Tampere University of Applied Sciences

3D Printing Alternatives for Consumers on a Budget in Finland

Ada Ikonen

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ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
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This thesis examined the increasing global awareness and interest in 3D printing, specifically among the public, creatives, and hobbyists. Despite being nearly 40 years old, 3D printing technology continues to possess an elusive quality to many individuals and, despite advancements in printer accuracy and cost, the heavy personal and financial commitment associated with purchasing a printer often dissuades those interested in the technology.

Due to the lack of concise and comprehensive information available on non-purchasing options for 3D printing, the objective of this thesis was to provide a comprehensive list of methods available to consumers and to present essential considerations such as quality, time requirements, prices, and other factors prior to starting the printing process.

To demonstrate this information, a humanoid 3D model, a figurine, was digitally designed and sculpted using a 3D program. The model is then printed multiple times using one of the alternative 3D printing methods. Additionally, the thesis offers a historical overview of 3D printing in general, as well as its history specifically in Finland. It also provides examples and guidance on setup, file formats, supports, and potential issues that users may encounter during the printing process.

The findings of this thesis revealed that the time invested correlates with the quality achieved, depending on the chosen method and the amount of personal time one is willing to spend. The most cost-effective option is found to be the utilization of public libraries for 3D printing purposes.

Key words: 3D printing, file format, setup

CONTENTS

ABBREVIATIONS AND TERMS

3D	Three-dimensional
FDM	Fused Deposition Modelling
SLA	Stereolithographic
TPU	Thermoplastic Polyurethane
PLA	Polylactic Acid
SLS	Selective Laser Sintering
MJM	MultiJet Modelling / PolyJet Modelling
FFF	Fused filament fabrication. Term used to avoid copyrighted FDM.
PVA	Polyvinyl acetate
STL	Stereolithographic / Standard Triangle Language/ Standard Tessellation Language. File format for 3D Printing.
OBJ	Wavefront Object or Object File. File format for 3D Printing.
AMF	Additive manufacturing file. File format for 3D Printing.
3MF	3D Manufacturing Format. File format for 3D Printing.
G-Code	Computer numerical control programming language. Used commonly in 3D Slicers.
YLE	Yleisradio, Finnish Broadcasting Company.
Polymerize	Where small molecules combine chemically to produce a very large chainlike molecule, called a polymer.

1 INTRODUCTION

As a digital artist specializing in 3D modelling, I have been passively researching 3D printing for the better part of two to four years now. Participating in online courses, reading books on the subject, as well as new printer reviews online. Yet despite all that I have yet to purchase a 3D printer. It is not due to the lack of subject matter for the printer. As a Media and Arts Bachelor specializing in 3D modelling my computer is full of models that could be tested for 3D printing. There are two reasons for my hesitation: the commitment, both financially and personally, to buying a 3D printer is too much at least currently. While the financial costs of printing are decreasing, faster printers continue to enter the market, what if one only ends up using it a few times and it ends up collecting dust? This is what personal commitment means. For young students or post-graduates, it is hard to make a financial decision that exceeds hundreds of euros if it does not get used for more than once. For these reasons, I delved into looking for alternatives to buying a printer in Finland. The aim of this thesis is to list these alternatives with concise examples of the resulting 3D prints to showcase quality and cost differences. It is not meant as a guide on how to model but it will look at good-to-know things before taking your work to be printed.

On top of this a project was conducted alongside the thesis where I created a 3D model to be printed on multiple printers to show differences among them. A humanoid 3D model, a figurine, was chosen as the subject to be created to demonstrate how different printers handle difficult areas in human designs. With human character design, it's not uncommon to encounter unexpected challenges, such as issues with intricate details like hair or tight corners in the arms. When such problems arise, it can be challenging to determine whether the fault lies with the printer, printing process, model, or printer user. A figurine was also chosen as it is one of the most popular models done by both hobbyists, such as those who play tabletop games, who wish to bring their design to life in games and artists to showcase their knowledge and skills in anatomy, as is the case for me.

2 3D PRINTING

To comprehend terminologies beyond the provided glossary, it is necessary to delve slightly into the materials, methods, and history of 3D printing to understand what is available to consumers and why. Definition is important as its explains not only what 3D printing is, it will also go over all forms of 3D printing which helps understanding the terminology in history and later in the thesis when looking at all the alternatives. This chapter will also provide information crucial to the reader, such as understanding printers available for their projects and their materials.

2.1 Definition

The Merriam-Webster dictionary describes 3D printing as such: “the manufacturing of solid objects by the deposition of layers of material (such as plastic) in accordance with specifications that are stored and displayed in electronic form as a digital model.” (Merriam-Webster n.d, 23). Another great definition would be by Hod Lipson and Melba Karman’s in their book Fabricated. “The 3D printer, guided by instructions in the design file, squirts out of solidified, powdered, molten, or liquid material into a specific flat pattern” (Lipson & Karman 2016, 20). Despite having written this almost a decade ago, this line still holds true to this day. All of this refers to additive manufacturing rather than the traditional subtractive manufacturing or moulding (Radaviciute, M 2022, 30). Additive manufacturing encompasses seven primary categories, each with several sub-categories. The differences in sub-categories are subtle, usually referring to adjustments made in printers due to how the material behaves, and thus are not covered in this thesis. The seven categories are: Material extrusion, sheet lamination, binder jetting, material jetting, directed energy deposition, powder bed fusion and VAT photopolymerization. Regardless of the specific method used, in essence 3D printing takes from the traditional printing, which works in X and Y axis and takes it to Z, by layering material rather than paper printer’s ink and guided by a digital code.

Industries have been utilizing 3D printers for several decades, and the diversity of materials employed has steadily expanded and vary as much as the creator.

- FDM/FFF or fused filament fabrication, material that gets melted and layered.
- SLA or stereolithographic: Where resin is hardened with points of light.
- Material jetting: Where material is sprayed and hardened either by UV, heat or milling.
- Binder jetting: Where binding agent binds with sand-like material.
- Direct energy deposition: Where material, like metal, is melted with a high heat laser and layered.

2.2 History

The history behind 3D printing helps to understanding the technology, infrastructure, cost, and communities around 3D printing. By understanding existing technologies, you can see the possibilities within the method and determine which is most useful for your needs. Moreover, by familiarising with the history, one can learn the terminologies used, find more information on their own, and be understood by communities when explaining their printing needs.

Additionally, by observing the number of infrastructures that currently utilise 3D printing and assessing the current level of technology, one may discover previously unknown possibilities. This includes finding new ways to improve existing objects around you through 3D design. In summary, by knowing the history of 3D printing, insights can be gained that enable one to make informed decisions, effectively communicate, and explore innovative applications within the technology.

2.2.1 History of 3D Printing

3D Printing’s roots are in the early 1980s when a Japanese inventor, Doctor Hideo Kodama published details of the first prototype of a 3D printing technology that used “Rapid prototyping” technique, where UV light was used to polymerize resin in layers. This was also one of the first forms of what we now call stereolithographic printing. However, the first patent for an SLA 3D printing technology, that used a design file to instruct the printer was filed by an American engineer Charles “Chuck” Hull in 1984. Hull is credited as the inventor of 3D printing due to creating and commercialising the SLA printing method and .STL file type that are still used for 3D printing today. There were multiple other people who were working on similar technology at the time, like French engineers Alain Le Méhauté, Olivier de Witte, and Jean Claude André, but Hull was ultimately the first one to file a successful patent for stereolithography. (Hellenic-CAM n.d, 12).

Later in 1986 Hull co-founded the engineering company 3D Systems which creates 3D printers ranging from entry-level kits to advanced commercial systems (3D Systems n.d, 2). Their first product was launched in 1986, the SLA-1 model. On top of stereolithography, selective laser sintering or SLS where a laser beam was used to fuse powdered material together, was created and patented by students at University of Texas. In 1988 founder of Stratasys Ltd, inventor S. Scott Crump filed a patent for 3D printing that would become synonymous in the minds of people when talking about 3D printing, the fused deposition modelling or FDM. (Ultimaker n.d; Hellenic n.d).

In 1990s to 1999 additive manufacturing started to rapidly develop and previous methods were refined and improved on. Despite creation of FDM and SLS in the 80s it wasn’t until the 90s until these forms of printing became commercially available. This period is built upon new companies appearing that start to cater to specific needs, like wax prints by Solidscape, or industries, like the Model Maker (1994) favoured by the jewellery industry. Thanks to technology moving forward the precision of the printers increased to the point where medical industries started to use them and the first 3D printed human bladder scaffold was printed by the scientists at Wake Forest's Institute for Regenerative Medicine. Towards the end of 1990s new printing technology was introduced, PolyJet 3D modelling, which was created by an Israeli company, Objet Geometries. This printing method employs precise droplets of liquid, light-curable polymer that swiftly solidify into the intended pattern as the printer sprays the material into a specific shape. This method is also called MultiJet modelling or MJM. (3Faktur n.d; Hellenic n.d.).

In the early 2000s when few of the early patents began expiring and thanks to the open-source initiative by RepRap project, founded by Doctor Adrian Bowyer, new low-cost printers started to appear to the public. First of these was the RepRap, which used FDM/FFF modelling and became a successful example of what a low-cost 3D printer would be. This project inspired entrepreneurs and manufacturers who then opened doors to both professional and amateur users that are commonly called “*makers*”. (Ultimaker n.d; Hellenic n.d). But it wasn’t until 2009 that 3D printing rose to the public awareness outside of makers and professionals when 3D creations started to get traction online. During this period, google search for "3D printing" went up tenfold (Appendix 1), with major news outlets like The Guardian running headlines such as "Forget Avatar, the real 3D revolution is coming to your front room," while The New York Times declared that "3-D Printing Spurs a Manufacturing Revolution." (Vance, 2010; McInnes, 2010.).

2010s to today have been years of finding new ways to use 3D printing. With cars and rocket parts, even houses, all created with parts made with additive manufacturing technology and improvements in speed, accuracy, and the scale of production in multiple fields. Stereolithographic printers finally become available for a cheaper purchase price. And many more 3D printing keeps expanding in its use in all fields. (Ultimaker n.d; Hellenic n.d.).

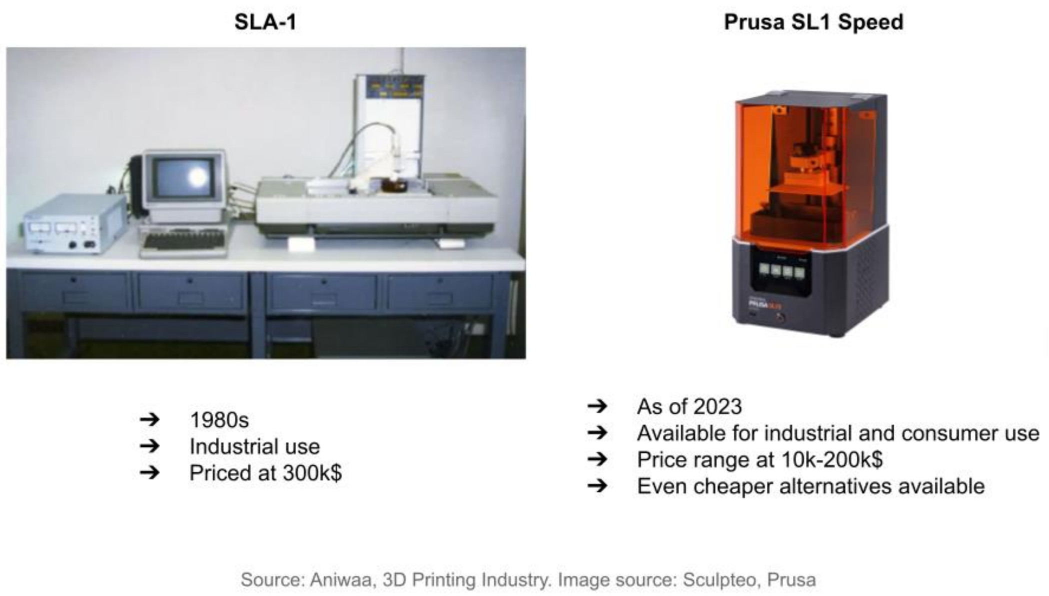


FIGURE 1. Price evolution for SLA printers (Ikonen 2023)

2.2.2 3D Printing in Finland

As the thesis looks at available printing methods within Finland it was vital to also research how these methods came to be. The origins of 3D printing in Finland is shrouded in relative mystery, and there is clear lack of compiled information, both in digital and physical form, that can provide insight into the subject. It is unclear who introduced the first 3D printer to Finland or identify the first 3D printer installed in the country. What we do know is by 1998, Finnish Rapid Prototyping Association or Firpa was established to promote additive manufacturing awareness, collaboration, and exchange of information on manufacturing techniques in Finland. Additionally, Firpa is working to promote awareness of Finnish companies and their work. (Firpa n.d, 8). Notable people that should be mentioned is one of the founding members and chairperson of Firpa, Jukka Tuomi. (Haikarainen 2019, 11). Tuomi is an alum of Aalto University who wrote his Doctorate in “Medical Applications of Additive Manufacturing – Application-Oriented Classification for Case Design and Documentation” (Tuomi 2018, 15). He has been incredibly open in driving forward Finnish medical and industrial 3D printing. In 2013, his 3D-printed face played a crucial role in medical research, serving as the basis for the first Nordic face transplant.

Based on Firpa’s creation, we can assume that the 1990s was the start to 3D printing in Finland, either engineering, medical students or their professors bringing 3D printing to Finland and then promoting and bringing awareness to its use in multiple fields as well as establishing companies like Firpa for those purposes. This shows how easily 3D printing has spread globally in just a few short years from Charles “Chuck” Hull’s first stereolithographic 3D print patent. From the early 2000s onwards, when smaller 3D printers started to become available, it also reached Finnish hobbyists and tinkerers until news articles in 2014 started appearing on YLE’s website. From “A company from Kuopio sells Batman as a 3D print - the American media giant has joined in” to “Finland's first 3D selfie service turns people into statues” (Nykänen 2014; Laine 2015). Startup companies started appearing and printing started to appear on a consumer level. Created by those interested in printing their and other people’s creations regardless of use purposes. Some of these companies have since gone bankrupt or simply stopped existing, in all probability due to niche markets or a general lack of 3D modelling solutions for the possible customer base. In conclusion, 2010s onwards is when news in Finland also started to talk about 3D printing regularly, sparking a loyal customer base among non-engineer hobbyists and entrepreneurs in Finland.

Several noteworthy events could be marked in the history of Finnish 3D printing, like the Nordic 3D Expo, which has displayed groundbreaking work in printing materials, such as Forest industry company UPM and Carbodeon's collaboration on cellulose and nano-diamond-based materials at the 2019 expo (Uusiteknologia 2019, 40). Another notable event in 2024 is the upcoming 3D & New Materials exhibition held in Tampere Exhibition and Sports Centre, which will feature the latest printers, printing services, research and the future of the technology (3D New Materials n.d, 1). The number of events showcases how popular and in-demand 3D printing technologies have become in the Nordics and especially Finland. In addition, libraries in Finland have been providing 3D printers for public use at least since 2016, making these printers increasingly common and accessible to everyone (Pitkänen, 2016, 27).

3 MODEL

A figurine, humanoid shaped model, created with free-to-use open-source 3D computer graphics software Blender, is being used as an example (Appendix 2). Libraries were chosen as the printing location because of limited time and budget. Since two different libraries were used, each with different printers, the 3D model for this thesis had to be divided into smaller pieces to fit the time and size constraints. These smaller pieces could then be assembled to create the complete model. Breaking the model into pieces, in theory, would enable the project's overall size to not be compromised depending on location and printer. Figurine was also chosen due to having complex shapes and angles that test the printer's quality and ability to handle them.

3.1 Setup

After the digital modelling step was finished, it needed to be separated into smaller manageable pieces. In commercial figurines it is common to see legs or mid sections that have been separated and later attached together for the attachment to be stronger. One part of the two pieces gets a peg and other gets hollowed out to fit the peg. With this the connection isn't just a flat surface against another, but multiple surfaces in and out to keep the model parts together. The model was separated into 8 parts: Head, left and right arm, left and right leg, torso, hips, and cape.

After separating the parts, the model was checked for non-manifold edges using an inbuilt 3D-printing addon within Blender. Non manifold is a term with multiple definitions, but the most descriptive way to describe it is that it is geometry that can't exist in real world (Makenica, 2020, 21). This could be for example a 2D plane that only has one side, in real world this wouldn't be possible. After making sure there were no non-manifold faces the model was exported into an STL file and moved to a USB stick.

Later in testing the setup needed to be changes. Such changes included filling in empty parts in between armours in the figurine. Fixing any gabs that might weaken the figurine such as a gab left between the shin armour and the shoes.

Moreover, the parts were exported as separate STL files rather than a single file to be later added into the slicing program.

3.1.1 Format

Just like there are many different types of printing, there are multiple file types and formats for 3D printing. The main file format however are, STL, OBJ, AMF and 3MF. The most common file format out of the four is STL. Created by Chuck Hull in the 1980s, originally, STL stood for "stereolithographic," but it is now commonly known as "Standard Tessellation Language" (STL). This file format takes the model and breaks it into triangular shapes. Due to its age, it is supported by almost all printers and slicer programs today. However, it does have its drawbacks. Due to this triangulation of the model, to gain more resolution the density of the triangles must increase and thus the file size as well and STL also does not contain scaling information which is important for precise printing. STL is also known to still leave non-manifold parts, holes, or rips in the model. Another limitation is that STL files do not support colour information, making it impossible to print certain parts in different colours, particularly when using a multi-nozzle printer. Despite these limitations, the figurine was exported in STL format for printing due to its nearly universal compatibility.

In addition to STL, there is another widely used file format called OBJ, or Wavefront Object format. OBJ files offer smaller file sizes and smoother surfaces compared to STL, primarily because it allows the model to be broken into shapes with more than three corners, such as hexagons. OBJ also supports colour data which has made it popular in the entertainment industry. The downsides to it were the colour data coming in a separate file and it still lacks the price scale information.

Last two commonly used formats are AMF and 3MF. AMF short for “Additive Manufacturing Format” and 3MF short for “3D Manufacturing Format”. AMF is an improved version of both OBJ and STL in that it does work in triangles as well, but the triangles must also conform to a curve. This means that the triangles do not have to be laid flat and can curve. AMF also supports texture, material, and other metadata without them being separated into separate files like in the case of OBJ. Despite these improvements it has been slow to catch on with users and is not as universally supported by slicer programs like SLA and OBJ are. 3MF is an open-source format that was created to improve any issues that AMF had and can incorporate manufacturing data or encrypted data in it. Generally, not used by consumers and is not able to be read by all printers. (Douglas 2022, 6).

3.1.2 Slicing

A slicer is a program used alongside 3D printer to turn 3D printing file format such as STL, 3DF, OBJ and AMF into toolpath file format such as G-code that the printer can interpret. Slicing programs visualise the model within the 3D print parameters allowing for scaling, rotation and moving of the 3D model to liking as well as options for print speeds and infills. Infills means the inside of a 3D model and its shape and density can be determined in the slicer.

The main job of a slicer is to break the model into 2d layers that the printer can thus follow. Slicers will also create necessary supports such as brims and raft as needed that can be adjusted by the user. For SLA slicers the print doesn’t get broken down into just layers but small dots where the light hits to harden the resin. (Xometry NUM).

3.1.3 Supports

No matter the technology used, 3D printing is always additive, building layers upon layers that take on a shape mandated by the file’s information. This means that there always must be a layer before that needs to be built on, like the build plate in which the printing starts from. For complex models that might have overhanging parts, *support* may be needed. Supports, in 3D printing, refer to either support brims, temporary structures meant to support overhanging parts that might collapse during printing and rafts that is a thin layer of material that holds the model in place on the build plate during printing. Overhang in 3D printing refers to shapes that project outwards, extending beyond the boundaries of the previous layer at an angle, usually over 45 degrees (C-Mac n.d, 4). These can be modified within the program, but raft is usually seen as a necessity to have a stable base to print on and to avoid the model from warping when cooling down during the printing process.

Support structures can affect the quality of the print, leaving marks on the surface and roughness when they are removed. (Hubs n.d, 12). In the case of the figurine created for the thesis the amount of supports that were done in the 3rd printing test were incredibly difficult to remove due to how small the print was and how dense the support was done. Removal of all the support was nigh impossible without proper tools for it. Libraries, such as Kerava's library and Tampere's Sampola seem to have removal tools for loan at the library, but they are not available to be loaned home.

PICTURE 1. Second print. Supports and raft. (Ada Ikonen 2023)

4 PRINTING

4.1 Alternatives

When looking for alternatives to buying a printer some of the options out there may not be what first comes to mind. Aside from buying a printer or paying for companies specialising in 3D solutions like modelling, scanning, and printing, there are other options on the market. Surprisingly many libraries in major cities and towns across Finland have 3D printers for public use. Some of them with a small fee and some without. Finland hosts multiple companies that specialise in creating industrial grade order of their prints, but some provide the option for non-company clients to 3D print with them.

On top of these two, there is the option to commission a single person, a free-lancer, rather than a company for your work. Sites like Facebook have multiple groups of hobbyists who might have the equipment and are willing to use it for printing for a fee of their choosing. Lastly are options not available to everyone such as university 3d laboratories, which are listed here under the others category since around million of over 15-year-olds in Finland have a university degree (Stat n.d, NUM). And as such might be amicable to the reader of this thesis. All the information gathered here is done during a year prior to publishing of this thesis.

4.1.1 Libraries

In recent years, public libraries have undergone a remarkable transformation from ancient tombs of books to becoming dynamic and innovative creative hubs accessible to everyone. This shift is especially evident in many large city libraries, such as those in Helsinki, Pori, Tampere, Kerava, and many more which now offer an impressive array of tools and resources to their visitors. From computers and printers to vinyl cutters, heat presses, sewing machines, overlockers, laminating machines, pin machines, drawing tables, and even 3D printers, these libraries have truly become versatile spaces for creativity and exploration. (Tampere n.d.; Porin Kirjasto n.d.; Kirjastohakemisto n.d.).

Public libraries in Finland most commonly use FDM/FFF 3D printers from the Dutch manufacturer, Ultimaker. These printers typically have a print volume of 20 x 20 cm, with the printing material utilised being bio-degradable PLA-filament. Libraries allow their machines to be used for free or with a small fee ranging from one to two euros but mandate a reservation. It's essential to have your model in an appropriate file format before heading to the library and USB stick might be needed. Additionally, it's advisable to check whether the library has provided instructions on how to operate their printers, as this can be incredibly helpful in ensuring a smooth and successful printing process. Typically, libraries allow a maximum printing time of four hours, as is the case in Pori and Tampere. However, there are exceptions, such as the Espoo’s Iso Omena library, which permits printing for the entire duration that the library is open - a generous 12 hours. Kerava library has also increased their printing times to six hours with possibility for longer if the library is open. (Kerava n.d.; Espoo Varaamo n.d.).

Most issues one faces in 3D printing at home include, clogged print head, wrong temperature, under or overheated print plate and printing at wrong height (REALvisionOnline n.d, 32). Public libraries offer the advantage of having their machines undergo regular maintenance with knowledgeable staff that can aid in printer use and minimise previously mentioned mistakes and increase the likelihood of a successful print in one go. However, despite that, it is still not a guarantee. 3D printers cannot print in air or up to certain angles and without supports liquid plastic will just fall on those spots. These are actions that the library staff cannot prevent and are up to the creator to fix in their files before heading to the library. On top of that each library has their own set of rules when it comes to responsibility of the printed model, some will not give assistance or fix any printing errors that start happening during the printing process.

Libraries offer access to 3D printing technology, which would otherwise be impossible for many. However, it's important to note that while the costs may be low at libraries, there are still certain things to account for. For instance, either due to the limitations of the printers themselves or for the safety of its visitors, libraries may have restrictions on the types of materials that can be used for printing. In many cases, the materials used have been limited to biodegradable material to prevent plastic from being harmful to a child if ingested and to avoid plastic pollution.

As mentioned, printing times are often limited since machines cannot be run outside of the library's opening times. This is done possibly to avoid risks related to electrical devices and to ensure that more than one person can access the printers for one day, thus preventing hogging of the machine. However, despite these limitations, the availability of 3D printing at libraries provides a valuable resource to everyone and offers a cost-effective way to gain access to 3D printing. Additionally, with the guidance of knowledgeable library staff, users can learn how to use the printer effectively and minimise the risk of errors or malfunctions during the printing process. It should be noted that any prints done at libraries are not to be done for commercial purposes, not even mold-making for possible commercial creations.

4.1.2 Companies

Finland hosts multitude of companies offering services in additive manufacturing solutions. Consulting, designing, modelling, scanning, and printing are all offered by a singular company to bring ideas to the physical realm. Every project is different and set prices are hard to come by due to variables that can create costs. Electricity, hourly print cost, material, cost of material and any post-process work needed effect costs to the customers (Viikinkikone n.d, 41). On top of this when searching for customer level 3D printing any website that is not for industrial work seems to get buried under Google’s first page.

In addition to industrial companies, which often do not serve to individual customers, there are other companies available. Although these companies offer similar pricing and business models to their larger counterparts, they offer an advantage in that their services are accessible to individual buyers. Furthermore, these companies distinguish themselves from other options, such as libraries, by providing a wider range of material options, including SLA and MJM printing. By ordering from a company, customers can benefit from the assurance that their model will be assessed and modified with the appropriate supports to minimise errors. Additionally chemical treatment needed for SLA or sanding for FFF can also be done at the company. Errors can cost company money, but tarnishing reputation on sending customer failed prints would hinder any later sales. Fundamentally, the payment you make is in exchange for a service that aims to minimise the amount of work required on the customer’s part.

4.1.3 Freelance printers

When referring to freelance work, this category does not adhere strictly to the definition provided in the Oxford dictionary for a freelancer. According to Oxford, a freelancer is defined as "a person who works freelance," with freelance meaning "self-employed and hired to work for different companies on particular assignments." In this context, freelance encompasses both true freelancers who are self-employed individuals taking on various assignments for different companies, as well as hobbyists who are willing to undertake commission work by printing items for strangers in exchange for a fee.

These types of freelancers or hobbyists can typically be found on Facebook and other social media platforms that facilitate easy communication and image sharing among users. Within these communities, members actively participate in sharing models and showcasing their latest 3D prints related to various topics, such as designing a new handle for a snow shovel or creating a holder for darts. When approached with inquiries about their willingness to print items for others, many members of these groups responded with a range of prices depending on the individual's requirements. Prices ranged from two euros per hour of print time to seven euros per hour as well as filament cost. If model needed to be made from scratch the cost was 25 euros per hour spent on creating the model. Moreover, it is important to note that shipping costs need to be factored in on top of the printing services. Apart from offering printing services, these groups consist of numerous makers who willingly provide guidance on model creation free of charge or offer to create models for those who lack the necessary skills, typically at a fee.

4.1.4 Other

It's worth noting that some resources are available only to select people for free. For instance, Tampere University and Aalto University have 3D printing laboratories created for their engineering and design students. These labs are also available to professionals upon request and offer multiple printers, including FDM/FFF printers, SLA, and Material jetting. Moreover, they provide unique materials like clay and fiberglass, on top of traditional plastic or resin, at no cost (Aalto 2018; Tampere University n.d.). However, to use most 3D printers in these labs, a relevant course must be assigned and passed beforehand. Such courses may only be offered to students of specific study paths.

Although non-students are not allowed access to these labs, universities are still a great resource for students and professionals to access a variety of printing methods and materials at no cost and with almost unlimited time for their projects. The negatives being, that certain machines may only be accessible to certain courses taught to students of specific study paths.

Outside of universities, Pupukahvila otherwise known as 3D Crush Café offers 3D printing as well. Located 6 km off from Tampere city center, offers 3D modelling services with SketchUp, scanning, and PLA printing for its customers. Their prices for these services are based on customer needs but their fees apparently never rise above 100 euros. It is the only one of its kind currently when it comes to offering 3D printing to café customers. (Pupukahvila n.d.; Sammeli 2023).

While the focus of this thesis is to explore alternatives to purchasing a printer, it is important to mention the availability of printers for those who may still choose to buy one. Major consumer electronics retailers in Finland, such as Gigantti, Verkkokauppa, Power, and Clas Ohlson, offer a wide range of printers and filaments with varying price points. For instance, the Weedo Tina2 printer is priced at around 250 euros, whereas the Flashforge Creator 4A HT FDM printer, designed with two nozzles, costs around 13,000 euros. The disparity in prices is not solely due to how many materials they can accommodate, but also because of differences in print size. The Tina2 can only print objects up to 10 cm in size, while the Flashforge printer has a capacity of nearly half a meter. (ClasOhlson n.d; Gigantti n.d).

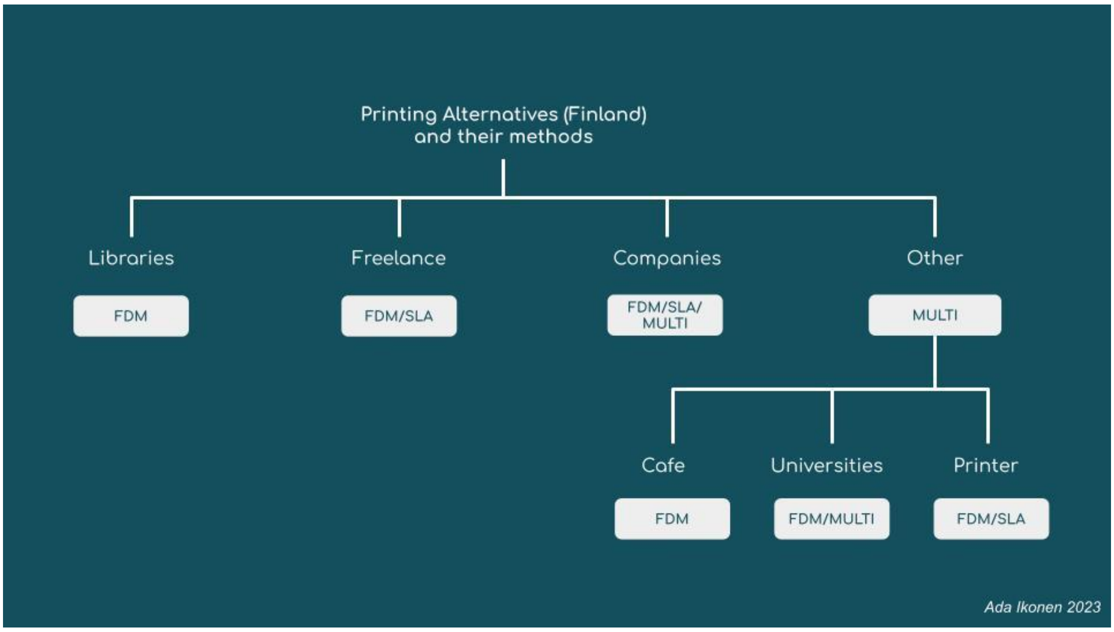


FIGURE 2. Printing Alternatives and methods. (Ikonen 2023)

4.2 Results

Out of three prints two were done at Kerava library and one at Sampola library in Tampere. Ultimaker 3 was used at Kerava and Prenta Duo XL at Sampola. The first print at Kerava library was a failure resulting in the legs on picture 1. The reason for this was that the model was cut up into parts in the 3D program and exported as a single file. The 3D printing program was unable to separate files within the same file and when made to print the file as a single 3D model failed leading to just legs. The probable cause for this failure can be attributed to the separation occurring within the file specifically at the legs. The second try happened in Sampola under limited time frame of 4 hours. The biggest sized model was done in these four hours and showed that there were still problems within the 3D file. The skirt's digital model was too thin, and the printer didn't recognize it. The shoulder pads were too thin and didn't attach enough causing overhang that needed to be clipped to shape. The third printing was done once again at Kerava and was done in 8 hours with higher quality from the second attempt but with other difficulties not initially seen in the second attempt. Both skirts had issues as seen in PICTURE 2 with left having not filled in correctly and right having slight cracking in the front.

PICTURE 2. Left to right attempts 1-3. (Ada Ikonen 2023)

PICTURE 3. Digital model errors in print. (Ada Ikonen 2023).

4.2.1 Quality

When it came to the quality of the printed pieces, even though there were only three, you could immediately see how much printer settings and user errors had affected the result. As mentioned, the initial print attempt had failed due to pre-cut pieces being in a single file. This was due to the separation process error and although the Ultimaker printer housed add-ons that allowed for separating a single file into separate parts, due to the high vertex count of the figurine, it would crash the whole program. Because of this, the printer was unable to understand what had been going on in the seams of the separated parts and had failed when reaching them, resulting in just legs. Very good quality legs, but still just legs.

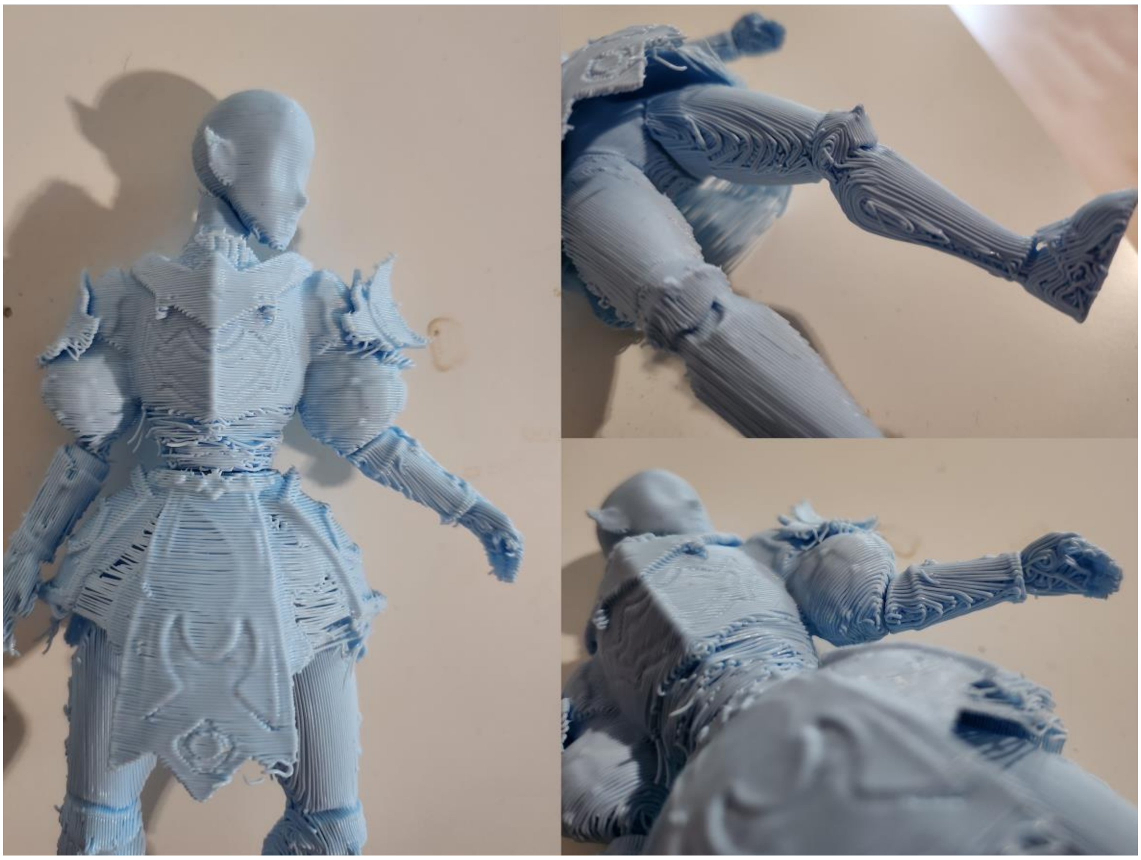
After fixing this mistake, the second print was done in Tampere on Saturday when the library had limited opening hours. To compact this limited timeframe, the arms and legs had been placed horizontally in the design file rather than vertically. The thought behind this had been that 3D printers took more time with the y-axis rather than the z and x-axes and thus would reduce the print time. Certain parts had to be left unprinted, such as the cape, sword, base, and the underskirt, leaving only the most important parts to be printed. In the settings of the 3D printer, the speed had also been adjusted to fast rather than quality mode, with the fill of the model set at 10 percent. All of this had resulted in the biggest version of the model made, but there had certainly been a lot of issues. For instance, the direction in which the hands and legs had been put to print had left clearer layers than on vertically done parts, and it had seemed like the quality of these pieces had been lower. The model had been light and very fragile; the infill had been the cause of this, on top of the resulting layered look. Due to the fast setting, all the layers had come out thick and some uneven, as the filament had fallen down the set edges and had not been allowed to set for long enough for the next layer. This print had also had some issues with the model itself. The skirt had had parts in it that had been too thin for the fast setting and thickness of the layers, resulting in empty spots where they hadn't been registered as being there. (PICTURE 3, 4)

The final print was made once again at Kerava library. During this time, only the base had been left out as it had been the biggest part of the model and had not been necessary, as the model had been in a straight position, allowing it to stand even without it. The printing had been set at normal printing speed with 30% infill. Notable issues with this print had been that though all the parts had come out fine, certain parts could still have been thicker, such as the dress, as well as the ankles, and there had been certain nooks in the model's dress where supports had been made that had been impossible to take out. One of the arms had failed as well. The biggest issue with the third attempt had been the settings for supports. The fewer supports that had needed to be used; the less post-fixing of the model had needed to be done. The thickness and amount of supports in this print had been too high, with some supports having been made in parts that hadn't seemed to need them. The large amount of supports caused slight damage and unevenness to the surfaces lowering the quality and adding to possible post-process.

Overall, when it came to public library printed prints, notable things to take note of had been settings, time, speed, and model. What had been made up with speed had cost in quality, but even then, if there had been issues with the model itself, the print would most likely have come out failed no matter the speed or quality settings. Important things when setting up a model for printing had been to make sure that there hadn't been any gaps between parts as they could weaken the structure. For fabric parts, it is important to ensure they are not excessively thin, while also considering the appropriate level of resolution for the model. Additionally, it is crucial that all components are manifold, meaning they have watertight and connected surfaces. Too high vertex count could have caused issues with the slicer program. If the printer was unable to process such high vertex count, rather than completely lacking them, the resulting 3D print might have had them patchily on. Manifold, on the other hand, had meant that there hadn't been any edges that had overlapped more than one other face (Shapeways, n.d, 34). Manifold had been important in avoiding printing failures, as had been the case with print attempt 1 and the overlapping of the parts.

4.2.2 Time

As seen in Picture 1 and 2, despite the limited time on the second print it also came out the biggest out of all of them. Initial failed print with the legs took approximately 2 to 4 hours while attempt number 2 took exactly 4 with the last attempt taking double that at 8 hours. The shortest print time had a lot of user error issues but also printer issues that caused the quality to be lower. Despite its high printing speed, the printer managed to capture intricate details remarkably well, such as the kilt, the delicate pearls adorning the buffy sleeves, and the intricate patterns on the chest armour. However, upon closer inspection, small holes can be observed scattered throughout the model, even in areas where the printing initially appeared flawless. Furthermore, the areas that did not exhibit any issues in the previous print attempts, like the hand and legs, now present problems. In essence the quality was heavily influenced by the speed of the printer.



PICTURE 4. Left armour detail. Right, overhang and print issues. (Ada Ikonen 2023).

4.2.3 Costs

The cost of 3D printing can vary significantly depending on the chosen printing method and alternatives. At the lower end of the cost spectrum, public libraries often provide printing services at a minimal fee, typically charging a few euros per print. This represents the most affordable option available. Universities may offer free printing services, but these are typically limited to a specific user base.

In the mid-range, freelance services and specialised establishments like 3D printing cafés offer their services at competitive rates. These options provide a balance between cost and quality.

On the higher end of the cost spectrum are professional printing companies and individuals who decide to purchase their own 3D printers. These options tend to be more expensive due to factors such as advanced equipment, expertise, and overhead costs.

It's important to note that costs are heavily influenced by the level of convenience and ease of use. If you prefer to minimise the time spent on post-processing or polishing the printed models, the price will likely be higher. Most service providers do not offer extensive post-processing as a standard service, except for companies and some freelancers. Therefore, the cost is not solely determined by the complexity of the model but also by the amount of time and effort the buyer is willing to invest in ensuring the final appearance of the model. The valuable human time involved in this process can contribute significantly to the overall cost.

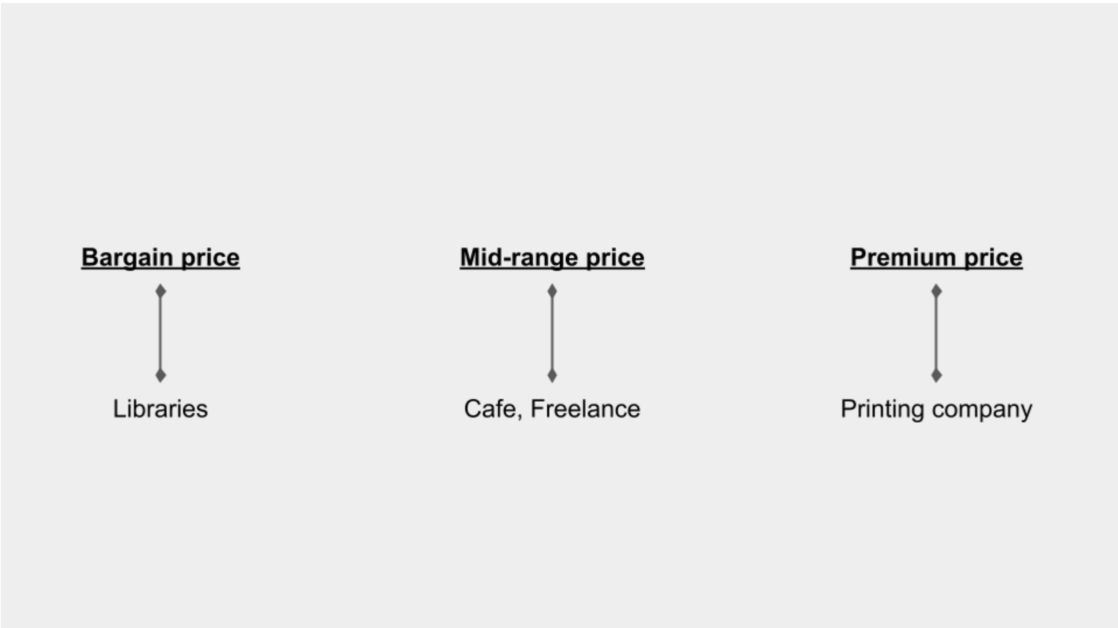


FIGURE 3. Price to print. (Ikonen 2023)

5 DISCUSSION

Overall, there is a vast number of options available for consumers in Finland whether artistically inclined or not. One's monetary situation does not seem to matter in the context of having things 3D printed either as there are services from cheap to expensive available regardless of one's background. From this research, it seems that the methods could be tiered further into their own categories based on needs such as:

- Freelance being good for both model makers and non-model maker in need of models offering relatively cheap price for the services with semi-guaranteed successful print and no limit on print time.
- Companies good for mass production and model methods outside of FDM also offering services for model creation for greater price but guaranteed successful print with no limit on print time.
- Universities offering multiple methods of printing without guarantee of print succession but only accessible to certain students and staff with limited print time.
- Libraries offering very cheap printing for modeler with no guarantee of print succession with limited print times.

As seen, the market in Finland currently caters to almost every type of need except for printing types outside FDM at cheap prices. This will probably change as SLA printers have started to appear cheaper in the market with other printing methods possibly also following suit later in the future filling this gap in the market. There will most likely be other gaps that will be filled such as modelling in universities extending to other educational institutions such as upper secondary schools or even elementary schools. 3D printing will most likely be used to promote a combination of digital skills and physical creation in the classroom.

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APPENDICES

Appendix 1. Google Trends data.

Appendix 2. Figurine.