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HOW TO DIGITALIZE SPARE PARTS BUSINESS

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ABSTRACT

This Master’s Thesis concentrates on explaining the possibility to utilize 3D printing in Small or Medium size Enterprises (SME) and by that to digitalize the spare parts process.

This Thesis is focused on mainly 3D printing of metal parts from which the author has most experience and on the other hand which has not been researched as much as 3D printing plastic parts.

Traditionally 3D printing has been seen only as prototyping method and something that needs specific Engineering practises. This Thesis is explaining that it is also possible to perform analysis to existing parts as well and not only to be bound to new parts that are created originally for 3D printing as manufacturing method.

Even if the results for finding partnering companies and to print a sample part for them, it was clearly seen during the interviews that the topic is interesting, and it raised a lot of questions inside companies that are producing small batch size parts with special requirements either from material or technological side.

The practical result from the Thesis is one 3D printed part as sample and discussion on its economical feasibility. It is clear that not every part can be realistically 3D printed, but there are already real-life samples that show the potential of 3D printing as suitable manufacturing method with economical feasibility.

As a final closure, there is a chapter which explains possible scenarios on creating business proposal on 3D printing spare parts, and this is also the area where future research should also be concentrated on.

Key words: 3D printing, Spare parts, Additive manufacturing, After sales, Service Business

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1 INTRODUCTION

The aim for this Thesis is to research the business possibilities and feasibility of the idea to produce machinery spare parts by 3D- printing. The focus is mostly on Finnish SME’s who do not necessarily have the practical knowledge on how the 3D- printing practises will change the business models in Spare parts supply chain.

In this Thesis, the main discussed topics are the current limitations in the techniques, feasibility issues, and business model for 3D- printed spare parts.

The main target is to open the topic to the reader so that he can have a clear vision of what is possible today and what will the near future look like regarding 3D- printing. When realizing this, the reader can then make his own assumptions and evaluate if printing is suitable business model for his enterprise by acknowledging the stated operating models in the Thesis.

2 3D- PRINTING IN GENERAL

3D- printing as it is known publically, is a manufacturing technique to create volumetric objects, usually constructing them in very thin layers of wanted material.

The main benefits of 3D- printing have traditionally been design freedom and effective manufacturing of small series when comparing to traditional manufacturing techniques.

From the beginning of 21th century, globalization has raised interest back to decentralized manufacturing and this area looks like being major interest on Spare parts business, which this Thesis is concentrating on.

2.1 Brief history of 3D-printing

3D- printing technique was originally developed in the 80's for fast prototyping of plastic parts. The development has gone rapidly forward, mostly during last decade, advancing from simple and not so high-quality mock-up parts into latest jewellery, human body replacements and even printable food type of inventions. (The Guardian, 2014)

The technique has been more widely available to public upon release of first consumer- oriented 3D- printers in 2012. This has happened relatively late, three decades after the original invention, mostly because of printing material price drop, cost reduction of machinery and availability of freeware computer software. (Wohlers & Gornet, 2014)

This Thesis is concentrating into printing of Spare parts, and to be precise, metal parts. The history of 3D- printing metallic parts is even shorter than plastic or composite materials. According to Wohlers & Gornet (2014), first commercial 3D- printing machines for metal was introduced in 1998. When comparing traditional manufacturing methods, one could say that the period of introducing the technology and its breakthrough into a respectable manufacturing tool took surprisingly short amount of time.

From the Figure 1 it can be seen the quite dramatic rise in metal 3D printer sales starting from 2012 onwards. This clearly states that the industrial use has evolved into a state where printing is used as one manufacturing method and not only as a prototyping tool.

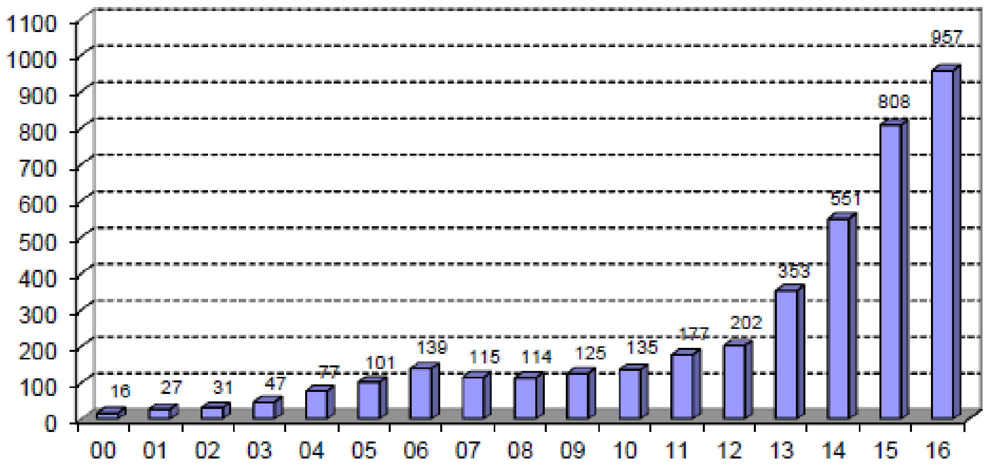
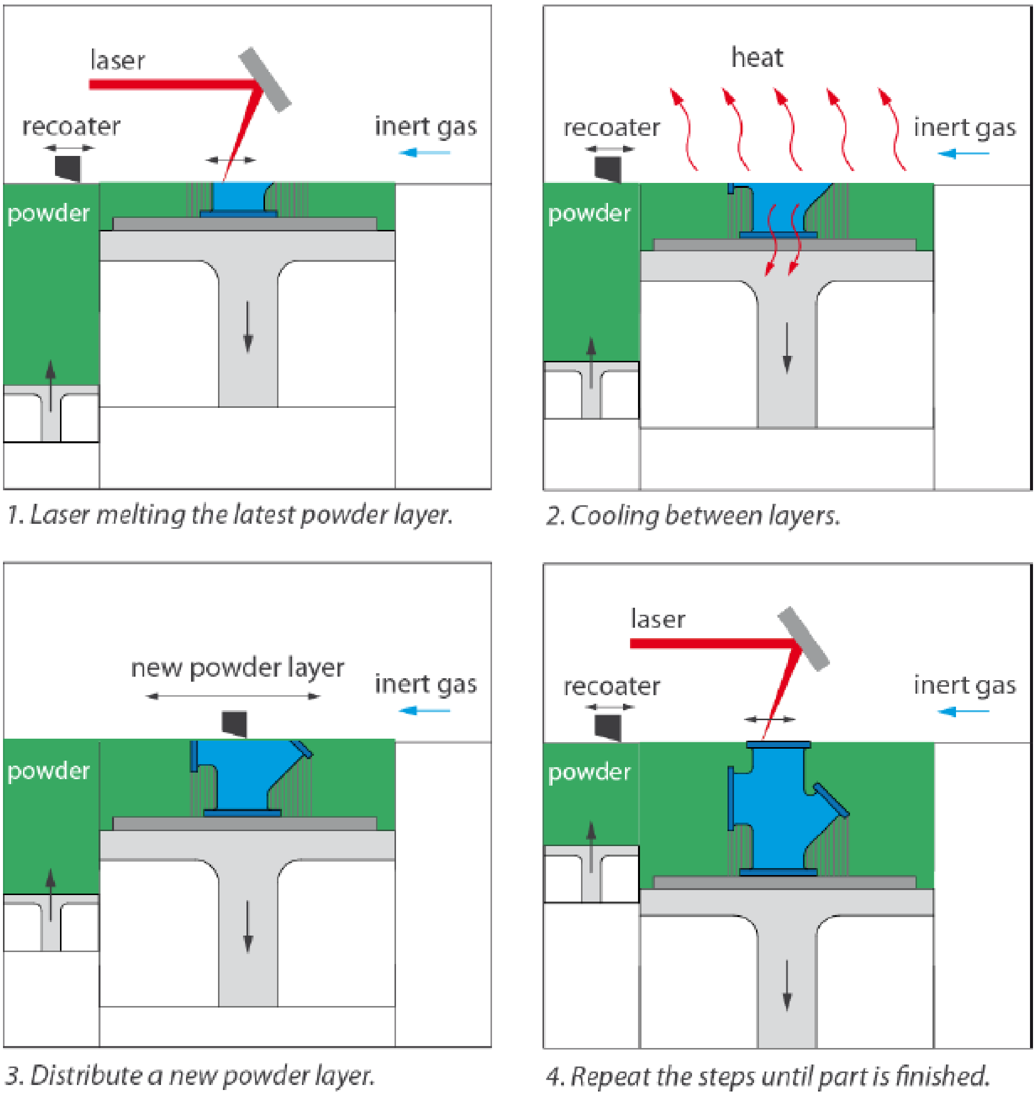


Figure 1, number of metal 3D printer systems sold (Vinnova 2017)

2.2 Techniques, their suitability and limitations

Metal printing techniques can be divided roughly to two categories, Powder bed techniques and Powder-fed techniques. The main difference between the two techniques is the operating mechanism. In Powder bed technique, the produced part is constructed by coating and melting layer on top of another (Picture 1). In this technique, the final part is the removed from a chamber that is filled completely with powder. Powder-fed technique (also known as Direct metal Deposition) is based on adding material through a nozzle in layers, only where it is needed. Powder-fed technique uses similar layer by layer forming technique, but the part is not surrounded by powder when being finalized. (EPMA, 2015)

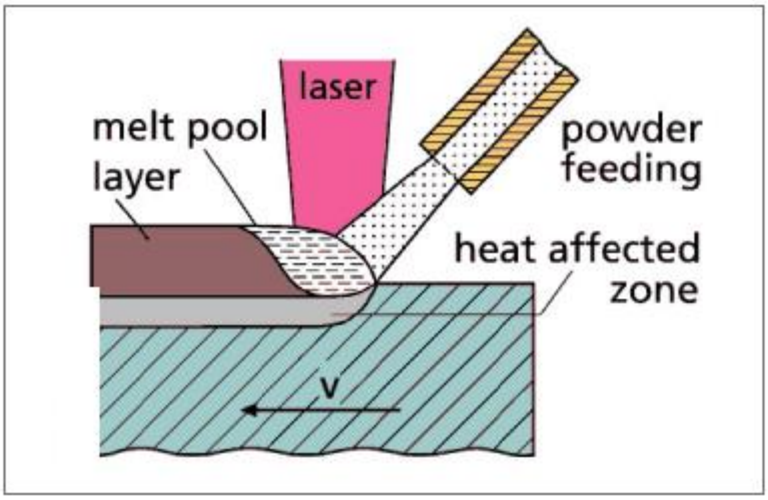
Major differences in applications are the accuracy requirement for the finished part, speed and complexicity of the part produced. Powder bed technique offers smaller layer thickness, typically 20-100µm, which leads to higher precision in part. Powder-fed technique provides layer thicknesses starting from 100µm to several centimeters. The layer thickness, and by that layer volume, is related directly to part build speed, where Powder-fed system takes the lead clearly. Surface roughness vary also depending on the chosen techniques, with Powder bed, it is possible to reach smaller surface roughness figures that Powder-fed systems. (EPMA, 2015)



Picture 1, basic principle of powder bed technique (VTT 2016)

Powder-fed technique offers one more interesting possibility, the ability to add material on top of existing part. This feature can be used on repairing existing parts, or combining manufacturing practise - such as cladding parts with different material or combining traditional machining with

Additive Manufacturing technique. This opens new possibilities on creating new products or improving them in manufacturing. Service and maintenance companies are also interested on the repair potential since expensive parts are usually serviceable if only the techniques are available. (Inovar Communications, 2017)



Picture 2. Powder-fed system illustration. (EPMA 2015)

Characteristics	LMD	SLM
Materials	Large materials diversity	• Limited and lower experience in comparison to LMD
Part dimensions	Limited by the handling system	Limited by the process chamber (Ø: 250mm, height: 160mm)
Part complexity	Limited	Nearly unlimited
Dimensional accuracy	≥ 0.1m	≥ 0.1 mm
Deposition rate	3 – 10 mm^3/s	1– 3 mm^3/s
Build-up on	• 3D-surface • On existing parts	• Flat surface • Flat preforms
Roughness R_z	60 – 100µm	30 – 50µm
Layer thickness	≥ 0.03 - 1mm	≥ 0.03 - 0.1mm

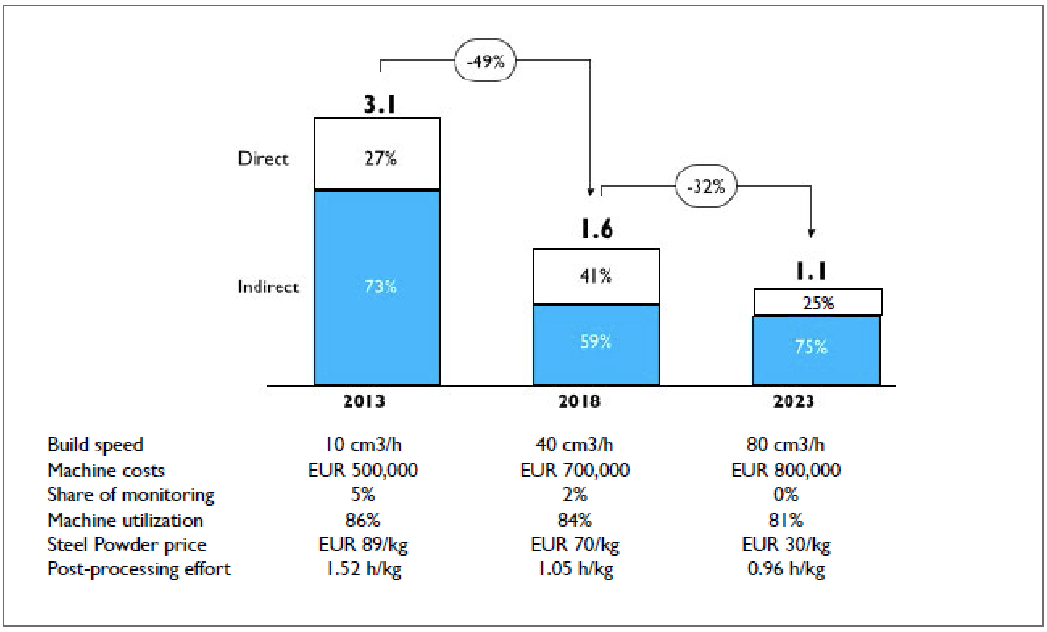
Comparison of LMD vs SLM (Courtesy of Fraunhofer)

Table 1. Comparison of Powder-fed (LMD) and Powder bed (SLM) techniques. (EPMA 2015)

According to Attaran (2017) major limitation in the techniques are part size, surface quality, general costs of printing in large quantities and material availability. When thinking about Spare parts process in Finnish machinery OEM's point of view, the most limiting factors would practically be part size and costs. Material properties for printing are in most cases not the problem, neither is the surface quality.

Typically, at the moment, majority of Powder bed systems can handle a maximum part size of appr. 250x250x250mm. There are larger printers available in the market, but their cost is relatively higher, and they are not widely available yet. A printer with the chamber size of 250x250x250mm costs appr. 400-700 000€ depending on the configuration and chosen materials to be printed.

Printing costs have decreased in past few years, mainly because there are more material providers available and several key patents for material production have expired in 2016.

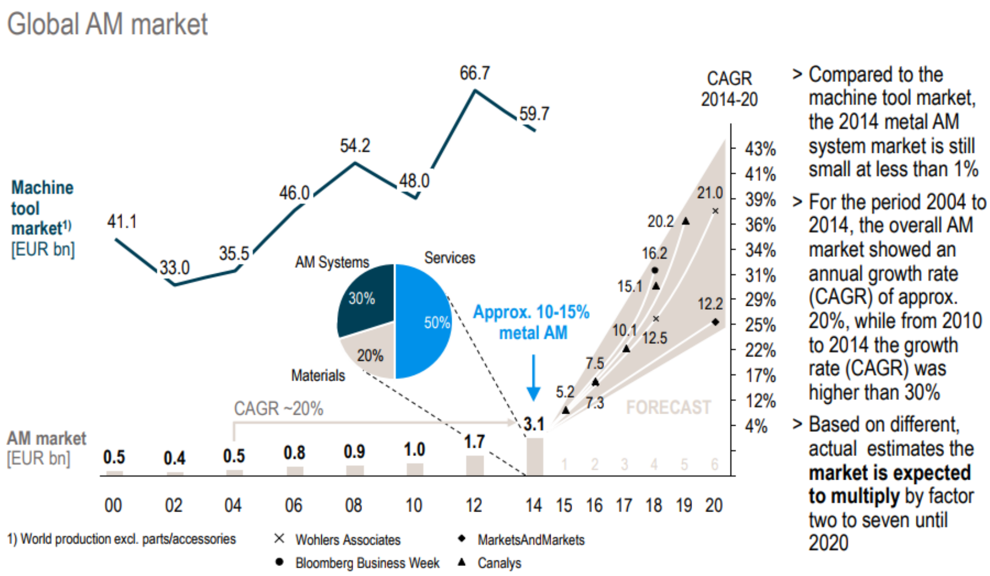


Graph: Forecast of metal AM costs in euros/cm³ (Courtesy of Roland Berger)

Picture 3, forecast of 3D printing costs (Roland Berger, 2013)

2.3 Near future changes and development

There are clear indications that the additive manufacturing market is booming and is expected to multiply by several factors in the next five years (Picture 4).



Picture 4, global AM market forecast (Roland Berger, 2016)

By the author’s experience there can be seen a division happening in the market to two different main techniques, SLM (powder bed) and powder fed systems. These two differ mainly in the accuracy vs. volume. SLM technique is used to provide parts that are directly (or almost) usable straight from the printer. The downside is slow process and because of that, costs. Powder fed systems can produce more volume in the same time frame and that is why it interests the companies to develop it further. On the flipside, the surfaces are not the fine and require post processing more – naturally depending on the application.

This division is driving the companies and it remains yet to be seen which companies and techniques remain as the winning ones in the game.

3 FEASIBILITY OF 3D PRINTING IN GENERAL

According to Vinnova's report (2017), the four major market areas where 3D printing is considered as a most feasible method for manufacturing are:

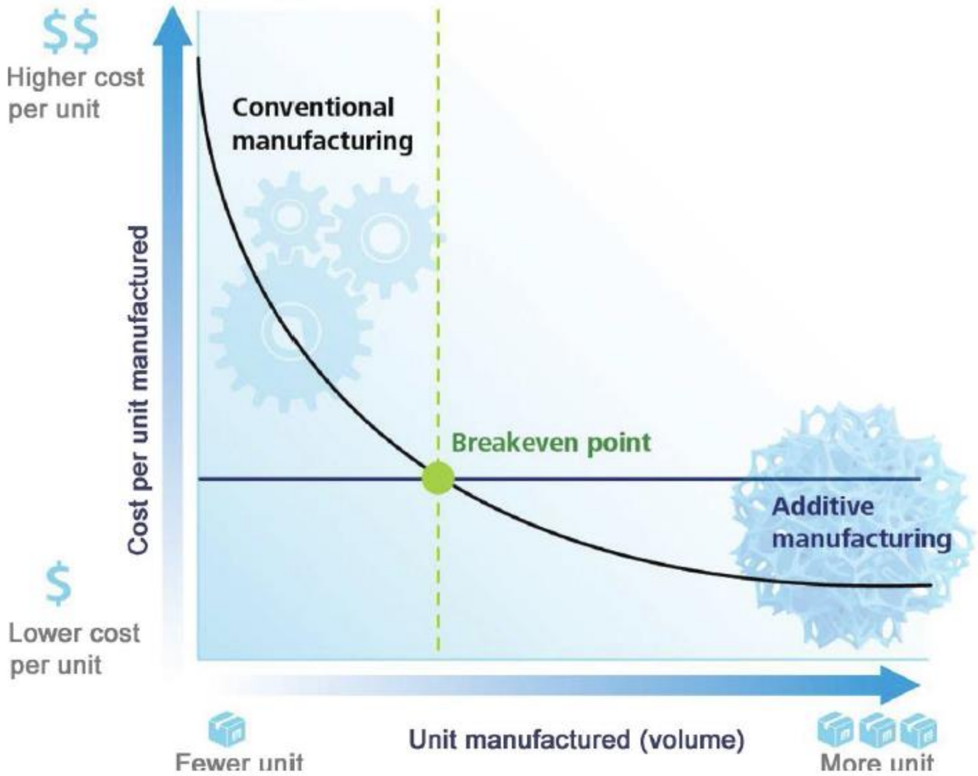
- Small production output, such as spare parts and prototyping
- Complex products, where current traditional manufacturing methods are not capable to produce parts
- Highly customized products, such as human implants or other personalized products
- Decentralized production of complex parts

Since 3D printing is considered as a good technique for Spare parts business, which is the topic of this thesis, it is assumed that in general the current limitations in production techniques are not necessarily show stoppers for creating new business opportunities.

3.1 Mass production vs. small batch size

According to Attaran (2017), 3D printing is not going to replace traditional manufacturing methods, but it is going to bring a viable option to manufacture complex parts with low volumes. According to the studies, there is a certain breakeven point found (Picture 5) when comparing 3D printing and traditional manufacturing methods. This may come from:

- high tooling costs per unit in traditional manufacturing
- customization needs and by that more complex parts, leading to higher costs in traditional manufacturing
- shorter time-to-market cycles, 3D printing is usually fast technique to produce first parts because of digital workflow from design to manufacturing
- simplified overall production system when 3D printing, such as material procurement, warehousing, preparation and handling



Picture 5, cost comparison between conventional manufacturing and 3D printing (Attaran 2017)

As en example, Optomec Inc. (2017) has stated that in race car part, the savings in material costs have been over 90%. This was achived by changing the manufacturing method or a small series part from machining (subtracting material) to additive manufacturing, which in this case is 3D printing only the necessary volume for the final part. As a second example from Optomec is a traditionally casted part with very long lead time (1 year), which was replaced by a hybrid manufacturing – in practice partly 3D printed solution. By this change, the lead time was reduced to 3 weeks (94% shorter) and additional 30% cost saving was achieved for the same part.

The examples in previous chapter are naturally meant for marketing purposes and chosen most likely to be from the extreme end, but there are similar examples found from many industries worldwide.

3.2 Low volume manufacturing challenges among SME's in Finland

According to Statistics Finland, there are appr. 350 000 small and medium-sized enterprises (SME) in Finland. They create annually over 100 billion Euros in value added production and employ 1,4 million people in total. (Statistics Finland, 2017)

From above statistics, it can be said that SME's are key to Finland's employment rate and major supplier of economic growth. In the next chapter, the topic is concentrating to area where 3D printed Spare parts would most likely be feasible - low volume products.

3.2.1 Low volume manufacturing in general

Low volume (or project based) manufacturing in Finland is usually seen in the context of a delivery project, such as production machinery, which is a part of end customer's investment project. Also building project can be seen as low volume manufacturing because of it's nature of being usually custom made to suit the need of end user. (Artto et al. 2011)

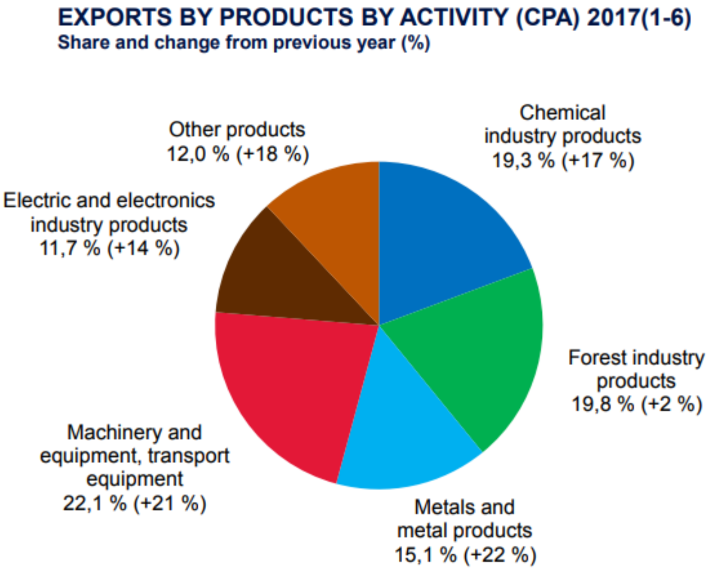
Since this Thesis is concentrating on Spare parts, the context is chosen to be manufacturing of machinery for investment projects.

Typically, investment projects are customized to specific needs and this translates often to at least partly custom products that may be produced only once to suit this kind of business (Artto et al. 2011).

Manufacturing of custom products means usually:

- higher costs per product because of small series
- higher Spare part costs because of small series
- less possibilities to keep large inventory of different products to serve several customers
- long lead time to produce new Spare part if inventory is not used

From this analogy, 3D printing may very well be suitable method to replace other traditional production methods since costs per piece is not so crucial issue.



Picture 6, Finland export figures by products. Tulli, 2017.

Imports and exports by products by activity (CPA 2008), 2016

Imports	**€ million**	**%**
Chemical industry products	10 050	18,3
Electric and electronics industry products	8 061	14,7
Transport equipment	5 950	10,8
Products from mining and quarrying	5 663	10,3
Machinery and equipment	5 108	9,3
Other	20 173	36,7
Exports	**€ million**	**%**
Forest industry products	11 357	21,9
Chemical industry products	10 223	19,7
Metal and metal products	7 475	14,4
Machinery and equipment	6 949	13,4
Electric and electronics industry products	6 324	12,2
Other	9 549	18,4

Table 2, Finland import & export figures by products. Statistics Finland 2017.

When looking at Pictures 6 & Table 2, it can be seen that the Machinery and equipment goods export from Finland is appr. 15% and 7 Billion Euros. Large part of this segment is investment goods, so the Business scale for low volume manufacturing can be calculated in Billions of Euros.

In the case of Finnish SME's, some of them have long history of making products and by that also supplying Spare parts to their products. As stated previously, the focus in this Thesis has been chosen to investment products, and to be specific - low volume products, which typically have longer lifetime.

According to Lintukangas et al. (2014), there are almost 350 companies in Finland that operate in low volume (project based) business. These companies had turnover of over 1M€ and represent mostly manufacturing of machinery and equipment which makes them interesting for Spare parts manufacturing. Keeping this in mind, there is potential for Spare parts business to grow in Finland.

4 SPARE PARTS AND MAINTENANCE PRACTISES

Traditionally Spare parts management has been divided to two categories, reactive and proactive models. In practise, reactive model steps into place when something breaks, and Spare part is needed immediately to ensure that production continues. Proactive model on the other hand tries to replace a Spare part before it breaks by using statistic methods or time-based techniques to predict the possible failure. (Ben-Daya et al., 2009)

4.1 Custom Spare parts

According to Ben-Daya et al. (2009), the most problematic Spare parts are customized or made-to-order ones. This is because there is usually long lead time and high costs because the parts are not produced to stock, but they are manufactured only on order basis byt the OEM supplier. The end Customer traditionally must hold an own stock of these parts to minimize the shutdown times in case of breakage. This naturally raises stock value and raises the risk of production loss if something unplanned maintenance is needed.

Because of the above circumstances, many process plants have developed proactive maintenance models which predict the need of maintenance operations and Spare parts before the breakage happens. This way of operating is usually called planned maintenance. With planned maintenance activity, it is easier to handle the needed Spare parts, even the long lead time ones. (Ben-Daya et al., 2009)

4.2 Spare part manufacturing

According to Khajavi et al. (2013), the main issues in maintaining good Customer response for Spare parts are:

- unpredictability of demand
- high inventory costs (if parts are produced to stock)
- supporting legacy products

- changes in current products

These above challenges usually drive the companies into situation where required Spare parts are only manufactured on order basis. This naturally leads to longer manufacturing costs, higher prices, higher labour demand in production and high logistics costs. (Khajavi et al., 2013)

5 DIGITAL SPARE PARTS AS BUSINESS CASE

Digital Spare parts is a term which has not been used widely yet, but represents the digitalization of Spare parts process. It means in practise that Spare parts manufacturing information of an Original Equipment Manufacturer (OEM) is stored digitally and distributed in file format only. By this it is possible to change the whole manufacturing network into a decentralized one, close to actual usage place and in the end use 3D printing to produce the actual part. There are several benefits on perfoming this kind of practice, smaller stocks, on-demand Spare parts and smarter Spare parts to name a few. (Aalto University, 2017)

The following chapters will represent the available information by the author in the form of Active research – a method which is used to gather personally acquired information on the subject.

5.1 How to identify 3D printable Spare part from the mass

According to studies by VTT (2017), 5% of Spare parts could be 3D printed. This figure seems to vary, some researchers believe that the number would be even up to 15%, but when thinking the actual economical feasibility as of today, 5% is most likely correct figure.

In a study of one a large Finnish equipment manufacturing company, the following figures were presented:

- Total of 200 000 Spare parts were listed through item inventory
- 6% of the above parts (12 000 pcs) were identified as printable by type and size
- 2% (4 000 pcs) of the total number were economically suitable for 3D printing

This kind of undisclosed study was performed by filtering the item information with: part material properties, physical size of the item, usage figures such as ordered amounts.

These above filters were used because – as explained in the previous chapters – 3D printing is usually most suitable for:

- Parts with very low or low annual consumption volume
- Complex parts, such as machined ones
- Parts with small size, fits into a cubicle of 500mm in size

When thinking about 3D printable parts, there is one interesting opportunity, casted metal parts. Traditionally casting has been done with for example wooden casting models and they have been kept in warehouse waiting for next casting batch. If the casting model is missing or destroyed, making new cast model is expensive and time-consuming process which adds to the cost and lead time for the final part. On the author’s opinion there could be actual business potential on offering a simple workflow of transforming old part drawing data into 3D printable format and offer one-stop-shop principle for manufacturers seeking options to produce old Spare parts cost effectively and with short lead time.

As a practical approach to identifying suitable 3D printable part, the following procedure could be used:

1. Filter the part inventory at first by general definition, if there is a manufacturing drawing for part or not (not a standard component)
2. Secondly, add filter for material type, such as cast iron, mild steel or stainless-steel grade
3. Apply another filter on size information if it is available, start with smaller parts, such as largest single dimension of 250mm
4. Apply another filter if available, is the part machined or not

By this kind of classification, it should be possible to define the most suitable parts for 3D printing at a rough scale. After this kind of filtering it is time to advance into economical feasibility of manufacturing.

One another important consideration is the question, is there some problem that can be solved with 3D printed Spare part in the sense of adding functionality to part, replacing the old part with better one?

5.2 Economical feasibility

Easiest way to start implementing 3D printing into Spare parts process is to find suitable part with the methods mentioned in previous chapter and calculate the actual costs of the part, starting from direct manufacturing costs at first. After investigating the manufacturing costs, the next step is to evaluate the whole process of delivering the part to the end Customer.

Since the main theme of this Thesis is low volume manufacturing, it can be assumed that Spare parts volumes are relatively low too. In any case, there will be benefits if the ordered amount would be larger than one, possibly at least between 2-5 pcs of each part, depending naturally of physical size. This is because the printing is done in batches, and if one order could fill one print batch, then there is usually a cost benefit found (based on author's experience).

Currently, machine cost (incl. investment) and material cost are typically the highest portions when printing metal parts. There are different variables in the process as can be seen in the Figure 2 (Thomas & Gilbert 2014) where studies have been made by different authors to compare cost calculation principles. If it is possible to either reduce the volume of the part, or the dimensions of the part, they will most likely lower the printing cost immediately.

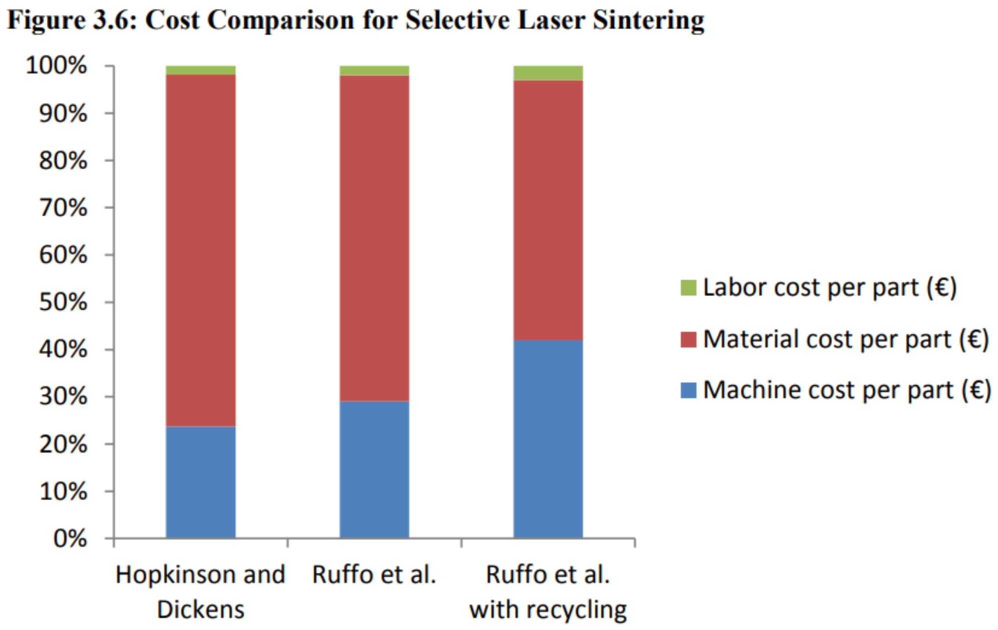


Figure 2, Cost Comparison for Selective Laser Sintering. Thomas, D. Gilbert S. 2014.

From author's personal experience and discussion with 3D printing supplier during the writing of this Thesis, the metal powder costs are roughly in the following range:

- Maraging steel MS1 90 €/kg
- Stainless steel 316L 120 €/kg
- Aluminium AlSi10Mg 110 €/kg

So based on this, even in small parts it is advicable to take into account the material volumes needed since it has major effect on the costs.

The choice of materials is expanding typically annually, and there is already rather large selection of different materials available (Picture 7). From these materials, it is possible to choose even higher-grade material than would normally be needed in the application and to optimize the part for 3D printing while saving weight for example.

Examples of powders available for AM manufacturing according to powder manufacturers

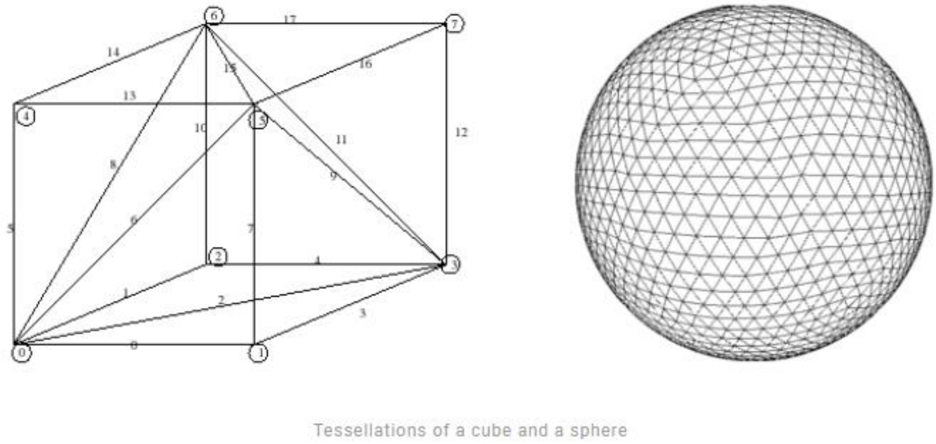
Stainless	Fe-base and Tool steel	Titanium	Aluminiu m	Hard metals	Nickel-based	Cobalt-based	Precious
304L S30403 1.4307	H13 T20813 1.2344	Pure Titanium	AlSi12		625 N06625 2.4856	CoCr F75 R31537	Gold
316L S31603 1.4404	X40Cr14 - 1.2083	Ti6Al4V	AlSi25		718 N07718 2.4668		Silver
420 S42000 1.4034	4140 G41400 1.7225	Ti5Al2.5Sn	AlMg3		738		99,9% Cu
? J94224 1.4848	M300 (K93120) 1.2709	Ti6Al2.5Sn 4Zr2Mo	AlSi10Mg		939		CuSn
15-5PH S15500 1.4545	INVAR 36 K93601 1.3912	Ti5Al5Mo 5V3Cr	AlSi7Mg		230 N06230 2.4733		
17-4PH S17400 1.4542		Ti6Al7Nb	AlSi9Cu3		Waspaloy N07001 2.4654		
347 S34700 1.4550			AlMg4.5M n0.4		HX N06002 2.4665		
Duplex 2205 S32205 1.4462					C-276 (N10276 ?) (Ni 6276 ?)		
2507 *S32750* *1.4410*					(C-1023?)		

Picture 7, Typically available metal materials. Vinnova 2017.

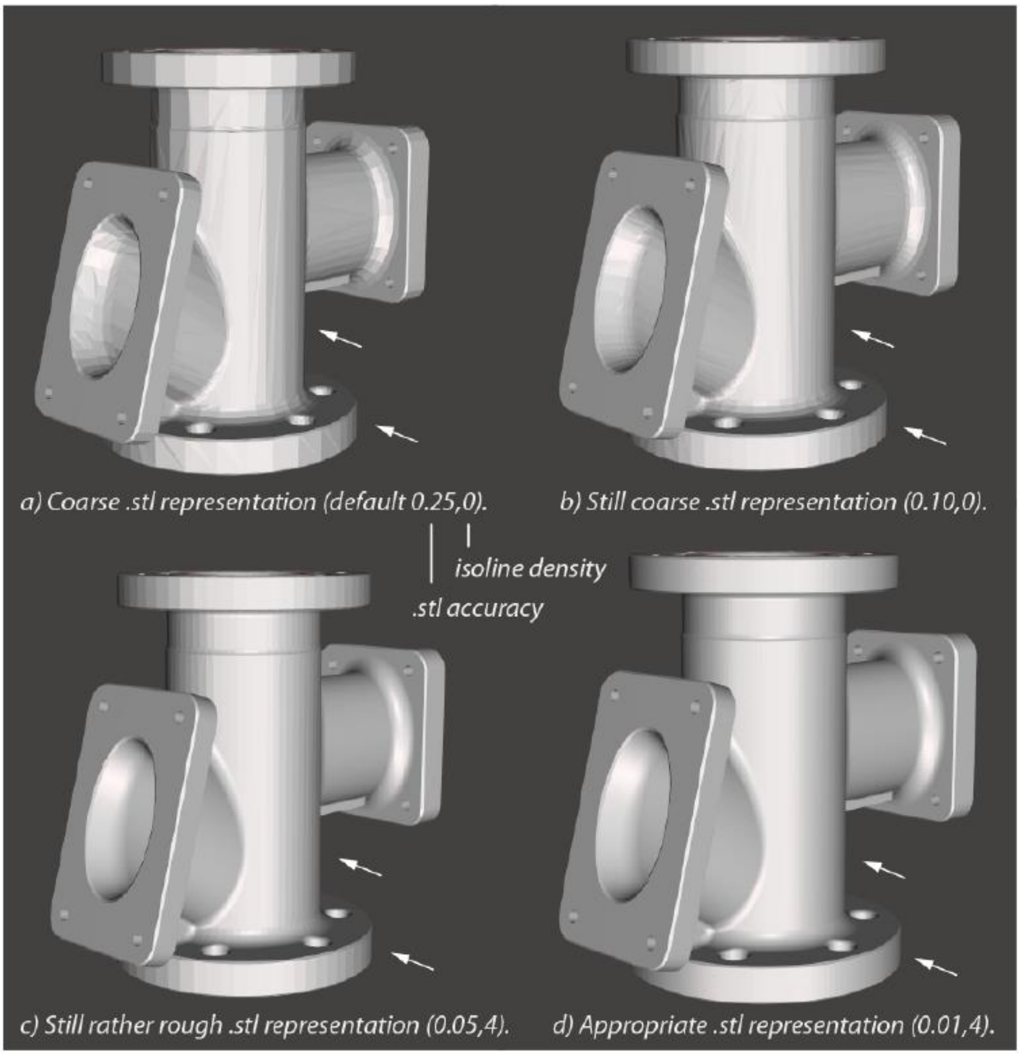
5.3 Working with 3D files

Printing Spare parts requires naturally three-dimensional data on the wanted subject. As of today, nearly all 3D printers understand the same neutral file format for printing, Stl (.stl, stereolithography). The origin of this file format comes from 1987 when the first 3D printers were developed. (All3DP, 2014)

There are limitations in the file format, maybe the most known one is that it is not able to handle curved surfaces, they must be calculated to small triangles which of course means that the surface is not exactly round. This can be sometimes seen in the final product, but if the 3D model is done with proper precision, the triangles are so small that it is impossible to recognize them any more.



Picture 8, Tessellation of different shapes into 3D data. All3DP, 2014.



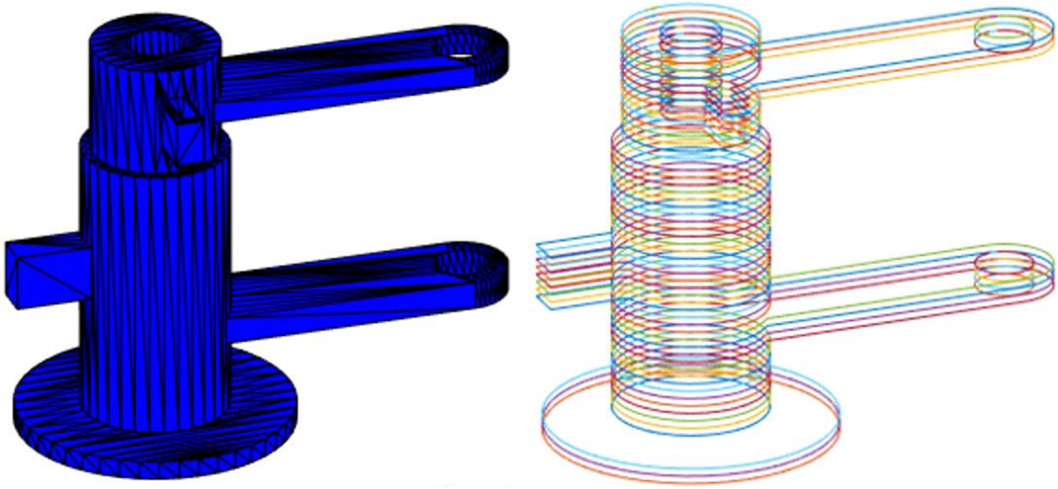
Picture 9, Surface quality with different .stl file settings. VTT, 2016.

When planning printing Spare parts, the first step is to check whether there is 3D model available for the part, and after that transform it into Stl-format file and verify that it looks correct. After creating the Stl- model, the file and relative manufacturing drawing can be sent to chosen supplier(s) for quotation use. Usually at this point the supplier can evaluate if the model is suitable for printing or not and if there are any limitations on the production.

If the 3D model data is not available for Spare part, the data must be created at first in Engineering or by 3rd party who is able to create 3D model for the part. There seems to be also an upcoming trend where for example Engineering service providers are offering complete package of

Designing the part, possibly modifying it to suit 3D printing and supplying the actual part throught their partner network. This is especially interesting business model since it requires no action from the Spare part seller other than providing enough specifications to the service provider to make the part.

After the 3D file is sent to supplier, it is input into the printing software where it is sliced into thin layers which contains only two-dimensional information. By this, the printer can create the final part layer by layer.



Picture 10, .stl model slicing example for 3D printing layers. Ding et al. 2016

5.4 Data handling and security

Companies usually tend to be very cautious on releasing their Engineering information to outsiders. This has been the traditional approach, but since a lot of manufacturing is performed in different kinds of supply chains, things have changed here in 21st century.

3D printing requires the detailed information of a part to be delivered to the manufacturing company in electronic format to allow printing in general. This forces the owner and receiver of data to agree on the delivery methods and standards so that the information flows without alteration and problems.

One clearly problematic area is controlling the manufacturing versions, meaning the 3D files in general. The neutral format for manufacturing (.stl) is practically always exported from native CAD file handling systems, which means that it is not under version control any more. This may create a situation when original data owner cannot be sure if the part is always printed from the latest 3D model data. There are software solutions available to assist in version control and this is an important aspect when choosing the printing partner in the supply chain.

5.4.1 Handling IPR issues

In consumer industry, copying products have been more than a standard for years. It does not take a long time when new consumer product is launced when illegal or just slightly altered copies start to appear to the market. The question is; how can this be taken care of in the investment industry products, and to be more specific, Spare parts?

In general, the field can be categorized to two optional models, one is designing the products so that they operate only in the wanted way if produced with original 3D information, the other is changing the business model towards selling only royalties on using the original data.

The first of the above options is most likely more time- and resource consuming because it requires careful planning and detailed Engineering to ensure that the part has such “smart features” that it is impossible to copy easily. One possible option could be to embed sensor or RFID- tag into the product as was tested by Yin, Mireles, Choudhuri & Wicker (2016). This kind of Smart part could give competitive edge to the manufacturer of original part.

Another possible solution could be to follow the consumer business examples. According to Intellectual Property Office (2016), music or movie service provides who can create such an easy and fluent way of using their service, the consumers do not want to spend time and effort on making illegal copies and distribute them. This kind of service solution for industry could allow the end user to just access their machinery Spare part repository and print a Spare part when needed. The payment to equipment manufacturer would then be charged according to used model data, in similar way as musicians are paid royalties.

5.5 Choosing the printing partner

Starting a new business model of printing Spare parts does not mean that one has to purchase their own printer, instead the most effective solution to start with would be to find suitable partners locally and most likely in the end globally as well. 3D printing has been quoted rather as an ecosystem than just a printer.

Some important aspects to take into account when choosing partner by the author's experience:

- Standardized manufacturing process, including; material handling, software translation, printing parameters and post processing
- Quality control practises developed to ensure stable production
- Technical knowledge to improve process and provide feedback and suggestion towards purchaser
- Possible value adding capabilities, such as Engineering or additional post processing services
- Willingness to operate in the logistics chain, to supply delivery services to purchaser's end Customer

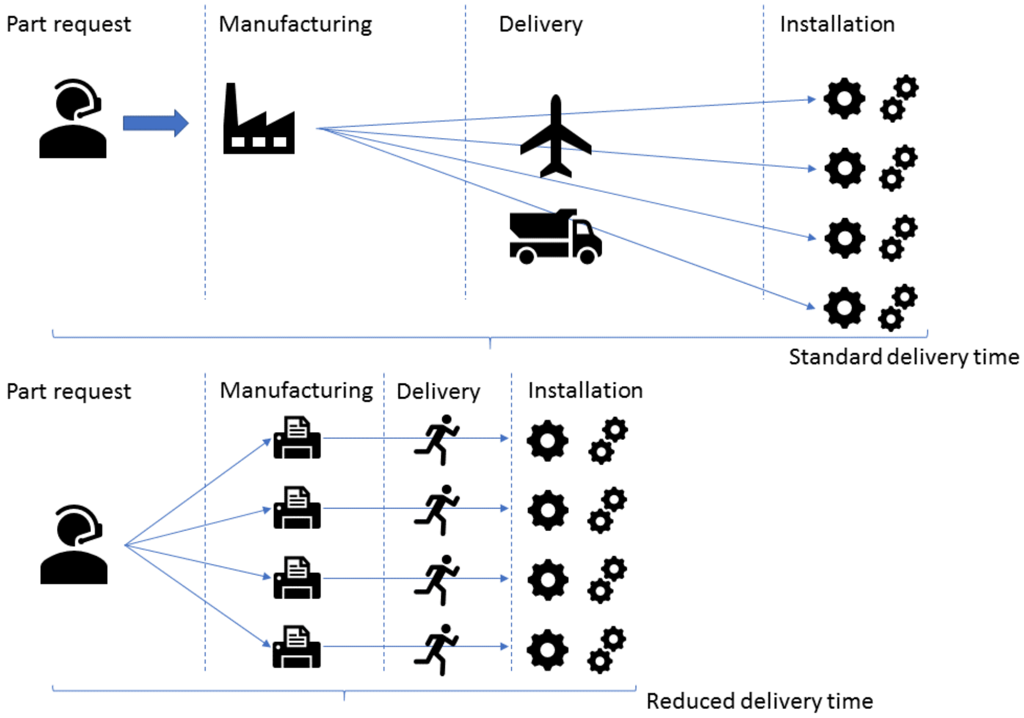
These above aspects are important because as said, 3D printing is usually a lot more than just printing the parts, it often generates need to improve the parts or develop the whole process and supply chain. When a supplier already has developed their own practises, they can support the purchaser in making right decisions to decrease costs, improve the products or streamline the whole print-delivery- process.

5.6 Logistics chain

3D printing in general has been described as game changing technique to alter the current centralized manufacturing of Spare parts. There are of course people who doubt that 3D printing is able to change the large scale of operations but in certain products such as highly complex and low volume parts, there is definitely acknowledged potential found.

According to Boon & van Wee (2017), 3D printing will clearly change the logistics chains in those products that are going to be printed. The main findings were:

- Local 3D printing hubs will be developed, by this local transportation will increase and long-distance transportation will decrease
- Distributed production will allow more flexible manufacturing schedules and choices between different manufacturers (printing hubs)
- Parts or products will be transported effectively and fast by shorter distances and raw material (3D printing feedstock materials, such as powders) can be delivered in more slower and bulky way
- Transportation costs will decrease because of local manufacturing and more efficient raw material transportation
- Simple parts can be produced even by the end customer, more complex parts require professional equipment which are usually found in printing hubs



Picture 11, delivery time difference example with 3D printing

In the Picture 11, the basic principle of 3D printing (or direct manufacturing in some examples) process is shown, including the practical effect of manufacturing time frame change with it.

It is seen that large logistics companies, such as DHL (2018) and UPS (2018) are interested on being a major partner in this kind of new logistics chain. There seems to be couple of viable options for supply chains to be seen in the future, either a 3D printing facility near major airport hubs to allow fast deliveries to several remote areas or small printing kiosks which are wide spread to cover smaller towns as well directly.

5.7 End Customer as manufacturer

One of the most extreme business models in Spare parts is the model where end Customer could be the manufacturer for parts and they would only pay royalties to the original manufacturer on using their 3D data to perform printing of Spare parts.

In this kind of scenario, the most important factor would be on how the payments can be verified and how to make sure there are no circumstances where the end user would take benefit of having the part information available and to misuse the usage and payment terms.

In this kind of scenario, liability issues should also be taken into concern, since who would be responsible of the proper quality and fit for the printed part? This question could be answered by building a flawless chain of manufacturing process parameters for each part, meaning in practise standardized:

- 3D data verification and translation to printer
- printing parameters
- material properties
- post processing procedure
- quality control & final inspection

If the above practises are well handled, the end user can be sure that the produced part will meet the initially meant technical performance.

The benefits for this kind of use scenario is mainly the flexibility for the end Customer, meaning in general that they can predict the Spare part usage and plan predictive maintenance effectively and in some cases, shorten the production stoppages since the parts are easily available with short notice. Other important value for Customer is decreasing the warehouse value and content. If the end user can 3D print at least some of the parts on-demand basis, the number of items in warehouse will decrease accordingly. This will naturally decrease the value of unused items in the inventory and avoid scrapping unused items.

6 CASE EXAMPLES

This part of the Thesis includes practical examples of digitalizing Spare parts. These are use cases where two companies have been chosen as example partners to see if 3D printing could be suitable for their process and business.

6.1 Company 1 profile and spare part sales

Company’s main office is in Southern Finland and is providing Equipment and Services for surface treatment processes. It is rated in Finland into Small business category and has its own product design practises which date back several decades. Company’s turnover has been as average just under 10 million euros, and employee count is appr. 20. There are no manufacturing premises, all manufacturing is subcontracted and the company is only having small spare part warehouse for the most common items.

Upon interviewing the company’s Service Manager, the basic facts for spare parts sales annually were:

- Total sales of spare parts are appr. 150 – 200 000€
- Spare part orders appr. 100-120 pcs
- Majority of spare part orders are 3rd Party components, such as sensors or automation components
- Oldest requested parts with company’s own design date back to over 30 years

Customers are situated mostly abroad, so spare parts are shipped from Finland around the globe. Typically, the Customers are ordering larger quantity of each spare part than just one piece, they are keeping most vital parts in warehouse to prevent any stoppages in production. The company is keeping small inventory of most common spare parts from where they can send the parts faster. The problem with this inventory is that there are several items which the Customer time to time request, but which are not included in the inventory. This causes long lead times and in some cases losses in production for the Customer.

6.2 Company 2 profile and spare part sales

Company's main office is situated in Southern Finland and is supplying equipment for industrial cleaning systems. The company is small in size and have their own products and design practises. The turnover has been in the range of appr. 1 million euros annually and the company employees 4 persons at the moment.

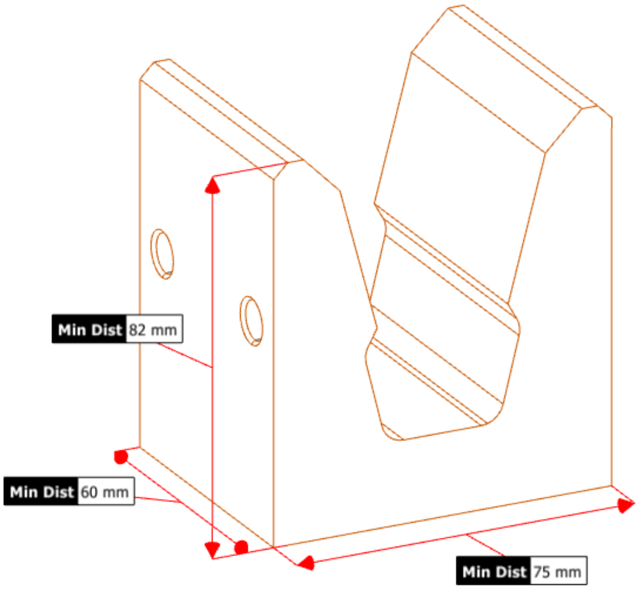
Based on the interview with the company's Managing Director, the basic facts for spare part sales annually were:

- Total sales of spare parts are appr. 50 – 100 000€
- Spare part orders appr. 100 pcs
- Majority of spare part orders are wearing parts from company's own design
- Oldest requested parts with company's own design date back to over 20 years

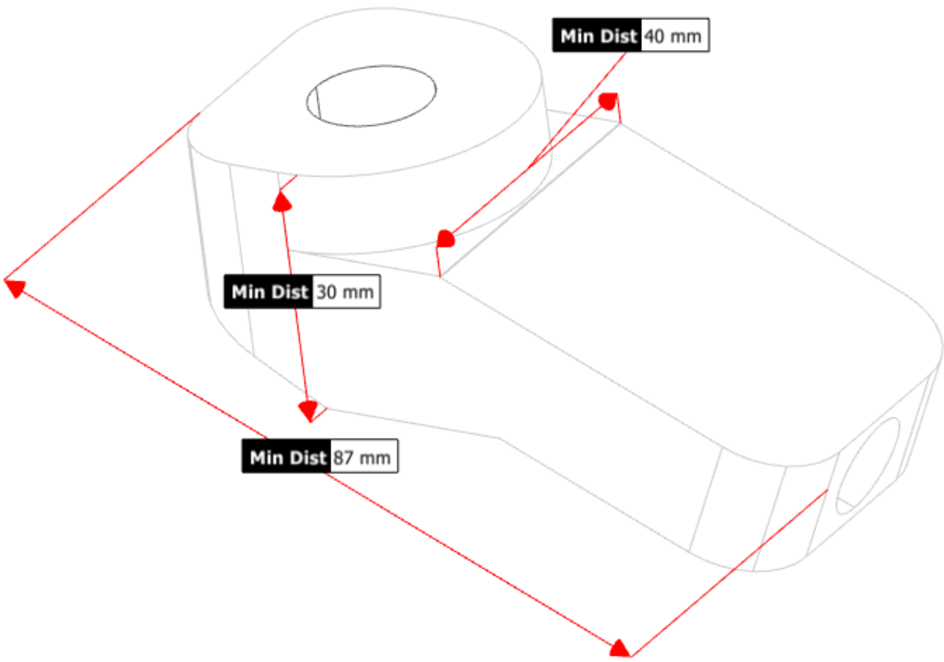
Majority of the deliveries of new equipment goes abroad from Finland, but for spare part sales, majority is still for Finnish Customers. Customers typically order small amounts of single spare part. Typically ordered spare parts are not highly crucial for the Customer's process, but in case the equipment is not working properly, there may be expensive costs arising from maintenance afterwards. There are requests for shorter lead times occasionally, but the Customer is not necessarily willing to pay high premium for that.

6.3 Chosen parts for Companies 1 & 2

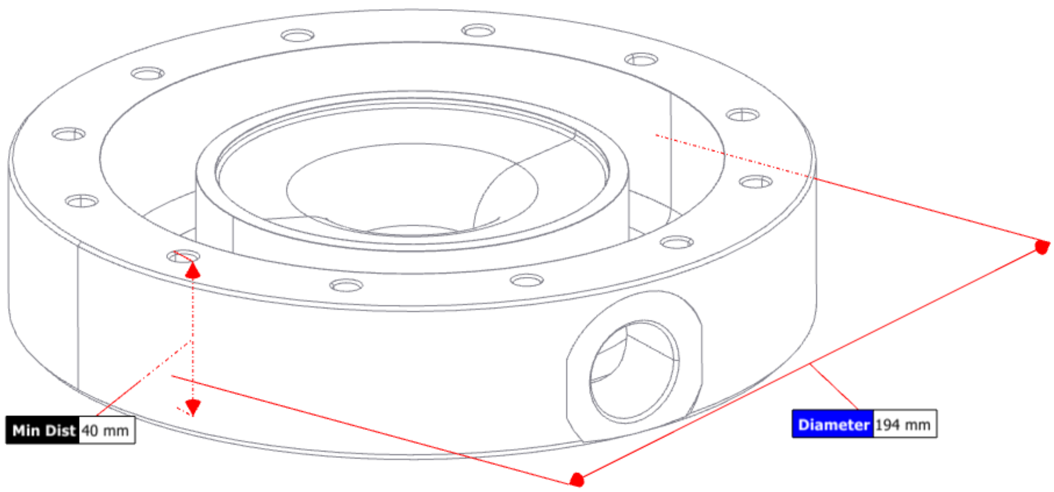
The parts that were chosen for the study were basic Spare parts that the companies regularly sell, they were medium and large ones in size and had machined surfaces or details in several places. The parts could be either casted or made from plate material, as long as the surfaces are meeting the dimensional requirements. Original base materials were Copper for Part 1, Plastic for Part 2 and Stainless steel for Part 3.



Picture 12. Company 1, Fork part. Originally made from Copper.



Picture 13. Company 1, Nozzle part. Originally made from plastic.



Picture 14. Company 2, Frame part. Originally made from Stainless steel.

After studying the parts more closely and having email- discussions with the 3D printing company, it came clear that two of the chosen parts were not suitable to be 3D printed at today's cost levels. The reason mainly was that the parts were easy to manufacture with traditional methods such as turning and milling, and their material volume was so high that 3D printing is not competitive solution at the moment.

In the end, the nozzle part from Company 1 was chosen to be printed after modifying the geometry and changing the part material from plastic to Stainless steel. Also, the channel inside the part was modified for better flow because channel form is no longer limited to possibilities of traditional manufacturing. This is a typical case where the Spare part may have different functionality compared to the old one, such as more durable material or better usage parameters (channel flow in this case).

Below is a table (Table 3) that describes the evaluation results for the parts.

Part description	**Material**	**Current cost with traditional manufacturing**	**Printing cost**	**Suitability mechanically for printing**	**Economical feasibilty**
Fork (Picture 12)	Copper	80€	2000€	Yes	No
Nozzle (Picture 13)	PTFE (plastic)	80	250€ (Stainl. steel)	Yes	Yes (depending on usage)
Frame (Picture 14)	Stainl. steel	210€	5500€	Yes	No

Table 3. Evaluation results for spare parts, Company 1 & 2.

6.4 Additive Manufacturing evaluation tool comparision

For the selected parts, a secondary study was done by using Aalto University's evaluation tool for Additive Manufacturing (2018). From this tool, the following price information was gathered to compare with enquiry from 3D printing company:

Part	**3D printing company quotation**	**Aalto University evaluation tool**
Fork	2000€ (incl. Machining)	1504€
Nozzle	250€ (incl. Machining)	149€
Frame	5500€ (incl. Machining)	4439€

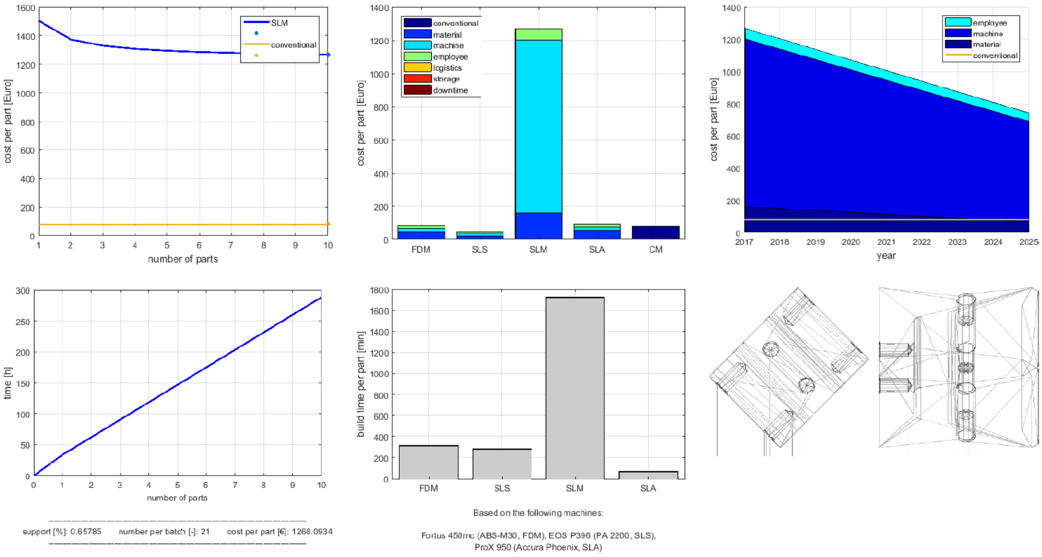
Table 4. Evaluation results for spare parts. (Aalto 2018)

The results were evaluated with the following parameters that have influence to the costs:

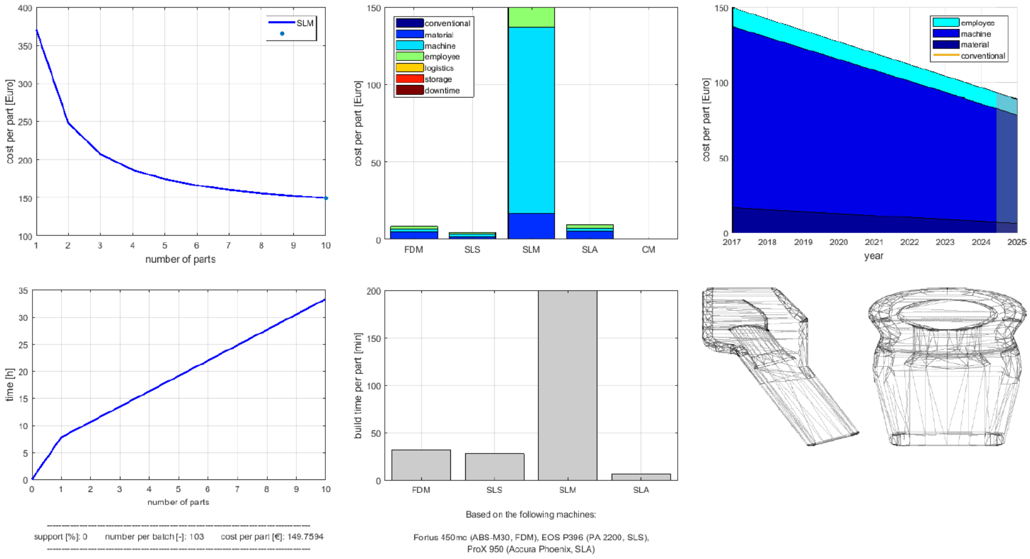
- Material Maraging Steel 1.2709

- Batch size 10 pcs for each part
- Machine used in the calculation Concept Laser M2 (400W)

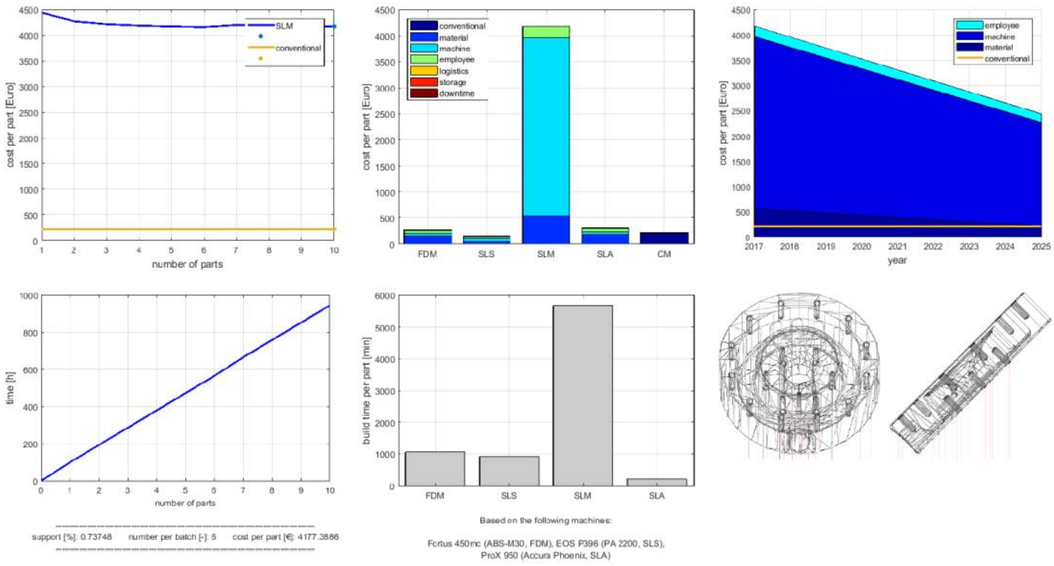
These above values were chosen to simulate the actual case for ordering 3D printed Spare parts.



Picture 15. Evaluation tool results for “Fork”. (Aalto 2018)



Picture 16. Evaluation tool results for “Nozzle”. (Aalto 2018)



Picture 17. Evaluation tool results for “Frame”. (Aalto 2018)

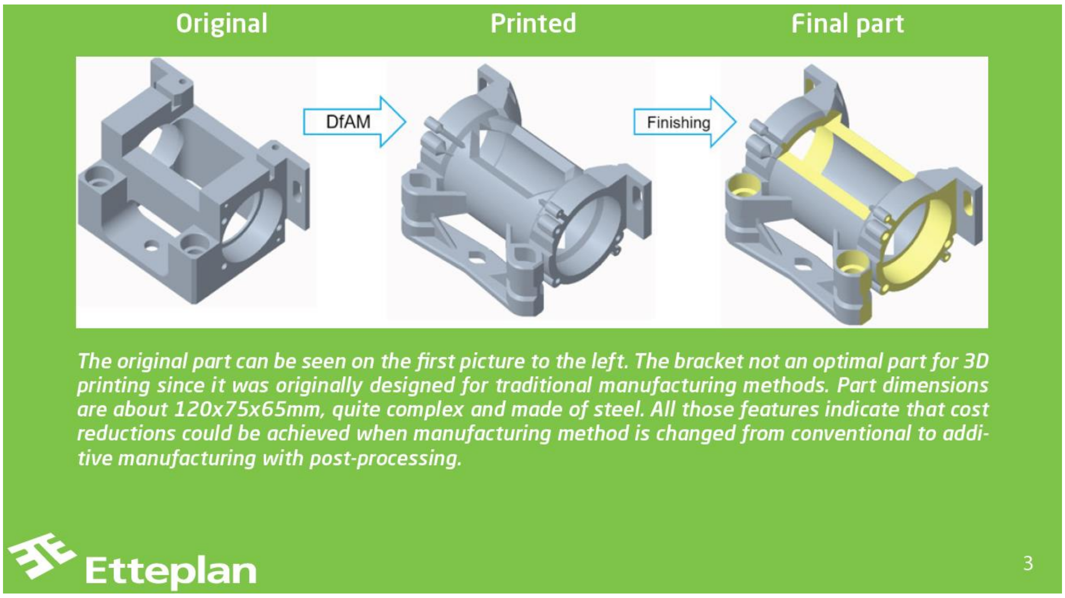
The results (Picture 15, 16 & 17) show that it is possible to get reasonably reliable figures from online calculator to evaluate the feasibility of 3D printing. In the Aalto University’s evaluation tool (Aalto 2018), there is no post processing considered such as machining the final surfaces, so that must be noted when using such calculators since the cost must be added on top of printing costs. In practise today still, it is always recommended to ask the final quotation from the service supplier to find out possibilities to reduce costs in some way that the online calculator cannot evaluate at the moment.

In all the samples above, the batch size was 10 pcs and annual consumption 20 pcs for each part. In the evaluation calculator there are several parameters that can be changed, and their effect can be seen immediately. By doing this for the part that is investigated one can see if the batch size has effect on the feasibility.

6.5 Reference study by Etteplan & Raute

For this Thesis, one especially interesting study has been the 3D printing cost evaluation for existing parts and the possibility to perform some changes in design to lower the costs of 3D printing parts.

According to Etteplan (2018), it is possible to achieve similar costs with 3D printing than traditional manufacturing methods and even lower them – especially if the design is adapted to suit better 3D printing. In this study there were several service providers that quoted the requested parts and it was seen that since the technology is not yet really mature, the pricing practises are also varying quite much. (Etteplan, 2018)



Picture 18. Etteplan's design that was altered and adapted for 3D printing (Etteplan 2018)

	Part	Machining	Material	Price	Price difference
Company A	Original	NO	316L	1,50	
	DfAM	**NO**	**316L**	**1,24**	**-18 %**
Company B	Original	NO	NO	NO	
	DfAM	**NO**	**316L**	**1,23**	**-**
Company C	Original	YES	MS1	0,74	
	DfAM	**YES**	**MS1**	**0,63**	**-15 %**
Company D*	Original	NO	Ti6Al4V	0,75	
	DfAM	**NO**	**Ti6Al4V**	**0,73**	**-3 %**
Company E	Original	NO	MS1	1,44	
	DfAM	**NO**	**MS1**	**1,29**	**-10 %**
Company F	Original	YES	316L	1,22	
	DfAM	**YES**	**316L**	**0,87**	**-29 %**

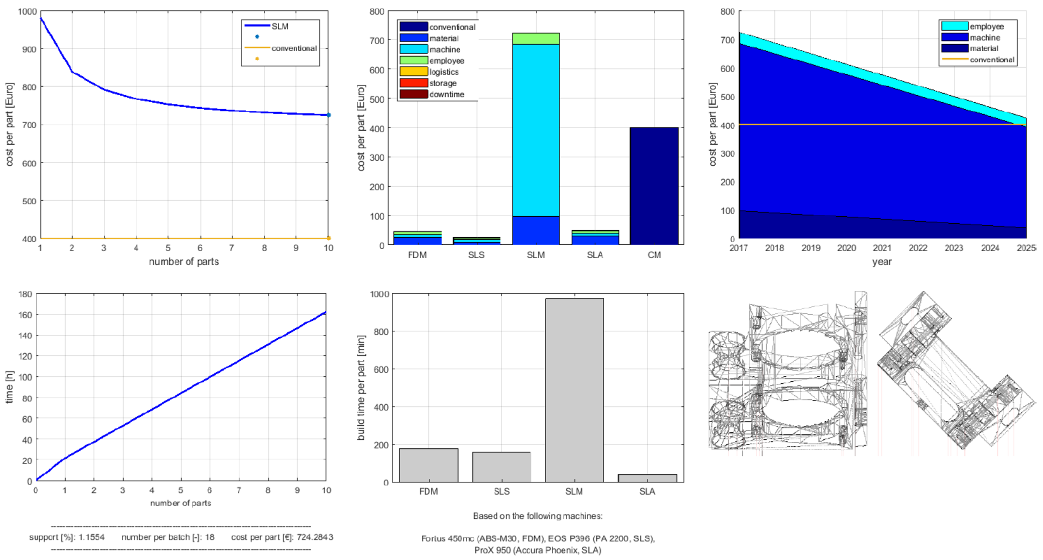
** Printed with EBM technology*

Picture 19. Cost comparision of different printing service providers, original part with conventional manufacturing Price is 1,00 (Etteplan 2018)

The results from this study was that with rather small amount of re-engineering for the part, savings of up to 37% in manufacturing costs can be achieved by changing manufacturing method to 3D printing. (Etteplan 2018)

This case study seems to be quite optimal case to see the effect of using 3D printing as replacing traditional manufacturing, and there are big differenciens on the chosen part which is feasible or not. The huge difference within the chosen case studies with two companies and the results from Etteplan's study shows that at the moment it is really each and every spare part that needs to be evaluated if 3D printing is feasible or not. This kind of screening practice will show the potential parts from each company's spare parts library that could be printed in practical way.

As a reference to the two parts from case companies, the same original unmodified part which was used in Raute's and Etteplan's case study was evaluated with the tool. In this case, the part is more complex and a lot of material is removed with conventional method, so 3D printing is more effective manufacturing method in this case.



Picture 20. Raute & Etteplan case part evaluated with Aalto's tool (Aalto 2018).

The graphs in Picture 20 start to look different than in the previous two parts. This is due to the fact that the part is less massive and has more complex geometry for manufacturing. The same result can be seen by running the Aalto tool that this particular example is well suited for 3D printing.

6.6 3D printing process

For this Thesis a partnering company for 3D printing was found from Lithuania. The company UAB 3DPrototipai is a Lithuanian based Small enterprise who is concentrated on producing 3D printed plastic or metal parts for industry. Company employs 6 people and it's turnover was between 300-500 000 € in 2017. (Rekvizitai, 2018)

For the test printing, the chosen part's geometry was at first converted to .stl- file which was sent to 3D Prototipai for evaluation. After the evaluation was done, it was mutually agreed that this part is suitable for 3D printing in general and that the printing process is feasible overall.

The printing took appr. 6 hours after which the part was post processed to remove support material and shot blasted to produce final surface outlook (Picture 21). The post processing took appr. 20 min. After post processing the part was measured and by that verified that it fulfilled the requirements in manufacturing drawing.

Picture 21. Final printed part for Company 2.

Typically, the whole 3D printing cycle from sending the order and receiving parts take appr. 1-2 weeks, depending in required material and batch size. If a part is needed fast and costs are not relevant, the delivery process can be performed in less than one week.

7 DISCUSSION

Upon the author's own experience and the studies performed with the two companies, the main limitations and obstacles on the way to utilize 3D printing as method to manufacture Spare parts are:

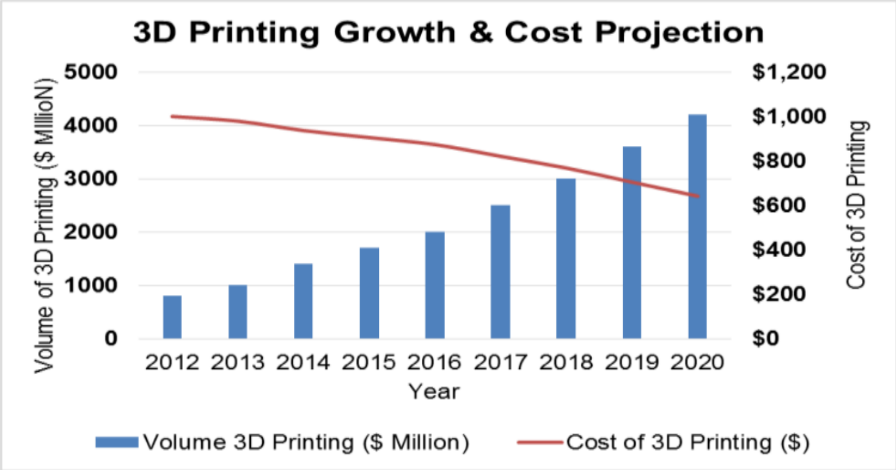
- Cost structure of 3D printing, still very expensive manufacturing technique (partly due to slow printing speeds)
- Lack of knowledge about the possibilities that 3D printing may offer
- Reputation of being only prototyping method, not an actual manufacturing method
- Limitations in the manufacturing process still and lack of standards
- Lack of processes

One of the most common surprises in the interviews done during the study has been: "are 3D printed parts really used in some production equipment at the moment"? This summarizes the fact that the technology is still not matured to a level where it would be amongst the traditional methods.

7.1 Printing costs

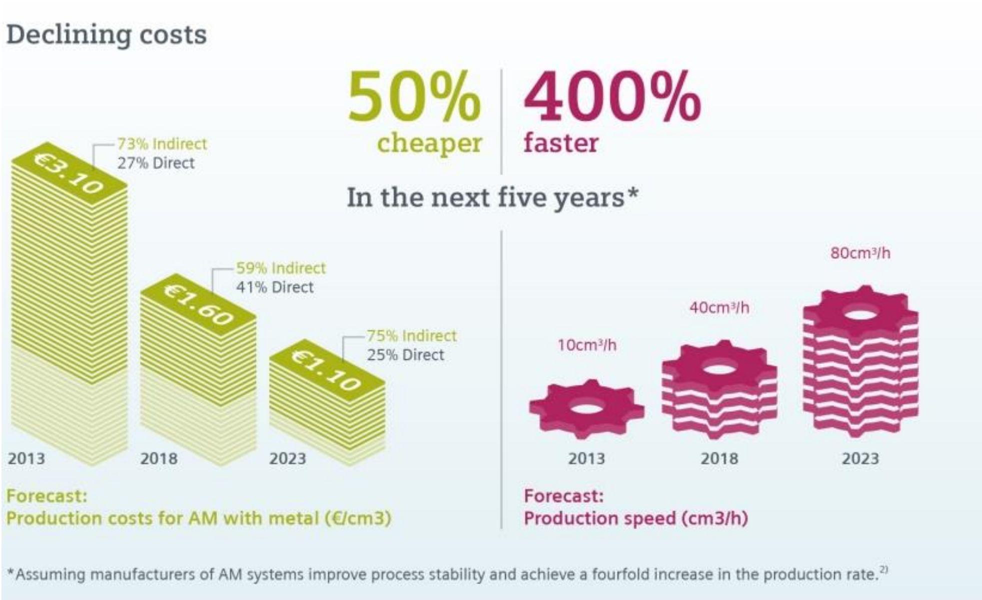
Costing is another major issue still with the technique, they can be dramatically higher that traditional methods still and that may be the crucial point on getting forward with 3D printing. The problem is the pricing methods used which do not support very well the introductionary nature of this kind of new technology. In Etteplan's study (2018) is was clear that there is high variation on how the manufacturing costs are calculated and that may also work against 3D printing if the quotation is asked from a supplier that does costing different way than other. In the study, the highest difference between the suppliers was 1,95 times when comparing same part from same material.

In general, it is presumed that 3D printing costs will decrease due to major adoption of new technology. 3D printing can be compared to for example adoption of LED- lights or RFID- tags which are nowadays very common but were once new and expensive technology. This has been evaluated by Bhasin & Bodla (2014) and the following graph (Picture 22) shows the general cost development trend which projects the cost going down by 36% in 2020:



Picture 22. 3D printing cost projection. (MIT 2014)

Part of the high costs is due to slow printing speed which increases the time one printer produces parts. Today 3D printing is still relatively labour intensive (excluding the printing process itself), there are steps where human interaction is needed but future development is increasing to that area. The machines themselves are getting faster every year, mainly because of Product development by the large players in the industry. The printing speed development is expected to be fast and to double by the year 2023 (Picture 23).



Picture 23. Printing cost and speed projection. (Siemens 2018)

7.2 Knowledge

Second major issue for entering 3D printing is lack of knowledge. According to author's experience, there is a lack of trained personnel to sell, design and manufacture 3D printed parts. This totals to general lack of knowledge on where 3D printing would be most suitable and what are the known limitations. To overcome this problem, universities for example have invested into machines lately or are trying to create ecosystems with 3D printing companies to allow students to access the technology. One example about these kind of co-operation projects is "Me3DI" by Lappeenranta University of Technology (https://research.lut.fi/converis/portal/Project/11106454?auxfun=share&lang=en_GB).

According to Deloitte (2018), number of job ads addressing 3D printing skills had gone up over 18 times between years 2010 and 2014 in USA. There is also evidence that with the currect education practises, 3D printing skills are most likely learned on the job than in education facilities. This is due to the slow implementation of new technology in the universities for example and reluctance to teach technology that has not been seen as a breakthrough yet. (Deloitte 2018)

To overcome these obstacles on the way with education, the author’s own recommendation is to increase the co-operation between educational institutes and companies that are either printing parts or ordering them. By this it is possible to utilize the best from both worlds, the need for skilled labor and the institutes providing the labor but lacking the access to technology.

7.3 Standards and materials

Third issue that can be raised is the unstandardized manufacturing methods, such as material properties, design rules, manufacturing methodology, international standards and quality control. All of these have been established decades ago for traditional manufacturing, but during the time if writing this Thesis, they have not been established for 3D printing. Lack of standardization and by that limitations in repeatability globally does not mean that the process is not stable or that it cannot produce good quality parts, it means that for example parts produced with different printer and/or material may have slight differencies in either outlook or in their microstructure. Standardization organizations such as ISO (Website, 2018) and ASTM (Website, 2018) are currently working on creating standards for Additive Manufacturing/3D printing.

Other limitation in addition to lacking standards is the lack of materials. At the moment there are only limited amount of materials available to be 3D printed. This is partly due to the printing processes that have been developed to certain materials only based on demand in high-tech applications initially. Naturally printer and material providers are expanding the selection all the time, but it may still come as a surprise that certain standard materials are not available for printing.

7.4 Process requirements

Typically, a company that has not utilized 3D printing earlier as manufacturing method for their products, have not thought the required processes through. This can be counted as an issue too to enter 3D printing – one does not know what is needed in general for acquiring printed parts.

In an ideal case for Spare parts, the company would have already created the processes for:

1. Screening potential 3D printed Spare part candidates from their products
2. Finding supplier(s) for 3D printing, possibly already close to the end user(s)
3. Creating 3D- geometry for the selected part if it does not exist already (possible partnering)
4. Purchasing the parts from supplier, including specifying requirements, delivering documents, quality control practises and possible post-processing requirements
5. Documents of manufacturing process if needed, such as material certificates and process values

Common method of creating these processes is through pilot case(s) which are documented properly and after that formed into actual processes. With this method it is relatively easy to see how the information flows inside the company and what are the possible improvements needed to make the process smoother in the future.

7.5 Benefits from 3D printing

Typically, the benefits from using 3D printing can be categorized to (at least) into these main topics:

- Single or small series of complex parts can be manufactured effectively

- Design freedom for products, possibility to combine parts into assemblies
- Distributed manufacturing possibilities, including digital repositories and data management
- New business strategies, such as selling data instead of selling parts

In the perspect of Spare parts, the following benefits are the most interesting ones:

- Single Spare part order can be fulfilled quickly in case there is a need for that
- By using network of distributed 3D printing suppliers, the process of delivering parts can be streamlined
- Possibility to introduce “better parts” for Customer and by that to add value on using 3D printed parts

If the end Customer requires new Spare part as soon as possible, is willing to pay premium for fast delivery and it must be sourced anyway from a 3rd party supplier, then that may be a potential case for 3D printed Spare part even by today’s cost level. The more complex part, the more suitable it may be.

In the mean time, the company selling Spare parts gets a valuable insight to 3D printing technology and learns how 3D printing changes the manufacturing and opens new possibilities for new product development as well.

7.6 Spare parts business by others

According to Siemens AG (2016), their development in Train Spare parts manufacturing has shown that with modified Spare parts that are 3D printed, weight loss or vibration reduction by design can be achieved. Also Deutsche Bahn (2018) has seen the benefits of 3D printing for their spare parts inventory in the form of lesser parts on the shelf and producing more burable parts than the original ones were.

Car manufacturer Porsche who has a long history of classic sports cars has launched an initiative to provide parts for classic cars by 3D printing. This is one interesting area since the same problems appear, such as missing tooling, missing drawings and no cost-effective manufacturing methods available for small series. (Porsche AG, 2018)

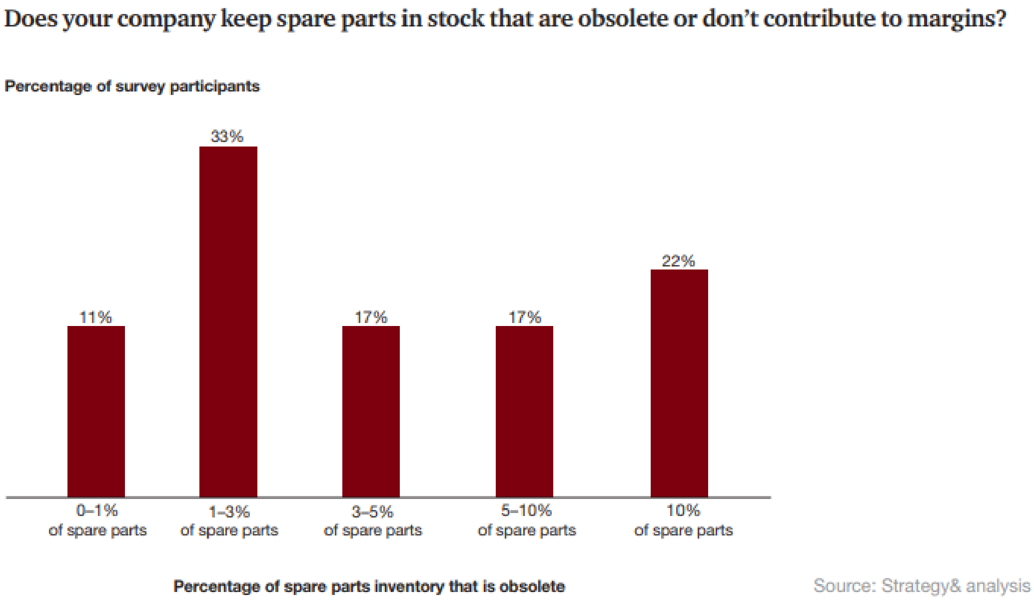
7.7 Future notes

When thinking about the fast evolution of 3D printing during the last decade, it is obvious that the technology will evolve even more in following decade. It is difficult to estimate the actual impact to manufacturing in general, but at least Spare parts business most likely will benefit from the possibilities that this technology provides.

There are quite clear signs that 3D printing will change the business landscape of logistics for example. Spare part sales will most likely move towards selling data instead of actual parts – at least in some areas of business.

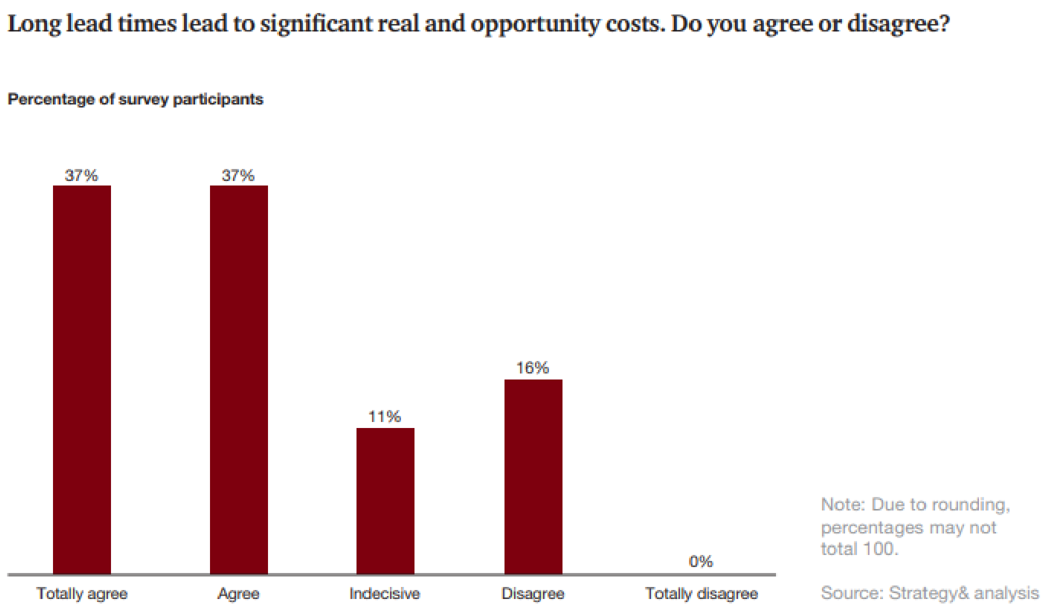
According to PWC (2017) study of 38 German companies, the following changes most likely will happen due to adoption of 3D printing:

- Over 85% of Spare part suppliers will incorporate 3D printing into their business
- Partnering in 3D printing will be the key to success
- Companies will sell a lot more copyrights that actual parts
- Huge savings potential in utilizing 3D printing for Spare parts



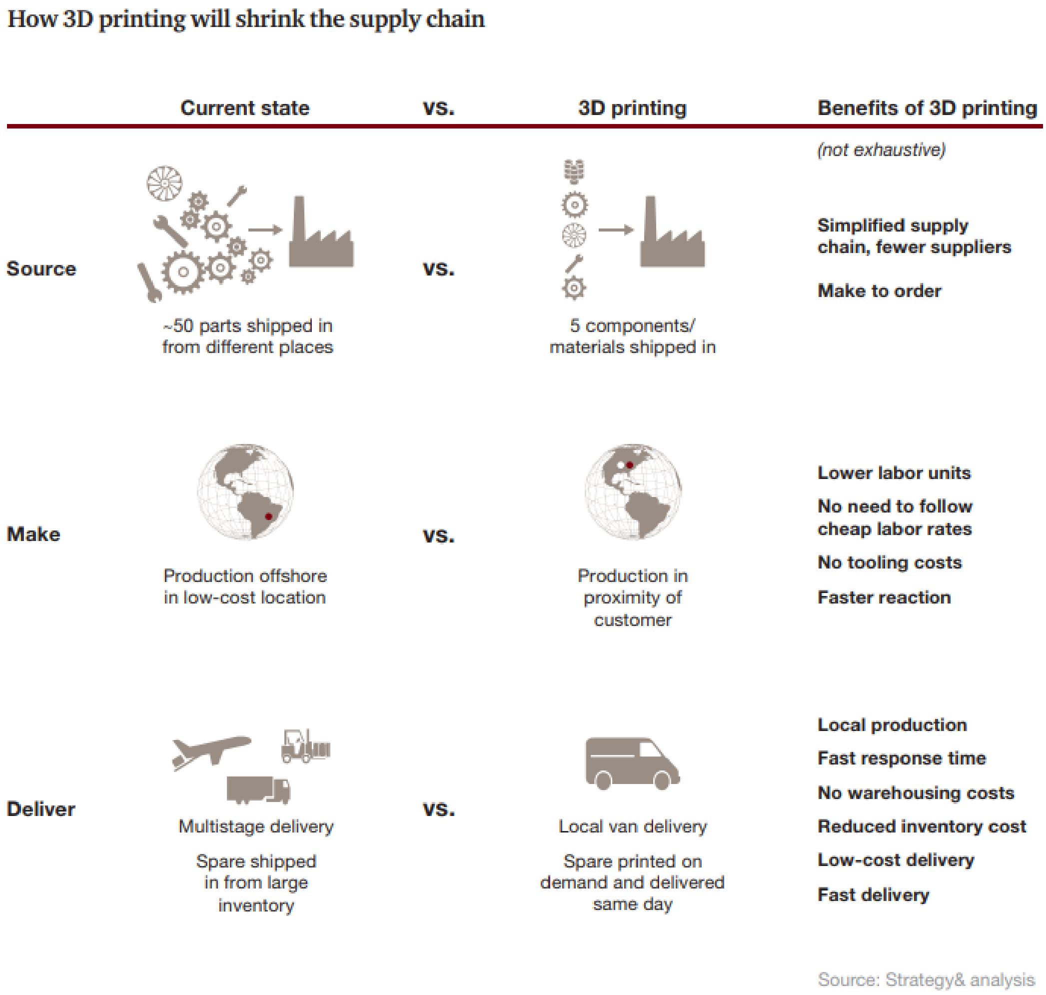
Picture 24. Share of obsolete Spare parts in inventory. (PWC 2017)

When looking at PWC (2017) report on Spare parts, there are couple of important figures when addressing issues with Spare parts, on of them is obsolete items in inventory (Picture 24). These items have generated costs in making and in storaging, how about if 3D printing could decrease the amount of item drastically?



Picture 25. Long lead time effect to sales. (PWC 2017)

The second interesting figure is the amount of interviewed companies agreeing that shorter lead times would give more sales opportunities (Picture 25), this goes up to 74%. What if 3D printing could happen locally, near the end Customer, maybe even in their own premises?



Picture 26. Logistics chain changes due to 3D printing. (PWC 2017)

One of the highest impact by 3D printing will most likely happen to logistics (Picture 26). When the printing data is transferred electronically in few seconds and production is possible to begin right away, that will change the business into totally different one. This of course is not the case for all Spare parts, but it will have effect to global logistics in the end anyway.

> *"In the future we will not buy spare parts anymore, but data."*
> —Reiner Rohr, BASF SE, Strategy& survey

Megatrends such as global warming and use of natural resources are also speaking on behalf of using material effectively and transporting only the goods that are really needed around the globe.

8 POSSIBLE NEW BUSINESS SCENARIOS

Megatrends and findings in the previous chapter shows that there is some potential new business that could be found by 3D printing spare parts. At the moment, highest potential may well be in consumer market, such as household equipment or 2nd hand equipment repairs to name a few. This does not work against the business of 3D printing Spare parts in industrial scale, quite the opposite. As the technology evolves and reaches into everyday life more and more in the future, it is quite clear that people working in industry positions will more likely adopt it also into their businesses.

8.1 General 3D printing shops

One possible business opportunity is to create a network of 3D printing shops that are easy to enter. These shops would allow the user to print their own parts – either in plastic or metal – and by that to see if 3D printing is the right manufacturing method or not. This kind of business is relatively easy to scale by establishing new shops with the same concept to new areas.

This kind of approach is already thought by for example DHL with their presented kiosk concept (2018). The problem may be in the fact that if it suits consumer market, it may not suit businesses. These general shops may produce parts that are suitable for not so demanding quality applications, but they may not suite to high precision or high strength technical parts that industry usually requires. Also, repeatability and quality control in this kind of general print shop is questionable. The concept could be francised as well so that local entrepreneurs would run the business and take case of local customer base, based on different demands in different regions.

On the other hand, general 3D print shops may very well suit to R&D prototyping purposes. One can easily access (reasonable) quality parts instead of purchasing own printer and learning to use it. This may very well a viable option to SME’s that do not want to invest into machinery but still want to try the technology to develop new parts or modify existing ones.

One could anticipate the direct establishing costs for this kind of general 3D printing shop to be somewhere in the range of 10 000 – 50 000€ depending on the chosen equipment (Hawk Ridge Systems, 2019). High-end and high output industry level plastic printer would then add the machine investment costs to level of 300 000€ (Business.com, 2019).

Success to create profitable business from this kind of general shop would require:

- Technology to be adapted quickly into consumer markets by enabling online repositories of spare parts either by consumers willing to model parts or manufacturers to release their design to be available.
- Strong marketing effort for exposing the business model to public in the beginning.
- Ease of operation towards user, including for example file handling and payment options. Possibilities for “printing on the go when needed”.

Earning logic could be either the print shop purchasing the usage rights and offer parts directly with margin, or the consumer to pay a fee for using the data and sending to print shop for 3D printing who takes margin on printing only. If consumers would be willing to model parts, there could also be royalties in the form of micro payments used to compensate the work towards them.

Risks in this kind of business model are most likely linked to:

- Availability of Spare part 3D data in general.
- Technology development in the form of keeping the manufacturing equipment up-to-date and competitive due to relatively low maturity of technology still.

- New technology reputation, ability to keep and even increase the quality and price competitiveness while streamlining the process.
- Speed of market entry to be able to win large enough market share.

8.2 B2B focused global printing shops

To overcome the repeatability and quality control issues stated earlier, another possible business model could be to establish a chain of strictly B2B printing shops. By this, one could assure the correct quality level and repeatability which is crucial to success in B2B context. Also, delivery time promises are important factor, and this could be guaranteed by distributed 3D printing shops relatively close to the end Customer.

The business could be started at first with only few companies that have similar products so that manufacturing stays effective and by that cost competitive. After establishing enough Customer base, the decision can be made if there would be dedicated printing shops for single Customer and where it would be located. Since 3D printer can be relatively easily installed into almost any premise, it could be either in company's own premises or even in Customer's premises.

This kind of symbiosis with the Customer enables possibilities to create an environment where IPR- issues and as an example practical file handling processes can be streamlined so that they will not cause a lot of manual work.

Major enablers in globalizing the business idea:

- Scalability available since the technology is well repeatable and capacity can be quite easily expanded by investing into several printers.
- Clear advantage in highly automated 3D printing process, user cannot affect much into the process itself. This is a clear benefit in eliminating human errors in the process and distributing manufacturing.

- Possibility to source the whole supply chain from single provider, including manufacturing and end to end logistics and by that reduce amount of parties involved into process.

To ensure that the model works with B2B- clients, the company should be able to:

- Assure the Customers that the manufacturing quality is repeatable and followed constantly.
- Prove that the operative business is profitable, trustworthy and sustainable, for example collecting good reference deliveries and experiences from other Customers.
- Show the willingness to invest into latest technology so that Customer can benefit from working together with a company who wants to stay on the leading edge in fast changing business.
- Respect the Customer’s IPR on spare parts and ensure that the data is handled in secure way.

When these conditions are met, it is much easier for the Customer to make the decision – in practise, basically outsource spare parts business to a 3rd party operator.

If the Customer is willing to allow 3rd party operator to handle spare parts in this extend, it will allow the future vision of delivering only digital spare parts data to the 3D printing operator and in practise selling only the data, not the actual product.

8.3 Future research

From the previously presented possible business model, most interesting – in author’s opinion – is the B2B focused spare part printing shop concept. By this kind of approach, OEM company could streamline the process of spare part sales, manufacturing and delivery into truly digital one. Once the technology evolves and becomes more cost effective, it would also allow major decrease in warehouse space needed for operative purposes.

Major change in spare part business concept will disrupt the existing manufacturing and delivery channels. It also requires complete digital end to end workflow from sales to delivery. Areas where author suggest future research to concentrate, are:

- 3D file handling practices and their standardization
- Data integrity in workflow, technical data transmission in the whole chain
- Techniques such as blockchain to be used in IPR protection and order-delivery processes
- Taxes and customs clearances in digital business between countries, possible changes in the future
- Outsourcing concept of whole spare parts business, franchising possibilities – selling only digital data

There is huge business potential available once the technology is truly mature and the momentum towards mass manufacturing by 3D printing can be seen in the near future. The time is now to look at the possibilities that 3D printing may bring to one’s business, the companies who start the journey early will have leading edge during the years to come.

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