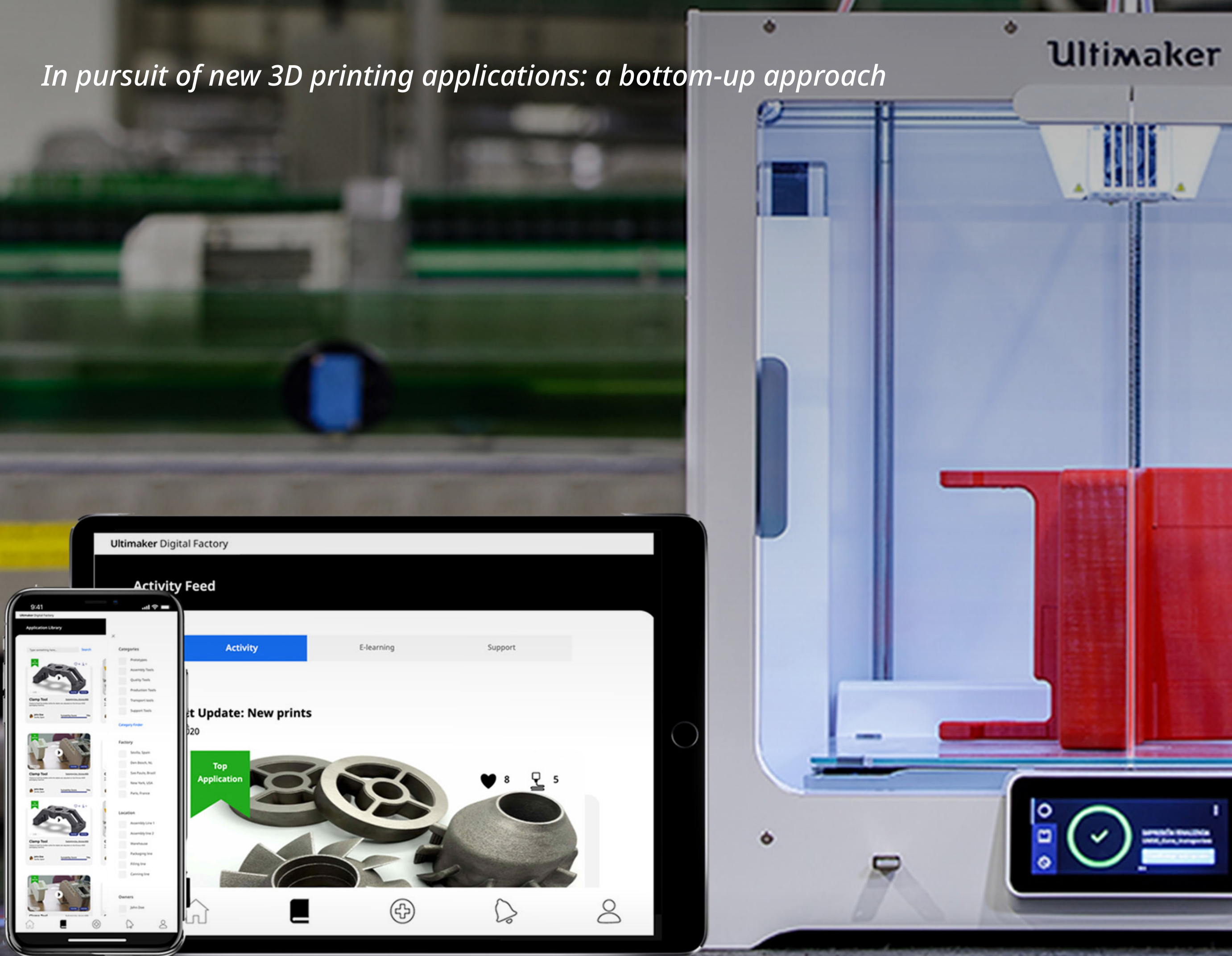
Facilitating Application Identification for 3D Printing in Manufacturing Environments

In pursuit of new 3D printing applications: a bottom-up approach



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MSc Thesis
Design for Interaction
Industrial Design Engineering

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MSC Thesis

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/ Preface

This document contains the results of the thesis project "Facilitating Application Identification for Additive Manufacturing in Production Environments" and has been written to complete the MSc Design for Interaction as part of Industrial Design Engineering, TU Delft.

This topic stemmed from my personal interest in the playing field between human behavior and groundbreaking technologies, which I have most definitely encountered in this project. I can confidently state that I have become a better researcher and designer and have taken a significant step towards achieving my personal learning goals, whilst having a great time as an intern at Ultimaker.

All the ups and downs and limitations of COVID-19, in addition to the general rollercoaster of graduating have asked for a certain amount of resilience and perseverance. I couldn't have done this without the help of my colleagues, supervisory team, family and friends.

First and foremost, Carien. You paved the way for me from the very first moment. Thanks to your efforts, I was able to visit some of the most interesting clients, including a trip to the Heineken brewery in Greece and the Royal Dutch Navy in Den Helder. These visits have not only been an amazing experience, they have really helped me to understand the context and bring the quality of my research to the next level. Apart from your continuous efforts to help me conduct research, you have been there throughout the entire process to listen, guide and support me. A thousand thanks to you!
My major appreciation for Zjenja and Gert, who have both helped me to structure my research, make decisions and have asked me the right questions at the right time. Thank you for your flexibility, empathy and continuous support throughout the project.

Thanks to the best neighbors and friends I could wish for. You guys were there to listen during both the ups and downs. Working from home was pretty great thanks to you. Another thanks to my family, not only for proofreading and thinking along with my project, but also just for being there as always.

A last shootout to my colleagues at Ultimaker. Even though our time at the office was limited, you guys were there to think along, ideate with me and guide me in the right direction. Thank you all for believing in my project and helping me further.

I sincerely hope this thesis reports speaks to your imagination and makes you just as excited about technology as I am, enjoy!

Kiki Deurvorst
Amsterdam, 2020

/ Executive Summary

The use of 3D printing technology in manufacturing environments has experienced rapid growth as manufacturers have realized the benefits of the technology. 3D printing has the potential to reduce costs and lead-times of parts, components and tools used in production processes. However, the adoption of this technology is facing various challenges. A major challenge is the identification of suitable parts for Additive Manufacturing technology.

Assessing a part's suitability for 3D printing requires a substantial amount of knowledge of 3D printing technology. The suitability of a part relies on various objective and subjective factors, such as potential savings and the part's complexity. The decision whether and when to print a part is therefore a constant trade-off for which a person needs experience and information. Within manufacturing and production environments, a select group of people is trained to understand the technology and assess parts. The limitations of this expertise prevents valuable applications from being identified in areas that are outside of these people's sight.

It is expected that the frequency and quality of applications will increase the value that will be added by 3D printing. This development will be driven by the capability to identify new applications. The more stakeholders are educated in this field and understand the technology, the more opportunities will be identified.

Given the above, this objective of this research project is to investigate how production line operators can be more actively involved in the initial stages of the 3D printing workflow.

Through extensive literature and contextual research, the potential to enable production line operators to identify parts and problems in their section of the facility has been exposed. Various influential opportunities and challenges in their participation have been established. After a round of internal validation of the research insights, a strategic decision was made to focus design efforts on developing a digital platform. The objective of this platform is to enable operators to participate in the relevant steps of the 3D printing workflow.

Through an iterative process, an Application Portal has been designed. This portal is a mobile application that supports production line operators in submitting new ideas. In addition to the above, the system offers the following functions:
1. Active collaboration between stakeholders
2. Exchange of project developments insights
3. Validation of application suitability

A prototype is developed in Axure. This prototyping software is used to validate the concept with a variety of manufacturing clients, operators and 3D print experts. The applicability of the concept has been validated for a majority of clients. These results illustrate that the solution offers significant value to achieve active participation of production line operators in the 3D printing workflow. Additional design goals have been achieved to a great extent.

The application portal provides operators with a tool to express their ideas. They can actively participate in innovation and take ownership of the applications they have identified themselves. Additionally, the platform offers Ultimaker and its manufacturing clients an opportunity to gather relevant data to work towards a future of automated part identification. Inevitably, the evaluation of the prototype had its limitations. The long term effects of the use of this product have not been evaluated and the range of manufacturing companies must be broadened in future research. However, this study represents a step forward in the acceleration towards accessible part identification by novice users in manufacturing environments.

To pursue the acceleration of 3D printing technology among manufacturing clients, it is key for Ultimaker to conduct further research on the potential of the proposed design concept.

“ The great driver of scientific innovation and technological innovation has been the historic increase in connectivity and our ability to reach out and exchange ideas with other people. And to borrow other people’s hunches and combine them with our hunches and turn them into something new ”

Steve Johnson

Author of **Where Good Ideas Come From: The Natural History of Innovation**

Glossary

AM Additive Manufacturing - the industry name for 3D printing

CM Conventional Manufacturing - such as milling, drilling and welding.

Application a (new) use of 3D printing technology

Operator someone who works in a factory putting together goods or working on the factory line

Champion a manufacturing employee who is an expert in the field of 3D printing. Champions are responsible for printing within manufacturing environments

Application Identification the act of identifying a new opportunity to 3D print a part/product or tool

AI Artificial Intelligence - computer systems designed in such a way that they can perform tasks that normally require human intelligence

Manufacturing Industry industrial companies that produce/assemble or develop products for the consumer market

AM suitability the degree to which an application is suitable for production with additive manufacturing technology.

Industry 4.0 a trend or revolution revolving the automation of production processes through digitalization/connected technologies

CAD Computer-Aided-Design - computer software that allows the design of things such as cars and other products

Application Engineering part of Ultimaker's Business Development Department. Application engineers are experts on 3D printing technology and visit clients to support the adoption of 3D printing technology

Bottom-Up Innovation "bottom-up innovation is fueled by many ideas initiated by employees, as opposed to top-down innovation, which is fueled by a strong vision – often by the company's founder" (Deschamps, 2017)

FDM Fused Deposition Modelling - a type of additive manufacturing that uses a continuous thermoplastic filament

Key customers Ultimaker's corporate manufacturing clients, such as Heineken, L'oreal and Eriks

Lead time the delivery time of parts following the order

Fly-to-Buy ratio the weight of the raw material at the start of production compared to the weight of the final part

Build material the primary material used in 3D printed applications

Support material material solemnly used to support the build material, usually disposed after printing

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CHAPTER

01

| INTRODUCTION

This chapter starts with an introduction to additive manufacturing technology. It is followed by an overview of Ultimaker’s history, portfolio and business strategy. It continues with an explanation of the design brief and an overview of how this report is structured.

Figure 1.1.0: The use of a 3D printed tool by one of Erik's operators (Ultimaker)

/ 1.1 Introduction

Additive manufacturing (AM), also known as 3D printing, is the technological process in which a digital 3D file is transformed to a physical object, layer by layer. This technology allows rapid and local production of objects and makes it possible to create complex, lightweight and customized products. Additive manufacturing is considered to "start a revolution in the way we design, produce and distribute products" (Thompson et al. 2016). Various industries have started to realize the benefits of this technology. These industries are adopting 3D printing in their businesses. Examples of such industries are dentistry, education, and arts. One important industry that has seen a significant increase in the adoption of 3D printing is the manufacturing industry (Gao et al., 2015).

Manufacturing environments are industrial operational facilities with the purpose to fabricate products. The tools in these environments enforce individual efforts to turn raw materials into goods that benefit society, such as communication tools, agricultural products, medical equipment and other consumer products (The Association For Manufacturing Technology, 2020).
The manufacturing industry "should be considered as one of the major sectors where transformative changes are needed towards sustainability" (Ahuja et al., 2015). Changing dynamics brought about by globalization encourages companies to invest in technologies that make sure there remains an opportunity to grow. As for the development and production of products with any level of complexity, "due to its ability to overcome barriers of conventional manufacturing processes, 3D printing plays a significant role in the industrial context" (Fera et al., 2018).

Some of Ultimaker's largest customers, such as Heineken, L'oreal and Volkswagen, are manufacturing or production businesses. To produce tools and parts to support processes, they have implemented 3D printing. This p technology has allowed them to reduce costs and lead-times up to 90% (Haenen, 2019). Additional benefits are improved safety and comfort for their factory employees.

AM is in its infancy, compared to conventional manufacturing. As more complexity comes at no (or little) additional costs, there are endless opportunities with 3D printing. On the other hand, the parts produced by the technology are limited by the dimensions of the printers and the selection of materials. As with the introduction of many other new technologies, to assure efficient use of the possibilities, new skills are required. Due to its infancy and complexity, there are no standardized development procedures. The various objective and subjective criteria that influence the suitability of a part for additive manufacturing make the assessment process complex. Therefore, this task is currently highly reliant on expertise.

To assess parts for Additive Manufacturing, Various methods and guidelines have been developed. However, a suitable method that aligns the concerns of different stakeholders in manufacturing industries appears to be lacking.

Assessing which part is suitable to be produced by AM requires a substantial amount of knowledge. Knowledge is currently limited to a select group of employees. Once part identification becomes more accessible to employees, such as production line operators, the quality and number of applications is projected to grow.

This study investigates how production line operators can be enabled to participate in the identification of parts and discover problems that can benefit from additive manufacturing.

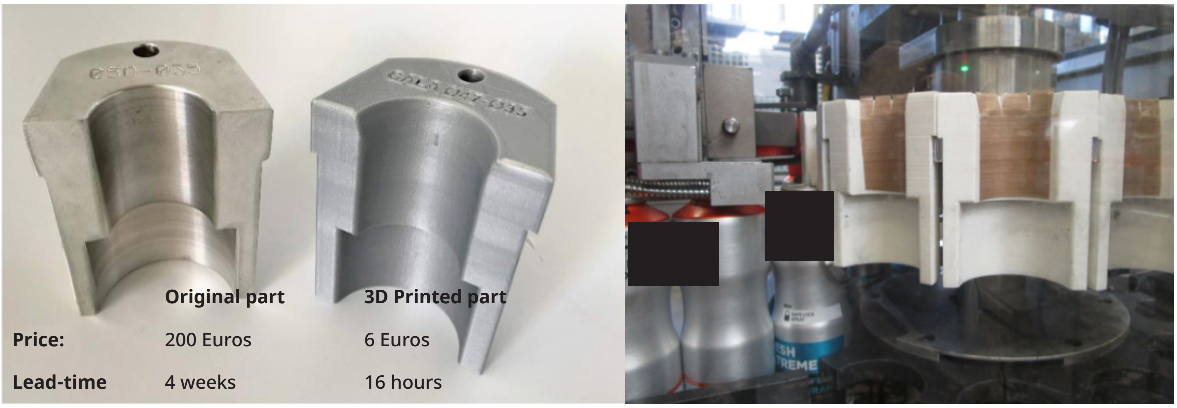


Figure 1.1.1: Example of a successful application for one of Ultimaker's clients. This application transports bottle caps of a consumer product throughout the production line. 3D printing this part results in estimated annual savings of 2.522 euros per facility (Ultimaker).

/ 1.2 Ultimaker

Siert Wijnia, Martijn Elserman and Erik de Bruijn founded Ultimaker, a 3D printer company, in 2010. The founders initially experimented with the open source designs of the RepRap project, initiated by Dr. Adrian Bowyer (Riley, 2013 & Wijnia, 2015). The RepRap project was created with the aim to provide low-cost printers that could print the majority of its own parts. Siert, Martijn and Erik continued to improve the RepRap design which was the foundation for the Ultimaker Original (see figure 1.2.1, 2011). The Ultimaker Original was a self-assembly kit that included everything, from laser cut panels to electrical components. The Ultimaker Original appeared to be extremely popular, and a community started growing around the brand. Due to its open sourced nature, the community has contributed to the development of Ultimaker printers throughout its entire history.

After the success of the Ultimaker Original, the company continued to develop 3D printers as well as software to communicate with the printers (figure 1.2.2, 2013). Cura, Ultimakers software to slice and prepare print jobs for printing, is used by millions of users (Ultimaker, 2020). Besides Cura, Ultimaker is also developing software that enables cloud-connections and printer management.

Currently, the company has over 400 employees with offices in the Netherlands, Singapore and in the United States. The Ultimaker was one of the first desktop printers and attracted many home-users, schools, libraries and small businesses with a goal to prototype and produce rapidly (All3DP, 2016). Ultimaker products are nowadays considered reliable pre-assembled 3D printers and “one of the leading manufacturers in the industry” (Fisher-Wilson, 2018). Ultimaker’s latest printer is the Ultimaker S5 (figure 1.2.2, middle). This printer comes with additions that optimize print possibilities, including an air manager for air filtering and a material station for more possibilities of material usage throughout printing.

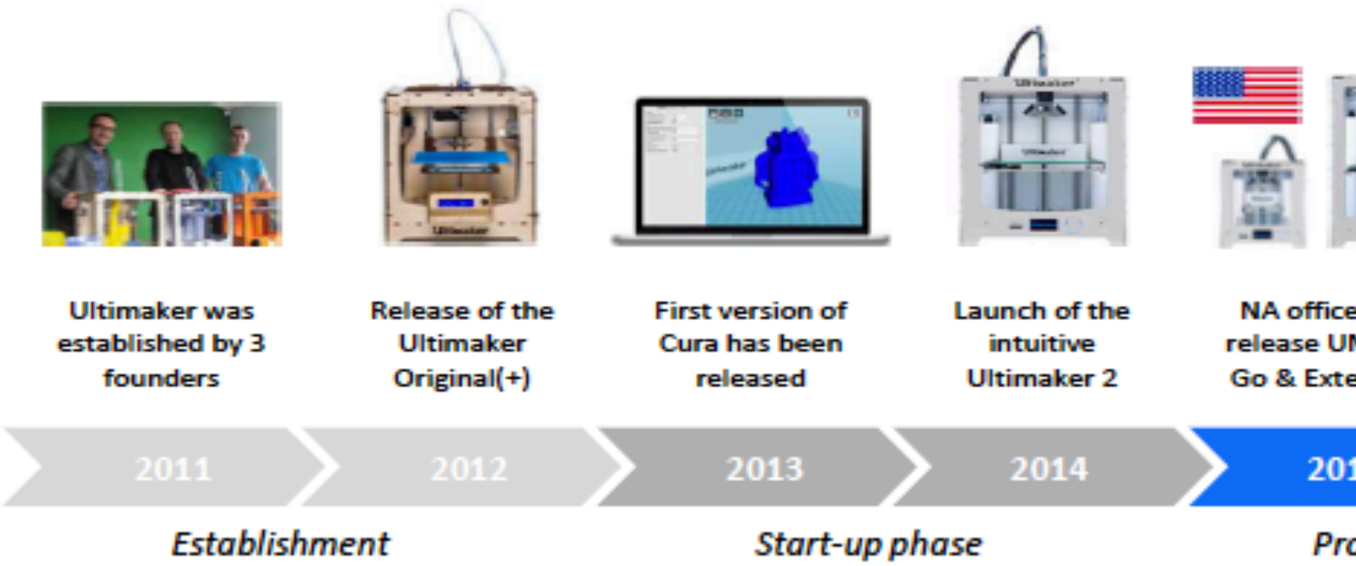


Figure 1.2.1: Ultimaker’s timeline from 2011 untill 2019 (Ultimaker, 2019).

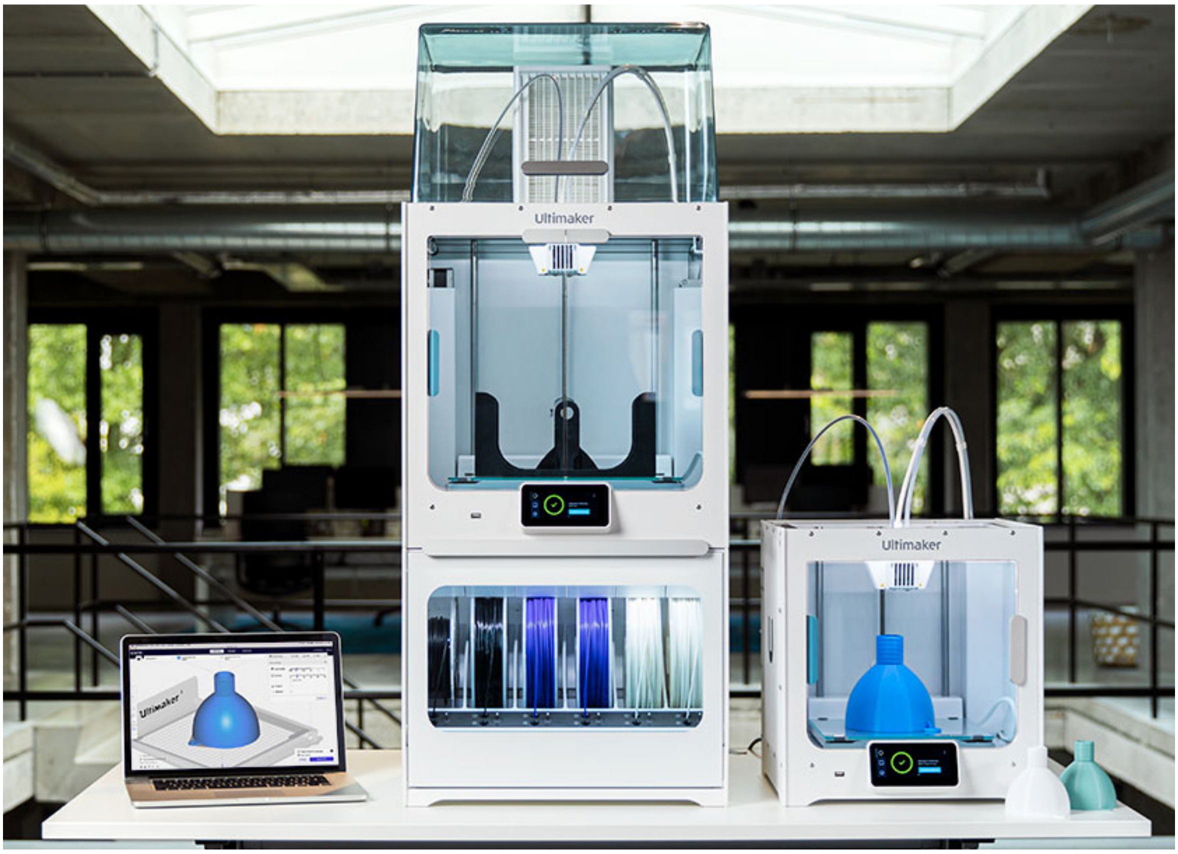


Figure 1.2.2: Ultimaker's software Cura(left), the Pro-Bundle (Ultimaker S5 with top cap & material station), and the Ultimaker S3 (right) (Ultimaker).

/ 1.3 Strategy

Throughout the years, Ultimaker has reached various user audiences. Starting with hobbyists, universities and makerspaces, a shifting trend towards more professional users has been observed. Professional businesses in various industries are starting to adopt additive manufacturing technology for the production of end products, prototypes and spare parts within their production facilities. Apart from maintaining a leading position in office environments, Ultimaker is striving to become a market leader in manufacturing environments, also referred to as the “concrete floor” or workshop (see fig 1.3.1). Additionally, Ultimaker differentiates its users in different segments (see fig 1.3.2). At the bottom are novices, mostly using the technology for product development. The entry level professionals are users with prior experience with 3D printing, with a purpose of product development and end-use of parts. In the scale up phase, Ultimaker identifies professional businesses and professional distributed businesses, such as Heineken and Schubert. See fig 1.3.2 for all industry verticals.

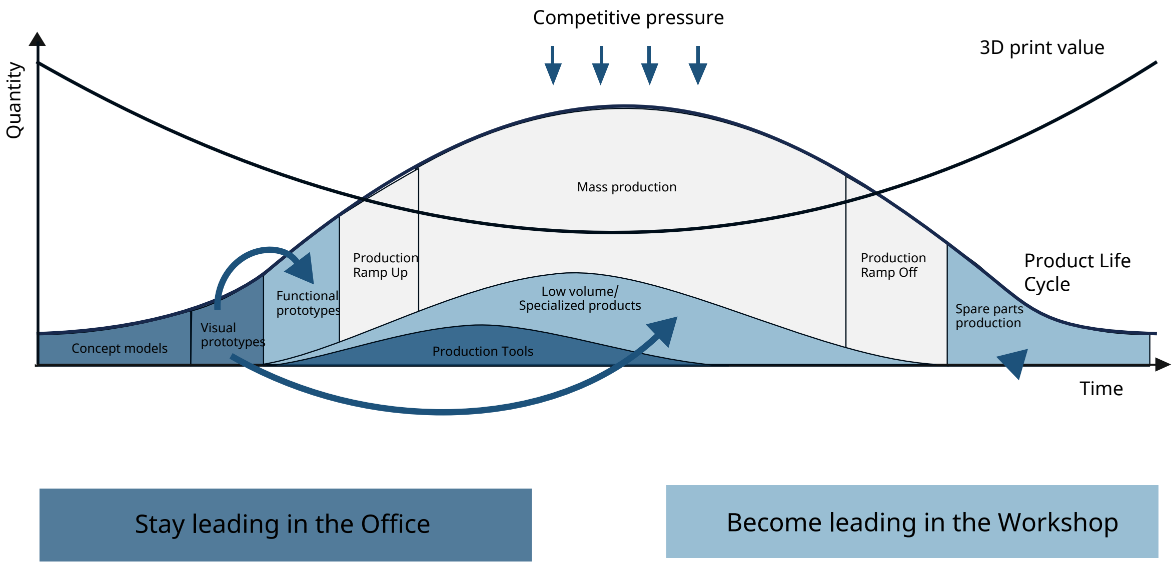


Figure 1.3.1: Ultimaker’s strategy; stay leading in office and in the workshop (Ultimaker, 2020).

Market segmentation (2020-2023)

From: Business planning 2020

A segment is a combination of maturity level, application and verticals

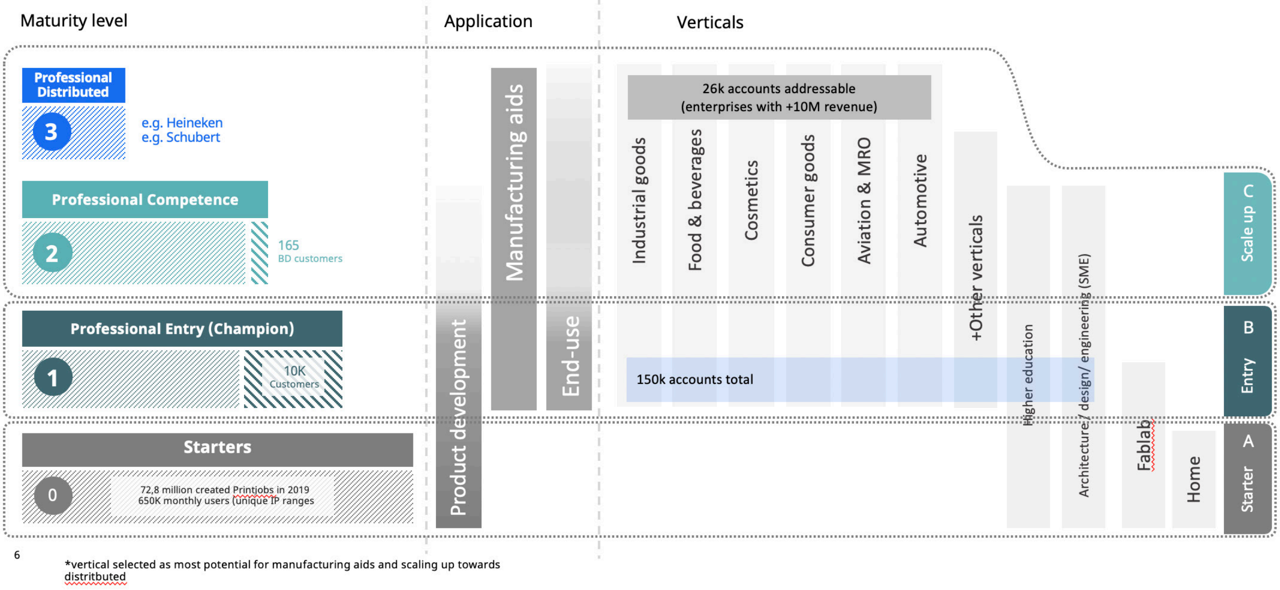


Figure 1.3.2: Market segmentation and verticals (Ultimaker business planning, 2020).

This report focuses only on the “concrete floor” customers, with high potential for growth in their additive manufacturing adoption. Due to their growth potential, businesses, such as Heineken (figure 1.3.3), L’oreal, Schubert and Eriks are considered key customers. They make use of distributed manufacturing by placing printers in multiple locations worldwide. To ensure scalability, these businesses pursue standardizing parts and processes throughout the AM workflow. This includes a need for further digitalization of each step, including the necessary files and information that explain each step of the printing workflow.

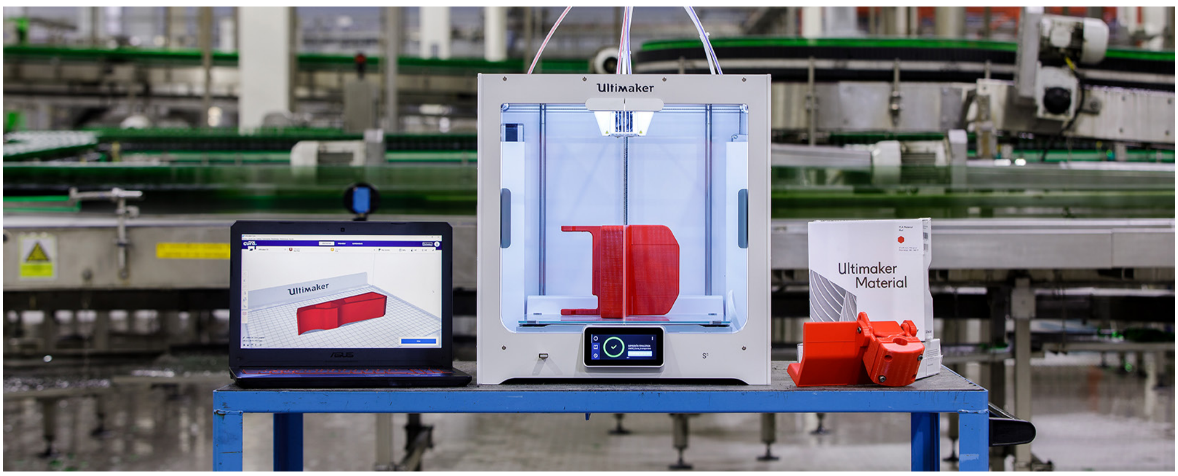


Figure 1.3.3: Ultimaker printers in Heineken’s production facility (Ultimaker).

/ 1.4 Design Brief

Background

Over the past years, Ultimaker has provided extensive training to enable their manufacturing clients to adopt 3D printing in their production facilities. These businesses are experiencing the benefits of AM through significant cost and lead-time reductions by replacing and developing production tools. However, various challenges in the adoption of this new technology remain. One of these challenges is the process of uncovering and assessing parts or problems that may benefit from AM, also referred to as “application identification”. In large manufacturing environments with numerous departments, machines and tools, uncovering the most valuable applications is extremely challenging. This is because there are various objective and subjective criteria that make a part suitable for AM. In order to increase the number and quality of applications, businesses would benefit from spreading the knowledge and making part identification more accessible.

Problem definition

Manufacturing employees, or operators, can be found all over the factory floor. Throughout the day, they encounter many bottlenecks. Operators are the local subject matter experts. Therefore, they are the most likely identifiers of problems that could benefit from AM technology. However, various challenges prevent this target group from identifying valuable parts for AM. Expected reasons for this are a lack of understanding of the technology and a lack of incentive to participate in the process (“skin in the game”).

Assignment

The goal of this project is to design a product or service that enables operators to initiate more, and more valuable opportunities for 3D printing. This requires a system that supports them in identifying potential applications. For engineers to take up these ideas, it is essential that information is documented. Furthermore, this project is set out to investigate how to empower operators to think beyond the existing field of applications and become part of the 3D printing workflow. By achieving this goal, it is expected that the use of 3D printing technology in such environments will accelerate and the dependency on Ultimaker as a supporting stakeholder will be decreased.

“How may we empower operators to identify new applications for 3D printing, also beyond the scope of existing applications, and enable them to document all relevant information as an entry point for the application workflow?”

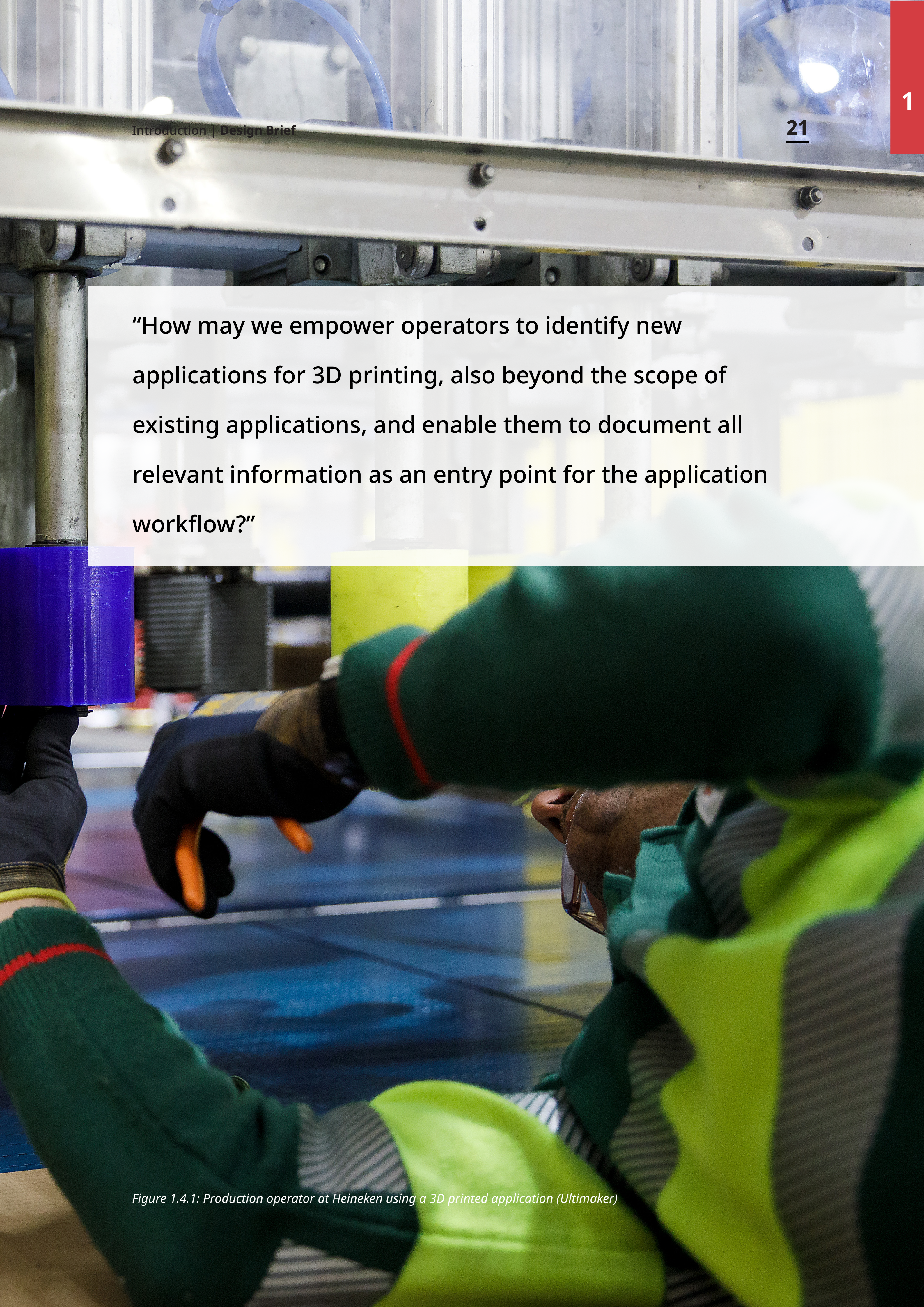


Figure 1.4.1: Production operator at Heineken using a 3D printed application (Ultimaker)

Figure 1.5.1: Production operator at Volkswagen using a 3D printed application to assemble a car logo (Ultimaker)

/ 1.5 Thesis Structure

The project is set up according to the fundamentals of design thinking methodology and follows four phases: analysis, synthesis, develop and deliver. Figure 1.5.2 illustrates the approach and the chapters that belong to each phase.

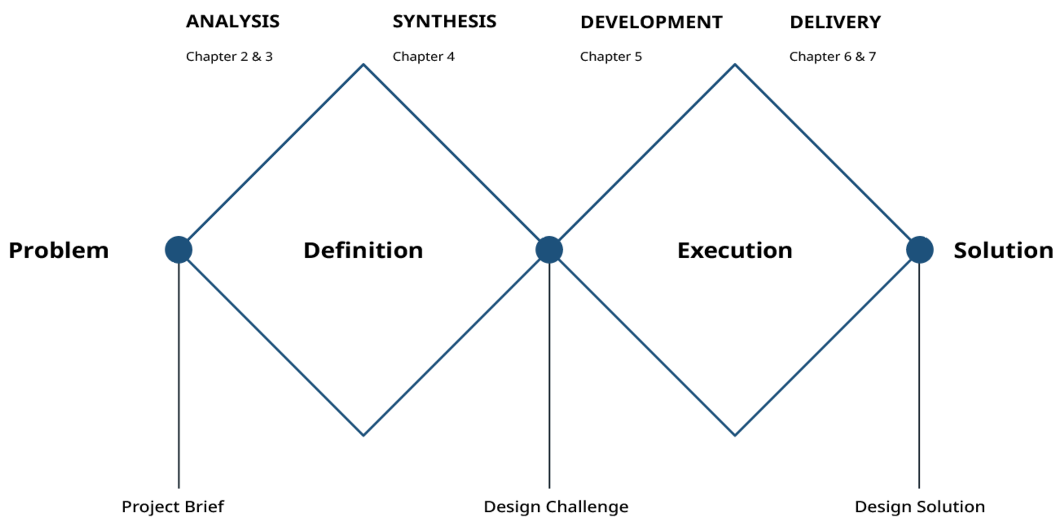


Figure 1.5.2: Double Diamond - the design process (originally from British Design Council, 2005)

Analysis

The analysis covers the initial research phase of this project. Chapter 2 discusses the literature study, internal research and a landscape analysis. Chapter 3 contains the results of contextual research, which involved various research activities such as observations, interviews and a survey.

Synthesis

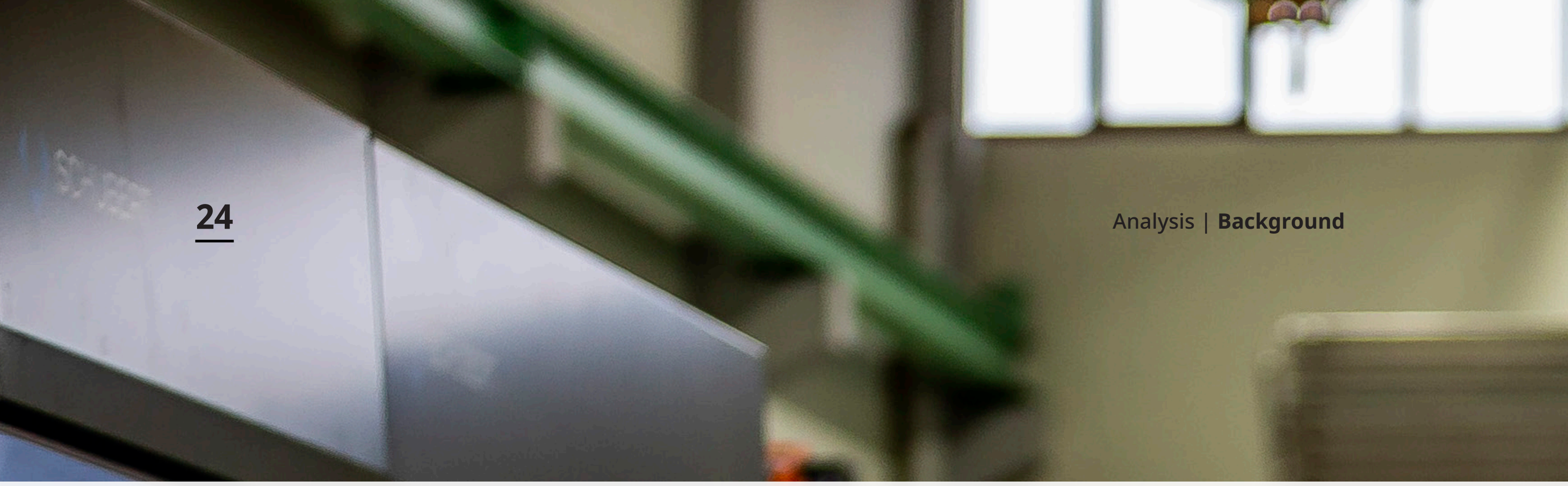
The synthesis chapter describes an internal round of interviews to validate the research findings and align the product strategy with various stakeholders within Ultimaker. It concludes with a design challenge and a list of requirements for the final product.

Develop

The development of the product was achieved through an iterative design process, described in this chapter. Three design cycles have brought an initial idea resulting from the design challenge to a fully functioning prototype.

Deliver

The delivery phase describes the validation of the concept through client interviews and concludes with further recommendations, a conclusion and a personal reflection on the project.



CHAPTER

02

ANALYSIS

| BACKGROUND

The first section of this chapter provides an introduction to Additive Manufacturing Technology. Literature is reviewed to investigate the unique benefits and limitations of AM in manufacturing environments. This is followed by an internal analysis of Ultimaker's approach towards application idetnification. The chapter closes with an analysis of existing identification methods, after which the knowledge gap is identified and further research questions are formulated.

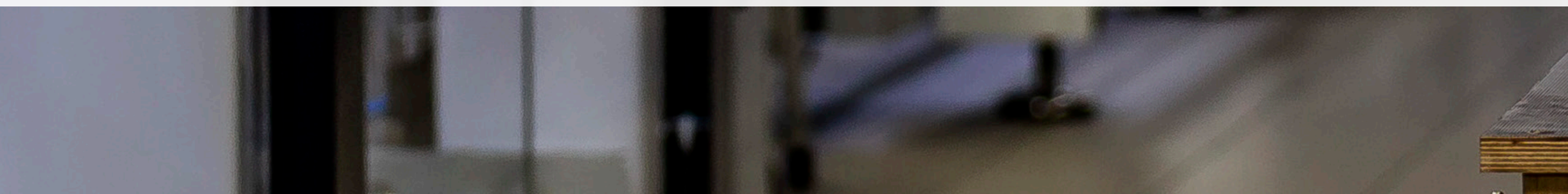


Figure 2.1.1: Ultimaker's latest printer: the S5 with air filter and material station (Ultimaker)

/ 2.1 Introduction

This chapter sets out to understand the basics of additive manufacturing. This includes gaining an understanding of the type of applications that are being developed and how they may be identified. Information was gathered through literature, internal Ultimaker documentation and through an online competitor analysis. This chapter aims to answer the following questions:

Research Question

How might novice users identify parts for AM in manufacturing environments?

Sub questions:

What is additive manufacturing and how does it work?

What are the key benefits of AM in manufacturing environments?

What are the specific characteristics of succesful adoption of industry 4.0 technology?

What is Ultimaker's approach towards application identification?

What other existing tools are there to support application identification?

/ 2.2 Introduction to Additive Manufacturing

Additive Manufacturing (AM)

Charles Hull's work resulted in the emergence of AM technology in the 1980's in stereolithography (Hull, 1986). Additive manufacturing forms products layer by layer. Additive manufacturing has been recognized as a revolutionary technology. It is also known as Rapid Prototyping, additive layer manufacturing, 3D printing and free-form fabrication (FFF), among others. Additive manufacturing processes differ in a fundamental way from traditional manufacturing, such as subtractive (milling/drilling), formative (casting/forging) and joining processes (welding) (Conner et al., 2014), as "end products are formed through placement, bonding or transformation of voxels (volumetric elements) of raw materials" (Thompson et al., 2016). The geometry of the part is defined by tool paths, projection patterns or both. AM technology allows for production of parts without a necessity of shaping tools (ISO, 2015).

Compared to conventional processes, additive manufacturing produces parts in an additive way. This allows for many benefits over traditional methods, such as increased design freedom, customization and a reduction in costs and lead-times. It becomes increasingly easier to produce one-off, complex parts, such as the Mojito Shoe, designed and created by Julian Hakes (see figure 2.2.1).

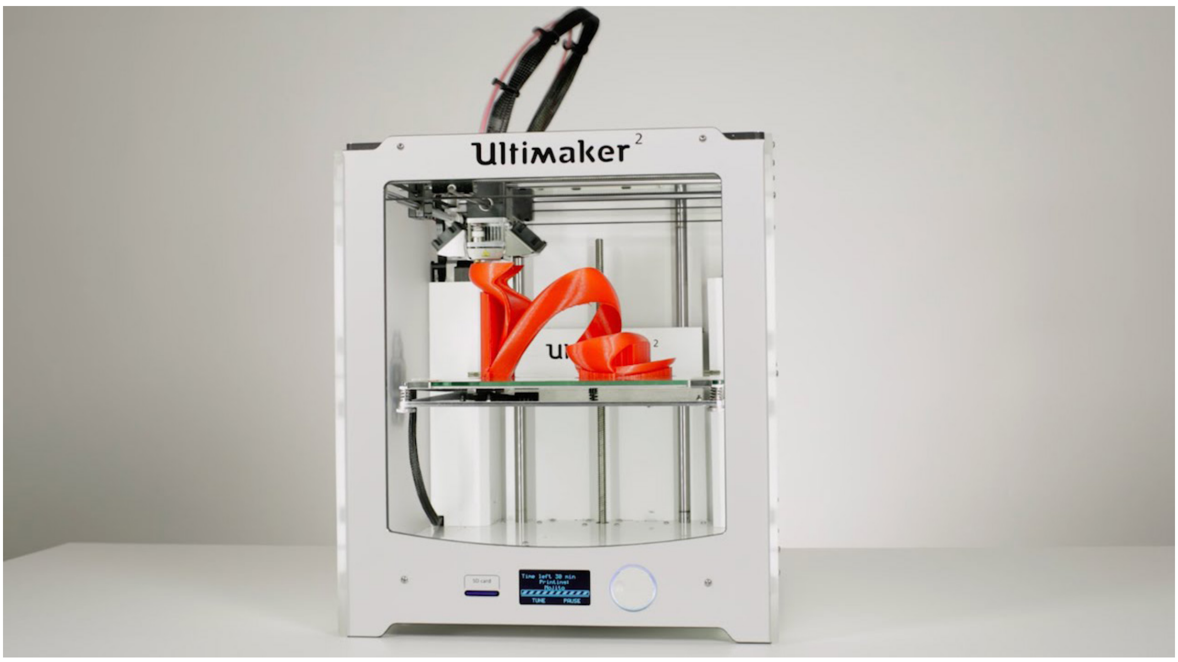


Figure 2.2.1: Complex figures with FDM printing technology (Julian Hakes, 2015)

2

Different AM technologies

There are different types of 3D printing technologies. Examples are material extrusion, powder bed fusion, binder jetting and others (conner et al., 2014). Each technology is different in their performance and has different advantages and limitations, such as “materials, build volume, processing speed, part quality (mechanical performance, dimensional accuracy and surface finish), and the amount of post-processing required to improve the material properties, surface finish, and/or dimensional accuracy (i.e., support removal or surface finishing)” (Conner et al., 2014). All 3D printing technologies are based on the same foundation; a 3-Dimensional digital model is sliced into cross-sections and are then placed on each other in layers of a certain material. However, different technologies are fundamentally different in the way they print these cross-sections, the materials they use, and the type of post-processing required. Although there are similarities, this report solely focuses on the Ultimaker’s technology: Fused Deposition Modelling (FDM).

Fused Deposition Modelling (FDM)

Ultimaker printers make use of FDM technology, which is “one of the most frequently used additive manufacturing technologies” according to Sculpteo’s 4th annual report (Zeijderveld, 2018). FDM is mostly used for the production of prototypes and end parts. Products are built layer by layer by extrusion of heated thermoplastic filaments onto a build plate. Plastic filament is melted slightly past its transition temperature and extruded through a hot end, into layered patterns, fused together into an object. Figure 2.2.2 visualises the technology of FDM printing with dual extruders.

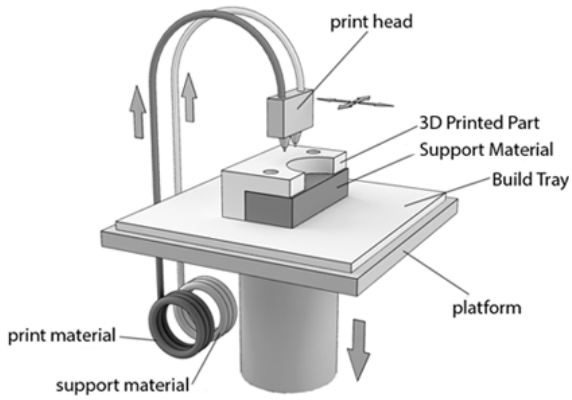


Figure 2.2.2. FDM with dual extrusion components (3D-arts.com)

Ultimaker Materials

Due to their size, Ultimaker's FDM printers are so-called Desktop printers. FDM allows to be used with many different types of build materials, most commonly thermoplastics. Build materials are the materials used for the end product. See figure 2.2.4. for an overview of Ultimaker's portfolio of build materials. Most historically used materials are the polymers PLA and ABS, yet the market is seeing an expansion towards both pure polymers and composites and even more exotic materials such as wood-infused thermoplastics. Ultimaker enforces an open material system, meaning that, besides their own materials, third parties are able to develop materials that can be used by Ultimaker printers.

The older Ultimaker models have a single extruder, yet the S5, Ultimaker latest printer, has dual extrusion. The benefit of having multiple extruders is having multiple materials readily available throughout printing. The most common use of dual extrusion is the use of support material for overhangs and other complex geometries (see figure 2.2.3). Support material is commonly lower-grade material. It's core function is to support the primary material and will most likely be discarded after the print finishes. It is possible to create support with the same material.However, with complex geometries, this is sometimes harder to remove. In this case, PVA is commonly used. This is a water-soluble material, as shown in figure 2.2.3.

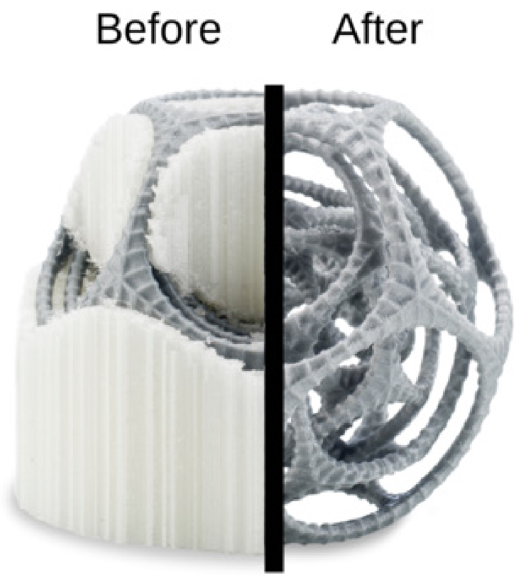


Figure 2.2.3: Complex figures with FDM printing technology using soluble PVA as support material (printyourmind3D)

AM Workflow

Various workflows for the AM process have been defined throughout literature, yet they fundamentally come down to the same. Ultimaker has identified the workflow as described in figure 2.2.5. Starting with an intention to print, setting up the requirements, going through the CAD modeling and printing process, post processing and finally usage. AM's infancy commonly often makes an iterative design and print process necessary to ensure optimization.

Figure 2.2.4: Ultimaker's build material selection (Ultimaker)

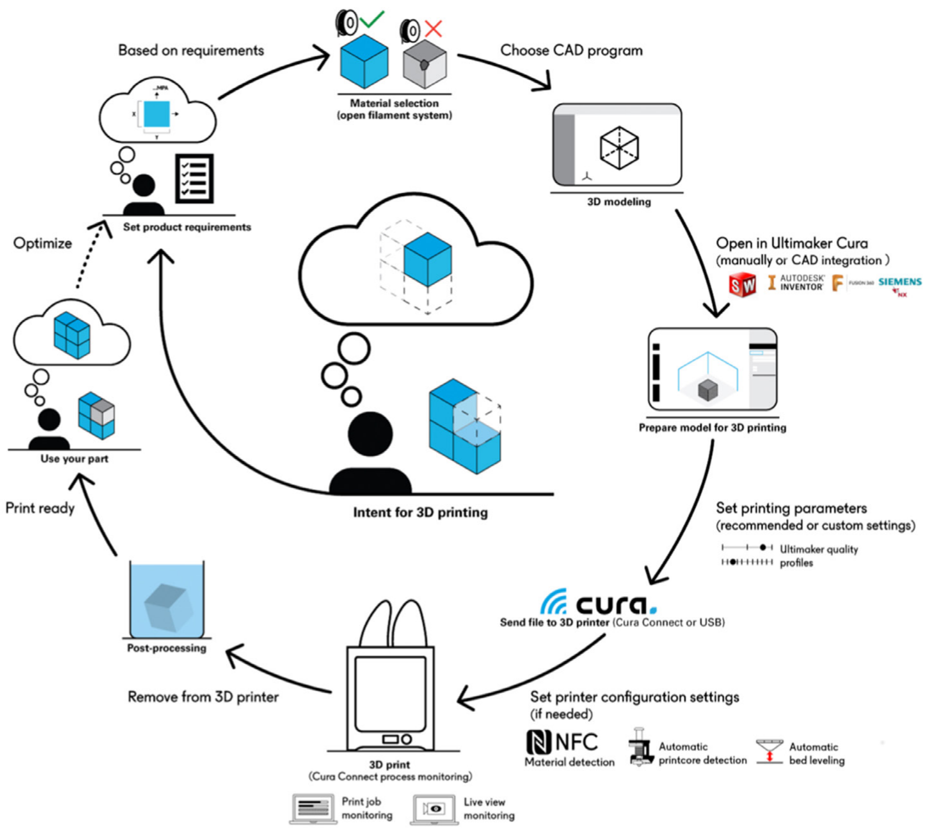


Figure 2.2.5: The AM workflow as identified by Ultimaker (Ultimaker).

/ 2.3 AM in Manufacturing Environments

Introduction

Manufacturing environments are industrial operational facilities with the purpose to fabricate products. The tools in these environments enforce individual efforts to turn raw materials into goods that benefit society, such as communication tools, agricultural products, medical equipment and other consumer products (AMT, 2020). Smart factories and smart supply chains have received growing attention in the industry. The effects of emerging technologies such as 3D printing have been emphasized by researchers (Do Chung et al., 2018). In current times of mass production, manufacturing businesses are paying attention to the efficiency of their processes, such as procurement and logistics, with the aim to reduce the costs of their inventories. Additionally, there is an emerging trend towards personalized customer needs, resulting in shorter product life cycles, pushing companies towards more flexibility in their supply chain. To meet these needs, Lean and agile systems have been introduced by many companies. The "Industry 4.0" entails smart factories with advanced ICT technologies such as the Internet of Things and 3D printing, developing new systems for manufacturing and supply chains, tailored to individualized requirements (Kagermann et al., 2013). AM has some unique benefits over conventional manufacturing. It is fundamentally different from conventional production methods, not only allowing businesses to create objects with unique geometries but also to simplify parts of the supply chain. AM will therefore "have a big influence on the product development cycle; the way products are designed, produced, distributed, consumed and recycled" (Doubrovski et al.). Wohlers report (2012), identified three drivers for businesses to adopt AM: financial, environmental or performance related. Within manufacturing environments, several advantages of AM predominate, which will be further discussed below.

Design & Geometry

Four design potentials of AM were identified by Klahn et al. (2014): individualization, lightweight, efficient, and integrated design, whereas ISO/ ASTM standards released six: "customization, lightweight, internal channels/ structures, function integration, surface structures and material options" (Yang et al., 2018). The layer-by-layer approach in additive manufacturing makes for the fact that complexity doesn't come at extra cost (Connor et al., 2014). AM allows to optimize the geometry for strength and material volume and reduce weight whilst maintaining mechanical requirements through the help of computational tools such as topology optimization (figure 2.3.1). Geometry optimization supports the design of digital models by adopting the design to make it stronger and more efficient. The use of tools, machines, chemicals and various processes significantly benefit the design freedom that AM offers.

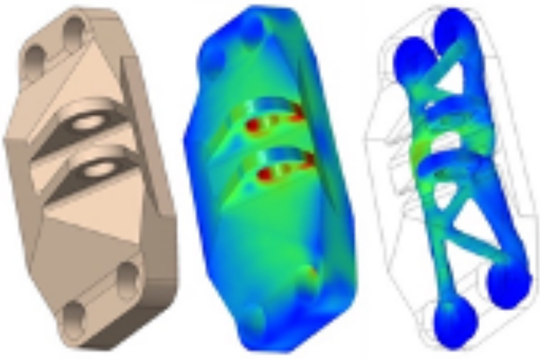


Figure 2.3.1: Geometry optimization (GrabCad, 2013)

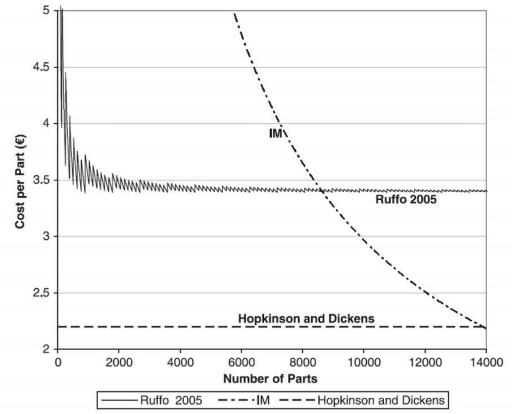


Figure 2.3.2: Break even analysis of AM costs compared to conventional methods (Ruffo, 2006).

Economic

Costs are frequently drivers for the choice of production method (Lindemann & Jahnke, 2012). As there is a potential to reduce costs throughout several parts of the supply chain, manufacturing businesses have a strong economic incentive to adopt AM.

A significant trend towards shorter lifecycles has been observed. Shorter lifecycles indicate the need for greater personalization and flexibility. AM is generally suited for “small and complex parts in low volumes” (Wohlers, 2014). Two studies showed that “for a production volume less than about 10,000 parts, a lower unit cost is realized using AM, compared to injection molding” (see fig 2.3.2) (Hopkinson & Dickens, 2006; Ruffo et al., 2006). Furthermore, parts with low complexity that are produced in low volumes are often more affordable when produced with AM compared to conventional menthods (Connor et al., 2014).

However, costs do not simply depend on the price of a part. There are many other factors that influence costs and that are very difficult to predict and to measure beforehand. Most literature only takes production costs into consideration (Hopkinson & Dickens, 2003; Ruffo et al., 2006).

Tuck et al. (2007) researched how AM alters “supply chain management thinking”. Just-in-Time (JIT), or a built-to-order strategy in manufacturing improves the efficiency of a lean supply chain and may eliminate waste. According to a special report on additive manufacturing (the Economist, 2012), “there is the possibility of reducing material waste by as much as 90%”. AM parts generally require fewer assemblies, tooling and fixturing. Changeover time is reduced and production becomes more cost effective than conventionally manufactured parts. Furthermore, AM reduces lead-time, material distribution and inventory holding, which are all relevant drivers for the adoption of AM.

Societal benefits

Huang et al. (2012) identified three main societal opportunities that AM may bring. Firstly, AM allows for customized products that may improve safety, quality and efficiency. Secondly, AM generally involves a reduction of raw materials and energy used, contributing to environmental sustainability. AM is more efficient in its material and water consumption, and does not involve auxiliary process inputs. As a result, this produces less waste and landfill. Lastly, on-demand manufacturing allows for adaptations in traditional supply chains, bringing affordable products to consumers whilst reducing resources.

Another societal benefit of local manufacturing is its affordance to manufacture spare parts in remote areas, therefore enabling businesses to produce what they need while reducing lead times and logistic costs. This may drastically change the dynamics of international trade in the future.

Limitations

Even though AM creates opportunities that were initially impossible, expensive or labor-intensive with conventional manufacturing, the technology has its limitations. There are two key limitations. One is the size of the print bed and the other is the type of materials. There are several limitations in the geometry of parts. One huge limiting factor is the need of structural support in overhangs, bridges and angles. In these overhanging geometries, the self-supporting characteristic of filament is tempered (Leary et al., 2013). Once there is a need for support material, costs and production time will increase. Furthermore, support usually involves post-processing which is time and labor intensive and sometimes requires specific skills. Additionally, the surface that was in contact with the support material may be marked, resulting in damaged surface finish quality. Furthermore, in order to quantify the differences between AM and conventional manufacturing (CM), there is a need to track resources, labor and time for both AM and CM manufacturing processes. Due to its complexity and the differences in supply chain, this is extremely difficult and most likely slowing down the adoption of AM (Thomas & Gilbert, 2015).

Although AM offers supply chain simplification and has proven cost reductions in manufacturing industries, AM requires a large upfront investment (Pereira et al., 2019). Furthermore, for parts that are currently being produced, AM cannot always compete with traditional manufacturing systems in terms of costs as the unit variable can't make AM more affordable or convenient (Fera et al., 2018).
As with any newly introduced technology, educating or hiring staff is also part of the cost picture that forms a barrier to adoption. AM's infancy compared to CM brings about "a lack of design rules for this type of technology "(Vicente et al., 2015).
The unique characteristics of AM make traditional design for manufacturing principles irrelevant to use ((Huang et al., 2013).

This, as with the introduction of many new technologies, challenges the integration within current ways of working and requires the adoption of a new approach towards manufacturing parts. Therefore, the next section is set out to investigate the criteria for successful adoption of such a new technology within the industry 4.0.

Figure 2.3.3. Heineken brewery in Sevilla, Spain (Ultimaker)

/ 2.4 Industry 4.0

The concept of a fourth industrial revolution began several years ago, when digitalization and the integration of robotic technologies began to find their way into manufacturing processes (Materialise, 2019). Additive manufacturing is at the center of this so-called industry 4.0, which adds to innovative, smarter and better-connected production processes. The true foundation of the industry 4.0 is a connected environment. Apart from 3D printing, technologies such as cloud computing, Internet of Things, and Big data are common (see figure 2.4.1). As the use of 3D printing technology is growing, businesses are validating and increasing the applications they are developing. Given the complexity of certain technologies, the transition to industry 4.0 requires the adoption of strategies custom to institutions and their organizational set-up (Müller, Buliga and Voigt, 2018). Apart from the technical challenges, this transition requires organizational and social changes (Kiel et al., 2017; Thoben et al., 2017). The following section sets out to take a closer look at the organizational and human factors that add to a successful adoption of innovation and digitalization in these industrial environments according to literature.

Corporate culture

Within the industry 4.0, the corporate culture effects the willingness and openness to adopt new technology. This includes the promotion of creativity and a democratic leadership (Veile et al., 2019). According to Kagermann et al. (2013), incremental bottom-up rather than top-down approaches are preferred in regard to the use of communication protocols. Additionally, the hierarchical structure requires alignment with developments on a technical level (Moktadir et al., 2018). Schuh et al. (2017), mentions the effectiveness of working in communities in the digital era, each suitable with workers competences. The formation of project teams with employees from various disciplines appears to be helpful in developing and implementing technologies (Veile et al., 2019). Additionally, low hierarchical and informal structures enhance "decentralized decision-making in industry 4.0 "(Hirsch-Kreinsen, 2014; Saberi and Yusuff, 2011). The use of agile and/or lean management systems may enhance a flexible environment (Schuh et al., 2017). Schuh also mentions the need for responsible managers that embrace the value of his employees and have a tolerance for mistakes. Commonly used activities to enhance corporate change include workshops and think tanks (Burmeister et al., 2016).

Employees

For employees to successfully work in smart factories, a set of competences is required. According to Schuh et al. (2017), humans require further decision-making skills, due to an increase of automation and thus planning and controlling activities. These competences can be acquired through trainings and educational workshops such as scenario-based or e-learning (Darbanhosseiniamirkhiz and Ismail, 2012; Erol et al., 2016). According to Erol et al. (2016), "the basic concern of adoption is confidence in technology". The interaction between humans and technology in smart environments is complementary and assisting systems may support workers in their use of the technology (Block et al., 2015). Due to rapid innovation, workers face regular changes in their work and thus require more flexibility. They must be open to change and innovation in order to enhance the adoption of technologies such as additive manufacturing. A form of compensation may enhance these developments (Veile et al., 2019). Veile et al. (2019) revealed that trainings programs must target employees' personal work activities to enhance adoption. Furthermore, intuitive design of technologies lowers the need for trainings. The study also indicates it has been proven that, as employees use technologies and operate the machines, it is best if they are involved in the learning process. This process includes trainings from external parties as well as internal R&D activities.

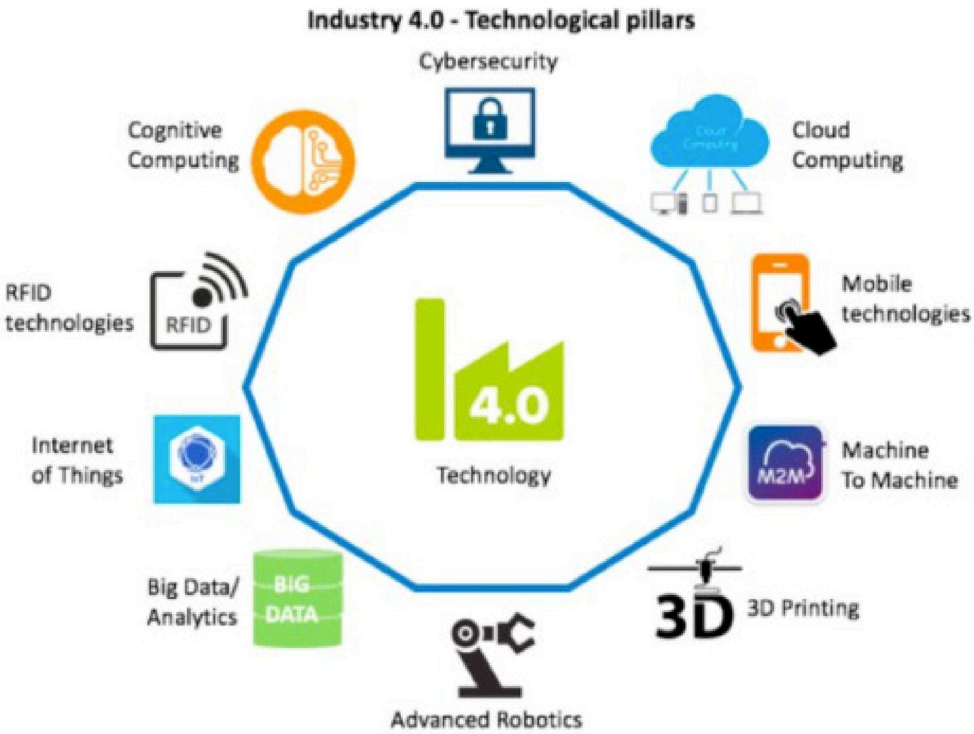


Figure 2.4.1 Industry 4.0 technologies (Saturno et al., 2018)

Figure 2.4.2: The development of new applications in Heineken's 3D lab (Ultimaker)

/ 2.5 Internal Research

Introduction

As described in the previous chapter, additive manufacturing offers various opportunities for companies to reduce costs in their production facilities. As part of the industry 4.0 developments, businesses must undertake various steps in order to achieve successful adoption of new technologies such as AM. Ultimaker offers such support throughout the introduction and implementation of 3D printing technology. This chapter describes an internal analysis of the training program that Ultimaker provides to support customers in their adoption.

Training programs

The AM training programs that Ultimaker provides are customized to the needs of their customers. Depending on their in-house technical abilities, goals and objectives, and organizational structure among others, the extent of the training is decided. Trainings for Ultimaker's key manufacturing customers usually have the end goal of reducing costs by using AM. Ultimaker training programs aim to teach customers about the technology and the software, but also contain their own strategy to teach users how to identify valuable applications within their businesses.

Customers have the opportunity to decide on the extensiveness of their trainings. Generally, there are three phases. The first phase, introduction, is a site-scan during which Ultimaker engineers visit the site and seek for applications together with the client that add to a valuable business case. If the customer agrees to continue with AM adoption, a lighthouse phase is started. During this phase, Ultimaker provides further trainings and support over the course of several months. For customers, such as Heineken, a global rollout plan is set in place in which Ultimaker provides trainings in all locations worldwide. In this case, a network between the different facilities can be established so in-house knowledge will increase.

Products

Apart from trainings, Ultimaker offers a variety of supporting software for its clients. Cura, the core software that allows for slicing parts for printing, is accustomed with cloud-based printer management software. This software is not directly focusing on the educational side of 3D printing yet is continuously improved to support users in their printing workflow. Furthermore, most software is linked to external information, such as the Ultimaker community, e-learning modules and other sources of information. This way, Ultimaker is providing a solid source of information for anyone who wants to learn about using the technology, both paid and unpaid.

Digital factory

Current efforts are focused on developing the so-called "digital factory", a cloud-based platform in which print jobs are documented and shared between stakeholders (see figure 2.5.1). The digital factory is currently being developed and targets the need for traceability of projects, versions and statuses of parts in development. For clients with multiple factories,

2

this product is especially relevant as it supports their internal communication in regard to the development of applications. The Digital factory will be part of Ultimaker's ecosysem and allows users to directly send jobs to printers, manage printers and jobs and keep track of information regarding versioning and print settings. The limitations of this software for operators is that it is more of a technical, back-end product proposal which can be used by champions with extensive knowledge of AM.

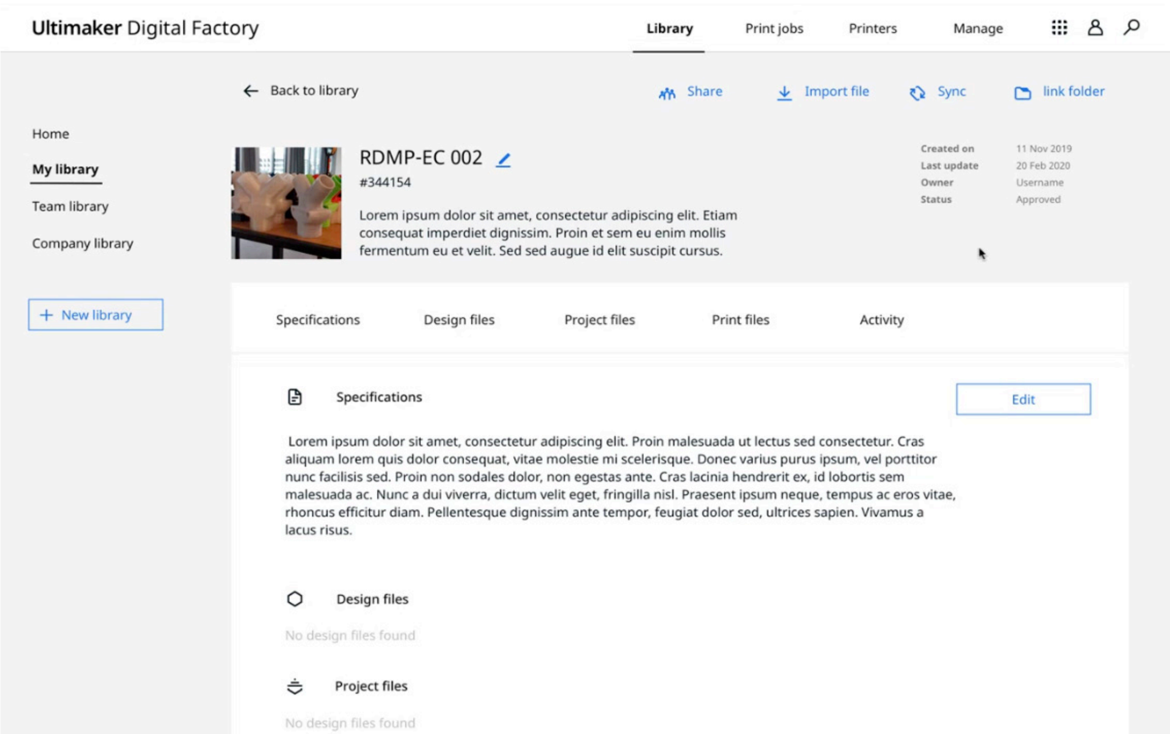


Figure 2.5.1 Screenshot of the first prototype of the digital Factory (Ultimaker)

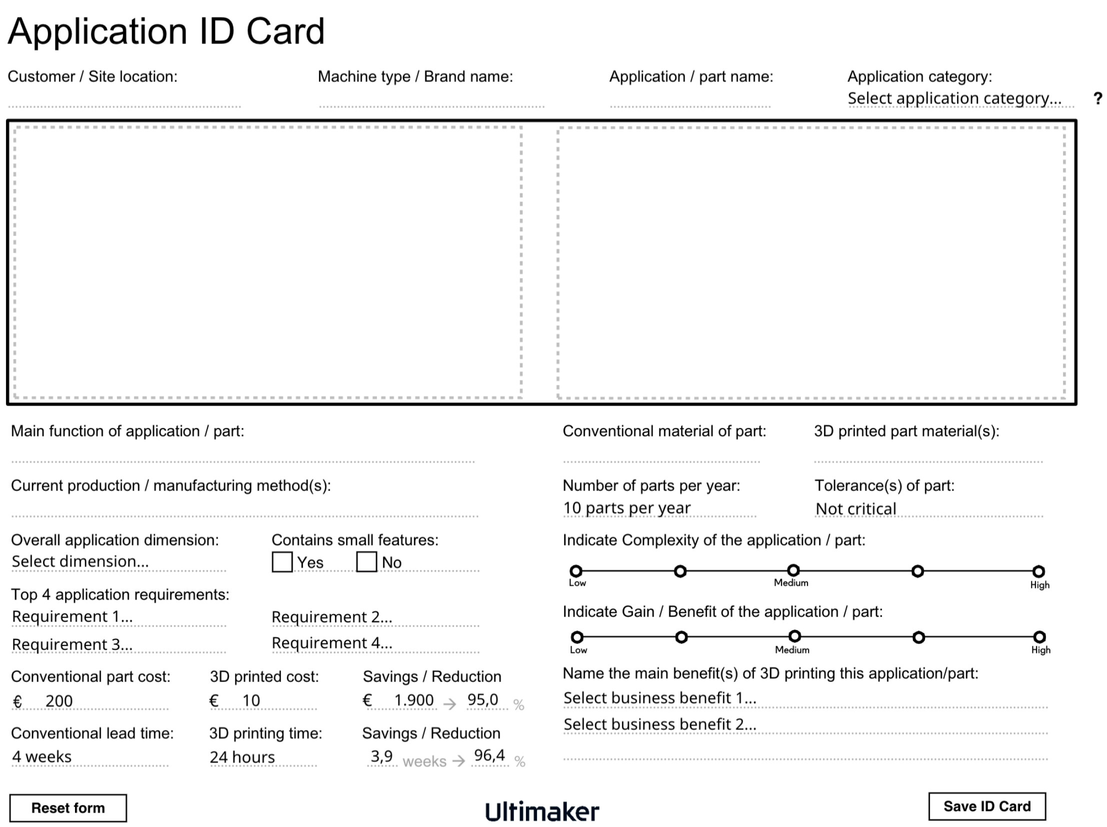
Application Identification approach

To inspire their new customers, Ultimaker makes use of examples of applications. Furthermore, they categorize applications and present a set of guidelines in the documentation of (new) applications.

Throughout the site scan and as a general tool for customers afterwards, ID cards are used (see figure 2.5.2). It is an interactive digital PDF with a possibility to upload pictures. Users can take an iPad or phone and fill in some details about the potential application, used as a way to document and share the findings and calculate the business case. This is a starting point to enter applications into a digital workflow.

Application categories

Ultimaker differentiates between different types of applications within manufacturing environments (see figure 2.5.3). This report only focusses on manufacturing aids, as those are the only relevant categories for our target user. Within manufacturing aids, there are support tools, assembly tools, quality tools, transport tools and production tools. Each will be briefly explained below with examples included.



Application ID Card

Customer / Site location:

Machine type / Brand name:

Application / part name:

Application category: Select application category... ?

Main function of application / part:

Current production / manufacturing method(s):

Overall application dimension: Select dimension...

Contains small features: Yes No

Top 4 application requirements:

Requirement 1...

Requirement 2...

Requirement 3...

Requirement 4...

Conventional part cost: € 200

3D printed cost: € 10

Savings / Reduction € 1.900 → 95,0 %

Conventional lead time: 4 weeks

3D printing time: 24 hours

Savings / Reduction 3,9 weeks → 96,4 %

Conventional material of part:

3D printed part material(s):

Number of parts per year: 10 parts per year

Tolerance(s) of part: Not critical

Indicate Complexity of the application / part: Low Medium High

Indicate Gain / Benefit of the application / part: Low Medium High

Name the main benefit(s) of 3D printing this application/part:

Select business benefit 1...

Select business benefit 2...

Reset form

Ultimaker

Save ID Card

Figure 2.5.2: the application ID card currently used to fill in information about applications (Ultimaker)

Manufacturing aids				
Support tools	Assembly Tools	Quality tools	Transport tools	Production tools
Tools used to support manufacturing, without shaping the end-product.				Tools integrated in the production line, directly shaping the end-products.
Goal: Improve around Manufacturing quicker and at lower cost	**Goal**: Improve assembly quicker and at lower cost	**Goal**: Improve QC costs and Leadtime	**Goal**: Improve production line quicker and at lower cost	**Goal**: Modify production line quicker and at lower cost
Use: Optimize Workshop organization or logistics, simple repairs	**Use**: Create solutions to increase assembly speed or reduce risks (injuries, quality) in assembling the final product	**Use**: Create better and more quickly replaceable QC tools	**Use**: Make parts of the automated production line quickly created, tuned or replaced.	**Use**: Make parts of the automated production line quickly replaceable.
Key identifier: Used in manufacturing environment, but not related to nor touching the end product. Can be a repair with simple replacement	**Key identifier:** Part is used by its operators to help assembling the end-product. Failing may stop the line but does not impact end-product.	**Key identifier:** Part is used by its operators to validate the end-product quality (function, fit or form) Failing may stop the line but does not impact end-product.	**Key identifier:** Part is interacting with end-product (moving, positioning) but not adding value to it. Failing may impact end-product. Positioned in production line	**Key identifier:** Part is adding value to the primary product – like assembling, constructing or forming it Failing will impact end-product Positioned in production line

Figure 2.5.3: Application categorization as Ultimaker defines them (Ultimaker)

Support tools

Support tools are tools that support workers in the organization, logistics and repairs of their workshop. Such as organizers and safety tools.

Benefits

Support tools are commonly used to support the operators in their daily work. Organizers allow them to have a structured workplace. Safety tools prevent injuries. AM allows for customization to a specific work situation. Furthermore, the use of different colors, such as red, allows for noticeable situations.

Requirements

Support tools are relatively simple to fabricate. There are usually no requirements such as wear/ tear or chemical resistance, as they will not be used within the machines.

(Image credits: Ultimaker)

Figure 2.5.4: Safety tool

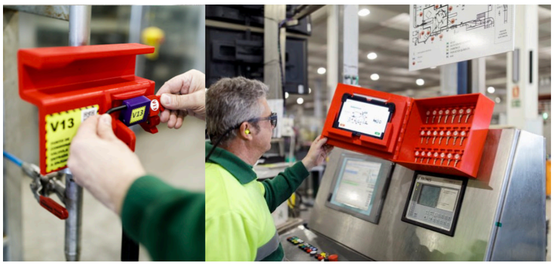


Figure 2.5.5: Safety and organization tools

Assembly Tools

Assembly tools that increase efficiency or ergonomics in the assembling of a product.

Benefits

Assembly tools are versatile and support operators in different parts of their work. These tools are frequently one-offs and therefore expensive to order in small batches. Furthermore, AM's customizability allows for easy adjustments when the part that needs to be assembles changes.

Requirements

Dimensional accuracy and strength are commonly important in the design of assembly tools.

Figure 2.5.6: Support tool for welding parts

Figure 2.5.7: Assembly tool for car lettering at Ford

Quality tools

Tools that support quality checks of parts. These are also tools that are used outside of the production line at the end of the production or assembly of a part.

Benefits

3D printed quality tools are frequently one-offs and therefore more cost efficient to print rather than to order. Furthermore, frequent changeover of products requires adjustments which can be easily achieved through AM compared to CM.

Requirements

Dimensional accuracy is the most important factor in designing and printing quality tools.

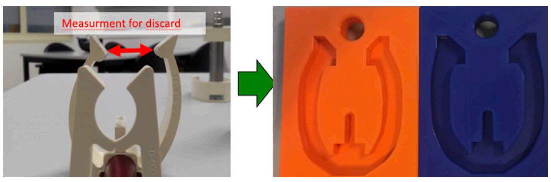


Figure2.5.8: a quality tool to measure material characteristics

Figure 2.5.9: a support tool to check label placement

Transportation tools

Transportation tools move the end part or product through the production line. These parts are in contact with the end product and may face high speeds, friction, temperatures and/or other environmental influences.

Benefits

Transportation tools can be expensive and employees may not know when they break. Dual extrusion in AM offers the possibility to indicate wear/tear more easily to the user through the use of different colors. This way employees will be able to tell the degree of wear (figure 2.5.9).

Requirements

The material must be resistant to wear, tear and sometimes chemicals and temperatures.

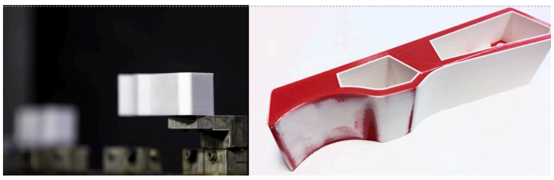


Figure 2.5.10: Can pusher with colored wear & tear layers

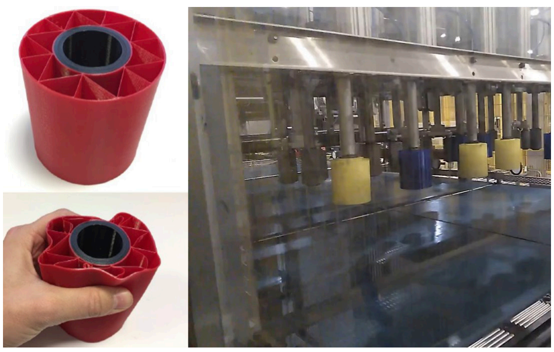


Figure 2.5.11: part of the production line that turns six-packs of beer 90 degrees

Production tools

Production tools are internal parts in the machine line that help shaping or forming the end part more efficiently.

Benefits

AM offers opportunities for improvements on these parts, as well as significant cost reductions.

Requirements

As these parts shape or form the end part, they are frequently used internally, at high speed and thus must be resistant to the conditions within the machine. Wear, chemical and vibration resistance are therefore common requirements for such pats. Therefore, the choice of material for the part is of great importance.

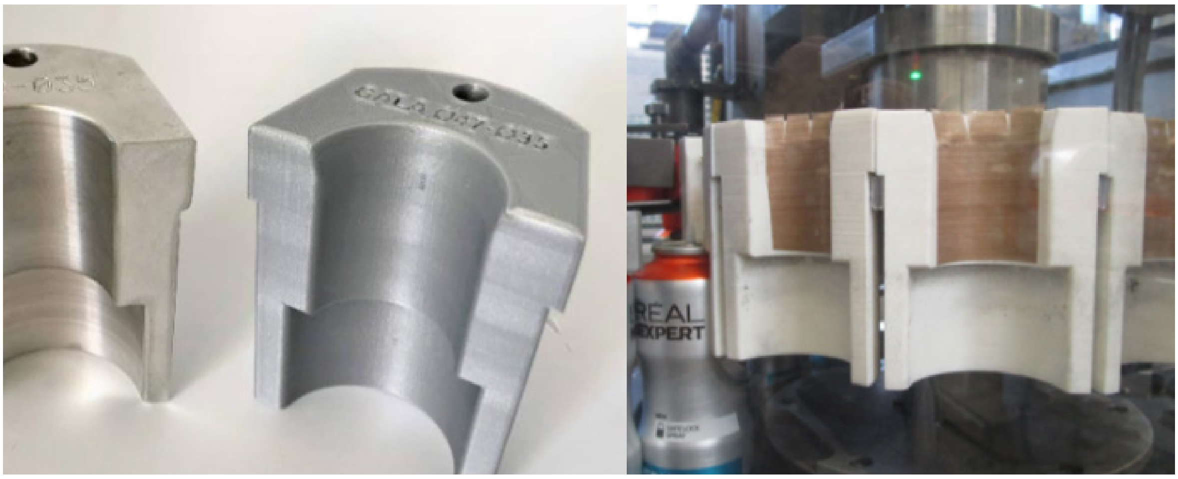


Figure 2.5.12: production tools used to move cans of consumer products throughout the production line (Ultimaker)

/ 2.6 Landscape Analysis

One of the challenges that AM is facing is accessible part identification. In comparison to older and established manufacturing methods, AM is still in its infancy. According to Stratasys' report, "one of the main challenges is finding and translating opportunities to real world applications and finding new ways to create value" (Stratasys, 2015). It is often seen that identification comes naturally over time due to experience with the potential and limitations of the technology. Successful part identification depends on many different factors, including the needs of a company and the requirements for the part. Even though some restrictive rules may support the decision-making process, such as the printer's limitations in size and volume (Doubrovski et al. 2011), there is not one clear recipe which results in the best use of the technology (Yang et al. 2019).

Different methods and systems have been developed that help solve the problem of identifying parts for AM. These systems differ in how they offer support to users in the 3D printing workflow, and also in the type of input required for optimal use of the system. Yang et al. have done extensive review on the existing methods, which are either heuristic or computational (Yang et al., 2019), and have also proposed their own. One research stream they have identified in existing methods focusses on using process constraints, which are "overly rigid and do not take redesign opportunities and added value of AM into consideration" (Yang et al., 2019). Additionally, most approaches are highly dependent on expertise or are limited in what potentials they measure (Yang et al. 2019). Their review of existing methods resulted in the following overview (figure 2.6.1).
A number of methods that target novice users are reviewed in the following sections.

Senvol has developed a list (figure 2.6.2) of criteria for AM suitability. If a part fits into one or more of these criteria, it may be a candidate for further evaluation for AM. If the part does not fit into any of the criteria, it will most likely not be suitable (Wohlers, 2013). This list is aimed at management level and supports their decision to adopt AM technology in their businesses.

	Candidacy criteria		Comprehensiveness		AM expertise		Implementation	
	Constraint	Potential	Single	Multiple	Novice	Skilled	Heuristic	Computation
Merkt et al. (2012)	✓	✓		✓		✓	✓	
Klahn et al. (2014)		✓		✓		✓	✓	
Materialise (2014)	✓	✓		✓	✓			✓
Lindemann et al. (2015)	✓	✓		✓	✓	✓[a]	✓	
Leutenecker-Twelsiek et al. (2017)		✓		✓		✓	✓	
Reiher et al. (2017)	✓	✓		✓	✓	✓	✓	
Senvol (2017)		✓	✓		✓		✓	
Yao et al. (2017)		✓	✓		✓			✓
Yang et al. (2018)		✓	✓		✓		✓	
Yang et al. (2018, 2019c)		✓	✓		✓			✓

[a]The first stage requires AM neutral knowledge, while the second stage needs AM experts to evaluate the response

Figure 2.6.1: suitability assessment methods (Yang et al., 2019).

These criteria are also relevant starting points to seek for new applications once adopted.

The method Yang et al. developed themselves targets the gap of automatically identifying AM part candidacy. Machine learning algorithms are utilized for the design of their Decision Support System, extracting data from digital CAD files (see figure 2.6.3). There are other computational methods that require the input of a CAD or STL file and sometimes additional information that work in similar ways from a user perspective, commonly developed by commercial 3D printing businesses, such as 3Daddict.com.

Scenario	**Description**
Expensive to manufacture	Do you have parts that are expensive because they are complex, have high fixed costs (e.g., tooling), or are produced in low volumes? AM may be more cost effective.
Long lead times	Does it take too long to obtain certain parts? Are your downtime costs extremely high? Do you want to increase speed to market? Using AM, you can often get parts more quickly.
High inventory costs	Do you overstock or understock? Do you struggle with long-tail or obsolete parts? AM can allow for on-demand production, thus reducing inventory.
Sole-sourced from suppliers	Are any of your critical parts sole-sourced? This poses a supply chain risk. By qualifying a part for AM, you will no longer be completely reliant on one supplier.
Remote locations	Do you operate in remote locations to where it is difficult, time consuming, or expensive to ship parts? AM may allow you to manufacture certain parts onsite.
High import/export costs	Do you pay substantial import/export costs on parts simply because of the location of your business unit and/or your supplier? Onsite production by AM can eliminate these costs.
Improved functionality	AM can enable a part to be redesigned to improve performance beyond what was previously possible.

Figure 2.6.2: Criteria for AM suitability (Senvol, from Wohlers, 2013).

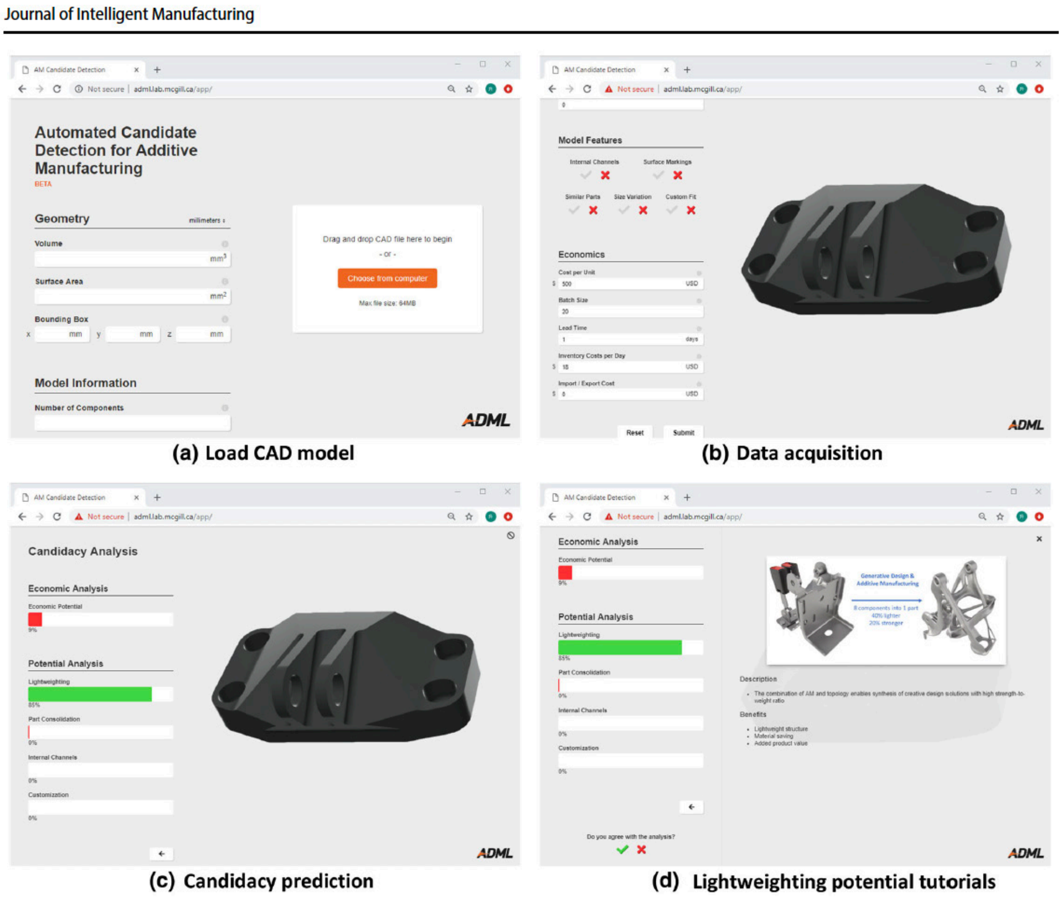


Figure 2.6.3: automated candidate detection system based on machine learning principles (Yang et al., 2016)

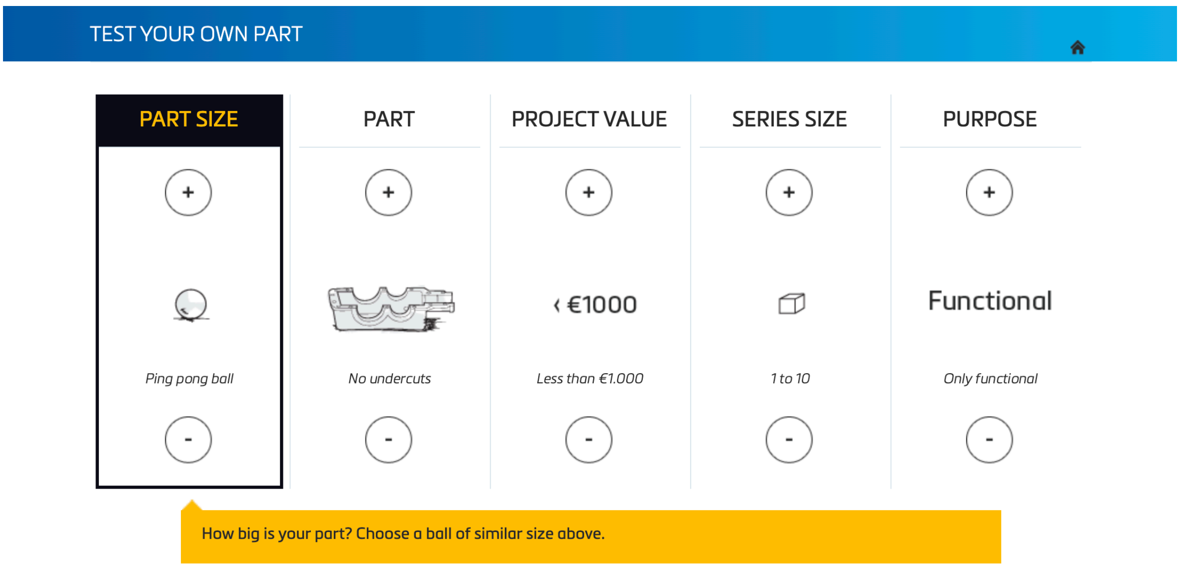


Figure 2.6.4: initial screening system for parts (Materialise, 2020)

There are also heuristic methods, such as the TOM matrix by Lindemann (figure 2.6.5). This method guides users through different phases. The first phase is about communicating basic understanding. The second phase requires the input of several criteria: dimensions, part classification (complexity, buy-to-fly ratio, post-processing), material decisions, geometric characteristics and processing time (Lindemann et al., 2015). The system ranks parts on suitability for AM. The last phase allows experts to perform further analysis before it is handed over to an engineer to design and print.

Other computational methods that do not require the use of a digital model are Materialise barometer (figure 2.6.4) and 3YourMinds use case scanner (figure 2.6.6).

Materialise (2014) have developed a 3D-print barometer as an initial screening for part eligibility. The input for this screening requires one to only several criteria: size, complexity, value, production volume and purpose of a part. This method targets novel users and only requires minimum information.

3YourMind has come up with a method that integrates into the ERP systems of businesses and generates scores based on potentials of parts. Another feature of their system is the use case screening (figure 2.6.6) which allows employees to fill in some data about parts they encounter throughout their work. They have the ability to fill in as much as they can, with the only required fields being part size, production volume and name. in this case, the more you fill in, the more reliable the score of the part for AM suitability. The score comparison takes all parts into consideration regardless of how detailed their information.

Existing methods that require high levels of input or an existing CAD file may be most accurate in assessing AM and financial suitability. However, for the context of manufacturing environments in which novel users without any or much prior training must assess parts and problems for AM, some of these methods are incomplete as they require STL files as input. Systems such as 3YourMind and Materialise's may have potentially interesting features, as they target novice users, but contain less accurate feedback.
In 3Yourminds software, the relationship between novice user and expert is targeted and feedback is provided to the users regarding their input, which provides significant benefits. Furthermore, they make a step in gathering and measuring data regarding the suitability and impact of parts. It may be strategic to focus on making either the accessible software options more valuable/accurate or make the valuable software accessible to users.

Figure 2.6.5: Excerpt of Trade-off Methodology Matrix (TOM) (Lindemann et al. (2015) and Reiher et al. (2017))

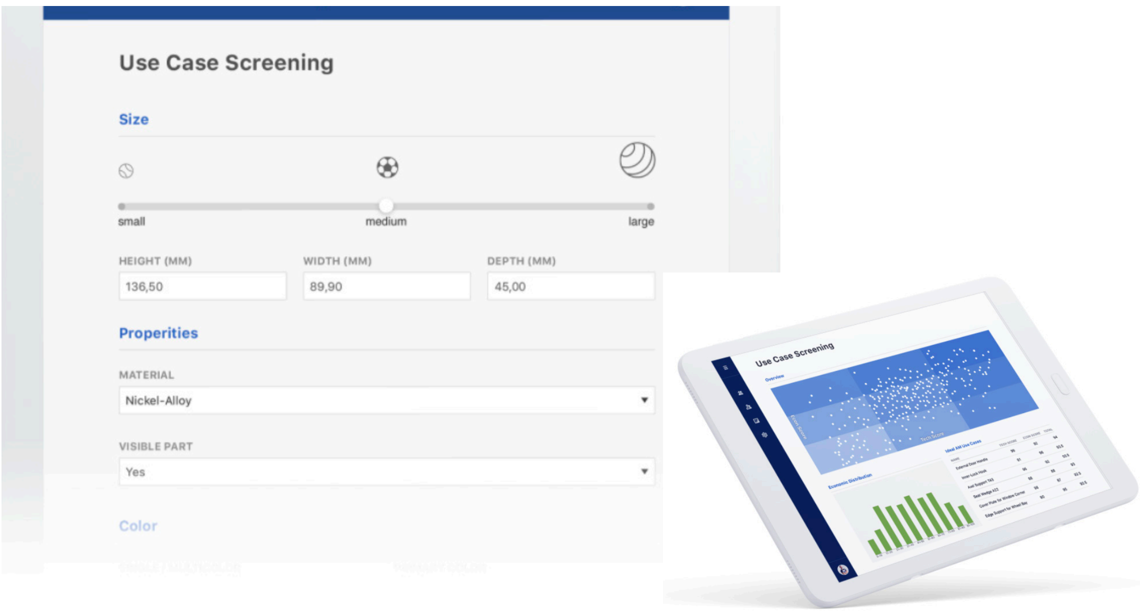


Figure 2.6.6: use case screening entry form and suitability score (3yourMind, 2020)

/ 2.7 Conclusions

The sub questions of this chapter will be evaluated as a means to answer the key research question.

What is AM and how does it work?

Additive manufacturing produces parts in an additive way, compared to conventional processes, such as subtractive, formative and joining processes. This allows for many benefits over conventional methods, such as unlimited design freedom and customization and a reduction in costs and lead-time. AM contains various different technologies, of which FDM is one. FDM, Fused Deposition Modeling is the technique used by Ultimaker, and disposes material on a print bed layer-by-layer.

What are the key benefits of AM in manufacturing environments?

Additive manufacturing offers many new opportunities for business to produce parts that were previously expensive, time consuming and/ or out of reach. Its unique ability to create parts layer by layer allows for extensive complexity, local manufacturing and many other financial, functional and societal benefits. Manufacturing companies are increasingly adopting AM in their facilities due to various of beforementioned benefits. Some challenges remain, however, due to AM's infancy compared to conventional manufacturing.

What are the specific characteristics of succesful adoption of industry 4.0 technology?

Several criteria have been proven to support manufacturing environments in the adoption of new technologies, such as low hierarchy and bottom up innovative mindsets. Extensive trainings and accessible products further accelerate understanding of the technology. However, when it comes to 3D printing, several challenges in its adoption remain.
One of these challenges is the assessment of suitable parts for printing.

What is Ultimaker's approach towards application identification?

Ultimaker has created their own approach towards the identification of parts. Through workshops and trainings, Ultimaker's engineers teach clients how to use the printers, how to design for AM and also how to seek for applications. One of their approaches is the use of examples from former clients in similar industries. For documentation the Application ID card is used. This is a form which can be used digitally and on paper where information can be filled in regarding the application. Furthermore, application categories guide users in their documentation.

What other existing tools are there to support application identification?

According to existing literature, a variety of different methods have been created that support users, from novel to experts, in the identification of suitable AM parts. Overall it can be said that the technology and its opportunities are complex, and there are relatively little boundaries that define a clear scope for assessing the potential of an application apart from build volume and size. Financial criteria, common drivers for manufacturing companies, are complex, due to the many adjustments in production and supply chain. Furthermore, even with the existing limitations in material availability, there are many opportunities for properties, such as stiffness and flexibility. So far, there are no clear guidelines yet on how to approach this process, as the intention to print may vary per person. Existing methods vary from initial screenings on size, material and build volume to computational models with machine learning principles. However, most of these methods assume the user has an intention and a digital file to assess for printing. Some methods, however, target novice users and are interesting to further investigate, such as the use of a communication platform (3yourmind), a suitability check (materialize) or potentially a checklist as seen in Wohlers (2013).

How might novice users identify parts for AM in manufacturing environments?

The complexity of 3D printing technology, in combination with a variety of factors that influence decision making, make the assessment of parts difficult, even for expert users. Some elements of existing methods, including Ultimaker's own approach, have been created to support the process of assessing parts, such as the use of categories for applications, visuals and checklists. However, automation through software appears to be extremely difficult, and current methods are often time consuming and yet complex. No established method has been developed to target novice users without much knowledge in the process of assessing new parts. There appears to be a need for further investigation into the manufacturing environment, its stakeholders, and their needs and motivations in order to facilitate active participation in the AM workflow.

CHAPTER

03

ANALYSIS

| CONTEXT

This chapter analyses the insights from research that was conducted through interviews, observations and a survey in two different manufacturing environments. The chapter starts with an introduction, in which the research questions are presented. It continues with an explanation of the methods used and the stakeholders that were involved in the research. Next, the research results are described and the chapter is concluded with implications for future design solutions.

Figure 3.1.0: Heinekens production facility in Sevilla, Spain (Ultimaker)

/ 3.1 Introduction

This chapter is set out to find answers to various research questions. The literature study has identified a gap of knowledge in regard to the identification of AM suitable parts within manufacturing environments that is accessible for production operators without any prior experience in AM. AM has proven to provide various benefits, such as simple cost reductions as well as lead time reductions, which especially benefits remote facilities. Most research is focused on the financial criteria to adopt AM and leaves out the identification of new parts once it is adopted. The methods that have been developed, however, are often computational or assume a part has been selected.

Therefore, this research is aimed at understanding the specific industry, the novice target user and the collaborations that take place in this context. Field research has been done in the form of interviews, surveys and observations, which aim to answer the following question:

Research question:

What is the potential role of production line operators in regard to identifying new applications for additive manufacturing?

Sub questions:

What organizational characteristics influence AM application identification within manufacturing environments?

What types of stakeholders are relevant for the AM workflow in manufacturing environments and what challenges do they face in their collaboration?

What is the operators role in regard to the AM workflow?

What are the barriers and motivations of operators to become part of the workflow?

Figure 3.1.1: Heinekens production facility in Sevilla, Spain (Ultimaker)

/ 3.2 Approach

Several methods were combined to gather data from different stakeholders. The research started with a 2-day observational visit to a production facility, during which qualitative interviews were conducted. Further interviews were held within Ultimaker and a survey was conducted with operators from Ultimaker's assembly line. The decision for semi-structured qualitative interviews was made as they support retrieving the story behind a participant's experience (McNamara, 1999). Observations were used to gain an understanding of user's ongoing behavior in a natural setting. Due to the COVID 19 outbreak, further interviews were limited, and an additional digital survey was distributed among operators. Ultimaker's client database was used to contact the target audience.

Target audience

As mentioned, the target users are operators in manufacturing companies within Ultimaker's client database. Heineken was used as a primary research location, as their facilities find themselves in various stages of the implementation of AM. For comparison, verification and further validation of the operator user group, Ultimaker's assembly line was researched through interviews and the survey.

Observations

Observations were done during a two-day visit to Heineken's production facility in Thessaloniki, Greece (figure 3.2.1). During the visit, Ultimaker provided trainings to the brewery's employees. The training was given by the following people:
1. One of Ultimaker's application engineers who is an expert on the technology and has given trainings on using FDM in manufacturing environments for several years (participant 7, see participant overview in appendix B)
2. Heinekens innovation manager – the person who is responsible for the global rollout of FDM in Heinekens facilities worldwide (participant 1). She is also setting up the network between the different engineers who are responsible for FDM within their Heineken facility.
3. A manufacturing engineer from Heineken Den Bosch – one of the facilities that has been using 3D printing for several years now. He is the FDM expert within this facility and the go-to person for employees who want to print something (participant 2).

Several employees from the Heineken brewery in Thessaloniki joined the training on a voluntary basis. This brewery had never made use of 3D printing in their facility before, but few employees showed an interest. From the local brewery, several operators and engineers joined. The training lasted two days. During the training, the attendees learned about the technology, the materials, the applications that have been developed within Heineken and other manufacturing businesses, how to design for FDM (CAD training) and how to use the printers. In addition, a site scan was organized in which the attendees were asked to identify applications in their own facility using digital ID cards. Observations were aimed at understanding the organization's objectives, the stakeholders, their knowledge, collaborations, and more. As there were stakeholders from facilities where 3D printing has been adopted, a comparison could be made between what was observed and what was shown to work in other facilities such as Heineken Den Bosch. Information was collected through notes and pictures. Further interviews were conducted to verify observations.

Figure 3.2.1: Images from the sitescan visit at Heineken's brewery in Thessaloniki, Greece (personal pictures)

Interviews

Several stakeholders were interviewed during and after the visit from both Heineken and Ultimaker. Application engineers, who frequently visit the sites and provide trainings on the use of AM, as well as engineers who operate in the facilities and use the technology. See figure 3.2.2 for an overview of all the stakeholders included in the interviews.

Survey

A survey was distributed among operators from Ultimaker's production facility. The survey was split into two directions; one for operators who had identified an application before, and for those who had no prior experience with initiating an application. The aim of the survey was to understand the experiences, motivations and barriers among operators and their involvement in the AM workflow. Seven operators responded to the survey.

Data analysis

During observations, thoughts and insights were written down and pictures were taken for documentation. Interviews were transcribed, resulting in a large amount of qualitative data. Data from the survey was also noted down. All insights were extracted and coded with short abbreviations of the topics concerning each insight. Then, two different methods were used to discover the main themes within the research data.

Top-down

Several themes were discovered throughout the research. These themes were stakeholder specific (operator, engineer, and the technology). All insights were linked to a theme, after which they were further divided and specified.

Bottom-up

A collaborative session was held with two colleagues from Ultimaker. The post-it notes with insights were distributed among the three participants, who were asked to separate them into their own categories. Collaboratively, different themes were discovered.

Afterwards, the results from both methods were compared and complemented each other to define the main themes. This was an iterative process of which the results will be presented in the next section.

See appendix E for a visualization of the data analysis, appendix C for a summary of the interviews and appendix D for the survey results.

Interview #	Participant #	Company	Role
1	P1	Heineken Global	AM Innovation manager
2	P2	Heineken Den Bosch	AM champion
3	P3	Heineken Greece	Production operator
4	P4	Heineken Greece	Production Operator
5	P7	Ultimaker	Application Engineer
6	P6	Ultimaker	Application Engineer
7	P5	Ultimaker	Application Engineer
8	P8	Ultimaker Zaltbommel	Manufacturing Engineer
9	P9	Ultimaker Germany	Application Engineer

Figure 3.2.2: overview of all interview participants for the analysis.

/ 3.3 Results

Research Question 1: What organizational characteristics influence AM application identification within manufacturing environments?

Business objectives

Heineken started introducing AM technology in the Sevilla, Spain. The facility realized 3D printing's opportunity to produce high quality and custom parts that could reduce costs and lead-time. Successful implementation in the first facilities have led to a global rollout plan for Ultimaker technology, where, according to Heineken's innovation manager "a reduction of costs and lead-time of roughly 70-90% have been observed" (interview 1). The success of one application multiplies due to the similarity of the breweries worldwide. Overall, the focus of using AM within their facilities lies on the reduction of costs. According to Ultimaker's application engineer, "the main reason why businesses adopt 3D printing is through innovation managers, who have quarterly targets. AM is a quick way to reduce costs" (interview 5). Furthermore, facilities in remote areas, such as Nigeria and Ethiopia, also significantly benefit from AM, as it reduces lead-times significantly due to import difficulties. Employees are therefore highly motivated to seek for parts that have either high lead-times and/or costs. Furthermore, Heineken has rules and regulations for safety. Employees are required to submit a minimum amount of safety improvements which may involve AM related solutions.

At Ultimaker, the use of AM among employees has a different nature. Management did not adopt the technology; they just happen to produce it. Therefore, there is little pressure to seek for cost-reductions among employees. There are other incentives to make use of the technology, such as improving ergonomics, safety and efficiency. Ultimaker may not be representative of larger manufacturing clients such as Heineken, yet larger companies may still have different incentives to adopt 3D printing.

Processes

Heineken's facilities are commonly divided into production lines with their own processes. Beer is brewed, stored, put into cans, bottles, kegs and other packaging, which are then put into larges packages such as crates and six-packs, and placed into pallets for distribution. Each process takes place on its own production line, each including its unique set of machines, people, and materials. Each brewery is different in their size, processes and products. Additionally, every production line has a different atmosphere. "Hygiene might be the biggest priority in the brewery, whereas time pressure is much higher in the packaging line" (interview 3). The different processes influence the needs of users and will therefore also require a need for different type of applications. At Ultimaker, where the employees do not make use of large machinery, this insight was confirmed. Operators assemble products, making their work significantly different from the operators at Heineken. Ultimaker operators work with their hands and directly touch the end product. As the survey results and one of the interviews showed, the types of applications differ significantly at both companies. At Heineken, applications from each category can be found, whereas the operators at Ultimaker have indicated the use of support and quality tools primarily (observations, survey).

Resources

One of the first things that became apparent during the observations and interviews among Heineken employees was the lack of time to design, print and test AM parts. With the introduction of 3D printers comes a need for understanding the technology, which, as has become clear, is complex and requires experience. The time that employees are given to spend on the development of applications will therefore highly influence the degree to which it "lives" within the company. The manufacturing engineer from Den Bosch mentioned "there is little time to play around" , as he only gets half a day per week to develop applications. One of his main concerns is employees dumping their problems on him, expecting he'll solve them with AM. A combined lack of time for printing and a core objective of reducing costs and only developing valuable parts will limit employees to initiate more experimental applications. At Ultimaker, there are more employees with the ability to design and print. As the manufacturing manager at Ultimaker mentioned, most submissions from employees are developed within a matter of days. "Rarely do we not accept a request, unless the problem is better solved without the use of AM".

Size and scalability

Heineken has over 165 breweries worldwide with over 85.000 employees (Heineken, 2019). Even within a single facility, such as the brewery in Thessaloniki, there are various production lines with many different employees. The size of the business offers both benefits and challenges when it comes to the scalability of AM. The global network allows for the opportunity to gather and share knowledge easily. When an application is developed in one facility, it may be used in another one, directly saving time and money, and nobody has to reinvent the wheel. Furthermore, there is an opportunity to share knowledge throughout the development of parts, as AM is relatively new to many employees. The challenges, however, are the differences in each facility. It is difficult to see which applications may be suited in each facility. "Currently, there is no system which allows engineers in different locations to easily share and compare applications. The database with applications does not inspire, and information is frequently lost" (interview 1).In addition, the systems used to report problems are useful for employees to view solutions of colleagues for problems that may also interest them. Due to the large number of problems, however, it is unlikely that employees can keep track of all solutions. Another problem that was reported is the risk to lose knowledge throughout data transfers. At Ultimaker, a much smaller facility, problems are discussed face to face and in groups. This direct and personal collaboration allows for easier feedback from other stakeholders within the company.

Cultural differences

Another relevant insight in international organizations such as Heineken is the influence of culture on the drivers of people within a company. “In Mexico, people are very driven by money. It is an honor to work for Heineken and people are very loyal” (interview 1). The cultural differences may influence the mindset of the people and the business in general and therefore also the focus on a certain range of applications.

Figure 3.3.1: Collaborative evaluation of an application at Ford, Germany (Ultimaker)

Research Question 2: What stakeholders are relevant for the AM workflow in manufacturing environments and what challenges do they face in their collaboration?

Interviews and observations have provided insight into the different stakeholders within a manufacturing environment such as Heineken. With this, the comparison was made with other key customers such as L'oreal, KLM and Volkswagen. The roles and titles of employees may vary in each company, depending on the processes, size, and more. However, in regard to the AM workflow, the relevant stakeholders can be narrowed down to three different ones.
For the purpose of this report, the following three titles are used as observed at Heineken: manufacturing engineers, maintenance engineers, and operators. In this situation (see figure 3.3.2), the manufacturing engineer, also referred to by Ultimaker as "champion"(3) is responsible for the AM workflow, the maintenance engineers (2), called in for repairs on machines, and the operators (3) are divided over the factory floors, making sure production is running.

Stakeholders

From interviews and the survey, information was gathered regarding the different personas (see figure 3.3.3, 3.3.4, 3.3.5 and 3.3.6). They are primarily based on the context observed at Heineken, as this was most representative of all the key customers. Most information is derived from interviews and the survey. One key insight is the differentiation between the operator personas. According to several interviews, and confirmed through the survey, two different operator personas can be identified, as described in figure 3.3.5 and 3.3.6. The personas have been complimented with Ultimaker's existing stakeholder research and previously developed personas.

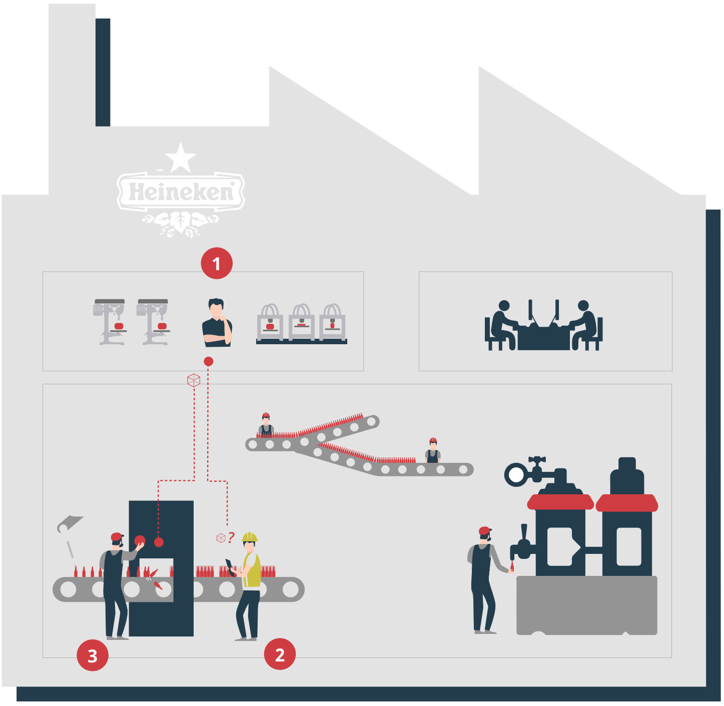


Figure 3.3.2: Illustration of the stakeholders and sub departments within manufacturing environments

Hugo

"Quality is my main concern"

Age 42
Role Manufacturing engineer
Industry Food & Beverage
Education Mechanical Engineering

Interests
- 3D printing
- Aerospace engineering
- Sports

Brands
- Nike
- Samsung

Bio

Hugo has a background in mechanical engineering and is now a manufacturign engineer at a large food and beverage production facility. He is in charge of the workshop, where he and his colleagues produce parts for the production facility. With his interest in technology, he introduced 3D printing within the business. He has experience and the skills to design and print parts, and is the go-to person for any requests. He does 3D printing on top of his regular activities so is under quite some time pressure.

Skills
- Technical knowledge
- Abstract thinking
- CAD & CAM

Motivation
- Quality
- Innovation
- Cost reductions

Concerns
- Time
- Change management

Preferred channels
- Facebook
- 3D hubs
- Television

3

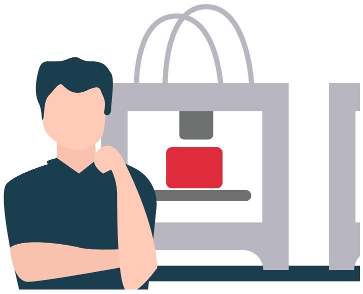


Figure 3.3.3: Persona of an AM champion (picture credits: Ultimaker)

Sam

"Quality is my main concern"

Age 57
Role Electrical maintenance Engineer
Industry Automotive
Education Electrotechnical Services

Interests
- Netflix
- Sports

Brands
- Vans
- Iphone

Bio

Sam is educated as an electrical engineer and is now working in the automotive industry as a maintenance engineer. Whenever there is an electrical issue, he is called in to solve it. He asks his colleagues for help whenever he runs into a new problem and likes to collaborate and learn. He once started as an operator but was able to promote due to his hard work. He has ambitions to groweven further within the company and is eager to learn.

Skills
- Electrical systems
- Systematic thinking

Motivation
- Efficiency
- Carreer
- Collaboration

Concerns
- Abstract thinking skills
- Administrational tasks

Preferred channels
- Facebook
- Instagram
- Television

Figure 3.3.4: Persona of a maintenance engineer (picture credits: Ultimaker)

Sarah

"Quality is my main concern"

Age 28
Role Production operator
Industry Technology
Education Trade School

Interests
- Concerts
- Comic books
- Pets

Brands
- Nokia
- Ecco

Bio

Sarah went to trade school before she started working in the technology industry. She has always been interested in technology and likes to work with her hands. She is eager to learn and grow within her company. She is a production operator, juggling many tasks throughout the day and making sure production is running as required. She is not always able to find the most suiting solutions for the problems she finds, so she calls in her colleagues for assistance.

Skills
- Technical
- CAD Design
- Business eye

Motivation
- Efficiency
- Innovation
- Collaboration

Concerns
- Time
- Lack of knowledge

Preferred channels
- Instagram
- Facebook
- Whatsapp

Figure 3.3.5: Persona of an operato (picture credits: Avopix)

Peter

"Quality is my main concern"

Age 57
Role Production operator
Industry Automotive
Education Carpentry

Interests
- Airplane models
- Puzzles
- Watching television
- Camping

Brands
- Nokia
- Ecco

Bio

Peter has always been a hands-on technical person. As a child, he was always very good at building things and had an eye for detail. He followed an education in carpentry and ended up working in the assembly line in the automotive industry. He is most likely the most reliable and loyal employee at his company, as he is never late and always follows his set routine. He is therefore a respected employee at the company. Peter is very comfortable with doing the same work everyday and is not too fond of change. He is somewhat old-fashioned and doesn't like to compete with new technologies.

Skills
- Eye for detail
- Good with his hands
- Reliable

Motivation
- Quality
- High output
- Predictability

Concerns
- Change
- Automation
- Feeling inadequate

Preferred channels
- News channel
- Email
- SMS

Figure 3.3.6: Persona of an AM champion (picture credits: Ultimaker)

Challenges in the collaboration

Apart from the personal challenges that each stakeholder faces in regard to the AM process, some general challenges in their collaboration will be discussed below.

Communication

There is no general alignment on how to communicate problems for AM. As is seen, some companies make use of the ID cards, whereas others have created their own system for documenting and communicating problems or parts on paper. Several problems with the use of ID cards have been identified, and not every company continues to use them after the site-scans. As was mentioned by one of Ultimaker's Application engineers (interview 5), "the problem with ID cards is that they try to solve everything at once". Furthermore, different collaborations take place. In some scenarios, manufacturing engineers will walk through the entire process by themselves. In another scenario, a maintenance engineers spots a part for AM after an operator reports a problem in the production line. In another scenario, operators solemnly suggest a part or problem for AM. The roles and stakeholders vary, and there is no set guideline on how to communicate.

Assessment

Assessment on whether a part is suitable for AM does not only require thorough AM knowledge, it often also requires access to financial data about parts, which is not accessible for everyone in the company. It is therefore difficult to assess parts easily, as there are thousands of small parts within a production environment. Not everyone can easily access the database, sometimes resulting in wasted time and effort. Also, the information needed to assess a part sometimes must come from different stakeholders, which is time consuming and inefficient. Manufacturing engineers are commonly the most suited people for assessing AM parts. In scenario 2, "operators sometimes come to me with silly ideas, out of their own interest in AM" (interview 2). This is due to a lack of assessment skills.

Traceability

As this information must come from different stakeholders, the ID cards that are currently used is often incomplete. This results in missing information on the cards (interview 2), making it more difficult to trace back if application requests pile up. Furthermore, "The process of digitalizing files is unstructured, and does not inspire when looking at it" (interview 1). This is a problem when sharing files with other breweries, and it is difficult to know which ones would function in other breweries (scenario 3). Also, the gains and complexity of a part are often discovered throughout its development, which is therefore not always documented correctly.

Objective alignment

Several issues may arise between the different stakeholders, as they have different objectives to use (or not to use) AM. A lack of generic objectives may cause challenges in the collaboration between these stakeholders. When an operator wants to apply AM for ergonomic issues, his request may be denied as the manufacturing engineer is only developing parts that have direct financial benefits. With this comes the challenge of communicating the benefits of AM to novice users from the beginning onwards.

Different scenarios

An operator (without any prior AM knowledge) sees other 3D printed parts around him in the manufacturing environment and is interested in the technology. He chooses a part or a problem he is bothered by and reaches out to the manufacturing engineer with a request to print it (figure 3.3.7)

Figure 3.3.7: Operator visiting a champion

A maintenance engineer, who followed the Ultimaker training, sees an opportunity in the production line when he is called by an operator regarding a bottleneck. He reports it to the manufacturing engineer, who decides to continue the development of a part with AM. If this is the case, he might return to the factory floor and, together with the engineer discusses the requirements for the part. They might need additional information from the operator or purchaser regarding pricing and functionalities (figure 3.3.8).

Figure 3.3.8: Operator visited by a maintenance engineer

The manufacturing engineer spends time seeking for opportunities and uses the spare part or the companies' application database for inspiration to find valuable applications (figure 3.3.9).

Figure 3.3.9: Champion developing an AM part

Research Question 3: What is the potential role of operators in the identification of parts for AM?

To answer this question, several interview topics concerned the abilities and opportunities for operators to become part of the workflow. The findings are primarily based on the interviews with application engineers, their observations, and from a manufacturing engineer with the unique role of extensively working with operators (interview 2, 4, 5 & 6).

Problem indication

Various stakeholders agree on the value of the operator as a starting point for identifying problems. “I think the operator is the most important valuable person to identify problems” (interview 5), and: “I think the operator knows best what issues there are, regardless of his time pressure” (interview 2). Further statements confirm that the operators know exactly what problems occur and what the effect is on the production. Operators are divided per production line and are therefore the expert of their own little segment. In Ultimaker’s assembly line, “operators hold more products in their hands than anyone else”. Manufacturing engineers and maintenance engineers also confirm the unique position of operators, as they are spread out over the factory floor and each know the ins and outs of their own segment.

Functional gains

Operators may not have access to financial information and might not have a primary interest in finding parts that save costs. However, “an operator can perfectly tell you what the problems are when something goes wrong and the effects on the production” (interview 2). If a bottleneck occurs, they are the ones who monitor how long production stops. In an assembly line, operators are the ones who know how much the malfunctioning of a tool slows them down. “Operators should be able to identify whether a part produces more production” (interview 5). Regardless of not having a direct economic view on using AM, their objective is functional, which has a significant indirect economic value.

Application information

Operators may not have extensive background knowledge on 3D printing and may not have access to certain information such as cost price. However, they are in the context in which a problem occurs, which gives them access to information which may be transferred to another person, such as a manufacturing engineer, to further assess the part for AM. The amount of information they have strongly depends on the company. At Heineken, operators know the lead-time of parts as they order them and through experience have developed a feeling for how long it takes to arrive. At Ultimaker, operators have little to do with the inventory. Regardless of these dependencies, operators always have access to location, size, environmental conditions such as temperature and chemicals. Additionally, “operators know best what interactions they have with the parts. Managers can’t see that from their offices” (interview 5).

Solutions

“The younger operators sometimes come up with a solution to their problem. Some operators already go ahead and print” (interview 8). This concerns a small percentage of operators. According to the survey, operators who have initiated applications needed the help and experience of others in several steps of the AM workflow. An important obstacle when letting operators design and print is that “they may sometimes overlook the core problem, and we want to prevent them from going into a solution space that we later have to adjust. If this happens, they don’t take ownership over the application anymore” (interview 8). This implies that there is a risk in asking operators with little experience to come up with a solution. Generally, it has been mentioned that many operators lack the capability to think of valuable solutions, and therefore is was suggested to limit the operator’s role to the identification of problems rather than solutions.

Learning process

Several interviews have led to the insight that operator’s role may evolve, as “3D printing is easier a second time around” (interview 4). Engineers have indicated the value of collaboration with operators to get to the core of the problem, together (interview 5, 7 & 8). As operators are relatively hands on and learn by doing and seeing, including them in the process will allow for a valuable learning opportunity. The need for layering in this process is also essential. A form of collaboration between an engineer and an operator allows for the possibility to get to the real problem, enables operators to learn about the opportunities and limitations of AM and empowers them to take the solution of the application seriously.

Approach

Throughout the interviews and observations, several starting points have come forward for operators in manufacturing environments for identifying potential applications. These findings indicate where operators may face potential applications.

1. Spare parts with high costs or long lead-times
2. High changeover (when the production line needs to be adjusted for new products)
3. Quality checks
4. Wear and tear
5. Parts that frequently break
6. Obsolete parts
7. Parts that are hard to find or get lost
8. Safety issues
9. Ergonomics

Limitations

Even though operators may have direct access to quite a rich body of information, “this information is something they probably won’t think of” (interview 2). An example was provided on the use of chemicals for cleaning. If a part is in contact with chemicals, the material needs to be resistant. Therefore, such information is important for manufacturing engineers to know when they develop an application in their choice of material. An operator at Heineken cleans his own production line and therefore knows what chemicals the parts are in contact with. However, if asked for requirements for an application as is now done through the ID card, an operator might not think of the chemicals as a requirement for AM, due to a lack of knowledge and/or experience.

The role of the operator in the AM workflow might therefore be limited. In current situations, operators mostly report problems, after which an engineer may seek a solution through AM. However, it has also been mentioned that "operators can definitely be supported in understanding AM suitability regarding requirements such as temperature, chemicals, and more" (interview 2). If they are guided to a greater extent, and taught where the opportunities and boundaries lie, they might be able to identify valuable new applications that others may not. Additionally, in the information transfer, they may be supported. Suggestions were made, such as "a tree diagram so operators don't skip any information, or deliberately do so because they don't know this information" (interview 7). This suggests that the right tools to guide operators in their identification and documentation are currently missing but may significantly support their role in the AM workflow.

Collaboration

The need for involving operators in the AM process has become apparent throughout several interviews. "It's ten times faster to do it together" (interview 9), and "it is essential to brainstorm together, this way the operator will take ownership" (interview 5). Some sort of initial screening may filter out some parts that are unsuitable for operators and take some load off the process. It has been mentioned that the engineers must take over from the operators at some point, and both stakeholders "have to get to the core of the problem, together" (interview 7). The operators also seem to think that collaboration is desirable, according to the survey responses. Collaboration allows for learning, prevent loss of information and for making sure the problems can't be solved in easier manners.

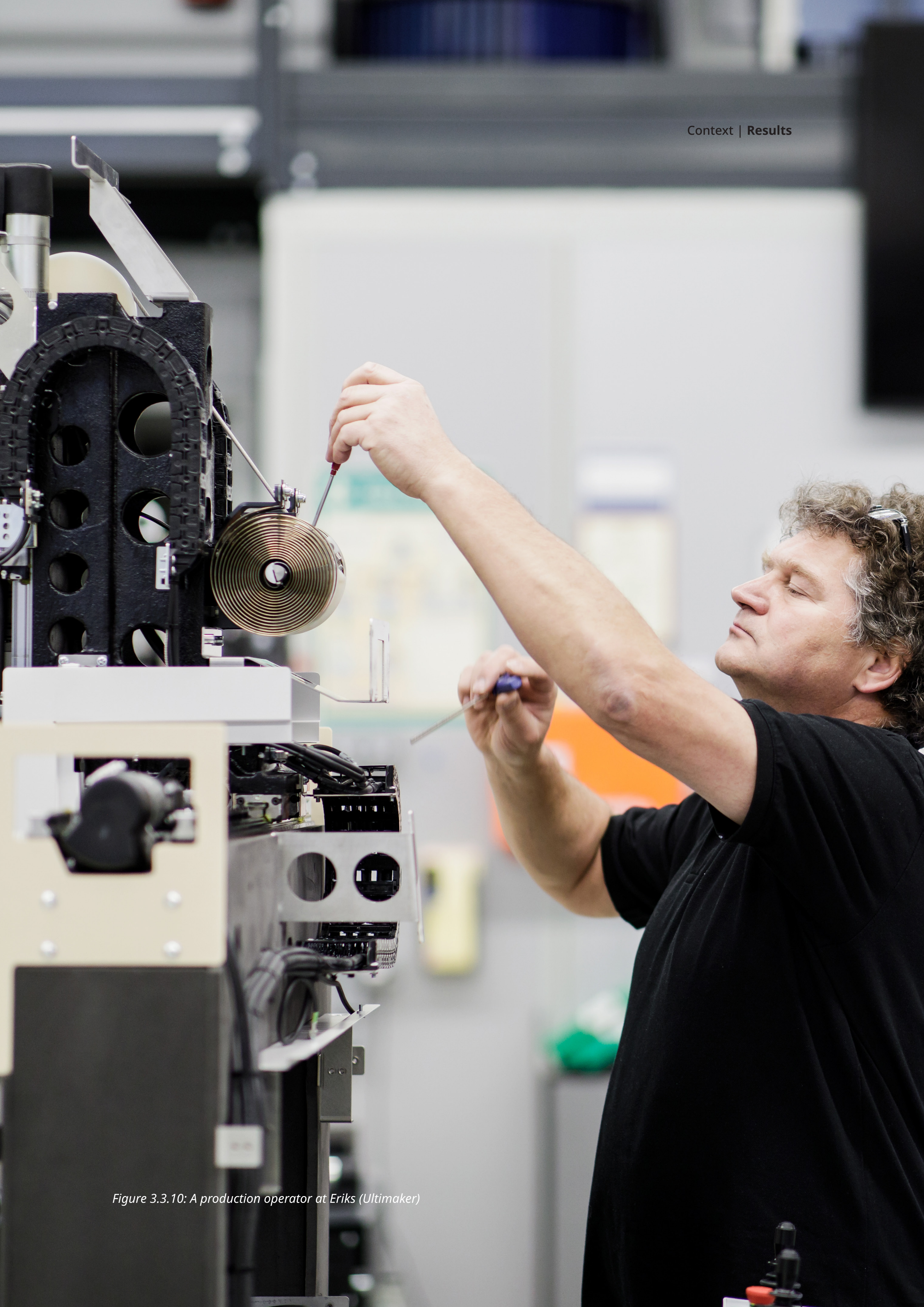


Figure 3.3.10: A production operator at Eriks (Ultimaker)

Research Question 4: What are the barriers and motivations of operators to become part of the workflow?

Survey and interviews have revealed several motivators and barriers for operators to take part in the application workflow. If overcome, elements that may currently form a barrier could become a motivator, such as the use of rewards.

Intrinsic Motivation

There is a group of operators that is intrinsically motivated to learn. “Especially the younger ones come up with good solutions” (interview 8). As mentioned earlier, this (usually younger) group is eager to make advancements in their career and have an interest in innovation. “Some operators suggest applications out of own interest” (interview 2). Some operators even teach themselves how to do CAD modeling and start printing parts. “This can be risky too, as they may print parts that damage the end product” (interview 8). Nevertheless, this group of operators can be considered as motivated and to learn, also when it comes to additive manufacturing. One survey respondent also mentioned the enjoyment of helping others through AM. For others, it is “rewarding to get away from daily tasks and support the AM workflow is a reward in itself” (interview 8).

Efficiency & Quality

According to the survey, being efficient is the main motivator for operators to do a good job. This was confirmed by several engineers, who mention that operators want to deliver good quality and high output. Furthermore, the biggest driver for operators to initiate an AM request is when they are annoyed by something or when something can be done more efficiently. Also, Operators enjoy to tell us (the engineers) when we make mistakes, which is absolutely fine!” (interview 8). Additionally, the most frequently mentioned gain of applications that operators have developed at Ultimaker is efficiency (survey Q34).

Acceptance & Safety

One of Ultimakers clients illustrated how important acceptance among employees is. A part was printed to support the assembly of car lettering onto a car. The operator received the part and discarded it while mentioning that he didn’t think the 3D printed part was valuable. Engineers post-processed the part and spray-painted it. They returned the part to the operator, who was not aware of the fact that it was the same part, who started using it with great joy. This example illustrates how the acceptance of a new technology is often more about accepting change.

Several other mental barriers have been uncovered throughout interviews, such as feeling safe, capable and feeling like you are taken seriously. According to Ultimaker’s production manager, it is key for operators to feel safe. “Once they feel it is safe to suggest new applications, they usually do” (interview 8). It is therefore essential to enable people in coming forward with their problems. However, there are also “operators who have fear not understanding the technology, preventing them from initiating requests” (interview 8). 1/3 of the survey respondents mentioned they wouldn’t want to become more involved in the

AM workflow. “This is not my task and I’d rather leave it up to people who know how to do this”, and: “Sometimes it is more of a challenge to do something new more than anything else” (interview 8). Furthermore, “operators don’t want to come across as whiny to their managers, so when I ask them for bottlenecks, I assure them I won’t tell their managers” (interview 6). Change takes time, as with any newly introduced technology. People are not used to it, and they may fear being judged when they do not understand it correctly. However, according to Heineken’s manufacturing engineer, it is common that some of the employees need time before they realize the benefits. Additionally, it is important for operators to feel responsible for their application. As mentioned previously, when operators don’t feel responsible, they are less likely to accept the solution.

According to Ultimaker’s Application Engineers (interview 9), “involving operators throughout prototyping is very important”. Acceptance is low when a final part is handed over to operators without consulting. Furthermore, it is important for them to understand 3D printing on a very basic level. Seeing machines and experiencing it first-hand are factors that may support operator’s learning curve.

Incentives

Currently, there is no direct benefit in identifying applications for operators. Their focus on short term solutions may form a barrier for them to initiate AM requests. Therefore, “Operators may need some kind of incentive to take part” (interview 5). This is more relevant at a large manufacturing environment such as Heineken, as there is a stronger focus on the reduction of costs than at Ultimaker. At Ultimaker, there is a direct incentive, as most applications are support and quality tools that benefit the operators directly in their work. Operators may have less of an incentive to seek for applications that do not directly benefit them, such as production tools that are often financially beneficial. Providing an incentive has proven to motivate operators according to 3YourMind, who launched a system for the German company in which a bonus is rewarded for employees who find applications. According to one of 3YourMind’s engineers, “this works well as an incentive in companies like this” (interview 9) However, competition might also scare operators. “some operators are afraid to be judged, even though that is not the idea of a competition” (interview 8). Creating teams for competitions mayhelp but not all production facilities are organized to make equal teams (interview 8).

Figure 3.3.11: A production operator at Ford (Ultimaker)

/ 3.4 Conclusion

RQ1: Organizations

Every organization is different in size, processes and culture. A comparison of Heineken's brewery with Ultimaker's assembly line allowed for several important factors to come forward. Firstly, the objective of a business to adopt AM has an effect on the type of applications that are being sought. Secondly, the processes within a business define the need for different categories of applications. The resources and time given for learning and applying AM also results in the degree to which employees may submit requests with or without significant value. Thirdly, the size and network of a company may both enhance and limit the identification of new applications. A global network may provide inspiration and existing solutions. However, communication in larger businesses tends to be less personal and large databases present further challenges. Lastly, there may be cultural influences on the types of applications that businesses seek, ranging from an economic focus to a more human-focused approach. These organizational influences have an effect on both the scope and type of applications that operators may initiate. The difference in individual needs on both management as well as employee-level implies that some level of customization may be required in a final solution.

RQ2: stakeholders & workflow

Every company has different employees, yet several important stakeholders have been identified that are relevant for the AM workflow in large manufacturing environments. There are "Champions", commonly manufacturing engineers, who have CAD and CAM skills and are the go-to people for AM requests. Maintenance engineers who often join the AM trainings and have good problem-solving skills, and thus may support in the identification of new applications. The operators can be split up in two different categories. The first group, young and motivated and the other group are somewhat older and less open to change. Different collaborations in the AM workflow take place, in which several challenges may arise with the assessment, documentation and objectives of parts. Information must come from different stakeholders, and there are only few "champions" who lack time and resources to take on all requests. These findings imply that there is a need for collaboration in the AM workflow between different stakeholders. The system must be accessible to use for different employees, support documentation and collaboration between them. Furthermore, assessment of parts or AM would preferably become easier, yet this is, as proven, difficult to achieve due to the large amount of both objective as well as subjective criteria.

RQ3: Role of the operator

Operators are in the unique position to identify problems with a functional gain for their segment of the production line. It varies per company what information operators can access regarding an application, such as cost price and lead time. However, they know the function, location and environmental characteristics as they are in the context. Operators may be limited in their ability to define the solution with AM, due to a lack of knowledge and experience with AM technology. As other employees are better capable of thinking abstractly, a form of collaboration may be desirable after a problem has been defined. However, operators may be supported in the process of identifying parts for AM and documenting their characteristics. Additionally, the learning curve of AM is relatively quick so their role may evolve over time. These insights show that operators are valuable stakeholders for the identification of problems for AM. In order to develop valuable parts that support the functioning of the production through efficiency, ergonomics, safety and more, operators must be utilized as a starting point for application development.

RQ4: Motivations and barriers

Operators have different motivations to take part in the identification of new applications. They are driven by efficiency and high quality, which may be enhanced by AM. Some operators show a personal interest in the technology and/or the ambition to make steps in their career. Others are motivated by helping others and/or enjoy doing something outside of their regular tasks. However, several barriers have been identified for operators. Acceptance is a major challenge among operators, especially the older group. Operators may feel judged, insecure and uncertain about their abilities to identify valuable solutions. Furthermore, as AM does not always offer quick and direct benefits for operators, they may lack an incentive to get involved in the workflow. In order to engage operators in AM, it may be strategic to engage the operators who already have a motivation to start with. It has also been mentioned that acceptance may grow once the technology becomes more mainstream, implying that others will follow in time. In order to ensure accessibility for operators, the barrier must be low, and a safe place for the submission of problems as well as exploration of the technology must be provided.

Conclusion

It may be concluded that operators have a high potential in becoming part of the AM workflow. However, several factors influence the degree to which they may become involved. Some factors are limiting, and may not be overcome, such as information access restrictions or lack of interest. However, a large part of the target audience may be involved, at least in the first stages of identifying problems for AM.

CHAPTER

04

SYNTHESIS
| DESIGN SCOPE

In this chapter, further research insights are gathered with the aim to specify the design direction. The chapter starts with a discussion of research insights that were gathered during interviews with Ultimaker employees regarding the scope and strategy of the project. Conclusions are drawn and the design requirements and vision is described.

Figure 4.1.1: An application to assemble car logo's at Ford (Ultimaker)

/ 4.1 Approach

A second round of interviews was conducted with internal stakeholders from Ultimaker with the aim to make a strategic decision regarding the solution scope of the project. Semi-structured interviews were held with a total of 8 Ultimaker employees from different departments including business development, portfolio management and application engineering. See figure 4.1.2 for further information on the stakeholders interviewed and their role in the company. The stakeholders were chosen due to their interest in the project from various perspectives. Portfolio management is expert in product strategy, business development is in charge of customer relations and the application engineers visit customers, provide trainings and thus closely work together with the end users. First, insights will be discussed. Then, conclusions are drawn in regard to a final design direction. These insights specify and finalize the list of design requirements.

Research question:
What is the preferred product strategy in regard to application identification from Ultimaker's point of view?

Sub questions:

What is the key problem that we are trying to solve?

Who is the end user of this product?

To what degree must the solution be scalable?

What is the company's vision towards the future of application identification?

See appendix C for a summary of the interviews.

Interview #	Participant #	Company	Role
1	P17	Ultimaker	Portfolio manager
2	P26, P29	Ultimaker	Product owners - software
3	P5, P6, P7	Ultimaker	Application Engineers
4	P19, P20	Ultimaker	Product strategy
5	P18	Ultimaker	Business development manager

Figure 4.1.2: Overview of participants interviewed during the synthesis

/ 4.2 Results

The research questions have led to interesting insights regarding the strategy of a potential product. The following key insights were gathered.

What is the key problem?

Throughout the research, it has become apparent that there two problems at hand rather than one. Firstly, operators are not able to identify parts and problems for AM yet. "It is important to note that the problem is not that there are too many ideas identified by operators. The problem is that operators are not able to identify valuable parts and/or problems that may benefit from AM" (Interview 1). Secondly, there is a need for support in the workflow once a potential part or problem is identified by an operator. "It would make sense that we need to think about the flow after a part or problem is identified" (interview 1). In order to design a suitable solution that will increase the engagement of operators in the identification workflow, both problems must be solved.

To effectively identify parts or problems suitable for AM, one must understand the technology on at least a basic level. As for Ultimaker's role, "it is extremely important that Ultimaker takes responsibility in educating its users" (interview 1). As became apparent throughout the literature study, successful implementation of technologies in the industry 4.0 requires extensive education, among other factors (Veile et al., 2019). Ultimaker is currently investing various efforts in educating manufacturing customers through trainings and the developments of e-learning modules. "educating users through software is not an option, trainings are key in this aspect" (interview 1). Literature states that learning about new technologies in the industry 4.0 requires trainings in the form of e-learning, workshops and/or "learning by doing" approaches (Veile et al., 2019).

AM is increasingly becoming part of technical educational curricula, implying an increase of skills and knowledge regarding technologies such as AM among future employees. Therefore, it can be assumed that the general knowledge of AM will only continue to increase among all technical employees. As the goal at this moment is to enable operators to identify parts and problems for AM, educational efforts do not have to encompass CAD and CAM training. The contextual research showed that those with a personal interest in AM are able to develop skills with available information.

Who is the user?

Information is available for these companies, yet "it is up to them to decide the extent of training they want to provide for their employees" (interview 2) and "it is up to Ultimaker to inspire and give them the right tools" (interview 3). Operators may be a difficult target audience, as they are unlikely to follow the trainings and are generally better at learning by doing. "Customers are still busy trying to enable the champions and are not thinking of enabling operators yet to the same extent" (interview 2). These factors make for a difficult scenario, additionally because businesses are dissimilar in their progress in regard to AM.

It is also important to note that not every operator wants to become part of the AM workflow. “We must enable the ones that are motivated and empower them” and “quality is much more important than quantity” (interview 3) are statements that indicate the need to direct the focus towards the operators that have high potential to learn. This implies that it is most feasible and effective to target a solution towards operators that are willing to learn about AM, the “Sarah” persona, (see figure 3.3.5 on page 66).

Scalability

Preferably, the solution “should target any production facility in the world” (interview 5). However, culture may have a large influence on the way users should be addresses in different countries. Additionally, in some countries, labor is much cheaper and involving more people in the workflow of AM may not be a goal at this time. For the scope of this project, it is key to keep the desired level of scalability in mind yet leave cultural influences out and focus on western societies with similar mindsets as was observed in the contextual research.

Trends and visions

Firstly, “due to AM’s infancy, Ultimaker has a leading role in defining the way our customers should use our products” (interview 1). This implies that we can advise our clients accordingly and shape the way users interact with our technology and products.

Looking at the future of application identification, “AI (artificial intelligence) will play a significant role” (interview 5). This is a widely recognized trend and is already applied to CAD files by various software producers. However, we are not there yet. “When it comes to assessing parts for AM suitability, automation is extremely difficult” (interview 1). Businesses are not measuring data on the impact of applications much further than the cost and lead time reductions. However, thanks to AI, it might be easier in the future to assess parts without a CAD file based on other criteria. In order to reach this future vision, collecting data becomes increasingly relevant. “We must find ways to collect as much data as we can, in order to create better business cases for potential new customers” (interview 3).

Another relevant trend that came forward in both literature and throughout interviews is the term of “bottom up innovation”. Bottom up innovation stands at the core of this project, as the goal is to enable more users to add value to the overall use of the technology within a company. “Bottom up innovation fits with the Ultimaker brand” (interview 4). This trend is highly dependent on the customer, yet trough appropriate design of Ultimaker’s products we can assure the opportunity for this trend to develop in regard to AM.

Conclusions

The transformation towards industry 4.0 is a continuous evolutionary process that involves the integration of people, machines and processes into a single information network. With a future vision in mind, we must take the incremental steps that are required to accelerate the adoption of a technological mindset among our users. Ultimaker carries a certain responsibility in providing the right information and tools for users to adopt at their preferred pace. Findings emphasize the need for further education as an essential enabler for the identification of new applications. This implies that, in order for operators to start identifying new parts, they must acquire a certain amount of knowledge on AM. On the other hand, we may assume that, as knowledge grows, future operators will increasingly be able to understand and apply this new technology. Thus, a second need arises to support their AM activities in an appropriate manner.

/ 4.3 Design Challenge

As a result from the interviews, the following refinement of the original design brief was formulated.

Design Direction

AM lends itself particularly well for a hands-on, learning-by-doing approach, which appears to meet the learning needs of this target audience quite well. As the application of AM technology is gradually growing among manufacturing employees, we must support their learning efforts as well as their workflow in a suitable manner. Thus, the design challenge is aimed at accelerating the involvement of production line operators in the AM workflow, particularly in the first steps of identifying new applications.

Digital Factory

Ultimaker is currently directing efforts in the development of the Digital factory, a file sharing platform which would allow users to store data about parts and share this within the business. This project is aimed at designing an entry point for novice users in the production line rather than in the 3D lab.

Therefore, the design challenge is formulated as follows:

“Design a digital, collaborative platform that facilitates active involvement of production line operators in the identification of new applications for the AM workflow”

/ 4.4 Design Requirements

Below, the design requirements are described. These requirements are based on the research insights from literature and contextual research and were verified and discussed with Ultimaker stakeholders throughout the described interviews.

Accessibility

Primarily, the design solution must be accessible for operators. Operators, as described in the persona's, must be able to use the product/service with their level of expertise regarding AM and technology in general.

Educational

The target audience consists of operators with a very basic understanding of AM and its possible applications. Therefore, the product must provide the opportunity to further learn about the technology in a manner that suits this target audience's needs and wishes.

Traceability

Operators must be able to trace the process of their idea throughout the development. Editing and adding information must be possible.

Availability/ time consciousness

Many operators do not have a lot of time and patience for AM as it is not their core task. Therefore, the solution must be suitable for operators with little time.

Incentive/ personal

The design solution must communicate the benefits of AM beyond its financial scope in order to speak to the objectives of operators, such as functionality and safety. In addition to this, an operator must receive credits and remain a stakeholder in the process.

Safety

The designed solution must provide an emotionally safe space for operators to discuss problems and ideas. This implies that operators should feel comfortable to submit ideas and feel free of judgement.

Valuable

The solution should add value to the users and the business in such a way that Ultimaker can sell it as a product and/or service. The solution must add value to the KPI's of a business.

Technical feasibility

As for the technology implemented in this solution, it must be feasible to develop and implement with current or near future technologies.

Measurability

Data used as input should be documented for later reference and with a vision to eventually automate the process of identifying parts.

Digital

Looking at the product portfolio that Ultimaker is offering, it is most logical to extend current sofware to part identification. This is also a requirement as documentation is important due to the size and location of Ultimaker's client's

“Design a digital, collaborative platform that facilitates active involvement of production line operators in the identification of new applications for the AM workflow”

facilities.

Scalable
The solution must be usable in all multinational production facilities worldwide. For the purpose of this project, cultural differences may be left out of consideration.

Aligned with Ultimaker’s brand
The design solution must have the look and feel of Ultimaker’s digital and/or physical products.

Wishes (optional):

Customizable
As companies operate in different industries, have various processes and the technical skills of their employees may differ, the solution may require some level of customizability to both the industry as well as the type of information that is being transferred and/or documented.

Incentive driven
The design solution may involve some form of competition among operators to enhance their participation.

Automated scoring
The assessment of parts may have some form of automatic scoring based on information input.

Connectivity
As the digital warehouse, a filesharing system, is currently being developed, the design solution could be an extension or element that integrates into this system.

/ 4.5 Design Vision & Strategy

Currently, the identification of new applications is done by a select group of people and the process highly relies on their experience. There is no predetermined system for the use of AM within manufacturing environments, resulting in various missed opportunities and an intangible process for operators. AM is frequently seen as complex and below quality standards of conventional manufacturing by this target audience. Furthermore, the use of AM revolves around saving costs, which may not be an objective of most operators. However, for operators, there are significant benefits that could provide an incentive to participate in the workflow. AM allows for improving their own working conditions through enhanced safety, comfort and efficiency in their work, factors that could potentially motivate operators to participate.

In an ideal scenario, operators will be able to understand the technology, identify parts and problem for AM, request parts from a digital warehouse and potentially even design and print themselves. The identification of parts will become highly automated, involving scanning technologies or potentially AI (artificial intelligence) driven suitability assessment systems. It will be possible to run through spare parts databases to filter suitable parts and significantly decrease costs through the integration of Ultimaker's technology in existing ERP systems.

In order to take steps towards this scenario, it is Ultimaker's responsibility to create products and services that accelerate growth and acceptance of the technology among all factory employees. Therefore, AM must become more accessible, fun to use, and collaborative. It should be perceived as a valuable extension of current tools that help improve working conditions. It should feel safe to submit ideas and explore the possibilities and limitations of the technology in a low-barrier environment. For operators, the experience should revolve around their needs, not their manager's needs. The technology inspires to explore and think beyond the scope of conventional methods.

A collaborative process would allow operators to learn beyond the identification and use of AM parts and gives room for learning about other steps in the workflow. This way, becoming involved in AM is another opportunity for operators to grow within the company.

CHAPTER

05

DEVELOPMENT

| Design

Chapter 5 describes the iterative design process that brought the initial idea of a digital platform to a working prototype. This chapter starts with an explanation of the method and continues to briefly summarize the key elements of each of the design cycles. The chapter continues with a final concept presentation and an overview of other potential solutions.

Figure 5.1.0: A production line bottleneck at Heineken (Ultimaker)

/ 5.1 Approach

After getting an understanding of the context, the users and the needs from Ultimaker's perspective, the time had arrived to start generating ideas for potential solutions. The design phase of this project is divided into three cycles: Ideation (cycle 1), conceptualization (cycle 2), and detailing (cycle 3).Each cycle had its own goal, activities and outcome. A design challenge and list of requirements, which can be found in chapter four, was used at the start of the first cycle, which was aimed at the generation of various ideas for a potential digital tool. The result of the first cycle, a list of envisioned tools, was used to generate concepts, created and described in cycle 2. At the end of cycle 2, a decision was made for a final direction which is detailed in cycle 3 (paragraph 5.4). Each cycle had various ideation sessions involving different stakeholders, all held digitally due to COVID-19. For an overview of all stakeholders involved, see figure 5.1.1. The next sections will explain the goal, participants and outcome of each cycle in further detail.

Cycle	Session #	Participants #	Activities
1	1	P30, P31 (friends/family)	Brainstorm about the workflow and potential touchpoints
2	2	P19, P20 (PM team)	Ideation
2	3	P19, P20, P21 (PM team)	Evaluation of concepts
3	4	P25, P7, P6, P9 (Application Engineering)	Detailing content
3	5	P23, P24 (UX team)	Detailing flow

Figure 5.1.1: Overview of participants involved during the design process

/ 5.2 Cycle 1: Ideation

Goal

The first goal of the first cycle was to define the touchpoints of a potential system that supports operators. These touchpoints are based on the current workflow of operators. The second goal of this cycle was to ideate about solution directions for a potential system.

Research questions

1. What does the identification workflow currently look like?
2. Who is involved in the process and what are their touchpoints?
3. At what moments are operators involved?
4. What tools are currently used for the identification of parts?
5. What potential tools could we envision to facilitate operator's involvement?

Setup

First of all, a large amount of information was retrieved from interviews with colleagues during the synthesis (chapter 2). Ideas were gathered on potential support systems, which were used to define potential solutions in the first design cycle. At the start of this cycle, a brainstorm session was held with a family member and a friend. Due to COVID-19 limitations, it was not possible to reach the target audience. However, involving outsiders allowed fro a new perspective on the topic. After the workflow was defined, the session continued with a brainstorm to define potential touchpoints and challenges for a design solution.

Execution

During the session, an introduction was provided on the goal and setup of the session. Four key starting points were provided: an explanation of the problem at hand, the stakeholders and their needs and challenges, examples of existing platforms for inspirational purposes and the design requirements as formulated in the previous chapter which were based on insights from the research and synthesis.

During this session, a group discussion was held regarding the most common workflow that the system must support. Each participant documented ideas on post-it notes, which were placed on the touchpoint in the workflow.

Results

The results from the sessions are vizualized in figure 5.2.1. This figure contains the workflow with the most common touchpoints when an operator is involved in the AM workflow, based on the workflow as visualized in appendix G. For each touchpoint, opportunities and challenges have been identified. From this overview, various opportunities were identified as envisioned tools, as explained in figure 5.2.2.

Current Tools:
Trainings, workshops, e-learning, online forums

1 Operator Identifies Application

An operator is triggered to think of a new idea for a 3D printed part. He might be triggered by seeing an existing application, learning from colleagues or trainings or because he runs into a problem during his daily work.

Challenges
Operators do not have a set moment/ trigger to think of AM. Operators don't know whether their part is suitable for AM, lack the time and an incentive to think about the possibilities.

Opportunities
Provide triggers and/or incentives, make AM visible, weekly updates, personal contact between champions and operators, specific weekly challenges.

2 Operator Suggests Idea

It is common that once an operator identifies a potential part for 3D printing, he or she directly contacts the champion who is the designated person to design and print parts. Operators may come to him with simply a problem or migh already have a solution in mind. A discussion takes place in which the problem and the possible requirements for a 3D printed part are discussed. Within some businesses, this happens in a group discussion.

Challenges
Missing information, assessing the business case and complexity in advance.Uncertain which solutions ae already existing and what the most suitable solution is.

Opportunities
Suitability check for operators, allow collaborative documentation, search for existing solutions.

Current Tools:
E-mail, Pictures, KANBAN boards, Standup

Current Tools:
ID Card, Drive, Ultimaker Support, E-learning and online forums, Excel

3 Part development

If the part has potential, a champion starts the development process. Throughout this process, he migth want to update the operator and potentially request further information about the requirements of a part. This iterative process involves the champion, operator and potentially other stakeholders such as procurement.

Challenges
Getting the right information from everyone, taking the time to test and iterate, operators must remain owner/ stakeholder in the process to accept the solution.

Opportunities
Provide updates/ clarify the ownership, involve other AM experts for their input.

4 Testing, Reviewing, Sharing

Once a part has been developed, an operator will test the part and provide the champion with feedback on its functioning. This information provides input for further iterations. Reviewing parts over time is relevant to complete the business case and establish the exact impact of AM.

Challenges
Impact depends on too many factors to specifically document. Forgetfulness, time, unclear who has to take ownership.

Opportunities
Set review moments, automatic documentation of data, reporting, publish/share with others

Current Tools:
ID Card, Drive, E-mail

Figure 5.2.1: An illustration of findings of the first design cycle: a common workflow including the challenges and opportunities

Envisioned Tools

Through the brainstorm session and synthesis, various opportunity areas to support operators have been identified. These are explained below. Quotes from the session and synthesis are included to indicate the origination of each idea (see figure 5.2.2).

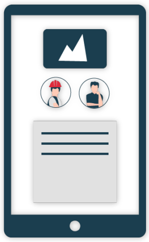
"I'd start by searching online for information"(P30)

Forum/ feed

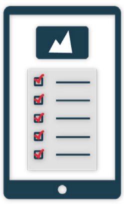
A forum-like platform could support "crowdsourcing" activities within a company regarding new ideas. This would also take the load off champions and allow 3D printing knowledge to organically grow within a business.

Shared documentation software

In order to support the collaboration between the different stakeholders, a shared documentation tool such as google drive, miro and others could offer significant benefits. This targets the challenge of involving various stakeholders and the need for an iterative process.



"Open documentation with user access levels could support involvement in the further workflow" (P31)



"You want to start gathering data for a future in which everything is automated" (Analysis, P7)

Suitability Check

In order to prevent operators from suggesting ideas that are unsuitable for AM, we could provide them with a suitability check. This would filter out key limitations of 3D printing technology while teaching operators about AM.

Workplace Walkthrough Support

As an educational tool, operators could follow a set of questions which would guide them to find new applications in their workspace. This set of questions could be presented as a tool or game which could be done together with an AM expert.

"You could support champions in getting the right information out of operators"(Synthesis, Int 2, P26)

Figure 5.2.2: illustrations of the envisioned tools

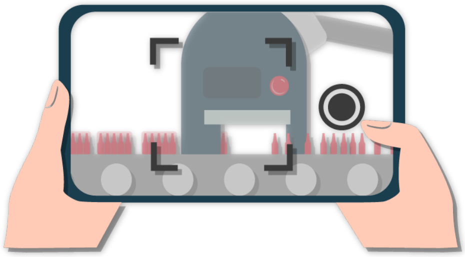
" In zaltbommel they like to work with KanBan boards. Heineken also uses it" (Observations, P31, Analysis, interview 8)

KanBan/ project management tools

Kanban boards are simplified project management tools which visualize the status of a project. These boards may be used as a talking point for group meetings, and anyone with access may reply or comment on an idea submission.

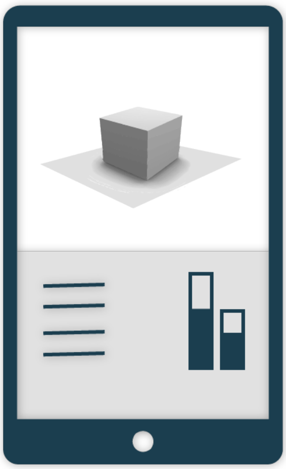
Gamification

Gamifying the identification of new applications could potentially trigger operators to seek for new opportunities. This idea is based on the lack of incentive for operators to get involved in the AM workflow. Gamification could be a way to grab the attention of this target audience. A potential form of gamification would be to apply the use of a "mission" to discover as many faults or points of improvement in their production environment.



"Gamification might be a way to attract new users" (P21)

"Operators may need some kind of incentive (Analysis, interview 5).



3D Scanner & suitability assesment

3D scanning technology is rapidly evolving and allows users to create a direct digital file of an object. A combination of a 3D scanner with a direct suitability assessment as presented in Yang's paper would allow users to directly verify the potential value and suitability of a part for AM. This would prevent users to submit ideas that are not suitable.

"We must think of the future and how to get there step by step" (Analysis, interview 6)

Figure 5.2.2: illustrations of the envisioned tools (continued)

/ Cycle 1: Conclusions

The list of design opportunities (figure 5.2.2) is a result of the brainstorm sessions. These potential solutions formed a solid foundation for the next design cycle, in which three concepts are developed and presented.

Decisions

The sessions clarified that some elements of the system are crucial and thus hereby decided upon. Operators must be able to

- Enter ideas
- Communicate them with champions
- Further keep track of developments

The decision was therefore made to consider these functionalities as essential for the final concept. However, as was concluded from the session, the way operators are triggered and how they submit their ideas into the system are still open for ideation. Therefore, the next cycle, cycle 2, is aimed at brainstorming ideas for potential ways to engage/attract the operator.

/ 5.3 Cycle 2: Conceptualization

Goal
The goal of the second cycle was to conceptualize the first design ideas into various concepts and choose one final concept.

Setup
Firstly, an individual search was done by taking the topics defined in the previous cycle and looking into existing solutions for such systems. Secondly, an online brainstorm session was organized with two portfolio management colleagues from Ultimaker to discuss potential solutions based on the provided inspiration. Next, three concept ideas were generated individually. These were then evaluated in a session with the same colleagues, after which a final concept direction was chosen, based on research insights and the design requirements.

Execution
The individual search was done online, searching for existing software that directly targets the defined needs and also searching for inspiration from other sources.

The brainstorm session was done online using Miro as a tool. The examples from the inspirational search (see figure 5.3.1) were provided and a brainstorm was held to ideate on potential directions.

After this session, individual work was done in conceptualizing three core ideas. The evaluation was done again online with the same colleagues using Miro.

Results
The results of this session were an overview of competitor solutions as a source of inspiration (see figure 5.3.1), three concepts (page 99, 101 and 103) and a final concept (page 105) direction, based on the evaluation.

How to Questions
How might we create a structured shared documentation system?

How to prevent operators from being exposed to parts of the workflow that are not of their interest?

How to provide a quick and easy suitability check?

How to gamify the identification of new applications?

How to support a walkthrough to identify problems/parts in operator’s workspace?

How to ensure users to stay on an activity feed platform when there is not too much traffic?

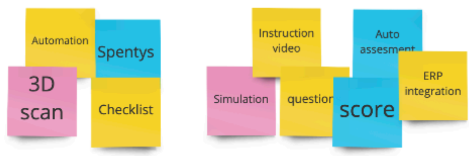
Opportunity	**Competitors**	**Strengths**	**Weaknesses**
Shared Documentation	Google Docs Miro	User access hierarchy Customization Instant accessible, live updates	Too open, not structured as every project is different.
Kanban Board/ project management	Asana Jira Monday.com	Supports the iterative process Visible to anyone Involves various stakeholders	Involves many parts of the workflow that may not be of interest to an operator
Suitability Check	Materialise 3YourMind	Quick and easy (materialize) Accessible for operators Feedback on the suitability of an idea	Not very educational Combined Suitability check with documentation
Gamification	Fitbit Mambo	Scores, personal dashboard Tracking others Seeing progress Setting goals	AM is not a daily thing, users may not be involved enough.
Process walkthrough	No set competitors, onboarding flow Instructional videos	Personalized, inspirational	One-time thing, users may forget afterwards.
Forum/Feed	Instagram Facebook Thingiverse Youmagine	Take ownership, Takes load of champions Crowdsourcing, easy gathering of information /ideas	There might not be enough traffic Liking/sharing may not be a relevant thing for this target audience

How to:

Create a structured shared documentation?

Prevent information overload to operators?

Provide a quick and easy suitability check?



Gamify the identification of new parts?

Support a walkthrough to identify opportunities?

Ensure a relevant activity thread when there is not a lot of traffic?

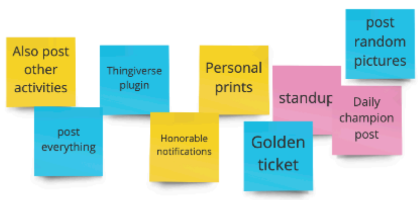


Figure 5.3.1: Results from the online brainstorm session in Miro. the How-to questions were used to brainstorm about functionalities for a potential feature within the design context.

5

Concept 1: Activity platform

Why

Teaching new users about AM is currently done in Ultimaker's trainings by showing examples of applications that can be printed. This is done because it immediately speaks to the imagination of people. It inspires and educates at the same time to see how AM is used in a particular context. Within large manufacturing environments, an activity feed in which users can share their ideas, updates or other information, creates a safe bubble. Examples of such feeds are social media and forums.

Key insights that led to this concept:

1. Learning by doing suits this target group best (analysis, literature/interviews).

2. Users have to take ownership of applications in order to achieve succesful adoption of AM (analysis, interviews)

3. It drives this target group to receive attention for their efforts (analysis, interviews).

How

By creating a digital environment in which operators can view developments, post their own activities around AM and like, comment and download other user's parts. This way, users can take full ownership of their ideas, crowdsource for potential improvements and thus accelerate the involvement of any operator with an interest in learning about AM.

What

The base for this concept is a digital platform, for sharing, liking and viewing other's parts, which is accessible on a mobile aplication.Users can easily upload their ideas, problems or print progress to the feed, to which anyone with an account and access may reply. It offers users a chance to take ownership of their ideas and take pride in sharing their involvement.

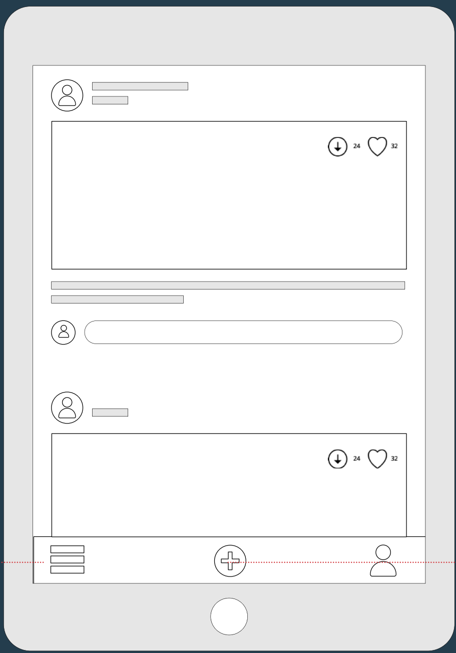
User Perspective

Users, operators, will be able to view others and see how many and what kind of parts they and others are developing. This provides users with inspiration whilst learning about the possibilities.

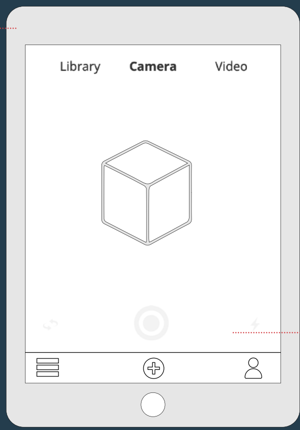
Ultimaker Perspective

Providing clients with an activity thread gives Ultimaker the opportunity to let go of a lot of the support they are currently providing and it makes their clients more self-sufficient.

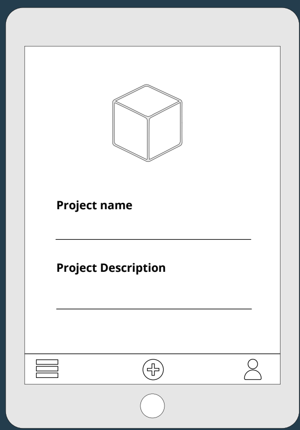
Activity thread



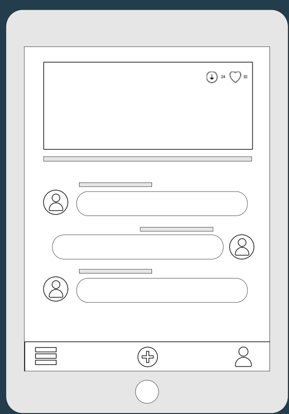
The activity thread contains uploads as seen in social media platforms. These uploads are posted by anyone who has an idea for a printed part or completed a new print. Anyone can view the parts, download/request them and like and comment on people's ideas.



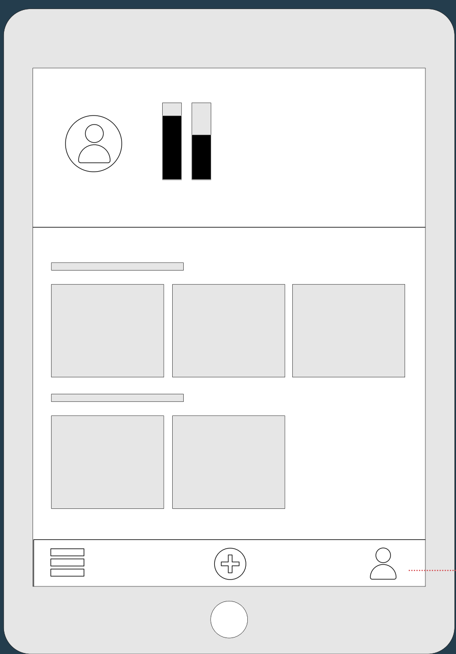
Users can take pictures and videos of the part they want to print, or have printed. This may also be an iteration or an update of your part in action. It is open and up to the user to post they want.



Quick description and post it to the feed or keep it as a private project. A private project will only be between the champion and the operator to ensure a safe environment. Users can invite other stakeholders to the project.



In the part overview, a user can communicate with an expert on the development of the part. Champions may request more information, ask for pictures and more. Users can also decide who has access to the project here.



The personal overview page shows your personal uploads and the statistics around your activity. It shows both personal projects and uploaded/posted projects

Figure 5.3.2: Illustrations of the first concept

Concept 2: Gamification

Why

Gamifying the search for new application provides operators with a reason/incentive to join the workflow. Once users increase their involvement, more potential ideas will be submitted to the workflow that may hold potential to benefit the business.

Key insights that led to this concept:

1. Users lack an incentive to take part in the identification of new applications (analysis, interviews).

2. Users are driven by efficiency and progress (analysis, interviews).

3. It drives this target group to receive attention for their efforts (analysis, interviews, survey).

How

Using game elements within the digital platform, such as rewards, goals and ranking would attract users to start using the platform. Setting targets, such as identifying a set amount of applications per month, clarifies the goal. A personal account with badges and rewards would provide users with a way to show others how “well” they are doing.

What

The gamified application finder is a platform that includes a gamified manner to identify new parts. A guided search allows users to identify new issues. Points are rewarded based on the application category and the benefits the application has for the business. These are decided upon by the champion or the company itself. For example, if a safety application is identified, users receive more points than a support application. User profiles gather the points and reward badges. Users can view others and their status.

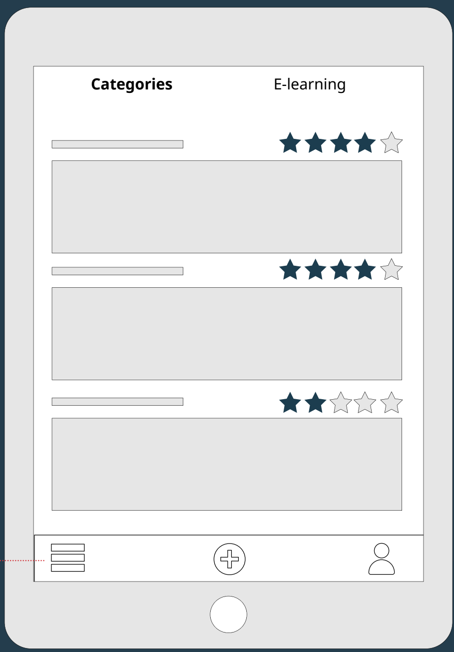
User Perspective

For users, a certain amount of competition is created. Not only do they have a driver to identify more applications, the type and benefit of the application is relevant as well. This way, companies can steer their employees in making targeted improvements.

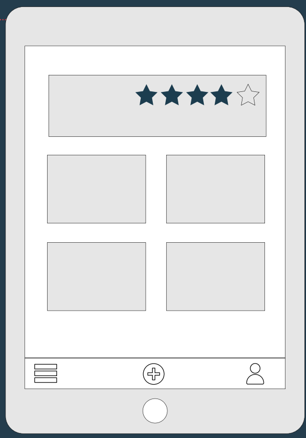
Ultimaker Perspective

This system would allow Ultimaker to keep track of relevant data in regard to the number and type of applications that are being developed by its clients. Furthermore, providing users with a particular motivation would increase self-sufficiency.

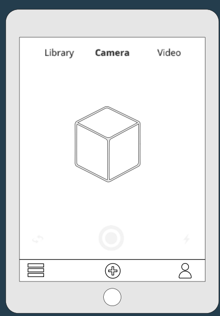
Gamification - finding new applications



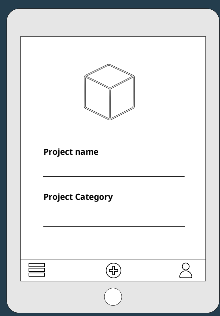
The search for new applications is guided by different topics. Clicking on each topic will guide users to tips & tricks on finding new applications within that topic. Topics may be: safety, ergonomy, efficiency and more.



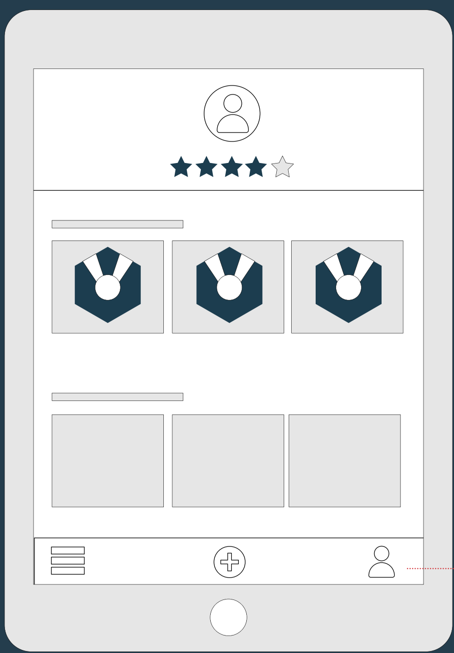
Each topics overview page contains examples of applications within that category and forwards users to identify applications within that category.



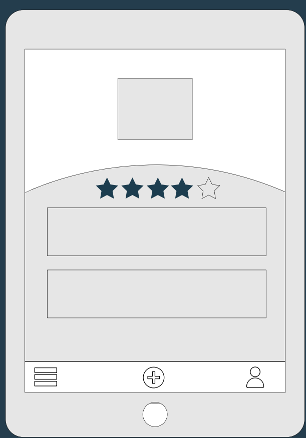
Users can take pictures and videos of the part they want to print.



The entry point for a new category here is very much aimed at the category/topic. This is used to measure the score/impact of a new idea.



The personal overview page shows the badges youÕve earned by identifying new applications. It is based on scores, levels and more. Personal challenges and targets will also be shown here. Users can also gain credits by following e-learning videoÕ



On the project overview page, users can keep track of the growth or development of their application while champions are developing them.

Figure 5.3.3: Illustrations of the second concept

Concept 3: Automatic assesment

Why
Supporting users in immediately identifying whether a part is suitable for AM or not would prevent them to initiate ideas that are not suitable and allows champions to easily select the most interesting solutions.

Key insights that led to this concept:
1. We must start taking steps towards automatic part assessment (synthesis)

2. The assessment of part identification is complex for this target audience (contextual research)

3. 3D scanning and Suitability assessment software is already technically possible (landscape analysis)

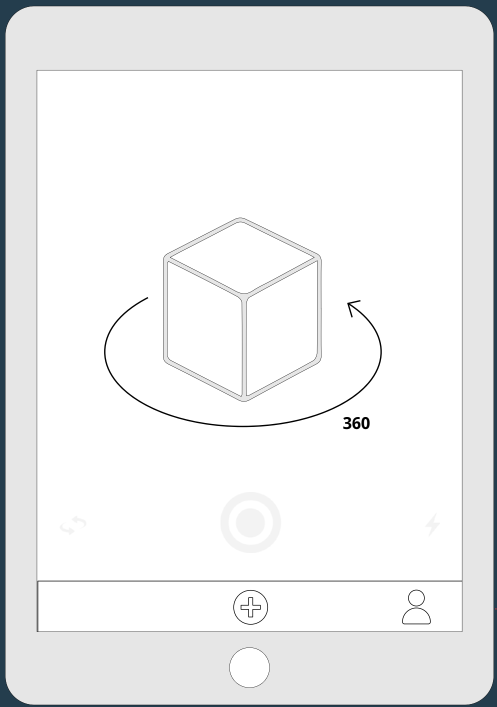
How
Landscape analysis has shown that automatic part suitability assessment is possible with 3D files. Additionally, 3D scanning technology is rapidly evolving. Therefore, it would be technically possible to assess parts for AM suitability with 3D scanning technology.

What
Users can scan objects and directly receive feedback of the suitability of a part for AM. The system may require some more manual input from users in regard to the environment in which the object functions. If the suitability score is promising, they can continue sending their part to the champion.

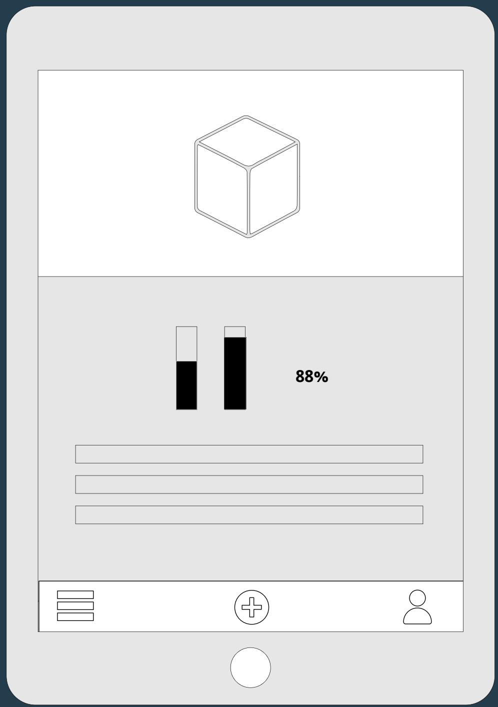
User Perspective
Users with little AM knowledge may have the opportunity to quickly view whether their part is suitable for AM. This highly technical solution could provide them with accurate feedback on why their part is or isn't suitable and is therefore immediately a learning tool.

Ultimaker Perspective
Part of the support that Ultimaker is currently providing would become redundant if technology allows our users to assess the suitability of parts themselves. This is considered as a positive development.

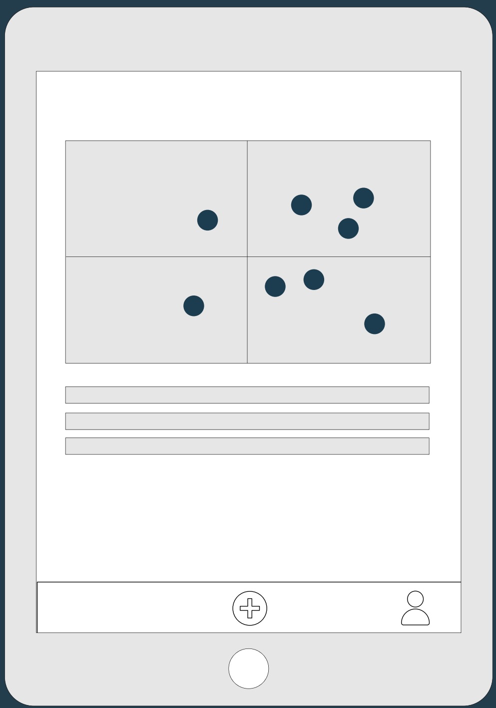
Automatic Part Assessment



Scanning an object would be guided through voice or text on the screen as it would require users to move the camera around an object in a certain manner.



The scanning technology would allow for a 3D model to be assessed on suitability. A machine learning algorithm would improve the system over time as more products are being assessed. Accurate feedback would be provided to the users in regard to their part suitability.



Champions would be able to see all the incoming requests in an overview with the most/least suitable parts for AM.

Figure 5.3.4: Illustrations of the third concept

Concept Evaluation

The three concepts were presented to Ultimaker colleagues. The discussions were recorded, transcribed and conclusions were drawn.

Self-sufficiency

The majority of stakeholders liked the idea of a platform that facilitates self-sufficiency “this would save us time and effort” (P21). As with many 3D print users, forums and social media are commonly used tools. Thus, an internal feed is an interesting feature. This may function as an incentive for users to share, take ownership and feel proud of their work. However, not all users may want to post their ideas in a group. This might be intimidating, as was also concluded from the contextual research. “You'd want to prevent people from posting irrelevant things” (P22). Furthermore, users might not want to wait on others to provide them with feedback on the suitability of their idea for AM. Thus, there must be some restrictions to posting on this feed.

Towards Automatic Assessment

Concept three describes an ideal situation, in which everyone can assess parts and directly find out their printability. However, Ultimaker is not there yet. Thus, we must take steps towards a future situation in which various parts of the identification process can be automated. It is therefore also relevant to think of manners in which we can retrieve more data from users which we can assess on suitability. This would also provide feedback to users, which would give them the possibility to submit or discard their ideas. The human aspect, however, is currently still needed. Also, if an operator has an idea, it means there is a problem. This might not be solved with AM, but then it still needs to be reported and solved.

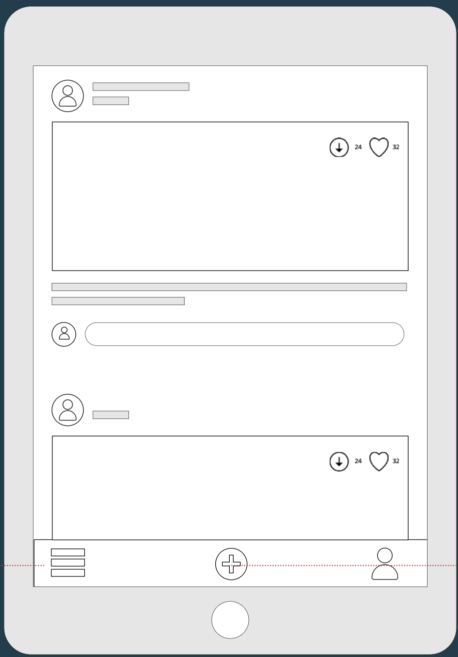
Gamification

Gamifying parts of the process has potential due to its characteristic to attract users. However, the concept as was described might be “too childish” (P21). Badges and rankings may not be familiar to this target audience; however, all participants liked the idea of “keeping track of scores, also for managers to reward them” (P20, P21, P22). Therefore, we might want to still use elements, such as a score and personal achievements, but present them in a more professional manner.

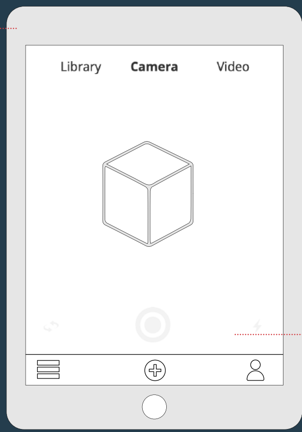
Conclusions

As described, elements from each concept were considered as desirable. However, the most interesting feature according to all participants was the activity feed. Therefore, the decision has been made to continue to the next design cycle with a digital platform as was presented in concept 1, yet the entry form will be further developed to target the need for further (manual) automatic suitability assessment. Additionally, a personal overview page for communication and keeping track of progress will be incorporated into the concept.

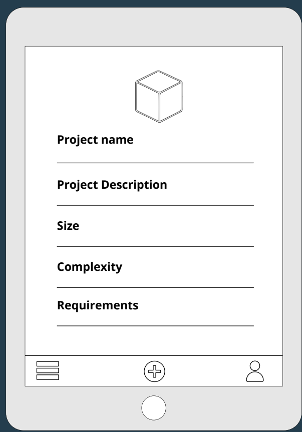
Concept direction



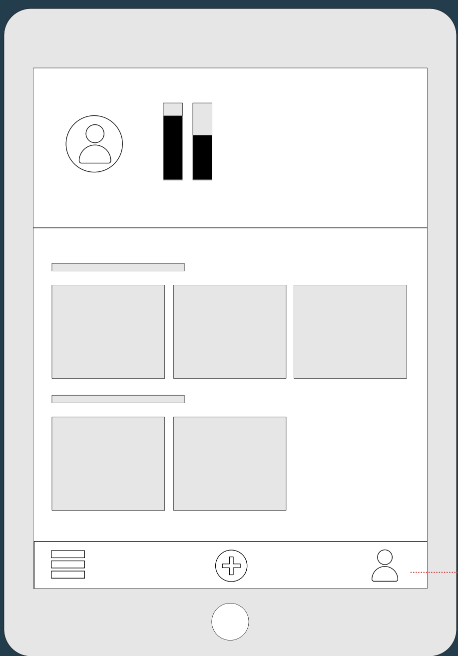
The activity thread contains uploads as seen in social media platforms. These uploads are posted by anyone who has an idea for a printed part or completed a new print. Anyone can view the parts, download/request them and like and comment on people’s ideas.



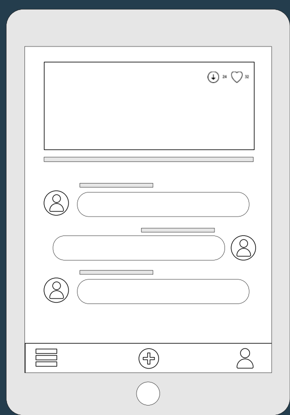
Users can take pictures and videos of the part they want to print, or have printed. This may also be an iteration or an update of your part in action. It is open and up to the user to post they want. Optionally, 3D scanning technology is appicable here.



A more extensive input field will be presented which will be further discussed in the next design cycle. The resulting feedback from the manual entry form should provide users with a clear suitability score.



The personal overview page shows your personal uploads and the statistics around your activity. It shows both personal projects and uploaded/posted projects



In the part overview, a user can communicate with an expert on the development of the part. Champions may request more information, ask for pictures and more. Users can also decide who has access to the project here.

Figure 5.3.5: Illustrations of the combined final concept direction

/ 5.4 Design cycle 3: Detailing

Method

The third design cycle took place in an iterative manner over the course of two weeks and involved various stakeholders from Ultimaker. Iterative implies that small iterations on the final concept direction were made without changing the foundation of its features. The starting point was a high-over concept as described in section 5.3. The end result was a final prototype, ready for validation with users.

Why this method

Iterative design is a collaborative process in which iterations are made on a design direction through rapid prototyping and validation with stakeholders. An iterative design process has been recognized as a suitable method for user interfaces as it is almost impossible to prevent usability issues at the very start (Bury, 1984; Buston and Sniderman, 1980; Gould and Lewis, 1985). As various stakeholders would be involved in the use of this product (engineers, operators, champion, Ultimaker as a company, clients), an iterative design process seemed most suitable as it allows for input from various stakeholders at different moments throughout the process.

Goal

The goal of the third design cycle was to develop the final concept into a test-worthy prototype that matches Ultimaker's needs. As was concluded from the previous design cycle, the final concept is a high over platform that allows for idea submission, has an activity thread supporting self-sufficiency, allows for communication regarding parts, and provides users with an overview or personal dashboard that visualizes their activities. As one of the conclusions from the previous cycle was that the idea submission form is extremely relevant, both for gathering user data and for providing them with feedback, this aspect of the concept required significant detailing.

Setup

The first part of the cycle was aimed at defining user interactions for the system's submission form with the UX team. The second part was aimed at defining the most desirable content of the application request. This last part was aimed at defining the desired level of involvement of operators. Various sessions were held with the design iterations as a foundation for discussion and ideation. See appendix F, cycle 3, to view images of the design iterations.

Execution

Each session was carefully prepared with an introduction to the prototype/concept and the goals of each session. The starting point of the first session was a detailed version of the resulted concept from the previous design cycle (see figure 5.4.1). The concept gradually evolved into slightly different variations throughout the cycles and was turned into a functional prototype after the first week. This first prototype was used as a foundation for the sessions with engineers to discuss the content of the applications as minimally required to effectively develop and communicate application details.

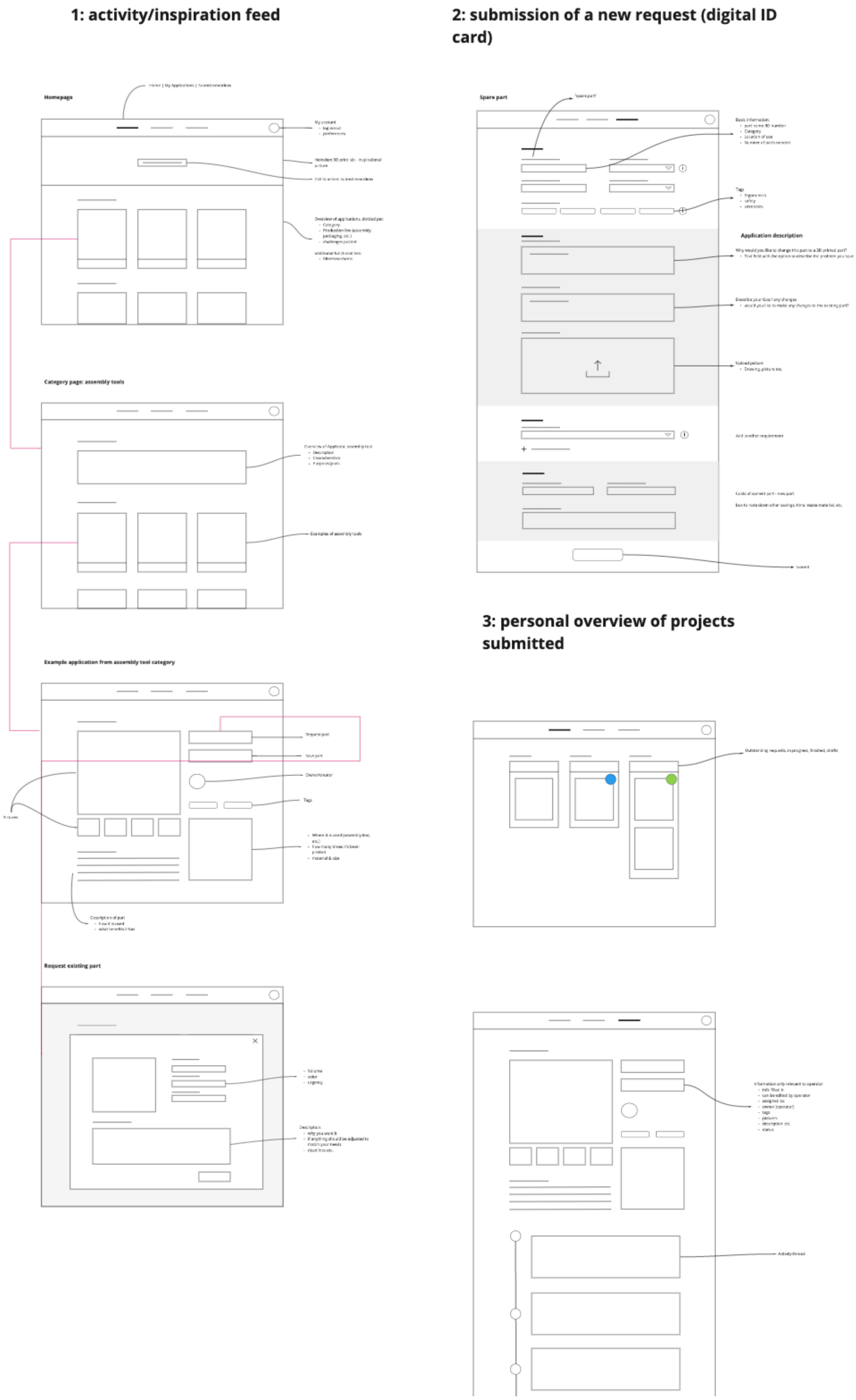
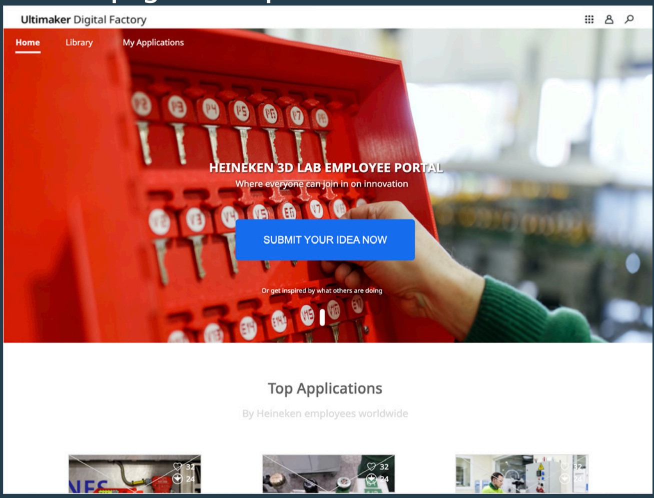
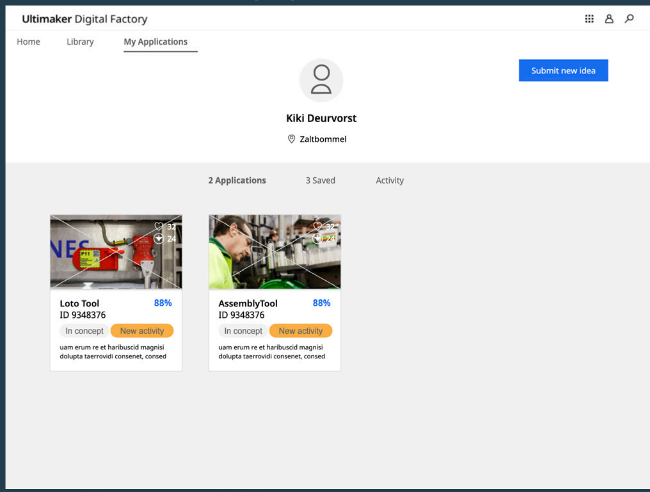


Figure 5.4.1: A visualization of the very first concept as described in the evaluation of design cycle 2. This concept involved three core parts; a library/activity feed, a submission form for new ideas, and an overview page in which users can track the parts they have submitted. See Appendix F for more details on the various design iterations.

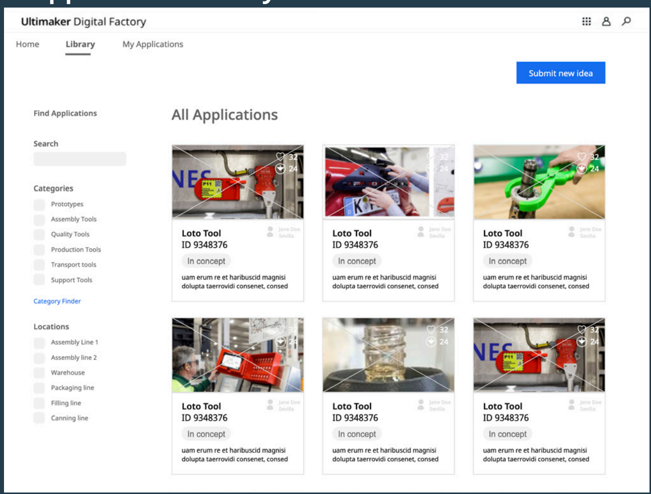
Homepage for inspiration



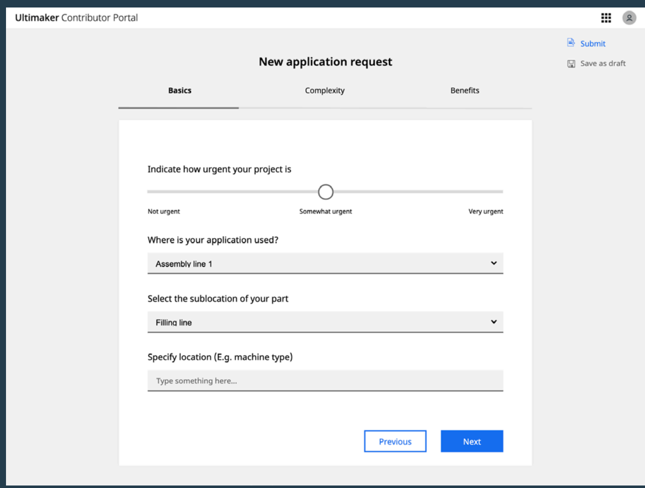
Personal overview page



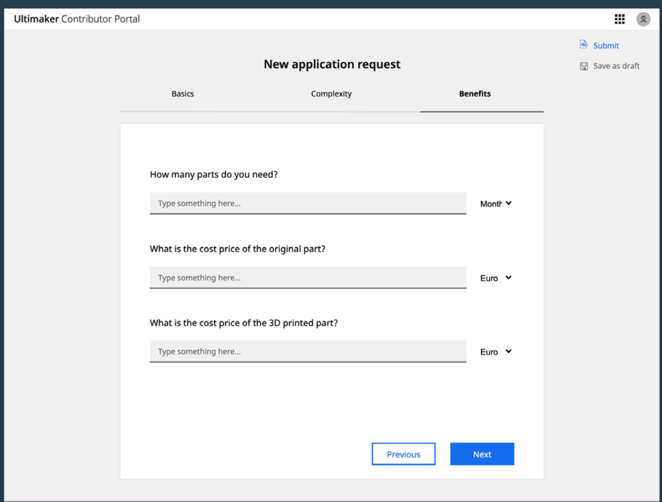
Application Library



New request form



Benefits



Complexity

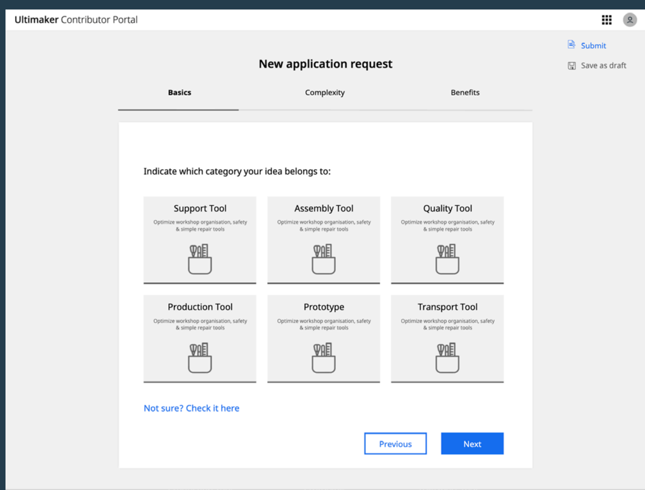


Figure 5.4.2: screenshots of the first prototype

/ Cycle 3: Conclusions

Design iterations

This page shows several screenshots from the first prototype, made in Axure (prototyping software). The concept is made up out of 3 main pages, an overview page with best practices, videos and a link to e-learning. The library allows users to download existing applications, and a personal overview page allows users to keep track of their projects. The "submit new idea" is always readily available and leads users to an entry form. Users are guided through a set of questions about their idea that, according to the ideation sessions with engineers, any user should be able to fill in. Not all fields are mandatory and the information is divided into basic, technical and financial details.

Design Decisions

Various design decisions were made throughout the design cycles. These decisions were based on literature findings, insights from contextual research and the ideation sessions with various Ultimaker employees. Overall, the design requirements as discussion in the synthesis formed the key elements in making the decisions throughout ideation. The next section explains the final concept, its functionalities and how these matches the design challenge and its requirements.

/ 5.5 Final Concept: Digital factory Application Portal

Facilitating the involvement of Production Employees in the AM workflow

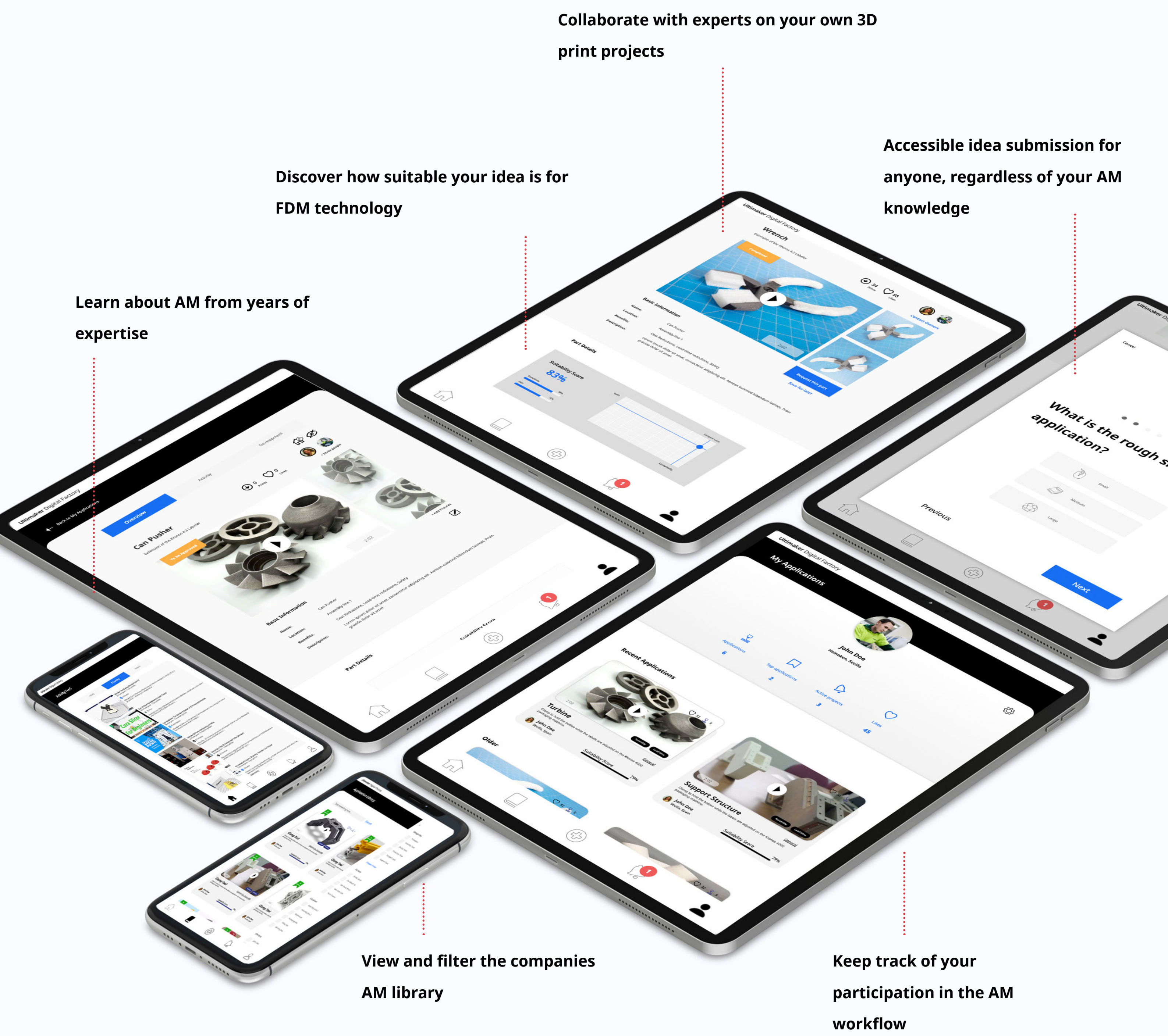


Figure 5.5.1: A representation of the final concept; the application portal

This section further explaines the designed concept as was detailled throughout design cycle 3. Functionalities and UI have been further developed and prototyped. At the end of this section, potential technologies will be described that may be added to this concept in the future.

Introduction

The Application portal is part of the Digital Factory, Ultimaker's answer to the growing need for assistance throughout the very first stages of the 3D printing workflow in manufacturing environments: identifying new applications. The Application portal is a mobile application that functions on mobiles and tablets, devices commonly used in manufacturing environments. The Application Portal is specifically designed for users who are new to 3D printing but have an interest in exploring the technologies' potential to add value to their workflow. Through the portal, production employees can submit ideas for new applications in an easy and straightforward manner. In addition, they can receive feedback on the suitability of their idea for 3D printing and collaborate on the application throughout the rest of the workflow. By creating an overview of all the parts created within the company, users will be learn about the ins and outs of 3D printing and become inspired to take part in the AM workflow.

Part selection

As the use of 3D printing technology is growing among manufacturing businesses, the selection of high-value parts becomes increasingly important. The application portal does not only allow every employee to create new application projects, it provides them with direct feedback on the suitability of their part for AM based on the information they enter into the system. The submissions of all employees will be forwarded to the in-house 3D print lab, where ideas can be compared and the decision can be made whether or not to continue the development of parts.

Collaboration

From the submission onward, a collaborative process is supported through the system between operators, champions and others. An open documentation system allows various stakeholders to collaborate on a single project. The champion and initiator may decide whoever has access to the document. The iterative process of trial and error with 3D printing allows everybody involved to keep track of what is going on. After approval, the project can also be published to the 3D activity feed so that anyone working for the company can view, comment and like your project. Changes made, such as reviewing a part or adding pictures to the documentation, may be published to the activity feed at any moment to support the visibility of AM activity within the company. The system makes use of different user access levels. The level of access for operators may be decided upon by their managers, as every business has individual preferences in regard to information access and knowledge.

A community to feel proud of

As the use of 3D printing technology grows, the activity feed is expected to create a community-like feeling in which every employee can keep track of developments surrounding 3D printing. Best practices, suitability scores and pictures and videos of the parts that are being created will allow for learning by doing and inspire operators to bring their 3D print knowledge to the next level.

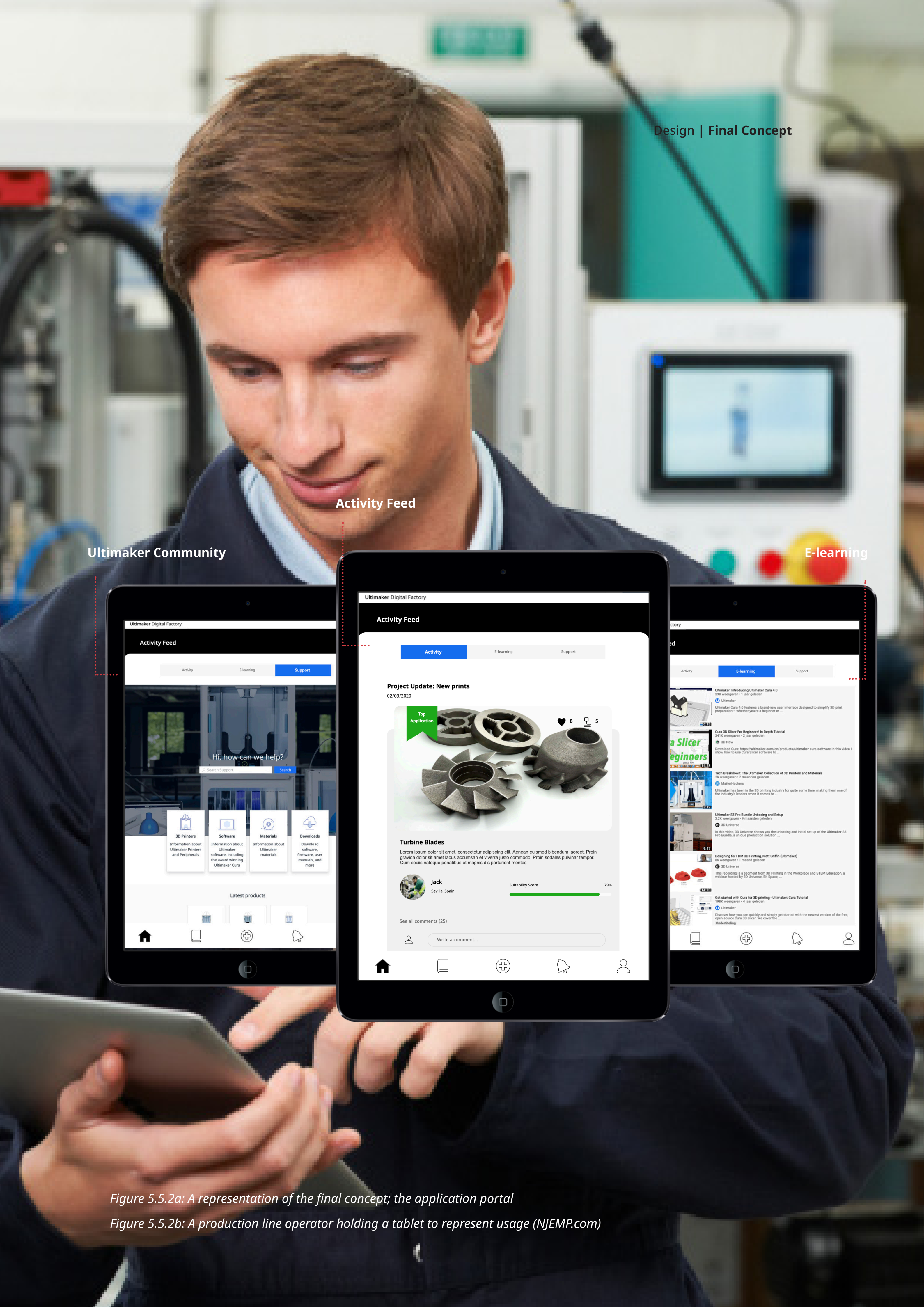


Figure 5.5.2a: A representation of the final concept; the application portal

Figure 5.5.2b: A production line operator holding a tablet to represent usage (NJEMP.com)

Tab 1: The Activity Feed

Introduction

The application is made up out of five main tabs. For the workflow of the application, see appendix G, page 190). The first of the five tabs is the homepage, or activity feed. The homepage is a place to learn about AM within your company. Whenever operators have a moment for themselves or are on the platform to submit new ideas, they will be able to view updates about projects. If they have their own active projects, they will be able to post updates to the activity feed as well.

What

A post may be any update regarding the development of a new or existing application. For example, when a part has been printed or information has been added to the documentation. An operator who receives the part for testing may take pictures and posts this to the feed. It may be an update on the suitability of the part or even a question that users would like to share. The post will contain the operator's name, a picture or video, the type of post, some details about the project and a comment section for others to reply.

In addition to the activity feed, the homepage also provides a link to e-learning content from Ultimaker's community database. This database contains videos and a forum which has grown into an extensive database of information by Ultimaker users over the past years. This function will support users with an interest to expand their knowledge even further.

How

Users can post what and whenever they want from the project overview page, which will be explained in the last section.

Why

Both literature and contextual research showed the need for education in regard to 3D printing. As various interviews have showed, seeing 3D printed parts is the best way to inspire (new) users and educate them about the type of applications that can be made. Making use of bottom-up innovation takes the load off champions and Ultimaker's engineers in offering support. In addition, being able to share progress offers the potential for users to take ownership and feel proud of their efforts, apart from being educational for both the person who posts something as well as the readers. For production environments such as Heineken, with thousands of employees worldwide, this functionality would increase self-sufficiency and create a community of its own.

Design Requirements

- ✓ Safety: giving users the option to post only voluntarily
- ✓ Educational: seeing existing applications (learning by doing)
- ✓ Personal: this allows users to take ownership.

Tab 2: The Internal Library

What

The library is an internal database of applications that have been created over time within the company. This functionality allows users to view everything that has been made and can be requested by operators.

How

Once applications are made public, they will enter the library. Users can filter applications by location, owner, name, and more, depending on the client’s company structure and preferences. For companies such as Heineken, this feature is extremely relevant due to their size and the multiplication of machines on a global level. Users can decide to keep the development of parts private due to confidentiality reasons. Operators may request parts or, depending on user access, download and print the parts themselves.

Why

Throughout ideation, it became clear, if an idea for an application arises, users commonly search for existing applications before developing parts themselves to make sure work is not being done twice. By providing operators with a library, it does not only become easier to request existing tools, it also prevents them from starting new projects that have already been developed.

Design Requirements

- ✓ Accessibility: allowing any employee to request parts
- ✓ Educational: learning by seeing/doing

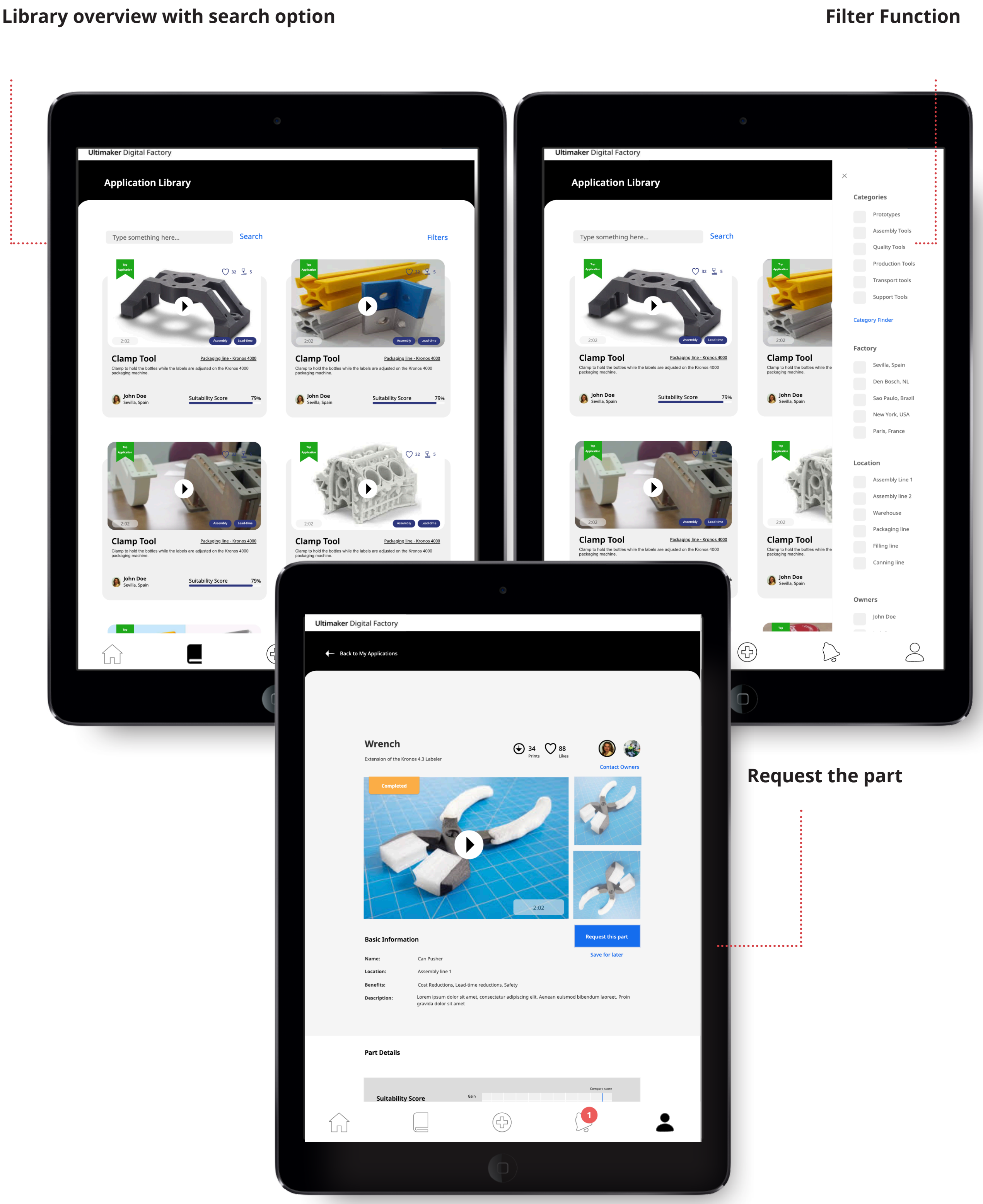


Figure 5.5.3: A representation of the final concept; the application portal

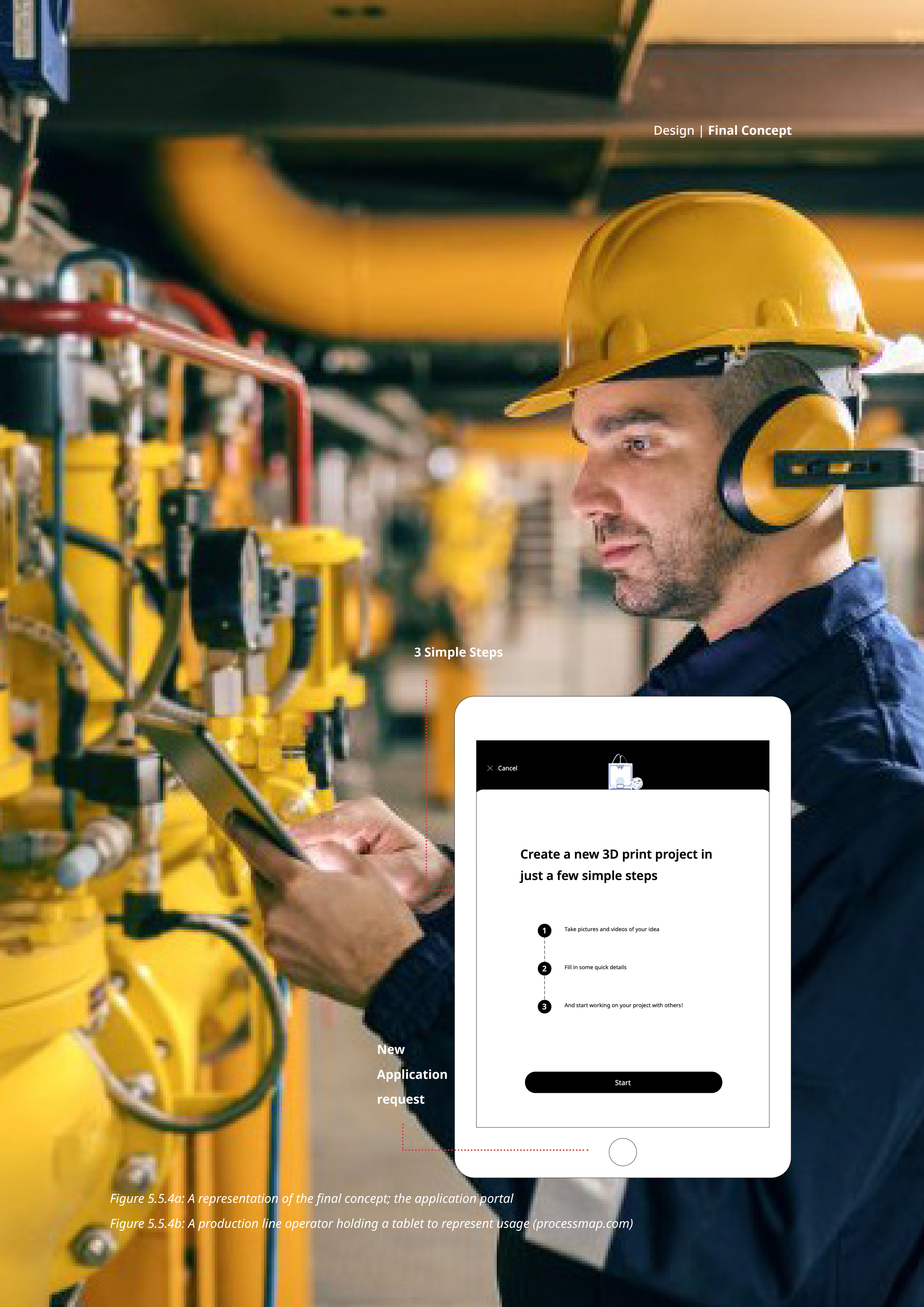


Figure 5.5.4a: A representation of the final concept; the application portal

Figure 5.5.4b: A production line operator holding a tablet to represent usage (processmap.com)

Tab 3: Start a new Application Project

What

One of the critical aspects of the concept is that users must be able to submit their ideas into the system. This functionality allows operators to start a new application project by taking a few simple steps.

How

The middle button on the 5 step navigation menu leads users to the start screen (left). This menu explains that starting a new application idea takes 3 steps. Taking a picture/ video of the part or situation, several basic questions, such as a project name, description, location of the part and key benefits that are expected. Afterwards, the project is created and shared with the 3D lab. Further steps are explained in the last section.

Why

Contextual research showed that users highly differ in their preferred level of involvement as well as their level of knowledge in regard to AM. Various iterations were made in the design process that involved extensive submission forms, surveys and step by step flows that would ask users to enter detailed information about their ideas and immediately provide them with feedback on the suitability of their part. However, after various ideations sessions, the decision was made to make this interaction as quick and easy as possible, as it would create accessibility for all users, one of the key design requirements. This interaction makes the submission of a new idea accessible for any user, after which the freedom is provided to enter as many details as a user wants. There is a high emphasis on making pictures and videos because this “speaks to the imagination of users” (contextual research, interview 2).

Design requirements:

- ✓ Time consciousness; only a few steps
- ✓ Accessibility; information that anyone can enter (name, description, benefits, location)

Take a picture/video | **Project Name** | **Project Description** | **Location** | **Key Benefits**

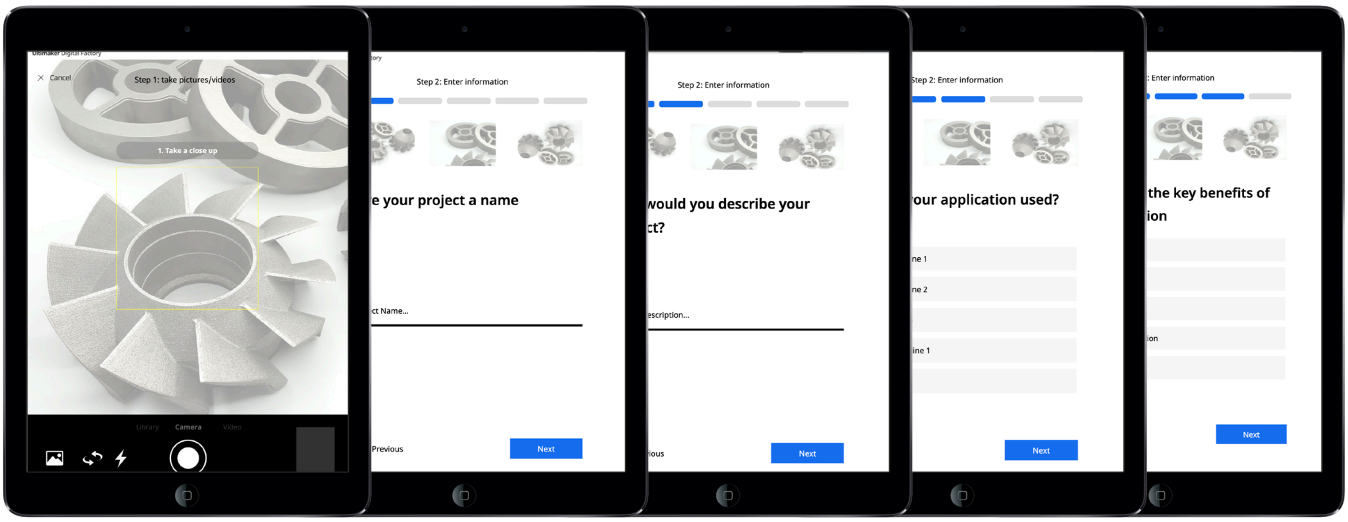


Figure 5.5.5: A representation of the final concept; the application portal

Tab 4: Project Overview Page

Part 1: all parts

Every user has an overview page, containing all project submissions he/she created. This also includes a personal overview of user's statistics, such as the total amount of applications requested, and number of active applications. Champions may choose top applications and reward the initiators with this in a symbolic manner. Companies may take on weekly or monthly votes for the best application or use a threshold of likes as an indicator for success. In the future, further statistics may be used in this overview, such as a more detailed value explanation of the parts created.

Why

This page benefits both operators and their manager with significant benefits. For operators, it is a place to oversee their projects and their statuses, as well as track their involvement in the AM workflow. Tracking operator's involvement is beneficial for their managers if they want to reward their employees for their efforts.

Part 2: project page

The project page is entered when you select an application from the overview page. This is the project page of that specific part and evolves over time as various users collaborate on it. The documentation is structured, and other users may be invited to join the project. Operators will automatically start a combined effort with a champion or someone from the 3D lab to the project once it is launched, who will receive a notification after a project is created. Champions and operators may discuss new requests in person, in a team meeting or privately, depending on their personal preferences.

The project page contains various other functionalities for operators. Apart from having a place to add information about the project, operators can invite others, make the project public or private, post updates to the activity feed and check the part's suitability. On top of the page, two other tabs can be found which lead to the comments from other users on your part, and the activity around your part by you and other invited stakeholders.

Posting to the feed

Users may also use this project page to place updates on the activity feed. As mentioned previously, users are free to post whenever and whatever they want. The system will also ask them to post updates after making changes to the project. A project update post contains a picture, update type and description.

Suitability check

The suitability check, as shown on the next page, is a pop-up window in which users are asked to fill in technical information about their part. This information has been elaboratively discussed in a session with Ultimaker's application engineers, aiming to define critical information which can be used to measure the suitability of a part whilst remaining accessible to uses with little knowledge. Once users go through this flow, a suitability score arises. In the part information below, they may further specify this information. When users decide not to go through the suitability check, the score will be formed based

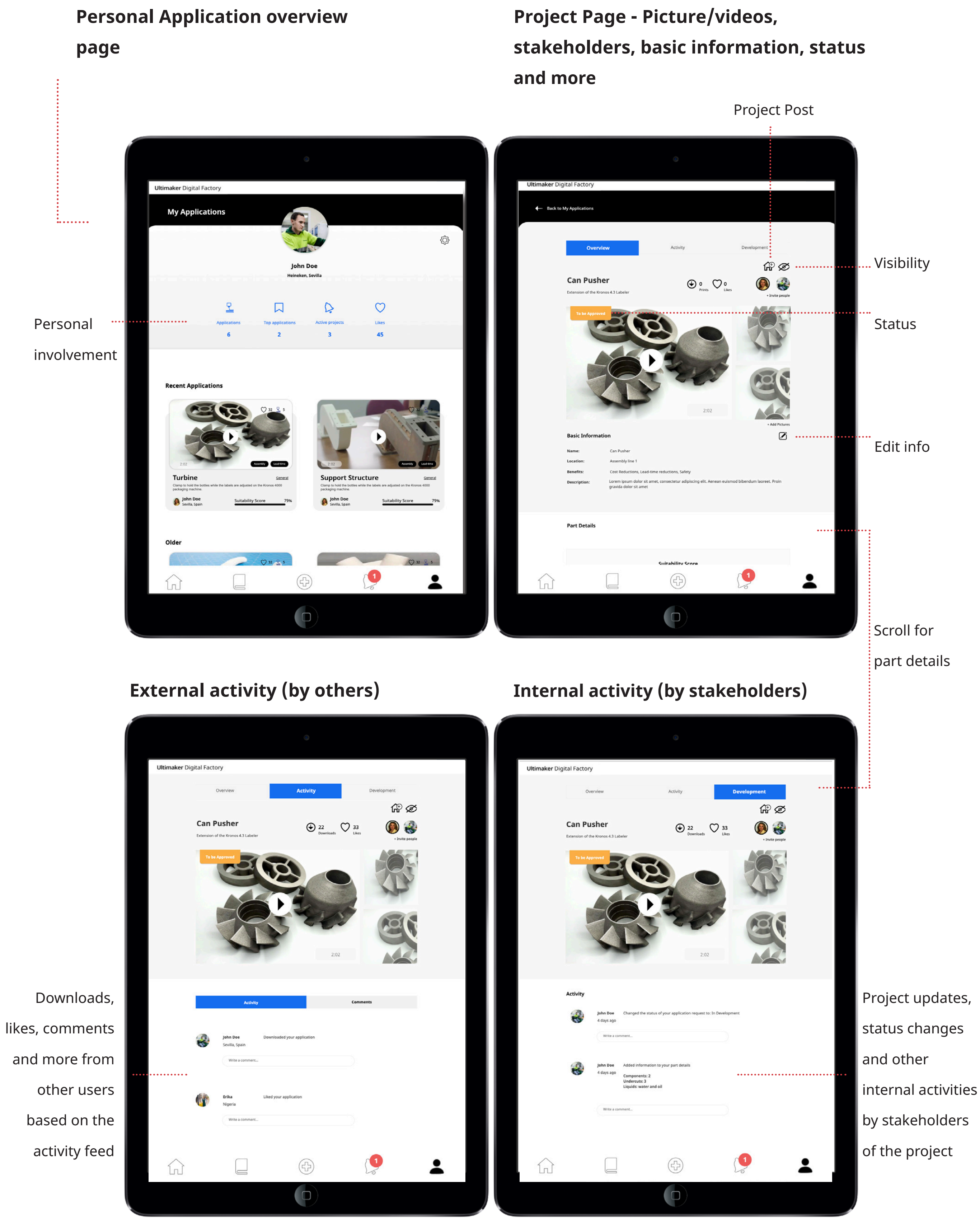
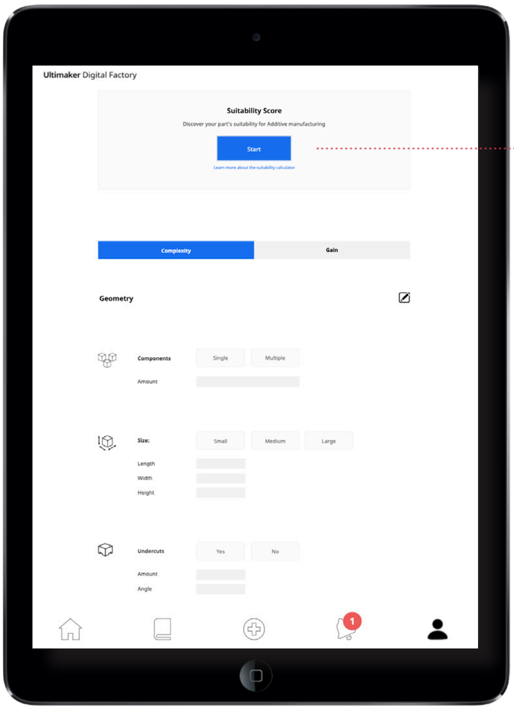
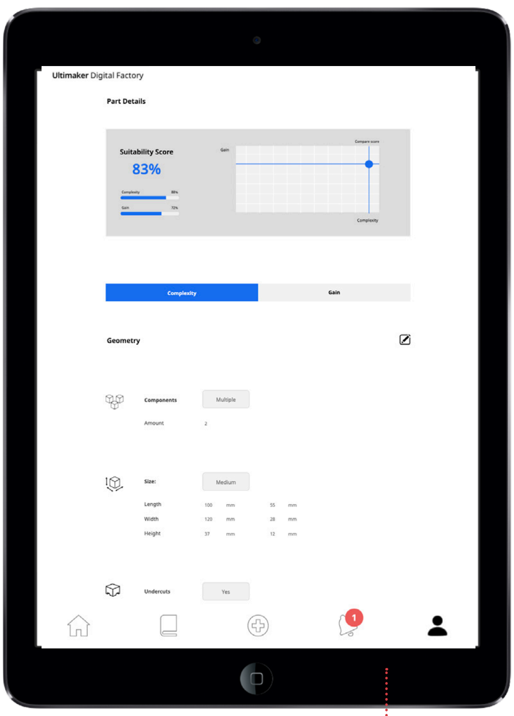


Figure 5.5.6: A representation of the final concept; the application portal

Before documentation



After documentation



Suitability quickstart

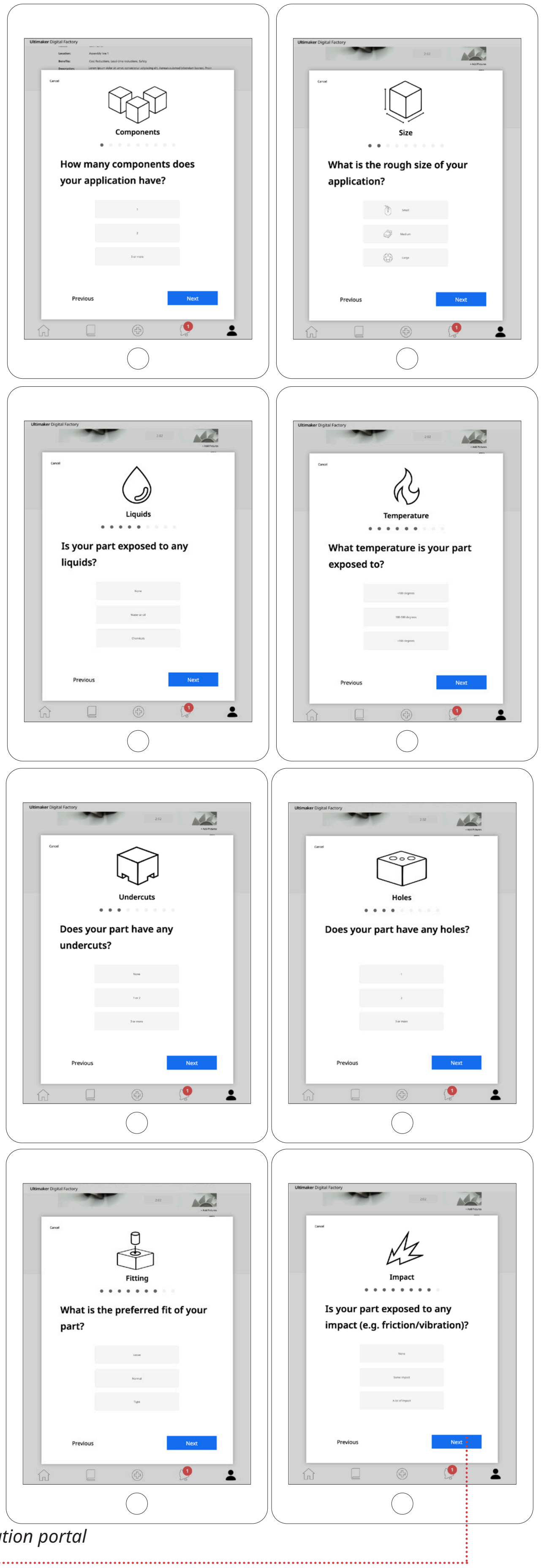


Figure 5.5.7: A representation of the final concept; the application portal

on the information that is documented below. Apart from the suitability check, the score will automatically adjust when information is changed.

The suitability check may be compared to a project kick-off and is a call to action to support users in filling in as much information as possible in an interactive way, rather than providing them with a simple form.

why

As the aim is to increase the involvement of users in the entire AM workflow, they must be able to take part throughout the workflow and thus collaborate with experts on their projects. Throughout ideation, the decision was made to create a shared document but with structured input fields. This way, users are not left in the dark about the information that is relevant in regard to a new application. The different sections in the documentation can be made accessible for users by champions based on company preferences.

Providing users with the option to post updates was a decision based on the insight that taking ownership of efforts is a major driver for operators to become involved. However, one of the requirements is a safe environment, thus the decision was made not to make posting mandatory.

Providing operators with a suitability score does not only mean that an increased amount of data can be gathered, forming a steppingstone towards automation of part identification, it also provides users with feedback on their ideas and is thus educational. This score is used throughout the entire application, and for champions who receive various submissions, to compare parts and make outweighed decisions on which ones to pursue.

Design requirements

- ✓ Traceable: checking updates and progress
- ✓ Personal: being able to take ownership of developments
- ✓ Educational: checking parts for suitability
- ✓ Collaborative: work together with AM experts and others on the project

Figure 5.5.8: A production line operator holding a tablet and receiving a notification (Alfapeople.com)

Tab 5: Notifications

Notifications

The last of five tabs is the notification tab. Here, notifications are shown in regard to the activity around your project. A notification may be a status change, a comment from a colleague on an application or more. This section may also be used in the future to notify users on other things, such as the end-of-life of an application. Notifying users means they will be able to reprint the part in time before it wears off.

Why

The aim of the notifications is to keep users actively involved in the AM workflow.

Design Requirements

- ✓ Traceable: keep track of developments
- ✓ Personal: Notifications are custom for each user

Notifications

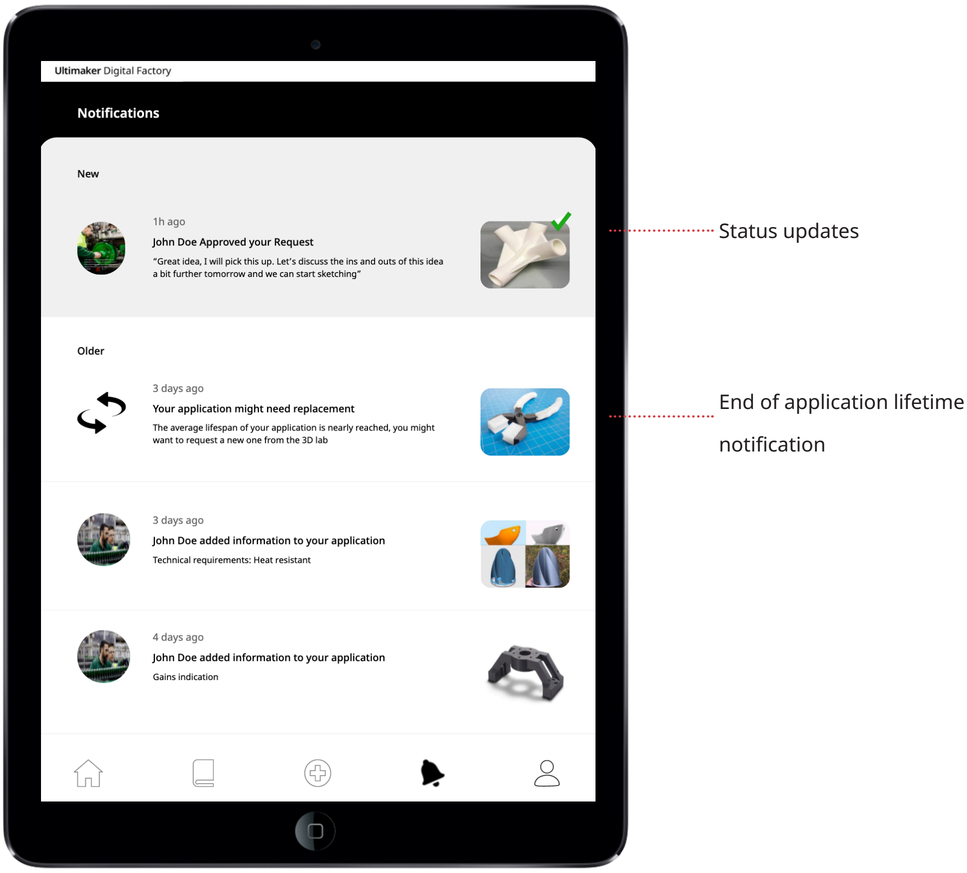


Figure 5.5.9: A representation of the final concept; the application portal

/ 5.6 Potential future technologies

The proposed concept allows for many future iterations. One important decision was made to stick to a realistic and technically feasible concept, which can be developed by Ultimaker at this moment. However, potential technologies may add significant value to the automation of part identification for AM. This section presents an overview of technologies that may be incorporated in the concept.

(QR) code Scanning

Depending on the company, it would make it easier to find back applications on the platform if parts have a code such as a QR code. Scanning the part with the app would easily guide them to the part's overview page to learn more about the part's characteristics.

3D scanning

As mentioned previously, 3D scanning technology could support operators in assessing the suitability of a part. Technology is already available, yet not always highly reliant (see figure 5.6.1 for examples). If the technology is incorporated, an automated complexity assessment can be made from the scanned data. This implies that operators do not have to fill in any additional information about the part while simplifying the process for champions in designing and printing the part. Examples of businesses who are currently working with possibly interesting scanning technologies can be seen in figure 5.6.1.

Enterprise Resource integration (ERP)

Many businesses make use of ERP systems to keep track of business processes, supply chain, sales and more. Integration with such systems through API's allows 3D printing technology to become an integrated part of existing business processes and open up further opportunities for keeping track of the impact of 3D printing, simplifying supply chain management and more. Additional interesting integrations include part database software, and integration with current activity feed or internal communication platforms such as slack, newsletters or even social media channels.

Project management integration

An integration with project management (PM) software such as Jira would allow champions to take requests into their planning or forward them to another department.

Automated suitability check

Existing software, such as presented in the landscape analysis, allows for checking digital 3D files for AM suitability. This technology, together with 3D scanning technology, would add significant value to the automation of part identification AM.

Ultimaker Ecosystem

This concept has been designed as a front end-employee portal of the digital factory that Ultimaker is currently developing. The digital factory, as mentioned previously, is currently intended for champions who want to document technical information about the parts they are developing. This concept proposal would be an extension of the digital warehouse so that any employee can view the developments and submit new ideas. The application portal has overlap (library, part overview) with the latest digital factory proposal and would therefore be integrated. The champion would have an overview of incoming requests and view them in a similar manner. However, champions may have additional information about the part, such as cost price, lead times, and other confidential data. Also, his task revolves around the technical aspect of the part and thus he must be able to document materials, print settings and upload Gcode files. Hereby it is again mentioned that champions differ in their user access to the system and are able to give individual operators access to view and/or edit parts of this additional information. As the digital warehouse is still in development, the exact integration of this proposal is yet to be decided upon.

Printer management

In a future vision, the entire Ultimaker ecosystem is connected. Identifying parts, development, printer management and all other software that supports the 3D printing workflow will be accessible from one location with different user access levels. This implies that operators would potentially be able to directly print parts from the library, manage their printjobs and more.

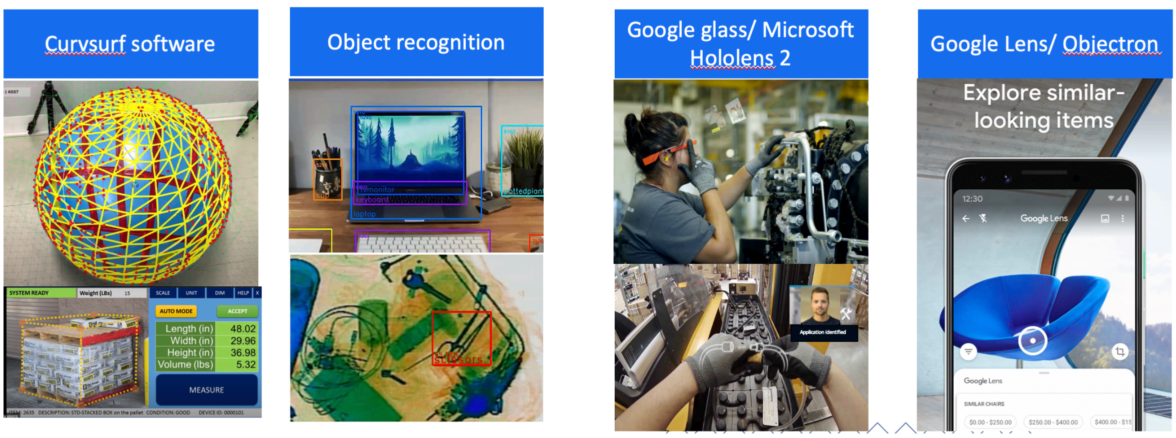


Figure 5.6.1: Examples of other technologies (Ultimaker internal research)

CHAPTER

06

DELIVER

| Validation

This chapter contains the results of the validation of the application portal concept. The prototype was tested with a variety of users with the aim to validate its potential value. This chapter explains the approach towards the validation, the results from the research and the implications of these results on future design iterations.

Figure 6.1.0: A production line in the Brewery in Sevilla, Spain (Ultimaker)

/ 6.1 Validation Approach

To test whether the prototype meets the needs of the target audience, interviews were held with several production line operators, managers and champions from the Royal Dutch Navy, Heineken, Ultimaker's own production line and Eriks. All companies make use of 3D printing technology on a daily basis and are therefore representative target users for this design project. The decision was made to interview not only production line operators but also managers and champions because the use of this system involves each of these stakeholders and must thus suit within everyone's workflow.

Objective

The objective of the user validation is to discover whether the prototype meets the design challenge to "facilitate active involvement of production line operators in the identification of new applications for the AM workflow". The validation sets out to understand the value of this product for the stakeholders by the hand of the design requirements defined in the synthesis.

Method

Due to COVID-19, not all user validation could be done in person. Interviews with members of the Royal Navy and with the operators at Ultimaker were done face-to-face during company visits in Den Helder and Zaltbommel. Validation with users from Heineken and Eriks was done online. As validation was set out to understand the value of the proposed product and could only be done with limited number of participants, the interview was used as a method for validation. Interviews allow for in-depth feedback on the desirability of the concept. An interview method is valuable for understanding "people's perceptions, understandings and experiences of a given phenomenon and can contribute to an in-depth data collection" (Ryan et al., 2009). Research questions were formulated, based on the list of design requirements.

1. Does the proposed solution provide a suitable form of education for production line operators regarding AM technology? (Educational)
2. Does the proposed solution facilitate an accessible entry point for new application requests? (Accessibility)
3. Does the proposed solution facilitate an easy way to keep track of the developments of parts and projects? (traceability)
4. Do operators feel safe to submit new application requests? (safety)
5. Does the proposed solution fit within the work activities of production line operators? (time-conscious)
6. Do operators feel as if they are owners of their requests? (Personal)
7. Does the proposed design solution add significant value to the AM workflow of Ultimaker's manufacturing customers? (
8. Is the solution scalable to other verticals? (scalability)
9. Is the solution technically feasible within current technological possibilities?

Participants

10 participants were recruited for the validation rounds. See the overview below in figure 6.1.1 for all participants included in the validation interviews, appendix B for a participant overview and appendix C for the key insights and quotes from the interviews. Due to COVID-19, no more operators could be recruited. However, various AM experts have once been operators and were therefore valuable participants for the validation.

Tools

Due to privacy issues, it was not allowed to take pictures. However, screen and audio recordings were made during the test. Interviews were transcribed and analyzed, from which conclusions were drawn to answer the research questions.

Activities

Most interviews lasted around 45 minutes and included the following activities:

1. Introduction to my project, the research topic and questions (5/10 min
2. Demo of the prototype (5 min)
3. General feedback & discussion (10-20min)
4. Follow up with specific interview questions (10-20min)
5. Closing (5min)

Limitations of the research

Only two production line operators were interviewed during the validation sessions due to COVID-19 limitations. Additionally, various companies were included in the research but not enough to fully cover the scope of Ultimaker's manufacturing client landscape.

See appendix C for a summary of the interviews and appendix H for in-depth research questions used as a foundation for the validation interviews.

Interview #	Participant #	Company	Role
1	P12, P13, P14	Navy	AM champions (2), AM manager
2	P1, P18, P21	Heineken, Ultimaker	Global AM manager Heineken, UM account manager, Portfolio management
3	P2	Heineken	AM champion
4	P26	Eriks	AM champion
5	P10	Ultimaker Zaltbommel	Operator
6	P11	Ultimaker Zaltbommel	Operator

Figure 6.1.1: an overview of the participants included in the validation of the concept

/ 6.2 Results

Generally, it may be said that the proposed concept was viewed as an interesting and valuable product for the majority of customers interviewed. Responses from users and clients were highly positive regarding both desirability and usability of the concept proposal.

Research question 1: Does the proposed solution provide a suitable form of education for production line operators regarding AM technology?

The proposed concept was perceived as a valuable learning tool by various stakeholders. "I really like how it allows users to see what is going on. We've been using example applications a lot in new breweries, and it amazes me how much it inspires and starts to live once people see how the technology can be applied" (interview 1). A production operator responded similarly: "You really have to see it, feel it, experience it, and at the end of the day, you will learn from each other" (interview 6).

In regard to the activity feed, users responded positive. "The activity feed is pretty nice. You could also use it in the development phase to quickly get feedback" (interview 3, P2). Another benefit of the activity feed (interview 6), is that the "social media aspect also really helps you to know who you can reach out to in regard to specific questions". However, it was suggested to further specify the use of the activity feed, for example by "using channels" (interview 3). This way, you can target users with more relevant information, rather than having one large pile of information. Also, it was suggested to make use of "academy learning modules" that Ultimaker recently launched (Interview 1, P18) rather than e-learning videos.

The suitability score was perceived to have potential for learning and/or feedback. "it tells you more than dry information, so that is always a good thing. And also, it might be a good reminder how all individual aspects in the suitability check influence the complexity of a part" (interview 5). However, the way in which information is presented may be improved. "the score is not really telling me too much at this moment. Maybe use a star diagram or something more visual" (interview 5). Additionally, "there are certain challenges in the suitability score, such as size. It would be nice to show users that these aren't limitations" (interview 4).

The library was considered as a desirable functionality in regard to learning. "It is really nice that you can just browse through and see what has been made" (interview 4, P26). Filtering would support usability once the libraries grows.

Research question 2: Does the proposed solution facilitate an accessible entry point for new application requests?

General: (easy to use etc.)
The general usability of this application on a mobile device such as a phone or tablet was considered very accessible. It depends slightly on the company what devices they have available, yet Heineken, Eriks, the Navy and Ultimaker all have some form of tablets or phones available for employees. Regarding the understandability of the prototype, it was

mentioned that "if someone knows about AM, they will know how to use an iPad" (interview 3, P3), and "anyone who has ever used social media will understand this. I understand exactly where to go after a 3-minute explanation" (interview 5). Some elements that may enhance accessibility of this application will be to install the app on iPads that are readily available and making use of a single sign-on feature (interview 4 & 2).

The idea behind the concept seemed to significantly overlap with the way users are currently gathering information and assessing parts. The Royal Navy makes use of an online portal with a "work request sheet". At Eriks, users fill in a potential sheet, in addition to a complexity form. This results in an overview of the complexity as well as the gain of an application. However, participants mentioned that this product proposal would add value to the accessibility of entering a new idea in various ways. "It is really nice that you can just click through", and "I think the suitability check really matches what we are doing right now, but then the flow is much nicer" (both interview 4). Additionally, participants mentioned that this product would increase the easy with which users can enter a new idea: "starting a new idea is much quicker this way" (interview 5).

The submission of a new idea was perceived differently per company. At the navy, the center of excellence has complete control over the development of applications and "users should not be able to start a project individually without permission". The roles are different at Ultimaker and Heineken however, where users have more freedom to initiate new projects.

Several ideas and improvements were mentioned during the evaluation in regard to the flow of submitting new ideas. Both users from the Navy, Eriks and Ultimaker mentioned that it would help significantly if users can choose whether they want to make a new project, modify an existing one or recreate an existing one before entering the rest of the submission flow. "I think users don't always know what solution they want to have. This app kind of expects it from a user. So maybe give them the option to just submit a problem" (interview 4). Additionally, linking existing part ID numbers to new project requests would also support users in their flow.

Research question 3: Does the proposed solution facilitate an easy way to keep track of the developments of parts and projects?

From the champion's perspective, the proposed solution would allow for easier and quicker documentation. "This would bring everything together. Rather than taking pictures on my phone and having a paper form at the office and other information in a third place" (interview 4). From the operator's perspective, it would enhance traceability as it would allow them to see the status of their requests much easier.

As contextual research made clear, information is often missing with current tools. This was confirmed and would potentially be solved with the proposed solution: "the information added such as environment, liquids and more is what we are currently missing. So that is really interesting" (interview 1, P3).

"Now if we have an idea, we don't know when or what happens, and it feels like a barrier to ask. This would make it much easier to track the progress and see what is going on" (interview 6).

Research question 4: Do operators feel safe to submit new ideas into the workflow?

Various operators and champions have mentioned that the proposed solution would lower the barrier to submit new ideas into the AM workflow compared to proposing a new idea face-to-face (interview 3, 4, 5 and 6). In regard to posting project updates, the AM champion from Eriks mentioned that "we use a tool that allows employees to show/post what they are proud of, so I assume there would be a desirability towards the acitivity feed too!".

However, champions appeared to be concerned with this potential development: "we don't want operators to dump all their problems on us" (interview 1). In regard to the activity feed, the same thing accounts.: "you don't want operators to start posting nonsense, that would be an overkill" (interview 2).

Research question 5: Does the proposed solution fit within the work activities of production line operators?

According to various interview participants, the concept is suitable within the schedules of production operators. "The quick request allows you to also do it quickly, that's great" (interview 5). Time pressure is different for every production line operator, so it also depends on the person. According to Heineken's AM champion, "you can expect quite a bit from these operators. They also use iPads for other things. If you want to submit something for AM, they can also do this, and the way I'm seeing it, it shouldn't be too difficult" (interview 3).

Research question 6: Does the proposed solution speak to the personal interest of production line operators?

The operators interviewed were very positive about the use of this product: "absolutely, people love showing others what they are doing and being creative" (interview 5), and: "it would make me really happy to find out that others are using my applications. I'd love that. I think it is a really good initiative" (interview 6). However, as was also seen in the contextual research, "older users might not use this, they hold their phones upside down sometimes..." (interview 4).

Research question 7: Does the proposed design solution add significant value to the AM workflow of Ultimaker's manufacturing customers?

As was mentioned in the results of prior research questions, the proposed solution would allow for better traceability and education among operators. Apart from beforementioned benefits, the following aspects would also add value to Ultimaker's clients. Operators also mentioned that the proposed solution would solve various issues they are currently facing. "We have an idea box, but last time I put something in it took a year and a half before someone did something with it" (interview 6).

For managers and champions, the solution would allow them to track the progress of their employees. "We want to be able to track our employees and their involvement so we can reward them" (interview 1, p1). In return this could be used as a way to provide incentives and/or rewards for users.

Heineken's AM champion mentioned the following: "I think it would save me a lot of time which I don't have right now. I don't have to go to people anymore to ask for ideas. It allows me to gather them easily and it also works as a filter "(interview 3). Eriks' champion mentioned the value of "bottom-up innovation" that the concept represents (interview 4). However, the system could further support the workflow if champions are allowed to compare incoming requests: "I'd like to see the scores of Mutliple parts to tell my employees why we would start with the best one!" (interview 4).

Research question 8: Is the solution scalable to all manufacturing businesses?

Heineken, Eriks and Ultimaker's champions, managers and operators responded very positive to the idea behind the platform. Heineken's global innovation manager commented that "this solution would really allow us to scale on a global level" (interview 1, P1). However, it appears that the proposed concept does not add value to every company. The Royal Dutch Navy had various concerns in regard to the system: "every work request has to go through the SAP system. So even if you have this application, you'd still have to enter it through SAP. That's a problem" (interview 1, 2). There were other concerns regarding the number of employees that would overwhelm them with their requests. In addition, the use of Cloud technology in their secured network environment would be a crucial barrier towards adopting this solution. There are significant differences between the Navy and other companies that would make implementation of such a product extremely difficult or even unsuitable for the navy. The navy is more advanced in their application of AM technology and use it alongside regular production methods. Therefore, all parts have official part ID numbers and are documented as regular parts. Additionally, the navy has strong hierarchical characteristics in which decisions are commonly made "top-down". A last difference is that it is a much bigger organization. These factors have been notes as potential complicators for the adoption of new software products.

Research question 9: Is the solution technically feasible?

Overall, the technology is technically very feasible. "It is technically very easy to make, you just need the manpower" (interview 2, P3). Difficulties might arise regarding hosting, privacy and cloud computing. Demands from customers may increase difficulty due to privacy, integration with current systems and more. It is out of scope for this project to further investigate.

/ 6.3 Conclusion

The proposed solution appears to match the user's needs in regard to learning about AM. Learning by doing, as was concluded from the contextual and literature research, is a suitable way to teach novice users about this new technology that is best understood by experience. The activity feed has various benefits apart from learning about the possibilities of AM, such as finding the right person to talk to and understanding how complexities may be overcome. The suitability check might require further iterations to add significant educational value.

The proposed solution appears to show overlap with the workflow of various companies in regard to requesting new ideas and checking the part's suitability. However, the research showed that the solution would enhance the workflow and thus the traceability of part information over time.

Operators appear to feel safer to submit new ideas through a platform than face-to-face. However, thinking of champions concerns and future growth, posting and submitting new ideas might require some form of regulation to prevent users to post irrelevant information on the platform.

According to operators, the proposed solution is suitable within their work schedules. Whether or not operators would use the product is therefore dependent on their motivation.

Positive responses from both operators and champions imply that the solution speaks to the personal interest of users. Features that allow users to share ideas, be creative and track progress appear to benefit both users.

Interviews with different companies allowed for a certain level of validation on whether the proposed solution is scalable across different companies in the manufacturing industry. Results clarified that a range of factors influence the applicability of the product. Factors that influence applicability are the use of current software, strong hierarchy (not open to bottom-up innovation), technological barriers (cloud vs Local Area Network preferences) and an open mindset towards digital innovation. To understand the exact challenges and how to overcome these, further research is recommended.

The validation research resulted in positive feedback regarding the potential of the proposed solution to enable operators to become more actively involved in the AM workflow, and particularly the first step: identifying new applications. Various companies and their different stakeholders have expressed an interest in such a system and have recognized its potential to easily submit and share ideas, updates and information within a business. Seeing application examples through a real-time activity thread and company library has been confirmed to support the learning process of novice employees, in addition to (automated) feedback from both the system as well as their employees. A platform, available on tablets and other mobile devices suits the workflow and schedule of the target audience.

However, adoption remains dependent on the motivation of users. It must be mentioned that there is potential value in such a system for clients, but various factors may prevent the system from being successfully adopted, such as size, hierarchy and the use of existing systems.

/ 6.4 Design Review

The research conducted as a means to evaluate the concept have led to the following recommendations on a next design iteration of the application portal.

Home/activity feed channels

Posting updates about projects can be done through channels, so users can decide which channels to follow and which not. Additionally, the two alternative tabs will be specified to lead to Ultimaker Academy and the Ultimaker community.

Regulation

As became clear, champions want to prevent an overkill of irrelevant information. Therefore, some sort of regulation on the information posted should become available. This would also allow champions to show information that matches the skill level of the operators.

Library

Additional tags may be used to parts in the library, which would allow companies to make a tag system that suits their way of working, such as filling in the part ID number or location code.

Submission form

The submission form would start by asking users whether they would like to submit a problem, modification or new application idea. Furthermore, it is hereby suggested to allow for customization to select which information is critical for the submission of a new idea. It has been seen that each company has its own preferred way of working. Therefore, it is suggested to create preset blocks of information, such as complexity, printability, design benefits and more. Another suggestion would be to push users to make videos rather than pictures as videos provide more information. Lastly, it should be possible to upload files in addition to taking pictures/videos.

Personal page

Making modular blocks of information would also allow clients to design their own workflow and match their employees' skills. This customizability appears to be necessary due to the different preferences of companies. The blocks of information would also be refered to on the personal page.

Backside (digital factory)

The system view for champions is out of scope for this project. However, it would be recommended to incorporate different levels of user access to divide information. Additionally, champions would like to compare incoming requests and their suitability in one overview.

Suitability score

The suitability score has significant potential, yet it must be improved to speak to the attention and understanding of operators in a more suitable manner. It would be recommended to view the score as a potential score, and let users decide what the threshold is to continue development of parts.

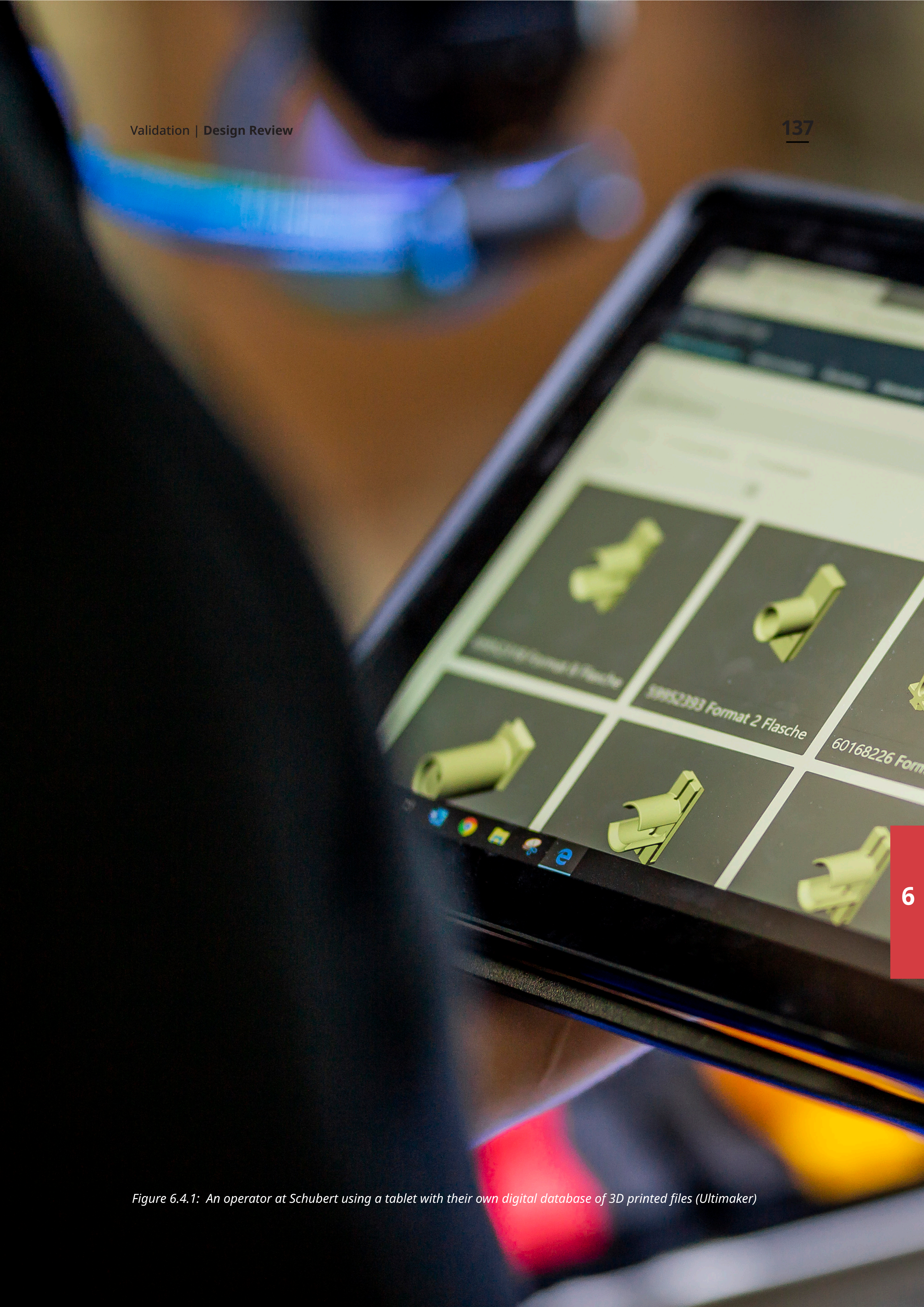


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Figure 6.4.1: An operator at Schubert using a tablet with their own digital database of 3D printed files (Ultimaker)

CHAPTER

07

DELIVER

| Closing

In this final chapter, the research project is concluded and discussed and a list of recommendations is provided regarding future research and implementation of the proposed design concept: the application portal.

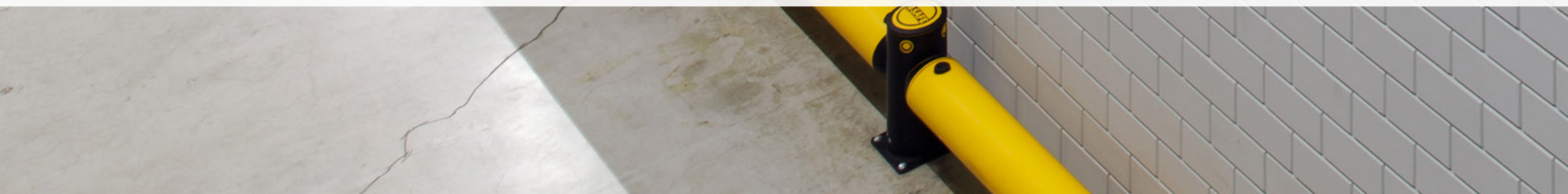

Figure 7.1.0:Erik's production facility (Ultimaker)

/ 7.1 Conclusion

The aim of this project was to design a product to support production line operators in the identification and documentation of new ideas for AM. It was expected that involvement of production line operators in the AM workflow would increase the number and the quality of applications developed by manufacturing clients. This would result in increased value of 3D printing technology that Ultimaker has to offer to its clients.

The original design brief that formed the foundation for this project was as follows: *"How may we empower operators to identify new applications for 3D printing, also beyond the scope of existing applications, and enable them to document all relevant information as an entry point for the application workflow?"*

In an effort to answer the sub questions as formulated below, specific research activities were conducted.

1: How may novice users identify parts for AM in manufacturing environments?

Secondary research has indicated that 3D printing technology has growing value for manufacturing and production industries. Compared to traditional technologies, 3D printing offers various advantages, such as cost and lead-time reductions. However, a major challenge remains. How do you assess which kind of components and materials are most suitable to be produced with 3D printing technology? As many variables determine a part's suitability, the method and process to identify and to assess suitable candidates appears to be highly complex. In particular for novice users, such as production line operators, the assessment of parts is a challenging task. To support this process, various methods have been developed. Some promising methods are automated part assessment from digital 3D files and basic suitability checklists. A more narrow selection of these methods offers interesting elements that may further support operators in their workflow. Yet, to understand how these elements would fit the context of manufacturing clients, further research is necessary.

2: What is the potential role of production line operators in regard to identifying new applications for AM?

Contextual research has provided insights into the need of active involvement of production line operators to identify new applications. It is concluded that there is a substantial benefit in the involvement of operators in the workflow, in particular in the identification of local problems and possible solutions. This agent is therefore a valuable source of information. Nevertheless, several factors may influence their involvement. Organizational factors include the structure of the organization and the corporate culture regarding internal communication. Personal barriers to get involved include the required skilllevel, the existing time pressure and the lack of incentives to participate in the process of identification. In addition, there is a clear distinction between "old" and "young" operators. Young operators can be considered as more motived to become involved in the AM workflow than older ones. Overall, it can be concluded that a significant part of the operator population has the potential to become a valuable stakeholder in identifying parts for AM.

3: What is the preferred product strategy from Ultimaker's point of view?

Another round of interviews was conducted to verify the research findings and establish a strategic solution scope for this project. Interviews lead to the conclusion that the preferred direction for a design solution is a digital platform that - once parts have been identified - supports the workflow of operators. The conclusion is that, in order to enable operators to start identifying parts, they must be given the opportunity to become involved in the AM process in a more holistic, collaborative manner. A critical starting point to achieve this commitment is better education. Education is currently provided through e-learning and workshops. Therefore, the decision was made to focus design efforts on supporting the workflow following the moment that operators identify parts . The design challenge is formulated as follows: "Design a digital, collaborative platform that facilitates active involvement of production line operators in the identification of new applications for the AM workflow".

4: What may a potential answer to the design challenge look like?

Once this design challenge was formulated, an iterative design process was executed, involving various stakeholders throughout ideation and detailing. Three (3) design cycles allowed for an initial design direction to evolve into a final concept; the application portal. The application portal is a front-end application for mobile devices that supports operators in submitting new ideas. This portal allows operators to view existing parts, share progress, initiate ideas, check their suitability based on various aspects, and exchange essential information with AM champions. This concept offers a platform in which operators may learn about AM as well as participate in an active manner.

5: Does the proposed design solution facilitate active involvement in the AM workflow?

Validation of the concept's desirability was done through six interviews with participants from four different clients: Heineken, Eriks, the Royal Dutch Navy, and Ultimaker's own production line. Managers, operators and champions were involved in the evaluation. Interviews have led to the conclusion that there is signification value in offering this product to Ultimaker's clients. The product has a high potential to increase active involvement of production line operators in the AM workflow. However, due to a variety of practical restrictions such as security and the use of existing systems, not all clients may benefit from this product, These restrictions may inhibit a successful implementation.

Conclusion

In conclusion, the Application Portal has the potential to empower production line operators to identify new parts for AM. As it includes an educational aspect that teaches users about the possibilities of AM, the portal provides inspiration to think beyond the existing fields of applications. The concept contains the most essential ingredients to facilitate documentation and to enable operators to become holistically involved in the workflow. As a next step the concept's long-term effects have to be evaluated.

/ 7.2 Short Term Recommendations

Design and prototyping iterations

The concept proposal is a starting point of which the value for various clients has been validated. However, the concept is not final and could be further improved. The design review section explains various ways in which iterations can be made on the prototype. It is highly recommended to further iterate the concept to increase usability and desirability for users.

Applicability

Research showed that certain business characteristics have a significant effect on the applicability of this product. Therefore, it is strongly recommended to verify the applicability of the product with other clients in the manufacturing industry. Hereby it is recommended to verify the concept with businesses that differ in size, location(s), cultures, business processes and phase of AM adoption. This way, the potential user market can be discovered and a grounded strategic decision can be made how and where to place this product on the portfolio roadmap.

Integration

The application portal has considerable overlap with other elements of the digital factory. Therefore, it is recommended to design and test an integration of this system with the digital factory as well as with Cura (Ultimaker's slicing software) to optimize the user experience and offer a complete solution in supporting the AM workflow.

Openness

As was observed, the role of the managers and the AM champion's attitude towards bottom-up innovation is decisive in enabling operators to identify parts. Whereas strict hierarchical environments are proven to slow down innovation, operators that feel safe will submit ideas and creativity flourishes. Therefore, it is recommended to take this issue into consideration throughout workshops and trainings with the client's champions.

Data tracking

Companies want to have insights into how their employees are taking part in the process. It is therefore recommended to focus on tracking user activity in the development of this product.

Pilots

I highly recommend running a pilot with manufacturing clients such as Heineken or Eriks who have confirmed the applicability of this concept for their business. Pilots will support the iterative design process to improve the design of the system.

/ 7.3 Long Term Recommendations

Modularity

On various levels, the research has shown how companies have their preferred ways of working. Therefore, it is recommended to conduct additional research to discover the most suitable way to support the need for modularity and customization of the platform.

Scalability

Investigating the applicability of this concept beyond the manufacturing industry could increase the potential target market for this platform.

Education

Research indicated the importance of education to motivate and enable users to identify new applications. Current efforts are aimed at e-learning modules, which may not entirely meet the needs of operators. It is therefore recommended to investigate more suitable ways of distributing or transferring knowledge that matches the learning capabilities of this target audience.

Integration

Many businesses use ERP systems. As AM will be a growing technology in present and future companies, any possible integration with current and future ERP systems makes the adoption of Ultimaker's software solutions more attractive to a larger group of clients. Since companies have their own specific ways to share new insights, updates and activities (such as news letters or an internal forum) it is recommended to investigate ways to integrate the activity feed with these ERP systems.

/ 7.4 Limitations

Literature

The literature study had a strong focus on AM technology and not so much on strategies towards the adoption of the technology and/ or bottom up innovation strategies. This limited the design from a theoretical point of view.

Contextual research

Only several companies were visited and interviewed throughout the research. The results are therefore not verified with the entire manufacturing industry.

Evaluation

Only two operators from Ultimaker's production line were interviewed during the evaluation. These operators are expected to represent the persona as seen in larger manufacturing companies, yet this is not verified.

COVID-19

Due to COVID-19, physical brainstorm and ideation sessions were not possible. This has had its limitations for creative brainstorming sessions as they are usually performed. In addition, the pandemic has prevented most research activities from being conducted physically. This has had its limitations on grasping the experiences from participants to a full extend.

/ 7.5 Future Research

Literature research
To create a broader understanding of industry 4.0 and the adoption of new technology, it is recommended to expand the literature research.

Bottom-up approach
In order to understand the potential strategies towards bottom-up innovation, it is valuable to further extend the research efforts in this area.

Competitor analysis
Yang et al. (2018) have created an extensive overview of potential suitability check initiatives. However, other software has been developed further out of scope of additive manufacturing. It would be recommended to expand the research of competitors in and outside of the field of 3D printing.

Contextual research
To continue understanding the entire context, it is recommended to further conduct research taking managers, champions and other stakeholders across different companies into consideration. This would be valuable to ensure a complete understanding of the needs for integration of this platform with client's systems as well as Ultimaker's digital eco-system.

/ 7.3 Project Reflection

Let's do this!

When I started my graduation project, I was extremely determined to graduate within the given time. Before starting this MSc, I took a bit of a different path. I started my BSc in Delft 7 years ago, switching to an international (HBO) bachelors in the Hague and back to the TU Delft through a bridging course. Standing at the beginning of the end of this road made me feel confident and proud. Plus, I had found a graduation project which allowed me to investigate a topic exactly in my field of interest at a company I liked. I was ready to go!

Lucky me

The first month or two I was given some amazing opportunities. I was allowed to follow an AM training from the Application Engineers for the Royal Dutch Navy, paid a visit to the Heineken Brewery in Greece and was introduced to various stakeholders that would add significant value to my project. It was incredible to experience this as an intern, it made me feel motivated to completely dive into the topic.

What is going on?

But then, COVID-19 happened. Everything was different. No more office, no more client visits, no more chit chat in the hallways, and no more students around to share my thoughts with. Everyone thought it wouldn't take more than a couple weeks before we'd be back to normal, but no less was true. I really had to switch to a different mindset, which wasn't always easy. I was lucky to have friends and family around, but the inspiration and creativity I found at the office was mostly gone. Corona also had some advantages. I didn't get disturbed too much so I could write in quiet. However, after sending my first version over made me realize that I was really struggling with the structure of my thesis. I don't mind writing but putting all the pieces of the puzzle together was something I could use a hand with. This was overwhelming, and probably slightly more difficult as I was spending most of the time writing alone and at home. Luckily, my tutors and company mentor were there to guide me and helped me pull through.

I changed my planning and started conducting interviews online. It felt like a bit of a hurdle every time, but I had to get over my fear of feeling like bothering people. Interviews provided me with many insights which I was happy to start documenting. I realized I just had to do what I could do with the sources I had.

Am I doing this right?

Throughout the synthesis and design phase, I went through many different states of emotion. Both extremely positive feedback as well as somewhat more questioning responses were exciting, insightful and scary at the same. I realized I'm not the best at receiving criticism, but that's something I was able to work on quite a bit throughout this project.

After the first weeks of the design phase, it became clear that corona had quite a big impact on my process. I was lacking inspiration and didn't go through the typical design process. If I could redo this phase, I would ask for more help and guidance.

I guess I'm doing something right!

However, positive responses from clients, colleagues and others gave me the confidence to stop worrying about the process. I was on a good path and had been asked to present my work to various departments within Ultimaker as there was a significant interest to develop my idea. My determination helped me to complete this project and become proud of the results I delivered and learned.

It feels strange to be typing the final words of all these years of studying. I'm relieved to say that, in the last 6 months I didn't only learn an incredible amount about the topic, I also learned a lot of things about myself as a designer and what I like about the profession. I really enjoyed conducting contextual research, as it allowed me to bring the human aspect to the forefront of a technical context. I struggle finding structure in large amounts of information, but I've become more confident finding my way. And I don't really enjoy facilitating a creative process, but at least now I know!

To anyone reading this; trust your own abilities and your instinct. I don't think graduation will ever go as you hope or expect, but it's a great opportunity to experiment and learn!

“The Only Thing That Is Constant Is Change “

- Heraclitus

Figure 7.3.1: Erik’s production facility (Ultimaker)

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