.
- If there are any known best practices, it is important to first consider the requirements in the context of the part to be redesigned as well as the differences with the part they were derived from to ensure that the best practice is applicable in the new case.
- Consider what the full design space is, where it is easy to make changes and where it would require more effort.

Case 3: Skin stretcher

Figure 28: Original part and product (Philips Nederland, 2025)

Figure 29: Final prototype in PLA

This case examined a Satinelle epilator attachment (figure 28), aiming to test minimal geometry adjustments rather than a full redesign. The part was designed for FDM in PLA. Printing with supports as well as sanding were in scope. The process consisted of four overarching iterations.

Key Challenges were:

- Achieving smoothness on skin-contact areas that have a curved surface.
- Ensuring dimensional accuracy for the click-fit without altering the geometry.
- Reinforcing critical load-bearing areas to prevent failure.

Redesign Approach

Orientation analysis was conducted to balance smoothness and strength, supported by slicer trials. Reinforcements were added in high-stress zones identified through FBD (free body diagram) analysis. The strategy shifted from avoiding supports to optimizing functional requirements, using selective support painting and regular supports instead of organic for stability.

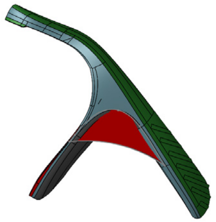


Figure 30: Reinforcement (in red)

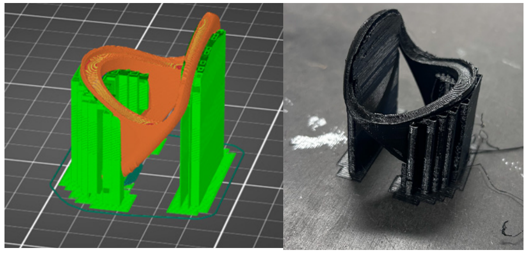


Figure 31: Final concept

Outcome and key learnings

First iterations focused on printing the original geometry in different orientations with automatic support generation. These supports were not removable. Only one orientation was found that could print without supports, but this was only possible on one printer and did not provide a functional result. Given that the goal of this case was to not rebuild the part from scratch, a different approach was needed. Since it had become evident that the part had to be printed with supports, subsequent iterations first focused on tweaking support settings to get removable supports with minimal damage to the part surface. The final slicer settings can be found in Appendix A7. After tweaking the support settings, the best print orientation still needed to be found, as the first trials had not led to anything succesful. The solution was found when considering how to satisfy the smoothness, accuracy and strength requirement separately first and then finding the best midway. This was done through a marking of all critical areas and areas with room for reinforcements, as well as an analysis of where the largest forces act. Then an ideation was done on what all different possibilities are to satisfy each part requirement individually. Based on these results, the part was reinforced (see figure 30) and printed in the orientation that addressed all the requirements in some way (see figure 31), refer to Appendix A7 for a breakdown of the design rules used for the explorations. Further experimentation showed that regular supports provided more reliable outcomes than organic ones and that painting only where you do not want support gave the most control, leading to a reliably printable outcome. The final prototype is shown in figure 29.

TAKEAWAYS

- For dimensional stability and repeatability, prefer regular supports over organic supports as they provide more even support during printing.
- For effective slicer support generation prefer only painting where not to generate supports for most control.
- The solution was found when considering how to satisfy the smoothness, accuracy and strength requirement separately first and then finding the best midway. This led to solutions previously overlooked.

Case 4: Nozzle

Figure 32: Original part and product (Philips Nederland, 2025)

Figure 33: Final prototype printed on DLP printer in Loctite3995

This case explored a nozzle attachment for the Philips Hairdryer 3000 series (figure 32) to anticipate future eligibility of heat-resistant parts. The redesign focused on validating geometry for printability and investigating material and process options to meet thermal and safety requirements.

The original part was manufactured in polycarbonate (PC) and must withstand continuous use at 125 °C.

Key Challenges were:

- Finding a material that complies with the heat requirements.
- Maintaining internal smoothness for airflow without excessive post-processing.

Redesign Approach

The process began with FDM prints to validate the geometry and assess print orientations (figure 34). Once printability was confirmed, the focus shifted to testing heat-resistant filament options (figure 35). These initial FDM prototypes enabled low-temperature testing but were not intended for full thermal compliance. Subsequent iterations expanded to include DLP and MJF processes and advanced materials.

Figure 34: Prototypes to test print orientation and fit

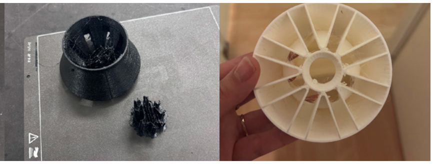


Figure 35: PETG and TPU prototypes

Table 6: Overview of prototypes (see figure 36 for prototype images)

Production technique & material	Heat deflection temperature at 1.8 MPa	Remarks
FDM - Ultem1010	213 °C — compliant	Fit achieved; excessive layer line visibility; considered succesfull but not prefered
DLP - Loctite3995	214 °C — compliant	Fit achieved (slightly tight); minor trapped powder; good internal smoothness; considered successful.
MJF- PA12 (Nylon)	106 °C — not compliant	Fit achieved but slightly loose; fails thermal requirement; not considered successful.

Figure 36: Ultem1010; Loctite3995 and PA12 prototypes

The results show that successful performance is dependent on the combination of material and production process, rather than the process alone. Because the materials tested were limited to what was available at the Product Research Center of Philips Drachten, the evaluation reflects the feasibility of these specific material–process combinations rather than the full landscape of options. Among the tested combinations, DLP (Digital Light Processing) printing with Loctite 3995 emerged as the approach that simultaneously met the heat-resistance requirements and delivered the best print quality. In contrast, FDM with Ultem1010 offered sufficient temperature resistance but showed excessive layer lines due to poor flow at low extrusion temperatures, and MJF (Multi Jet Fusion) with PA12 showed acceptable geometric output but lacked the necessary heat resistance. It is recommended to broaden future testing beyond the current material set. The final prototype is shown in figure 33.

TAKEAWAYS

- Heat-resistant FDM filaments absorbed moisture, causing stringing or showed pronounced layer lines due to poor flow at low extrusion temperatures.
- Though internal smoothness is considered critical for airflow, no noticeable disruptions were observed with the printed parts due to the roughness in the internal channels.

5.3 Design Principles and Printability Rules

Based on the case studies, a set of generalized design principles were derived. These principles synthesize recurring printability challenges, structural requirements, and performance considerations observed across the four case studies. They are organized into four themes: orientation, adhesion, stable printing, and support-free design.

1. Orientation principles

- Cosmetic priority: When the surface requiring the highest cosmetic quality can lie flat, orient this surface downward on the build plate to achieve the smoothest finish.
- Curved or small cosmetic-priority surfaces:
  If the critical cosmetic area is curved or represents only a small portion of the overall surface, orient the part at an angle up to 45° to balance surface quality and print reliability
- Strength priority: Align the direction of the highest functional loads with the x-y plane (i.e., perpendicular to the Z-axis/layer stacking direction) to maximize strength along the load path.

2. Buildplate adhesion

- Ensure the first extrusion path can follow a full, uninterrupted back-and-forth stroke.
- At least one dimension of the first layer should be a multiple of 2 × nozzle diameter (e.g., 0.8 mm for a 0.4 mm nozzle) to ensure adhesion and prevent early-layer defects.

3. Stable printing

- Avoid sharp internal corners; add fillets to reduce internal stress and improve extrusion flow.
  Rule: Use internal radii ≥ 0.5 mm where geometry allows it.
- Avoid large flat surfaces parallel to the build plate to reduce warping.
  Rule: Tilt surfaces slightly (5–10°).
- Whenever possible, design features such that the nozzle follows continuous paths rather than short, interrupted segments, which tend to create stringing.
- Dimensional multiples:
  - All heights should ideally be a multiple of the layer height.
  - All dimensions in the x-y plane should ideally be multiples of the nozzle diameter.
- Wall Thickness
  - Should always be a multiple of the nozzle size.
  - Recommended: 2.0 mm for reliable structural integrity.
- To reduce burring on edges, opt for a steep outward extrusion.

4. Avoiding supports

- The maximum unsupported overhang angle is 45°.
- For horizontal overhangs longer than 10–15 mm, add reinforcing ribs or extrusions:
  - At least 10 mm apart to reduce stringing.
  - No more than 15 mm apart to prevent sagging in the first overhang layers.
- Favor consistent rib patterns or symmetry rather than pushing the maximum span purely for aesthetic reasons.
- Use rib profiles that allow a continuous circular extrusion path for improved printability.
- For parts where no flat base exists, orient the part at an angle of up to 45° to reduce support requirements and improve surface quality. If a full 45° tilt is not possible, any angle below 45° will still have a positive effect on surface quality.

REDESIGN CATEGORIES

A key outcome of the four case studies is the recognition that not all redesign efforts require the same depth of modification. Although they followed the same overarching workflow, the starting point, degree of intervention, and type of design decisions varied between parts. These differences influenced the number of iterations required, and the strategies used to reach a printable outcome. Redesign efforts can be classified into four categories based on the extent of changes required. Each category refers to a different entry point in the redesign workflow, as can be seen in figure 37.

Orientation & Support Optimization: Parts that can be printed without altering geometry, requiring only adjustments in print orientation or custom supports to ensure successful printing.

Minor Design Adjustments: Parts needing small modifications, such as fillets, reinforced walls, or tolerance tweaks, to improve printability that can be applied within the original CAD model.

Full AM Redesign: Parts that require complete re-engineering to meet functional requirements or leverage AM capabilities, where it is easier to start from scratch than to adapt the original model. Typically applicable when original geometry conflicts with AM constraints.

Parametric Variant Adaptation: Applicable when a validated redesign in the same cluster of parts already exists. The base design remains unchanged requiring only dimensions or features to be scaled for new variants without changing the underlying design logic.

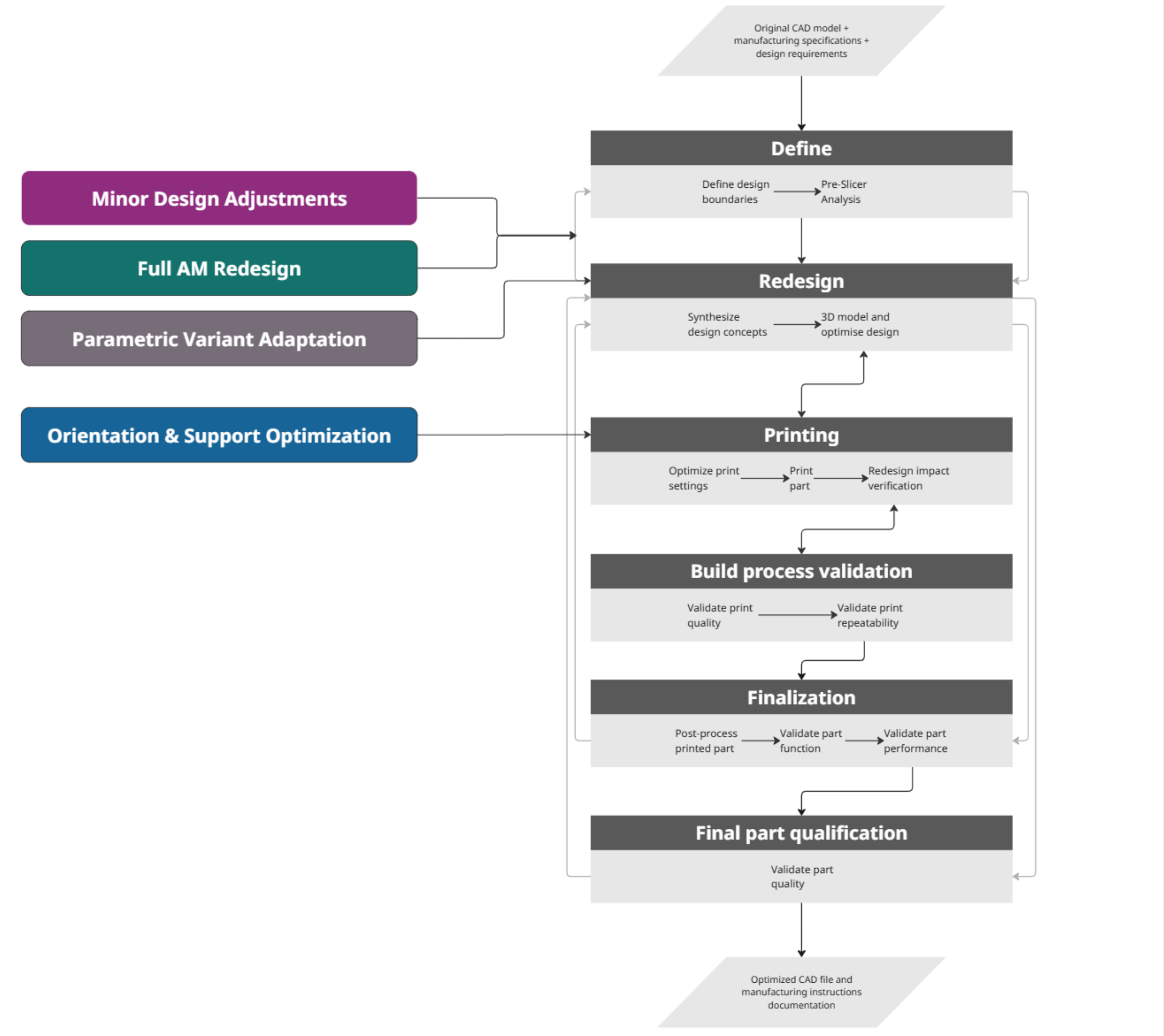


Figure 37: Redesign categories and their entry point in the redesign workflow

DESIGN PROCESS LEARNINGS

From the cases, the following process learnings were found (for more technical learnings on the design of the parts please refer to the detailed prototyping documentation in Appendix A7):

1. **Asset-based modelling:** Asset-based modelling (as used in this thesis) refers to a design approach in which pre-defined geometric building blocks, referred to as assets (e.g., tooth profiles of a shaver comb), are imported into the CAD model. The designer then develops the rest of the part around these assets to ensure functional consistency, repeatability, and design efficiency. It was found that this approach accelerated the redesign process, but this advantage may more be a reflection of undocumented "design rules" rather than significant gains in efficiency.
2. **Reuse of best practices:** Best practices derived from similar earlier redesigns accelerate concept generation. However, applying those lessons to differently shaped bodies requires re-experimentation, highlighting the need to define the applicable design space before applying precedents.
3. **Document original requirements:** Documenting original part requirements at the start of the process enables more systematic decision-making and allows each design step to be evaluated against the intended function.
4. **Balancing smoothness, accuracy, and strength:** Considering these three performance dimensions separately, then seeking an optimal compromise, yields novel solutions that meet all requirements and encourages use-focused thinking over technology-led constraints. While only one case explicitly demonstrated this in practice, the two comb redesigns were derived from precedents that originally applied this principle, thus it is included as a key learning.
5. **Reducing orientation trial-and-error:** Significant time was lost early in the process due to indiscriminate testing of print orientations. A more targeted exploration strategy that explicitely states what to look out for during these explorations could reduce unnecessary experimentation and yield more insights that might otherwise go unnoticed.
6. **Standardising design rules:** Considerable time was also lost iterating exact fit dimensions. Standardized design rules might reduce trial-and-error here.

PRACTICAL PROCESS CONSTRAINTS

During the redesign process several systemic gaps were identified that reduced efficiency:

1. **Fragmented requirements and regulatory information:** Part-specific requirements and regulatory constraints are not consolidated in one place. Requirements had to be inferred based on general product categories, or by contacting many different stakeholders for specific clarifications.
2. **Restricted CAD file access:** CAD files exist in a central system, but access is limited to certain departments. Everyone who has access only has access to CAD files of their business unit. Locating and obtaining the correct CAD files therefore frequently required additional requests and delays. Thus, checking a CAD file for quick reference during early candidate assessment was not feasible.
3. **Undocumented learnings:** Previous Fixables redesigns have CAD deliverables but lack documented lessons learned. Recovering design rationale and practical insights required contacting the original designers.
4. **Limited physical part availability:** Especially for older products, physical versions of parts and products are not always readily available at the office and must be ordered from stock. This adds lead time when a quick physical reference is needed during early candidate assessment.

5.4 Concluding chapter insights

The selected parts were successfully redesigned for additive manufacturing through iterative prototyping, with each case completed more efficiently than the previous one. The greatest opportunity for improvement lies in the first phase of the process, where redesign boundaries, functional requirements, and printability constraints are established. Providing clearer guidance during this phase can reduce trial-and-error iterations and accelerate the overall workflow. Other bottlenecks in the process were mainly experienced during the gathering of part information and files, as it required contacting many different stakeholders.

RQ5 asked what design modifications are necessary to ensure that 3D-printed spare parts meet functional and aesthetic expectations compared to traditionally manufactured parts. The case studies showed that meeting functional and aesthetic expectations with 3D printing requires targeted geometric adaptations that compensate for the limitations of consumer-grade FDM printing. Necessary modifications included orientation-driven adjustments to ensure smooth surfaces on critical areas, reinforcements and thickening of thin features, additions of ribs or extrusions to support overhangs, tolerance adaptations, and simplification of geometries that gave issues with printability.

RQ6 asked what process gaps and constraints currently hinder the application of DfAM during part redesign. The case studies highlighted several barriers that hinder the effective application of DfAM during part redesign. The most significant constraints occurred early in the process, where the lack of consolidated information, on e.g. part requirements, material constraints, and CAD files, made it difficult to get started Additionally, design rationale and learnings from previous redesigns had not been documented, resulting in repeated mistakes and unnecessary re-experimentation. The general absence of standardized design rules further contributed to inefficiencies, particularly in establishing functional fits and tolerances, which often required multiple iterations.

Taken together, the insights from the case studies and process analysis highlight which types of decisions could benefit from additional support, and which recurring patterns shape AM redesign, highlighting the need for a structured approach that supports designers during the early decision-making stages of the redesign process. These findings define the opportunity space for the to be developed redesign framework, one of the core deliverables of this thesis. Building on these insights, the next chapter synthesizes the research outcomes into a design vision, identifies the users and stakeholders involved, and formulates the requirements that the redesign framework must fulfill.

6. Design vision and requirements

This chapter discusses the next step in developing a design solution in the form of a redesign framework that supports Philips designers in adapting Personal Health spare parts for reliable consumer 3D printing. It brings together the strategic foundation for the design framework developed in chapter 3; the framework for identifying and redesigning parts for AM within Philips developed in chapter 4 and the consolidated insights from the explorative redesign of four representative parts as presented in chapter 5, in order to provide actionable guidance, design principles, and workflow structure for future redesign efforts. Chapter 3, 4 and 5 have shown that the framework should focus on the early stage concept generation and decision making phase, where printability constraints, part requirements, and redesign opportunities must be established. This chapter will consolidate learnings into design drivers, describe the envisioned stakeholders and users, formulate a design vision and formulate requirements to guide the design process in subsequent chapters.

6.1 Design drivers

From chapters 3 and 4, four user and workflow drivers can be derived. From chapter 5, four feature and functionality drivers can be derived. They are based on key insights and practical learnings.

User and workflow drivers

1. Ensure scalable framework

The framework must support current eligible parts and allow easy extension as new parts or requirements emerge.

2. Design for future user base

Make the framework usable for Philips engineers and designers, as well as external contributors as contributor capacity expands.

3. Integrate with existing workflows

Embed the framework into Philips processes and data sources to minimize disruption and leverage information that is readily available.

4. Include all stakeholders

Provide accessible explanations of AM capabilities so non-engineering decision-makers can effectively participate in eligibility and redesign decisions.

Feature and functionality drivers

5. Leverage cluster best practices

Leverage best practices from existing redesigns and provide guidance on when and how to reuse these learnings.

6. Guide redesign space

Help users identify the specific redesign space of a part where changes are possible and effective within part constraints.

7. Prioritize usage-driven constraints

Prioritize constraints driven by part performance needs (surface, strength, tolerances) over constraints imposed by manufacturing technology.

8. Highlight trade-offs and interrelations

Make dependencies between design choices visible to guide informed decisions.

6.2 Envisioned stakeholders

The envisioned stakeholders can be derived from the end-to-end workflow. On a high level the envisioned workflow is as following:

Assess and nominate parts
Procurement and supply chain teams evaluate feasibility and nominate candidate parts.

Confirm AM eligibility
AM expert validates technical suitability and documents printability constraints.

Redesign part
Initial redesigner performs the redesign based on eligibility and constraints.

Create final CAD model
CAD engineer produces the final CAD file using redesign outputs and AM documentation.

Finalize and approve for production
AM expert completes printability documentation and signs off for production.

To translate the design vision into practice, it is needed to define who the user will be of the redesign framework. As can be seen in the workflow, the primary user is the initial redesigner, who converts eligibility and technical constraints into actionable redesign concepts. This “front-end” role differs from the CAD specialist responsible for producing the final file, making it essential that the framework supports early-stage decision-making while ensuring a smooth transition downstream.

Currently with Fixables, this front-end step is handled by Philips engineers with 3D printing experience primarily from a hobbyist background, while dedicated CAD engineers finalize models and an agency (Prusa) performs printability checks. As capacity expands, Philips designers or external contributors may take on redesign tasks. Therefore, the framework cannot assume prior familiarity with parts and must remain intuitive for diverse users. Additionally, procurement and supply chain teams play a role in assessing feasibility and nominating parts, requiring basic understanding of AM capabilities.

Thus, the primary users of the redesign framework are the engineers and designers, internal or external, who take on the initial redesign step. These users are generally familiar with CAD and 3D printing, but not necessarily with designing end-use parts for consumer AM. The framework must therefore support them in developing the reasoning and mindset required for designing functional AM end-use parts.

6.3 Design vision

To guide the development of the redesign framework, the insights from the research phase were synthesized into a design vision. This vision is grounded in the insights derived from Chapters 3–5. Chapter 3 established home printing as the near-term horizon in the long-term AM roadmap, with future scalability regarding production and business models depending on developments in regulation, certified materials, and professional AM ecosystems. Chapter 4 showed that most of the currently eligible CRPs fall within the capabilities of consumer FDM printing. Chapter 5 proved for a selection of parts that reliable design is achievable with this production model and also highlighted the opportunity for early stage guidance in the redesign process.

Given that there are horizons to work towards, and in line with the original design challenge (see Chapter 1.2), the redesign framework should support a scalable approach. Focusing the redesign framework on consumer printing does not narrow the long-term ambition of a scalable AM-driven spare parts strategy. Instead, it enables scalability along a second, equally essential axis: increasing the number of designers capable of producing AM-ready parts. Regardless of whether future production occurs through home printing, licensed hubs, or OEM-controlled AM, designers will need to understand how to translate functional requirements into AM-friendly geometry. Developing this competency now, on the production model that is immediately feasible, creates the foundation for later expansion of eligible parts and production pathways.

Therefore, the design vision is to provide early-stage guidance that builds this shared AM redesign mindset while remaining adaptable to future production models. The framework focuses on consumer printing because this is the current entry point into AM for Philips PH, while the structure, reasoning steps, and requirement-driven logic can intentionally designed to be flexible, so the framework can evolve as AM capabilities expand. The resulting design vision expresses the overarching intention of the framework.

Design vision

"Enable designers to develop a shared way of thinking when redesigning Philips Personal Health parts for consumer 3D printing by providing a framework that offers structured guidance and highlights feasible redesign directions without relying on prescriptive rules, focusing on the early exploration phase of the redesign process."

6.4 Design requirements

To translate the insights from the research chapters into a design framework, a list of design requirements is compiled. These requirements are based on findings from the research, the project scope as well as wants from Philips. This will be used to evaluate ideas generated in the ideation phase as well as the final redesign framework. The requirements are categorized under Project Goals, Project Scope, User Goals, Features & Functionalities and Embodiment (see tables 7-11).

Table 7: Project scope requirements

Project scope requirements	**Source**	**Mandatory/ desirable**
Req. 1: The redesign framework should provide a repeatable, documented process for redesigning Philips Personal Health spare parts for additive manufacturing.	Philips	Mandatory
Req. 2: The redesign framework should target methods and constraints for: • FDM printing using PLA or PETG. • Post-processing steps such as support removal and sanding.	Chapter 3; Chapter 5	Mandatory
Req. 3: The redesign framework should be extensible to additional processes, materials, and workflows.	Chapter 3; Chapter 4	Mandatory

Table 8: Project goals requirements

Project goals requirements	**Source**	**Mandatory/ desirable**
Req. 4: The redesign framework should help minimize iterations needed for successful AM redesign.	Chapter 5	Desirable
Req. 5: The redesign framework should ensure redesigned parts follow consistent design principles based on cluster-based precedents across the printable parts portfolio.	Chapter 5	Desirable
Req. 6: The redesign framework should ensure that geometric changes are kept to a minimum while ensuring printability.	Philips	Desirable
Req. 7: The redesign framework should ensure redesigned parts remain functionally equivalent to their traditional counterparts.	Philips	Mandatory

Table 9: User need requirements

User need requirements	**Source**	**Mandatory/ desirable**
Req. 8: The redesign framework must be usable by all envisioned users, including • Philips designers and engineers. • External contributors.	Chapter 6	Mandatory
Req. 9: The redesign framework should communicate a clear, consistent decision-making approach so diverse users follow the same steps and reasoning.	Philips	Mandatory
Req. 10: The redesign framework should help users identify and apply the right design rules contextually.	Chapter 5	Mandatory
Req. 11: The redesign framework should clearly communicate what information users need for the process.	Chapter 5	Mandatory
Req. 12: The redesign framework should integrate with existing workflows and leverage available data.	Philips; Chapter 5	Mandatory

Table 10: Features and functionality requirements

Features and functionality requirements	Source	Mandatory/ desirable
Req. 13: The redesign framework should make use of examples from past cases and physical sample artifacts for tactile reference.	Chapter 5	Mandatory
Req. 14: The redesign framework should be based on Philips-rooted learnings and common failure modes to prevent repeated mistakes.	Chapter 5	Mandatory
Req. 15: The redesign framework should provide tools to identify areas requiring smoothness, strength, and dimensional accuracy, and map these to design strategies.	Chapter 5	Mandatory
Req. 16: The redesign framework should encourage use of cluster-based best practices.	Chapter 5	Mandatory
Req. 17: The redesign framework should recommend orientation and support strategies tailored to part usage constraints to reduce trial-and-error.	Chapter 5	Mandatory
Req. 18: The redesign framework should classify redesign effort into categories and route users to the appropriate category.	Chapter 5	Mandatory
Req. 19: The redesign framework should provide a non-technical communication layer for AM capabilities and limitations to support cross-functional understanding.	Chapter 4	Mandatory

Table 11: Embodiment requirements

Embodiment requirements		Mandatory/ desirable
Req. 20: The redesign framework should be usable by both individuals as groups.	Philips	Mandatory
Req. 21: The redesign framework should be accessible for all stakeholders.	Chapter 5	Mandatory
Req. 22: The redesign framework should invite (tactile) interaction.	Chapter 5	Mandatory

6.5 Concluding chapter insights

This chapter consolidated the insights from the research phase into a strategic foundation for the redesign framework. It defined the design drivers derived from Chapters 3–5, identified the key stakeholders and primary users within the end-to-end workflow, and articulated the design vision that will guide the development of the solution. Building on this foundation, a set of requirements was formulated to ensure that the framework aligns with the derived insights as well as Philips' needs and ambitions.

In the following chapters, it will be explored how the redesign framework can be translated into tangible and useable components to support designers in the AM redesign process. The design requirements defined in this chapter will be used in chapter 8 to evaluate the developed redesign framework.

7.

Ideation and conceptualization

This chapter explores how the redesign framework can be translated into tangible and usable components that support designers during the early, exploratory stages of the AM redesign process. Building on the insights from the case-based research in Chapter 5 and the requirements defined in Chapter 6, the goal of this chapter is to examine different ways the framework could be embodied and to evaluate which directions best align with user needs and existing workflows.

The chapter begins by positioning the framework within the redesign process. It then evaluates several redesign tools that emerged throughout the research. Based on the insights from chapter 6 the core components of the framework are decided, ideation is done to explore how these components can be embodied. The chosen directions are further conceptualized and presented to stakeholders in the form of initial mock up prototypes. The chapter concludes with a clear view on how the framework will take shape, setting the foundation for the detailed embodiment in the following chapter.

7.1 Positioning of the framework in the redesign process

The following two insights are most relevant for shaping the framework:

- Most efficiency gains can be done early in the process where a lot of unnecessary print iterations took place to develop a viable concept.
- Successful redesign steps consider all part requirements (surface smoothness, dimensional accuracy and strength) individually, while being explicit about trade-offs.

Thus, the framework should target supporting the early stages of the design process, specifically the “Define” phase (see Chapter 5.3).

7.2 Evaluation of redesign tools

During the case-based redesign process performed during this research, several redesign tools were proposed, each addressing different aspects of the redesign process. The following sections summarize these concepts and explain why they were adopted or discarded. Figure 38 shows sketches of the ideation process of the redesign tool concepts.

1. Asset library

This concept involved developing a library of reusable features commonly found in Philips parts (e.g. comb teeth, locking hooks) that designers could insert directly into their models. Although it was found that this does speed up the design process, stakeholders noted that only a small set of features are sufficiently generic to be reused across different parts, and that for experienced CAD users it is not that difficult to build these features manually. Thus, the idea was discarded due to limited generalizability.

2. Philips standardized DfAM design guidelines

For portfolio consistency, as well as to simplify the redesign process, it would be beneficial to develop a standardized set of AM design rules for Philips to replace the many slightly different versions currently available. Though it is identified that this is a necessary step, the limited number of cases completed in this research are insufficient for generalizing design rules. Thus, this concept is marked as a necessary long-term step, but out of scope for this research.

3. Redesign decision pathway

This concept aims to define the different categories of redesigns that were derived from the research cases as well as previous and ongoing trials and to specify the corresponding pathway through the redesign process. This concept was continued with as the approach aligns well with research findings, and is thus adopted as the core structure of the framework.

4. Functional requirement visual cards

This concept introduces visual cards illustrating examples from the research cases to help designers consider functional part requirements in the context of AM, such as areas requiring smoothness, strength, or dimensional accuracy. This was also continued with as it provides the visual reference explaining why redesign decisions are made.

Tangible attribute

In addition to the functional redesign tool, it was determined that the framework should include a tangible attribute that showcases original IM parts and their AM counterparts printed in different AM technologies and materials. This component serves two functions:

- For designers it should offer tactile interaction with examples to guide redesign decisions
- For decision-makers unfamiliar with AM it should provide a hands-on understanding of the differences between traditional manufacturing and AM.

This display should also serve as a communication tool between people familiar with AM and people who are not, bridging technical and non-technical perspectives.

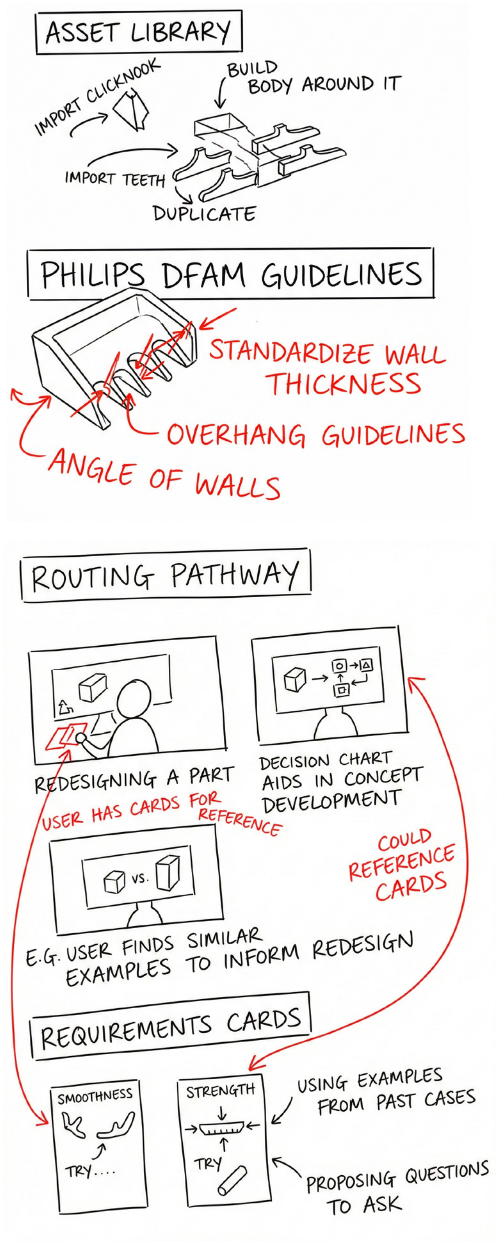
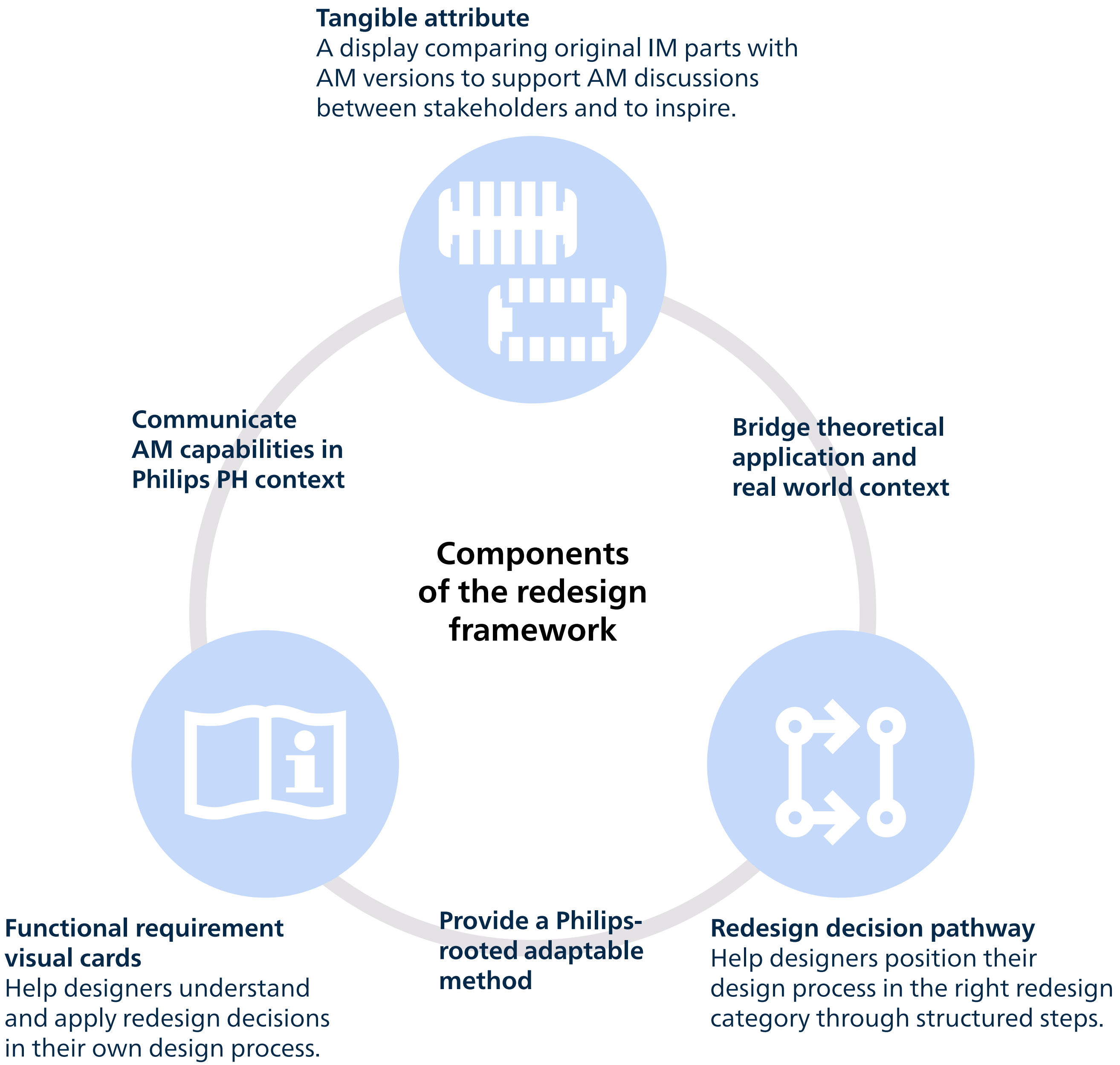


Figure 38: Sketches of redesign tool concepts

Figure 39 visualizes the three components that together form the redesign framework: the redesign decision pathway, the functional requirement visual cards, and the tangible prototype display. The decision pathway provides the structural backbone of the framework, guiding designers toward the appropriate redesign category and position their work in the broader workflow. The redesign guidance cards complement this by illustrating functional considerations through concrete examples. The tangible display complements both tools by offering physical reference points that bridge technical and non-technical perspectives. Combined, these elements create a coherent system that supports designers during the front-end of the redesign process.



Tangible attribute
A display comparing original IM parts with AM versions to support AM discussions between stakeholders and to inspire.

Functional requirement visual cards
Help designers understand and apply redesign decisions in their own design process.

Redesign decision pathway
Help designers position their design process in the right redesign category through structured steps.

Figure 39: Overview of the components of the redesign framework

7.3 Ideation

Now that the components of the solution are defined, the next step is to explore how these components can be embodied in a way that fits the redesign process. The solution consists of two main elements that require embodiment:

1. Redesign guidance (the redesign decision pathway + visual example cards)
2. Tangible display (physical examples of IM vs AM parts)

This section explores how each of these could be embodied and motivates the direction chosen for the final design.

HOW TO OFFER REDESIGN GUIDANCE

The core question guiding this ideation phase is: *How might we offer designers effective guidance during the (re)design process for AM?*

To explore this, an ideation was conducted (see figure 40) to map different potential embodiments. These ideas were structured into three main clusters:

1. Physical embodiments for the redesign decision pathway (bottom right)
2. Physical embodiments for the visual example cards (bottom left)
3. Digitial embodiment (top)

SELECTING AN APPROPRIATE EMBODIMENT

When considering the use case, it is essential that the tool fits naturally into the designer's workflow. Several context factors guide the embodiment direction. Firstly, designers work in both physical and digital environments. Secondly, design occurs as individual desk work as well as collaborative sessions. Considering existing

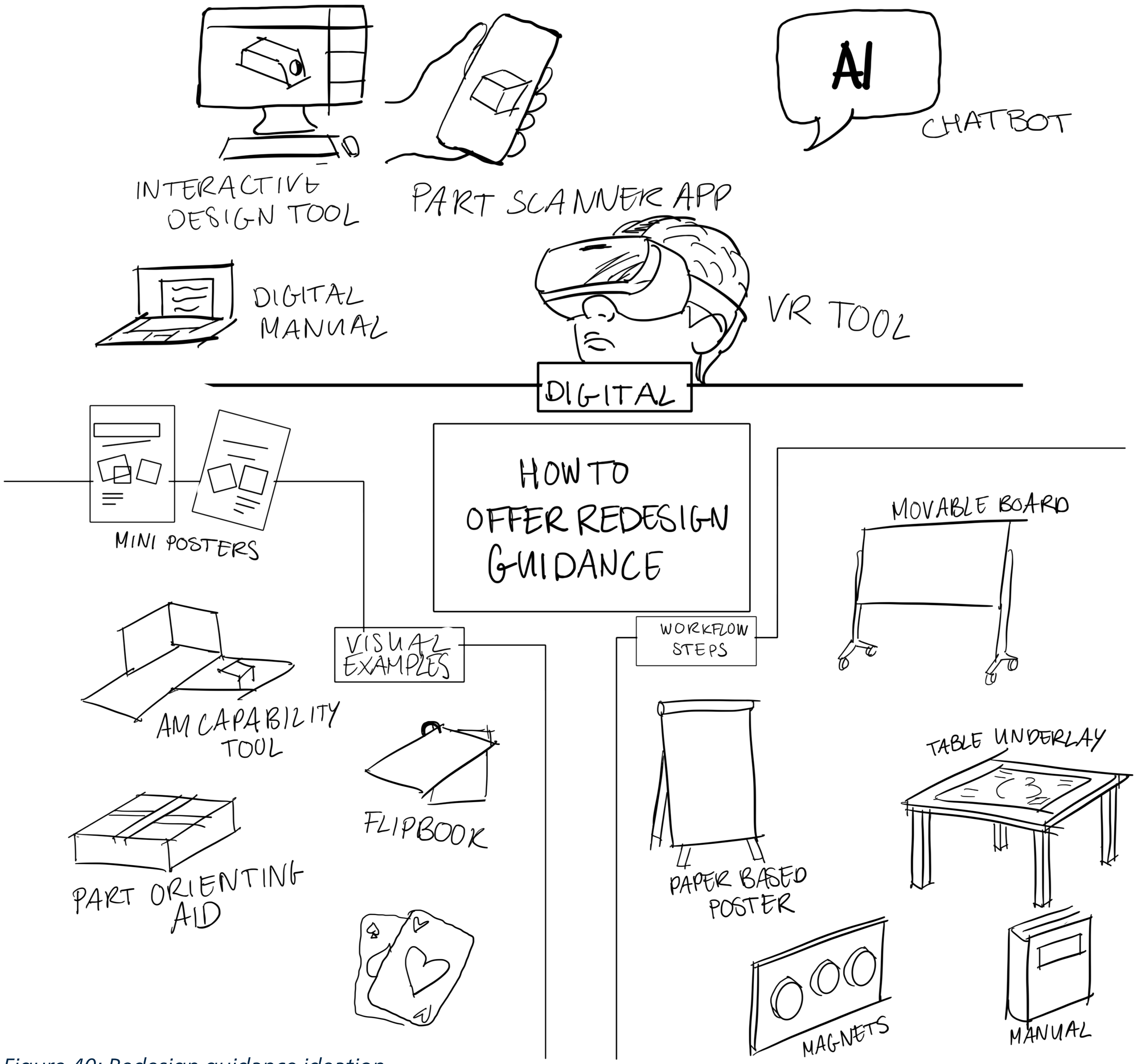


Figure 40: Redesign guidance ideation

tools in this context, wall posters and their digital counterparts, as well as miro boards already exist as embodiments of design tools. Whiteboards or project boards, or a digital version in Miro, are used in collaborative sessions. In line with these established practices, a poster-based hybrid system emerged as the best fit. The posters can be printed in different sizes depending on the setting, while they also remain available in digital form for flexible use. The decision pathway, forming the core of the guidance, could be a bigger poster, whereas the redesign guidances cards could be smaller (e.g. A5) to also encourage individual use in a format suitable for quick reference.

PROTOTYPE DISPLAY

To determine how the prototype display should be embodied, several questions were explored: *Where should it be placed? How should people interact with it? And what should it communicate?*

Placement

Figure 41 shows an ideation on places where the display could stand based on a typical layout of a design studio. Figure 42 shows an ideation on how to attach the prototypes given these different scenarios. As the display needs to serve multiple stakeholders and should invite interaction, it must be placed somewhere highly visible and approachable. Furthermore, to encourage interaction, it should not appear fragile or inaccessible. Hanging it on a wall limits visibility and is less intuitive regarding touch. Placing it as a standalone object may make it seem less approachable or fragile. Given this, the recommended placement is on a cabinet or central surface in the middle of a room, where it

Figure 41: Ideation on placement of the display

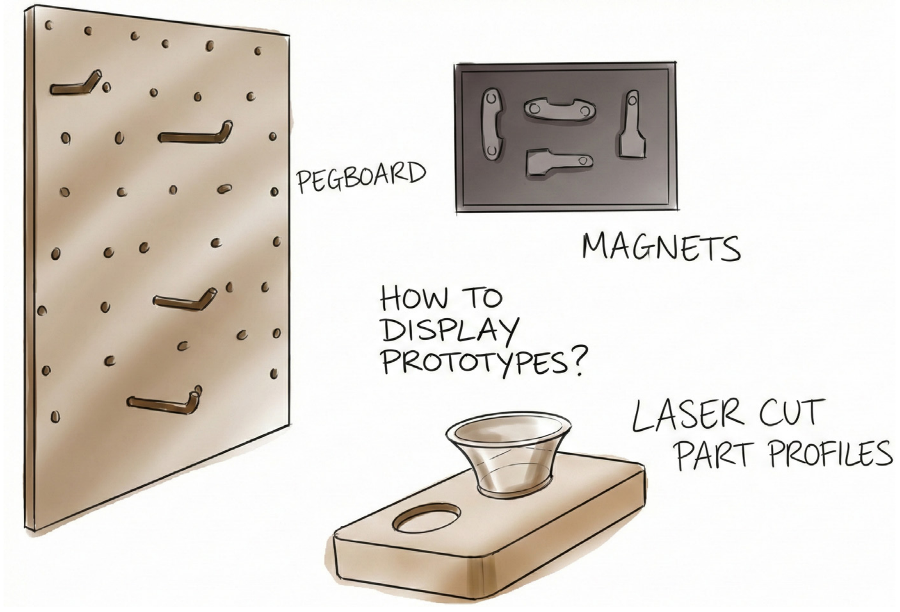


Figure 42: Ideation on display embodiment

is visible from all sides and naturally encourages people to walk up to it and pick up the parts. As for embodiment, this would make a laser cut display with the profiles of the part etched into it for accurate placement the most suitable option.

Interaction

A key goal of the display is to invite tactile exploration. The prototypes should not be glued down; users should feel free to lift them, compare them, and observe details up close. The display should entice people to:

- Touch and hold the parts
- Compare IM vs AM versions
- Notice differences in surface finish, strength, flexibility, and geometry
- Learn by physically experiencing the material and printer outcomes

Small cues such as an icon ("Touch me") or a QR code linking to supporting material can reinforce this invitation. Furthermore, the parts should be arranged in a logical sequence that tells a clear story. For example, prototypes that most closely resemble the original part can be placed nearest to it, encouraging users to compare them directly. Prototypes with a noticeably different surface finish or quality can be positioned further away to intuitively signal that they are less accurate matches. A visual indication can be added to signal what is considered the best suited prototype. Figure 43 shows an exploration of a part layout.

Because the display must bridge technical and non-technical understanding, the information presented must remain clear, simple, and experiential rather than overly technical. Figure 44 shows an overview of information it could communicate.

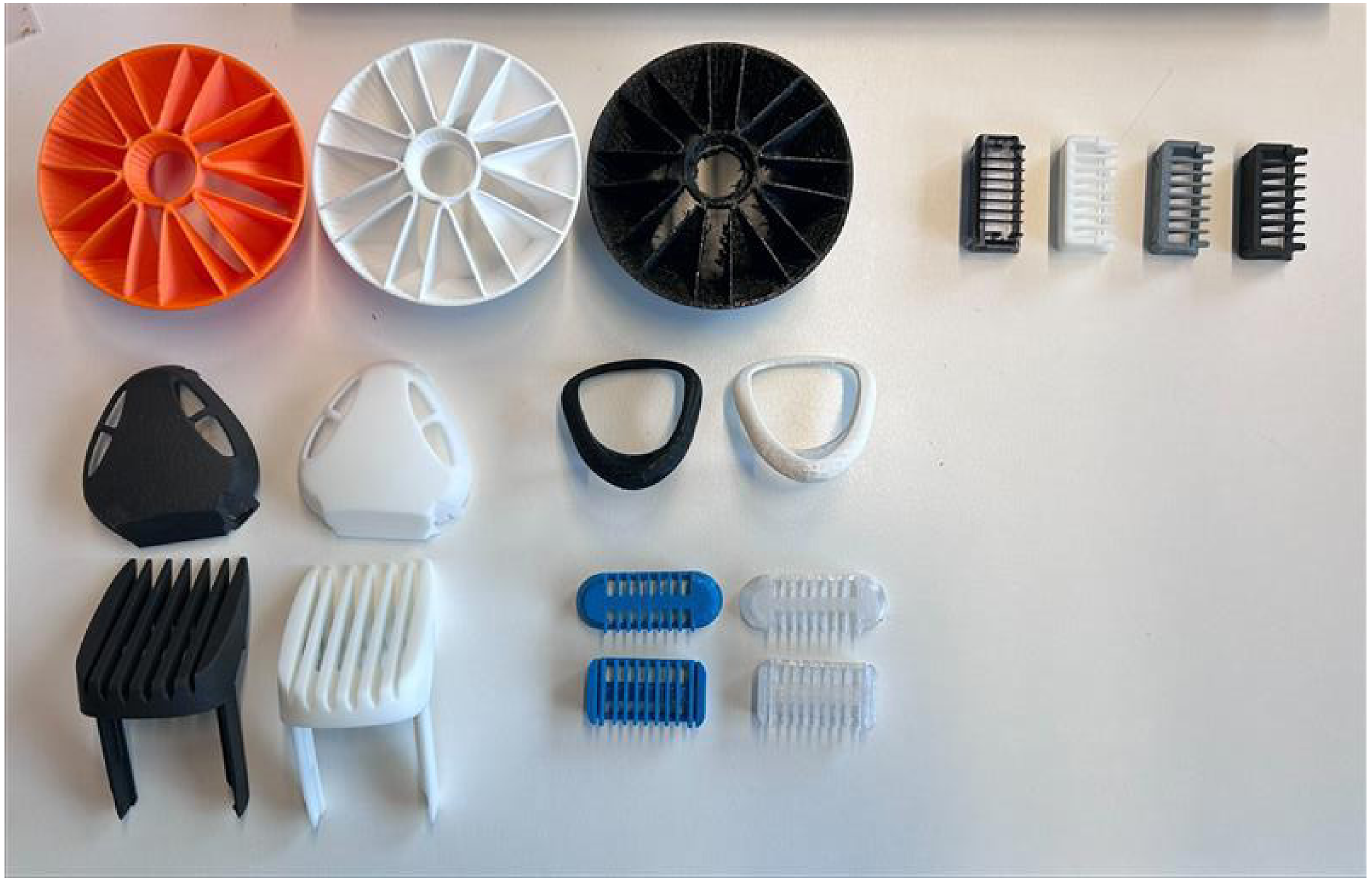


Figure 43: Exploration of part layout

Part-related information

Part name / number

Production technique,

Material

Other inviting cues

Performance highlights

"Touch me"

QR code linking to redesign materials

Figure 44: Display information ideas

7.4 Conceptualization

This section shows the key steps from the conceptualization process of the components of the framework.

FRAMEWORK

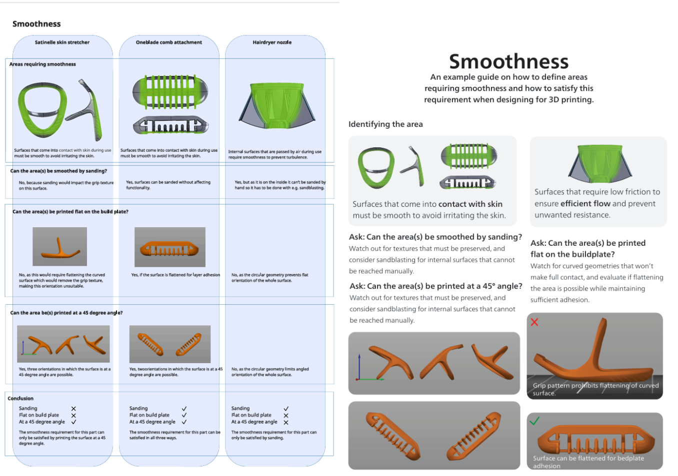
To translate the selected components of the framework into a usable form, two initial concept directions were developed: a workflow poster and two versions of the redesign guidance cards (figure 45). Refer to Appendix A8 for the full sets. These early prototypes focused on testing how the redesign decision pathway and functional requirement cards could be communicated clearly.

These concepts were presented in their printed form (figure 46) to three Philips designers for early feedback. From this the following insights were gained:

- Between the two concepts for the visual cards, Concept 2 was preferred for visual style, but the hierarchy of Concept 1 was preferred for structure, specifically if the purpose is to follow specific steps. Given that the design vision was to not not be prescriptive, it was decided to continue with concept 2.
- The layout of the workflow poster was seen as clear.

PROTOTYPE DISPLAY

To determine the arrangement of parts and information, several layout concepts were sketched and compared (figure 47). It was found that with all the intended information to display as well as handling the different sizes of the parts the portrait layout was the best suited option. Mock-ups were developed in Illustrator to evaluate proportions, text readability, and part spacing (figure 48). These were shared with stakeholders, who noted that the initial visual density was too high. This feedback informed the decision to reduce the number of displayed parts as well as reduce the amount of text and cues, as the current setup was visually too overwhelming.



Smoothness

	Satinelle skin stretcher	Oneblade comb attachment	Hairdryer nozzle
Areas requiring smoothness	Surfaces that come into contact with skin during use must be smooth to avoid irritating the skin.	Surfaces that come into contact with skin during use must be smooth to avoid irritating the skin.	Internal surfaces that are passed by air during use require smoothness to prevent turbulence.
Can the area(s) be smoothed by sanding?	No, because sanding would impact the grip texture on this surface.	Yes, surfaces can be sanded without affecting functionality.	Yes, but as it is on the inside it can't be sanded by hand so it has to be done with e.g. sandblasting.
Can the area(s) be printed flat on the build plate?	No, as this would require flattening the curved surface which would remove the grip texture, making this orientation unsuitable.	Yes, if the surface is flattened for layer adhesion	No, as the circular geometry prevents flat orientation of the whole surface.
Can the area be(s) printed at a 45 degree angle?	Yes, three orientations in which the surface is at a 45 degree angle are possible.	Yes, twoorientations in which the surface is at a 45 degree angle are possible.	No, as the circular geometry limits angled orientation of the whole surface.
Conclusion	Sanding ✗ Flat on build plate ✗ At a 45 degree angle ✓ The smoothness requirement for this part can only be satisfied by printing the surface at a 45 degree angle.	Sanding ✓ Flat on build plate ✓ At a 45 degree angle ✓ The smoothness requirement for this part can be satisfied in all three ways.	Sanding ✓ Flat on build plate ✗ At a 45 degree angle ✗ The smoothness requirement for this part can only be satisfied by sanding.

Smoothness

An example guide on how to define areas requiring smoothness and how to satisfy this requirement when designing for 3D printing.

Identifying the area

Surfaces that come into **contact with skin** must be smooth to avoid irritating the skin.

Surfaces that require low friction to ensure **efficient flow** and prevent unwanted resistance.

Ask: Can the area(s) be smoothed by sanding?
Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

Ask: Can the area(s) be printed at a 45° angle?
Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

Ask: Can the area(s) be printed flat on the buildplate?
Watch for curved geometries that won't make full contact, and evaluate if flattening the area is possible while maintaining sufficient adhesion.

✗ Grip pattern prohibits flattening of curved surface.

✓ Surface can be flattened for bedplate adhesion

Figure 45: Examples of visual card concepts (left is concept 1 and right concept 2)

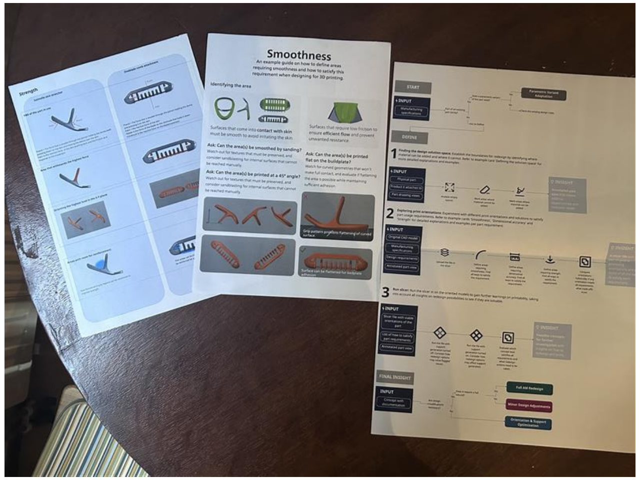


Figure 46: Printed framework examples

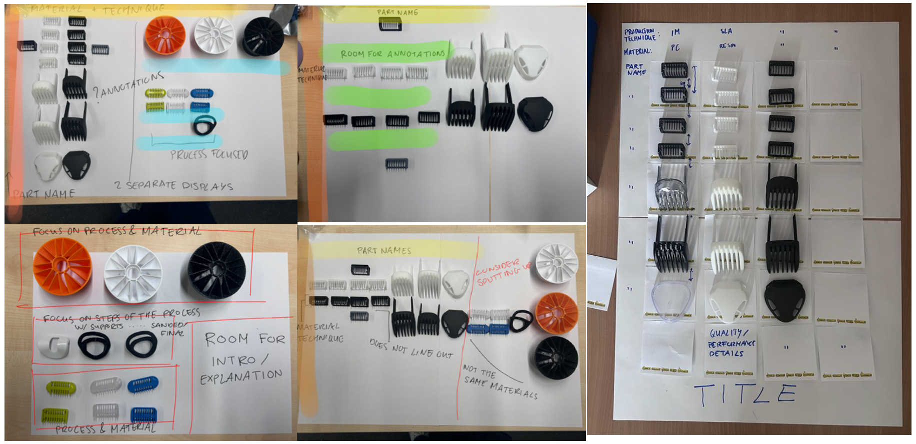
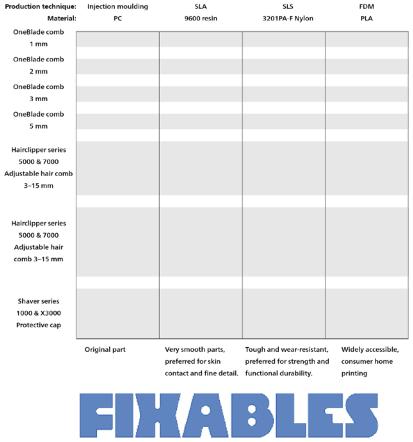


Figure 47:Exploration of part layouts



Production technique:	Injection moulding	SLA	SLS	FDM
Material:	PC	9600 resin	3201PA-F Nylon	PLA
OneBlade comb 1 mm				
OneBlade comb 2 mm				
OneBlade comb 3 mm				
OneBlade comb 5 mm				
Hairclipper series 5000 & 7000 Adjustable hair comb 3–15 mm				
Hairclipper series 5000 & 7000 Adjustable hair comb 3–15 mm				
Shaver series 1000 & X3000 Protective cap				
	Original part	Very smooth parts, preferred for skin contact and fine detail.	Tough and wear-resistant, preferred for strength and functional durability.	Widely accessible, consumer home printing

FIXABLES

Figure 48:Illustrator mockup

7.5 Concluding chapter insights

The ideation and conceptualization activities in this chapter resulted in a clear definition of the three components that form the redesign framework:

1. The redesign decision pathway, which helps designers position themselves within the redesign process and guides them toward appropriate solution spaces.
2. The redesign guidance cards, which illustrate how functional needs such as smoothness, strength, and dimensional accuracy translate into design decisions, using real examples from the case studies.
3. The tangible prototype display, which showcases original IM parts alongside their AM counterparts to support both designer reasoning and cross-functional communication.

Through iterative exploration and intial stakeholder feedback, these components were synthesized into concept directions. The decision pathway and visual cards will be realized as a poster-based system, suitable for both individual and collaborative design work, while the prototype display will take the form of a laser-cut board placed on a central surface, inviting tactile exploration and facilitating AM discussions across stakeholders.

8.

Embodiment

This chapter presents the developed redesign framework that enables redesigns of Philips Personal Health Consumer Replaceable Parts for AM. Building on the insights and requirements, established in earlier chapters, it details how the framework is configured, how each component functions, and how the components work together to guide designers toward consistent and efficient redesign decisions.

The design vision for the framework was:

"Enable designers to develop a shared way of thinking when redesigning Philips Personal Health parts for consumer 3D printing by providing a framework that offers structured guidance and highlights feasible redesign directions without relying on prescriptive rules, focusing on the early exploration phase of the redesign process."

The final solution consists of three integrated components (figure 49):

- A redesign decision pathway: a pathway that guides designers into the correct AM redesign category and provides structured steps for establishing the solution space during the Define phase.
- Redesign guidance cards: example-based cards that translate key part requirements into concrete design strategies to support the decision pathway.
- A prototype display: a physical set of AM and their IM counterparts that enables hands-on exploration, supports early-stage decision-making, and acts as a communication tool across technical and non-technical stakeholders.

Together, these elements form a comprehensive framework that reduces unnecessary print iterations, clarifies redesign boundaries, and increases portfolio coherence across redesign efforts.

The redesign guidance cards and decision pathway are also included as separate PDF files for those interested in viewing the full sized versions.

Figure 49: Redesign framework

To support understanding of how the framework is used in practice, a storyboard was created to visualize a typical interaction with the three components: the prototype display, the decision pathway, and the visual guidance cards. Figure 50 illustrates an example of the intended use.

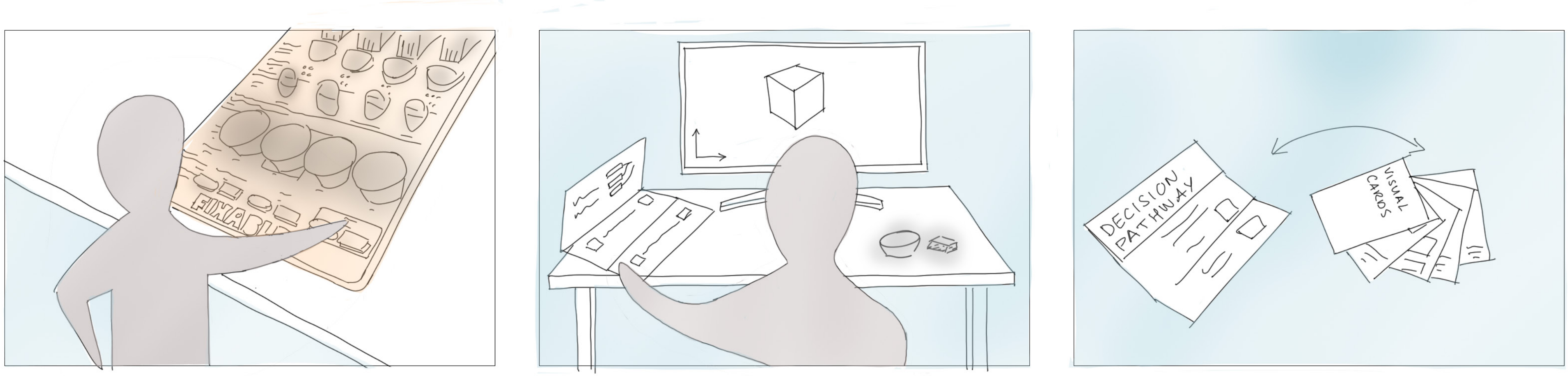


Figure 50: Storyboard of the use of the redesign framework

The designer begins by interacting with the prototype display, which showcases original IM parts alongside their AM counterparts. They can pick up prototypes and take with them any examples that may be of interest to them.

This tactile reference helps them understand how materials, technologies, and redesign choices translate into physical outcomes.

Next, the designer uses the Redesign Decision Pathway to structure the early stages of the redesign. They can also refer to the prototypes (they selected) from the display, using them as tangible reference points throughout this process.

The pathway guides them through redesign concept development before making any geometric changes.

Throughout this process, the designer can refer to the Visual Guidance Cards for concrete examples and Philips-rooted insights.

The cards expand on the pathway by illustrating how to handle smoothness, dimensional accuracy, strength, and solution-space reasoning, helping designers apply these principles directly to their part.

8.1 Redesign decision pathway

The redesign decision pathway is the central operational component of the framework. It structures the Define phase and guides designers through a set of steps that ultimately places each part into the correct redesign category.

The pathway functions as a handover between manufacturing specifications and design modeling activities. Its purpose is twofold:

- Ensure designers understand the redesign boundaries before making geometric changes.
- Guide designers into the appropriate redesign category early, preventing over-engineering or failing to recognize when a full rebuild is required.

The following section will describe each step in the pathway. Figure 51 shows the start and first step.

Step 0: Check for parametric variants

Before entering the Define phase, the designer evaluates whether the part belongs to an existing part family for which a validated AM redesign already exists.

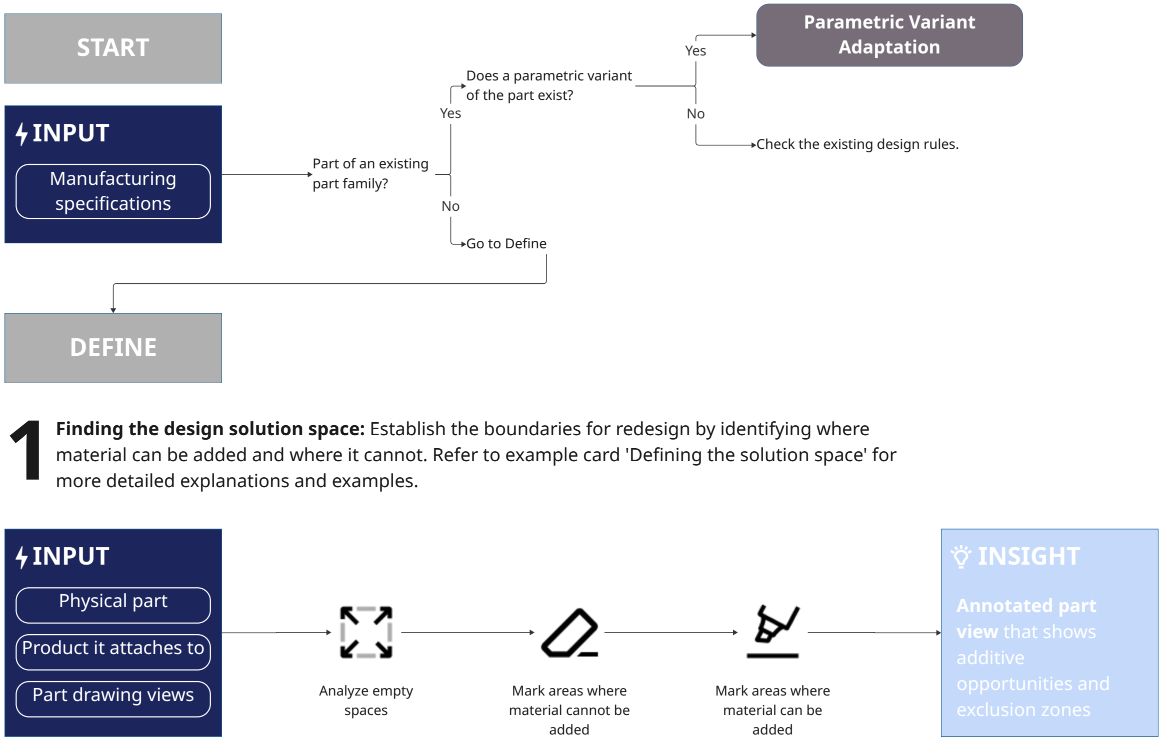
If yes, the part follows the Parametric Variant Adaptation route and bypasses the remainder of the pathway. If no, the designer proceeds into the full Define workflow.

Step 1: Establish the solution space

This first step clarifies where material can and cannot be added. Designers use the “Finding the modifiable areas” card (see Section 8.2) to:

- Identify functional voids that must remain open
- Mark areas where added material would interfere with assembly, airflow, hair passage, or safety constraints
- Highlight regions that can be reinforced or closed, often originally shaped for IM constraints

The output of this step is an annotated part view showing opportunities and exclusion zones. This prevents unrealistic redesign concepts and anchors the subsequent AM feasibility analysis in functional constraints.



Finding the design solution space: Establish the boundaries for redesign by identifying where material can be added and where it cannot. Refer to example card 'Defining the solution space' for more detailed explanations and examples.

Figure 51: Framework step 1

Step 2: Explore print orientations through part requirements (figure 52)

After establishing the solution space, designers evaluate print orientations through the lens of three functional part requirements:

- Smoothness (e.g., skin contact zones, airflow channels)
- Dimensional accuracy (e.g., click attachments, interfaces with consumer products)
- Strength (e.g., load-bearing features or high-stress regions)

For each requirement, designers use the corresponding visual cards to identify all ways the requirement could be satisfied (e.g., sanding, 45° orientation, parallel-to-bed printing).
Multiple promising orientations are explored, and each orientation is assessed for whether it satisfies each requirement individually before considering the full trade-off set.

The output is:

- A slicer file with several promising orientations
- A summarized list of all ways that each requirement could be fulfilled
- Annotated images highlighting requirement-relevant surfaces

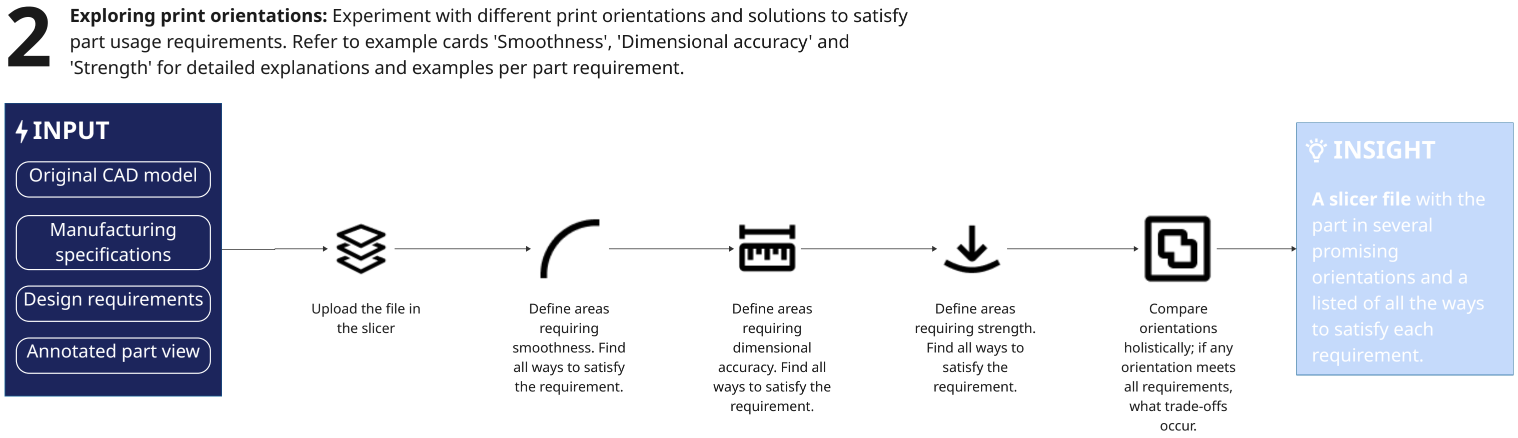


Figure 52: Framework step 2

Step 3: Run slicer simulations (figure 53)
The slicer is used n to validate the feasibility of the orientations identified in Step 2.

Designers run the slicer in:

- A version with supports turned off to reveal unsupported features, overhangs, and fragile geometries
- A version with supports turned on to assess effort, accessibility, and how redesign options may reduce unnecessary support structures

The result is a set of feasible concepts with clear documentation of how each orientation performs and what redesign actions they require.

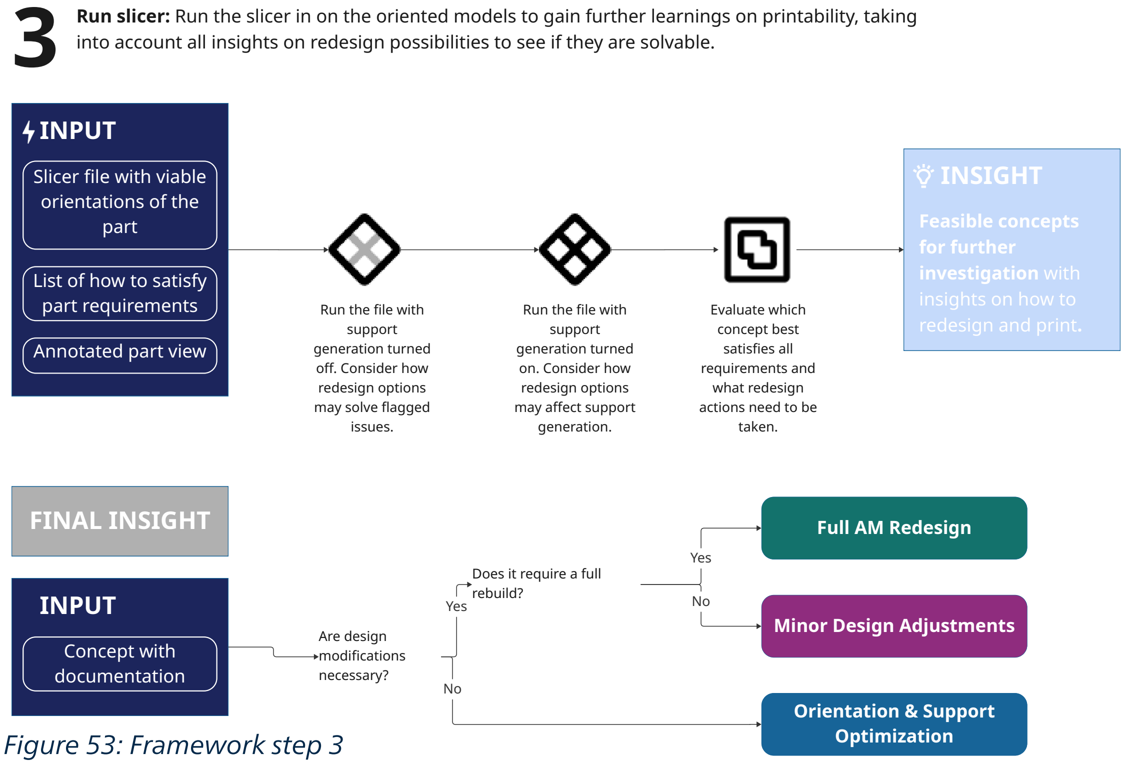
Step 4: Select redesign category
Based on the insights gained from Steps 1–3, the designer evaluates:

- Whether feature modifications are necessary
- Whether modifications are additive or require redesign of original elements
- Whether the original geometry is fundamentally incompatible with AM

The pathway naturally leads the user to one of the three remaining redesign categories:

- Orientation & Support Optimization
- Minor Design Adjustments
- Full AM Redesign

This categorization determines the appropriate entry point into the full redesign workflow and ensures no unnecessary modeling steps are taken.



3 **Run slicer:** Run the slicer in on the oriented models to gain further learnings on printability, taking into account all insights on redesign possibilities to see if they are solvable.

INPUT

Slicer file with viable orientations of the part

List of how to satisfy part requirements

Annotated part view

Run the file with support generation turned off. Consider how redesign options may solve flagged issues.

Run the file with support generation turned on. Consider how redesign options may affect support generation.

Evaluate which concept best satisfies all requirements and what redesign actions need to be taken.

INSIGHT

Feasible concepts for further investigation with insights on how to redesign and print.

FINAL INSIGHT

INPUT

Concept with documentation

Are design modifications necessary?

Yes

Does it require a full rebuild?

Yes

Full AM Redesign

No

Minor Design Adjustments

No

Orientation & Support Optimization

Figure 53: Framework step 3

8.2 Visual cards

The redesign guidance cards (figure 54-57) support the decision pathway by giving designers immediate, example-driven insights into how key AM constraints can be met for Philips parts. They act as rapid decision aids, ensuring designers do not rely solely on AM intuition but on Philips specific knowledge.

Smoothness

An example guide on how to define areas requiring smoothness and how to satisfy this requirement when designing for 3D printing.

Identifying the area

Surfaces that come into **contact with skin** must be smooth to avoid irritating the skin.

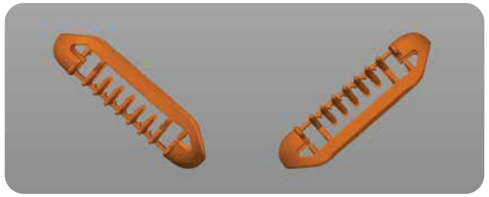
Surfaces that require low friction to ensure **efficient flow** and prevent unwanted resistance.

Ask: Can the area(s) be smoothed by sanding?

Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

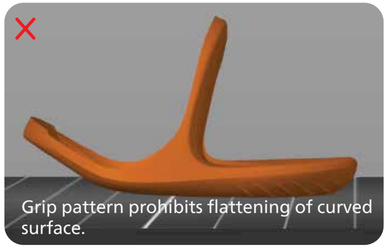
Ask: Can the area(s) be printed at a 45° angle?

Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

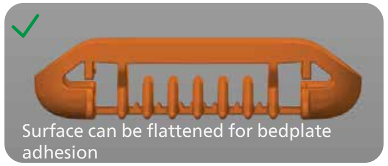


Ask: Can the area(s) be printed flat on the buildplate?

Watch for curved geometries that won't make full contact, and evaluate if flattening the area is possible while maintaining sufficient adhesion.



Grip pattern prohibits flattening of curved surface.



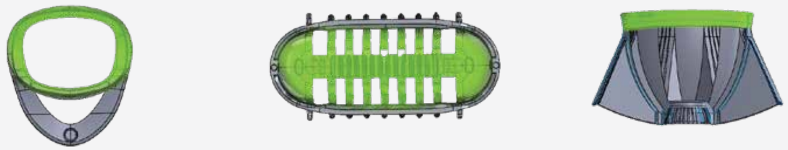
Surface can be flattened for bedplate adhesion

Figure 54: Smoothness card

Dimensional accuracy

An example guide on how to define areas that require dimensional accuracy and how to satisfy this requirement when designing for 3D printing.

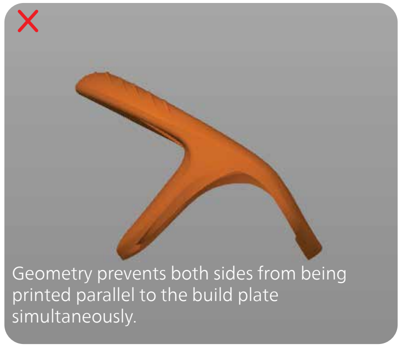
Identifying the area



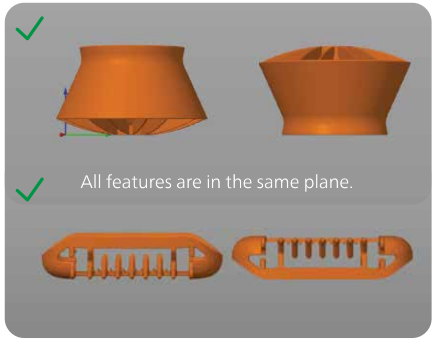
Identify all areas that **interface** with the device or assembly they attach to, look for features such as **click-fits,** or **alignment profiles** that must match precisely.

Ask: Can the area(s) be printed parallel to the build plate?

Consider whether all identified features lie in the same plane.



Geometry prevents both sides from being printed parallel to the build plate simultaneously.



All features are in the same plane.

Ask: Can the area(s) be printed with supports?

Explore how support structures could stabilize the identified features during printing.

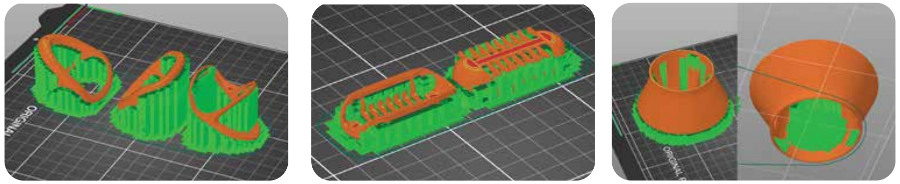
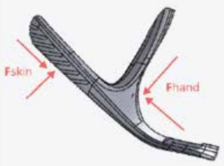


Figure 55:Dimensional accuracy card

Strength

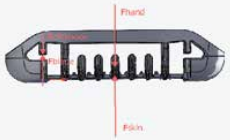
An example guide on how to define areas that require strength and how to satisfy this requirement when designing for 3D printing.

Free body diagram (FBD) of the part in use



Fhand: User-applied force pressing the device against the skin and driving its movement.

Fskin: Reactive force of the skin, including resistance to pressure and friction due to motion.



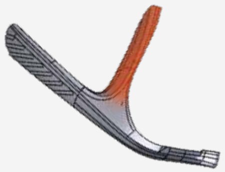
Fhand: User-applied force pressing the device onto the skin

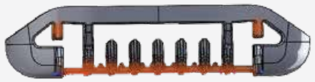
Fskin: Skin reaction force

Fblade: Force of the blade acting on the click hook

Fclickhook: Reactive force resisting blade motion

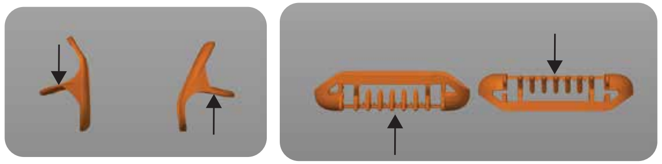
Find the area that withstands the highest force



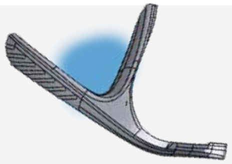


Look for **thin** or **unsupported** features where forces are **applied** or **transferred**.

Orient the highest load in the x-y plane



Free body diagram (FBD) of the part in use



Look for **non-functional empty regions** where material can be added, **thin features that can be thickened**, and **unsupported walls that could can have additional structural support.** Assess whether the reinforcements reduce the identified loads.

Figure 56: Strength card

Finding the modifiable areas

Step 1: Analyze Empty Spaces
Ask: Why does this empty space exist?

- Is it functional? (e.g., light passage, airflow, hair clearance)
- Is it aesthetic? (e.g., design language, user experience)
- Were these voids left for injection moulding material savings?

Step 2: Mark Areas Where Material Cannot Be Added
Examples:

- Adding material would block a functional path (light, hair, airflow).
- Adding material would interfere with assembly or movement.
- Adding material would violate safety constraints.

Step 3: Mark All Areas Where Material Can Be Added
Examples:

- Hollow sections created for injection moulding.
- Non-functional aesthetic gaps or cavities.
- Thin walls or ribs that could be thickened without affecting function.

Examples

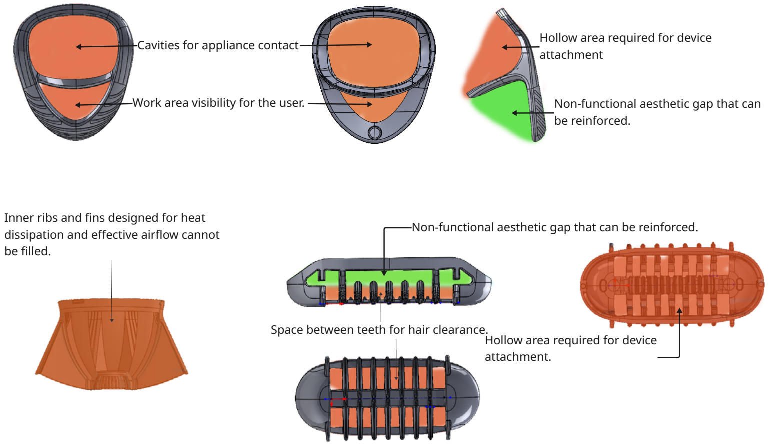


Figure 57: Modifiable areas card

8.3 Prototype display

The display, as shown in figure 58, is designed to serve as both an experiential learning tool and a communication medium. It includes:

1. Original IM parts
2. Their redesigned AM counterparts: Side-by-side examples printed in multiple AM technologies and materials
3. Annotated details showing manufacturing technology, material and high level details on charachteristics relating to the material or technology where relevant. For each part, the prototype that is considered the best fit is outlined.

This component serves three functions:

1. Facilitating redesign decision-making by allowing designers to physically compare features, support marks, surface quality, and structural behavior.
2. Accelerating onboarding for designers new to AM by making abstract concepts concrete.
3. Supporting decision-making conversations with technical and non-technical stakeholders.

Parts from Fixables printed in SLA, SLS and FDM to showcase differences in print technology capabilities

A selection of characteristics relevant to Philips Personal Health parts, compared across printing technologies using a dot-based scoring system to make differences immediately visible.

The four parts redesigned during this research, each illustrating a different redesign objective and printability challenge explored to help inform and inspire future redesign work

Figure 58: Prototype display

8.4 Requirements review

To assess how well the final redesign framework meets the defined requirements (see the design requirements listed in section 6.4), a requirement review was conducted. This review maps each component of the solution to the specific requirements it addresses. Figure 59 provides an overview of this mapping.

Some requirements could not be fully validated within the scope of this project. These include:
Req. 22 ; whether users actively engage with the tactile display during the design process
Req. 6 and Req. 4; whether the solution effectively minimizes geometric changes and reduces the number of redesign iterations in practice

These aspects require evaluation during future implementation or extended use.

Redesign decision pathway

The decision pathway provides a clear, traceable workflow with defined inputs, outputs, and checkpoints. By guiding designers toward the correct redesign category early, it reduces unnecessary iterations and offers a consistent decision-making structure across users and parts.

Requirements addressed: 1, 4, 5, 9, 11, 16, 18

Redesign guidance cards

The visual cards ground decision-making in concrete Philips precedents, and usage-driven constraints. They help designers define the solution space, interpret part requirements, and apply AM strategies contextually. New cards can be added as more cases emerge.

Requirements addressed: 2, 3, 6, 7, 8, 10, 12, 14, 17

Prototype display

The display introduces the tactile, experiential component of the solution. By allowing users to handle and compare IM vs. AM parts, it bridges technical and non-technical perspectives and supports cross-functional communication.

Requirements addressed: 13, 19, 22

Digital and physical availability of materials

Providing the framework in both physical and digital formats ensures it is usable in individual and group settings and accessible across different workflows and collaboration styles.

Requirements addressed: 20, 21

Figure 59: Requirements review

8.5 Concluding chapter insights

The embodiment of the framework brings together the redesign decision pathway, redesign guidance cards, and tangible prototype display into a single coherent system. These components collectively address the key redesign difficulties identified earlier:

- Reducing early-phase wasted effort
- Helping designers identify the correct redesign category
- Breaking down functional requirements into manageable decisions
- Ensuring portfolio coherence across part families
- Providing Philips-specific precedents to avoid repeating earlier mistakes

By guiding designers into the correct solution space, rather than prescribing exact geometric rules, the framework empowers informed, consistent, and efficient AM redesigns across the Personal Health portfolio. The following chapter will provide a validation of a selection of the components of the proposed redesign framework through a user test with Philips designers

9.

Evaluation

This chapter presents the user test conducted with Philips designers to evaluate selected components of the proposed redesign framework. It begins by outlining the goal and setup of the test, and then reports the aggregated insights derived from the participants' interactions with the materials.

Full test results can be found in Appendix B2, and the complete test plan is included in Appendix A9.

9.1 Test goal and plan

The primary goal of the user test is to understand how designers interact with the developed materials, and to assess whether the materials are clear and usable. Specifically, the test aims to explore:

- How intuitively participants navigate the redesign decision pathway
- Whether the redesign guidance cards are understandable and helpful
- How designers engage with the AM prototypes
- Whether the materials collectively help participants generate the expected redesign insights

Four Philips designers participated in the test.

9.2 Test materials and setup

Participants worked with the core components of the redesign framework:

- Printed versions of the decision pathway and the redesign guidance cards
- The AM prototypes developed during the research (not the full display)
- The physical part they are asked to analyze
- A printed worksheet with part views on which they can annotate their insights

It was deliberately decided to not include the full prototype display in the test, but merely the standalone prototypes, since the focus of the test was on testing of the contents of the provided materials.

Two parts were used for the exercise, either a OneBlade comb or a Satinelle skin stretcher, selected because they closely resemble the parts shown in the examples on the visual cards without being exactly the same, ensuring both familiarity and novelty.

Rather than creating a CAD model, participants have:

- Followed the steps of the redesign decision pathway
- Used the visual cards to interpret part requirements
- Marked insights on the provided part-view worksheet
- Demonstrated proposed print orientations physically using the part and AM samples

The facilitator observed and noted:

- How participants interacted with the material
- Which components they relied on most
- Where confusion or hesitation occured

After completing the task, participants were asked about:

- Their overall experience
- Clarity and usefulness of the materials
- Whether the materials supported their reasoning process
- Suggestions for improvement

9.3 Results

This section presents the aggregated findings from the user test with four Philips designers. The results describe how participants interacted with the three core components of the redesign framework, how they reasoned through the redesign task, and whether the materials supported them in generating the expected insights. Observations around clarity, usability, and designer behaviour are included throughout.

INTERACTION WITH THE DECISION PATHWAY AND VISUAL CARDS

Overall, participants understood both the decision pathway and the redesign guidance cards as intended. They were able to follow the steps in the pathway and interpret the role of each card without any help. However, the physical setup introduced some practical challenges. The large printed pathway and the loose visual cards created a cluttered workspace, and participants occasionally struggled to handle all materials simultaneously. A smaller, foldable format for the pathway, and e.g. a booklet structure for the visual cards could improve usability.

While all four participants had prior 3D printing experience, two participants were currently routinely engaged with 3D printing, while the other two had not recently engaged in 3D printing. The more experienced participants immediately began proposing concepts based on intuition and only consulted the cards afterward. The less experienced participants began by reading the cards before ideating. Both approaches are compatible with the non-prescriptive nature of the framework, but it highlights that highly experienced designers may feel less dependent on the detailed content of the cards.

All participants demonstrated correct understanding of the card content. One participant explicitly noted that the "Identifying the modifiable areas" card aligned extremely well with their natural problem-solving approach.

Another notable observation was that some participants used the reasoning steps as an opportunity to consider visual and geometric refinements, such as adding new curvartures or modifying shapes that they did not like in the original design. This suggests that designers instinctively take the freedom to propose their own redesigns, underscoring the value of a structured method to maintain alignment with the original geometry when that is required.

Across cases, the decision pathway and cards helped participants structure their thoughts and develop well-supported redesign concepts.

INTERACTION WITH PHYSICAL PART AND AM PROTOTYPES

Participants consistently interacted with the physical part and the original product. All participants began by familiarizing themselves with the attachment, placing it on the product, simulating use, and examining contact surfaces. The physical part was referenced throughout the task, especially for imagining print orientations and validating assumptions about smoothness and click-fit areas.

Interaction with the AM prototypes varied more widely. One participant in the OneBlade case did not interact with AM prototypes at all, explaining afterward that they were occupied with the other materials. This suggests that when many items are present, prototypes may be overlooked. A more prominent prototype display may help ensure they receive adequate attention. Even still the participant came to a well reasoned conclusion.

By contrast, another OneBlade participant interacted extensively with the AM prototypes and used them as inspiration for alternative printing strategies, mentioning that they thought they could do it better. This individual also had frequent personal 3D printing experience, and viewed prototypes as more insightful than the cards. This raises the question of whether failed prototypes or explanatory notes should be included to communicate why particular strategies are not viable, preventing participants from assuming they can "outperform" the examples shown.

Both participants working with the Satinelle case used AM prototypes primarily during the strength assessment step to gauge how printed material affects the durability of critical features. For most other steps, they relied mainly on the visual cards and the original part and product, stating that the cards were sufficiently clear.

ABILITY TO REACH EXPECTED DESIGN RESULTS

All participants identified the relevant redesign considerations and produced coherent, and well reasoned concepts. Specifically:

- They correctly identified areas requiring smoothness and recognized when sanding was necessary.
- They accurately identified accuracy-critical features such as click hooks and click ridges.
- They proposed appropriate reinforcement strategies for stressed or load-bearing features.
- They evaluated print orientations through both reasoning and physical manipulation of the part.

Although final proposed concepts differed slightly across participants, their reasoning was logically consistent with the framework. Figure 60 shows some key participant insights from the user test. One participant explicitly noted that their intuition originally suggested a different orientation, but reasoning through the cards led them to reconsider, demonstrating that the framework made their thought process more reflective and explicit.

All participants proposed at least two viable concepts, and one participant generated three concepts for further exploration. This indicates that the materials stimulated ideation rather than constraining it. Figure 61 on the next page shows an overview of the final proposed redesign concepts and print strategies.

OVERALL PERCEIVED USEFULNESS

All participants understood the potential value of these tools. The two designers more experienced with AM emphasized the usefulness for people

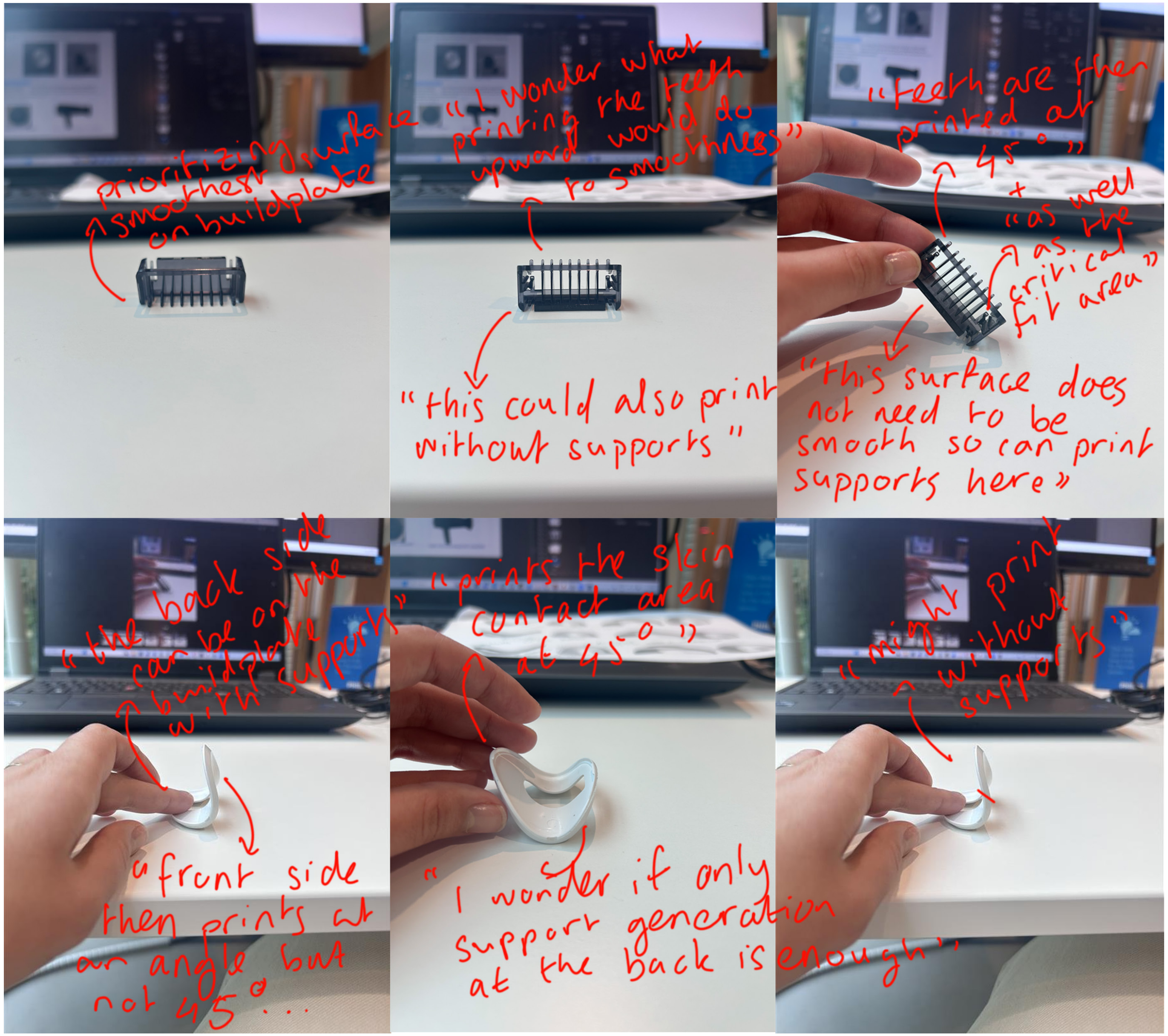


Figure 60: Insights from user test

with less 3D-printing experience, while noting that they themselves would rely more on their personal experience and reasoning. They mentioned that the provided information aligned with what they already intuitively knew. The two other participants, who were less routinely engaged with AM, noted that the cards helped them ideate and consider multiple redesign angles. This reinforces that while the materials provided are logical and understandable, they provide more value for less routinely experienced users.

From the observer's perspective, the materials made the reasoning process more explicit and structured. Even the experienced designers, who began ideating before reading the cards, became more deliberate and articulate about their reasoning once they engaged with the materials. While this does signal that the tools make the reasoning more explicit, for these two parts used in this test, it does not simplify the design task, especially not for more experienced users who might intuitively guess the final conclusion on the first try. This could be because the parts were not so complicated or different from the examples in the cards, or because the current card set is too general or obvious. Testing the framework with more complex parts is therefore recommended.

Though findings show that the framework is usable, designers with routine 3D printing experience may not feel compelled to use it. Though this setup of the framework was deliberately designed so users can interact as much as they need to, consistent interaction with the decision pathway is desirable for process traceability and consistency. Thus, a key recommendation is to explore how to properly

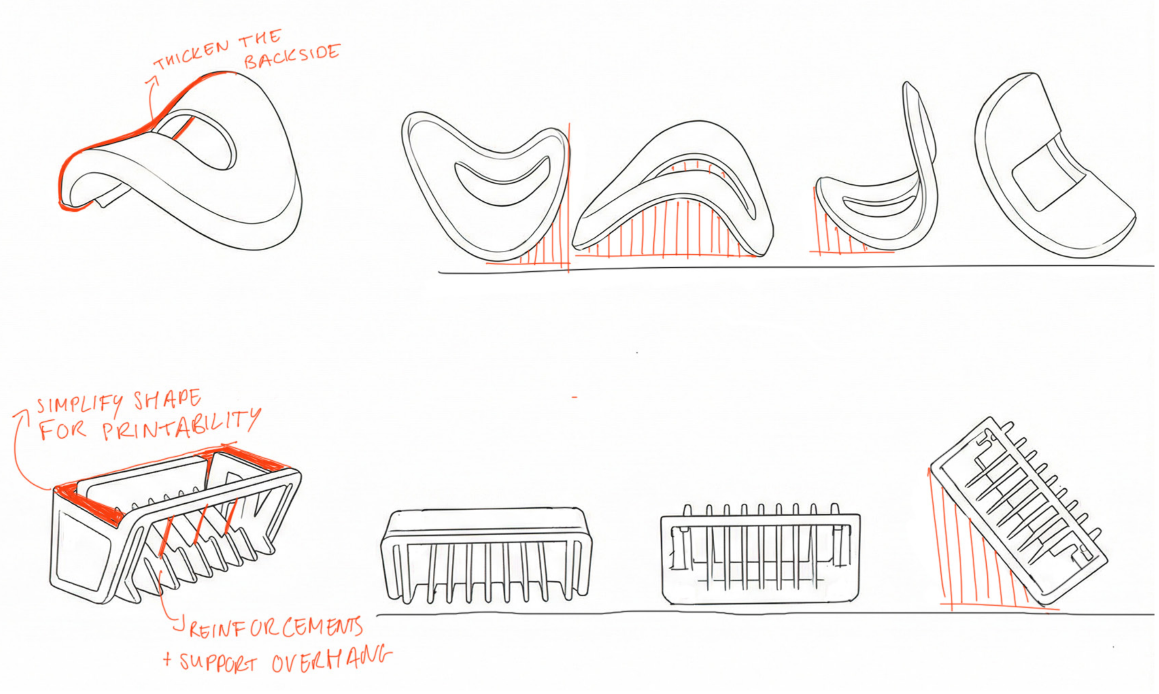


Figure 61: Final proposed redesign concepts and print strategies from the user test; part outlines were created using Vizcom

explain that this is why the tools are needed, not only to teach people who have little experience how to design for 3D printing.

9.4 Observation experiment with prototype display

An informal observation experiment was conducted to explore how the prototype display invites interaction. The display was placed on a desk without any additional explanation to observe spontaneous behaviour. People who encountered the display were visibly intrigued and approached it out of curiosity. They picked up the parts and interacted with them. People commented on the visual appeal of the setup, and several also expressed interest in understanding the purpose of the display.

Although this was not a structured test, these observations indicate that the display successfully fulfills its intended function, inviting engagement and encouraging tactile exploration, while also demonstrating potential to generate interest and visibility for the project.

9.5 Concluding chapter insights

The user test provides a clear indication of the strengths and remaining challenges of the proposed redesign framework. Evaluating the results from the perspectives of desirability, viability, and feasibility shows where the redesign framework has potential, while also highlighting areas that need refinement.

From a **desirability** perspective, the tests showed that participants understood why such a tool could be useful and were able to use the tools to generate AM redesign concepts. Designers with less routine 3D-printing experience explicitly stated that the cards and pathway supported their reasoning and helped them generate insights. The more experienced AM designers, however, did not feel the same personal need for the tools but acknowledged the value for people with less experience.

Considering this from a **viability** perspective, this becomes a concern, because the framework aims not only to support redesign but also to make the reasoning process more explicit and consistent. While the framework is purposefully designed to be non-prescriptive, allowing users to engage with the materials as much as they need to, it is still desirable that also experienced designers engage with the materials in some way to foster a shared way of thinking. A way to achieve this could be to design a workshop around the introduction of the framework to ensure that the purpose is clearly communicated.

From a **feasibility** perspective, the tests showed that the tools are understandable and lead to well-reasoned outcomes. Though only the paper-printed versions were tested, it was found that it is somewhat inconvenient to work with in current formats. While this does not say anything about the usability in a digital environment, further exploration of the printed embodiment is recommended, such as making the decision pathway foldable, and turning the visual cards into a booklet, so they have a more purposeful manifestation and don't take up as much space. Given the relative ease of implementing these changes, as printing the cards on A5 format and folding the workflow, does not require any redesign work regarding the content, this was already implemented in the final embodiment as shown in Chapter 8.

Thus, in their current form, the tools are understandable and effective in guiding designers' reasoning, but further refinement is needed regarding their physical format and the communication of their purpose. Future work could focus on improving the physical manifestation of the tools, conducting the test again with different parts to validate generalizability, and evaluating the use of the tools in both digital and group settings. These steps will help ensure that the framework is both practical and consistently adopted across varying levels of AM experience.

An informal observation experiment with the prototype display indicated that it effectively invites engagement and tactile interaction. However, a structured user test should still be done to fully validate this and to confirm the contribution to the framework.

10.

Discussion

10.1 Project discussion

This chapter provides a reflection on the project's outcomes across the three deliverables, followed by a broader discussion on the implications for Philips, limitations of the project and recommendations for future research.

FUTURE VISION ROADMAP

Chapter 3 proposed a strategic roadmap for integrating AM into the Philips PH spare parts ecosystem, outlining four horizons: Now, Short Term (2026), Near Future, and End Goal. The visual on the next page (figure 62) represents these same horizons and adds five layers that may influence the feasibility of each proposed horizon: product category readiness, market and consumer maturity, technical readiness of AM, business and production model evolution and legal and regulatory maturity.

Each row represents an overarching theme that this research identified as influencing the feasibility of AM for end-use parts from a company perspective. Each cell in Figure 61 shows an example of a key development within a theme that may be essential for enabling a specific horizon, or that may serve as a signal indicating whether a horizon is becoming feasible. By reading the figure horizontally (within each layer) and vertically (within each horizon), the roadmap shows both the necessary developments and the dependencies between factors.

The long term ambition is a fully hybrid AM enabled spare parts system in which consumer home printing, licensed local hubs and Philips controlled production coexist, and contributes to refurbishment and repair. Parts are dynamically routed between AM and traditional sourcing routes based on viability, requirements and service model needs. Through backcasting, three intermediate horizons were defined to reach this end state. In doing so, the roadmap successfully delivers the first project deliverable by translating the strategic findings into a clear and actionable direction for Philips.

The "now" horizon, DIY consumer printing through Philips Fixables, was found to be both feasible and inherently limited. The part selection and redesign work showed that consumer grade FDM printing can reliably produce functional, non critical parts within the grooming and beauty portfolio. Mother and child care and oral health care parts are excluded under current regulatory requirements. While the printed parts are functional, they do not match the quality of the original IM parts. And although some consumers are willing and able to print these parts, a substantial portion of the user base is excluded. For this reason, the only realistic business model at this stage is to offer the printable files free of charge. The value for Philips is therefore indirect, delivered through an enhanced service offering that supports repairability and may positively influence brand perception.

The "short term (2026)" horizon, proposes expanding Fixables to more than fifty parts. This ambition is supported by the part selection results: 133 consumer replaceable parts across PH were found eligible for AM, and 104 were found suitable for home printing, confirming that scaling to 50+ parts could be realized. No business model shifts are expected at this stage, as quality and accessibility constraints remain unchanged within such a short timeframe.

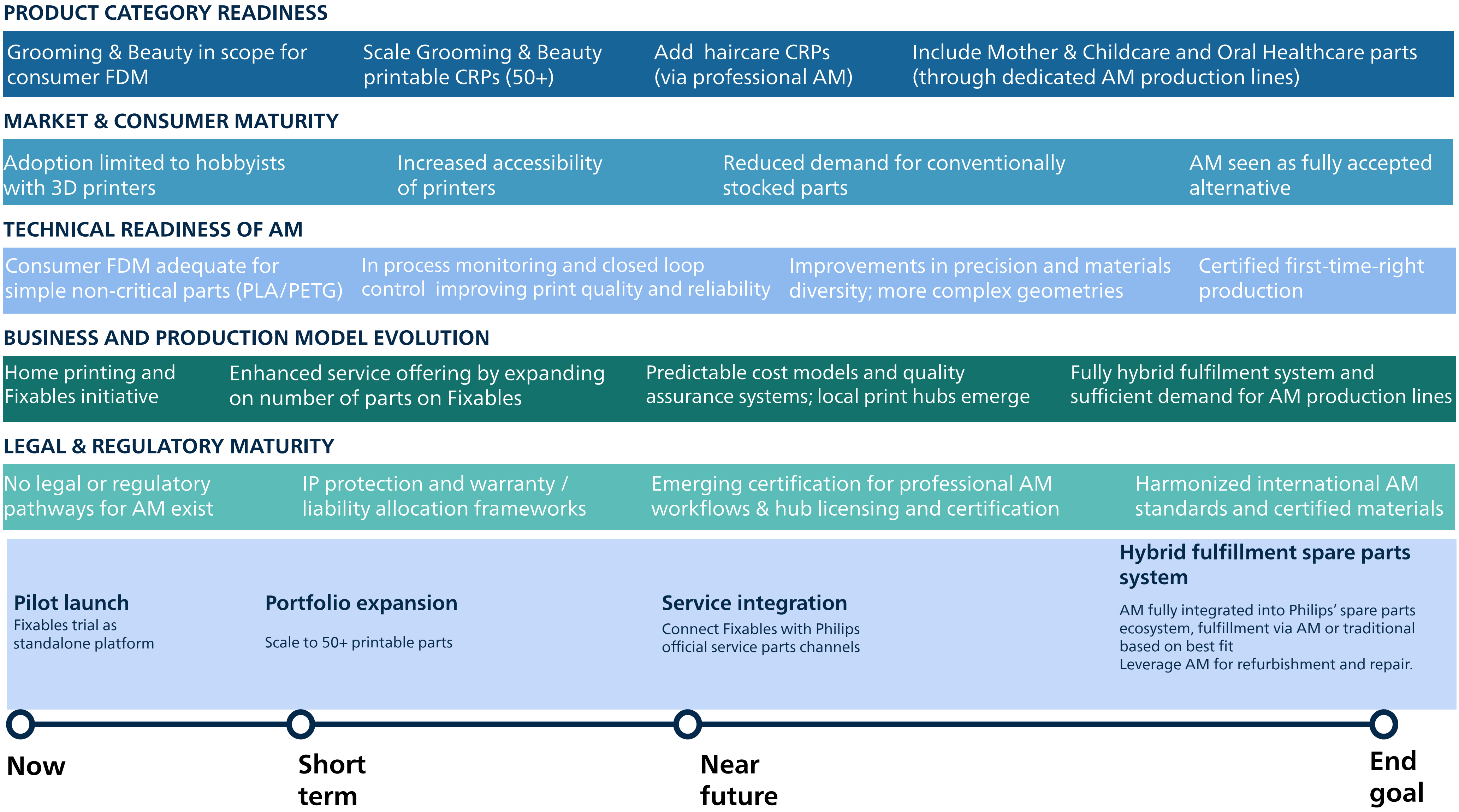
The "near future" horizon, where Fixables is integrated with Philips' traditional spare parts offering and licensed local printing hubs emerge, represents a more transformative step. The eligibility analysis revealed that further portfolio expansion depends on access to professional printing environments, where certified materials, controlled post processing and predictable quality can be guaranteed. Professional printing may be relevant once quality becomes reliably 'first time right' and AM workflows are certifiable. This would also broaden reachability, as AM parts could be offered as finished goods rather than printable files. This expands AM access beyond hobbyists and to services in repair and refurbishment. Business model evolution becomes feasible as files could be licensed to hubs, or Philips could sell printed parts directly.

The long term horizon envisions a fully hybrid fulfilment system in which AM, hubs and Philips controlled production coexist and support repair and refurbishment operations. This enables dynamic routing based on viability, AM for low volume, legacy, or long tail parts; IM for high volume components. Over time, Philips could maintain a digital spare parts library, enabling product support far beyond what traditional spare parts systems can provide.

This roadmap was proposed to scope the project and provide Philips with a structured direction for further development. It represents one plausible, strategically grounded pathway rather than the only possible future. Further research is recommended to deepen the analysis, explore alternative trajectories and refine assumptions as AM technologies, regulations and consumer behaviour evolve.

Layered roadmap

Each cell highlights an example of a development that could support the feasibility of the corresponding time horizon (Now/Short-term/Near future/End goal). Reading horizontally shows how AM might evolve within each layer, while reading vertically within each time horizon suggests how different factors could progress together to enable the feasibility of AM spare parts.



	Now	Short term	Near future	End goal
PRODUCT CATEGORY READINESS	Grooming & Beauty in scope for consumer FDM	Scale Grooming & Beauty printable CRPs (50+)	Add haircare CRPs (via professional AM)	Include Mother & Childcare and Oral Healthcare parts (through dedicated AM production lines)
MARKET & CONSUMER MATURITY	Adoption limited to hobbyists with 3D printers	Increased accessibility of printers	Reduced demand for conventionally stocked parts	AM seen as fully accepted alternative
TECHNICAL READINESS OF AM	Consumer FDM adequate for simple non-critical parts (PLA/PETG)	In process monitoring and closed loop control improving print quality and reliability	Improvements in precision and materials diversity; more complex geometries	Certified first-time-right production
BUSINESS AND PRODUCTION MODEL EVOLUTION	Home printing and Fixables initiative	Enhanced service offering by expanding on number of parts on Fixables	Predictable cost models and quality assurance systems; local print hubs emerge	Fully hybrid fulfilment system and sufficient demand for AM production lines
LEGAL & REGULATORY MATURITY	No legal or regulatory pathways for AM exist	IP protection and warranty / liability allocation frameworks	Emerging certification for professional AM workflows & hub licensing and certification	Harmonized international AM standards and certified materials
	Pilot launch Fixables trial as standalone platform	**Portfolio expansion** Scale to 50+ printable parts	**Service integration** Connect Fixables with Philips official service parts channels	**Hybrid fulfillment spare parts system** AM fully integrated into Philips' spare parts ecosystem, fulfillment via AM or traditional based on best fit Leverage AM for refurbishment and repair.

Figure 62: Layered roadmap

PART SELECTION FRAMEWORK

Applying the part selection framework presented in Chapter 4 to the full list of PH CRPs (Appendix B1) demonstrated that regulatory constraints are the dominant exclusion factor in the current home printing context. This is a limitation, but it is mitigated by the fact that this still represents two thirds of the portfolio (332 out of 492 parts). From these, 133 parts were identified as eligible for AM, and 104 as suitable for consumer printing. Exclusions from home printing resulted from material availability limitations, particularly the absence of accessible heat resistant materials.

When evaluating the eligible parts against ideal printing processes (between FDM, SLA and SLS), only 17 parts were best suited to FDM using PLA as a filament material. Extending the scope to include PETG increased this to 35 parts. FDM was especially suitable for shaver combs with level tooth geometries, where PLA is preferred for rigid variants and PETG for more flexible ones. SLA was preferred for thin walled combs, haircare components requiring smooth internal channels and geometries that demand high dimensional accuracy. SLS was mainly suitable for protective caps that do not require aesthetic quality, and is not relevant for most visual, skin contact CRPs.

The results confirm that home printing can support a meaningful subset of the grooming and beauty portfolio. Expanding the consumer material scope to PETG does not increase the number of eligible parts but may improve part quality, particularly for components requiring flexibility. The analysis also reinforces that AM suitability is shaped not only by geometry but by regulatory classification and material constraints. Some parts were excluded for geometric reasons, often because they were subassemblies containing metal elements required for functionality.

It was also considered whether applying DfAM principles during original product development, using an equivalent design approach as described in chapter 4, could increase future AM suitability. While this may reduce some geometric exclusions, it does not address the dominant regulatory or material drivers. Geometric conditions relating to subassemblies or the use of metal would also not be eliminated this way as these are key to the usability of parts. Moreover, the redesign cases showed that adapting existing parts for AM was possible within the given timeframe, suggesting limited added value from embedding full DfAM in the original design process. However, documenting exclusion reasons remains important to avoid reproducing these constraints in future generations.

The framework also exposed organisational limitations. The necessary part data are not stored in a single consolidated location, meaning only technical and regulatory criteria could be applied in this research; demand related criteria could not be considered. The manual selection approach used introduces the risk of missing relevant parts. Future work should revisit eligibility using complete datasets. Eligibility assessments should also be extended beyond PH CRPs to domestic appliances, and to repair components. Overall, adopting a structured decision making framework is recommended, but its effectiveness depends on how Philips structures and maintains the underlying data. With these outcomes, the part selection framework successfully delivers the second project deliverable by providing a validated and scalable method to identify AM-eligible parts within the PH portfolio.

REDESIGN FRAMEWORK AND PROTOTYPE DISPLAY

A redesign framework was developed with the goal of enabling designers to develop a shared way of thinking when redesigning Philips PH parts for consumer 3D printing. The framework consists of an AM Redesign Decision Pathway, a set of Additive Manufacturing Redesign Guidance Cards, and a prototype display (Chapter 8).

The prototype display was created as a direct result of the successful redesign and fabrication of multiple parts. These prototypes, redesigned and printed across materials and processes, demonstrate both current and near-future possibilities for AM spare parts in the PH portfolio. Insights from this process informed both the goal and content of the rest of the redesign framework.

A user test of the redesign framework with Philips designers showed that the content of the framework was understandable and that the tools supported structured reasoning during part analysis. Less experienced designers indicated that the materials helped them generate ideas. More experienced designers recognised the value for onboarding others, but did not feel a personal need for the materials. The presence of physical prototypes helped participants assess design decisions, although the extent to which they were used varied across participants.

The findings indicated that the redesign framework successfully communicates the logic behind AM redesign and helps make decision making steps explicit. However, the limited engagement of experienced designers shows that the underlying purpose of the framework, as a mechanism to build shared mental models, was not fully achieved. For a framework intended to help scale AM redesign capability, this is an important insight: if experienced designers do not feel the need to interact with it, its organisational role must be communicated more clearly. These insights highlight the need to embed the framework into a broader onboarding strategy rather than as a standalone aid.

An informal observation experiment with the prototype display indicated that it effectively invites engagement and tactile interaction. People commented on the visual appeal of the display and several expressed interest in learning about the purpose of the display.

The user test evaluated the content but not the finalized embodiments, which is a limitation as physical format may influence usability and adoption. Furthermore, testing was done only with Philips designers, while future users may also include Philips engineers and external contributors. Additionally, the test parts were similar to the examples shown on the cards, which may have increased perceived intuitiveness. Testing with more diverse geometries could reveal different behaviours or usability needs.

Within this research the decision was made to focus the framework on scalability from the perspective of contributor capacity. Future work could look into other approaches to design aids supporting a different stage of the design process, such as defining AM specific design rules for high frequency part families (e.g. shaver combs) or developing a testing protocol for printed part quality. Furthermore, as the AM portfolio grows, capturing AM design knowledge in a structured way will be essential for long term scalability.

CONCLUSIONS ABOUT THE ROLE OF AM VERSUS IM

AM fills a different role than IM, and that role may be valuable even when part quality is lower. AM is not a replacement for IM, which will continue to deliver better quality parts for a lower price for mass manufactured parts. However, AM becomes an interesting alternative when economies of scale don’t apply, particularly for low volume, intermittent or end of life demand. In these situations, its less efficient production process and lower quality are outweighed by the ability to produce parts on demand and to extend product life.

For consumers, AM’s value lies primarily in enabling repairs that would otherwise not happen. Home printing makes it possible to replace parts that are unavailable, too expensive or too slow to source through traditional channels. For motivated users with access to a printer, the lower quality of printed parts may not be a barrier if the alternative is to replace the device entirely.

In summary, AM should not aim to match IM. Instead, it should expand on what is possible in the spare parts ecosystem. Now, it empowers a subset of consumers to repair products at home. Eventually, AM may enable Philips to guarantee long term part availability while strengthening repair, refurbishment and broader service offerings across the product lifecycle.

IMPLICATIONS FOR PHILIPS

The findings of this research pose several important implications for Philips. The first concerns understanding who the user is, now and in the future. At present, the Fixables initiative targets hobbyists with access to 3D printers, but the long-term roadmap in this research proposes professional printing and integration with traditional spare-parts channels. Philips will therefore need a clearer understanding of the different user groups involved between consumers who would print at home and consumers who would purchase printed parts, to gain insights on what their needs are. Understanding users’ motivations, what drives them to seek a spare part, and what would enable or prevent a repair will be essential for positioning the AM offering and making informed decisions about future expansion.

A second implication relates to data consolidation. The part selection process revealed that data required for AM decision-making is fragmented across different systems within Philips. This prevented a full viability analysis, increasing the risk of oversight. If Philips wants to systematically identify and evaluate AM opportunities, it is recommended to consider centralizing this information. The feasibility of any long-term AM strategy will depend on this foundation.

A third implication concerns the scope and structure of the PH spare-parts portfolio. Many CRPs in the grooming and beauty category are inherently challenging for AM due to skin-contact and hygiene as requirements. This raises the question whether the AM scope should eventually include not only CRPs but also (internal) repair components, which may offer greater technical and economic feasibility for AM. Additionally, the eligible parts list shows substantial redundancy among similar shaver combs. This raises the question whether Philips could benefit from simplifying its spare-parts portfolio and avoiding unnecessary design variation across product generations when features are functionally equivalent. Such consolidation could reduce the complexity of both AM eligibility analysis and redesign, while potentially increasing demand per part, improving AM viability.

Finally, Philips should decide how AM relates to traditionally sourced parts, whether AM parts should always replicate the IM original, and how much design freedom should be allowed. These decisions will determine which skills are needed and how redesign processes should be governed.

PROJECT LIMITATIONS

This research has several limitations that should be acknowledged. The first limitation is the broad scope of the project. While this broad scope was necessary to position the project within the full end to end AM spare parts context and to ensure that all stakeholders would understand why such an initiative is needed, it inevitably limited the depth of certain analyses.

A second limitation is the explorative nature of redesign cases. Because insights from earlier Fixables cases had not been documented, this research had to begin largely from the ground up, relying on verbal feedback from previous designers. The resulting redesign work was highly explorative. In hindsight, if general learnings had already been captured and accessible at the start, more targeted exploration, such as focusing specifically on improving AM designs for shaver combs, could have delivered insights that would have been more impactful in the short term.

Another key limitation concerns user testing. The redesign framework was tested only in its provisional form, not in the final envisioned physical embodiments of the tools. The test also involved only Philips designers, even though the intended user group extends to engineers and external contributors. Similarly, the prototype display was not validated with these broader stakeholders. A more diverse test set may reveal different usability needs or behaviours.

Beyond that, user testing was also limited in terms of consumers. The project primarily reflects the manufacturer's perspective, focusing on building internal foundations rather than assessing user acceptance. Printed parts were deemed "finished" based on expert judgement, but no evaluations were performed with actual end users. Even though this was beyond the scope of this project, it is essential for future work.

Overall, these limitations highlight the need for deeper, more focused studies on part specific redesign, broader and more representative user testing, and a stronger integration of consumer perspectives in future work.

FUTURE RESEARCH

Based on the findings and limitations of this research, three directions are proposed as interesting areas for future investigation. The first is deepening the consumer perspective. This project focused primarily on the Philips perspective. However, the actual value of AM for spare parts depends heavily on consumer behaviour: e.g. why users seek replacement parts, what prevents or enables repair, how they perceive AM part quality and what level of deviation from IM they consider acceptable. Understanding this will be essential for positioning the AM offering, prioritising parts and designing appropriate fulfilment routes.
The second direction is to define what is currently inferior in AM versions of parts and how to overcome these shortcomings. While this research identified general redesign principles, it did not explore specific feature level improvements. Given that many eligible parts are shaver combs, future work could examine AM specific design requirements such as hair inlet geometry, skin glide behaviour, and use in the bathroom context.

The third direction concerns future AM fulfilment routes. As this research suggests to move towards professional printing, it could be valuable to explore whether redesigning parts for FDM, the lowest common denominator in terms of quality, also results in parts that print successfully on higher quality technologies such as SLA and SLS. This would support scalable production flexibility and reduce redesign effort across technologies.

10.2 Personal reflection

This project grew out of a wish to complete my master's with a challenge that brought together the pillars of industrial design: business, people and technology. I feel fortunate to have found that opportunity at Philips. Working with so many different stakeholders allowed me to explore whether I truly enjoy operating at the intersection of disciplines. I am very grateful for the input, time and knowledge shared by the many talented people I had the pleasure of working with.

Looking back, I am proud of what I achieved. The project was challenging at many moments, but those challenges taught me a great deal about myself, both strengths and weaknesses. Some lessons confirmed things I already knew , such as my struggle to keep things concise. Others were new discoveries, such as realising that I enjoy complexity. I also really enjoyed noticing how many small skills from courses I followed and previous projects resurfaced throughout the project, from making a quick technical drawing in SolidWorks for communicating with a supplier to building communicative prototypes. It made me realize that I now carry my own, personal toolkit built over seven years of studies.

I also received encouraging feedback on the project throughout my time at Philips. People I spoke to were very enthusiastic about the initiative and eager to contribute their knowledge. Although the project is oriented toward the long-term future of AM at Philips, it was rewarding to see that some outcomes already had immediate impact. For example, I was able to convince the Fixables team to expand the scope of home printing materials to include PETG. I am really curious to see what impact this will have in practice.

Throughout the project I further developed soft skills, particularly communication and at the same time, deepened several hard skills, most notably, obviously, 3D printing, which I now understand in far greater detail. I challenged myself by daring to ask, which led to many great interactions and new insights. A more surprising challenge was realising how many different "users" this project had: Philips as the client, Philips consumers as the end users of AM spare parts, and then the various internal stakeholders across the end-to-end AM workflow who became the users of the redesign framework. Shifting between these perspectives was both interesting and complex at times. Another interesting experience was conducting a user test with designers deliberately as the end user: designers, who are typically familiar with the process of user testing themselves, tend to give input in a very different way than regular users would.

While this project was centered around product design, the design challenge was tightly linked to the strategic context of spare parts management and sustainability. This added economic and operational relevance to the technical dimension of additive manufacturing and the need to make it practical for a diverse group of stakeholders. At times, it was very challenging to maintain oversight of all these different aspects, but ultimately I feel like I succeeded in bringing them together and delivering on all components.

The most difficult period by far was the beginning. A delayed contract prevented me from starting at Philips while the project itself had already begun. Looking back, I wonder how the project might have developed had I been embedded in the Philips context from day one. Early interviews could have changed the direction entirely. Still, while this delay made the middle section of the project more demanding, I was able to do and learn everything I wanted to and I am satisfied with the final result.

One of my biggest personal lessons is the importance of how things are written down. Being deeply involved in a project makes it easy to forget that others are not. Especially when reviewing feedback on my reporting, I was surprised by several moments of miscommunication that arose from ambiguous phrasing on my side. I also learned the value of a clear design brief to guide decisions and prevent constantly diverging, which is something that I have a tendency to do when given the freedom.

Overall, it was hard work, but absolutely worthwhile. I end this project with a clearer sense of my strengths, a deeper understanding of how I like to work, and the confidence that I am ready to be a designer in the real world.

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Appendix A:
Public Appendix

Appendix A1: Philips Personal Health Product Portfolio

This appendix gives a brief overview of the Philips Personal Health product portfolio. For each business unit the associated product categories are shown and briefly described based on their associated requirements.

GROOMING AND BEAUTY (GNB)

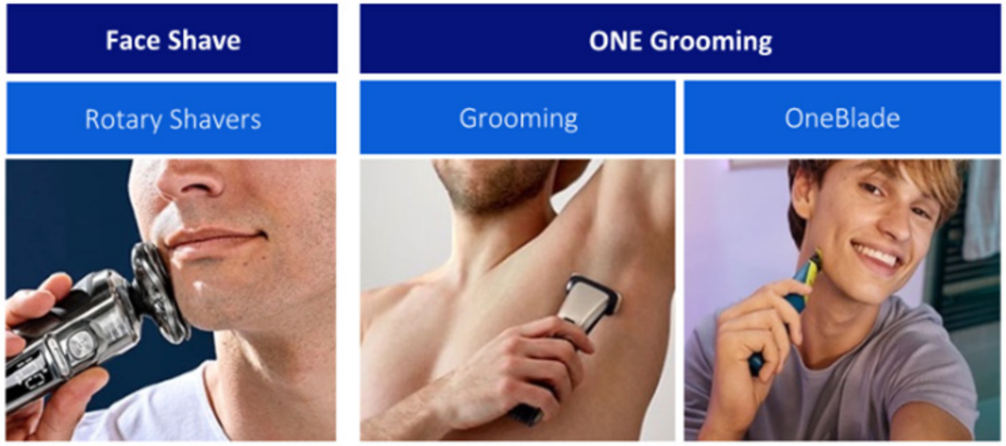


Figure 63: Male grooming portfolio (Service Parts Manager, 2025)

The male part of the portfolio consists of shavers and groomers. Important product requirements are water resistance, chemical resistance to common hygiene products, and ease of cleaning/maintenance.

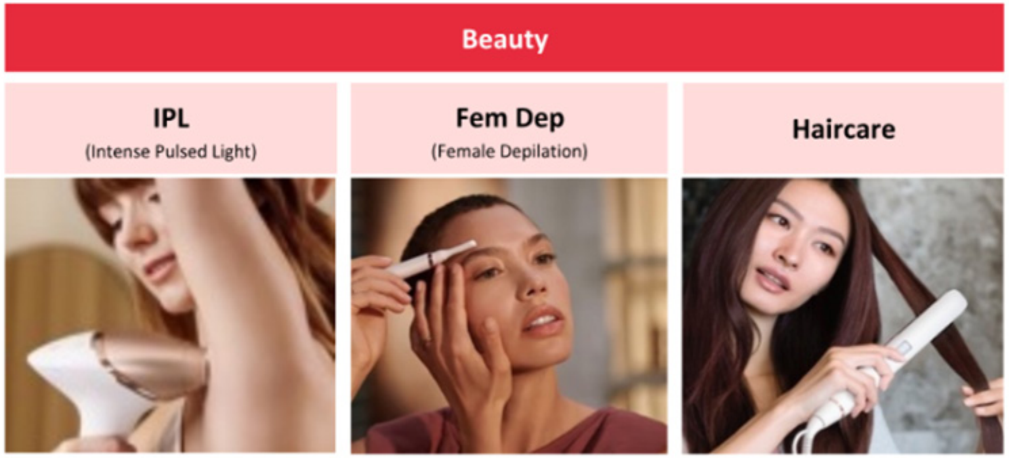


Figure 64: Beauty portfolio (Service Parts Manager, 2025)

The beauty portfolio consists of IPL, a laser hair removal device, classified and regulated as a medical product. Female depilators and shavers, which have similar requirements to the shaving and grooming portfolio. Lastly haircare, comprising all hairstyling tools, which have thermal and heat resistance as primary requirement.

ORAL HEALTH CARE (OHC)

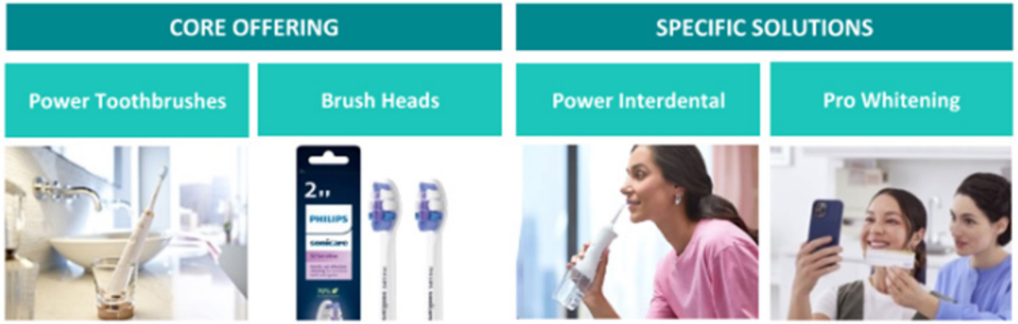


Figure 65: Oral health care portfolio (Service Parts Manager, 2025)

OHC comprises a core offering of electric toothbrushes and brush heads. There is also a specific solution category with products for flossing and whitening. In some regions, such as the US, these products are classified as medical products. Furthermore, they need to adhere to food safety standards.

MOTHER AND CHILD CARE (MCC)

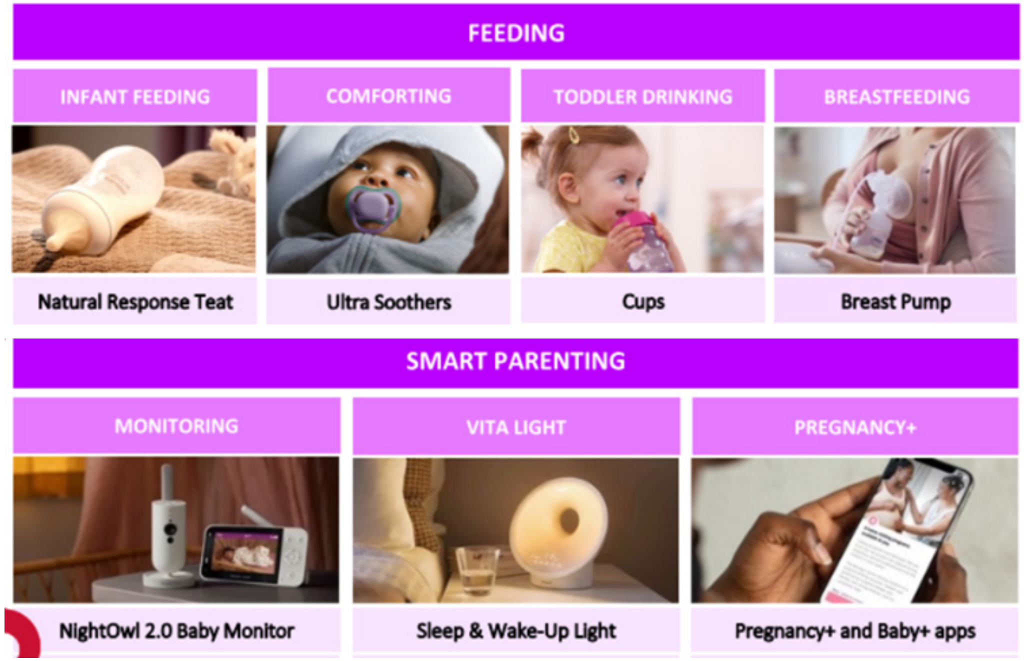


Figure 66: Mother and child care portfolio (Service Parts Manager, 2025)

The MCC portfolio is divided into feeding and smart parenting. Products in this portfolio are classified as Children's Products/Childcare Articles. Feeding products related to infant feeding, comforting and toddler drinking are also classified as Food Contact Materials. Breastfeeding products are classified as medical products.

Appendix A2: Scope of applicable AM technologies

This appendix provides the detailed evaluation of the suitability of different AM technologies for further consideration within this research.

To identify the most suitable AM processes for further consideration, it is necessary to compare them based on the maturity of both the technologies and the providers, as choosing processes that are already applied in real-world scenarios provides a foundation of practical insights and validated methodologies upon which design guidelines can be established. This evaluation must be framed within the specific context of end-use parts, polymer-based printing, and applications within the consumer product sector. Furthermore, documentation in literature is also important, as selecting technologies that are extensively studied offers a distinct advantage: a larger and more reliable body of existing knowledge can inform the design process. Moreover, as the widespread availability of design knowledge and established best practices is useful in delivering quality and aiding in the redesign of parts.

(Mika & Pei, 2023) conducted a comprehensive literature review examining AM processes and materials used for spare parts across a broad range of industrial sectors, focusing on publications from 2019 to 2022. This study can be used as the basis for the choice of technology for this study. The study found that the most commonly utilized AM processes for producing spare parts and end-use components are Powder Bed Fusion (PBF), Material Extrusion (MEX), and Vat Photopolymerization (VP). These technologies are widely adopted due to their respective strengths: PBF offers high-quality mechanical properties and design flexibility; MEX is broadly accessible and cost-effective; and VP delivers superior surface finish and dimensional accuracy. PBF and MEX in particular are prevalent across a wide range of industrial applications.

In contrast, Material Jetting (MJ), Binder Jetting (BJ), and Sheet Lamination (SL) are generally considered unsuitable for end-use polymer component manufacturing due to limitations in material performance, particularly with regard to mechanical strength and durability. Directed Energy Deposition (DED) is primarily employed for the repair and refurbishment of metal components and is therefore beyond the scope of this study, which focuses on polymer-based manufacturing.
PBF, MEX, and VP exhibit high process maturity for plastic printing and collectively span different material input forms, powder, filament, and resin.

Table 12: Analysis of different AM processes for spare parts(Mika & Pei, 2023)

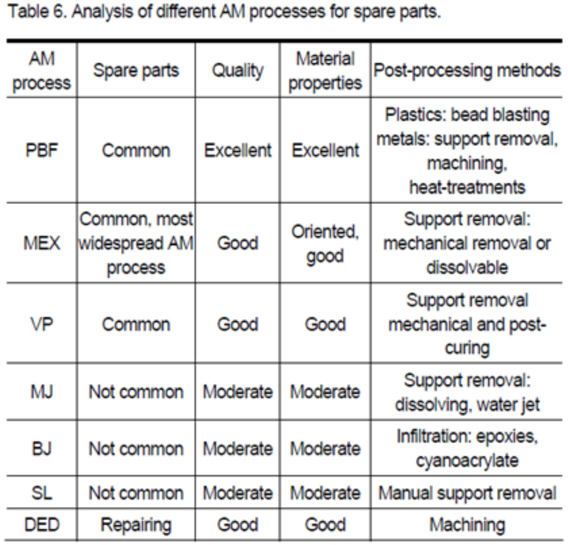


Table 6. Analysis of different AM processes for spare parts.

AM process	Spare parts	Quality	Material properties	Post-processing methods
PBF	Common	Excellent	Excellent	Plastics: bead blasting metals: support removal, machining, heat-treatments
MEX	Common, most widespread AM process	Good	Oriented, good	Support removal: mechanical removal or dissolvable
VP	Common	Good	Good	Support removal mechanical and post-curing
MJ	Not common	Moderate	Moderate	Support removal: dissolving, water jet
BJ	Not common	Moderate	Moderate	Infiltration: epoxies, cyanoacrylate
SL	Not common	Moderate	Moderate	Manual support removal
DED	Repairing	Good	Good	Machining

Table 13: Overview of AM process maturity (Mika & Pei, 2023)

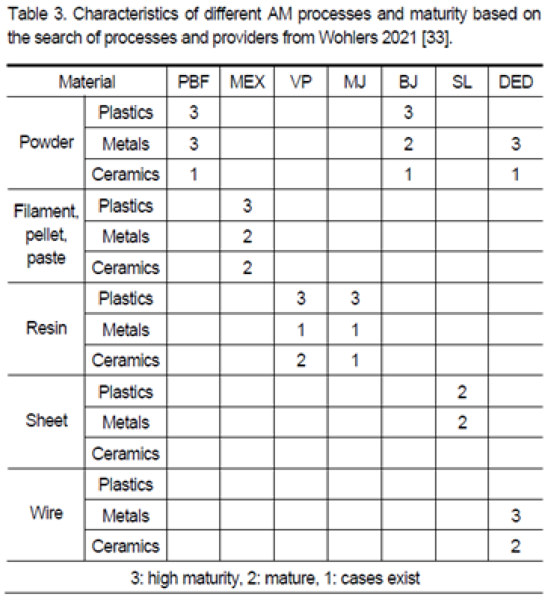


Table 3. Characteristics of different AM processes and maturity based on the search of processes and providers from Wohlers 2021 [33].

Material		PBF	MEX	VP	MJ	BJ	SL	DED
Powder	Plastics	3				3		
	Metals	3				2		3
	Ceramics	1				1		1
Filament, pellet, paste	Plastics		3					
	Metals		2					
	Ceramics		2					
Resin	Plastics			3	3			
	Metals			1	1			
	Ceramics			2	1			
Sheet	Plastics						2	
	Metals						2	
	Ceramics							
Wire	Plastics							
	Metals							3
	Ceramics							2

3: high maturity, 2: mature, 1: cases exist

When narrowing the focus specifically to the consumer product sector, PBF, MEX, and VP emerge as the most relevant AM processes for polymer printing. Although MJ and BJ are occasionally reported in the consumer product domain, their use is typically associated with ceramics such as zirconia (ZrO_2) and stainless steel–bronze composites (e.g., 316SS/bronze), placing them outside the scope of polymer-focused applications. (Izdebska-Podsiadły, 2022) also confirms that the main 3D printing processes currently used are MEX, VPP and PBF, with SLS technology dominating VPP and SLA dominating PBF, both due to their special role in industrial applications.

Continuing with PBF, MEX and VP, these need to be subdivided in their derivative technologies to find the most established one. The process classification of (Izdebska-Podsiadły, 2022) is used.

FDM and FFF are explicitly referenced as two commonly used equivalent technologies and a current base technology for 3D printing with polymers. As they are equivalent, this research will continue with FDM as the technology representing the MEX category. SLA is the oldest VPP technology, is considered a base technology, and plays a special role for industrial applications. CDLP/CLIP is noted as a much faster alternative to SLA, it is not selected as the primary VPP derivative for this research due to the established knowledge base and industrial prominence of SLA. SLS is considered the base technology for PBF, and together with SLA, plays a special role in industrial applications. MJF is highly prominent with dynamic growth projected in market forecasts. However, here also the decision is made to continue with the longer-established industrial base of SLS.

Table 14: AM processes for end-use parts (Mika & Pei, 2023)

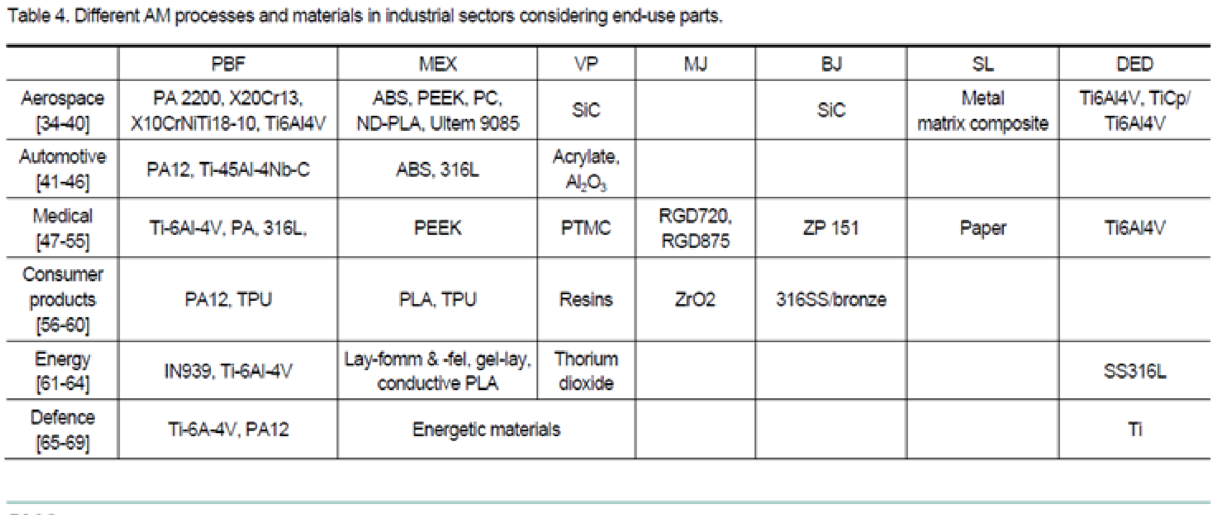
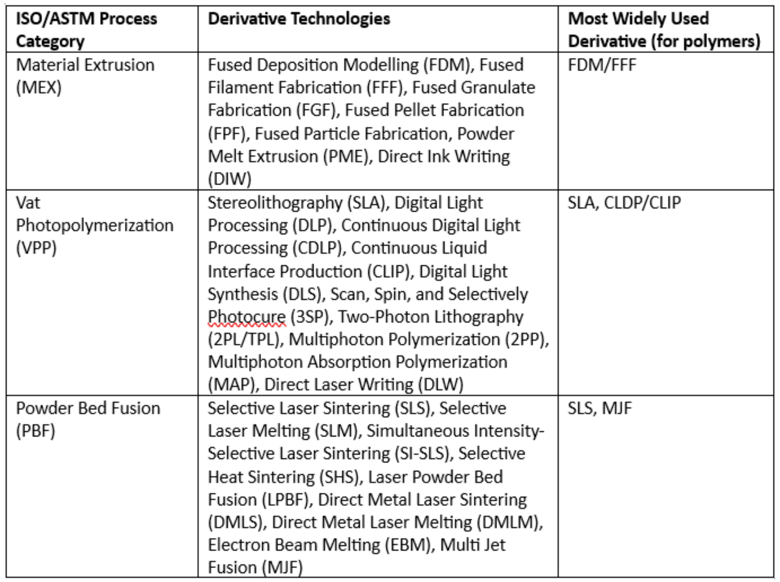


Table 4. Different AM processes and materials in industrial sectors considering end-use parts.

	PBF	MEX	VP	MJ	BJ	SL	DED
Aerospace [34-40]	PA 2200, X20Cr13, X10CrNiTi18-10, Ti6Al4V	ABS, PEEK, PC, ND-PLA, Ultem 9085	SiC		SiC	Metal matrix composite	Ti6Al4V, TiCp/ Ti6Al4V
Automotive [41-46]	PA12, Ti-45Al-4Nb-C	ABS, 316L	Acrylate, Al_2O_3				
Medical [47-55]	Ti-6Al-4V, PA, 316L,	PEEK	PTMC	RGD720, RGD875	ZP 151	Paper	Ti6Al4V
Consumer products [56-60]	PA12, TPU	PLA, TPU	Resins	ZrO2	316SS/bronze		
Energy [61-64]	IN939, Ti-6Al-4V	Lay-fomm & -fel, gel-lay, conductive PLA	Thorium dioxide				SS316L
Defence [65-69]	Ti-6A-4V, PA12	Energetic materials					Ti

Table 15: Overview of derivative technologies for MEX, VPP and PBF



ISO/ASTM Process Category	Derivative Technologies	Most Widely Used Derivative (for polymers)
Material Extrusion (MEX)	Fused Deposition Modelling (FDM), Fused Filament Fabrication (FFF), Fused Granulate Fabrication (FGF), Fused Pellet Fabrication (FPF), Fused Particle Fabrication, Powder Melt Extrusion (PME), Direct Ink Writing (DIW)	FDM/FFF
Vat Photopolymerization (VPP)	Stereolithography (SLA), Digital Light Processing (DLP), Continuous Digital Light Processing (CDLP), Continuous Liquid Interface Production (CLIP), Digital Light Synthesis (DLS), Scan, Spin, and Selectively Photocure (3SP), Two-Photon Lithography (2PL/TPL), Multiphoton Polymerization (2PP), Multiphoton Absorption Polymerization (MAP), Direct Laser Writing (DLW)	SLA, CLDP/CLIP
Powder Bed Fusion (PBF)	Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Simultaneous Intensity-Selective Laser Sintering (SI-SLS), Selective Heat Sintering (SHS), Laser Powder Bed Fusion (LPBF), Direct Metal Laser Sintering (DMLS), Direct Metal Laser Melting (DMLM), Electron Beam Melting (EBM), Multi Jet Fusion (MJF)	SLS, MJF

Appendix A3: Review of AM benefits and limitations

This appendix gives the detailed results of a literature review of the benefits and limitations of AM

To investigate the benefits and limitations of AM, a structured literature search was conducted using Google Scholar. A Boolean search string was employed to identify relevant review articles, combining key terms such as “additive manufacturing” OR “3D printing” AND “benefits” OR “advantages” AND “challenges” OR “limitations” AND “review”. Results were filtered to include only publications from 2021 onward. The focus on review papers enabled the collection of synthesized insights across multiple studies, ensuring a balanced and comprehensive understanding of AM’s strengths and limitations in a modern industrial context.

Table 16: List of AM benefits

Benefit	Sources
Design freedom and geometric complexity: Additive Manufacturing (AM) enables the creation of highly intricate and complex geometries that are difficult or impossible to achieve using traditional manufacturing methods	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Customization and on-demand production: AM supports cost-effective, small-batch, or single-unit production tailored to specific requirements, enabling personalized and ondemand products	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Material efficiency and waste reduction: AM minimizes material waste by adding material only where needed, enhancing sustainability and cost savings	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Cost and production efficiency: AM reduces setup and tooling costs, making low-volume and customized production more economically viable	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Speed of production: AM accelerates product development and manufacturing by enabling rapid prototyping and significantly shortening lead times.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Reduced assembly: AM can consolidate multiple parts into a single component, minimizing assembly operations, reducing time, and lowering costs.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Decentralized production and Supply chain efficiencies: AM facilitates local, on-demand manufacturing, reducing logistics costs and simplifying the supply chain.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Lightweighting and improved structural performance: AM enables the production of lightweight, topology-optimized structures with enhanced mechanical performance.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Material versatility: AM supports a wide range of materials, including polymers, metals, ceramics, and biomaterials, expanding design possibilities and enabling innovative product types.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)

Table 17: List of AM limitations

Limitation	Sources
High costs and limited economic viability for mass production: Despite technological advances, the high cost of AM hardware, materials, and maintenance, combined with poor scalability, continues to limit its economic feasibility for large-scale production.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Limitations in resolution, accuracy, and mechanical properties: AM processes struggle to consistently deliver fine resolution, smooth surface finishes, and reliable mechanical strength due to defects, poor adhesion, and technology-specific constraints.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Challenges related to process consistency: AM outputs remain highly sensitive to machine settings, environmental conditions, and operator skill, leading to variability in part quality and repeatability	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Quality Assurance and Post-Processing: Extensive post-processing and inspection are often required to meet quality standards, adding time, cost, and complexity while highlighting the lack of standardized QA practices.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)
Ecosystem and workforce maturity deficiencies: The AM ecosystem faces shortcomings in software integration, digital infrastructure, and skilled labour, which collectively hinder efficient implementation and industrial scaling.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Praveena et al., 2022; Zhou et al., 2024)

Limitation	Sources
Regulatory and intellectual property challenges: The absence of harmonized regulatory frameworks and unresolved IP protection issues pose significant barriers to AM adoption in regulated industries.	(Kanishka & Acherjee, 2023; Zhou et al., 2024)
Environmental and sustainability challenges: Despite its potential for material efficiency, AM is hampered by high energy demands, limited material recyclability, and environmental risks associated with certain feedstocks.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Zhou et al., 2024)
Material variability and performance uncertainty: Inconsistent material behaviour, such as porosity, anisotropy, and brittleness, creates uncertainty in the structural and functional performance of AM-produced components.	(Iftekar et al., 2023; Kanishka & Acherjee, 2023; Zhou et al., 2024)

Appendix A4: PEST analysis

This appendix gives the results of a PEST analysis which was conducted to identify external determinants on a political, economic, socio-cultural, and technological level that could impact AM adoption.

Political & Legal

The expiration of key patents will continue to democratize access to advanced manufacturing processes, reducing monopolization by industry pioneers (Chua & Leong, 2017). However, this growing accessibility introduces complex ethical and legal challenges regarding intellectual property (IP). The ease of replicating digital product files through 3D modelling software and scanners raises concerns about unauthorized reproductions and patent infringements (Ben Said et al., 2025). Moreover, the rise of open-source 3D printing platforms and online design marketplaces challenges traditional IP frameworks, prompting industries to reconsider how design patents and digital assets are defined and protected (Gao et al., 2015). Novel forms of IP are emerging, such as creative commons licenses (Jiang et al., 2017) and encryption and hidden structural signatures that safeguard CAD models without limiting innovation (Gao et al., 2015). Beyond patent infringement, the ability to make replicated products when 3D modelling software and scanners are available, can also lead to unauthorized reproductions (Ben Said et al., 2025), raising new questions of legal and ethical liability (Ben Said et al., 2025; Jiang et al., 2017). At the same time, the 3D printing sector faces the urgent need for harmonized standards that ensure safety, quality, and interoperability. Despite progress, such as ASTM's F2924-12 material standards and global collaboration through ISO/TC 261 and ASTM Committee F42 (Chua & Leong, 2017), the rapid diversification of technologies and proprietary systems continues to hinder unified global standards (Gao et al., 2015; Khorram Niaki & Nonino, 2017). The future of AM will therefore depend on the creation of frameworks that balance open innovation with protection and accountability.

Economic

Additive manufacturing is set to transform the global economy by reshaping supply chains and business models. Production will increasingly occur closer to consumers, reducing transportation needs and logistical complexity (Ben Said et al., 2025; Khorram Niaki & Nonino, 2017). This shift enables localized, flexible, and sustainable manufacturing ecosystems that rely on digital supply networks rather than physical inventories (Ben Said et al., 2025). The result is a more agile, cost-efficient, and responsive manufacturing system capable of producing customized goods on demand while minimizing waste and lead times.

In parallel, AM is disrupting traditional business and competition dynamics. As production becomes more digitized, competitive advantage will increasingly depend on ownership of design data, digital access, and rapid prototyping capabilities rather than scale or location (Jiang et al., 2017). Challenges in quality assurance, warranty management, and the validation of AM-produced parts, will require new industry standards and certification frameworks. Advances in monitoring technology are also crucial for addressing these issues. Integrating cameras and sensors into 3D printers enables real-time monitoring and closed-loop control, improving consistency, quality, and reliability of printed parts. (Ben Said et al., 2025).

Furthermore, the ability to estimate and manage production costs will be central to AM's broader adoption (Khorram Niaki & Nonino, 2017). Accurate early-stage cost modelling, combined with AM's unique capacity to produce multiple components simultaneously and reduce material waste, will support the transition from physical production to digital-driven, service-oriented value creation.

Socio–Cultural

Additive manufacturing is driving a cultural shift toward personalization and co-creation (Gao et al., 2015). Consumers increasingly expect products that reflect their individual needs and preferences (Egan, 2023), and AM provides the technical foundation for mass customization at scale (Jiang et al., 2017). This shift also represents a strategic adaptation to evolving IP conditions, as personalization becomes a key differentiator in markets where replication and imitation are more difficult to control (Jiang et al., 2017).

At the societal level, the democratization of AM, driven by falling hardware costs and accessible design software, has given rise to the DIY and Maker Movements. Individuals, startups, and small enterprises now have the ability to prototype and produce functional parts, fostering innovation from the ground up (Gao et al., 2015), through platforms like Shapeways and Sculpteo, bridging creativity with commercial production.

In education, the affordability of desktop 3D printers is integrating AM into curricula across schools, colleges, and universities (Chua & Leong, 2017). This diffusion nurtures future generations of designers, engineers, and entrepreneurs fluent in digital manufacturing, reinforcing long-term innovation capacity (Gao et al., 2015). From a labour perspective, AM is redefining roles and skills within organizations, demanding expertise in digital design, materials, and hybrid production management (Gao et al., 2015). As automation and customization expand, traditional manufacturing jobs may decline, but new opportunities in creative, digital, and technical fields will emerge.

Technological & Environmental

Technological advances in additive manufacturing are driving rapid improvements in precision, material diversity, and production speed (Chua & Leong, 2017; Diegel et al., 2019). As quality and scalability increase, limitations that once constrained AM will diminish, positioning it as a viable alternative to traditional manufacturing (Gao et al., 2015). This evolution will be accompanied by the widespread integration of Design for Additive Manufacturing (DfAM) principles, enabling products to be conceived and optimized specifically for AM processes, leveraging geometric freedom, lightweight structures, and functional integration to deliver new levels of performance and efficiency (Egan, 2023).

From a production standpoint, AM enables decentralized, on-demand manufacturing, transforming supply chains into flexible, localized networks that minimize dependency on large-scale facilities (Ben Said et al., 2025). This supports both industrial agility and environmental sustainability. By reducing waste and energy use, achieving low “buy-to-fly” ratios, and enabling local production, AM significantly reduces transportation emissions and overall carbon footprints (Gao et al., 2015). Furthermore, AM facilitates circular business models, replacing physical stock with digital inventories and encouraging repair and reprint rather than disposal (Ben Said et al., 2025). Nonetheless, challenges remain around material recycling and reuse. Future trends are expected to focus on the integration of eco-friendly, biodegradable materials to align with global sustainability goals (Ben Said et al., 2025).

Key external determinants and opportunities

Based on the PEST analysis, several external factors are expected to influence the future of AM:

- Political & Legal Factors: Harmonized international standards could enable AM growth, while fragmented regulations may hinder it. Effective IP frameworks and clear policies are needed to protect designs and balance innovation with accountability.
- Economic Factors: Accurate cost models and robust quality assurance systems are essential for commercial viability. Efficient digital supply chains can boost agility, and companies must shift focus from economies of scale to digital design agility to stay relevant.
- Socio-Cultural Factors: Democratizing access to AM could distribute innovation widely, provided cost and skill barriers are reduced. Education systems must integrate AM skills to evolve the workforce. Consumer preferences for personalized products can drive mass adoption.
- Technological & Environmental Factors: Advances in AM precision and material diversity will determine its competitiveness with traditional manufacturing. Integration with AI and sensors will improve reliability. Decentralized production models could reduce emissions and logistical costs.

Appendix A5: Feasibility of specialized requirements

This appendix discusses the feasibility of specialized requirements for products in the Philips Personal Health portfolio (appendix A1). These include specialized requirements for childrens products and childcare articles; food safety requirements; medical grade requirements and heat resistance requirements.

CHILDREN'S PRODUCTS / CHILDCARE ARTICLES AND FOOD SAFETY

Both requirements relate to the MCC category. Children's products should adhere to the strictest mechanical and physical safety requirements, as it is hard to accurately predict how a child would use a product. Additionally, baby bottles, bowls, and other items that come into contact with food and drink require compliance with specific substance regulations, following guidelines for food contact materials (Gronkvist, 2023).

Regulatory Context

Food-contact safety requires that all materials interacting with the product throughout its lifecycle (production, processing, and storage) should comply with Regulation (EC) No 1935/2004 (European Commision, 2025a). This means validated, end-to-end production workflows are essential to guarantee compliance with strict hygiene and safety standards. Such workflows include certified feedstocks, controlled (post-)processing, and full traceability to meet toy and food-contact regulations. Finished parts must remain safe during use, which means they cannot be porous. Achieving this typically requires surface smoothing (e.g., chemical smoothing) and, in most cases, applying a food-safe coating.

Feedstock and Process Considerations by AM Technology (Formlabs, 2025c):

- FDM: FDA and EU-approved filaments for desktop printers exist, but FDM parts are inherently porous and require post-processing and sealing.
- SLA: Certified biocompatible resins exist, but resin is not inherently food-safe. Uncured resin may migrate from SLA parts, even after post-curing, requiring controlled manufacturing and post-processing protocols.
- SLS: Food-grade powders (e.g., PA12 variants) are available, but surface particles and incomplete fusion leave porosity and moisture/mold risks. Autoclaving may be possible for some nylons, but sealing with a food-safe coating is typically recommended.

Food safe coatings or sealants can mitigate material limitations, but they require equally strict production controls and compatibility testing (Dizon et al., 2021). Even still, coatings don't guarantee food safety, as the coating may interact with the original material or degrade over time, exposing the original, potentially non-safe surface.

Currently, no specific regulatory frameworks exist for additive manufacturing of children's products. Therefore, even if compliant materials are available, producing such items with AM may still impose liability risks.

Feasibility depends on:

- Clear AM-specific regulatory frameworks for childcare and food-contact applications.
- Availability of certified materials and coatings at viable cost.
- Sufficient demand and ability to justify investment in compliant production lines.

MEDICAL GRADE

Current research on medical grade AM mainly focuses on implants, prosthetics and related tools (Srivastava & Rathee, 2022). The use case for Philips is less critical as it concerns external use parts, it still has to adhere to the same standards, such as using biocompatible materials and adhering to stringent quality control and traceability during the production process.

Regulatory Context

The FDA treats 3D printing as a manufacturing method under existing medical device rules, so printers, materials and printed parts must meet premarket, quality system and post market requirements (Ergometa, 2025). These process controls and validation requirements rule out home printing and necessitate the setup of a dedicated, regulated production line.

Material Considerations

Medical-grade feedstocks exist but are costly. Examples include SLA resins such as Tough 1500 (≈$149), Nylon 12 powders for SLS (often exceeding $1,000), and specialized filaments for FDM (around €300) (Ensinger, 2025; Formlabs, 2025b).

Feasibility

Thus, while this category benefits from existing AM adoption in healthcare, reducing regulatory uncertainty, the main determinant is economic viability of scaling a compliant process for consumer health products. For Philips' external-use components, feasibility hinges on:

- Access to certified materials at viable cost.
- Sufficient demand to justify investment in compliant production lines.

HEAT RESISTANCE

The feasibility of using AM to create heat-resistant parts is highly established in automotive and aerospace application and rapidly increasing due to the development of high performance polymers and resins (Formlabs, 2025a). Haircare products, such as hairdryer attachments, require thermal stability under continuous use. Meeting these requirements is critical for safety and performance.

Performance Requirements:

- Glass transition temperature: ≥ 100°C
- Heat deflection temperature: ≥ 100–120°C
- Maximum continuous use temperature (Vicat): ≥ 90–110°C

The original material is typically polycarbonate (PC).

Feedstock and process considerations by AM technology:

For FDM: Heat-resistant filaments such as PC (≈140°C), ULTEM (≈150°C), and PEEK (≈260°C) require printers capable of high extrusion and bed temperatures. A closed build chamber is recommended to maintain thermal stability during printing. Filaments with the highest heat resistance, like PEEK and ULTEM, are only compatible with specialized industrial FDM printers. However, PC can be processed on some advanced desktop printers, making it the most accessible option for consumer-level setups.

SLA: Proprietary resins vary by manufacturer. Formlabs offers High Temp Resin (HDT 238°C) and flame-retardant resin (HDT 111°C), suitable for professional setups.

SLS: All SLS materials are inherently heat-resistant, with Nylon 12 offering HDT ≈171°C, making it ideal for functional parts in high-temperature environments.

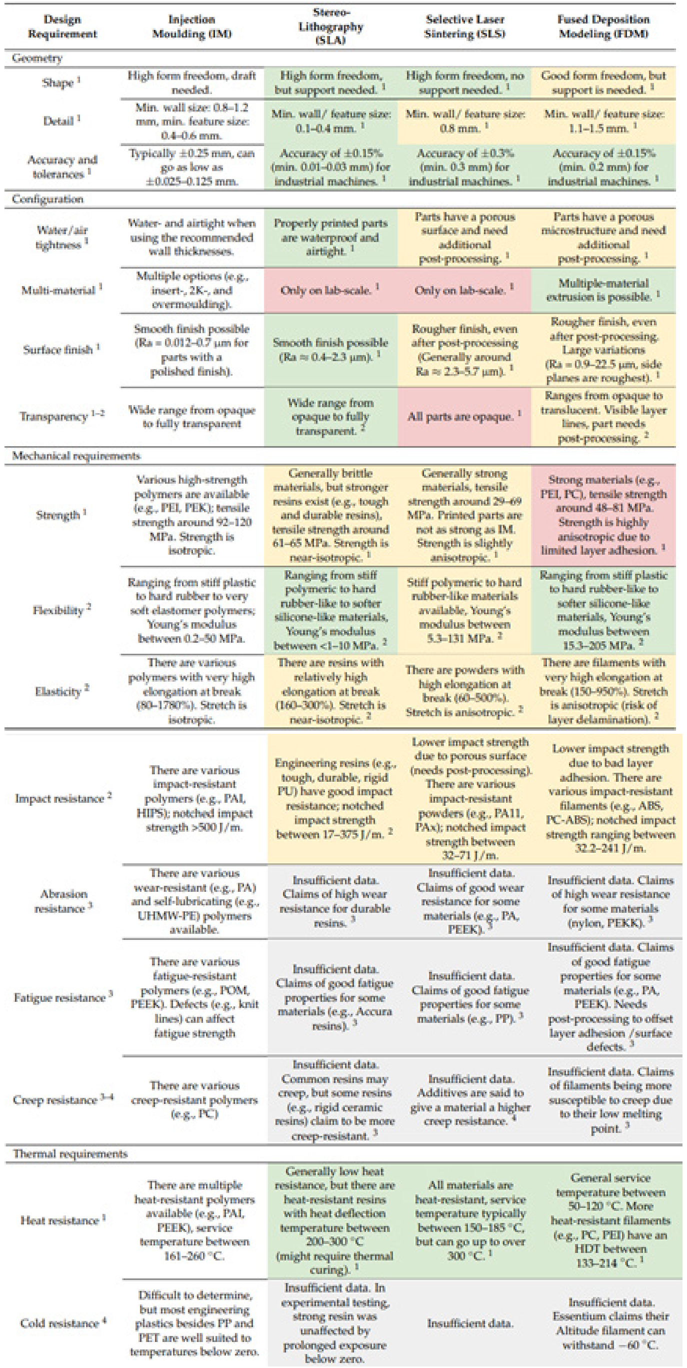
Home printing with FDM and PC may be possible, but further research is needed to confirm safety factors, compliance, and risks if not executed correctly. High-temperature AM parts are technically feasible today using advanced polymers (e.g., Nylon CF, ULTEM) and specialty resins; however, economic and accessibility constraints remain significant here. This requirement, however, is considered technically achievable and will be included for further exploration within the scope of this research.

Appendix A6: DfAM tools

This appendix shows the DfAM tools introduced in chapter 4.

Function Category	Function Specifics	Expected design requirements
Fitting	Connect	Accuracy, detail, shape, strength, flexibility, elasticity
	Position	Accuracy, detail
	Lock	Accuracy, detail, shape, strength, flexibility
	Seal	Accuracy, water/airtightness, flexibility, elasticity, multi-material
Structural	Strengthen	Shape, strength, impact resistance, fatigue resistance, creep resistance
	Support	Shape, detail, strength
	Resist	Strength, flexibility, elasticity, impact resistance, abrasion resistance, fatigue resistance, creep resistance, heat resistance, cold resistance, water resistance, UV resistance, chemical resistance
	Protect	Impact resistance, abrasion resistance, multi-material
Dynamic	Push	Shape, detail
	Rotate	Shape, detail
	Hinge	Detail
	Slide	Abrasion resistance, surface finish, detail
	Bend	Elasticity, flexibility
	Stretch	Elasticity
	Compress	Elasticity
Showing	Show, display	Transparency
	Inform	Detail
Containing	Contain, hold, store	Airtightness, accuracy
Transporting	Direct, channel	Shape, detail
	Ventilate	Detail
Aesthetic	Colour	Colour
	Contrast	Shape, detail, surface finish, multi-material, colour
	Pattern	Detail, surface finish
Tactile	Texture	Detail, surface finish, multi-material
	Grip	Detail, surface finish, multi-material
Speciality	Any keyword not mentioned above.	For example, food safety

Figure 67:The Function identification tool by A. van Oudheusden et al. (2025)



Design Requirement	Injection Moulding (IM)	Stereo-Lithography (SLA)	Selective Laser Sintering (SLS)	Fused Deposition Modeling (FDM)
Geometry				
Shape [1]	High form freedom, draft needed.	High form freedom, but support needed. [1]	High form freedom, no support needed. [1]	Good form freedom, but support is needed. [1]
Detail [1]	Min. wall size: 0.8–1.2 mm, min. feature size: 0.4–0.6 mm.	Min. wall/ feature size: 0.1–0.4 mm. [1]	Min. wall/ feature size: 0.8 mm. [1]	Min. wall/ feature size: 1.1–1.5 mm. [1]
Accuracy and tolerances [1]	Typically ±0.25 mm, can go as low as ±0.025–0.125 mm.	Accuracy of ±0.15% (min. 0.01–0.03 mm) for industrial machines. [1]	Accuracy of ±0.3% (min. 0.3 mm) for industrial machines. [1]	Accuracy of ±0.15% (min. 0.2 mm) for industrial machines. [1]
Configuration				
Water/air tightness [1]	Water- and airtight when using the recommended wall thicknesses.	Properly printed parts are waterproof and airtight. [1]	Parts have a porous surface and need additional post-processing. [1]	Parts have a porous microstructure and need additional post-processing. [1]
Multi-material [1]	Multiple options (e.g., insert-, 2K-, and overmoulding).	Only on lab-scale. [1]	Only on lab-scale. [1]	Multiple-material extrusion is possible. [1]
Surface finish [1]	Smooth finish possible (Ra = 0.012–0.7 µm for parts with a polished finish).	Smooth finish possible (Ra ≈ 0.4–2.3 µm). [1]	Rougher finish, even after post-processing (Generally around Ra ≈ 2.3–5.7 µm). [1]	Rougher finish, even after post-processing. Large variations (Ra = 0.9–22.5 µm, side planes are roughest). [1]
Transparency [1–2]	Wide range from opaque to fully transparent	Wide range from opaque to fully transparent. [2]	All parts are opaque. [1]	Ranges from opaque to translucent. Visible layer lines, part needs post-processing. [2]
Mechanical requirements				
Strength [1]	Various high-strength polymers are available (e.g., PEI, PEK); tensile strength around 92–120 MPa. Strength is isotropic.	Generally brittle materials, but stronger resins exist (e.g., tough and durable resins), tensile strength around 61–65 MPa. Strength is near-isotropic. [1]	Generally strong materials, tensile strength around 29–69 MPa. Printed parts are not as strong as IM. Strength is slightly anisotropic. [1]	Strong materials (e.g., PEI, PC), tensile strength around 48–81 MPa. Strength is highly anisotropic due to limited layer adhesion. [1]
Flexibility [2]	Ranging from stiff plastic to hard rubber to very soft elastomer polymers; Young's modulus between 0.2–50 MPa.	Ranging from stiff polymeric to hard rubber-like to softer silicone-like materials, Young's modulus between <1–10 MPa. [2]	Stiff polymeric to hard rubber-like materials available, Young's modulus between 5.3–131 MPa. [2]	Ranging from stiff plastic to hard rubber-like to softer silicone-like materials, Young's modulus between 15.3–205 MPa. [2]
Elasticity [2]	There are various polymers with very high elongation at break (80–1780%). Stretch is isotropic.	There are resins with relatively high elongation at break (160–300%). Stretch is near-isotropic. [2]	There are powders with high elongation at break (60–500%). Stretch is anisotropic. [2]	There are filaments with very high elongation at break (150–950%). Stretch is anisotropic (risk of layer delamination). [2]
Impact resistance [2]	There are various impact-resistant polymers (e.g., PAI, HIPS); notched impact strength >500 J/m.	Engineering resins (e.g., tough, durable, rigid PU) have good impact resistance; notched impact strength between 17–375 J/m. [2]	Lower impact strength due to porous surface (needs post-processing). There are various impact-resistant powders (e.g., PA11, PAx); notched impact strength between 32–71 J/m.	Lower impact strength due to bad layer adhesion. There are various impact-resistant filaments (e.g., ABS, PC-ABS); notched impact strength ranging between 32.2–241 J/m.
Abrasion resistance [3]	There are various wear-resistant (e.g., PA) and self-lubricating (e.g., UHMW-PE) polymers available.	Insufficient data. Claims of high wear resistance for durable resins. [3]	Insufficient data. Claims of good wear resistance for some materials (e.g., PA, PEEK). [3]	Insufficient data. Claims of high wear resistance for some materials (nylon, PEKK). [3]
Fatigue resistance [3]	There are various fatigue-resistant polymers (e.g., POM, PEEK). Defects (e.g., knit lines) can affect fatigue strength	Insufficient data. Claims of good fatigue properties for some materials (e.g., Accura resins). [3]	Insufficient data. Claims of good fatigue properties for some materials (e.g., PP). [3]	Insufficient data. Claims of good fatigue properties for some materials (e.g., PA, PEEK). Needs post-processing to offset layer adhesion /surface defects. [3]
Creep resistance [3–4]	There are various creep-resistant polymers (e.g., PC)	Insufficient data. Common resins may creep, but some resins (e.g., rigid ceramic resins) claim to be more creep-resistant. [3]	Insufficient data. Additives are said to give a material a higher creep resistance. [4]	Insufficient data. Claims of filaments being more susceptible to creep due to their low melting point. [3]
Thermal requirements				
Heat resistance [1]	There are multiple heat-resistant polymers available (e.g., PAI, PEEK), service temperature between 161–260 °C.	Generally low heat resistance, but there are heat-resistant resins with heat deflection temperature between 200–300 °C (might require thermal curing). [1]	All materials are heat-resistant, service temperature typically between 150–185 °C, but can go up to over 300 °C. [1]	General service temperature between 50–120 °C. More heat-resistant filaments (e.g., PC, PEI) have an HDT between 133–214 °C. [1]
Cold resistance [4]	Difficult to determine, but most engineering plastics besides PP and PET are well suited to temperatures below zero.	Insufficient data. In experimental testing, strong resin was unaffected by prolonged exposure below zero.	Insufficient data.	Insufficient data. Essentium claims their Altitude filament can withstand −60 °C.

Figure 68: Design requirements comparison by van Oudheusden et al. (2024)

Appendix A7: Case-based redesign process

This appendix discusses the detailed results of the four case-based redesign processes.

Case 1: Body comb intimate

This part is an attachment for the OneBlade Intimate, designed for use with the SkinProtect blade, which features the same cutting edge as the standard OneBlade blade but includes a T-shaped guard for added protection. It is designed to trim body hair at 3 mm.

Original material: Polycarbonate
Redesigned for: FDM using either PLA or PETG

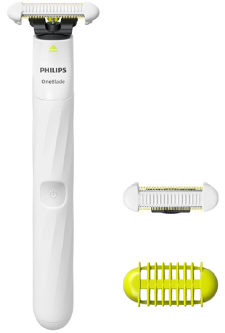


Figure 69: Oneblade intimate bodycomb (Philips Nederland, 2025)

PART FAMILY IDENTIFICATION

This attachment belongs to the same family as other OneBlade attachments already redesigned for Fixables. Specifically, the 3mm comb can be used as reference. From those previous efforts, the following key learnings were derived:

Skin-contact areas must be smooth:

- Teeth should be oriented flat on the build plate to achieve maximum smoothness.
- Edges of teeth extruded upward must avoid burrs; extrusion paths should move outward first, then inward for cleaner edges.

Bedplate adhesion requirements:

- The first layer of each tooth must have a thickness at least twice the nozzle size (=0.8 mm for a 0.4 mm nozzle), which further defines tooth design parameters.

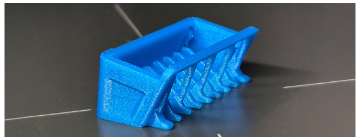


Figure 70: Print orientation


Figure 71:: Teeth extrusion

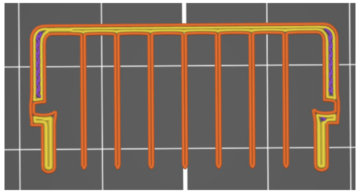


Figure 72: First print layer

Managing unsupported overhangs:

- Angled extrusions from teeth to the overhang improve strength and reduce support needs. The recommended angle is 15°
- To avoid stringing due to unnecessary travelling of the nozzle during printing, try to limit the amount of extrusions. It is recommended to stick to around 10 mm distance between extrusions.
- Extrusion profiles should also be twice the nozzle size to ensure proper adhesion.

Click-hook redesign:

- Original hooks were too weak for FDM printing.
- Solution: integrate hooks into the body rather than as standalone protrusions.

General design rules:

- Ensure all wall thicknesses and profiles use dimensions that are multiples of 2 × nozzle diameter (e.g., for a 0.4 mm nozzle, use increments of 0.8 mm).
- Align all vertical heights to multiples of the layer height (e.g., 0.15 mm) to improve print accuracy and consistency.
- For a smooth body finish, extrude the body at an angle between 10° to 15° to minimize visible layer lines and avoid large flat surfaces; ideally, surfaces should be angled at approximately 10° to 15°.

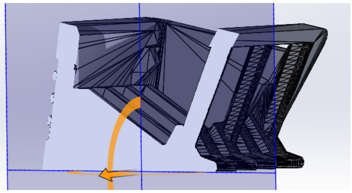


Figure 73: Overhang supports


Figure 74:Click hook redesign

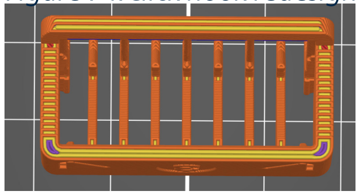


Figure 75: Nozzle paths

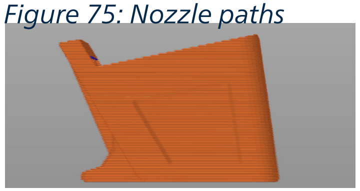


Figure 76: Body walls

PART REQUIREMENTS DEFINITION

The part must fulfill the following requirements:

The part must cut hair at 3 mm length.

The part must maintain a fixed distance of 3 mm between the shaver blade and the skin. For the redesign this means:

- The height of the click hooks must remain the same as in the original design.

- Tooth length, shape, and spacing must remain consistent, considering 3D printer tolerances. These parameters can be referenced from the existing 3 mm Oneblade comb on Fixables.

The part must click on the Skinprotect blade.
For the redesign this means:

- Internal ribbing must match the ribbed T-bone interface of the SkinProtect blade for proper fit.

The part should glide smoothly over skin.
The surface contacting the skin must have a smooth finish. For the redesign this means:

- To achieve this, the part should be printed with the teeth oriented toward the build plate.

The part should not damage the blade.
Click hooks must be rigid enough to hold the blade securely but flexible enough to allow easy attachment without excessive force. For the redesign this means:

- Hooks should connect on one side only (as in the flap-style redesign).
- Hook height must be precise, as incorrect height could allow blade movement, causing damage.

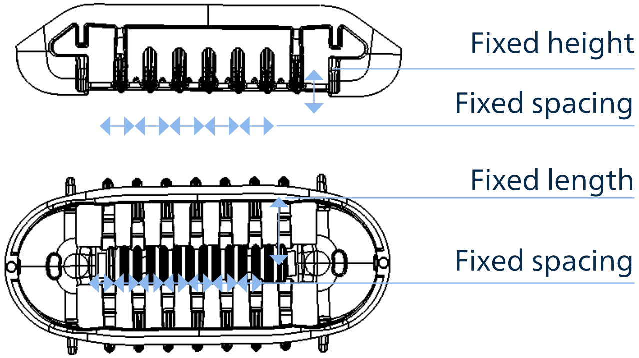


Figure 77: Critical dimensions

REDESIGN PROCESS

The redesign process followed an iterative approach, starting with exploratory steps and gradually refining the part for printability and functionality.

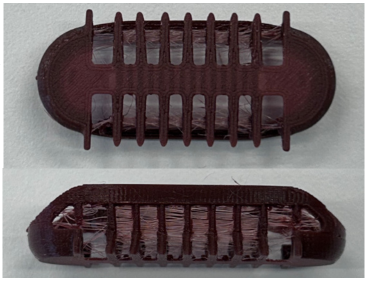


Figure 78: Iteration 1

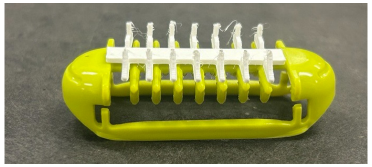


Figure 79: Iteration 2

It 1-2: Exploration & Validation. The original CAD model was printed in multiple orientations, including one adapted for support-free printing. This confirmed that insights derived from Fixables during the analysis phase were applicable. The teeth were redesigned from scratch based on Fixables principles, and an alternative approach was tested by creating an asset from the Fixables teeth and building the row from there. The asset-based method proved significantly faster than a full rebuild. Dimensional checks against the original part revealed the need for tolerance adjustments, and testing showed that the teeth were prone to breaking, highlighting the need for a thicker base in subsequent designs.

Figure 80: Iteration 3

It 3: Parametric Build-Up: The body of the part was parametrically built around the improved bottom section from Iteration 2. Extrusion patterns were tested, and alternating three extrusions with a 0.8 x 2 mm profile delivered the best results. This design was validated by printing on two different printers in both PLA and PETG, showing consistent output across machines. PETG demonstrated flexibility comparable to the original design.

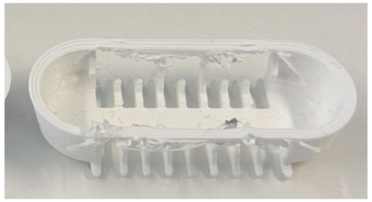


Figure 81: Iteration 4

It 4:Structural Refinement: Wall thickness was increased to 2 mm, which successfully improved strength. Then, the click hooks were modeled. It was found that the material removal here extended the unsupported overhang. This change disrupted the previously optimized extrusion pattern, causing insufficient support

and resulting in print failures on the overhang.
It 5: Feature Integration & Refinement: Extrusion patterns were refined, settling on four alternating extrusions starting immediately at the first tooth for aesthetic consistency (three was also feasible). Rib features were added to accommodate the blade, and the profile fit was validated in both PETG and PLA prints. A successful click-fit was achieved with PETG, while the PLA version experienced failure in one click hook, indicating material-dependent strength limitations.

It 6: Final Optimization: The focus was on optimizing the dimensions of the click-hook system. The design was parametrically set up so that the distance between the click hook and the blade remained constant, while the wall thickness of the click hook was varied. Testing revealed that PETG performed well with thicknesses between 0.8 mm and 2 mm, whereas PLA failed at anything below 2 mm. A thickness of 2 mm worked reliably for both materials and was adopted as the final specification.

The part was successfully redesigned through six iterations (comprising multiple prints), including two exploratory steps followed by four functional refinement phases. This process resulted in a functional, printable design without supports, optimized for both PLA and PETG. The preferred print material is PETG, as its flexibility matches the original design, ensuring better functional performance.

Figure 82: Extrusion patterns

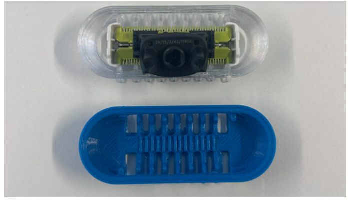


Figure 83: Rib features

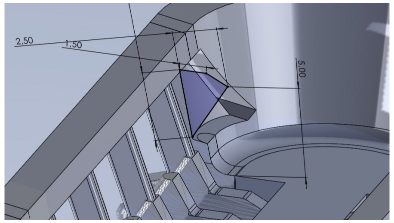


Figure 84: Parametric setup

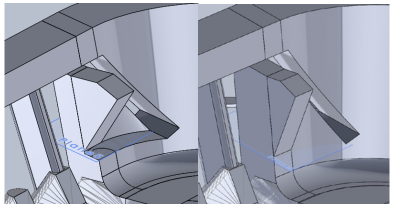


Figure 85: 0.8 - 2mm wall thickness

Figure 86: Final prototypes in PETG (left) and PLA (right)

TAKEAWAYS OF THE REDESIGN PROCESS

Wall thickness and click system:
- Use 2 mm body wall thickness.
- Maintain 2 mm thickness for click walls when the system engages from two sides with four hooks.
- Ensure the click system is positioned on a straight wall, not on a curved surface.

Teeth design approach:
- When working with shaver comb teeth:
  Convert one loose tooth into a reusable asset and build from there.
- Start by creating a single tooth, then build a row of teeth, and finally construct the body around that assembly.

Extrusions and overhang support:
- 10-15 mm unsupported overhang is acceptable
- Use alternating extrusions

Material Considerations
- PETG is more forgiving than PLA for thin features. Thus, when optimizing a design for both, prioritize PLA's stricter limits to ensure compatibility with both.
- Fillets improve printability for extrusions but do not help hooks or click features, apply selectively.

Slicer analysis

ORIGINAL DESIGN

Putting the original model in the slicer shows that printing without supports is not possible. Mostly the overhang requires supports for printability.

The analysis also reveals that the part lacks a suitable flat surface to orient it on. The teeth are slightly offset from the rest of the body, and orienting the part on the ridge causes the entire body to become an unsupported overhang. Moreover, the teeth themselves have a curved surface, which would result in poor build-plate adhesion even if they were not offset.

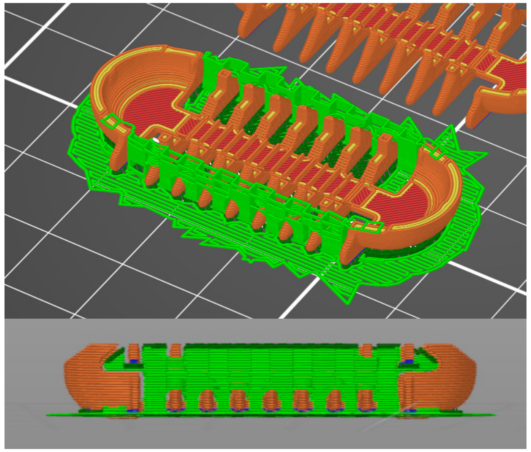


Figure 87: Recommended print configuration

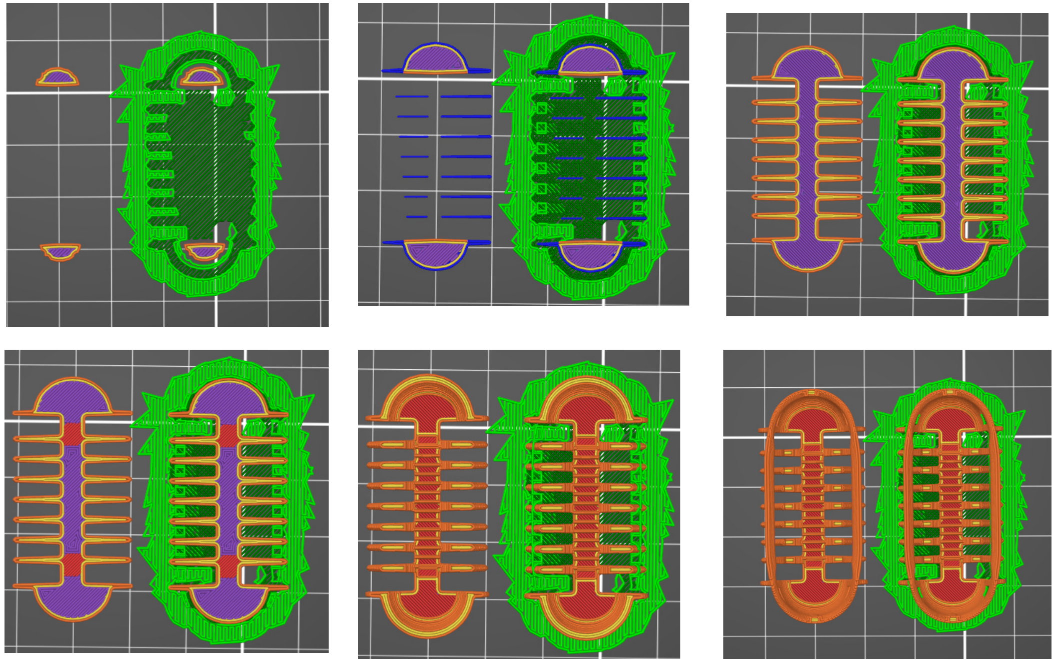


Figure 88: Top view of the print process with and without recommended supports

FIXABLES 3 MM COMB

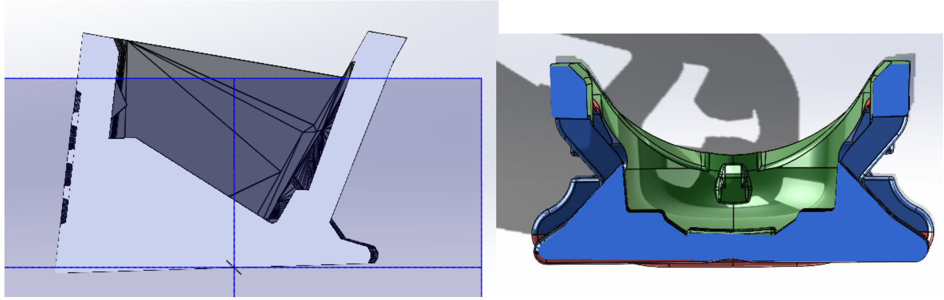


Figure 89: Profile comparison AM (right) vs IM teeth (left)

For the AM version, a wall thickness of 2 mm was chosen to ensure sufficient strength and reliable printabilit (a multiple of the 0.4 mm nozzle size). In comparison, the IM version utilizes a 1.8 mm wall thickness. Additionally, to minimize burring, the teeth in the AM design are shaped to first extrude steeply outward and then taper inward, whereas the IM version features a more gradual, fluid geometry.

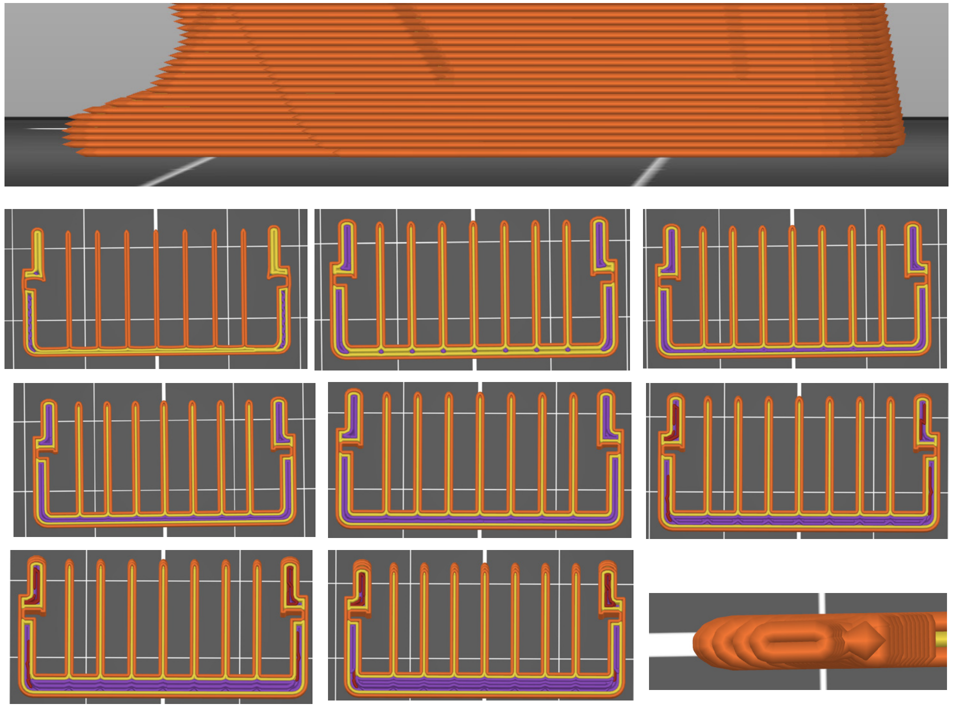


Figure 90: Top view of the print process of the teeth

Iteration 1

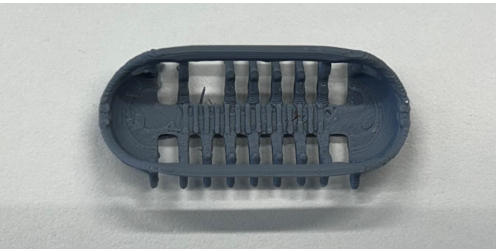
Printer under 45 degree angle

Surface of teeth was smooth, little to no roughness around the edges. Part of the body angled towards the buildplate printed well, angled upwards had staircase effect.

Support on the inside difficult to remove, parts broke while removing.

Printed with teeth on printbed

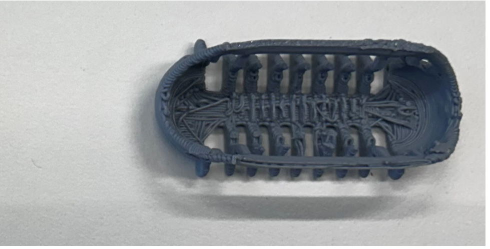
Spaghetti effect on teeth surface, support adhesion to model too strong; teeth broke of while removing.



Inside printed smooth.

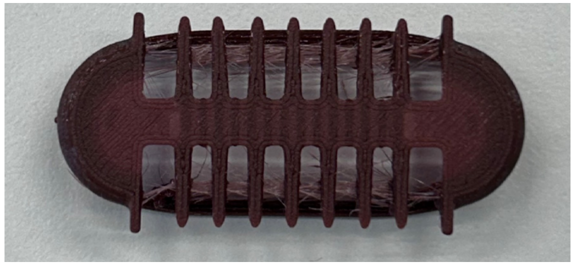
Printed with outer edge on printbed

Staircase effect on the whole body as well as the surface of the teeth.

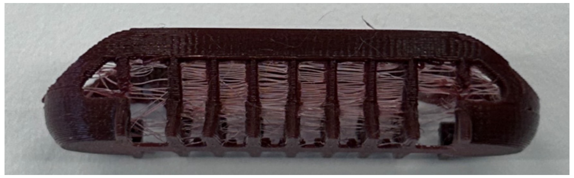


Spaghetti effect on the inside, but support was removable.

Sliced of surface until teeth and rest of body were leveled, made extrusions to support the outer overhang. Printed without support.



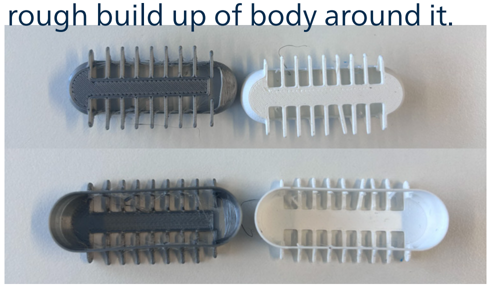
Smoothness of surface was good, but the edges of the teeth are very sharp.



Overhang printed well; excessive stringing occurred between the extensions of the teeth, and the inside of the curved side of the body.

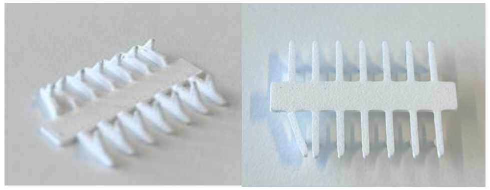
Iteration 2

Redesigned teeth from scratch, rough build up of body around it.



Printed well without supports, but features were too thin.

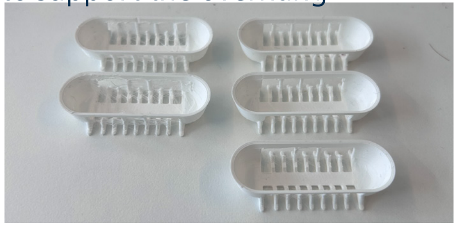
Bottom row assembly of reused teeth from Fixables comb



Smooth print, teeth broke of very easily. Need to increase the thickness of the bottom.

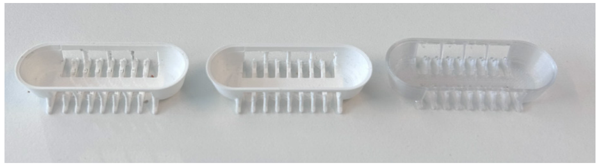
Iteration 3

Experimented with different pattern and profiles of extrusions to support the overhang



Alternating (3 extrusions) with a 0.8 x 2 mm profile came out best

Tested design on two different printers (Prusa left and Bambulab right) and printed in PETG (right)



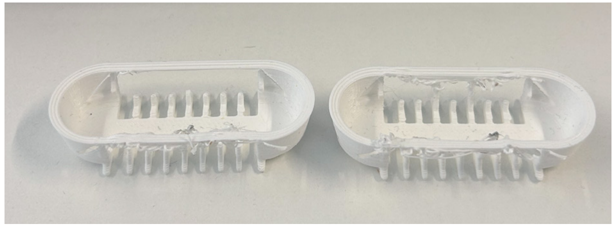
Achieved good output on both printers; PETG provided similar flexibility to original part

Iteration 4

Increased wall thickness to 2 mm

Confirmed that it was strong enough

Modelled the click hooks



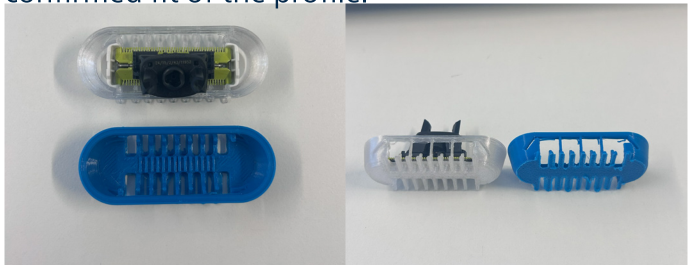
The click system lengthened the unsuppored overhang, thus the previously derived extrusion support pattern did not support enough anymore.

Iteration 5

Refined extrusion patterns.

Both printed well . Continued with the bottom version for aesthetic reaons

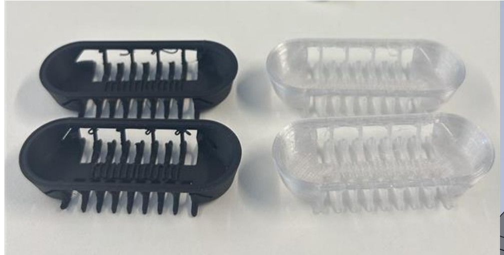
Modelled the ribs to accomodate the blade and confirmed fit of the profile.

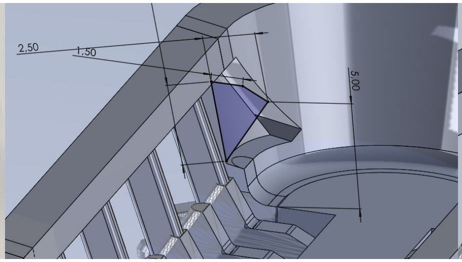


Successful click fit was achieved with PETG; PLA version broke one click-hook.

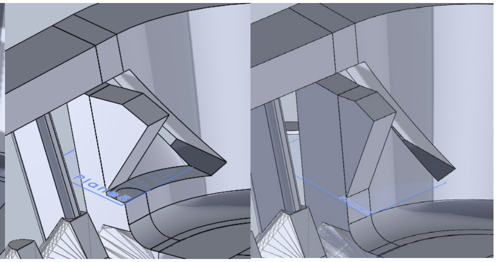
Iteration 6

Experimented with click hook wall thickness, distance tbetween click hook and blade stays same but varies in ckness of the wall, for PETG found that everything between 0.8mm and 2mm works, PLA broke except for at 2 mm, derived that 2 mm works for both





Parametric setup



0.8mm - 2mm wall thickness

Case 2: Body comb

This part is an attachment for the OneBlade designed for use with the regulare OneBlade blades. It is designed to trim body hair at 3 mm.

Original material: Polycarbonate
Redesigned for: FDM using either PLA or PETG

Figure 91: Oneblade bodycomb original (Philips Nederland, 2025)

PART FAMILY IDENTIFICATION

This attachment belongs to the same family as other OneBlade attachments already redesigned for Fixables, as well as the intimate bodycomb from the previous case. Thus the same learnings apply as well as the key takeaways derived in the previous case.

PART REQUIREMENTS DEFINITION

The same requirements apply as for the previous use case. The only difference is that this part directly clicks on to the blade requiring more careful attention to the attachment not damaging the blade.

REDESIGN PROCESS

A new approach was adopted to speed up dimension alignment and improve accuracy. The original model was split into a quarter (due to symmetry), and the redesign was built alongside the original geometry for reference.

Iteration 1: Building the body: Reused the teeth assembly from the previous part and built the body around it within the original model to maintain correct spacing, later suppressing the old geometry. Achieved a reliably printable part with minor dimensional tweaks.
Insight: Map printer tolerances early and align new features to the original geometry immediately.

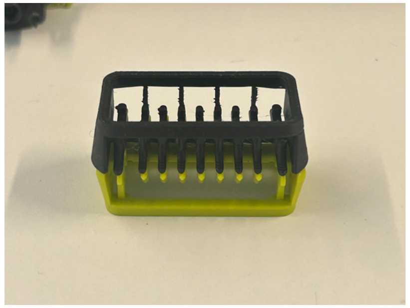


Figure 92: First print

Iteration 2: Feature integration: Modeled click hooks, initially testing two hooks on the short sides instead of four. This configuration allowed excessive vertical blade movement, causing blade damage.
Insight: Four hooks are required, positioned to clamp the blade corners for stability.

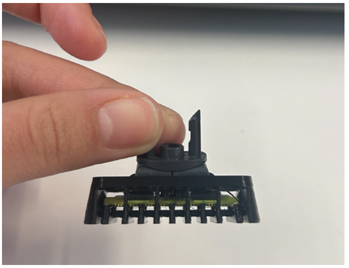


Figure 93: Vertical movement

Iteration 3: Structural refinement: Printed in PETG and PLA with two hooks placed as far outward as possible to clip the blade corners. Fit and function were achieved, using the 2 mm thickness insight from the previous case. However, direct blade insertion without its protective attachment caused damage.
Insight: Wall thickness needs re-evaluation for this configuration.

Figure 94: Click fit

Iteration 4: Explored wall thickness for the click hooks, finding that 1 mm was sufficient for both PETG and PLA. The blade without the attachment requires less clamping force, reducing breakage risk.
Insight: For this part, 1 mm wall thickness provides adequate strength and functionality.
The part was completed in four iterations, one of which was an exploratory step.

Figure 95: Final prototypes

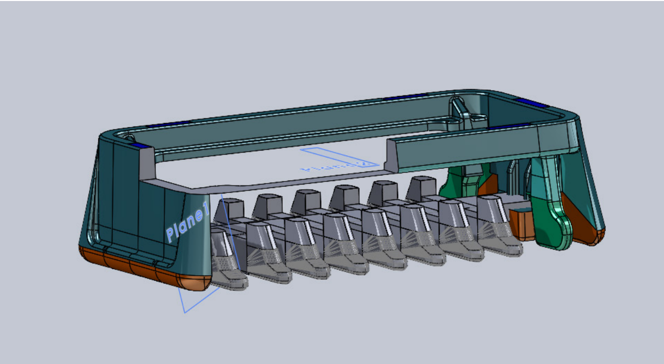
TAKEAWAYS OF THE REDESIGN PROCESS

- Leverage symmetry by splitting and mirroring the model and use the original geometry as a reference during redesign for faster and more accurate dimensioning.
- Maintain the original number of click hooks.
- Blades without the protective attachment are more fragile and need less insertion force, so use a 1 mm wall thickness for click hooks.

PROTOTYPING PROCESS

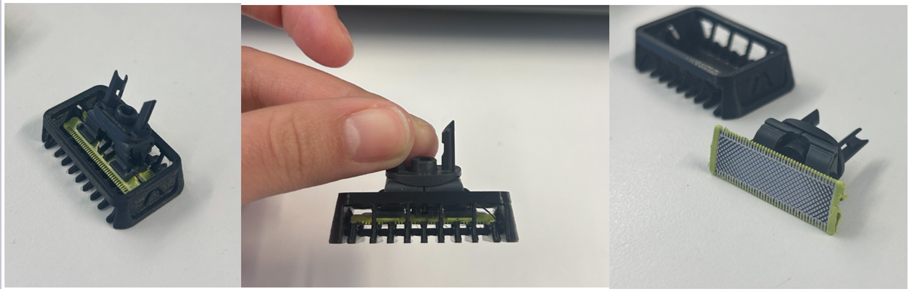
Iteration 1

Reused the teeth assembly and built the body around it within the original CAD model to maintain correct spacing. Achieved a reliably printable part with only minor dimensional tweaks.



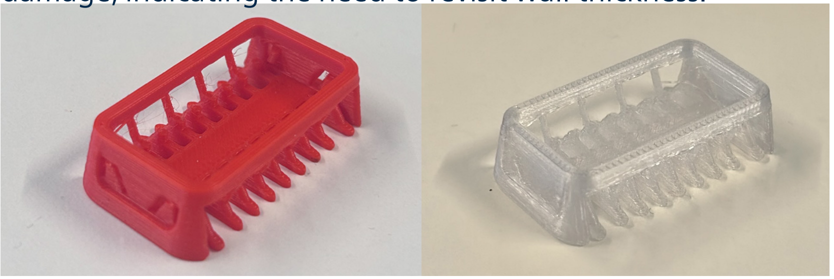
Iteration 2

Tested a design with a single click hook on each short side. This configuration allowed excessive vertical blade movement, causing damage. Insight: four hooks clamping the blade corners are required for stability.



Iteration 3

Added two click hooks positioned as far outward as possible to clip the blade corners. Printed in PETG and PLA using 2 mm wall thickness from previous case. Fit was achieved, but direct blade insertion without its protective attachment caused damage, indicating the need to revisit wall thickness.



Iteration 4

Reduced click hook wall thickness to 1 mm, which worked for both PETG and PLA. The blade without its attachment requires less clamping force, making 1 mm sufficient for strength and functionality.

Case 3: Stretcher

This part is an attachment for the OneBlade designed for use with the regulare OneBlade blades. It is designed to trim body hair at 3 mm.

Original material: Polycarbonate
Redesigned for: FDM using PLA

Figure 96: Satinelle stretcher original (Philips Nederland, 2025)

PART ANALYSIS

1. Skin Contact Area
Requirement: The surface that touches the skin must be smooth.
Dimensional Accuracy: Not critical for this area because its main function is to stretch the skin.
Challenges: Printing directly on the bedplate would achieve smoothness, but this is not possible due to the curved geometry. Sanding is not an option because the surface has an essential grip pattern for stretching.
Alternative: Print at 45° orientation to minimize layer lines.

Figure 97: Skin contact area (marked in green)

2. Device Connection Area
Requirement: This side must be dimensionally accurate to ensure a proper click-fit with the device.
Challenges: Normally, dimensional accuracy is best when printed close to the build plate, but this is not possible here due to geometry.
Solution: Explore different orientations through prototyping to determine which provides the best accuracy.

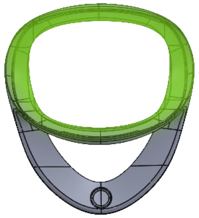


Figure 98: Device connection area (marked in green)

The Free Body Diagram (FBD) indicates that the largest force acts on the area marked near the click mechanism (coloured in blue).
Preferred Print Orientation: To maximize strength and reduce risk of failure, this force should be in the X-Y plane of the print. This minimizes the chance of layer separation under load.
Reinforcement Options: If additional strength is required, there is available space in the region marked in blue to add material.

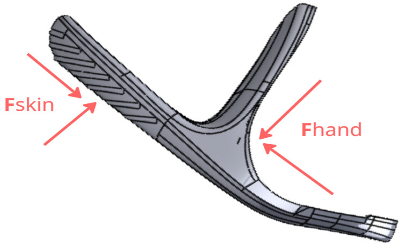


Figure 99: Simplified FBD of the part in use

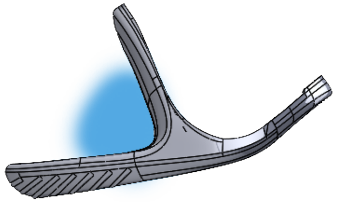


Figure 100: Design space for reinforcements

SLICER ANALYSIS

From the slicer analysis the following orientations were found.

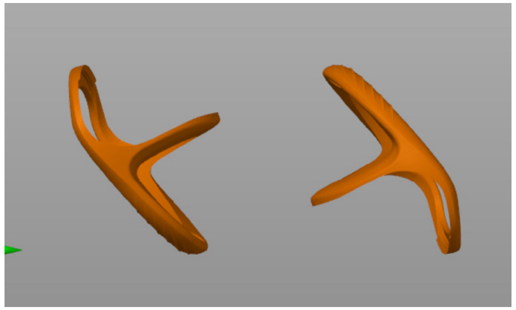


Figure 101: Orientations prioritizing force

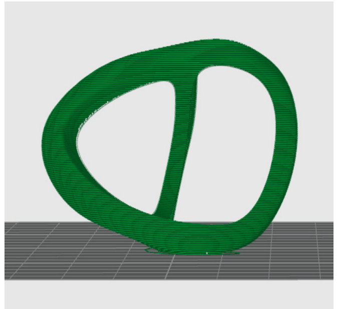


Figure 102: Orientation without support

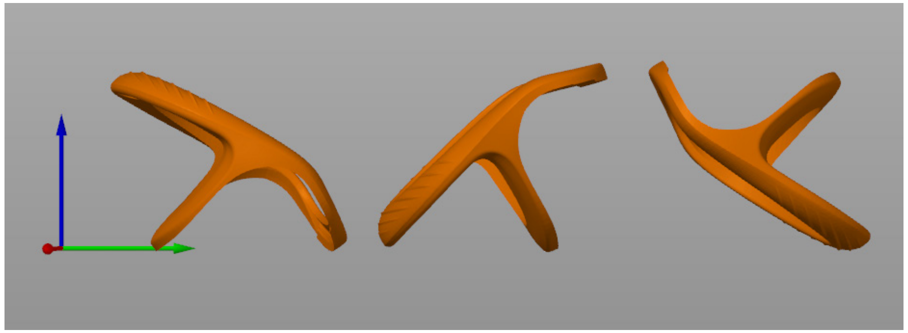


Figure 103: Orientation prioritizing surface smoothness

SLICER SETTINGS

For generating the removable supports, the following slicer settings were used.

Raft

Raft layers: 0 layers
Raft contact Z distance: 0.2 mm

Options for support material and raft

Style: Organic
Top contact Z distance: 0.2 (detachable) mm
Bottom contact Z distance: Same as top mm
Pattern: Rectilinear
Pattern spacing: 2 mm
Closing radius: 2 mm
Top interface layers: 1 (light) layers
Bottom interface layers: 0 (off) layers
Interface pattern: Rectilinear
Interface pattern spacing: 0.2 mm
Support on build plate only: ☐
XY separation between an object and its support: 100% mm or %
Don't support bridges: ☐

Organic supports

Maximum Branch Angle: 60 °
Preferred Branch Angle: 28 °
Branch Diameter: 2 mm
Branch Diameter Angle: 3 °
Branch Diameter with double walls: 3 mm
Tip Diameter: 0.8 mm
Branch Distance: 5
Branch Density: 10 %

Figure 104: Slicer settings

MODEL AND SUPPORT ORIENTATION

Use “paint-on-supports” and paint all the areas that require smoothness to not have supports.

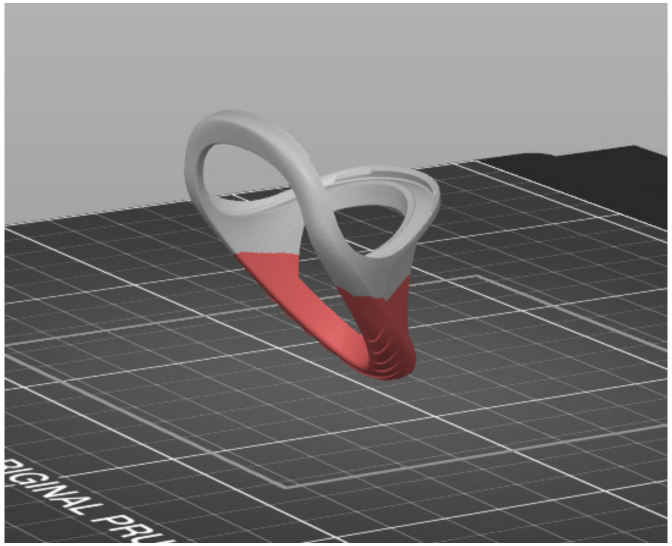


Figure 105: Selective support painting

Add a brim in the model to ensure accurate orientation.

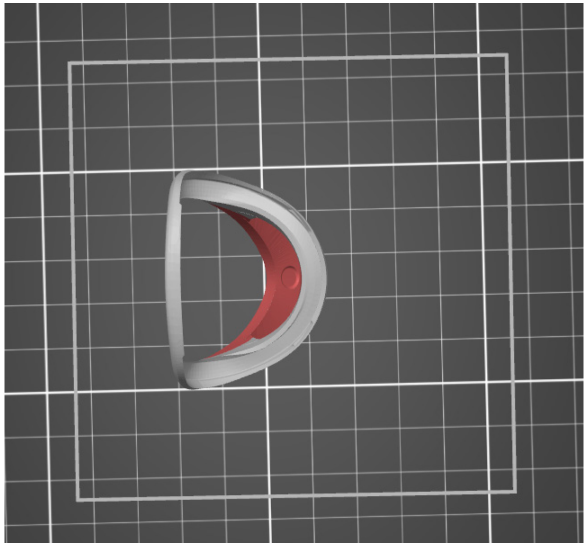


Figure 106: Brim for positioning

DESIGN RULES USED

Criterion	Can be achieved by:
Smoothness	Printing the area flat on the buildplate; Printing the area at an angle between 10 and 45 degrees; Sanding
Accuracy	Orienting the features in the x-y plane; Printing with supports; Redesigning the feature with printer tolerances in mind
Strength	Thickening or reinforcing of the feature; Aligning the loda path to the x-y plane

REDESIGN PROCESS

Iteration 1: Printed in derived orientations with regular supports, but they were impossible to remove. Organic supports worked slightly better. Positions 2 and 3 gave the best smoothness on the skin-contact area, but none fit properly—most broke during assembly, and shrinkage remained an issue. One support-free orientation was tested but this was only possible on Bambulab printers and also suffered from shrinkage.

Iteration 2: Since strength and smoothness couldn't both be optimized in one orientation, reinforcement was added in critical areas and prints were repeated. Tested three support strategies: painting where supports were wanted (failed), painting where supports were not wanted (better, one successful prototype), and continued with this approach. PETG was tested but proved unsuitable because the part needs rigidity, so PLA was preferred.


Figure 107: Iteration 1


Figure 108: Prototypes after testing fit

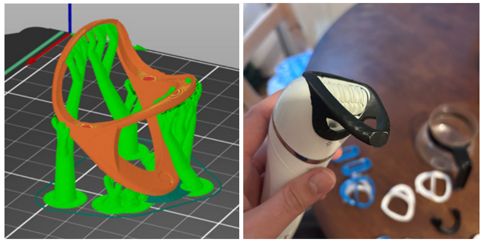


Figure 109: First succesful iteration


Figure 110: Shrinkage example

Iteration 3: Printed the successful prototype multiple times but faced adhesion and consistency issues. Slicing off the tip improved orientation but caused rough edges and did not improve adhesion Switching to regular supports instead of organic solved adhesion and supported the click system fully, fixing the shrinkage problem. Removal was also easier.

Iteration 4: Printed several more times, including on a different printer. The successful model worked, though slight roughness remained on the tip and click edge touching the skin, fixable with sanding. Brim roughness is inherent to slicer fill paths and would require a full redesign, so it was accepted.

Position 3, derived during the analysis phase, proved to be ideal, aligning with theoretical predictions.

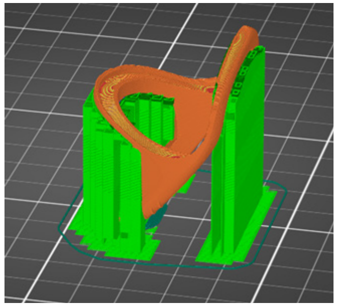


Figure 111: Final print file

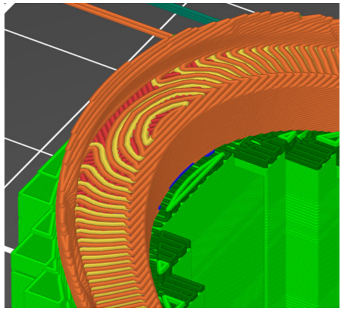


Figure 112: Close up of rough surface due to infill pattern

TAKEAWAYS OF THE REDESIGN PROCESS

- For dimensional stability, prefer regular supports over organic supports.
- For effective slicer support generation prefer only painting where not to generate supports.
- Shifting the mindset from "avoid supports" to "optimize for functional requirements" leads to more effective results.

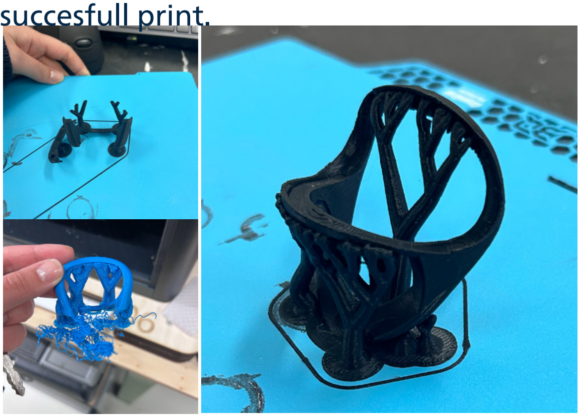
PROTOTYPING PROCESS

Iteration 1

Regular supports were unremovable, organic supports were removable but left marks. Parts that were undone of supports none of them fit and most of them broke. Part printed without supports was only possible on the Bambulab printer

Iteration 2

Added reinforecements and printed in the samel orientations using less supports, as well as organic. Ran into bedplate adhesion issues, but also had one succesfull print.



Iteration 3

One trial with PETG, but failed because it was too flexible

Continued printing the successful iteration and tested slicing off the tip to improve bedplate adhesion, but this failed and results remained inconsistent across printers due to shrinkage of the click edge. Switching to regular supports (non-organic) and allowing supports near the base solved adhesion issues, and as the supports reinforced the entire click edge also improved dimensional stability. However, roughness persisted at the tip and the opposite click edge that contacts the skin. Slicer analysis showed this was due to the print pattern, which can only be resolved through a full redesign.

Iteration 4

Focus on printing a few more times to check consistency of results and tried sanding of the edges, this was able to improve the smoothness sufficiently.

Case 4: Nozzle

This part is an attachment for hairdryer 3000
Original material: Polycarbonate
Redesigned for: FDM, DLP AND MJF in various materials

Figure 113: Original part and product (Philips Nederland, 2025)

PART ANALYSIS

For heat requirements, the most important requirement is exposure to 125°C. The original material is PC (PolyCarbonate), which has the following properties related to heat:

- Heat Deflection Temperature: 130°C
- Glass Transition Temperature: 150°C
- Vicat Softening Point:165°C

Key risks associated with heat resistant parts are material failure due to warping or cracking under heat stress as well as the potential release of harmful fumes from unsuitable polymers Beyond heat requirements, the nozzle has an exceptionally smooth surface on the inside where the air passes to ensure smooth airflow during use.

Furthermore, the product itself has 3 temperature settings, at the outlet these measue approximately:

- Cool setting: 25–30°C
- Medium setting: 45–60°C
- Hot setting: 70–90°C

For this case study, the decision was made to focus on material exploration, so MJF and DLP were included in the scope alongside FDM. Materials were selected based on availability at the Product Research Center of Philips Drachten. See table 18 for the materials evaluated and their corresponding thermal properties.

Before testing with these materials, print orientations and fit were tested using FDM printing, also to evaluate the influence of internal surface roughness on airflow. These tests were conducted with commodity filaments, starting with PLA to determine optimal orientations and fit, followed by PETG and TPU, which offer slightly improved heat resistance. This allowed safe testing of the parts on the product at lower temperature settings. Table 19 shows the thermal properties of the evaluated FDM filaments.

Table 18: Overview of production techniques and materials tested in Drachten

Production technique & material	Heat deflection temperature @ 1.8 MPa	Glass transition temperature	Vicat softening temperature
FDM - Ultem1010	213 °C	215 °C	214 °C
DLP - Loctite3995	214 °C	252.7 °C	Not in data sheet
MJF- PA12 (Nylon)	106 °C	Not in data sheet	Not in data sheet

Table 19: Overview of heat properties of commodity filaments tested

Production technique & material	Heat deflection temperature @ 1.8 MPa	Glass transition temperature	Vicat softening temperature
PLA	55 °C	Not in data sheet	Not in data sheet
PETG	68 °C	Not in data sheet	Not in data sheet
TPU	78.6 °C	Not in data sheet	101.6 °C

TAKEAWAYS OF THE REDESIGN PROCESS

- Heat-resistant FDM filaments absorbed moisture, causing stringing or pronounced layer lines due to poor flow at low extrusion temperatures.The internal roughness of the printed parts did not cause noticeable airflow disruptions when the hairdryer was operated.
- Resin printing (DLP) currently offers the most reliable outcome due to a combination of part quality and strong thermal performance. FDM would become a viable option if filaments can be stored and printed in moisture controlled environments.

Iteration 1

Printed on FDM printer in PLA to validate geometry and determine optimal orientation. Two options were tested, one with the outlet oriented on the buildplate and one with the click ridge on the buildplate, both with support generation turned on. The concept with the outlet on the buildplate was chosen to continue with as the removal of supports here was the easiest and it gave the best finish on the internal channels. The click fit was also validated, as can be seen in figure 115.

Iteration 2

The second iteration tested PETG and TPU, two commodity filaments that have a better thermal resistance than PLA. Both prototypes showed excessive stringing on the inside due to moisture absorption. Both prototypes were tested on the hair dryer on the low temperature setting. No noticeable disruptions in airflow were observed compared to the original part.

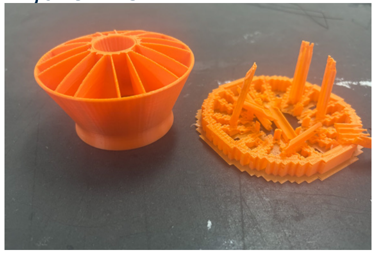


Figure 114:PLA; orientation 1

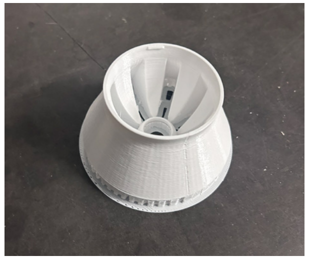


Figure 115:PLA; orientation 2


Figure 116: Click fit validation

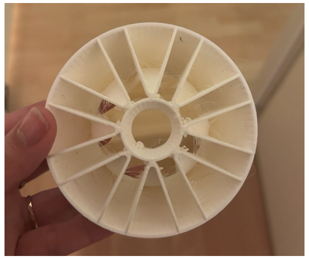


Figure 117:PETG

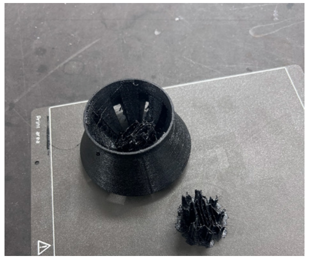


Figure 118:TPU

Iteration 3

Prototypes were ordered from Drachten using three processes. The MJF prototypes in PA12 showed inconsistent fit: one sample was too loose, and another fit marginally but still not satisfactorily. In addition, PA12 does not meet the required heat-resistance specification for this part. The DLP prototype printed in Loctite3995 exhibited a very good fit, even slightly tight, with some residual powder in the crevices, but overall resulted in a high-quality part. The FDM prototype printed in Ultem 1010 showed excessive layer lines due to poor flow at low extrusion temperatures.

Accordingly, the DLP prototype printed in Loctite 3995 was chosen as the final version, as it delivered the most reliable fit and finish and satisfied the thermal performance requirements.


Figure 119: FDM - Ultem1010


Figure 120: MJF - PA12


Figure 121: DLP - Loctite3995

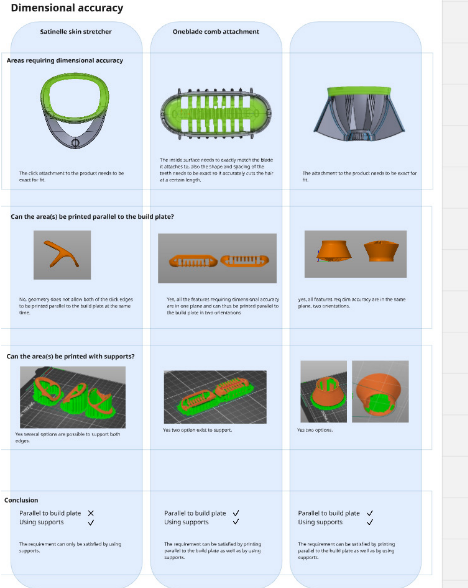

Figure 122: Final prototype; DLP - Loctite3995

Appendix A8: Concepts of redesign guidance cards

Concept 1

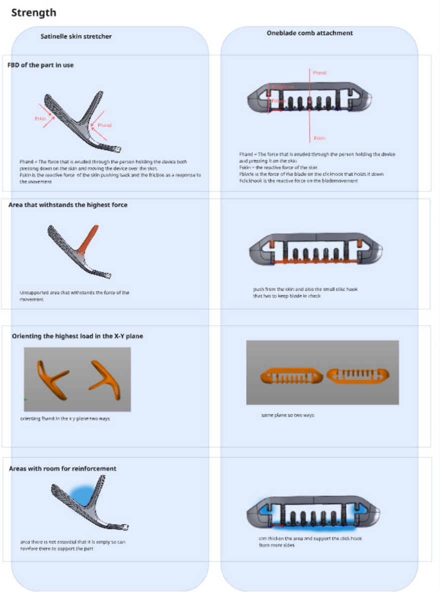
Smoothness

	Satinelle skin stretcher	Oneblade comb attachment	Hair dryer nozzle
Areas requiring smoothness	The area that glides over skin requires smoothness.	The area that glides over skin requires smoothness.	Inside that comes into contact with air requires smoothness as to not disrupt airflow
Can the area(s) be smoothed by sanding?	No, due to grip texture on the area.	Yes	Yes, but as it is on the inside it can't be sanded by hand so it has to be done with e.g. sandblasting.
Can the area(s) be printed flat on the bedplate?	Technically yes, but curved surface would need to be flattened and this is prohibited by the grip texture so no,	Yes but the surface would need to be flattened for layer adhesion	No, due to its circular form
Can the area be(s) printed at a 45 degree angle?	Yes, 3 options	Yes, 2 options	No, due to its circular form



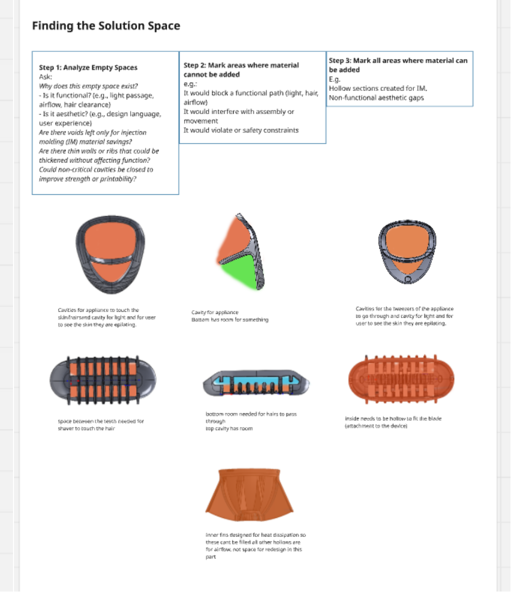
Dimensional accuracy

	Satinelle skin stretcher	Oneblade comb attachment	
Areas requiring dimensional accuracy	The click attachment to the product needs to be exact for fit.	The inside surface needs to exactly match the blade it attaches to, also the shape and spacing of the teeth needs to be exact so it accurately cuts the hair at a certain length.	The attachment to the product needs to be exact for fit.
Can the area(s) be printed parallel to the build plate?	No, geometry does not allow both of the click edges to be printed parallel to the build plate at the same time.	Yes, all the features requiring dimensional accuracy are in one plane and can thus be printed parallel to the build plate in two orientations	yes, all features req dim accuracy are in the same plane, two orientations.
Can the area(s) be printed with supports?	Yes several options are possible to support both edges.	Yes two option exist to support.	Yes two options.
Conclusion	Parallel to build plate ✗ Using supports ✓ The requirement can only be satisfied by using supports.	Parallel to build plate ✓ Using supports ✓ The requirement can be satisfied by printing parallel to the build plate as well as by using supports.	Parallel to build plate ✓ Using supports ✓ The requirement can be satisfied by printing parallel to the build plate as well as by using supports.



Strength

	Satinelle skin stretcher	Oneblade comb attachment
FBD of the part in use	Fhand = The force that is exuded through the person holding the device both pressing down on the skin and moving the device over the skin. Fskin is the reactive force of the skin pushing back and the friction as a response to the movement	Fhand = The force that is exuded through the person holding the device and pressing it on the skin Fskin = the reactive force of the skin Fblade is the force of the blade on the clickhook that holds it down Fclickhook is the reactive force on the blademovement
Area that withstands the highest force	Unsupported area that withstands the force of the movement	push from the skin and also the small click hook that has to keep blade in check
Orienting the highest load in the X-Y plane	orienting fhand in the x y plane two ways	same plane so two ways
Areas with room for reinforcement	area there is not essential that it is empty so can reinfore there to support the part	can thicken the area and support the click hook from more sides



Finding the Solution Space

Step 1: Analyze Empty Spaces	Step 2: Mark areas where material cannot be added	Step 3: Mark all areas where material can be added
Ask: *Why does this empty space exist?* - Is it functional? (e.g., light passage, airflow, hair clearance) - Is it aesthetic? (e.g., design language, user experience) *Are there voids left only for injection molding (IM) material savings?* *Are there thin walls or ribs that could be thickened without affecting function?* *Could non-critical cavities be closed to improve strength or printability?*	e.g.: It would block a functional path (light, hair, airflow) It would interfere with assembly or movement It would violate or safety constraints	E.g. Hollow sections created for IM. Non-functional aesthetic gaps

Cavities for appliance to touch the skin/hairsand cavity for light and for user to see the skin they are epilating.

Cavity for appliance
Bottom has room for something

Cavities for the tweezers of the appliance to go through and cavity for light and for user to see the skin they are epilating.

Space between the teeth needed for shaver to touch the hair

bottom room needed for hairs to pass through
top cavity has room

inside needs to be hollow to fit the blade (attachment to the device)

inner fins designed for heat dissipation so these cant be filled all other hollows are for airflow, not space for redesign in this part

Concept 2

Smoothness

An example guide on how to define areas requiring smoothness and how to satisfy this requirement when designing for 3D printing.

Identifying the area

Surfaces that come into **contact with skin** must be smooth to avoid irritating the skin.

Surfaces that require low friction to ensure **efficient flow** and prevent unwanted resistance.

Ask: Can the area(s) be smoothed by sanding?
Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

Ask: Can the area(s) be printed at a 45° angle?
Watch out for textures that must be preserved, and consider sandblasting for internal surfaces that cannot be reached manually.

Ask: Can the area(s) be printed flat on the buildplate?
Watch for curved geometries that won't make full contact, and evaluate if flattening the area is possible while maintaining sufficient adhesion.

✗ Grip pattern prohibits flattening of curved surface.

✓ Surface can be flattened for bedplate adhesion

Dimensional accuracy

An example guide on how to define areas that require dimensional accuracy and how to satisfy this requirement when designing for 3D printing.

Identifying the area

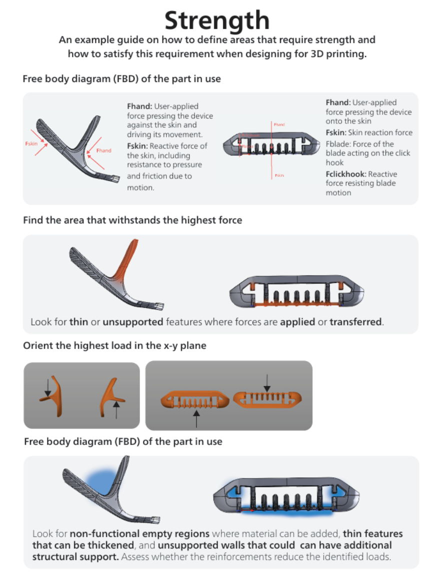
Identify all areas that **interface** with the device or assembly they attach to, look for features such as **click-fits,** or **alignment profiles** that must match precisely.

Ask: Can the area(s) be printed parallel to the build plate?
Consider whether all identified features lie in the same plane.

✗ Geometry prevents both sides from being printed parallel to the build plate simultaneously.

✓ All features are in the same plane.

Ask: Can the area(s) be printed with supports?
Explore how support structures could stabilize the identified features during printing.



Strength

An example guide on how to define areas that require strength and how to satisfy this requirement when designing for 3D printing.

Free body diagram (FBD) of the part in use

Fhand: User-applied force pressing the device against the skin and driving its movement.
Fskin: Reactive force of the skin, including resistance to pressure and friction due to motion.

Fhand: User-applied force pressing the device onto the skin
Fskin: Skin reaction force
Fblade: Force of the blade acting on the click hook
Fclickhook: Reactive force resisting blade motion

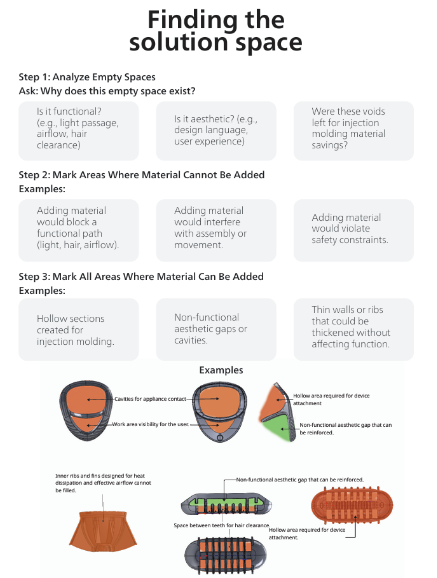
Find the area that withstands the highest force

Look for **thin** or **unsupported** features where forces are **applied** or **transferred**.

Orient the highest load in the x-y plane

Free body diagram (FBD) of the part in use

Look for **non-functional empty regions** where material can be added, **thin features that can be thickened**, and **unsupported walls that could can have additional structural support.** Assess whether the reinforcements reduce the identified loads.



Finding the solution space

Step 1: Analyze Empty Spaces
Ask: Why does this empty space exist?

Is it functional? (e.g., light passage, airflow, hair clearance)	Is it aesthetic? (e.g., design language, user experience)	Were these voids left for injection molding material savings?

Step 2: Mark Areas Where Material Cannot Be Added
Examples:

Adding material would block a functional path (light, hair, airflow).	Adding material would interfere with assembly or movement.	Adding material would violate safety constraints.

Step 3: Mark All Areas Where Material Can Be Added
Examples:

Hollow sections created for injection molding.	Non-functional aesthetic gaps or cavities.	Thin walls or ribs that could be thickened without affecting function.

Examples

Cavities for appliance contact
Work area visibility for the user.
Hollow area required for device attachment
Non-functional aesthetic gap that can be reinforced.
Inner ribs and fins designed for heat dissipation and effective airflow cannot be filled.
Non-functional aesthetic gap that can be reinforced.
Space between teeth for hair clearance.
Hollow area required for device attachment.

Appendix A9: User test

This appendix gives the plan for the user test of the developed redesign framework

Objective

Understand if and how participants interact with the developed design tools and evaluate whether the steps in the developed workflow and the visual cards are understandable and usable by designers. Specifically:

- Can participants correctly identify areas requiring smoothness, strength, and dimensional accuracy?
- Can they propose print orientations that align with AM capabilities?
- How do they interact with the material?

Participants

- Number: 5
- Profile: Designers familiar with CAD and product design, with experience in 3D printing but not necessarily AM experts.
- Distribution:
    - First test participant tries both cases.
    - 2 participants test the epilator case.
    - 2 participants test the shaver case.

Materials

- Physical original product and attachment.
- Printed papers with part views:
    - One sheet with multiple rows of the same views for annotation.
- Printed workflow and visual cards:
    - A simplified version of the workflow (remove steps not tested, such as manufacturing specifications and final insight).
- 3D printed prototypes of the parts referenced in the visual cards.
- Markers for annotation.
- Observation sheet for facilitator

.

Data Collection

- Name, age and previous experience with 3D printing
- Annotated part views.
- Notes on orientation choices.
- Observations on interaction with provided materials.
- Feedback from reflection questions.

Test Setup

Two cases similar to those used in the framework but not identical:

- One OneBlade attachment comb.
- One Satinelle skin stretcher.

Test Procedure

Step 1: Introduction (5 min)

- Explain the context of the research:

"We are developing a method to help redesign parts for Additive Manufacturing. The goal is to make the early steps of the redesign process easier and more structured."

- Explain the purpose of the test:

"We are testing whether the steps in this framework are clear and usable. You'll work through an example part, mark areas based on functional requirements, and show how you would orient a part."

- Hand over the consent form, give participant time to read and sign
- After signing ask participant their age and previous experience with 3D printing.

Step 2: Explain Workflow and Cards (5 min)

- Show the simplified workflow and visual cards.
- Explain:
    - The workflow references the cards for guidance.
    - Introduce the 3D printed example parts and explain that they can be used for reference.
    - No slicer will be used; orientation will be demonstrated physically.

Step 3: Identifying the Solution Space (5 min)

- Hand over the physical product and printed part views.
- Provide the Solution Space card and explain:

"Please mark on the printed views which areas are off-limits for adding material and which areas have room for changes."

- After they finish, hand over the Smoothness card and ask:

"Now, mark areas where smoothness is critical. How would you orient the part to satisfy this requirement?"

- Then hand over the Strength card:

"Mark areas that need reinforcement or are likely to experience stress during use. How would you orient the part to satisfy this requirement?"

- Finally, hand over the Dimensional Accuracy card:

"Mark areas that must remain dimensionally precise for proper fit or function. How would you orient the part to satisfy this requirement?"

Step 4: Evaluating the Insights (5 min)

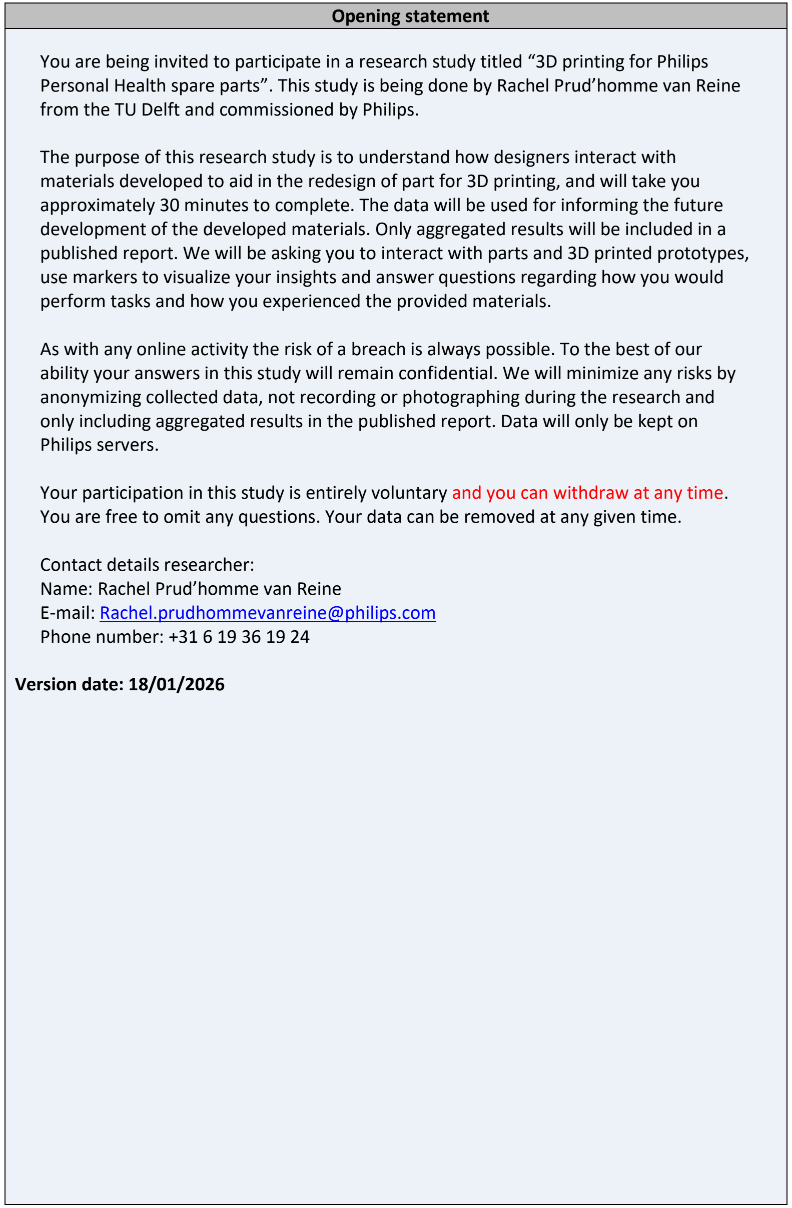
- Ask participants to review all the markings and conclusions they made in the previous steps.
- "Looking at everything you've marked and the decisions you've made, what do you think is

now the best orientation to print this part?”
Step 5: Feedback and Evaluation (10 min)
Ask:

- “Were the steps clear?”
- “Did the visual cards help you make decisions?”
- “Did the physical prototypes help?”
- “What was confusing or missing?”

Informed consent form template

The following section presents the template of the informed consent form used in the study. Signed copies are not included to protect participant privacy but can be accessed upon request by contacting the researcher.



Opening statement

You are being invited to participate in a research study titled “3D printing for Philips Personal Health spare parts”. This study is being done by Rachel Prud’homme van Reine from the TU Delft and commissioned by Philips.

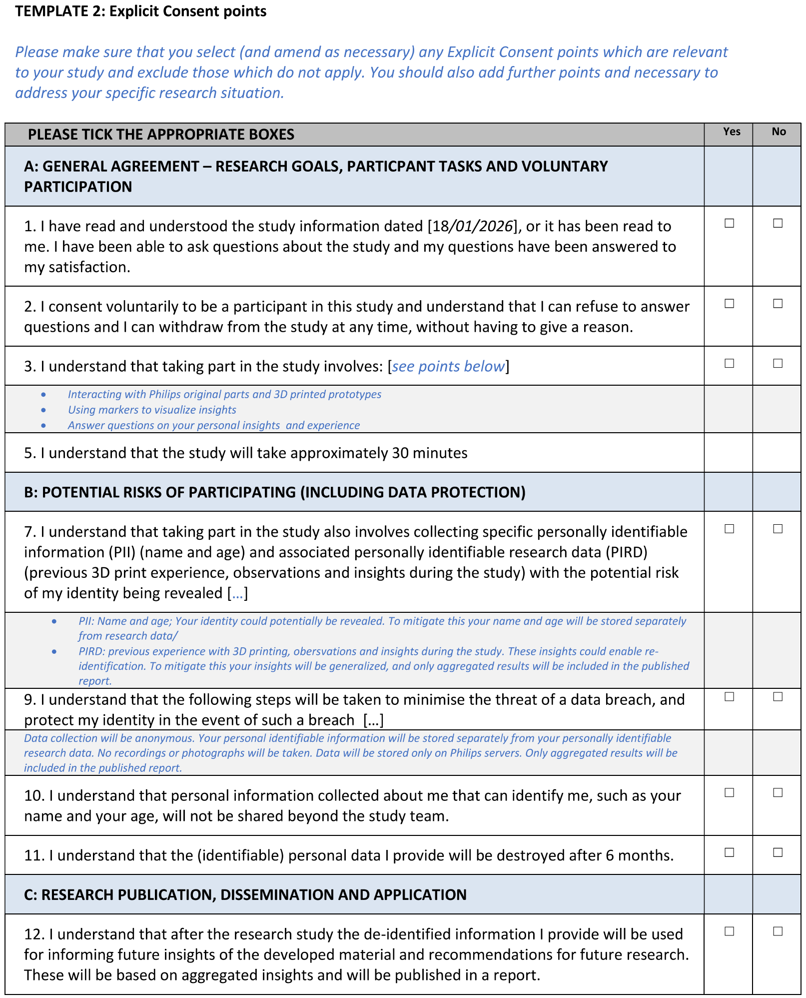
The purpose of this research study is to understand how designers interact with materials developed to aid in the redesign of part for 3D printing, and will take you approximately 30 minutes to complete. The data will be used for informing the future development of the developed materials. Only aggregated results will be included in a published report. We will be asking you to interact with parts and 3D printed prototypes, use markers to visualize your insights and answer questions regarding how you would perform tasks and how you experienced the provided materials.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by anonymizing collected data, not recording or photographing during the research and only including aggregated results in the published report. Data will only be kept on Philips servers.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions. Your data can be removed at any given time.

Contact details researcher:
Name: Rachel Prud’homme van Reine
E-mail: Rachel.prudhommevanreine@philips.com
Phone number: +31 6 19 36 19 24

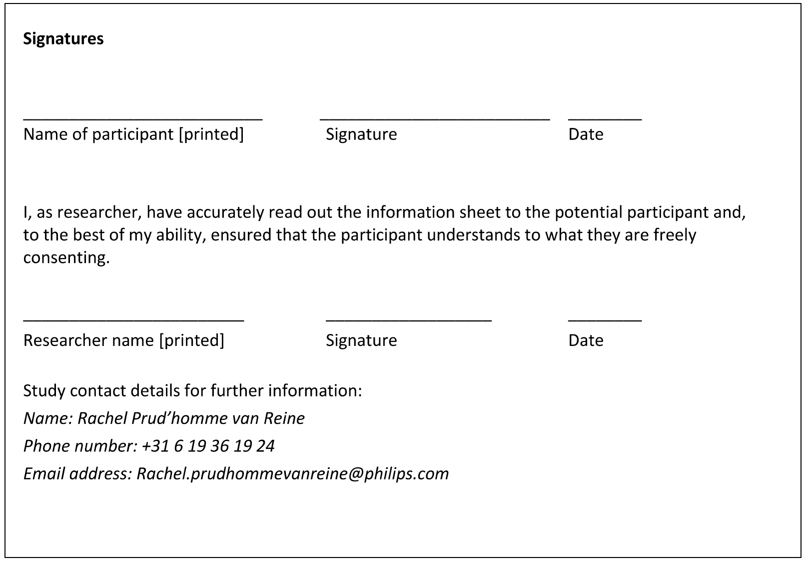
Version date: 18/01/2026



TEMPLATE 2: Explicit Consent points

Please make sure that you select (and amend as necessary) any Explicit Consent points which are relevant to your study and exclude those which do not apply. You should also add further points and necessary to address your specific research situation.

PLEASE TICK THE APPROPRIATE BOXES	**Yes**	**No**
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [18/*01/2026*], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
3. I understand that taking part in the study involves: [*see points below*]	☐	☐
• *Interacting with Philips original parts and 3D printed prototypes* • *Using markers to visualize insights* • *Answer questions on your personal insights and experience*		
5. I understand that the study will take approximately 30 minutes		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
7. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) (name and age) and associated personally identifiable research data (PIRD) (previous 3D print experience, observations and insights during the study) with the potential risk of my identity being revealed […]	☐	☐
• *PII: Name and age; Your identity could potentially be revealed. To mitigate this your name and age will be stored separately from research data/* • *PIRD: previous experience with 3D printing, obersvations and insights during the study. These insights could enable re-identification. To mitigate this your insights will be generalized, and only aggregated results will be included in the published report.*		
9. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach […]	☐	☐
Data collection will be anonymous. Your personal identifiable information will be stored separately from your personally identifiable research data. No recordings or photographs will be taken. Data will be stored only on Philips servers. Only aggregated results will be included in the published report.		
10. I understand that personal information collected about me that can identify me, such as your name and your age, will not be shared beyond the study team.	☐	☐
11. I understand that the (identifiable) personal data I provide will be destroyed after 6 months.	☐	☐
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
12. I understand that after the research study the de-identified information I provide will be used for informing future insights of the developed material and recommendations for future research. These will be based on aggregated insights and will be published in a report.	☐	☐



Signatures

___________________________ ___________________________ ________
Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_________________________ ___________________ ________
Researcher name [printed] Signature Date

Study contact details for further information:
Name: Rachel Prud'homme van Reine
Phone number: +31 6 19 36 19 24
Email address: Rachel.prudhommevanreine@philips.com

Appendix 10: Project brief

TUDelft

Personal Project Brief – IDE Master Graduation Project

Name student Rachel Prud'homme van Reine **Student number** 5079942

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title 3D printing for spare part offering in the Philips Personal Health portfolio

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This project explores the potential of 3D printing for providing spare parts for Philips' Personal Health portfolio, focusing, driven by the EU's "right to repair" regulations. Effective since March 1, 2021, these regulations currently mandate spare part availability for new models of washing machines, dishwashers, fridges, and displays, with expectations of broader future applications. Philips aims to proactively address these regulations by investigating alternative methods for spare part provision, focusing on consumer-replaceable parts, building on a current internally initiated trial and external offerings of 3D printed accessories.
The domain bridges academic research and practical application, with key stakeholders including Philips (seeking technological and user insights, part selection criteria, and scalable business models), TU Delft (validating research in real-world contexts), and consumers (demanding accessible, reliable solutions). The primary opportunity lies in leveraging 3D printing to produce parts on-demand, reducing the need for physical inventory with unused/unneeded parts, while also enabling new business models creating opportunities to enhance sustainability by enabling local production and reduction of waste, as well as cost savings.
Limitations include the scalability of current pilots and the need to balance technical feasibility with consumer satisfaction. The project aims to develop a framework for identifying eligible parts, specifying production methods (3D technology, materials, post-processing methods) and redesign guidelines, as well as optimizing the end-to-end consumer journey. It will scope available technologies, map technical and user requirements, and prototype solutions in collaboration with Philips' Rapid Prototyping department. By validating academic knowledge, exploring circular business models, and improving consumer experience, this initiative seeks to bridge theory and practice in a scalable, adaptable solution.

➔ *space available for images / figures on next page*

TUDelft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

While 3D printing offers promising opportunities for on-demand spare part production, there is currently no validated method to systematically assess which consumer-replaceable parts are technically and experientially suitable for 3D printing that is applicable for Philips. Although TU Delft has conducted foundational research, this has not yet been translated into a practical business case. This gap limits the ability to leverage 3D printing at scale and in a way that aligns with Philips' standards and consumer expectations.
Key Knowledge Gaps
1. Technical Feasibility: Which 3D printing technologies, materials, and post-processing methods align with Philips' quality and design requirements across different product categories?
2. User Acceptance: How do consumers perceive 3D-printed spare parts, and what factors drive their acceptance? How do these perceptions vary among user groups and product categories?
3. Part Eligibility Criteria: What objective criteria, balancing technical feasibility and user experience, can be used to identify and prioritize parts for 3D printing? What design modifications are necessary?
4. Scalability: How can these insights be integrated into a framework, informing both eligibility and the steps to redesign and produce the part, that can be consistently applied across Philips' diverse product portfolio?

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Develop a framework to assess and guide the 3D printing of consumer-replaceable spare parts, balancing technical and user experience criteria, supported by prototyping activities, for Philips' Personal Health portfolio.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

Phase 1: Literature Research A literature review and technology mapping will identify suitable 3D printing technologies, materials, and post-processing steps. Philips' R&D, design, and manufacturing teams will define part-specific experience and aesthetic, durability, and manufacturability requirements. Preconditions for business model and consumer journey will be defined. Phase 2: User Research Surveys, interviews, and trial data analysis will assess user perceptions, acceptance criteria, and segmentation, revealing key drivers and pain points. Phase 3: Criteria Development & Validation Technical and user insights will create objective eligibility criteria for consumer replaceable parts, validated by cross-functional experts. Phase 4: Practical Demonstration One prototype per product group will be 3D-printed and tested for technical feasibility and user acceptance with users and experts. Phase 5: Framework & Implementation Prototype findings will refine eligibility criteria and develop a scalable part selection framework. Business model and the consumer journey will be refined with commercial teams to align with Philips' goals. Phase 6: Delivery & Recommendations A framework will guide part selection, production, and design, including a prioritized list of eligible parts, prototypes with test results, and a proposed business model and consumer journey.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting***, ***mid-term evaluation meeting***, ***green light meeting*** *and* ***graduation ceremony***. *Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting September 18th

Mid-term evaluation 17 november

Green light meeting 28 jan 2026

Graduation ceremony 27 februari

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	☐
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

The reason why I originally wanted to pursue industrial design stems from my broad curiosity and the promise of IDEs interdisciplinary approach, bridging people, technology and business. Still to this day, I enjoy working with cross-functional teams and using my design expertise to connect the different perspectives. This assignment in particular enables me to combine technical expertise (designing for end-use with 3D printing) with user insights (what is the user perception of 3D printed parts) in a business context (how to implement this at Philips). With this project I hope to develop a solution that is not only technically feasible but also experientially suitable, that can realistically be applied in a business context. Doing this project for Philips will allow me to work with R&D, Manufacturing, Design and Commerical teams and gain hands on experience with the Rapid Prototyping Team in Drachten.

Throughout my studies I have 3D printed a lot, but only for prototyping purposes. This project will allow me to learn about how to apply 3D printing in an end-use setting, giving me the unique opportunity to work with tools that are not available at the faculty. I am also excited by the potential of this project to contribute to sustainable impact by enhancing product repairability on a larger scale. It also allows me to deepen my understanding of circular business models, buidling on courses such as design for the circular economy.