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Additive Manufacturing Needs and Practices in the Finnish Industry

Master's Thesis

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Abstract

<table>
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<tr><td colspan="2">The purpose of this thesis is to present the current needs and practices of additive manufacturing in the Finnish industry. To obtain the necessary information, a survey of eight companies was carried out. An introduction to additive manufacturing and its applications is given to give the reader a better understanding of the survey.
A survey was designed and the process explained. The main tool, the questionnaire, was chosen to be the best option to conduct the survey and was designed to consist of a combination of open questions and scale questions. The questionnaire was presented to eight companies of varying size in the research and development industry. Fifteen people from these companies were chosen for the survey.
All of the qualitative answers were analytically quantified and expanded upon. The findings of the survey were compared to the findings of other worldwide reports.
The results obtained through this study include data regarding familiarity of AM technologies, ownership of machinery, outsourcing practices, and general perception of AM in Finnish companies.
It was found that while the Finnish industry is somewhat lagging behind on some fronts of AM usage, the trend is showing that AM is becoming more widely understood and its usage in more advanced applications is on the rise.</td></tr>
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Tiivistelmä

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Tämän työn tarkoituksena on esittää Suomen teollisuuden nykytarpeet ja käytännöt materiaalia lisäävään valmistukseen liittyen. Työssä suoritettiin haastattelututkimus kahdeksassa yrityksessä vaaditun tiedon saamista varten. Työssä annetaan lyhyt johdatus materiaalia lisäävään valmistukseen tutkimuksen parempaa ymmärtämistä varten.

Haastattelututkimus kehitettiin ja prosessi selitettiin. Pääasiallinen työkalu tutkimuksessa, kyselykaavake, valittiin parhaaksi tavaksi suorittaa tutkimus. Kyselykaavakkeeseen sisällytettiin avoimia kysymyksiä ja skaalakysymyksiä. Kysely suoritettiin kahdeksassa erikokoisessa tuotekehitysyrityksessä. Viisitoista ihmistä valittiin haastateltaviksi.

Kaikki kvalitatiiviset vastaukset kvantifioitiin analyyttisesti. Tutkimuksen tuloksia verrattiin muihin maailmalla suoritettuihin tutkimuksiin. Tutkimuksen tulokset sisältävät tietoa suomalaisen teollisuuden AM-tekniikoiden tuntemuksesta, koneiden omistamisesta, ulkoistamiskäytännöistä, sekä yleisistä käsityksistä liittyen AM-tekniikoihin. Tutkimuksesta ilmeni, että Suomi on jonkin verran muuta maailmaa jäljessä AM-tekniikoiden omaksumisessa, mutta trendi osoittaa, että adoptio on käynnissä ja kehittyneempien sovellutusten käyttö on nousussa.

Avainsanat: Materiaalia lisäävä valmistus, Rapid Prototyping, Rapid Tooling, Rapid Manufacturing, teollisuuskysely

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I would like to thank the companies involved in the SuperMachines project, the companies that participated in the survey, and especially Risto Ojala of Multiprint Oy.

In addition, my gratitude goes to the instructor of the thesis Jukka Tuomi, the supervisor of the thesis professor Jouni Partanen, and everyone else in the 3D manufacturing research group.

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in Espoo 26.5.2014

Sergei Chekurov

Contents

Glossary and abbreviations

3DP	Three-Dimensional Printing
ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
.AMF	Additive Manufacturing File Format (file format)
EBM	Electron Beam Melting
DLP	Digital Light Processing
DM	Direct Manufacturing
DPP	Direct Part Production
FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
HDPE	High-density polyethylene
LENS	Laser-Engineered Net Shaping
MJM	Multijet Modeling
PC	Polycarbonate
PCL	Polycaprolactone
PEEK	Polyether Ether Ketone
PLA	Polylactic Acid
R&D	Research and development
RM	Rapid manufacturing

RP	Rapid prototyping
RT	Rapid tooling
RTV Silicone	Room Temperature Vulcanizing Silicone
SHS	Selective Heat Sintering
SL	Stereolithography
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
.*STL*	STereoLithography (file format)
UAM	Ultrasonic Additive manufacturing

1 Introduction

Additive manufacturing (AM) is a group of technologies that create physical objects using digital files containing a three-dimensional representation of parts without the use of traditional molding techniques. All AM technologies produce parts by constructing them layer by layer, but they can be divided into seven categories of processes, each using different materials and a unique way of producing the layers. [1]

The invention of the first viable AM process, stereolithography, is credited to Charles W. Hull in 1986. Using that as a reference point AM technology is 27 years old at the time of writing, making it a relatively young technology. During the past decades AM has improved significantly from the state it was in at the beginning of its lifespan. In the past, using AM was only possible with polymer based materials, whereas now producing parts out of metallic and ceramic materials is possible. [2]

Until the developments in the last decade, AM was considered a technology used exclusively for rapid prototyping (RP), causing it to be named after the application. Nowadays AM is not limited to producing prototypes but can also be employed in tooling purposes (rapid tooling, RT) and in direct part manufacturing (rapid manufacturing, RM). This development is important because it allows for a far wider range of applications for AM, and it is important that companies recognize these advancements. [1]

The biggest technical challenges of AM are limited speed, accuracy, nonlinearity, build volume and cost. Due to these reasons, conventional manufacturing is more efficient in high volume production. In low level parts with high geometrical complexity, nevertheless, AM is rapidly gaining prominence as companies such as NASA, Boeing and Renault are starting to use it on a large scale [2]. Apart from speed, reasons to use AM are generally divided into four categories, which are user-fit requirement, improved functionality, parts consolidation, and aesthetics [3]. To use the full potential of AM, the parts that are created using AM technology should be designed according to a new set of restrictions and possibilities. One such possibility is the geometrical optimization of parts from the perspective of stress distribution [4]. An example of AM usage is a re-engineered latch that allows for tighter installation and optimized geometries, shown in Figure 1.

Figure 1: Traditionally manufactured latch on top. Latch re-engineered for AM at bottom. [5]

The goal of this thesis is to map out the extensity of the use of additive manufacturing (AM) in different sectors of the Finnish industry and compare them to that of other countries. Additionally, this thesis will evaluate the progress of the spreading of AM and provide guidelines to further speed up its creep. Global state of the art reviews are done on a yearly basis by several research centers [6]. However, the country specific information they provide is not extensive and commonly focuses on AM technology development companies and research centers. In order to review the actual use of AM, a survey consisting of a series of interviews was conducted. Eight Finnish companies were interviewed and the results were consolidated in order to preserve the non-disclosure agreements.

A variety of factors were investigated in order to get a clear view of the current usage of AM. The ownership of machinery was looked into and reasons for owning and operating certain machinery in a certain way was examined. Reasons and criteria for outsourcing AM services were looked into.

2 Overview of Additive Manufacturing technologies

Additive manufacturing is a term used to describe the technologies, process and use that makes possible the rapid production of parts from digital data. Using AM eliminates or radically diminishes the importance of pre-production planning and depending on the application reduces R&D cycle time or improves performance of the final product [1].

While all AM technologies follow the same concept of delivering parts without the need of tooling, they differ from each other and are classified according to an ASTM standard. All of the technologies also have different characteristics that limit their use to different applications. The applications in the industry can be divided into three rough categories: rapid prototyping, rapid tooling, and rapid manufacturing, each divisible into subcategories. The need to divide the technologies into classes and the applications into categories is not solely academic. Companies rely on these denominations when considering adopting AM technology and when looking to produce a certain part. [7] The distribution of AM usage by industrial sectors is provided in Figure 2.

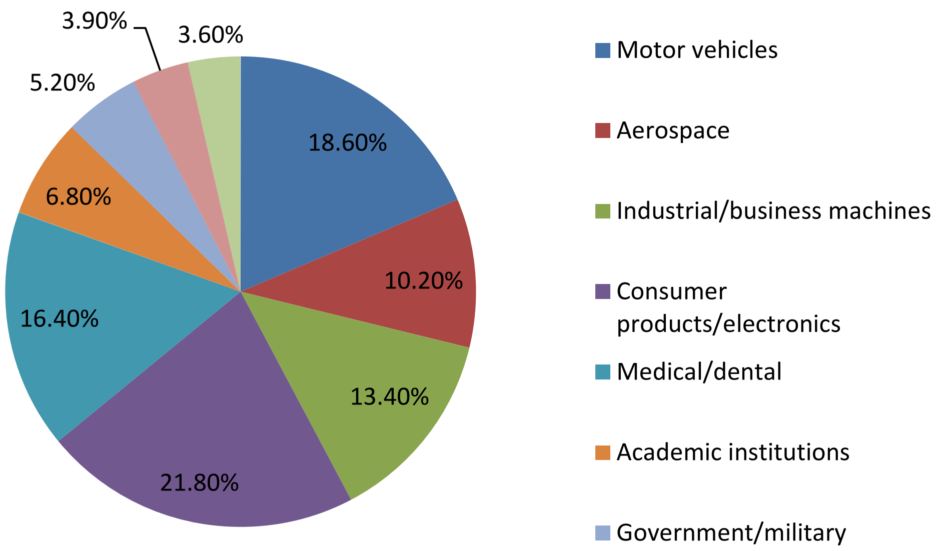

Figure 2: AM usage by industrial sector [6]

Motor vehicles, aerospace, industrial/business machines, and consumer products/electronics amount to a total of 64% of all AM usage. This thesis will primarily focus on investigating the needs and practices of the industrial/business machines and consumer products/electronics sectors which together cover 35.2% of AM usage.

3 Classifications of AM

Even though all of the current AM technologies produce parts by constructing one cross-section at a time, their work principle varies. The range of the way of producing layers on top of each other varies from using lasers to melt plastic powder to cutting and gluing sheets of paper. This has an effect on the main attributes of parts manufactured with additive manufacturing: size, cost, accuracy, and material. The technologies can be divided into classes according to their technical processes or according to their applications. [8]

3.1 Classification of technologies

The technical terminology of AM technologies has been standardized by dividing them into seven different categories. These categories are binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat photopolymerization [9].

A short description of the seven categories is given in this chapter and the most common technologies associated with the categories are presented in table 1.

Table 1: Classification of AM technologies

Technology	Category
Three Dimensional Printing (3DP)	Binder jetting
Laser-Engineered Net Shaping (LENS)	Direct energy deposition
Fused Deposition Modeling (FDM)	Material extrusion
Polyjet	Material jetting
Selective Laser Sintering (SLS)	Powder bed fusion
Selective Laser Melting (SLM)	Powder bed fusion
Electron Beam Melting (EBM)	Powder bed fusion
Selective Heat Sintering (SHS)	Powder bed fusion
Laminated Object Manufacturing (LOM)	Sheet Lamination
Stereolithography (SL)	Vat photopolymerization
Digital Light Processing (DLP)	Vat photopolymerization

The most common technology used by service providers worldwide is stereolithography (SL), the second most common is Fused Deposition Modeling (FDM) and third most common is Selective Laser Sintering (SLS) [6]. In order to better introduce the general idea of how AM technologies work and how severely they differ from each other, a description of each process is given, advantages and disadvantages are discussed and material choices presented.

3.1.1 Binder jetting

Binder jetting is a powder based process in which a liquid bonding agent is deposited according to the cross-section of an object [9]. Although most commonly used with gypsum, sand and metallic materials are also used. In the case of plastics a layer of colored ink can be deposited on top of the each powder to give the part a colored outer shell. When using binder jetting technologies that allow the use of metallic materials, the final part needs to be sintered and infiltrated with another metal for the part to be durable. The commercial name for binder jetting is 3D Printing (3DP). [1]

3.1.2 Direct energy deposition

Direct energy deposition is a metallic process closely associated with welding. A stream of metallic powder or metallic wire is projected onto a pre-existing object and a heat source is used to melt the powder on top of it [9]. The most notable commercial brands using this approach include direct metal deposition (DMD), laser consolidation (LC), and laser-engineered net shaping (LENS) [1].

3.1.3 Material extrusion

Material extrusion is an approach that melts solid material and extrudes it selectively onto an x-y plane [9]. As this type of technology has the largest installed base of AM machines, its working principle is explained in detail through commercial brands.

Fused deposition modeling (FDM), or fused filament fabrication (FFF), is a material extrusion technology which uses filaments of plastics to extrude layers in order to create parts. An FDM or FFF process set-up consists of a movable build platform, extrusion nozzles, and a build material spool.

Filament material is fed from the build material spool to the heated extrusion nozzles which proceed to melt the material on extrude it onto the build platform in the form of a 2D cross-section of a part. If the machine is equipped with multiple nozzles, the secondary nozzle can extrude support material on the same layer. Once the layer is done, the build platform is lowered by the thickness of one layer, and the extrusion nozzles continue building the second layer.

Once all layers of the part are done, the part is removed from the machine. Post processing in FDM or FFF only requires the user to submerge the part in an ultrasonic bath to remove the water soluble support material. A variety of optional post processing methods exist for the technology, such as using acetone vapor to smooth the part from the outside [2]. A schematic of the set-up of and FDM or FFF machine is presented in Figure 3.

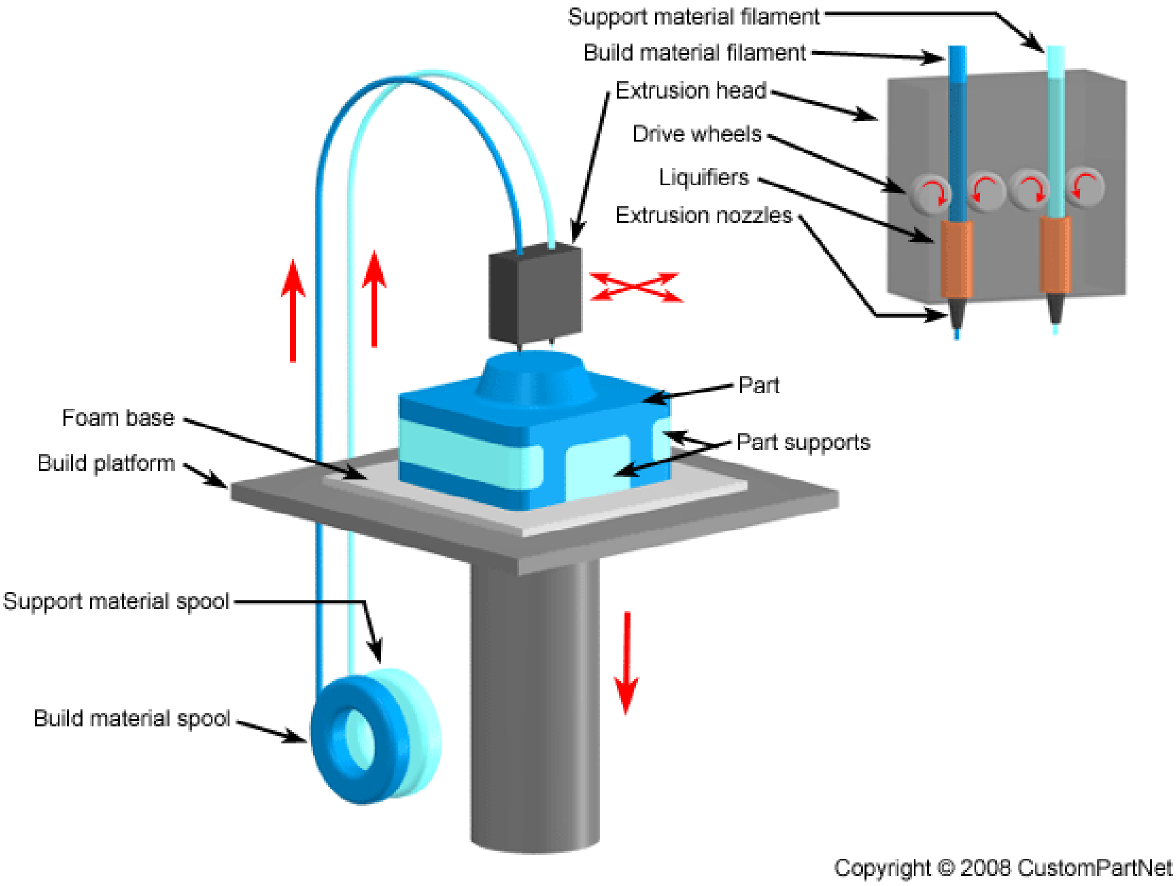

Figure 3: A schematic of an FDM or FFF set-up [10]

FDM or FFF technology ranges from very low end machines to high end machines. The technology operates in an open air environment which requires it to use supports in order to build parts with overhang structures. The ease of the post processing is one of its advantages as it is completely hands-off. The materials for FDM or FFF include plastics such as ABS, PLA, PC, Nylon, HDPE, and PCL. [2]

3.1.4 Material jetting

Material jetting is based on selectively depositing droplets of ultraviolet-curable materials on a plane and subsequently curing them with ultraviolet light [9]. The materials compatible with the technology are photopolymers and wax-like materials. The commercial brands that use this approach are PolyJet and multi-jet modeling (MJM) [1].

3.1.5 Powder bed fusion

Powder bed fusion works on the principle of selectively focusing energy on a cross-section of powder to bind it together [9]. Powder bed fusion technologies represent some of the most widely spread technologies and is explained in detail through the commercial brand selective laser sintering (SLS).

Selective laser sintering (SLS) is a powder bed fusion process in which plastic powder is sintered by a laser and bound to the layers of material below it. An SLS process consists of two or three chambers, one of which is the build chamber and one or two are powder supply chambers, pistons to raise or lower the powder in the chamber, a leveling roller or blade, lenses, and a scanning mirror. [2]

At the beginning of the process the build chamber is empty and the powder feed supplies are full. The process starts by moving one of the feed pistons up by a distance that is equivalent to the desired thickness of one layer in the final part and lowering the build piston an equal distance. A leveling roller or a blade moves from behind the elevated powder supply chamber, spreads the powder evenly on the build chamber and positions itself either behind the second powder supply or returns to the original position depending on the machine. A laser then activates and projects a beam into the lens system, which focuses the beam and sends it to the mirror which in its part projects the beam onto the build chamber surface and traces a cross-section of a part. Once the process reaches this stage the laser de-activates, the pistons move in their intended directions and the work starts on a new layer. This process is continued until all layers of the part are produced. Once the part is ready it is removed from the machine and all excess powder removed. [1]

SLS is capable of using nylon 11 and nylon 12 powders and PEEK. Composites of nylon materials are created for the process by mixing the nylon with other powders such as glass, carbon, or aluminum. One of the most notable advantages of SLS is the fact that due to the part being surrounded by powder it does not need support structures. This allows for a greater degree of freedom in designing objects [11]. SLS is also the best technology to be used in order to produce parts with moving features, including joints [12]. The set-up of an SLS machine is presented in Figure 4.

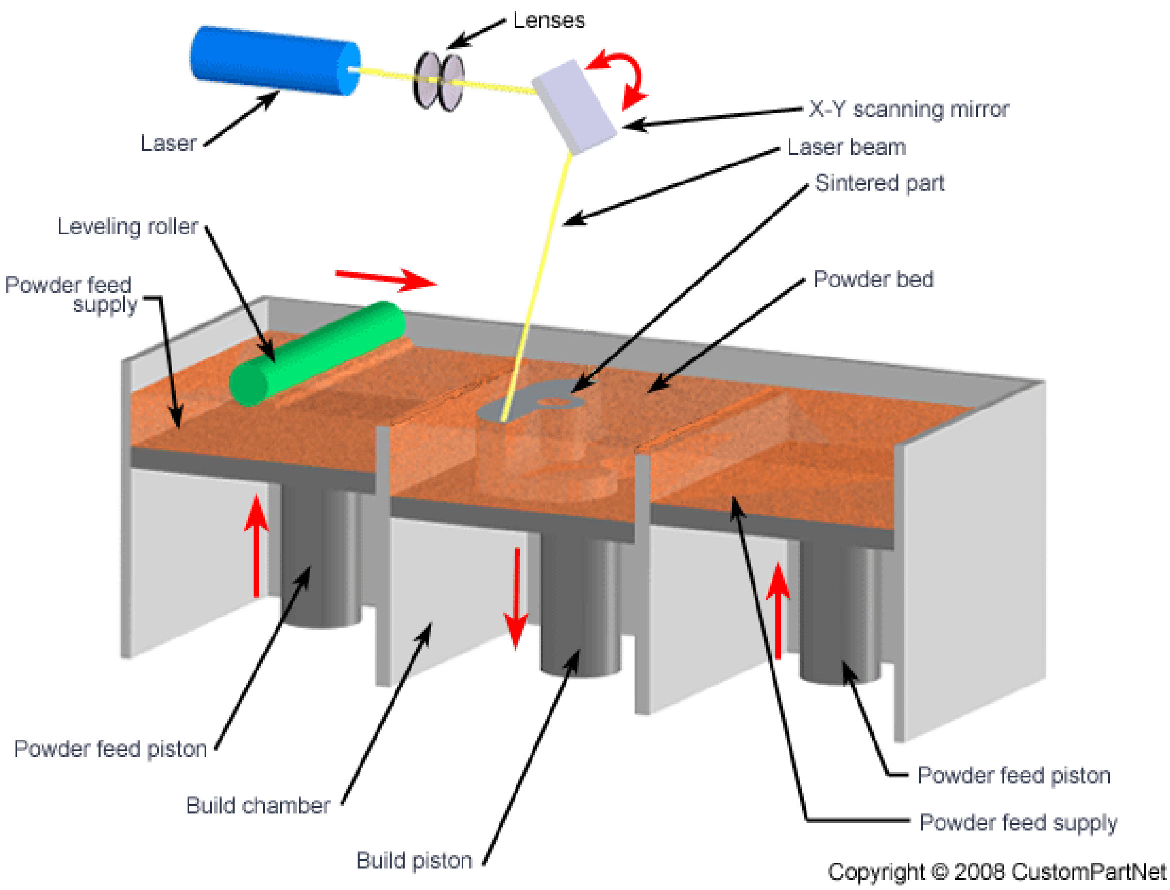

Figure 4: A schematic of an SLS set-up [13]

Other commercial brands based on powder bed fusion include selective laser melting (SLM), direct metal laser sintering (DMLS), electron beam melting (EBM) and selective heat sintering (SHS). SLM and DMLS work in the general same way as SLS but replace the carbon dioxide laser with an ytterbium fiber laser and work in an inert gas-filled environment which allows it to melt metallic powders. EBM follows the same concept but replaces the laser with an electron beam and the gas environment with a vacuum. SHS is very similar to SLS but replaces the laser with a heat thermal print head in order to lower the cost of the process. Parts produced with a powder bed fusion method require extensive post processing in the form of machining and placing the part in a furnace. [6]

3.1.6 Sheet lamination

Sheet lamination is a method of AM in which sheets of material are placed on top of each other and bonded together [9]. This can be achieved by preparing the cross-sections beforehand and stacking them or by stacking layers of material first and cutting a contour of a cross-section of the part on each layer. Notable commercial brands using this method are laminated object manufacturing (LOM) using paper, and ultrasonic additive manufacturing (UAM) using metal tapes and foils. [6]

3.1.7 Vat photopolymerization

Vat photopolymerization is a process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization [9]. Stereolithography (SL) is a vat photopolymerization process in which a laser is used to cure photopolymer resin to for solid parts. The process set-up consists of a vat, a build platform, an elevator, a sweeper, a laser, lenses, and a scanning mirror. In some variations of the process, the elevator is replaced with a piston underneath the build platform.

The build platform is lowered into the vat and the sweeper deposits photopolymer resin across the platform in the thickness of one layer of the final part. A laser then activates and sends a beam to be focused by the lenses and from there to a mirror that scans a 2D cross-section of the part.

Once the layer is done, the laser de-activates, the build platform is lowered by the thickness of one layer, and the process starts again by adding more photopolymer resin. After all layers have been finished the build platform is raised and the part taken out of the machine. Stereolithography requires post processing in which the part is first submerged into a chemical bath to remove excess resin and then placed in an ultraviolet oven to cure it further. [1]

The schematic of the process of stereolithography is presented in Figure 5:

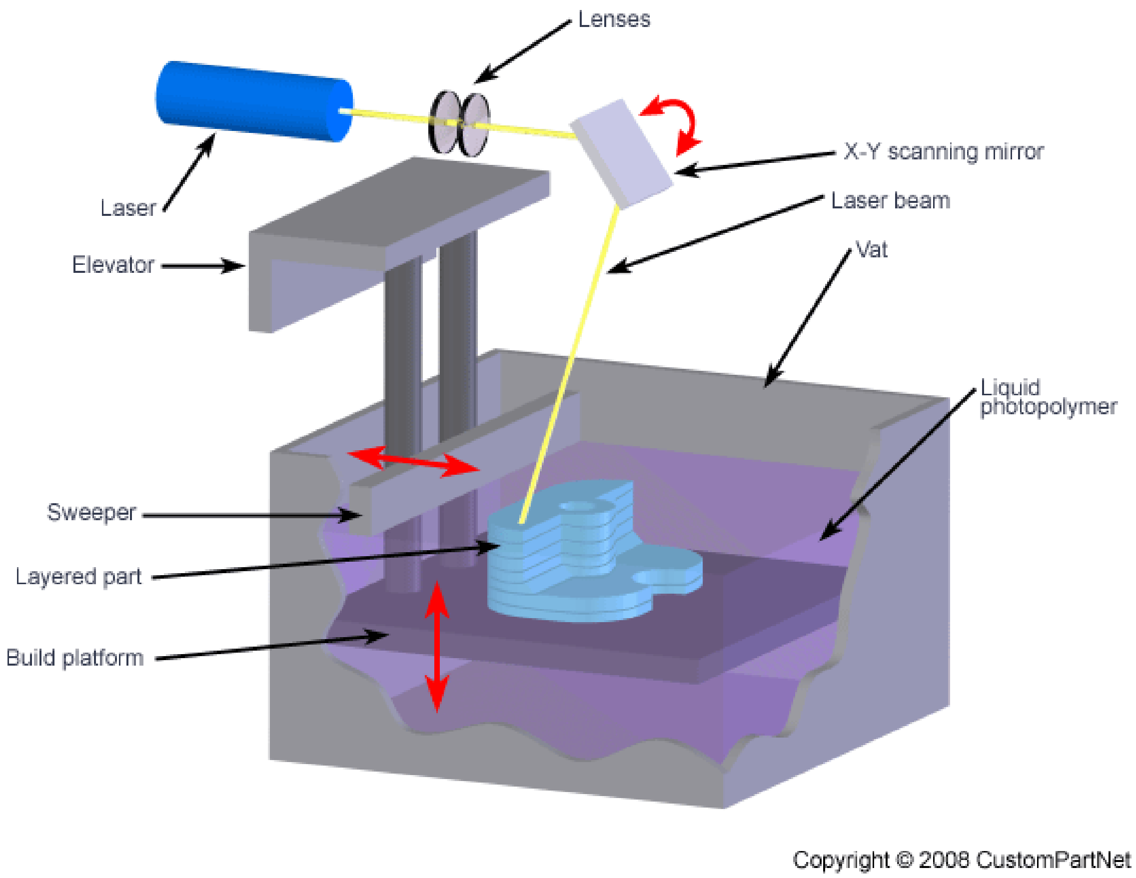

Figure 5: Sterelithography process schematic [14]

Stereolithography is one of the most accurate technologies available and it allows layer thicknesses as low as 0.05 mm. As the resin cannot physically support solidified parts of the build, support structures are needed for overhanging features. Stereolithography is one of the faster technologies but is also one of the more expensive ones. Materials used for stereolithography are proprietary resins manufactured exclusively for the process and varying in attributes from strength to flexibility. [15]

3.2 Classification of applications of AM in the industry

Industrial applications of AM are generally divided into three categories: rapid prototyping (RP), rapid tooling (RT) and rapid manufacturing (RM). It should be noted that the classification of applications in this chapter only applies in industrial use and that it does not fit the applications in the medical field. [16]

3.2.1 Rapid prototyping

Prototyping is the action of producing an approximation of a product. A prototype can be analytical, digital, or physical. The scale of a prototype can be defined by its dimensions of interest which are singular features that are in the need to be examined and iterated before finalizing the product. In the field of product development and R&D it is common to create two separate prototypes, one which looks like the final product and one that works like the final product. [17]

Rapid prototyping is producing a physical representation of an object in a manner that is rapid compared to conventional manufacturing. RP is mostly used in R&D where it serves to increase the iteration speed and produce tangible prototypes for verification of feel and proportion. [18]

RP can be divided into visual prototyping and functional prototyping. Visual prototyping entails using AM to produce parts solely for visual and limited tangible examination to physically present the design attributes such as dimensions. In functional prototyping a part is created to showcase its functionality. Assembly tests can be performed on both prototyping categories although functional prototypes tend to be more accurate. Visual prototypes typically do not contain moving parts whereas functional prototypes do. [6]

3.2.2 Rapid tooling

Rapid tooling (RT) can be divided into indirect tooling and direct tooling. In indirect tooling a mold is manufactured using a master created using AM. An example of indirect tooling is investment casting. In direct tooling a tool is created directly using AM. An example of direct tooling is conformal cooling used widely in plastic injection molds to improve the geometry of cooling channels. [16]

Conformal cooling is a method of creating cooling channels in a way that is challenging or impossible with traditional machining. Commonly, the cooling channels take the form of a spiral or, as the name suggests, conform to the shape of the object itself [19]. Traditionally cooling channels have to be created by drilling or boring, which means that the channels have to all be straight and in some designs the excess holes have to be plugged as shown in Figure 6.

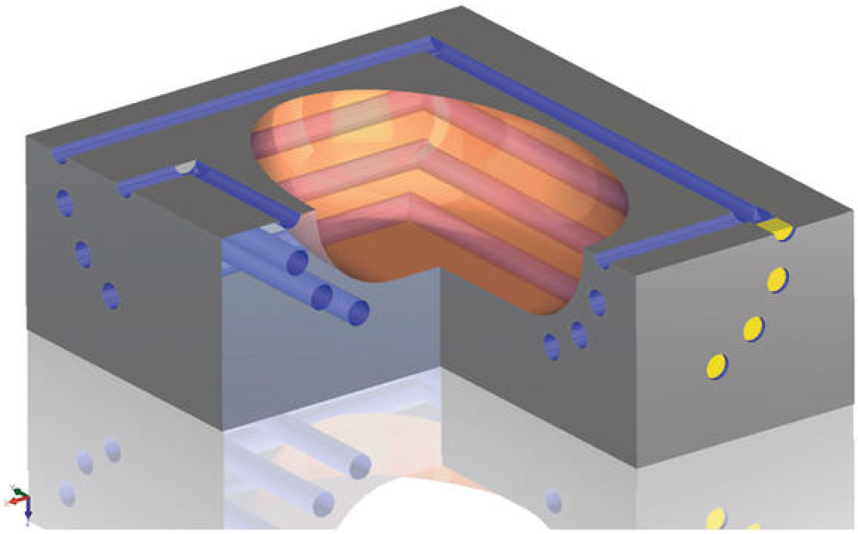

Figure 6: Traditional cooling channels in an injection mold. [20]

Conformal cooling can be used either in parts themselves, as shown in the example in Figure 7, or it can be used in production molds, as shown in Figure 8.

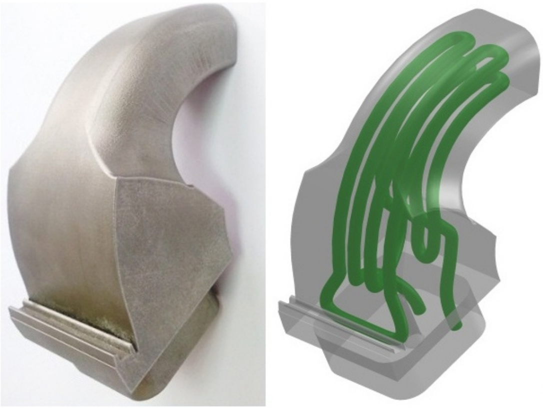

Figure 7: Conformal cooling in a part. [21]

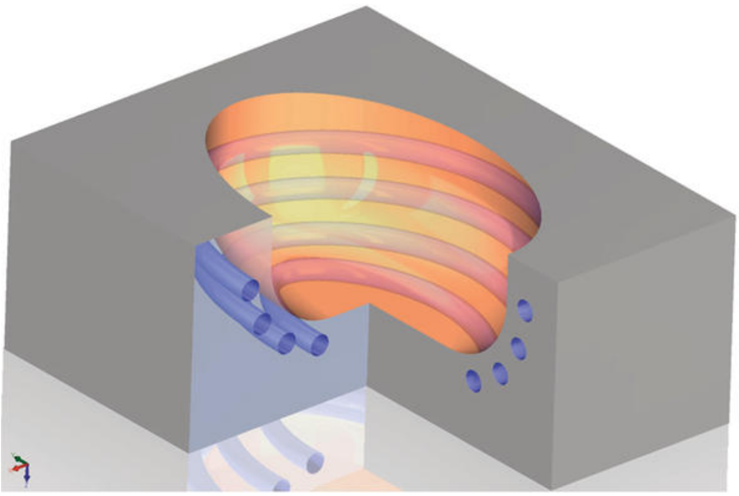

Figure 8: Conformal cooling in an injection molding mold. [20]

Silicone molding is an indirect method for producing low volume batches of silicone parts using AM. In silicone molding a master model is created using vat photopolymerization, which is post processed to achieve the required surface finish.

Liquid room temperature vulcanizing silicone (RTV silicone) is then poured on top of the master model and left to cure. Once cured, the silicone mold is split in half and is then ready to be used as a low volume injection mold. [22]

The process of direct mold tooling includes creating a two-part negative mold directly with a sufficiently accurate technology, such as vat photopolymerization, post processing to achieve the desired surface properties, pouring liquid silicone inside the mold and closing it for curing. This process creates silicone parts. Using processes capable of producing metallic parts, metallic injection molds can be manufactured directly using AM. [23] Sand molds are possible to manufacture using binder jetting AM technologies [24]. Figure 9 demonstrates direct mold tooling.

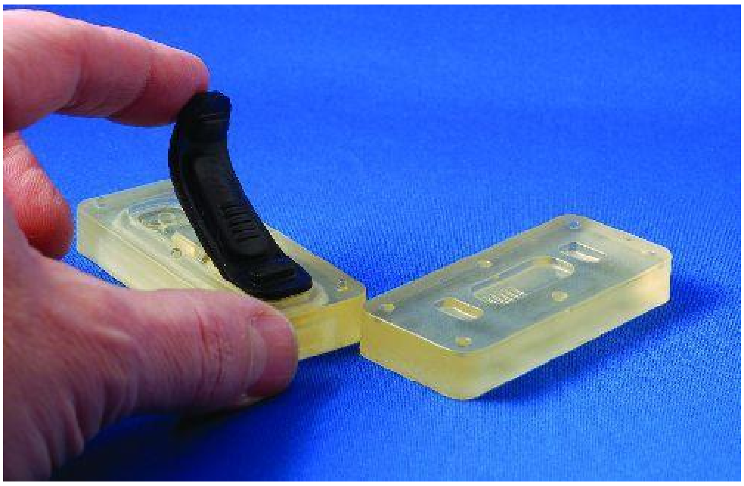

Figure 9: Direct mold tooling. [25]

Investment casting is used in conjunction with AM to create metal parts with minimal molding. The process includes using a master created with AM using materials of low ash content such as wax and certain plastics. [26] The master is coated with ceramic slurry, gas exhaust channels added, and after a period of drying the master is burned out leaving a hollow ceramic shell to cast liquid metal into. After the casting, the shell is cracked and excess material removed from the part by machining. [24] Figure 10 demonstrates the process of investment casting.

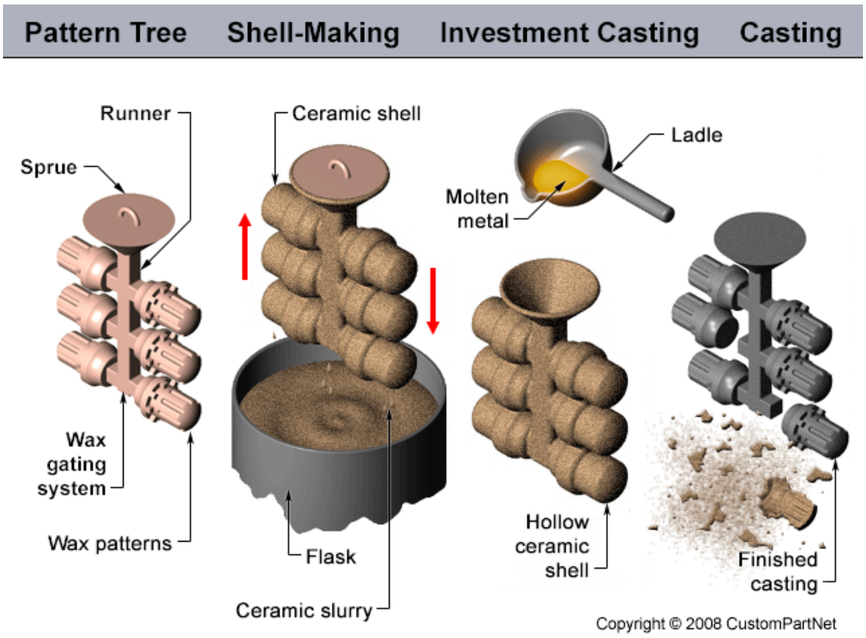

Figure 10: Investment casting. [27]

3.2.3 Rapid manufacturing

Rapid manufacturing (RM), also referred to as direct part production (DPP) and direct manufacturing (DM), is creating the part directly for end use using AM. Depending on the needs of the user, plastics or metals are used. In order to achieve the quality of a finished product, extensive post processing is usually required. In 2012 the share of direct part production was 28.3% which is a considerable percentage compared to 3.9% it was in 2003. While in the medical industry producing parts with AM is commonplace, it has only niche applications in the industry. [6] [28]

3.3 Previous surveys on AM

In order to accurately assess the needs and practices of the Finnish industry it was essential to take a look at past research done in the field. The most relevant reports to this thesis were Wohlers report 2013 [6], Selvitys 3D-tulostuksen tilanteesta Suomessa [29], and Thinking ahead the Future of Additive Manufacturing [30].

3.3.1 “Wohlers report 2013”, 2013

Wohlers 2013 conducted a survey on 74 service providers from 19 different countries, the closest one to Finland being Sweden. Additionally, Wohlers report 2013 contains state of the art reports from 23 countries written by AM experts from each country. Such information would prove useful for this thesis but it is unfortunately provided on a very large scale without going into details. The report contains information on the distribution of AM usage. This information is presented in Figure 11.

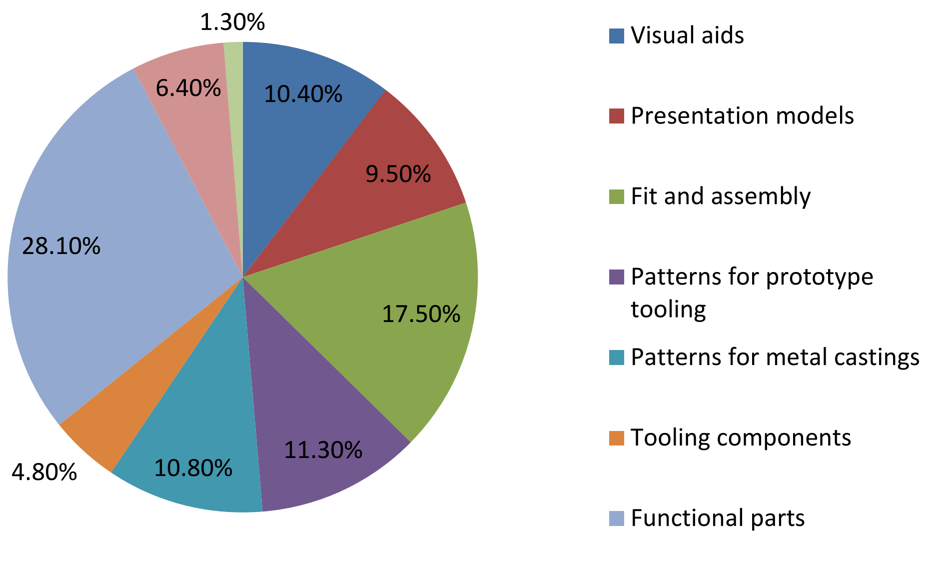

Figure 11: distribution of AM usage. [6]

As can be seen from Figure 11 functional part production is at 28.1%, tooling components at 4.8%, patterns for prototype tooling at 11.3%, patterns for metal castings 10.8%, fit and assembly 17.5%, presentation models 9.5%, visual aids 10.4%, education and research at 6.4%, and other uses at 1.3%.

In order for this information to be relevant to the thesis, it needed to be formatted to correspond with the RP/RT/RM model presented earlier. Presentation models and fit and assembly can be seen to be rapid prototyping. Patterns for prototype tooling and metal castings and tooling components are rapid tooling and functional part production translates well into direct manufacturing. Taking this into consideration and leaving out educational and other use, the distribution of RP/RT/RM of AM according to Wohlers is shown in Figure 12.

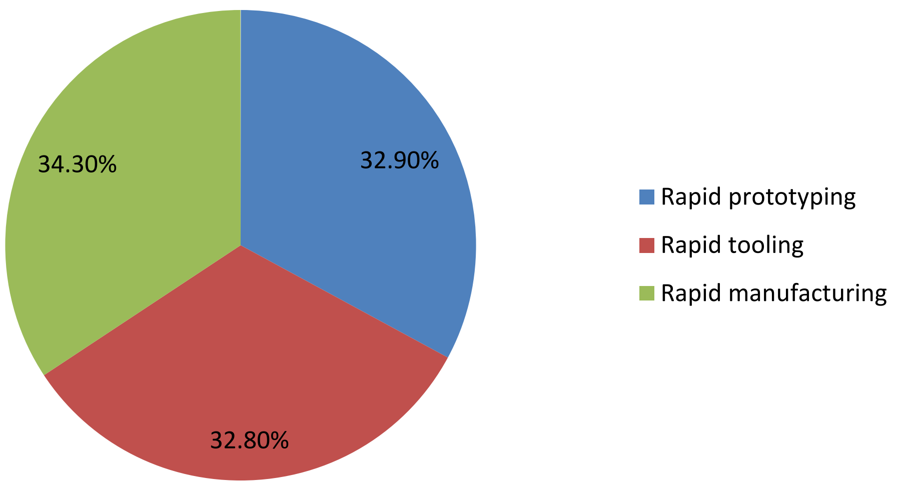

Figure 12: Distribution of applications of AM formatted in RP/RT/RM.

Transformed into the RP/RT/RM format the distribution of applications according to Wohlers is very closely divided into equal categories with RP having 32.9%, RT 32.8% and RM 34.3%.

The data in the Wohlers report regarding the distribution of technologies employed by service providers is presented in Figure 13.

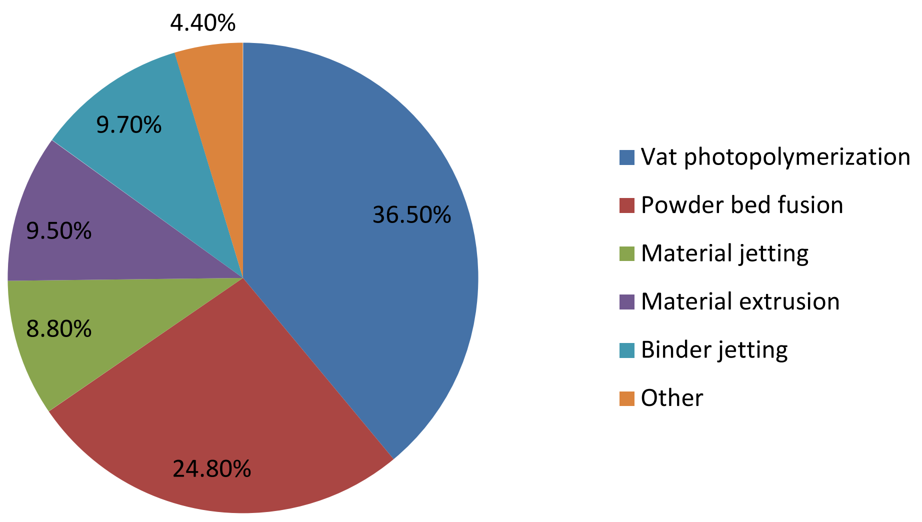

Figure 13: Share of technologies used by service providers worldwide [6]

Vat photopolymerization and powder bed fusion form a 61.3% share of all AM technologies used by AM companies. Using powder bed fusion processes such as SLS has many advantages for service providers that include high process stability, high accuracy, relatively low cost of material, and easy post processing. The large share of vat photopolymerization can be partially explained by the accuracy of the process and a large material library available for stereolithography but it should be noted that while stereolithography has currently the largest install base, it is in a steady decline. [6]

3.3.2 “An investigation of the state of the industry of 3D printing in Finland”, 2011

In 2011 Oulu University of Applied Sciences released the thesis work of Jarkko Lohilahti with the topic of “Selvitys 3D-tulostamisen tilanteesta Suomessa” which translates to “An investigation of the state of the industry of 3D printing in Finland”. The goal of the thesis was to map out the AM service providers of the Oulu region and compare them to the service of Oulu PMC. Another goal of the thesis was to find a preparative way to monetize 3D printing and to create a draft of marketing material. The thesis compared five service providers including Oulu PMC. Financial information of the service providers was provided. A grading system was created to include evaluation of the web pages, marketing, machinery, utilization time and turnover of the service providers. No surveys were conducted that included the personnel of the service providers or industrial companies. [29]

3.3.3 “Thinking ahead the Future of Additive Manufacturing”, 2013

The Direct Manufacturing Research Center (DMRC) of the University of Paderborn released a study concerning the future prospects of AM. Two surveys were conducted for the study. The first survey was conducted on 325 experts in the field. The survey was completed by 56 of the experts amounting to a 17% response rate. The survey consisted of four parts; the first one addressing the professional background of the experts, the second asking the experts to assess multiple general requirements for AM, the third asking more specific questions concerning AM technologies, and the fourth outlining final statements of the experts.

According to the results, 41% of the respondents were users but no distinction was made between service providers and industrial companies. It is indicated in the report that 77.3% of the users used AM for direct manufacturing, 72.7% for rapid prototyping, 54.5% for rapid tooling, and 4.5% for other purposes. Direct manufacturing is another term for rapid manufacturing. These figures are different compared to the ones in Wohlers report which can be explained by the fact that multiple choices were allowed in this questionnaire. These results are presented in Figure 14.

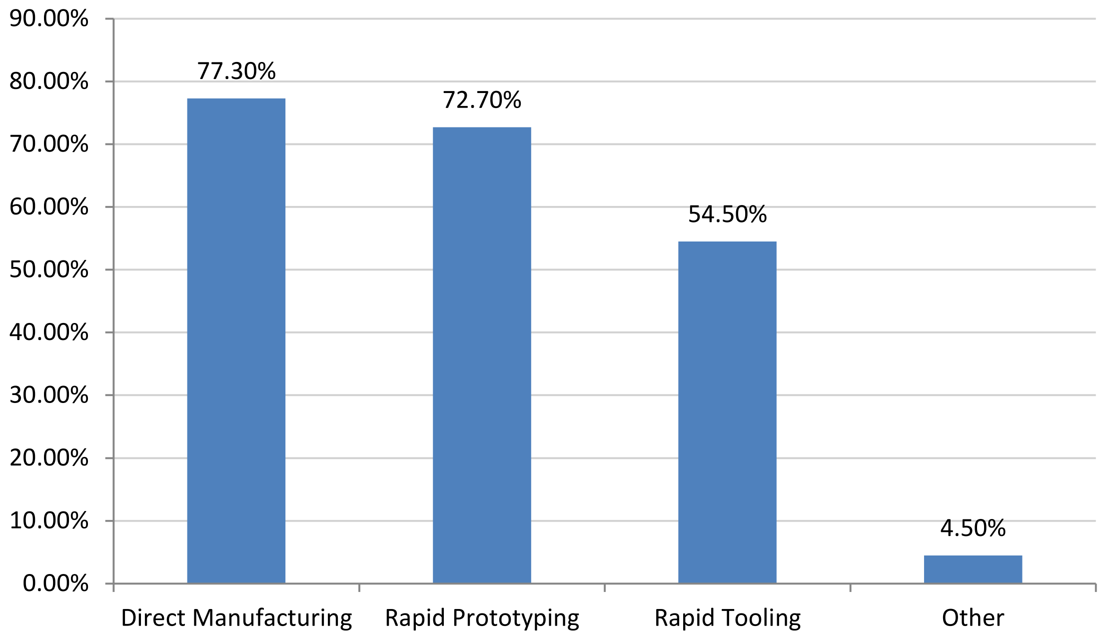

Figure 14: Percentage of users using certain applications [30]

According to the study, the experts valued high process stability, databases containing material properties, quality control processes, continuous certification, design rules, recyclability of materials, possibility to use carbon-fiber-reinforced polymers, fire resistance of AM materials, larger build chamber volumes, faster build speeds, better surface quality, higher dimensional accuracy, and lower maintenance costs. A large portion of the study focused on expert opinions on the future development of powder bed fusion processes.

The second survey was conducted on 395 experts out of which 75 answered which gave a 19% answer rate. In this study 50% of the respondents identified as users. This time 78.6% of the users reported to be using direct manufacturing, 64.3% rapid prototyping, 31.4% rapid tooling and 15.7% reported to be using AM for other purposes. While the amount of participants using direct manufacturing and rapid prototyping stayed roughly the same, the amount of participants using rapid tooling had declined by 23.1% and the amount of users using AM for other purposes rose by 18.6%. [30]

3.3.4 “AM in South Africa: building on the foundations”, 2011

In 2011 Ian Campbell, Deon de Beer and Eujin Pei from the Vaal University of Technology, Vanderbijlpark, South Africa, released an article in rapid prototyping journal concerning the state of the industry of AM in South Africa.

The report states that South Africa had an install base of 138 AM machines at the time of writing of the report. Out of the 138 machines, 120 were low end FDM machines and 18 unspecified high end AM machines. The report also states that 91% of the machines in the industry were low end FDM machines and 82% of the machines in universities and research centers were high end machines. [31]

4 Assessing the needs and practices of AM in the industry

In order to understand the needs and practices of AM in the Finnish industry, an investigation into the steps required to run a survey was conducted. Appropriate works of literature were chosen as guides.

The five stages in the development and completion of a survey according to Ronald Czaja [32] are the following:

1. Survey design and preliminary planning
2. Pretesting
3. Final survey design and planning
4. Data collection
5. Data coding, data-file construction, analysis, and final report

These first part of the process, designing the survey and planning its execution, includes going through the goals and methods of the survey, determining who and how many companies and people were to be surveyed, looking into available resources, designing the questionnaire, and preparing guidelines to analyze the data.

4.1 Goals

The goal of the assessment was to find out how and how much the Finnish industry was using AM and what lead them to specific choices. The points of interest outlined for this goal are the following.

- Mapping out how well different AM technologies are known and how they are being utilized

- Understanding how companies procure machinery, what machines they have, and how they use them
- Understanding company practices in outsourcing, how much of their AM activity is outsourced, and what are the reasons behind this
- Acquiring a hypothetical link between ownership of machinery and outsourcing of AM activity through the means of finding general information concerning both.

4.2 Determining sampling decisions

As it was not viable to investigate every single company in Finland to determine how they are using AM or if they are using AM at all, a decision had to be made to narrow down the list of companies to those that potentially use AM. The first criterion for being accepted to the list of potentially surveyed companies was that they should be in one of the fields cited as users of AM in Wohlers report 2013 which meant that companies in the following fields qualified:

- Motor vehicles
- Aerospace
- Industrial/business machines
- Consumer products/electronics
- Medical/dental
- Academic institutions
- Government/military
- Architectural

Because the goal of the survey is to find out how AM is used for industrial purposes in Finland, a second criterion was put into place demanding that the companies must be industrial, leaving the following fields as acceptable categories for companies to survey:

- Motor vehicles
- Aerospace
- Industrial/business machines
- Consumer products/electronics

Keeping the two criteria in mind, AM experts were consulted on which companies would fit the profile. The list of potential companies consisted initially of 28 companies, of which eight agreed to be interviewed, which gives a reply rate of 29% which is slightly higher than the 19% response rate cited in University of Paderborn's survey. [6] [30]

The hesitant approach of the companies is explained through a variety of reasons. Most of the companies did not agree to be interviewed because of their lack usage of AM. Some companies refused to participate on the grounds that their practices in usage of AM are sensitive. Others declined citing lack of time.

The remaining eight consisted of both small and medium-large companies. The majority of the companies were in the field of consumer products and electronics and the rest were in the field of industrial and business machines. No companies from the motor vehicles and aerospace fields chose to participate.

4.3 Choice of interviewees

The interviewees within the companies were chosen on the grounds of being close to the usage of AM or being decision makers regarding the technologies in use. Fifteen employees spread as evenly as possible between the companies were chosen to be interviewed. Among occupations of the interviewees were machine operators, production managers, project managers, industrial designers, CAD specialists, and CEOs.

4.4 Determining available resources

In order to properly plan the scope of the survey an evaluation of available resources was necessary. The resources needed to conduct the survey were the amount of people working on the survey, the cost of conducting the survey, and the duration of time until the survey had to be done. The staff of the survey consisted of a master's thesis worker whose salary was covered by the budget of the survey, and the duration of time until delivering final results was five months.

4.5 Questionnaire

One of the most important decisions to make when constructing a questionnaire is to decide whether to make the questions open-ended or closed-ended, which roughly correspond with qualitative and quantitative methods. The United States department of energy uses the comparison chart shown in Table 2 to determine how their surveys should be structured.

Table 2: Qualitative/quantitative comparison chart [33]

Qualitative Methods	**Quantitative Methods**
Methods include focus groups, in-depth interviews, and reviews	Surveys
Primarily inductive process used to formulate theory	Primarily deductive process used to test pre-specified concepts, constructs, and hypotheses that make up a theory
More subjective: describes a problem or condition from the point of view of those experiencing it	More objective: provides observed effects (interpreted by researchers) of a program on a problem or condition
Text-based	Number-based
More in-depth information on a few cases	Less in-depth but more breadth of information across a large number of cases
Unstructured or semi-structured response options	Fixed response options
No statistical tests	Statistical tests are used for analysis
Can be valid and reliable: largely depends on skill and rigor of the researcher	Can be valid and reliable: largely depends on the measurement device or instrument used
Time expenditure lighter on the planning end and heavier during the analysis phase	Time expenditure heavier on the planning phase and lighter on the analysis phase
Less generalizable	More generalizable

While quantitative methods are more objective, cover a large number of cases, and are more generalizable, qualitative methods provide more in-depth information.

In order to produce results that are easily comparable to each other and scientifically valid, the method of data acquisition had to be of a quantitative nature. However, many of the goals were too ambiguous to be answered with a closed-ended question.

As a result of evaluation between different types of assessment methods, a multi-part questionnaire consisting of both qualitative and quantitative questions was devised in order to gather data. The qualitative answers would then be converted into quantitative data. Because of the fact that the resulting questionnaire contained open-ended questions, the best approach was seen to be a personal interview with each interviewee. This approach consumes more time in the data gathering and analysis stages but as there were enough resources it was deemed acceptable.

Questionnaires are typically organized into sections that follow the logic of the pursuit of the survey's goal. [32] The questionnaire was made to consist of five parts. The first and fifth parts were completely quantitative and second, third, and fourth part contained multiple qualitative questions. Each interview lasted between an hour and two hours.

The introductory first part consisted of assessing how familiar the interviewee was with certain technology brands. This was deemed to be a good way to introduce the interviewee to the goals of the survey and to make them more inclined to give more straightforward answers in the content heavier parts of the interview. The familiarity of technology brands was graded in binary. The technology brands examined were:

- Three dimensional printing
- Laser cladding
- Fused deposition modeling
- PolyJet
- Selective laser sintering
- Selective laser melting
- Electron beam melting
- Selective heat sintering
- Laminated object manufacturing
- Stereolithography
- Digital light processing

The second part focused on the ownership of machinery inside the company and consisted of the following questions:

1. Do you own AM machinery?
    a. Which technologies/machines do you own?
    b. On what grounds were they chosen?
2. Who operates the machinery?
3. What are the practices of maintenance of the machines and are the machines upgraded?
4. How high is the utilization rate of the machines?

The third part focused on the outsourcing of AM parts and consisted of the following questions:

1. Do you outsource manufacturing of AM parts?
2. Could a part of the manipulation of CAD parts be outsourced?
3. How secret are the CAD files?
4. How is it decided what to outsource?
5. Is secrecy a deciding factor in outsourcing?
6. Is quality assurance carried out on the outsourced parts?
7. Are the costs of outsourced parts monitored?
8. Are there technologies that the company would like to use but the investment costs are too high?
9. Is there a need to use a certain technology but they are not available?

The fourth part focused on information relevant to both outsourcing and producing parts in-house and contained the following questions:

1. How fast do you receive parts from the moment you have a finished CAD file and intend to print it or outsource it?
    a. Less than a day
    b. Approximately a day
    c. Multiple days

   d. Approximately a week
2. Is there a need to shorten this time or is a slower time acceptable?
3. In which distribution do you use RP/RT/RM?

The fifth part examined the perceived importance of different factors related to AM, which were:

1. Receiving the part quickly
2. Accuracy of the part
3. Suitability of the material
4. Security of CAD files
5. Optimality of processes
6. General knowledge in the field of AM

The questionnaire was tested on AM experts to verify that the questions were valid and the potential data extracted using them was useful.

4.6 Collecting data

Once the companies were selected and contacted to participate in the survey, the data collection process was straightforward. A time slot of two hours was reserved with each employee and a place for the interview was set. The location of the interview varied from interview to interview using Business Innovation Technology's meeting rooms or available spaces in companies' premises. If convenient, multiple employees from the same company were interviewed in one session. The data collection period lasted three months.

4.7 Analyzing data and writing a report

It is important to decide what questions are being sought answers for before the actual implementation stage [32]. As was listed in the goals and methods of this chapter, analyzing the data should be from the perspective of technologies, machinery ownership, outsourcing, and general information. These sub-goals were further broken down into topics of interest and data analyzed from their perspective. Quantitative information was to be sorted into tables and charts and qualitative information was to be presented as is and quantified wherever possible.

Mapping out the knowledge and usage of AM technologies was to be divided into a section describing the familiarity of technologies and ranking them according to how many interviewees were familiar with a technology, and a section where each technology was examined and all information given by interviewees explained. A further analysis of the ratio of usage of AM applications was also to be written. The list of viewpoints used to analyze the data was the following:

- Familiarity of technologies
- Individual view of each technology
- Distribution of applications

Analyzing ownership of machinery was to be done by listing how many machines companies owned in average, what their practices were in procuring machinery, who they employed to operate the machines, what was the utilization rate of the machines, how they maintained the machines, what was the average build time, and how they monitored the costs of using the machinery. The list produced to analyze the ownership was the following:

- Practices in procuring AM machinery
- Operating AM machinery
- Utilization rate

- Maintenance of machinery
- Build time
- Monitoring costs

Outsourcing of AM parts was to be analyzed through the viewpoints of how much of their AM activity was outsourced by percentage and its cost, how their quality assurance works when outsourcing, how they monitor costs inflicted by outsourcing, how important the security of their intellectual property is, what is their average lead time, and what is their maximum benefit threshold. The viewpoints used for analyzing this data were:

- Quality assurance
- Information security of CAD files
- Order lead time
- Maximum benefit threshold
- Monitoring costs

The general factors to connect ownership of machinery and outsourcing were to be presented as a table and expanded upon. A report of the analyzed data was written in Finnish and is appended to the thesis as appendix 1. This report was sent to the participating companies immediately after completion.

5 Results

Fifteen people from eight companies were interviewed and each gave a separate answer to the questions in the questionnaire. The interviews were stored separately and later combined into single file consisting of the questionnaire and each individual answer under every question. The quantitative answers were analyzed through statistical means by listing the answers and calculating the percentage of interviewees to give a certain answer and calculating the average and percentiles where applicable. Qualitative answers were quantified where possible and given the same statistical analysis as quantitative answers. In the case of qualitative answers that could not be quantified, they were arranged together and an impartial interpretation conducted.

5.1 Familiarity of technologies

In the first part of the survey, the familiarity of the chosen technologies was investigated. The results of this part of the questionnaire are listed in Table 3. The results are given as the amount of interviewees familiar with the technology divided by the total amount of interviewees. A technology by technology breakdown in the familiarity is given in subsequent subchapters.

Table 3: Familiarity of technologies

Place	Commercial name	Familiarity (%)
1.	FDM	88.9
-	SLS	88.9
-	SL	88.9
4.	SLM	77.8
-	LOM	77.8
6.	Polyjet	55.6
7.	3DP	22.2
-	DLP	22.2
9.	EBM	11.1
-	SHS	11.1
11.	LENS	0

88.9% of the interviewees were familiar with FDM, SLS, and SLA. 77.8% were familiar with SLM and LOM. 55.6% were familiar with Polyjet. 22.2% were familiar with 3DP and DLP. 11.1% were familiar with EBM and SHS. None of the interviewees were familiar with LENS. Generally, only FDM, SLS and SLA were widely known and the rest of the technologies were more obscure. It can be expected that the familiarity of technology would directly relate to the distribution of usage of technologies.

5.1.1 Fused Deposition Modeling

In order to produce clarity, Fused Deposition Modeling (FDM) technology is divided into consumer devices and industrial devices. Devices manufactured by Stratasys can be seen as industrial devices and the ones based on the RepRap project can be seen as consumer devices. Approximately 15% of the companies owned several consumer FDM devices. These have been acquired to try out accelerating R&D in-house. Generally these devices have been considered very inaccurate and unreliable among the interviewed companies.

25% of the companies owned an industrial FDM device and utilized them approximately 19 hours per week. Approximately 8% of the companies outsourced the creation of FDM parts but the amount of outsourced FDM parts compared to the total amount of outsourced parts is minimal. The selection of materials, which is adequately strong and durable according to the users, was noted to be a positive factor in FDM. The ease of post processing was also seen as a positive aspect.

High end devices of 100,000 euros and up were not well known. The improved accuracy and an expanded material library of the high end machines were received as news.

5.1.2 Selective Laser Sintering

None of the participating companies owned a Selective Laser Sintering (SLS) machine. However, companies outsource SLS models heavily. The durability of the material was seen as positive and the accuracy divided opinions. Out of the companies that outsource SLS models, half have been satisfied with the accuracy of SLS and the other half only employ SLS when the accuracy does not need to be high. The rough surface quality was universally seen as a problem.

As it is faster and more cost efficient to produce more than singular parts at once with SLS, companies with less usage tend to avoid buying an SLS machine and outsourcing the part instead. SLS also requires special facilities for usage because the plastic powder it uses to produce parts has a tendency to spread around and disturb a work space. A post processing station is needed and material handling planned for an SLS process. These are also contributing factors to why SLS machines are not acquired by companies looking for an office friendly solution for AM.

5.1.2 Stereolithography

12.5% of the companies owned a stereolithography (SL) machine. 50% of the companies outsource SLA models with the main suppliers being a well-known German service provider with a subsidiary in Finland, and several foreign suppliers from China.

Stereolithography continues being the one technology associated with outsourced quality parts. While it is partially true that stereolithography is one of the most accurate AM technologies, its popularity can also be attributed to the fact that it was widely spread at an early stage of AM development in the 1990s. Several more affordable technologies have surfaced since and have been proven to be as effective as SL in select applications. According to Wohlers report 2013 SL is the most profitable technology for service providers yet it is not anymore the most acquired machine type in the industry. [6] This supports the hypothesis that the use of SL will diminish in the coming years and gradually lose its share to other technologies.

5.1.3 Selective Laser Melting

None of the companies owned Selective Laser Melting (SLM) machines or actively outsource SLM models. The technology has been attempted in some projects with differing levels of success. The major problems were seen to be the cost, quality, and slowness of the technology. Smaller problems were the removal of supports and the accuracy of the technology. 75% of the companies showed interest in using SLM in the future.

A restricting factor in acquiring SLM machines is the abundant need for post processing. In order to produce parts of desired quality, the part needs to be heat treated in an industrial oven and machined afterwards. This not only discourages companies from acquiring this type of machines but also service providers are vary, because it would mean a large investment and either training or hiring of staff in order to be able to carry out the post processing tasks. This limits the availablility of the technology and drives up the cost. However, as there is considerable interest in producing metallic parts through the use of AM, it can be seen as a gap in the market for service providers.

5.1.4 Laminated Object Manufacturing

None of the companies owned a Laminated Object Manufacturing (LOM) machine or outsourced LOM models. The high familiarity of the technology is caused by its wide use in the 1990s. When working with paper, the biggest restriction of LOM is the limitation of the mechanical properties of paper. If the machine used can handle plastics, the loss of material in the form of excess in each sheet is an issue. However, the material in the newest iteration of LOM is commonly available A4 paper, which makes it a tempting option for companies that produce a lot of visual prototypes. These companies are commonly architectural or planning offices which were not included in the survey and thus do not show up in the results.

5.1.5 PolyJet

37.5% of the companies owned a Polyjet or a comparable Multijet Modeling (MJM) machine. The machinery has been perceived as very sensitive and as needing a lot of continuous preventive maintenance.

The users have noted that the need for a consistently high utilization rate to prevent degradation of the build quality is a problem. With Polyjet, the manually intensive post processing process is another problem. With MJM the warping of the parts during post processing is a problem. The shrinkage effect inherent to the technology is also seen as problematic. Positive factors included the accuracy of the parts and the excellent flatness was cited. The materials have been generally adequate for their intended use. PolyJet machines are well adopted by industrial companies due to its ability to produce high quality parts quickly and the simplicity of post processing.

5.1.6 Three-Dimensional Printing

None of the companies owned a Three-Dimensional Printing (3DP) machine or outsourced 3DP models. The biggest problem was seen to be the fragility of the parts. Producing colored parts was not seen as a value adding factor. As with LOM, 3DP is generally used for visual prototypes in the fields of planning and architecture which are not represented in this survey.

5.1.7 Digital Light Processing

None of the companies owned a Digital Light Processing (DLP) machine or outsourced DLP models. The familiarity of the technology is low. Major factors preventing the penetration of DLP are the relatively small build volume and the fragility of the parts. As it is a very accurate technology, DLP is well applied in the fields of jewelry and dentistry which were not present in this survey.

5.1.8 Electron Beam Melting

None of the companies owned an Electron Beam Melting (EBM) machine or outsourced EBM models. The familiarity of the technology is low. EBM is generally used for the production of implants and as there were no medical companies involved in this survey, the technology is not well known.

5.1.9 Selective Heat Sintering

While the only machine using Selective Heat Sintering (SHS) is already on the market and has a Finnish importer [34], it is not yet widespread. None of the companies owned an SHS machine or outsourced SHS models. The recognizability of the technology is low. After becoming familiar with the technology, a few companies showed interest in using the technology in R&D once the details of the technology are made available. The major attraction of SHS is its low price but it comes at the cost of reduced quality and mechanical properties which concerns companies.

5.1.10 Laser-Engineered Net Shaping

None of the companies owned a Laser-Engineered Net Shaping (LENS) machine or outsourced LENS models. None of the interviewees were familiar with the technology. LENS is largely used in the aerospace and automotive industries in niche applications and repairs which give reason for it not to be popular among the participants of this survey.

5.2 Distribution of applications

The applications of AM are divided into rapid prototyping (RP), rapid tooling (RT), and rapid manufacturing (RM). When outsourcing the application is determined by the end product ordered by and delivered to the outsourcing company. If the product is a prototype producer through silicon molding, the application is seen as RP. If the product delivered is the silicon mold itself, the application is seen as RT. 37.5% of the companies use silicon molds but most of these molds do not leave the service provider. The obtained data on the distribution of applications of AM in the companies is presented in Table 5.

Table 5: Distribution of applications

Application	Average	25th percentile	50th percentile	75th percentile
RP	84%	80%	90%	90%
RT	6%	0%	0%	5%
RM	10%	1%	10%	20%

RP is overwhelmingly the largest application of AM in the companies. 90% of the companies do almost exclusively RP. Compared to the rest of the world, RT is used to a very small extent in Finland. Silicon molding is common but usually the company only sees the end product. Investment casting has been experimented with but abandoned due to high expenses. The demand for RM would be large but its high price and insufficient quality have thus far been restricting factors. In companies with production facilities fixtures are being made for facilitating production. For some companies AM is the only type of production they have in Finland with everything else being outsourced to other countries. Compared to the data provided by Wohlers Report 2013, the distribution of applications in Finnish companies is highly skewed towards RP. A visual representation of the comparison of the distributions is given in Figure 15.

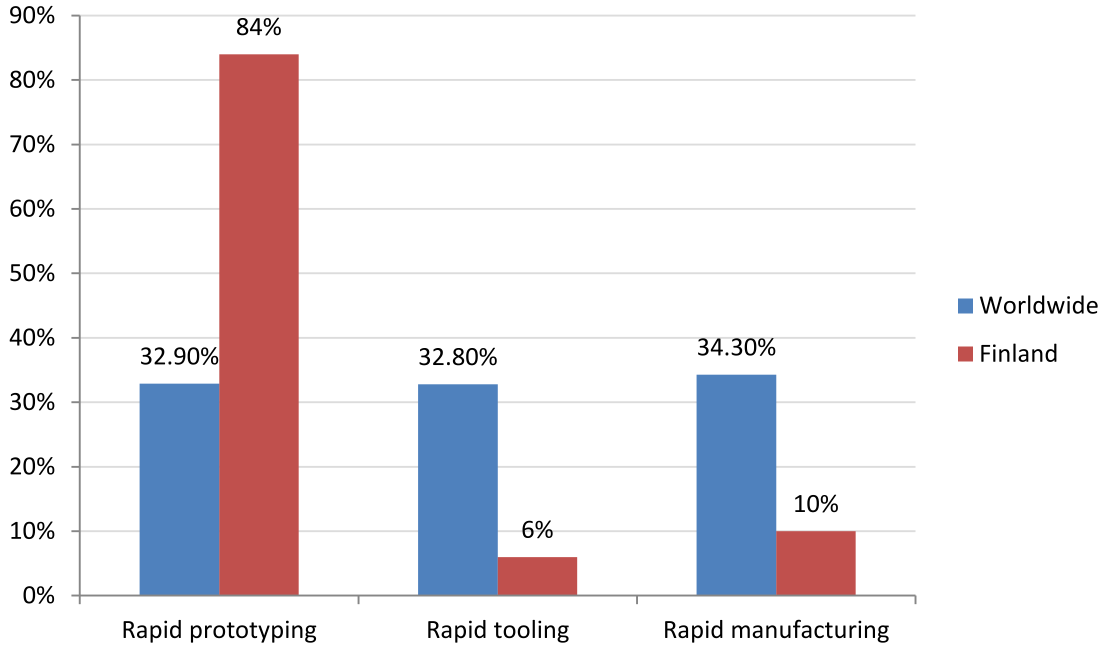

Figure 15: Distribution of AM applications in Wohlers Report 2013 and this survey

There are several points to consider as to why the distribution of applications in Finland is so drastically different from the worldwide one. The major reason is that the companies surveyed for Wohlers Report 2013 were service providers, whereas in this survey they were the companies that needed AM parts. The rising awareness of AM and the reduction of the cost of machinery has driven many industrial companies to procure their own AM machines which they use for prototyping, hence diminishing the amount of prototypes manufactured by service providers. The second reason is that the companies surveyed for this thesis were mostly in the field of consumer electronics which is heavily slanted towards RP. In addition, there is not as much automotive and aerospace engineering in Finland, which are big users of RM.

Even when taking all of the above reasons into consideration, the difference in the distributions is too large to fit into the margin of error. While RP is well understood and used in Finland, RT and RM are novel applications and the industry has not yet adapted to their usage.

5.4 Ownership and usage of AM machinery

The share of companies owning an AM machine is shown in Table 6. The amount of companies owning a machine is equal to the amount of companies with no machine. 25% of the companies own several machines. The quantity of machines by percentage of companies is given in Figure 16.

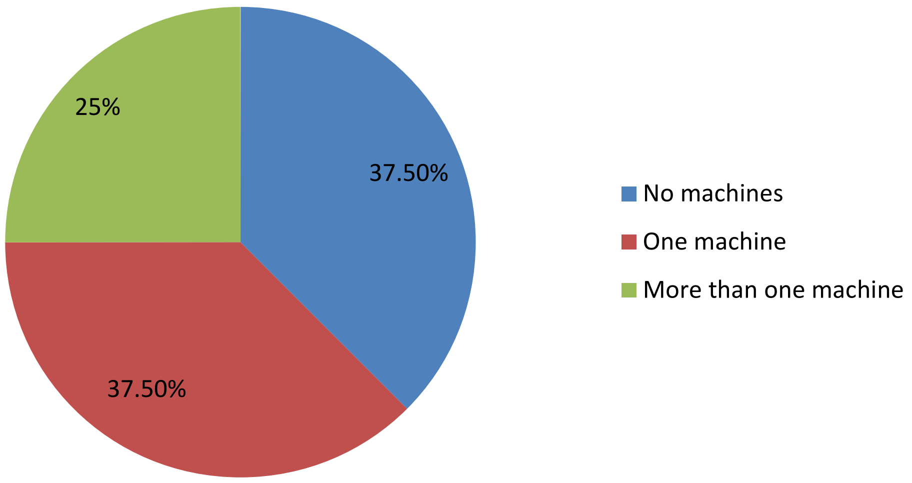

Figure 16: Quantity of machines in companies by percentage

Figure 16 shows the distribution of companies that own machinery. While this is important information from the point of view of companies showing interest toward AM and having a high probability of investing in it later, a representation of the distribution of industrial machine gives a better picture of how many companies are able to produce AM parts in-house. This information is given In Figure 17.

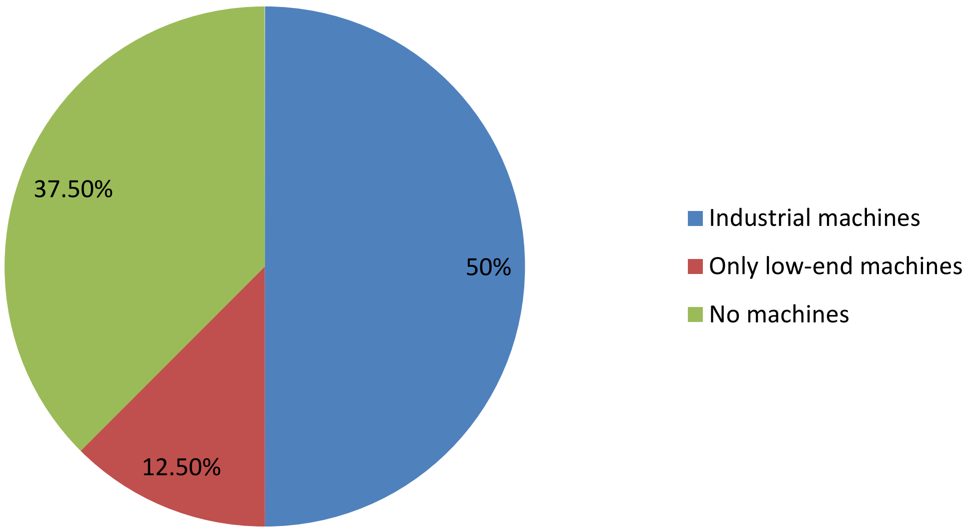

Figure 17: Distribution of companies by machine type

A company that owns an industrial machine is less likely to outsource the manufacture of AM parts. The ownership also improves their speed of obtaining a part and offers better protection of the secrecy of their CAD files. According to Figure 17, 62.5% of the companies own a machine and 37.5% do not and instead rely solely on outsourcing.

5.4.1 Practices in procuring AM machinery

The procurement of an in-house machine has typically been preceded by heavy outsourcing of AM parts. Companies have wanted to get an in-house machine in order to remove delivery times, speed up R&D iterations and to incentivize the use of AM machines for the R&D personnel. Another reason for procuring an in-house machine has been cost efficiency because producing parts with an in-house machine is cheaper than outsourcing and there are no hidden costs. The technologies of owned machines are shown in Figure 18

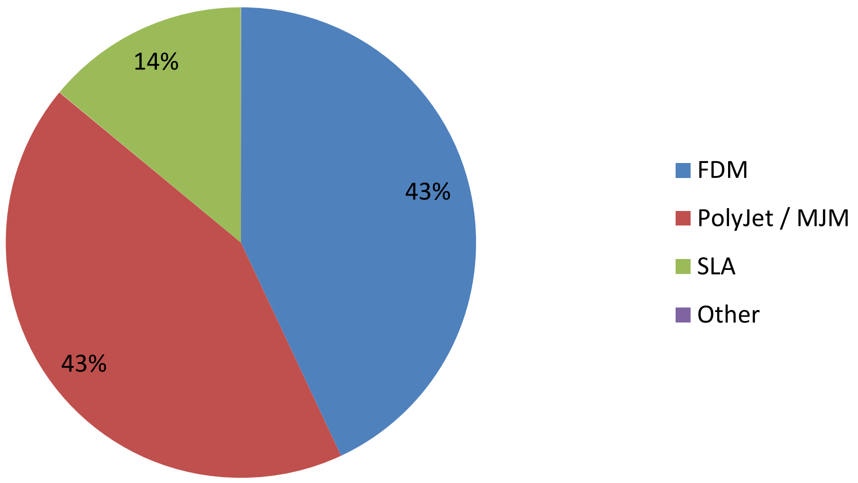

Figure 18: Technologies of owned machines by percentage

Purchasing any sort of machinery should be preceded by a careful examination of needs of the company and the options available to fulfill those needs. In the case of procuring machinery, the need is usually the ability to produce prototypes quickly and cost-effectively. A solution that leads to the procurement of an AM machine is that the company decides that the best solution to the need is to buy an AM machine. Further, the type of machine has to be decided on, which is where knowledge of the AM field becomes very important.

A general understanding of all AM technological categories is required along with an in-depth knowledge on the possibilities of their applications. After an AM technology category has been selected, it is equally important to know what kind of machines exist in that category, who manufactures them, how much do they cost to procure and maintain, what sort of maintenance and warranty deals does the manufacturer offer, what materials can the machine use, what special abilities do different machines offer and a complete view of its technical specification.

As an example of such a process, the AM category of powder bed fusion can be divided into subcategories by material or power source. The material subcategory can be divided into plastics and metals. The plastic sub-subcategory can be divided into machines that are able to create parts out of Nylon 11 and 12 mixed with fibers of different sorts, machines that can only handle Nylon 11 and machines that work with all the aforementioned plastics and PEEK in addition. In the metal sub-subcategory the choice is larger with machines that can handle everything from gold to titanium to machines that only work with certain types of metallic powder.

The power source category can be divided into laser, thermal printhead, and electron beam power sources. While machines that use a thermal printhead and an electron beam are proprietary and manufactured only by Blueprinter ApS [35] and Arcam AB [36] respectively, machines that use a laser are provided by EOS GmbH [37], 3D Systems [38], ReaLizer GmbH [39], SLM Solutions [40], Concept Laser GmbH [41], AFS Co. Ltd. [42], Shaanxi Hengtong [43], Trump Precision Machinery Co. [44] Wuhan Binhu Mech. & Elec. [45], Renishaw [46], and Matsuura [47]. A company has to look into each machine provider and evaluate it and its product. This includes finding the machines’ speed, power consumption, maintenance rate among other technological specifications.

As can be seen, the process of procuring an AM machine is fairly long and requires a lot of information on the field of AM and specific technological knowledge. As AM as a field is relatively new and progressing fast, companies are hard pressed to find employees among their ranks with enough knowledge to be able to make an educated procurement. This is where familiarity of technologies plays a large role as, according to the interviews, companies often buy a machine from a technology category they are familiar with. Low levels of knowledge of AM also make the companies more susceptible to the marketing of AM machine manufacturers. Some companies are satisfied with the amount of information they get from a machine importer at a trade show to purchase an AM machine.

5.4.2 Operating AM machinery

AM machinery is highly automatized when it is operating but can also be labor intensive during set-up and part removal phases. The presence of a machine operator is needed in the phase of machine set-up, when the machine is inspected and made sure that it is completely operational, .STL files are prepared to be included in the build, and the machine is started. The presence of an operator is also required when the build is finished. The parts have to be taken out of the machine and the machine has to be cleaned and maintenance conducted. The demand of post processing varies greatly between technologies but more often than not it takes several hours to remove all the support material from a full build and to finalize the parts. Operator presence is also required during the time a machine is running in case it stops or produces an error for any reason. Failure to intervene in such cases often means the loss of the entire build and damage to the machine.

The question of who is operating the AM machine is vital. The two most common ways to organize the usage of an AM machine are:

1. Letting the personnel responsible for 3D modeling use the machine themselves
2. Appointing an operator for the machine

The amount of companies using an appointed person to operate the machines is equal to the amount of companies using an open access policy. According to the interviews, the companies using the open access policy have been having frequent stand-stills, lowered build success rate, and an overall drop in appreciation of AM among the users.

5.4.3 Utilization rate

As AM machines are fully automatic during operation save for failures and errors, they should be able to run close to 24 hours per day. Companies owning an AM machine have a utilization rate averaging 47.25 hours per week. This utilization rate is relatively low presuming that the machine could be operated without a break except for maintenance and setup breaks. The percentage per week has been calculated for a full 168 hour week.

Table 5: Utilization rate

Utilization rate	**Average**	**25th percentile**	**50th percentile**	**75th percentile**
Hours per week	47 h	25 h	38 h	60 h
Percentage of week (168 h)	28%	15%	23%	36%

It is worth noting that the utilization rate alone does not represent how efficiently the company is running it. In most AM technologies the amount of time needed to produce one part cannot be linearly interpolated to calculate the time needed to produce multiple parts. In fact, the more parts there are in the build the less time the process takes to manufacture each part. This is due to the fact that the process time does not consist only of directly solidifying, growing, or cutting out a cross-section of the part on a layer, but it also takes time to go from one layer to another. An example of this is distributing a new layer of powder in selective laser sintering, which requires the build platform to move down, the material reservoir to move up, and a roller or blade to take the powder from the reservoir to the build bed. This process of moving from one layer to another takes an equal amount of time regardless of how many parts are in the build or how much of the surface needs to be worked. Thus, the time is calculated for each part decreases as their amount increases. Some technologies are less prone to this effect, such as fused deposition modeling, in which an extruder works on each piece individually and the only common process is lowering the bed by the thickness of a layer but even in this case the effect is noticeable enough for it to be worth to maximize the build. The set-up time needed for starting the machine is also approximately the same regardless of the amount of parts to be produced.

Let us call the time needed to produce the cross-sections of part 1 T_{p1}, part 2 T_{p2}, the accumulated time to move from one layer to another T_l, the set-up time T_s and the amount of time needed for the entire build T_b. The formula for calculating the time needed to produce an entire build is (1).

$$T_{p1} + T_{p2} + T_s + T_l = T_b \qquad (1)$$

In case only one part is printed, Formula (2) applies to calculate the relative time used to produce a part compared to how long the entire build took. F_{p1} is defined as the fraction of total build time part 1 is being produced.

$$\frac{T_{p1}}{T_{p1}+T_s+T_l} = F_{p1} \qquad (2)$$

If two parts are being produced, F_{pb} is the fraction of total time both parts are being produced and the following applies:

$$\frac{T_{p1}+T_{p2}}{T_{p1}+T_{p2}+T_s+T_l} = F_{pb} \qquad (3)$$

Even though in the second case the build time is longer, the time used on directly producing parts is higher in comparison to the entire process. The range of the fraction of time used on parts compared to the total build time is from 0 to 1. The closer the result is to 1, the more efficient the process.

Additionally, in processes such as SLS, all material that is not used for the part cannot be recycled, thus producing more waste the less of the build volume is used for parts. In the process, it is general practice to mix 50% of fresh powder with 50% used powder until the powder is no longer usable due to causing faults in parts [48].

It is possible to calculate the amount of powder not used in the process that suffers from degradation. Let us assume two parts of the same height and call the volume of part V_{p1}, volume of part 2 V_{p2}, the volume of the build V_b, and the unused volume V_u. The following formulae apply:

$$V_{p1} + V_{p2} + V_u = V_b \tag{4}$$

$$V_u = V_b - V_{p1} - V_{p2} \tag{5}$$

As V_b remains the same regardless if one or two parts are included in it, the following is true:

$$V_b - V_{p1} > V_b - V_{p1} - V_{p2} \tag{6}$$

Even though SLS is the most extreme example of the economies of scale of producing multiple parts with AM simultaneously, they apply to every other technology in the form of used electricity and operator wages.

As there are considerable time and cost benefits in producing more parts at once, downtime for the machine is acceptable if the operator is in the process of waiting for more CAD files to come to maximize the efficiency of the machine. Therefore, it is important to look into how companies handle gathering enough parts to run the machine at full capacity, or indeed if they have enough parts to fill an entire build.

The companies that do not have an operator do not have a formal build filling program in place. As many people are allowed to use the machine without informing others, the machines are often running few parts and any parts that arrive during the machine running are placed in a queue.

The companies that employ an operator for their AM machines have rules on how and when the machine should be run. Most commonly the machine is run in two cycles: one starting in the morning and one starting in the afternoon. The intention is to make sure that one cycle ends before the other one begins and that there is sufficient time between them to make the set-up preparations. In case there are not enough parts to warrant such a rigid program, a certain volume limit can be set and it could be prohibited to start the machine until it is reached. If there is a recurring problem reaching the limit it can be lowered or a timer can be put in place to allow starting the machine after a certain time the first part has been submitted.

5.4.4 Maintenance of machinery

In order for any machine to function properly it needs to be maintained on regular basis. It is noteworthy that preventive maintenance of AM machinery is extremely important due to their sensitivity to failure. Preventive maintenance and upgrades of AM machines is usually done by the manufacturer or by a certified retailer or maintenance bureau closer to the customer. It is common to make a yearly service contract with one of these entities that includes a finite number of upgrades and visits. These contracts are generally perceived as expensive but worth the investment as in some cases they cost less than even a single fatal machine failure. 80% of the companies are doing preventive maintenance which is a relatively high percentage. However, only 40% of the companies report having a service agreement for preventive maintenance. The preventive maintenance practices by percentage are presented in Figure 19.

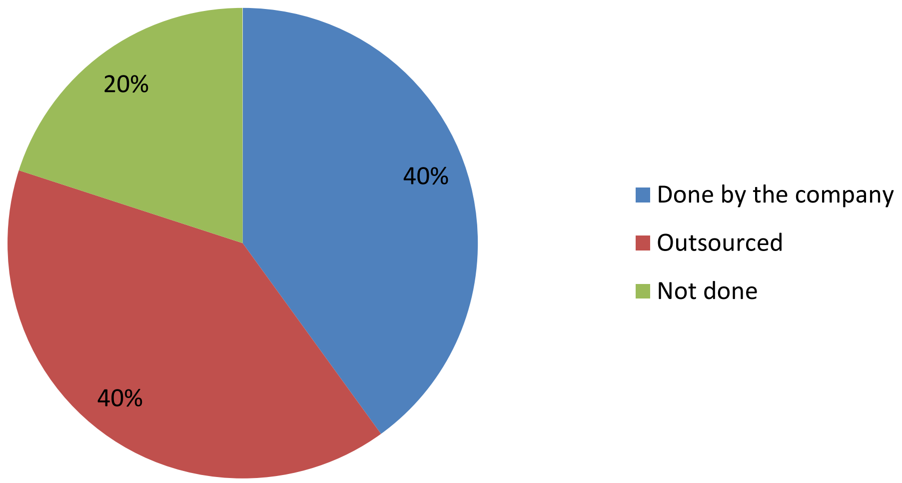

Figure 19: Preventive maintenance practices by percentage

According to the interviews, companies that do not perform preventive maintenance on their machines suffer from prolonged down times and constant failures in parts. This has led to frustration among the users and degradation in confidence that users have in AM. When a machine is not performing properly, the company either outsources the AM parts or avoids the usage of AM altogether.

5.4.5 Part production time

As explained in subchapter 5.4.3, the build time in AM consists of the actual part production and of time spent on general process actions such as set-up and moving from one layer to another. This means that a high utilization rate can be interpreted as detrimental and beneficial to the part production. In case of a high utilization rate, the machine is running often but there is a possibility of a queue forming thus extending the part production time. Nevertheless, if the utilization rate is low due to the fact that the machine is often waiting for a certain volume limit to be fulfilled, parts have a better chance to enter the build making the part production time of some parts longer but lowering it on average. However, if there is heavy demand for AM parts to be produced with the machine, which would be signified by a constant high utilization rate, the average part production time would grow longer. 50% of the companies report the average part production time to be less than a day and another half report it being approximately a day. Both times are extremely good with current technologies and imply a very low waiting time. This means that there is no case of a high demand and high utilization rate, and it is backed by the fact that the average utilization rate is relatively low. The distribution of average part production times is shown in Figure 20.

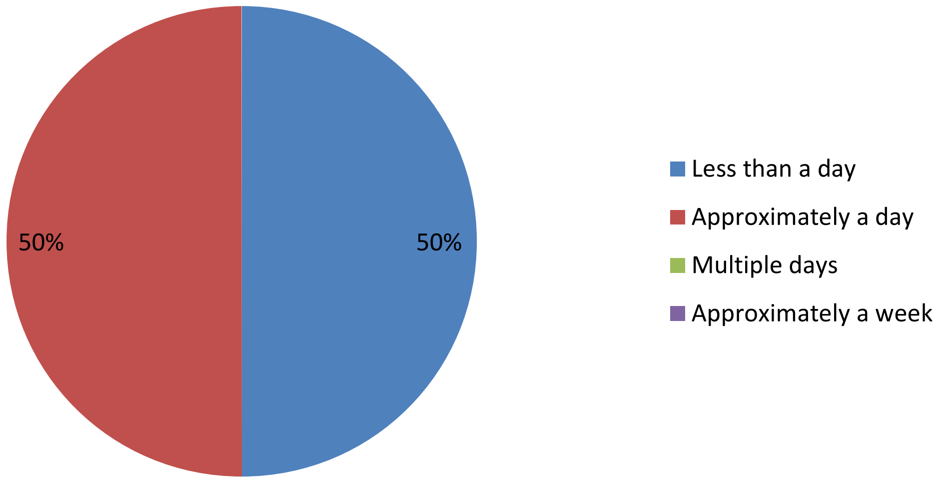

Figure 20: Part production time

5.4.6 Monitoring production costs

Costs of AM machinery can be divided into fixed costs and variable costs. Fixed costs consist of the initial investment cost of the machine and peripherals, post processing equipment, a yearly service agreement and rent of space needed for the machine.

Variable costs include material costs, labor, and electricity. Oftentimes the only costs companies consider when procuring machinery is the costs of the machine, post processing and the material cost. The costs of the service agreement and labor are often ignored or understated. This can lead to not hiring a separate operator for the machines which in its part leads to downtime and raised costs.

Monitoring costs of parts built with in-house AM machinery is strongly in relation to the size of the company. Smaller companies monitor the price of every part and the production decision is made based on that. In bigger companies the fabrication costs are either budgeted annually or not monitored at all. Commonly the costs are only calculated at the investment stage and not calculated at a later point. Nevertheless, the only companies reporting to suffer from inflated costs in relation to AM are the ones that do not perform preventive maintenance and suffer from constant breakdowns of machinery and lost labor caused by them. Figure 21 presents the distribution of companies' different monitoring practices.

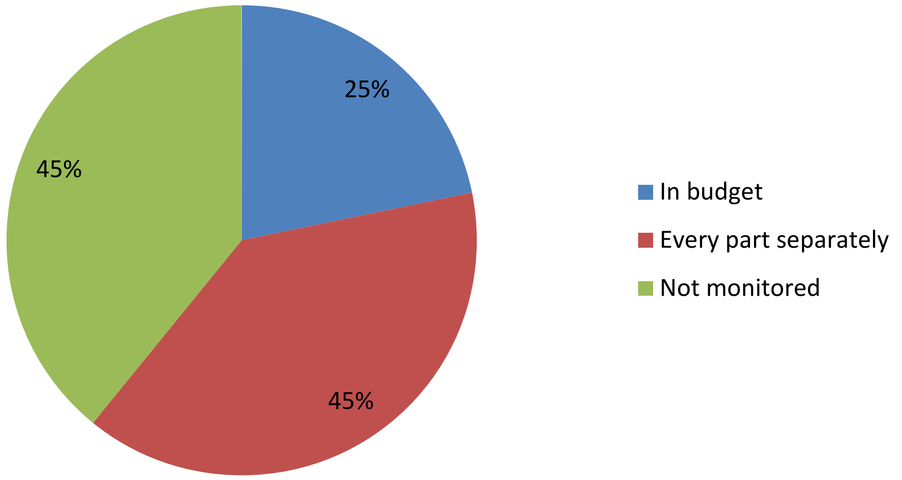

Figure 21: Monitoring costs in own production

5.5 Practices in outsourcing of AM services

Companies are increasing the amount of outsourcing because the opportunities of AM have become more widely known and accessible. In the case a machine is overloaded and the company does not own a second machine, outsourcing is a faster way to get all the parts. Oftentimes the quality of the in-house machine is insufficient in regards to the surface quality, the durability of the material, or producing finer details such as snap on parts. Usually outsourcing also includes post processing as it is perceived that service bureau employees are more capable of handling it than company employees.

Larger quantity series consisting of over twenty parts are usually outsourced. The size of the part intended for production matters if its size exceeds the maximum build envelope of the in-house machine. Silicon molds and parts made using silicon molds are outsourced in the majority of cases. On rarer occasions, especially when a company is thinking of buying a machine of their own, it is willing to try out a new to technology which leads to the outsourcing of test parts.

Several companies outsource higher quality parts and produce lower quality parts in-house. The same distinction applies with functional prototypes and visual prototypes.

Table 6: Outsourcing compared to all AM usage

Type of measurement	**Average**	**25th percentile**	**50th percentile**	**75th percentile**
Percentage of all AM usage	56%	25%	53%	100%
Currency	41,000 €	10,500 €	25,000 €	45,000 €

5.5.1 Quality assurance

Unlike the practice of specifying surface quality and dimensional tolerances in traditional manufacturing, companies often order parts from service providers according to the specifications of the machines. It is reasonable to expect outsourced parts to represent the specifications given by the machine supplier but as with all manufacturing processes, producing parts with AM is subject to many variables that affect the quality of the product. For example, the heat distribution in SLS builds is not even and can vary from build to build which leads to varying results in material strength and dimensional accuracy of the part. Therefore, it is not always guaranteed that the produced part is exactly of as high a quality as advertised.

In the case of outsourcing parts without post processing, companies trust the service provider to perform quality assurance tests in order to comply with the requirements, but as there often are no explicit requirements the test commonly consist of only verifying if a fault in the process caused a defect in the part.

When ordering parts with post processing, or with the use of rapid tooling, companies are more precise in defining the desired qualities of the part. These processes require manual labor and as such are subject to more variables than a part that is produced directly with a machine.

Most companies trust that the service providers perform the quality assurance tests and perform simple visual checks of the ordered parts. This applies especially to service providers that have been used extensively in the past. When ordering from less known service providers, a more rigid approach to quality assurance is taken. A small percentage of the companies inspect the parts’ dimensions and material properties. The distribution of companies’ practices in quality assurance of outsourced parts is presented in Figure 22.

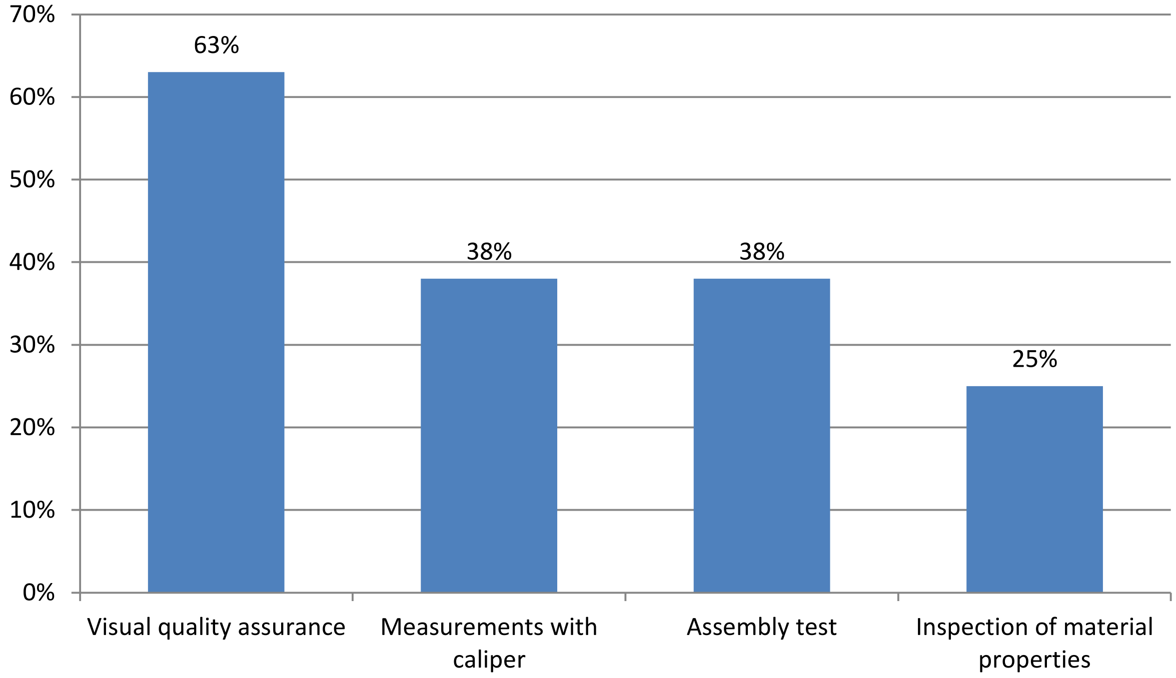

Figure 22: Distribution of quality assurance in outsourcing

5.5.2 Information security of CAD files

The importance of CAD file security varies from field to field. In consumer electronics, a part the company is working on can contain several innovations and be crucial to the overall value perceived by the customer. A leak of the design of such a part can be damaging to the company so strict measures are taken to protect them. In the machine building industry, a part is a part of a much larger assembly and a leak of a CAD file of a part of the machine, while not desired, is not detrimental to the success of the final product.

Most companies rate their service providers and only work with those who are trustworthy and willing to sign an NDA agreement. A problem with security on the service providers' side can lead to a leak and subsequent copies of the product being made.

Sending CAD files to a trusted service provider is not a problem but sending the files to anyone else is avoided in case of leaks. If the files are secret, the company produces the part in-house with available technologies.

In order to produce parts with AM machines, the CAD files have to be transformed into .STL format. In many cases the change of file format causes unexpected errors and the file needs to be processed for it to be accepted by the machine. Most service providers in the AM field offer a service of transforming CAD files into .STL or fixing them. The Additive Manufacturing File Format (.AMF) has attracted the interest of a small percentage of the companies because of its ability to store color, materials, lattices and constellations unlike the .STL file format.

An equal amount of interviewees perceived outsourcing of post processing of .STL files as useful. The distribution of the degree of secrecy in the companies is shown in Figure 23.

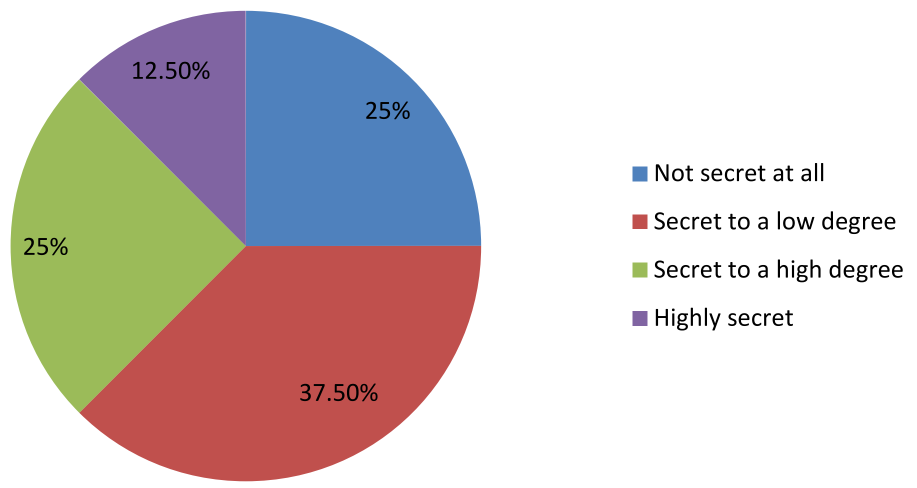

Figure 23: Degree of secrecy of CAD files

5.5.3 Order lead time

The order lead time is the time it takes from the order being placed to the customer receiving the part. This time includes the service provider processing the order, evaluating the CAD file or .STL and producing the part, and the time it takes to ship the part from the service provider to the customer.

A small part of the companies receive parts from the supplier in approximately a day. 86% of the companies receive the parts from days to approximately a week. The distribution of the average order lead time is presented in Figure 24.

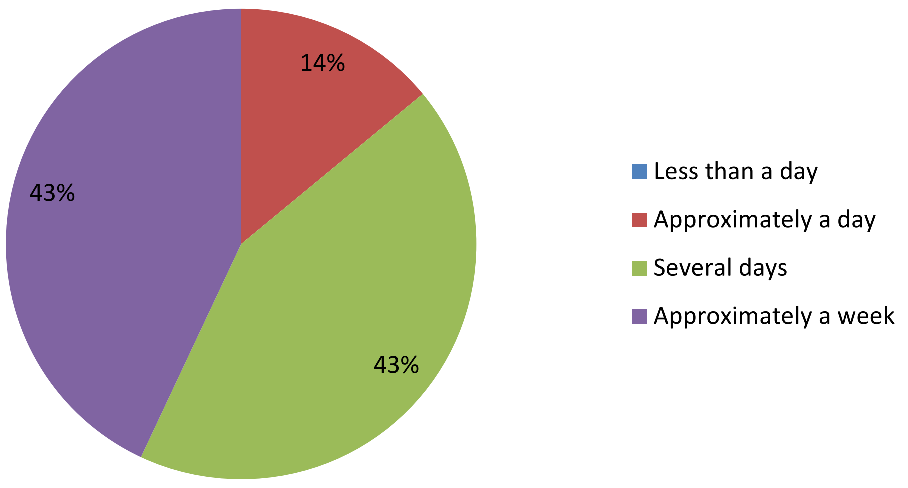

Figure 24: Order lead time

The times presented in Figure 24 are much longer than when companies produce parts with their own machines. A comparison of part production time and outsourcing lead time is presented in Figure 25.

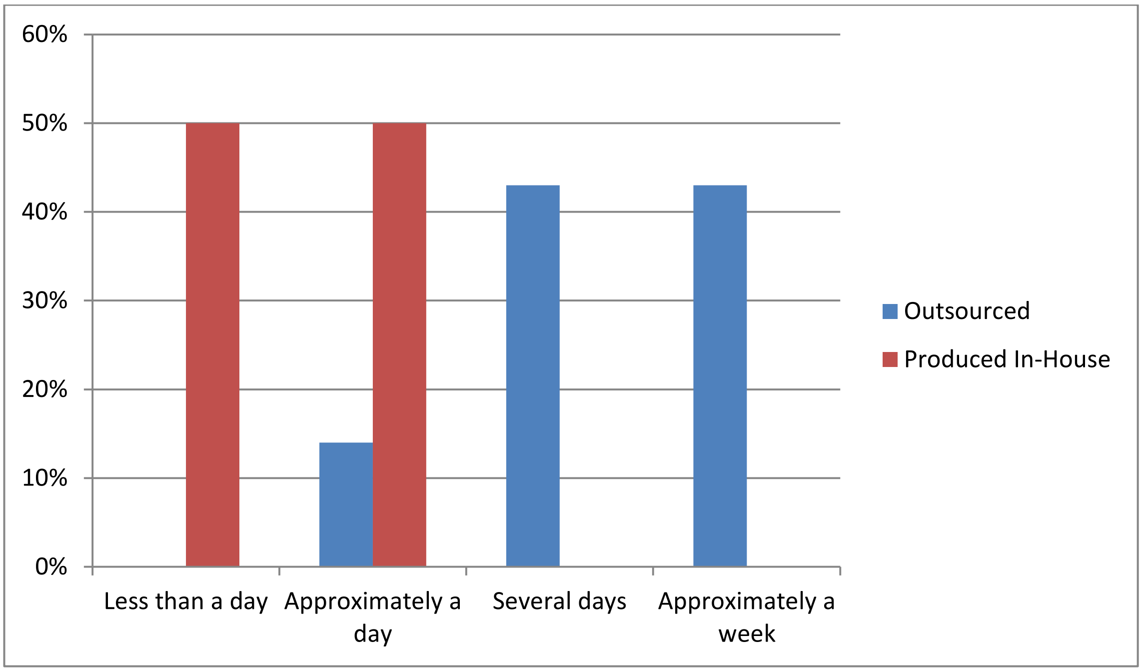

Figure 25: Comparison of part production time in-house and outsourcing lead time

5.5.4 Maximum benefit threshold

The maximum benefit is the threshold in delivery time after which there is no benefit in being faster. For most of the companies the threshold is set at approximately days to a week. Some companies have the threshold set at approximately a day. At the moment the delivery times are slightly longer than the maximum benefit threshold but according to the interviews it is not seen as problematic. The maximum threshold distributed by company is shown in Figure 26.

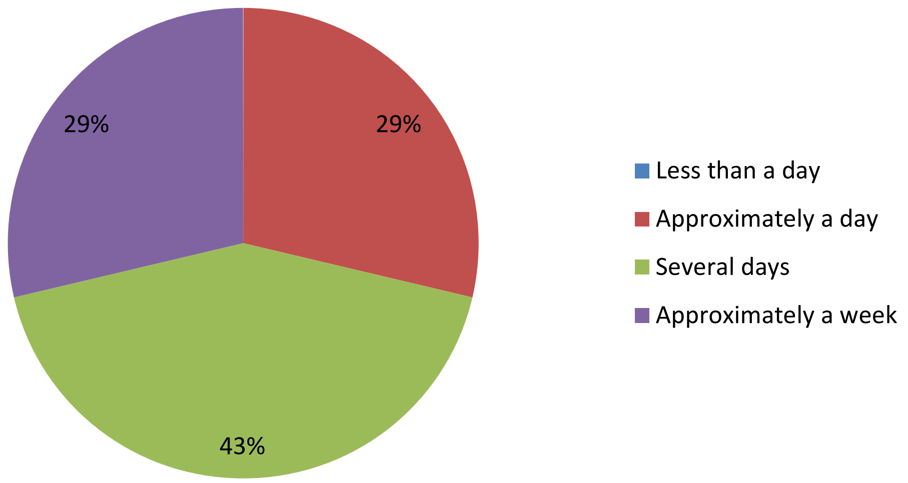

Figure 26: Maximum benefit threshold

5.5.5 Monitoring outsourcing costs

Most companies monitor costs for each order separately. Larger companies have a budget for the usage of AM on a yearly level. None of the companies reported being surprised by hidden costs of outsourcing and have been satisfied with the pricing. The practices of monitoring costs in outsourcing are presented in Figure 27.

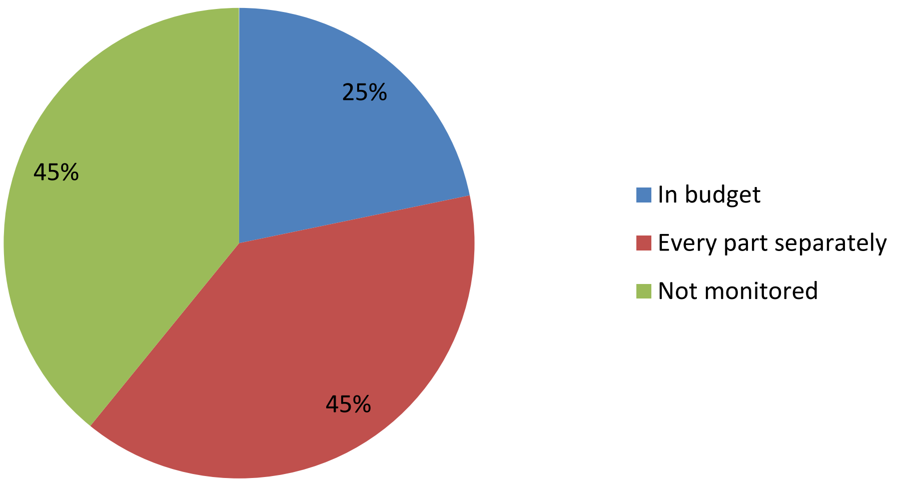

Figure 27: Monitoring costs in outsourcing

5.6 Importance of factors related to AM

In the last part of the questionnaire, general factors that are related to AM were examined. The interviewees were told to rate the importance of the listed factors from 1 to 5 and to expand on their answer. The acquired data is presented in Table 7.

Fast access to AM parts and their accuracy were seen to be the most important factors among the interviewed companies. The suitability of material and general knowledge of AM were seen as relatively important on average but the spread between companies was large. For some companies it is very important to have the part created out of a certain material for it to perform as wanted and for some is it of no real importance. The need for parts to have a certain material commonly comes from their functionality and for this reason the companies that rated the importance of material low are highly likely to be the ones that generally produce or outsource visual prototypes.

Security of CAD files was not an issue for most of the companies either because they are in a business where the leak of one file does not pose a threat to the final assembled product, or they are confident enough in their service providers. The optimality of technology was rated low among all but a few companies. This means that most companies are not concerned with which methods are used to produce the parts as long as they are made of the correct material and are able to serve the desired purpose.

Additive manufacturing is seen as an important tool in presenting conceptual models to engineers but showcasing AM models to shareholders is not perceived as useful as the parts are too rough to present the commercial value of the final product.

Table 7: Importance of factors related to AM, range 1-5, 1 is lowest, 5 is highest

Factor	**Average**	**25th percentile**	**50th percentile**	**75th percentile**
Fast access to part	4,09	4	4	5
Accuracy of part	4,27	4	4	5
Suitability of material	3,64	2,5	4	5
Security of CAD files	3,18	2,5	3	3,5
Optimality of technology	2,82	1,5	3	4
General knowledge of AM	3,64	2,5	4	4,5

6 Summary and conclusions

A need was identified to examine of the needs and practices of AM in the Finnish industry in order to understand what the situation is and how it is in relation to the rest of the world. In order to accomplish this, a survey consisting of eight companies and fifteen persons was conducted.

The surveyed fields were chosen according to the criterion that they needed to be industrial and with potential in AM usage, which led to the selection of the automotive, aerospace, industrial machines, and consumer products fields. From these fields 28 companies were asked to participate out of which eight agreed to be a part of the survey, giving a 29% response rate. The companies that decided to participate were from the industrial machines and consumer products fields. The position in the company of the interviewed persons ranged from CAD designer to CEO.

The goals set for the survey were mapping out the usage and familiarity of different AM technologies, understanding how companies procure machinery, and understanding their practices in outsourcing AM parts.

A five-part questionnaire consisting of qualitative and quantitative questions was designed and presented to the interviewees during the interviews which lasted from one to two hours each. The questionnaire was laid out in the way that would draw information to the subchapters of Chapter 5.

The results to the question of how familiar different technologies were were close to expectations and previous research worldwide considering the restrictions of the surveyed fields. FDM, SLS, and stereolithography were the most recognized and used technologies, SLM and LOM were known but not used, PolyJet was used to a moderate degree, and the rest of the technologies were poorly recognized and not used.

The knowledge of FDM machines was heavily skewed towards the lower end and mid range machines and higher end machines did not have a large presence in the industry.

SLS was known for its material properties and high degree of freedom in design and was often used for outsourcing even though none of the companies owned an SLS machine. Stereolithography was the most associated with high quality AM parts but a trend can be seen according to which it is losing ground to other AM technologies. PolyJet machines were seen as sufficient for the purposes for the companies but costly to maintain.

The average distribution of applications of AM, rapid prototyping, rapid tooling, and rapid manufacturing, were 84%, 6%, and 10% respectively. These results are radically different from the previous surveys, which was partly due to the different approach taken in this survey. In the previous surveys service providers were surveyed whereas in this survey it was the companies that needed AM parts. As some companies use their machines for the faster rapid prototyping applications more than for rapid manufacturing, the percentaged is skewed in the favor of the former. Additionally, the majority of the companies were from the consumer products field in which the volumes are so high that rapid manufacturing is not viable. However, these factors are not enough to account for the entire difference in the distribution between the surveys leading to the conclusion that Finland is behind other countries in rapid tooling and rapid manufacturing.

62.5% of the surveyed companies owned at least one AM machine and 50% of the companies owned an industrial AM machine. 43% of the machines were using FDM technology, 43% Polyjet or MJM, and 14% stereolithography. Procurement of an AM machine is a lengthy process due to the wide spectrum of technologies and it was found that most companies do not do enough preparations and evaluate their needs in enough detail to acquire a machine best suited for them.

The practices in operating AM machinery turned out to be an important topic as two ways of operation were identified. The first one was to let the designers use the machines themselves and the second one to appoint an employee to exclusively operate the machinery. There were multiple problems found with the first approach including lack of maintenance and lowered build success rates. The second approach is recommended to be used.

The average utilization rate of AM machinery was found to be 47 hours per week. A 28% utilization rate was calculated using a full 168 hour week as the machines can theoretically be used around the clock with the exception of set-up times and maintenance breaks. As was demonstrated in Subchapter 5.4.3, the utilization rate is not the direct measure for the efficiency of AM machinery usage, as the duration of a build is not linearly dependent of the amount of parts in the build.

Maintenance of machinery was found to be very important and according to the interviews the lack of it led to prolonged down times and constant failures in parts. 80% of the companies reported doing preventive maintenance and 20% reported only doing corrective maintenance.

Part production time varied from less than a day to approximately a day. The part production time is related to the utilization rate and because it is fast, implies that the waiting times and a utilization rates are low. When outsourcing, the lead time was found to be between several days and approximately a week on average. This presents a difference between the two but companies reported that they are willing to wait for outsourced parts longer than in-house parts. The maximum benefit threshold for outsourced parts was divided between approximately a day, several days, and approximately a week in the distribution of 29%, 43%, and 29% respectively.

The amount of outsourced parts differs between companies as some prefer to do all of their own production and some prefer to outsource all of it. The average percentage of outsourcing was found to be 56% with the 25th percentile being 25% and the 75th percentile being 100%. The average annual budget for outsourcing was 41,000€.

Rigorous quality assurance was not performed on most parts in most companies because the service providers were trusted to handle the process. For the most part, companies settled on inspecting the parts visually in case of major failures. It was also discovered that most parts are not ordered with specifications to quality. The matter of CAD file security concerns some companies and is seen as non-consequential by others. The perceived benefit of post processing of .STL files by service providers is equally divided as some companies prefer to do finalize their own files and others would pay for the post-processing.

The practices of monitoring costs of AM vary depending on the size of the company and generally do not depend on outsourcing or producing parts in-house. 25% of the companies have a budget for outsourcing, 40% monitor the cost of every part, and 40% do not perform any sort of monitoring. Smaller companies monitor their AM expenditure more than larger companies.

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Materiaalia lisäävän valmistuksen tarpeet ja käyttö suomalaisessa teollisuudessa

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Sisällysluettelo

1. Raportin tarkoitus ja laajuus

Tämän raportin tarkoituksena on tutkia materiaalia lisäävän valmistuksen (AM-tekniikoiden) nykytilannetta Suomen teollisissa yrityksissä.

1.1 Haastattelujen laajuus

Tutkimuksessa haastateltiin kahdeksaa eri yritystä ja yhteensä viittätoista eri henkilöä. Yritysten yhteenlaskettu liikevaihto vuonna 2012 oli noin 3,2 miljardia euroa. Osallistuvat yritykset valittiin teollisten yritysten keskuudesta sillä perusteella, että niiden potentiaalinen tai toteutunut AM-tekniikoiden käyttö on suurta.

Haastattelututkimukseen osallistui kuusi suurta ja kaksi PK-yritystä. Haastateltavat henkilöt valittiin sen mukaan, ketkä yrityksessä vastaavat materiaalia lisäävän valmistuksen toiminnasta ja päätöksistä. Haastateltavat henkilöt olivat AM-laitteiden operaattoreita, CAD-mallintajia, tuotekehityspäälliköitä ja tuotantovastaavia.

1.2 Haastattelujen kysymykset

Haastattelu koostui neljästä osasta. Ensimmäisessä käytiin läpi kuinka hyvin haastateltava tuntee teknologiat ja millaisia kokemuksia hänellä on tietyistä teknologioista kyseisessä yrityksessä. Toisessa osassa selvitettiin laitteiden omistamista koskevat asiat, kuten hankintaperusteet ja toimintakäytännöt. Kolmannessa osassa selvitettiin ulkoistamisen käytännöt. Neljännessä osassa haastateltavaa pyydettiin antamaan arvo tietyille AM-tekniikoihin liittyville tekijöille.

1.3 Raportin rakenne

Raportti mukailee rakenteeltaan haastattelua. Jokaiselle haastattelun osalle on annettu oma kappale. Tutkimuksessa löydetty data on esitetty määrällisesti taulukoissa, joiden vieressä tai alla on niiden selitykset.

2. Teknologioiden tunnettavuus

Tutkimuksen ensimmäisessä osassa selvitettiin kuinka hyvin erilaiset AM-teknolgiat tunnetaan. ASTM-standardi jakaa ainetta lisäävät menetelmät seitsemään ryhmään, jotka on esitetty taulukossa 1. Tähän taulukkoon pohjautuen tutkimukseen valittiin jokaisesta kategoriasta edustavimmat teknologiat, jotka on myös esitetty taulukossa 1.

Taulukko 1. AM-kategoriat ja valitut kaupalliset nimet

Teknologia	Kaupallinen nimi
Binder jetting	Three Dimensional Printing (3DP)
Direct energy deposition	Laser Engineered Net Shaping (LENS)
Material extrusion	Fused Deposition Modeling (FDM)
Material jetting	Polyjet
Powder bed fusion	Selective Laser Sintering (SLS)
Powder bed fusion	Selective Laser Melting (SLM)
Powder bed fusion	Electron Beam Melting (EBM)
Powder bed fusion	Selective Heat Sintering (SHS)
Sheet Lamination	Laminated Object Manufacturing (LOM)
Vat photopolymerization	Stereolithografia (SLA)
Vat photopolymerization	Digital Light Processing (DLP)

Taulukossa 2 on esitetty haastatteluissa annetut vastaukset siitä, tunnetaanko teknologia vai ei. Prosenttimäärä kuvaa ”kyllä”-vastausten määrää kaikista vastauksista.

Vastaajista 88,9 % tunsi FDM:n, SLS:n ja SLA:n. 77,8 % tunsi LOM:n ja SLM:n. Polyjetin tunsi 55,6% 3DP:n ja DLP:n tunsi 22,2% ja EBM:n ja SHS:n 11,1% LENS-teknologiaa ei tuntenut kukaan haastateltavista.
Yleisesti kaupallisista nimistä tunnetaan hyvin vain FDM, SLS ja SLA. Muita tunnetaan huomattavasti huonommin.

Taulukko 2. Teknologioiden tunnettavuus

Sija	Kauppa-nimi	Tunnet-tavuus
1.	FDM	88,9 %
-	SLS	88,9 %
-	SLA	88,9 %
4.	SLM	77,8 %
-	LOM	77,8 %
5.	Polyjet	55,6 %
6.	3DP	22,2 %
-	DLP	22,2 %
8.	EBM	11,1 %
	SHS	11,1 %
9.	LENS	0,0 %

2.1. Fused Depostition Modeling (FDM)

Selkeyden vuoksi on hyvä jakaa FDM-teknologia edullisiin loppukäyttäjälaitteisiin ja teollisiin laitteisiin. Näiden kahden raja on tässä raportissa asetettu 5000 euroon. Noin 15%:lla yrityksistä on käytössä muutama halvemman hintaluokan FDM-laite, jolla testataan R&D-iteroinnin nopeuttamista talon sisällä. Yleisesti tämän hintaluokan laitteet on havaittu erittäin epätarkoiksi ja epäluotettaviksi yritysten keskuudessa.

Korkeamman hintaluokan laitteen omistaa 25% yrityksistä ja keskimääräinen käyttöaste on 19 tuntia viikossa. Noin 8% yrityksistä ulkoistaa FDM-mallien valmistusta, mutta niiden kokonaismäärä kaikista ulkoistetuista kappaleista on hyvin vähäinen. Positiiviseksi on havaittu teknologian materiaalivalikoima, joka on käyttäjien mielestä tarpeeksi vahvaa ja kestävää. Positiivista on myös jälkityöstön helppous.

Korkean hintaluokan (100,000€ +) laitteistoja ei tunnettu kovin hyvin. Suurimmalle osalle yrityksistä tuli yllätyksenä, että laitteistoille on saatavissa mm. ULTEM-materiaali, ja että niillä päästään noin 100 mikrometrin kerrospaksuuteen.

2.2. Selective Laser Sintering (SLS)

Yhdelläkään tutkimukseen osallistuneella yrityksellä ei ollut SLS-laitteistoa. SLS-malleja ulkoistetaan hyvin paljon ja Alphaform on ylivoimaisesti suosituin SLS-mallien tarjoaja. Positiiviseksi on katsottu suhteellisen hyvä materiaalin kestävyys.

SLS-menetelmän tarkuus on jakanut mielipiteitä. Menetelmän käyttäjistä noin 50% ovat olleet täysin tyytyväisiä mittatarkkuuteen ja toiset 50%käyttävät SLS:ää, kun kappaleen ei tarvitse olla kovin tarkka. Pinnan karheus nähtiin ongelmana.

2.3. Stereolithografia (SLA)

Stereolitografialaitteita omistaa 12,5 % yrityksistä. Stereolitografiamallien tuotantoa ulkoistaa 50 % yrityksistä. Ulkoistetut kappaleet teetetään Alphaformilla tai kiinalaisilla alihankkijoilla. Silikonimuottien teettäminen stereolitografian avulla on käytössä 37,5 % yrityksistä. Ongelmana nähdään materiaalien heikkous muihin valmistusmenetelmiin verrattuna. Positiivisena nähdään materiaalien laaja kirjo ja erinomainen mittatarkkuus.

2.4. Selective Laser Melting (SLM)

SLM-laitteistoja ei ole yhdelläkään tutkimukseen osallistuneella yrityksellä eikä yksikään aktiivisesti ulkoista SLM-kappaleita. Menetelmää on kokeiltu muutamassa projektissa useassa yrityksessä vaihtelevalla menestyksellä.

Suurimpina ongelmina nähdään menetelmän kalleus, laatu ja hitaus. Pienempiä ongelmia ovat jälkityöstön tarve ja laitteistojen tarkkuus. 75% yrityksistä ilmaisi mielenkiintoa käyttää SLM:ää tulevaisuudessa.

2.5. Laminated Object Manufacturing (LOM)

Yhdelläkään yrityksellä ei ollut käytössä LOM-laitteistoa eikä yksikään yritys ulkoistanut LOM-mallien tuotantoa. Menetelmän erittäin hyvä tunnettavuus johtuu siitä, että se oli 90-luvulla laajasti käytössä.

2.6. Polyjet

Polyjet-laitteistoja tai niihin verrattavia Multijet Modeling (MJM)-laitteistoja on 37,5 %:lla yrityksistä. Laitteistot on koettu hyvin herkiksi ja on havaittu, että ne vaativat paljon jatkuvaa ennakkohuoltoa. Ongelmina on nähty se, että laitteiston käyttöaste on pidettävä korkeana tasaisen laadun saamista varten sekä jälkikäsittelyn manuaalinen vaativuus. Teknologialle ominainen kutistuma on myös nähty ongelmallisena. Positiivisena on nähty kappaleiden mittatarkkuus ja varsinkin erinomainen tasomaisuus. Materiaalit ovat olleet pääosin tarkoitukseensa riittäviä.

2.7. Three Dimensional Printing (3DP)

Yhdelläkään yrityksellä ei ollut käytössä 3DP-laitteistoa eikä yksikään yritys ulkoistanut 3DP-malleja. Ongelmana nähtiin materiaalin heikkous. Värillisten kappaleiden valmistamisen ei nähty tuovan lisäarvoa.

2.8. Digital Light Processing (DLP)

Yhdelläkään yrityksellä ei ollut käytössä DLP-laitteistoa eikä yksikään yritys ulkoistanut DLP-malleja. Teknologian tunnettavuus on alhainen.

2.9. Electron Beam Melting (EBM)

Yhdelläkään yrityksellä ei ollut käytössä EBM-laitteistoa eikä yksikään yritys ulkoistanut EBM-malleja. Teknologian tunnettavuus on alhainen.

2.10. Selective Heat sintering (SHS)

Yhdelläkään yrityksellä ei ollut käytössä SHS-laitteistoa eikä yksikään yritys ulkoistanut SHS-malleja. Teknologian tunnettavuus on alhainen. Muutama yritys ilmaisi mielenkiintoa SHS:n käytössä R&D-toimistossa, kunhan menetelmän laadusta saadaan varmaa tietoa.

2.11. Laser Engineered Net Shaping (LENS)

Yhdelläkään yrityksellä ei ollut käytössä LENS-laitteistoa eikä yksikään yritys ulkoistanut LENS-malleja. Teknologiaa ei tuntenut kukaan haastateltavista.

3. Käyttökohteiden osuus kokonaiskäytöstä

Tutkimuksessa jaettiin käyttökohteet kolmeen kategoriaan: rapid prototyping (RP), rapid tooling (RT) ja rapid manufacturing (RM).

Tässä raportissa on katsottu, että ulkoistettaessa käyttökohde määritellään sen mukaan, mikä on toimitettu lopputuote. Silikonimuottien ulkoistamisessa on katsottu, että käyttökohde on RP, mikäli toimitettu tuote on silikonimuotin avulla tehty malli, ja RT, mikäli toimitettu tuote on itse silikonimuotti. Yrityksistä 37,5 % käyttää silikonimuotteja, mutta suurin osa näistä muoteista pysyy toimittajan tiloissa.

Taulukossa 3 on esitetty käyttökohteen suuruus kaikesta vastanneiden yritysten AM:n käytöstä. Esitettäviksi arvoiksi on valittu keskiarvot sekä 25., 50. ja 75. persentiilit.

Taulukko 3. Käyttökohteet

Käyttökohde	Keskiarvo (%)	25. persentiili (%)	50. persentiili (%)	75. persentiili (%)
RP	84	80	90	90
RT	6	0	0	5
RM	10	1	10	20

RP on tällä hetkellä ylivoimaisesti haastateltujen yritysten suurin käyttökohde. 90 % yrityksistä tekee lähes pelkästään RP:a. Maailmaan verrattuna Suomessa käytetään hyvin vähän RT:a. Silikonimuotteja teetetään paljon, mutta usein yritys näkee prosessista vain lopputuotteen. Vahamuotteja tarkkuusvaluun on kokeiltu, mutta sen on nähty olevan liian kallista. Yrityksissä, joilla on tuotantoyksikkö, tehdään jigejä tuotantoon. RM:n kysyntä olisi muuten suurta, mutta sen hinta ja laatu ovat tähän mennessä olleet estäviä tekijöitä. Joillakin yrityksillä AM on ainoaa valmistusta Suomessa, kun kaikki muu on ulkoistettu ulkomaille.

4. Laitteiden omistaminen ja käytännöt

Taulukossa 4 on esitetty kuinka iso osa yrityksistä omistaa laitteita. Yhden laitteen omistavia yrityksiä on yhtä monta, kuin yrityksiä, joilla ei ole laitteita. 25 %:lla on omistuksessa useampi kuin yksi laite.

Taulukko 4. Omistettujen laitteiden määrä

Laitteiden määrä	Määrä (%)
Ei laitteita	37,5
Yksi laite	37,5
Useampi kuin yksi laite	25

Taulukko 5. Laitteiden määrä yrityksissä

Teknologia	Omistavien yritysten prosentti (%)
FDM	42,8
Polyjet / MJM	42,8
SLA	14,3

4.1. Laitteiden hankintaperusteet

Oman laitteen hankintaa on usein edeltänyt mittava ulkoistaminen. Oma laite on haluttu hankkia, koska toimitusaikojen poistaminen nopeuttaa tuotekehitystä ja madaltaa käyttäjien kynnystä käyttää AM:ää. Syynä oman laitteen hankkimiseen on myös kustannustehokkuus, sillä omalla laitteella on halvempaa tuottaa kappaleita ja ulkoistuksen piilokustannukset ovat tiedossa.

Tietty laite on hankittu erilaisin perustein eri yrityksissä. Selkeästi yritykset ovat halunneet koneen, jolla saa riittävän isoja ja tarkkoja kappaleita, jotka ovat myös helppoja käyttää. Usein kone on valittu valmiiden mallien perusteella, joissa on kiinnitetty huomiota materiaaliin. Nopea jälkikäsittely on ollut kaikille prioriteettina. Osa yrityksistä on nähnyt, että ostettu laite on hankittu kevein perustein.

4.2. Laitteiden operointi

Laitteiden käytössä on oleellista, kuka niille toimii operaattorina. Yleisimmät tavat järjestää asia ovat:
1. Annetaan 3D-mallinnuksesta vastaaville työntekijöille mahdollisuus käyttää laitetta itse
2. Nimetään laitteille tarkoitukseen palkattu operaattori

Taulukossa 6 on esitetty missä suhteessa yritykset käyttävät yllä mainittuja käytäntöjä. Ainoastaan laitteita omistavat yritykset ovat taulukon tiedoissa mukana.

Yhtä monta yritystä antaa mallintajien käyttää laitteistoa kuin käyttää nimettyä henkilöä. Haastattelujen perusteella on huomattu, että operaattorin käyttäminen voi nostaa koneen käyttöastetta ja laskea toimettomana seisomista.

Taulukko 6. Käytäntöjen jakauma

Käytäntö	Määrä kaikista (%)
Tarpeen mukaan	50
Nimetty henkilö	50

4.3. Käyttöaste

Yrityksissä, joilla on omistuksessaan AM-laite, käyttöaste on ollut keskimäärin 47,25 tuntia viikossa. Tämä käyttöaste on verrattaen alhainen olettaen, että laite voisi olla käynnissä tauotta asetusaikoja ja huoltotaukoja lukuunottamatta. Prosentuaalinen käyttöaste on laskettu täydelle 168 tunnin viikolle.

Taulukko 7. Laitteiden käyttöaste

Käyttöaste	Keskiarvo (h)	25. persentiili (h)	50. persentiili (h)	75. persentiili (h)
Tunteina viikossa	47	25	38	60
Prosentteina viikosta (168 h)	28 %	15 %	23 %	36 %

4.4. Laitteiden huolto

Ennakoivaa huoltoa tekee 80 %yrityksistä, mikä on melko korkea aste. On huomionarvoista, että AM-laitteiden ennakoiva huolto on äärimmäisen tärkeää niiden herkkyyden takia.

Taulukko 8. Ennakoiva huolto

Ennakoiva huolto	Määrä kaikista (%)
Tehdään itse	60
Ulkoistetaan	20
Ei tehdä	20

4.5. Valmistusaika

Yrityksistä 50 %saa kappaleen valmiiksi alle päivässä ja toiset 50 %noin päivän sisällä. Kummatkin ajat ovat nykytekniikoilla erittäin hyviä ja viittaavat hyvin lyhyeen odotusaikaan. Tämä johtuu osittain alhaisesta käyttöasteesta

Taulukko 9. Oman koneen kappaleenvalmistusaika

Valmistumisaika	Prosenttimäärä (%)
Alle päivä	50
Noin päivä	50
Useita päiviä	0
Noin viikko	0

4.6. Kustannusten valvonta

Omalla koneella valmistettavien osien kustannusten seuranta riippuu suuresti yrityksen koosta. Pienemmät yritykset seuraavat jokaisen kappaleen hintaa ja päättävät sen mukaan tehdäänkö kappale. Suuremmissa yrityksissä materiaalikulutus on joko budjetoitu vuositasolla tai sitä ei seurata ollenkaan. Usein kustannuksia lasketaan vain investointivaiheessa, mutta ei lasketa enää sen jälkeen.

Taulukko 10. Kappaleiden valmistuksen kustannusten seuranta

Kappaleiden valmistuksen kustannusten seuranta	Prosentti yrityksistä (%)
Budjetoitu	20
Jokainen kappale erikseen	40
Ei seurata	40

5. Ulkoistaminen

Yritykset ulkoistavat yhä enemmän, koska ollaan tultu tietoisiksi AM:n mahdollisuuksista. Yrityksille, joilla on oma laite, ulkoistamispäätös on usein harkittu.

Mikäli oma kone on ylikuormitettu eikä konsernista löydy toista konetta, ulkoa tilaaminen on joskus nopeampaa. Usein oman koneen laatu ei riitä pintalaadun, materiaalin kestävyyden tai kuluvuuden tai esimerkiksi snap-on-yksityiskohtien valmistukseen, jolloin ulkoistetaan. Usein ulkoistukseen kuuluu myös jälkikäsittely, sillä nähdään, että AM-toimittajat ovat siinä kokeneempia kuin oman talon työntekijät. Isot yli 20 kappaleen sarjat yleensä ulkoistetaan. Kappaleen koko ratkaisee ulkoistuksessa, jos omistetun koneen valmistustilavuus on pienempi kuin haluttu kappale. Silikonimuotit ja niiden kautta valmistetut kappaleet ulkoistetaan lähes kaikissa tapauksissa. Harvemmissa tapauksissa, varsinkin oman laitteen hankkimista suunniteltaessa, yritys haluaa kokeilla tekniikkaa, jota sillä ei ole, jolloin se luonnollisesti ulkoistaa.

Usealla yrityksellä on mentaliteettina, että laadukkaat osat ulkoistetaan ja talon sisällä valmistetaan heikompilaatuisia malleja. Sama jako pätee myös siinä, että toiminnalliset prototyypit ulkoistetaan ja visuaaliset prototyypit tehdään omalla laitteella.

Taulukko 11. Ulkoistamisen määrä kokonaistoiminnasta

Mittaustapa	Keskiarvo	25. persentiili	50. persentiili	75. persentiili
Prosentteja kokonaiskulu-ista	56 %	25%	53 %	100%
Euroja	41,000 €	10,500€	25,000€	45,000€

5.1. Laadunvalvonta

Tilatun osan laadun tarkistaminen suoritetaan yleensä vain visuaalisesti ja kokeilemalla kokoonpantavuutta. Yleisesti luotetaan toimittajaan ja jätetään kappaleen laatu tämän vastuulle. Muutama yritys mittaa kappaleiden mittatarkkuuden ja materiaaliominaisuudet.

Taulukko 12. Laaduntarkastuskäytännöt

Laaduntarkastusmenetelmä	Prosentti yrityksistä (%)
Visuaalinen tarkastus	63
Mittatarkkuuden mittaus työkalulla	38
Kokoonpantavuustesti	38
Materiaalin ominaisuuksien tarkas-tus	25

5.2. CAD-tiedostojen tietoturva ja käsittely

Luotetuille toimittajille tiedostojen lähettäminen ei ole ongelma, mutta muille tiedostoja ei usein lähetetä tietovuotojen varalta. Mikäli tiedostot ovat salaisia, laitteen omistavat yritykset valmistavat kappaleen itse.

Taulukko 14. .STL-tiedoston jälkikäsittely toimittajalla

Nähdään hyödyllisenä	Prosenttimäärä (%)
Kyllä	50
Ei	50

Taulukko 13. CAD-tiedostojen salaisuus

Salaisuusaste	Prosenttimäärä (%)
Ei lainkaan salaisia	25
Jonkin verran salaisia	37,5
Suurimmaksi osaksi salaisia	25
Hyvin salaisia	12,5

5.3. Toimitusaika

Pieni osa yrityksistä saa kappaleet toimittajalta noin päivässä. 86 %yrityksistä odottavat toimitusta useista päivistä noin viikkoon.

Taulukko 15. Ulkoistettujen kappaleiden yleisin toimitusaika

Toimitusaika	Prosenttimäärä (%)
Alle päivä	0
Noin päivä	14
Useita päiviä	43
Noin viikko	43

5.4. Maksimaalisen hyödyn raja

Maksimaalisen hyödyn raja on se toimitusnopeus, jolla ylimääräinen nopeus ei tuota hyötyä. Suurrimmalla osalla yrityksistä maksimaalisen hyödyn raja on muutamista päivistä noin viikkoon, mutta muutamalla yrityksellä maksimaalisen hyödyn raja on noin päivä. Tällä hetkellä toimitusajat ovat hieman maksimaalisen hyödyn rajaa pidempiä.

Taulukko 16. Maksimaalisen hyödyn raja

Ajanmääre	Prosenttimäärä (%)
Alle päivä	0
Noin päivä	29
Useita päiviä	43
Noin viikko	29

5.5. Kustannusten seuranta

Kustannuksia seurataan suurimmassa osassa yrityksistä jokaisen tilauksen kohdalla erikseen.Isommat yritykset ovat budjetoineet AM-tekniikoiden käytön vuo -sitasolla

Taulukko 17. Ulkoistamisen kustannusten seuranta

Ulkoistamisen kustannusten seuranta	Prosentti yrityksistä (%)
Budjetoitu	25
Jokainen tilaus erikseen	50
Ei seurata	25

6. Yleistä ja tulevaisuusnäkymät

Taulukko 18. Materiaalia lisäävään valmistukseen liittyvien tekijöiden subjektiivinen tärkeys asteikolla 1-5, jossa 1 = ei lainkaan tärkeä ja 5 = hyvin tärkeä

Tekijä	Keskiarvo	25. persentiili	50. persentiili	75. persentiili
Saada kappale nopeasti käsiin	4,09	4	4	5
Kappaleen mittojen tarkkuus	4,27	4	4	5
Materiaalin sopivuus	3,64	2,5	4	5
CAD-tiedostojen tietoturva	3,18	2,5	3	3,5
Menetelmien optimaalisuus	2,82	1,5	3	4
Yleinen tietämys AM-tekniikoissa	3,64	2,5	4	4,5

Materiaalia lisäävä valmistus nähdään tärkeänä esitettäessä konseptimalleja insinööreille. Osakkeenomistajille pikavalmistetut mallit nähdään liian karkeina. Selkeänä trendinä yritykset haluavat valmistaa isompia kappaleita. Kiinnostus SLM:ää kohtaan on suurta. Toimitusaika on suurimman osan mielestä hyväksyttävä ja palveluun yleisimmiltä toimittajilta ollaan oltu tyytyväisiä. Suoraan eri väreillä toimivat valmistusmenetelmät ovat saaneet jonkin verran huomiota, mutta suurin osa yrityksistä mieluummin maalaa mallit jälkeenpäin. Pikavalmistettujen kappaleiden pinnanlaatuun ei olla tyytyväisiä, vaan sen pitäisi olla parempaa. Omien laitteiden nopeus on tällä hetkellä hyväksyttävä, mutta tulevaisuudessa toivotaan laitteiden olevan monta kertaa nopeampia.

Uuteen .ATF-formaattiin on kiinnitetty jonkin verran huomiota ja osa yrityksistä toivoo saavansa käännettyä tulevaisuudessa CAD-tiedoston .ATF-tiedostoksi. Tarkkuusvaluille (investment casting) on kysyntää ja toivotaan, että Suomeen tulisi tarkkuusvaluja tekevä toimittaja. Malleja käytetään harvoin sellaisinaan, vaan ne viimeistellään varsinkin reikiä aventamalla.

Edistyneimmät käyttäjät ovat aloittaneet RM:n käytön ja trendin mukaan tulevaisuudessa sitä tullaan käyttämään Suomessa enemmän kuin nyt. Kokonaistietämys materiaalia lisäävän valmistuksen ympäriltä vielä suhteellisen alhaista.