BRNO UNIVERSITY OF TECHNOLOGY

Faculty of Electrical Engineering
and Communication

# BACHELOR'S THESIS

Brno, 2024 Marek Thomas

# BRNO UNIVERSITY OF TECHNOLOGY

VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

## FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

FAKULTA ELEKTROTECHNIKY
A KOMUNIKAČNÍCH TECHNOLOGIÍ

## DEPARTMENT OF FOREIGN LANGUAGES

ÚSTAV JAZYKŮ

# 3D PRINTING WITH SILVER AND ITS USE IN JEWELLERY

3D TISK SE STŘÍBREM A JEHO VYUŽITÍ VE ŠPERKAŘSTVÍ

**BACHELOR'S THESIS**

BAKALÁŘSKÁ PRÁCE


**AUTHOR** Marek Thomas

AUTOR PRÁCE

**SUPERVISOR** Mgr. Bc. Magda Sučková, Ph.D.

VEDOUCÍ PRÁCE


**BRNO 2024**

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

# Bachelor's Thesis

Bachelor's study field **English in Electrical Engineering and Informatics**

Department of Foreign Languages

***Student:*** Marek Thomas ***ID:*** 229201

***Year of study:*** 3 ***Academic year:*** 2023/24

**TITLE OF THESIS:**

**3D printing with silver and its use in jewellery**

**INSTRUCTION:**

The main goal of this thesis is to determine what type of 3D printer is the most suitable for silver jewellery additive printing. The thesis describes various types of additive printers (FDM, SLA, DMLS, etc.), their practical applications, and the physical and chemical behaviour of silver in additive printing. A particular emphasis will be placed on the practical application of these specialized 3D printers, especially in the field of jewellery making. The final section will discuss the question of whether it is technically and economically feasible to assemble and safely operate such a 3D printer in small businesses or in a household setting.

**RECOMMENDED LITERATURE:**

Chua, C. K., & Leong, K. F. (2017). 3D Printing and Additive Manufacturing: Principles and Applications. World Scientific Publishing Co.

Gebhardt, A., Kessler, J., & Thurn, L. (2018). 3D printing: understanding additive manufacturing. Hanser Publication.

Damiano Zito, D. V. A., Sbornicchia, P., & Rappo, S. Why Should We Direct 3D Print Jewelry? A Comparison between Two Thoughts: Today and Tomorrow.

***Date of project specification:*** 22.2.2024 ***Deadline for submission:*** 24.5.2024

***Supervisor:*** Mgr. Bc. Magda Sučková, Ph.D.

**doc. PhDr. Milena Krhutová, Ph.D.**
Subject Council chairman

**WARNING:**

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| | |
|---|---|
| **Author:** | *Marek Thomas* |
| **Author’s ID:** | *229201* |
| **Paper type:** | *Bachelor’s Thesis* |
| **Academic year:** | *2023/24* |
| **Topic:** | *3D printing with silver and its use in jewellery* |

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# Abstract

The main goal of this thesis is to determine what type of 3D printer is the most suitable for silver jewellery additive printing. The thesis describes various types of additive printers (FDM, SLA, DMLS, etc.), their practical applications, and the physical and chemical behaviour of silver in additive printing. A particular emphasis will be placed on the practical application of these specialized 3D printers, especially in the field of jewellery making. The final section will discuss the question of whether it is technically and economically feasible to assemble and safely operate such a 3D printer in small businesses or in a household setting.

# Keywords

3D, silver, printers, jewellery, melting, printing, additive

# Abstrakt

Hlavním cílem této práce je najít vhodný typ aditivní tiskárny, která by byla schopna kvalitního 3D tisku stříbrných šperků. Práce seznámí čtenáře s několika typy aditivních tiskáren (FDM, SLA, DMLS a dalších), jejich využitím v praxi a fyzikálním a chemickým chováním stříbra při aditivním tisku. Důraz bude kladen na praktické uplatnění těchto speciálních 3D tiskáren, a to především ve šperkařství. Poslední část práce se pokusí zodpovědět otázku, zda je technicky a ekonomicky proveditelné sestavit a bezpečně provozovat danou 3D tiskárnu v menších firmách či v domácím prostředí.

# Klíčová slova

3D, stříbro, tiskárny, šperky, tavení, tisk, aditivní

# Rozšířený abstrakt

Tato bakalářská práce se zabývá 3D tiskem stříbra a jeho využití ve šperkařském průmyslu. Značná část práce se věnuje popisem speciálních 3D tiskáren, které jsou schopny přímého tisku stříbra.

První část má charakter rešeršní. Úvod první kapitoly seznámí čtenáře se stručnou historií a vývojem 3D tiskáren a to především tiskáren *stereolitography* (SLA), které byly průkopníky ve světě 3D tisku, využitím digitálních modelů *computer aided design* (CAD) pro vizualizaci tištených modelů před samotným 3D tiskem a formátu STL, který slouží jako primární nosič digitálních informací z CAD návrhu do samotné 3D tiskárny a je tak nezbytnou součástí pro 3D tisk. 3D modelování a tisk se staly silným nástrojem v dnešní době a hrají velkou roli v inženýrské sféře, vzdělávání či medicíně.

Během několika let vznikalo různých typů 3D tiskáren, které se liší svým zdrojem tištění a materiálem, ze kterého tisknou model. Velmi známým jsou např. SLA tiskárny, které jsou využívané pro svoji vysokou preciznost a kvalitu 3D tisku. Existují ale i sofistikovanější, které jsou schopny tisknout z kovu ve formě prášku. Tyto speciální 3D tiskárny používají jako zdroj tisku laser, který pomocí vysoké teploty roztaví kovový prášek či tekuté pojivo (binder), který vniká do volných prostor práškových částic, kde funguje jako lepidlo a volné částice mezi sebou ztvrdnou. Těmito způsoby vznikají vrstvy, ze kterých vzniká daný 3D tištený model.

Druhá část práce se zabývá 3D tiskem pro obor šperkařství, kde zaručil inovativní kroky, které posunuly šperkařství o hranici výše. Šperky se v dávných dobách vyráběly primárně ručně. Postupem času se pomocí odlévání mohla vyrábět řada stejných kusů a zlevnila se výroba. Pro odlévání šperků hraje velkou roli výroba formy, která je vyrobena z vulkanizované pryže, kde hlavní částí je jádro (šperk), který se vloží do formy, pryž se zahřeje a po zaschnutí se pryž odřízne a jádro se vyndá. Vzniklé cestičky ve formě slouží ke vstřikování voskových modelů, které se po zaschnutí zalijí do sádry, v peci se roztaví a v sádře zanechají chodbičky ve tvaru daného šperku. Do těchto otvorů se nalije tekutý kov a sádra se vloží do vody, kde se rozpustí a jako finální produkt vznikne odlitek šperku.

Implementace 3D tiskáren do šperkařství umožnila zrychlení a jistou cenovou redukci v produkci šperků, např. jádra se už nemusí vyrábět ručně, ale mohou být vytištěné na 3D tiskárně a poté vloženy do pryžové formy. Tato metoda využívání 3D tiskáren je velmi používanou pro šperkařský obor, ať už pro výrobu pár kusů či pro velkovýrobu.

SLA tiskárny, které využívají pro 3D tisk tekutou pryskyřici, se mohou využít i pro inovativnější kroky ve šperkařství, a to především využitím speciálních tekutých pryskyřicích na bázi vosku, které umožní 3D vytištění modelu, který se rovnou může zalít sádrou a nemusí se tak pracně vyrábět forma.

Přestože je odlévání šperků velmi cenově výhodné je na druhou stranu velice časově náročné. Kroků, které jsou potřeba k získání šperků je několik. S častějším využíváním 3D tiskáren, které tisknou z kovu, v různých technických odvětví se šperkařství stává jedním z nich.

Třetí část práce se zabývá otázkou, proč vůbec využívat tyto tiskárny pro přímý tisk šperků, a to primárně ze stříbra. Hlavním cílem adaptace této technologie do šperkařské výroby je snaha o její zrychlení. Tento faktor vysoce ovlivňuje firmy a jejich podnikání. V dnešní době již existují 3D tiskárny, které mohou tisknout ze stříbra, vyskytují se zde ale problémy, a to především se samotným 3D tiskem stříbra, který jako materiál pro 3D tisk je jeden z nejvíce problematických. Hlavním důvodem je vysoká odrazivost laseru, při které stříbrný prášek nedosáhne značné tepelné hodnoty k jeho roztavení. Další problematikou je samotná cena stříbrných prášků, které jsou pro 3D tisk vysoce nákladné. Největším mínusem kovových 3D tiskáren je jejich vysoká cena, která odrazuje od pořízení této aditivní technologie.

Přes negativita kovových 3D tiskáren již existují 3D tiskárny schopné přímého tisku stříbrných šperků včetně firem, které se touto specifickou výrobou specializují.

Čtvrtá část bakalářské práce je částí praktickou, kde hlavním záměrem je najít vhodnou kovovou 3D tiskárnu, která se může použít do menších šperkařských podniků. Praktická část se dělí na tři analýzy, které přiblíží výsledek hledané 3D tiskárny. První částí je soubor 3D tiskáren, které jsou schopny přímého 3D tisku stříbra a které jsou srovnány na základě jejich velikosti, ceny a schopnosti počtu vytištěných šperků. Druhá část analýzy se zabývá kroky zpracováním vytištěného modelu a jeho srovnáním s dvěma vybranými 3D tiskárnami, které byly vybrány z první analýzy. Poslední částí je třetí analýza, která má za úkol porovnat ceník odlitého a vytištěného stříbrného šperku.

Práci končí diskuse, zda je možné a zda se vyplatí pořídit takto drahou technologii do menších šperkařských firem. Problém nespočívá jen ve vysoké ceně 3D tiskáren, ale i v pořizovacích nákladech, které majitele mohou stát velké investice. Proto je důležité pořádné zvážení koupě těchto aditivních strojů.

# Bibliographic citation

THOMAS, Marek. *3D printing with silver and its use in jewellery* [online]. Brno, 2024 [cit. 2024-05-23]. Available from: https://www.vut.cz/studenti/zav-prace/detail/160166. Bachelor's Thesis. Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, Department of Foreign Languages. Supervisor Magda Sučková.

# Acknowledgement

I would to thank Dr. Sučková for her kind suggestions and pragmatic approach towards my thesis through the academic year, and Prof. Koutný for his technical guidance. A big thank you goes to my family, especially parents, whose love and support enabled me to successfully complete my academic studies.

Brno, May 24, 2024

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Author‘s Signature

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# SYMBOLS AND ABBREVIATIONS

Abbreviations:

| | |
|---|---|
| AM | Additive Manufacturing |
| 3D | Three-dimensional |
| PBF | Powder Bed Fusion |
| DMP | Direct Metal Printing |
| CAD | Computer-Aided Design |
| UV | Ultraviolet |
| FDM | Fused Deposition Modeling |
| VP | Vat Photopolymerization |
| SLA | Stereolitography |
| SLM | Selective Laser Melting |
| DMLS | Direct Metal Laser Sintering |
| BJT | Binder Jetting |

Symbols:

| | | |
|---|---|---|
| $P$ | power | [W] |
| $l$ | micrometer | [μ] |
| € | euro | |
| $ | dolar | |

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# INTRODUCTION

Jewellery became a daily wearable item for people to express their personality. Jewellery has been one of the main personal accessories in history which displayed the status of a person in society. Over the centuries traditional jewellery manufacturing evolved into to casting which allowed the creation of multiple pieces at lower production time then handcrafted. Today casting jewellery is one of the most important methods for producing jewellery and many famous jewellery brands have benefited from this production technique. Casting jewellery allows not only bigger jewellery brands but also smaller jewellery brands to adopt this production process and use it for their own needs. Casting over the years has become the method of choice among jewellery producers and with the advent of 3D printing has transformed the industry allowing freelance jewellery designers to design their jewellery pieces at home and 3D print them to create models for mould creation a key part for mass production in casting.

The invention of wax-based resin for 3D printers has allowed jewellers to omit moulds which helps to reduce production time. Yet, new methods in the jewellery industry have developed helping to revolutionize jewellery production. New types of 3D printers have come onto the market allowing for different types of jewellery production. Many of these printers utilize precious powder as a main material source for 3D printing jewellery including material with silver; however, silver has turned out to be one of the hardest metals to 3D print with an embedded laser because of its high energy reflectivity. That is why jewellery businesses using this technology have to have a good understanding of printing with silver prior to utilizing such technology. There are several types of theses silver metal 3D printers with some using a laser as a printing source, and some using liquid binder for hardening the silver powder.

The implementation of metal 3D printers in the jewellery industry is promising since it reduces production time and allow designers to create intricate designs which would be hard or impossible to cast otherwise. However, purchasing, and operating metal 3D printers is not without obstacles, e.g., 3D printers are expensive, post-processing of finished 3D printed jewellery is labour intensive and a high degree of skill operating the 3D printer is required before purchasing one. Jewellers must consider both the advantages and disadvantages of adding metal 3D printers to their production process and when properly assessed can open new doors to design and production of jewellery. This topic is discussed more and more between jewellers where metal 3D printers might be an interesting way of revolutionizing the jewellery industry.

This bachelor’s thesis is divided into two parts – theoretical and practical. The theoretical part defines different 3D printers used in the jewellery industry and will introduce their technical characterization, printing source and material. The 3D printing example will focus on a piece of jewellery from wax-based resin. For this thesis, silver will be discussed as the printing material and its unique characteristics, including its challenges when 3D printed. A selection of jewellery companies will be introduced who are using metal 3D printers for their gold and silver jewellery production. The practical part of this thesis will deal with finding a metal 3D printer which would be suitable for small jewellery businesses. Several technical parameters will be evaluated for determining the right metal 3D printer. The thesis will conclude with a discussion and hypothesis about the future of these metal 3D printers and their impact on direct jewellery printing.

# 1. THE CURRENT STATE OF KNOWLEDGE

Additive Manufacturing (AM) plays a large role in many modern industries because it allows, “the creation of parts with a high degree of design complexity by building three-dimensional (3D) parts layer-by-layer.” [1, p. 1]. These single layers, which form a physical model, are defined by a certain layer of thickness which affects the 3D printed model. The thinner the layer, the greater the precision of the final product. The first attempt at AM occurred in 1987 by introducing stereolithography (SLA) technology which operated via the application of UV light along with a laser. The UV light forms a physical layer made of polymer material. Since then, many different AM machines have been developed and introduced [2].

The core part of AM is the creation of a digital model via computer aided design (CAD). In order to physically print out the digital model it is necessary to convert the digital data to the STL format which is the typical configuration for many different AM printing machines [3]. Once this is completed the printer can print the physical model in the desired material.

AM has been essential to engineers, designers, and medical professionals, allowing them to create physical models quickly and efficiently to assist in many tasks and processes. For example, in the medical field AM offers new opportunities for patient treatment, e.g., body implants. These can be hard to manufacture; however, with AM technologies it is more feasible to meet patient’s needs. Learning and understanding CAD software and 3D printers can be a game changer for both businesses and households, allowing them to print objects that can assist in repairing equipment, appliances or anything requiring small parts [4].

3D printers can be utilized for educational purposes in schools or similar institutions. For instance, ancient artifacts no longer need to be observed either in museums or as photographs in textbooks, as students can 3D print them at their schools to better visualize and understand these physical objects. Another very promising area is in mathematics where complex geometrical objects, which are hard to imagine, can be 3D printed and used as study material for classes. In chemistry AM can be used for visualizing molecular structures or in biology to study human organs [5]. Over the years, AM has become faster, capable of producing intricate shapes, and more affordable [6].

## 1.1 Additive Manufacturing in jewellery industry

New data shows that from 2021 to 2031, the jewellery industry is expected to increase by 10 % from $489 million to $989 million. Many jewellery establishments are implementing AM technology in their production which is helping to achieve higher efficiency and lower production costs, while assisting in the creation of intricate jewellery designs that would be hard to make by hand. With the success of AM in the fashion industry, it is expected to increase the use of AM technology in jewellery business [7]. The two leading countries for jewellery production worldwide are China and the United States. In China the market grew from $16.2 billion (2004) to $107.2 billion (2018) [8]. AM allowed bigger and smaller jewellery firms to use this technology to help them accelerate their sales. Although many were satisfied with the introduction of AM which modernized the jewellery industry, many jewellers struggled with the idea of replacing traditional jewelry making techniques with these newer methods, e.g., direct 3D printing jewellery. However, utilizing AM in jewellery design brings fresh ideas to the industry, together with shorter production time [9].

There are three ways to make a piece of jewellery: Crafting by hand, lost-wax casting of numerous copies, and direct metal 3D printing. These different ways highly depend on the costumers' needs, production time and cost, and the number of pieces. Handmade jewellery takes much more time to make than cast jewellery where hundreds of pieces can be manufactured over the same period as the handmade jewellery. Direct 3D printing jewellery introduces better production and time efficiency [10].

Tab. 1.1 below displays the most common 3D printers used for modern jewellery manufacturing. Each of these involve various 3D printing steps, and apply to different industries, applications, and costumer requirements. The printers also differ in price and size which means that some are made only for commercial purposes and others for home applications.

Table 1.1: The most common types of 3D printers

| 3D printing process | Examples of additive technologies | Printing source | Material | Manufacturer |
|---|---|---|---|---|
| Vat Photopolymerization (VP) | Stereolitography (SLA) | laser | liquid resin | Elegoo |
| Powder Bed Fusion (PBF) | Selective Laser Melting (SLM) | laser | metal powder | SLM Solutions |
| | Direct Metal Laser Sintering (DMLS) | laser | metal powder | EOS |
| Binder Jetting (BJT) | | liquid binder | metal powder | Desktop Metal |

## 1.2 Vat Photopolymerization

Vat Photopolymerization (VP) (Figure 1.1) is a type of 3D printing which uses a liquid resin that polymerizes when it reacts with a laser. The resin consists mainly of chemicals called monomers which are the main source for solidification. VP is excellent for its high precision rate of printing; however, the curing time of each 3D printed layer can prolong the production process [11].

### 1.2.1 Stereolitography

Stereolithography (SLA) printing is the process in which liquid resin chemically reacts when a laser strike a layer of the resin leading to polymerization and solidification [12]. To build layers, a scanning system (operates the laser to create a physical layer) is implemented inside the printer along with a laser [13]. Another similar printing process to SLA is masked stereolithography (MSLA) which is commonly used because of its lower price and faster printing time. The major difference between MSLA and SLA is that SLA includes the built – in liquid crystal display and UV light as the main source [14].

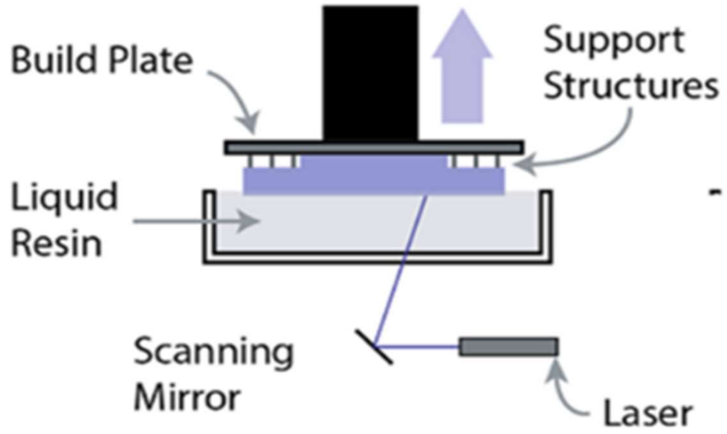


Figure 1.1 SLA process [11]

The post-processes for SLA printers called washing and curing are important in order to obtain a high-quality finished model. After removal from the built plate the 3D printed model is still covered in liquid resin which needs to be eliminated. Finished 3D models are washed in isopropyl alcohol and UV light is used for curing to enhance their mechanical properties [15].

## 1.3 Powder Bed Fusion

Today Powder Bed Fusion (PBF) plays an increasingly important role in AM. PBF operates mainly with plastic or metal powder particles which are melted via laser or electron beams. There are many advantages to PBF, e.g., in some PBF printers no supports are needed on the printed model. PBF includes various types of 3D printers which differ in the type of printing source [16]. There two types of PBF printing processes- Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS).

### 1.3.1 Selective Laser Melting

Selective Laser Melting (SLM) is the process of using a laser for melting and fusing powder particles (Figure 1.2). A laser forms layers of a designed CAD object. Printed objects emerge from the powder and are attached to a building plate where the laser interfaces with the powder. After a layer is formed, the building platform descends to make space for a new melted layer. This process is repeated until all layers are created forming a finished designed object. Chambers where the melting process is done are closed, and filled with an inert gas, e.g., Argon [17].

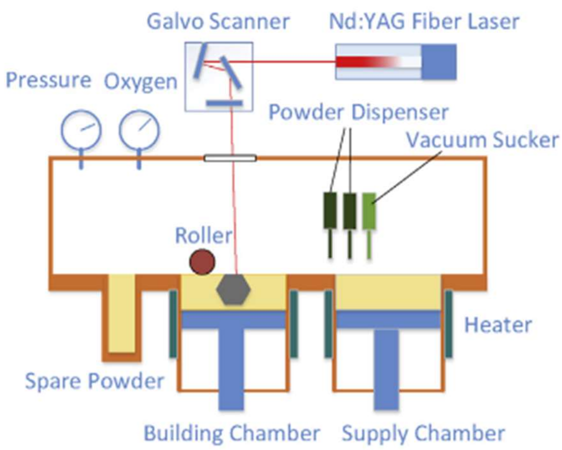


Figure 1.2: SLM process [17]

### 1.3.2 Direct Metal Laser Sintering

Direct Metal Laser Sintering (DMLS) printers are very similar to SLM printers. They both print with metal powders; however, DMLS printers use the sintering process instead of the melting process like in SLM technology. In DMLS the powder is not completely melted whereas in SLM printers the powder is completely melted [18].

## 1.4 Binder Jetting

Binder Jetting (BJT) is a type of additive printing that is very similar to PBF. The printer is loaded with metal powder which is applied to the surface by a re-coater. Unlike in PBF, the particles of the metal powder inside the printer are not melted and fused by a laser but are bound together via a binder. The binder is a liquid glue that is poured onto the powder particles filling up empty spaces between them, thus creating a solid piece. There is no need to use any supports to hold the model during the printing process. BJT, along with PBF, also relies on post-processing which leads to increased production time. Post processing is important for BJT since the printed object is not fully ready for its use and requires elimination of the excess binder. This can be done via curing and sintering [19].

## 1.5 Material Extrusion

3D printers based on material extrusion are one of the most common. These types of printers vary in price range, size, and operation. They utilize layers of heated polymer. Material extrusion 3D printers are more commonly known as Fused Deposition Modeling (FDM) printers [20]. FDM technology was first introduced by Scott Crump in 1989. It prints with a polymer-based material called PLA which is utilized in all FDM based 3D printers [20]. FDM printer is designed to print out physical models with filament layers that flow from an attached extrusion nozzle tip. The filament is made of a thermoplastic polymer and is heated, melted, deposited into a thin layer and solidified [12]. Ever since the FDM printers were first introduced to the market, not only there has been a high costumer demand for such machines, but also an increase in competition between high-tech companies manufacturing these printers lead to their greater affordability [3].

This AM process is however not used much for a jewellery production so in the further study would not be included.

# 2. THE IMPLEMENTATION OF 3D PRINTERS FOR JEWELLERY PRODUCTION

For jewellery designers and jewellers SLA printers have become an essential part of turning their concept jewellery ideas into physical objects using 3D printing. The biggest advantage of SLA printers is their simple construction design and settings which allow the user to easily learn and operate them. Thanks to technological advances in 3D printing, users can now afford to buy these printers and use them at home which is great for independent jewellery designers and jewellers. Using SLA printers in the jewellery industry has variety of applications such as allowing the user to fully inspect if there are mistakes or defects on the resin objects, master for mold creation or even for directly printing molds which do not need to be created by hand. All these improvements lead to saving time and money [21].

## 2.1 SLA 3D printers used in jewellery production

3D printers allow jewellers to use this technology to enhance their jewellery designs where some might be hard to handmade [22]. The jewellery market is increasing its production of jewellery which have an interesting design and are interesting to be worn [23]. 3D printers have become an interesting tool to create such complex designs [21]. There is a wide variety of SLA printers for beginners who want to start from a scratch. For instance, the Elegoo Mars 2 Pro (Fig. 2.1 and Fig. 2.2) is a suitable entry level 3D printer for new jewellery brands and designers. Tab. 2.1 shows another possible models of SLA 3D printers.

Table 2.1: SLA 3D printers

| **Technical parameters** | **Anycubic Photon Mono** | **Elegoo Mars 3 4K** | **Crealty LD-006** |
|---|---|---|---|
| Build volume | 130x80x165mm (L)x(W)x(H) | 143x90x175mm (L)x(W)x(H) | 192x120x250mm (L)x(W)x(H) |
| Resolution | 0.035 mm | 0.035 mm | 0.05 mm |
| Layer thickness | 0.15 mm | 0.01-0.2 mm | 0.01-0.1 mm |
| Printing time | 0.01 s | 1.5-3 s | 1-4 s |
| Price | $150 | $143 | $435 |

Figure 2.1 SLA printer

Figure 2.2: Liquid resin in a tank

## 2.2 3D printing jewellery models for mold creation and casting

Once printed, the model is used for creating a mold of vulcanized rubber which consists of two silicon slices. They are placed around the printed model along with a sprue that serves as a path for injecting liquid wax. Slices are pressed together and placed into a vulcanizing machine. The two rubber slices are then heated and compressed which makes the two slices conjoin into one solid piece. After vulcanization the mold is left to cool and then carefully cut open into two pieces [24].

The cut- open mold is attached to the wax injector via a nozzle and the liquid wax is poured in creating a wax model called the master. After the wax has solidified, the mold is opened, and the master is taken out. This process is repeated according to the required number of pieces of jewellery. The wax models are then attached onto the wax sprue, which, along with the masters, creates a wax tree [22].

The wax tree is placed into a metal flask and covered with liquid plaster, called investment, that is based on gypsum. Investment is mixed with water, poured into the flask up to the rim and placed in a vacuum chamber to prevent the formation of air bubbles. Having air bubbles inside the plaster material could cause visible defects on the jewellery such as holes [22].

The flask is placed in the burnout furnace, where the wax evaporates after a few hours under the addition of temperature levels. During the wax evaporation process, it is important to follow the burn-out cycle, which indicates the individual steps of adding temperature. Increased heat needs to be regulated to avoid cracks in the plaster. After hours of burnout process the evaporated wax tree leaves imprints in the investment ready for metal casting [24].

The flask with harden plaster is then taken out of the burnout furnace and is ready to be poured with melted metal. For this a crucible inside a casting machine is used for melting precious or other metals, e.g., gold, silver, copper, or brass. After achieving the melting point of the given metal, the flask is ready to be filled with the melted metal by a crucible. The metal is then left to cool and solidify inside the flask [25].

The flask is rinsed with water in order to dissolve the plaster. The metal tree castings are cut from the tree sprue with cutters and the remaining imperfections are manually removed. After finishing, the goldsmith or other worker will check whether there are no manufacturing errors or other defects visible on the finished product [24].

## 2.3 Different approaches of creating molds via SLA printers

### 2.3.1 Direct 3D printing molds

SLA printers are effective and achieve a high degree of accuracy in printing of resin jewellery models. Despite the use of SLM printers and their improvements in reducing time in jewellery lost-wax casting, the molds are still created by hand which is expensive and prolongs the jewellery production process. 3D printing can replace handmade molds by using SLA printers with special resin which creates flexible molds (Fig.2.3). This is a new approach to using SLA printers for jewellery production which has many benefits with the most important one being speeding up the lost-wax casting process. However, there are several problems which complicate this new approach of mold making. For example it is important to choose a suitable flexible resin which is able to withstand large pressure when bending the mold during the extraction of wax jewellery models [26].

Figure 2.3: Flexible mold [26]

### 2.3.2 Wax-resin based printed model

Another innovation in the jewellery industry is to completely dispose of molds, both handmade or 3D printed and replace them with wax resin models (Fig. 2.4) suitable for casting These resins are available to purchase and are becoming more utilized by jewellers. The major advantage is they can be printed using SLA printers at home. Printed wax-resin jewellery models are ready for burnout and casting. With castable resin, no molds are required for jewellery making. This appears to be a very effective way of saving time and money in production. However, printing with this type of resin is not easy and it comes with various obstacles, e.g., bad results during the burnout process. The main issue is that due to a large thermal expansion of the resin it could potentialy lead to the creation of holes, surface irregularity which leads to the decrease of the quality of the surface or the wax resin evaporation in the flask. Production problems while casting the jewellery makes the wax-resin material not always reliable. Formlab is among the most well known companies selling castable resins for jewellery industry [27].

Figure 2.4: Castable resin rings [27]

## 2.4 Replacing SLA printers with more advanced printers

Today SLA printers are one of the most significant printing devices in the jewellery industry producing high quality, precision molds and allowing jewellers to simplify their job. In the jewellery industry 3D printers have become one of the most important parts of the production process. Jewellers no longer need to hand-craft their wax masters for mold creation but can instead be directly 3D printed with resin at home in a few hours [28]. Nonetheless, there are still several steps after 3D printing for completing final jewellery pieces (burnout, casting and finishing). Apart from effective SLA printers, there are also other solutions that can be implemented into the jewellery business, namely special metal 3D printers (SLM, DMLS or BJT) which can directly print jewellery without the need of casting techniques which prolongs the jewellery making process [10].

# 3. DIRECT SILVER PRINTING IN JEWELLERY PRODUCTION

## 3.1 Why directly 3D print jewellery

The lost – wax casting process described in the previous chapter has proved to be one the most efficient ways to mass produce jewelry and it continues evolving. However, there are several impracticalities when considering this process. For instance, manufacturers usually prefer to produce a larger number of jewellery pieces per one casting than fewer pieces because it is more economical and time efficient. This can be impractical for newly set up jewellery brands or small designers who do not have many clients and therefore do not require as many jewellery pieces in their stock; for example, some designers even create a singular piece without copies. This can present a problem with production because manufacturers are more interested in creating multiple pieces as casting just one would be very costly. For this situation, direct metal printing (DMP) is a solution opening new doors within the jewellery field [23].

Other advantages of DMP include:

- Complex designs: Intricate and more advanced designs can be created by additive metal printers due to their precise scan layering technology [29].
- Time reduction: It is essential today to understand production as an entire system and how to create efficencies in numerous ways. One of the most important parameters of 3D printing is speed. DMP can reduce the production time which is important to costumers. Long waiting times can have a significant negative impact on business. Additive metal printers are capable of manufacturing jewellery faster than investment casting [10].
- Materials: Precious metals, e.g., gold and silver, can be utilized in DMP. This allows the possibility to directly 3D print jewellery from gold and silver [3].

However, metal 3D printers also some with several disadvantages.

- Energy consumption: Energy efficiency presents a serious drawback since the energy consumption is high for metal printers. There are two different types of energy consumption concerning metal printers: primary (energy consumed by laser sintering) and secondary (energy that is needed for machine operation). Energy consumption depends on the type of metal printer. PBF printers are the least efficient. BJT does not use expensive and energy demanding lasers, making it the most efficient type of printer. The disadvantage of BJT printers however is the post-processing requirement, e.g., heat treatment [30].

- Metal powders: Are expensive due to their cost to produce. Moreover, operating with such powders can be impractical when cleaning the powder from nozzles inside the printers. A regular cleaning needs to be done since the accumulation of powder inside of the nozzle may cause significant inaccuracies.
- The high cost of such metal printers since they are equipped with expensive lasers and high number of electronics [3].

## 3.2 Metal 3D printers used for direct printing silver jewellery

Despite SLM and DMLS being similar to each other, BJT operates with different printing source, liquid binder, and with different parameters. For SLM and DMLS the printing parameters are: the laser power of a fiber laser of a metal printer (which needs to achieve at least 200 W to melt down the silver powder), scan speed and layer thickness. Specific to BJT is the type and amount of liquid binder used for printing. For SLM/DMLS and BJT technologies post-processing steps are important to consider. Medium-sized machines are a better choice since the bigger machines are very expensive. There are still a small number of 3D printers which are implemented for direct silver jewellery printing. Companies such as EOS, SLM Solutions, Reinshaw and Desktop Metal offer the most suitable metal 3D printers for direct printing silver jewellery [30] [31].

### 3.2.1 SLM printers

SLM printers were first introduced by the German company SLM Solutions. For silver jewellery printing the SLM 125 (Fig. 3.1) and TRUPRINT 1000 (Figure. 3.2). post processing, e.g., heat treatment and finishing are needed [31].


Figure 3.1 SLM 125 [31]


Figure 3.2 TRUPRINT 1000 [31]

### 3.2.2 DMLS printers

DMLS printers were introduced by the EOS company from Germany. Various printers were manufactured such as EOS M 100 (Fig.3.3) and MYSINT 100 (Fig. 3.4) from Sisma and occured efficient for silver powder melting [31].


Figure 3.3: EOS M 80 [31]


Figure 3.4: MYSINT 100 [31]

### 3.2.3 BJT printers

Two companies Formula 3D and Desktop Metal cooperated to directly 3D print silver jewellery. Desktop Metal‘s P-1 (Fig. 3.5) is a suitable BJT printer used for silver printing [32].

Figure 3.5: P-1 [32]

## 3.3 Direct silver printing

For various types of metal 3D printers, it is more common to print with non-precious metals such as titanium or copper, but today it is also feasible to 3D print with precious metal powders, e.g. silver. Jewellery industry became highly innovative using such precious metals in PBF printers. Precious metal powders are widely used in 3D printing of intricate or hollow jewellery. Precious metal powders used for printing are mostly made of gold, silver and platinum. Each is defined by given parameters such as energy reflectivity which has a high impact on the process of powder melting [10].

### 3.3.1 Silver powder characterization

Silver powders are grey and have a sand-like structure. They consist of small spherical silver particles. The powder is made of either atomized pure (99,99 %) or sterling (92,5 %- 92,5 % silver and 7,5 % zinc or copper) silver. These two types of silver are very similar in terms of their structure but have different impacts on 3D printing [33]. Pure silver powder is much finer because the silver particles (Fig. 3.6 a, b) are more rounded which leads to better particle flow and printing results. Powder with sterling silver contain oval shaped particles (Fig. 3.6 c, d) which makes the printing with this powder more complicated [34].

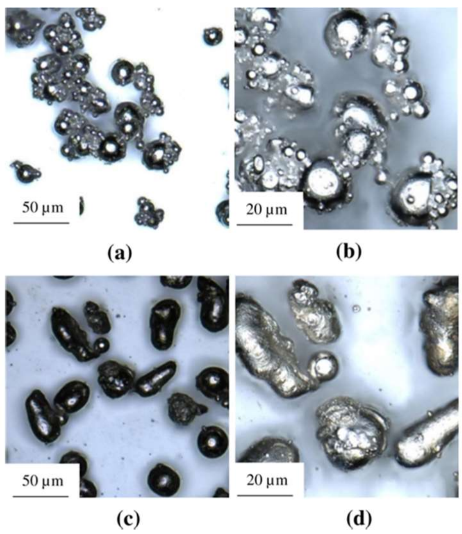


Figure 3.6: Pure (a,b) and sterling (c,d) silver powder [34]

### 3.3.2 Process of direct silver printing

Both type of SLM and DMLS printers operate with a built-in laser. Different lasers are used for different metal powders. This is because the metals differ in their ability to absorb heat needed for the creation of layers [31]. A container built inside a printer is filled with a metal powder up to the rim (Fig. 3.7 a). A recoater distributes the metal powder from the container to the build plate, (Fig. 3.7 b) where the melting process of powder particles via laser is done. The built plate (Fig. 3.7 c) mechanically levels down the build plate after a layer is printed to make a place for another one (Fig. 3.7 d). This process is repeated until the model is finished [35].

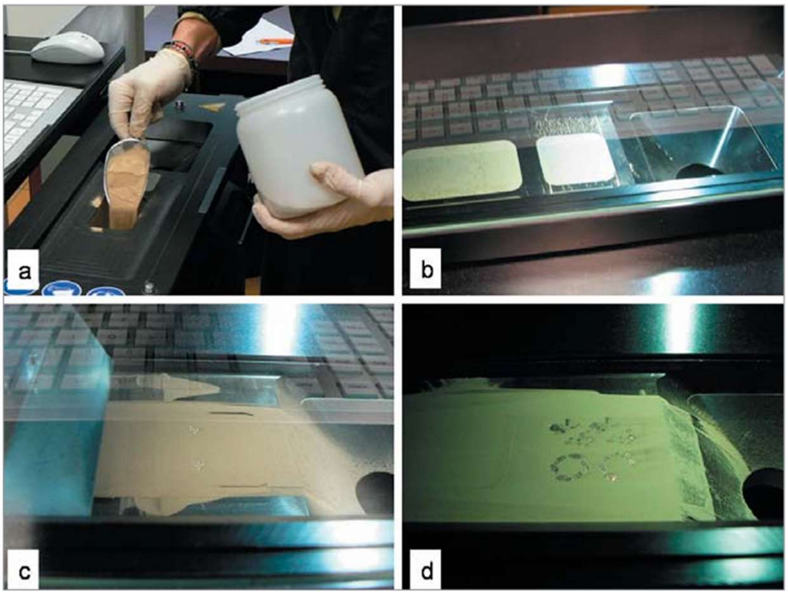


Figure 3.7: SLM/DMLS printing [35]

In Robinson‘s [34] study of fusing pure silver, the metal powder was melted with a laser of power approximately 350-370 W which was shown to be the most efficient for melting the silver powder. This process was demonstrated on SLM printer EOS M290. Silver appears to be one of the most difficult of precious powders to melt. The main reason is the high energy reflectivity which reflects almost half of the obtained energy in the form of heat. Another very important parameter of melting silver is the speed of scanning. Both the source of laser along with the speed of scanning are crucial for the absorption of heat in the powder [34].

### 3.3.3 Cost of silver powders

Apart from significant high energy reflectivity of silver powder, one of the main reasons of the limited use of silver in direct 3D printing is the price. Silver powders, along with other precious metal powders, are costly and due to their high price range, users need to operate with precious powders carefully to prevent excess waste. According to Korium [18, p. 9], "most of the industrial PBF machines on the market have huge sizes and require large amounts of powders." Prices also depend on the manufacturers of these silver powders.

## 3.4 Companies directly printing jewellery

Despite the fact direct jewellery printing is a relatively new area of additive manufacturing, and that direct printing with silver powders and purchasing metal 3D printers is expensive, there are companies which are successful, and their businesses thrive. Direct jewellery printing technology has become an interesting business field in Europe where countries like Italy and Germany are the most successful in direct jewellery printing research. Many EU metal printing companies operate with various materials: some work only with gold or silver, some with all precious metals. Two of the most successful companies that 3D print with precious metals are Progold (Italy) and Cooksongold (United Kingdom). Cloud Factory, which was set up in 2018 in Tallin, Estonia also offers direct printed silver jewellery. For silver printing this company use the SLM 125 printer with which they are able to 3D print quality silver jewellery (Fig. 3.8) [36].

Figure 3.8: Direct 3D printed silver jewellery [36]

# 4. PRACTICAL PART

Even though there is a relatively low number of metal printers to directly 3D print silver it is hard to determine which would be the most suitable for jewellery business owners. In the current AM market there are metal printers which are available for direct silver jewellery printing; however, some are very large or too expensive. Despite this there are jewellers and jewellery companies which still use the lost-wax casting methods; yet, with limitations, e.g., complex designs or production time have major issues on this type jewellery of manufacture, there are new jewellery establishments setting up metal printers for their jewellery production which makes them innovative. In the future metal printers, i. e., SLM, DMLS or BJT will transform the jewellery business [7].

## Specification of the task

The practical part of this thesis is to find a suitable 3D printer for smaller jewellery businesses which is able to print silver. The result will be evaluated by parameters, e.g., price, build plate or price of printing silver jewellery and final comparison with traditional casting. The last part deals with a discussion whether it is technically and economically feasible to construct and operate such metal 3D printer, e. g., for smaller jewellery brands or households.

Ideally a perfect metal 3D printer which is available on the market is one with dimensions that does not take up a large amount of space. At first glance this task might seem easy to solve in finding a proper metal printer; however, to find such printer in the current market for jewellery businesses is not easy. The main problem is the silver material for direct printing due to its high laser reflectivity which is 98 % (higher than gold which holds 96 %) and its thermal conductivity is 429 W [10]. Various technical parameters are needed to understand to produce a proper conclusion, e.g., printing accuracy, reliability, printer and material price and maintenance costs. The applicable 3D metal printers might bring new business opportunities for established jewellery companies [9].

## 4.1 Comparison between casting and DMP jewellery

A study done by Zito [10] compared traditional casting (the creation of molds), direct casting (direct casting with wax resin models) and SLM (direct 3D printing). They studied the difference between production time, market prices or carbon footprint of these three jewellery production techniques. The research was based on 1 piece, 10 pieces and 100 pieces of a hollow ring. The production time results from one manufactured piece were: Traditional casting (34.0 h), Direct Casting (18.5 h) and SLM (2.0 h). The results in (Fig. 4.1) show that traditional casting occurs with the longest production time (mold creation and the longevity of manufacturing casting processes). The high production time of a single cast jewellery piece makes manufacturing one piece prohibitive; however, once a mold is created it is shorter than direct investment casting. The mass production of 100 pieces occurred the longest for SLM metal 3D printer: traditional casting (37.5 h), direct casting (28.5 h) and SLM (78.5 h). The comparison between 100 jewellery pieces produced by traditional investment casting and direct investment casting is that the traditional is still longer to manufacture than direct.

The level of $CO_2$ emissions from the technology was measured in three different jewellery production. The emissions come from the amount of electricity used for casting, e.g., the electricity for heat furnaces and the operation of SLM. Values in (Fig. 4.2) show that traditional casting reported the highest emissions compared to direct and SLM technology.

Then price for finished jewellery was calculated. The final price calculation of course consists of hourly costs of workers. For this research, the price quotations were from Italy. The result was that traditional investment casting is the least expensive versus direct investment casting and direct 3D printing jewellery.

The conclusion of Zito's research was not to dictate which technique is the best for today's jewellery industry but to compare different parameters and values. SLM was better for the environment and had better results utilizing complex designs and suitability when producing single or minimum quantities of jewellery than traditional and direct investment casting. SLM from this perspective might be interesting to adopt for jewellery businesses; however, there are drawbacks which make this additive technology hard to fully implement. Concerning jewellery surface quality, the SLM had the lowest values whereas traditional casting had the best results. For mass jewellery production the SLM has the longest production time which is not ideal for jewellers or their customers. Direct 3D printing jewellery is still the most expensive whereas traditional investment casting is the most economical for jewellers.

It is apparent that each jewellery production technique differs from one another with advantages and disadvantages for the jewellery business and that it is for the jewellery business owner to decide. For mass production of jewellery designs traditional investment casting likely the best economical option. If jewellers want to offer intricate designs to their customers, then an SLM printer might be the better option; however, the customer will have to pay a larger price [10].

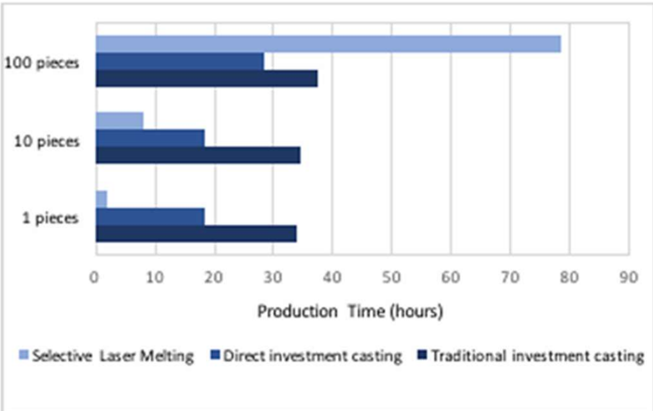


Figure 4.1: Jewellery production time [10]

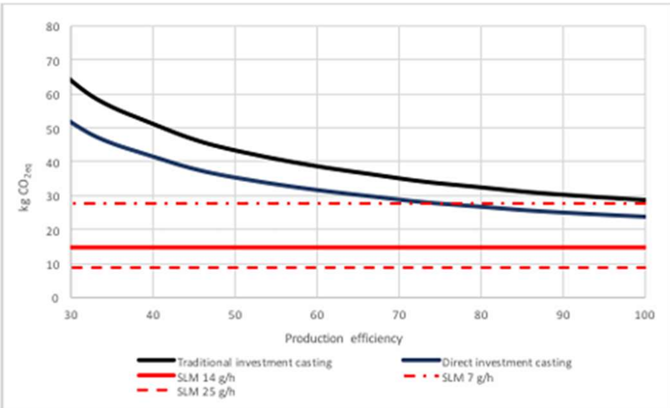


Figure 4.2: $CO_2$ emmisions [10]

## 4.2 Definition of a small jewellery business purchasing a metal 3D printer

For this thesis and its research, it is important to define which jewellery business the research is going to be conducted on. The core elements on which to determine and ideal jewellery business candidate is the number of employees where everyone deals with their own tasks, and the type of advanced technologies, e.g., high precision SLA printers, own studio, capital, other types of technology, loyal customers, a good business plan with revenue which allows them to grow, and an openness to invest into metal 3D printers for their own jewellery production. It will become clear that once implementing metal 3D printers this business has a new perspective on jewellery making apart from traditional jewellery casting.

Theoretical model:

**Number of employees:** around 10 employees, e.g., 3D designers and customer service assistants
**Production method:** 3D designs send for investment casting
**Number of sold jewellery:** around 10 000 jewellery pieces/per year
**Material:** silver jewellery
**Revenue:** around $500,000/per year
**Service:** mass production, complex designs

Jewellery businesses owning such metal 3D printers can work with a wide range of customers from smaller to bigger jewellery brands. Metal 3D printers allow the production of intricate or hollow jewellery pieces which are hard to cast. This allows the business to enter niche jewellery markets. Additional advantage of owning metal 3D printers from a casting service is the variety amount of jewellery pieces produced. Some jewellery brands might just need a couple of pieces to add to their collection, larger brands will be interested in mass produced jewellery. The production can still be done via casting combined with metal 3D printers.

Since metal 3D printing is an automated process, it does not require many workers like casting where there must be multiple people involved around the process. If a jewellery business would acquire a metal 3D printer the only employees required to work would be 3D designer, an engineer to operate the metal 3D printer and third person for post-processing. This is significant if we talk about mass producing jewellery since casting, e.g., producing hundreds or thousands of jewellery pieces, requires a high amount of people. However, it must be said that the utilization of metal 3D printers into a jewellery businesses is expensive and depends on the organization's understanding of the metal 3D printers market in order to select the right printer for the business's needs.

### 4.2.1 Analysis of a suitable metal printer for smaller jewellery businesses

For emerging small jewellery businesses, the cost to produce jewellery pieces pays a large role. In chapter 3.2.1 various 3D printers were introduced which are suitable for direct 3D printing of silver for the jewellery industry. There are various crucial parameters which are important to think off when purchasing a metal 3D printer that can have a large impact on their business:

**Dimensions:** The size should be practical for the jewellers to work with. When talking about dimensions we talk about the external and build plate dimensions. The larger the build plate the higher number of pieces that can be 3D printed which is great for mass production; however, larger build plates require a higher number of precious powders which are expensive.

**Price:** Metal printers are expensive and if a jewellery brand owner is determined to purchase such technology, they need to consider the potential and drawbacks of acquiring metal 3D printers for their jewellery business.

**Post-processing:** One of the most crucial parts of metal printing. After printing, the object needs to be processed and polished. When purchasing a particular metal 3D printer the owner needs to understand which types of post-processing steps come with each metal 3D printers and whether it would be economical or not for the jewellery production.

**Safety measures:** Personal protection is important when operating metal 3D printers. SLM or DMLS utilize high power lasers. Users must wear specialized clothes, e.g., face masks (Fig. 4.3) or gloves. Also a personal training for the staff is required [37].

Figure 4.3: Safety clothing [37]

**Maintenance costs:** Additional machinery needs to be added to the direct 3D printing process, e.g., the precious powders need to be stored in special cabinets to avoid humidity or oxidation [38].

**Production time:** This will have a high impact on their printing business. Some printers are slower which increase waiting time which might affect delivery times for the business.

### 4.2.2 Technical data collection

The analysis is divided into three stages. **I. stage:** the comparison of dimensions, price, layer thickness and build plate, **II. stage:** post-processing, safety measures, maintenance, and printing time and **III. stage:** the price quotation of a silver pendant and a price comparison between cast and directly 3D printed silver pendant. Technical data from various metal 3D printers appropriate for silver printing jewellery were collected in Tab. 4.1 and inserted into Python. There are other metal 3D printers which are able to 3D print silver, e.g., MPRINT (One Click Metal), DMP Flex 100 (3D systems), GE Additive Concept Laser Mlab R, FS121M system. These however are not yet fully implemented for the jewellery industry and will not be mentioned in the further study of this thesis [32]. The data from the Tab. 4.1 were taken from [31] [32].

**I. Stage of the analysis**

Table 4.1: Technical parameters of SLM, DMLS and BJT printers

| 3D printer | Process | External dimensions | Build plate/box | Price | Layer thickness |
|---|---|---|---|---|---|
| EOS M100 | DMLS | 800 mm x 950 mm x 2 250 mm (W x D x H) | Ø 100 x H 95 mm | $350.000 | 40 µm |
| InnoventX | BJT | 1 146 mm x 794 mm x 1 344 mm (W x D x H) | 160 x 65 x 65 mm | $250.000 | 30-200 µm |
| MYSINT 100 | SLM | 1 390 mm x 777 mm x 1 600 mm (W x D x H) | Ø 100 x H 100 mm | $170.000 | 20-40 µm |
| Realizer SLM 50 | SLM | 800 mm x 700 mm x 500 mm (W x D x H) | Ø60 x H 27 mm | $112.000 | 20-50 µm |
| TRUPRINT 100 | SLM | 780 mm x 1 160 mm x 2 050 mm (W x D x H) | Ø 100 x H 100 mm | $170.000 | 20-60 µm |
| EOS Precious M80 | DMLS | 800 mm x 950 mm x 2 250 mm (W x D x H) | Ø 80 X 95 mm | $119.000 | 40 µm |

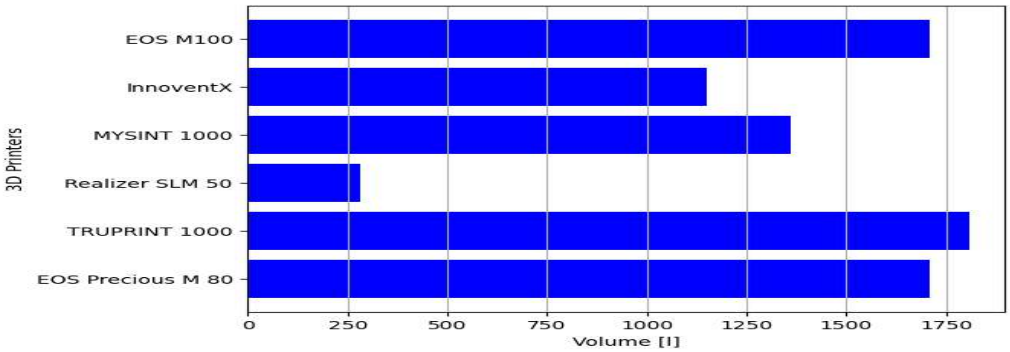


Figure 4.4: External dimensions comparison

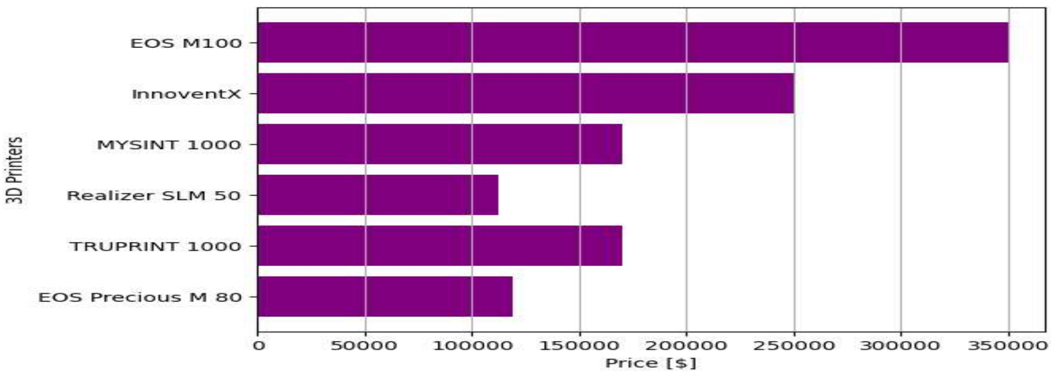


Figure 4.5: Price comparison

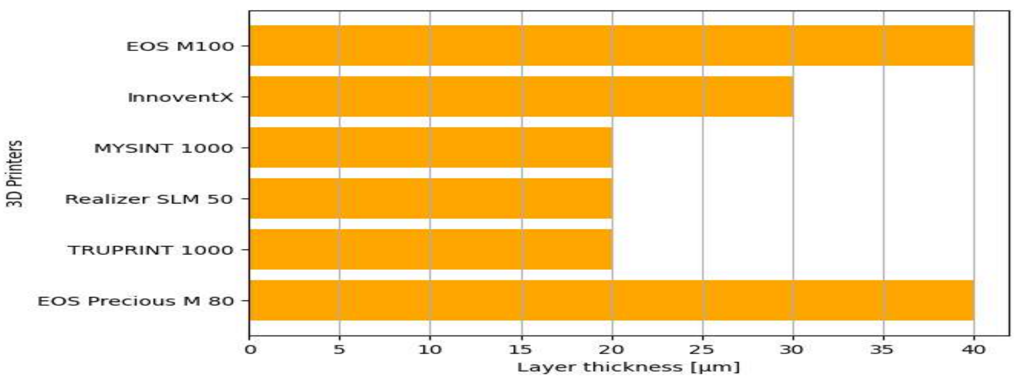


Figure 4.6: Layer thickness comparison

Values from the given bar graphs (Fig. 4.4, Fig. 4.5 and Fig. 4.6) show that from the perspective of size and price the Realizer SLM 50 seem like a great solution. The Realizer SLM 50 was designed for either dental or jewellery applications. It was the first desktop metal printer which was great for smaller spaces; however, since the Realizer SLM 50 was made in 2009 it is an older 3D printer and is no longer available in the AM market only through second-hand purchase which is not very efficient [39]. EOS Precious M 80 operates only with alloys and utilize laser power of 100 W which is not suitable for printing silver [34]. From the perspective of external dimensions, price and layer thickness the TRUPRINT 1000, MYSINT 100 and InnoventX are great options for smaller jewellery businesses. Despite TRUPRINT 1000 and MYSINT 100 being relatively similar to each other from the perspective of experience in the jewellery industry the MYSINT 100 (Fig. 4.7) from Sisma already 3D printed silver objects. For the further study only MYSINT 100 (SLM) and InnoventX (BJT) were selected.

Figure 4.7: SLM printer
MYSINT 100 [31]

For a next investigation of this practical part, it is also important to think about the amount of silver jewellery the owner wants to 3D print per week, month, or a year. The higher the number of printed jewellery pieces the better for the business. That is why a consideration of a build plate dimensions is important. Metal 3D printer with a smaller external dimension does not fully mean it is better for the smaller jewellery business than the bigger printers. For mass production of silver jewellery, it is good to consider larger build plates. Generally, SLM and DMLS printers have smaller build plates. They are rounded usually around Ø 100 x H 100 which prolongs the jewellery production time.

BJT technology is more efficient in manufacturing larger numbers of jewellery at the same time as SLM/DMLS printers. That is why it is important for the jewellery business owner to think about a BJT build plate advantage [7].

InnoventX's build plate is 160 x 65 x 65. Desktop Metal, the manufacturer of InnoventX, offer even larger BJT 3D printers such as the P-1 (BJT) which has a larger size and build plate and this 3D printer is used for their mass production of jewellery; however, it is much more expensive and the build box of InnoventX is enough for the defined jewellery business owner.

Fig. 4.8 shows a modeled pendant which is used for this practical part for price calculations. To illustrate how a pendant is designed, two 3D modeling applications, Rhino (version 7 SR32) and Blender (version 3.6 LTS), were used. In Rhino, the base of the pendant was modeled, which consists of a cylinder with a diameter and a round bail. The total precise dimensions of the pendant are 16.199*15.641*7.514 mm.

Figure 4.8: 3D model of a silver pendant

Tab. 4.2 shows the maximum amount of silver jewellery pendants produce via InnoventX and MYSINT 100 per one print. Fig. 4.9 shows that BJT allows much greater number of printed units than SLM printers.

Table 4.2: Maximum amount of printed pendants per one printing

| Printer | Build plate | Printed pendants |
|---|---|---|
| InnoventX | 160 x 65 x 65 mm | 156 |
| MYSINT 100 | Ø 100 x H 100 | 30 |

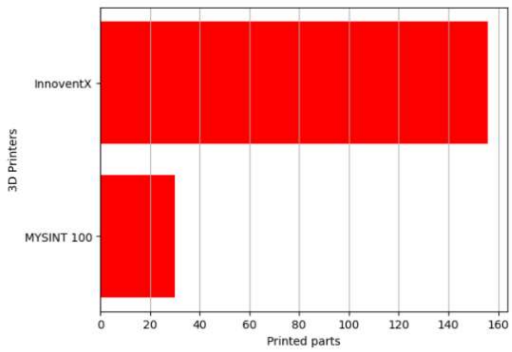


Figure 4.9 Maximum printed jewellery amount per one print

External dimensions, price and build plate dimension play a large role for the jewellery business owner when determining which metal 3D printer to purchase to their establishments; however, these are not the only technical parameters which evaluate the definitive decision of purchasing this additive technology. A major part which also defines the decision is post-processing and the quality of surface finishing [9].

**II. Stage of the analysis**

**Post-processing**

Post-processing is an import step to take after direct 3D printing and is compulsory for either BJT or SLM printers. For instance, it is needed to achieve support removal, increase mechanical (properties) or left- over metal powder cleaning [3].

**InnoventX:** After direct 3D printing the silver jewellery is very brittle. 3D printed jewellery, also called a green part, can be compared to chalk in its structural composition. If a technician applies a significant amount of pressure, they can destroy the product so there needs to be an additional steps for hardening the 3D printed part and that is putting the entire build box into a crosslink oven for hardening, called crosslinking. Then there is the depowdering step (Fig. 4.10) where the powder is removed manually from the part with a brush. The last part of post-processing is the sintering process (Fig. 4.11) in which objects are put in a box which is placed into a furnace where heat and pressure. The final step of BJT is polishing the silver jewellery [40] [41].

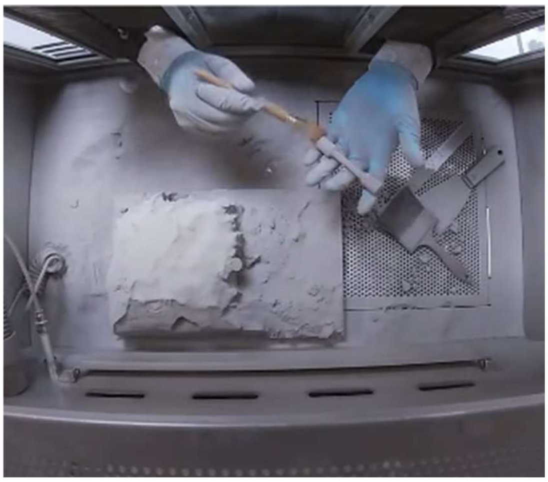

Figure 4.10: Depowdering (BJT) [40]

Figure 4.11: Sintering (BJT) [40]

**MYSINT 100:** After 3D printing the residual silver powder is removed via a brush (Fig. 4.12) and the printed jewellery must be put into a heat furnace. The parts are left in the furnace for about 1-4 h between 400-800 °C. The heating is applied to reduce residual stresses. Then the parts are taken out of the furnace and the supports holding the object are cut off. The machine then needs to be cleaned off so that another laser melting process can be done as there is metal powder residue on the machine and optics and the filters need to be replaced. This procedure requires technicians which are qualified for this task. Additionally, containers with gas, e.g., Argon, after 100 h of use need to be changed [35] [41].

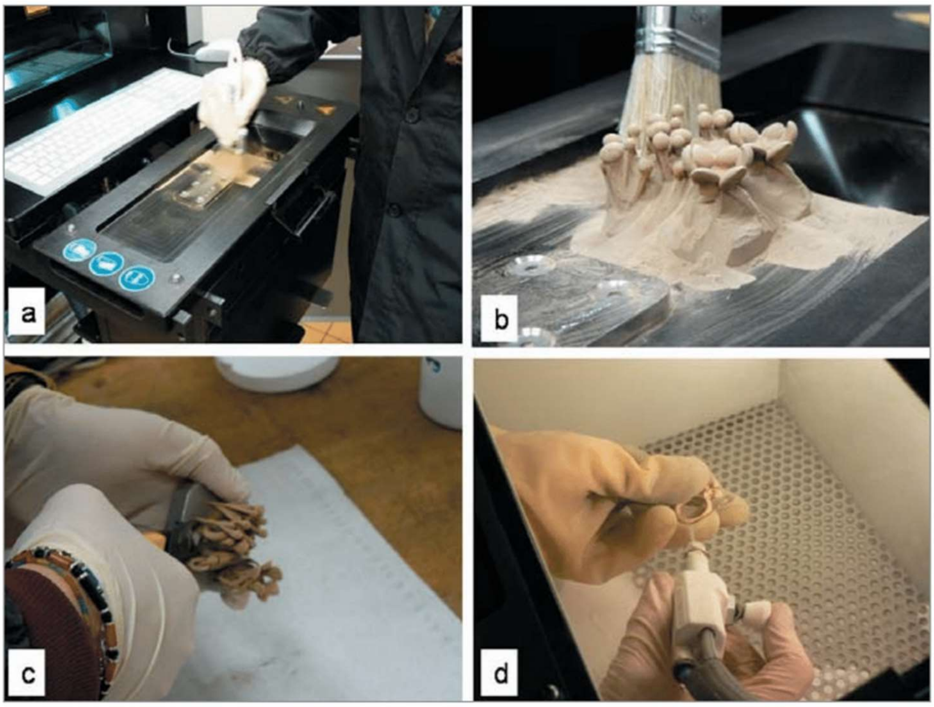


Figure 4.12: The powder removal and surface finishing (SLM) [35]

The results from I. and II. Stage of analysis show that BJT technology holds a large advantage in no supports during the printing process which allows a lesser production time [41]. From the aspect of a build plate the MYSINT 100 with the build plate diameter allow only around 30 silver pieces to be printed whereas the InnoventX allows 156 pieces which is highly beneficial for the jewellery business owner. Tab. 4.3 shows the advantages and disadvantages of InnoventX and MYSINT 100 printers.

Table 4.3: Comparison between the InnoventX and MYSINT 100

| Parameters | InnoventX | MYSINT 100 |
|---|---|---|
| Supports | + | - |
| Post-processing | - | + |
| Printer price | - | + |
| Production time | + | - |
| Amount of prints | + | - |

**Results**

From the given results of the analysis the InnoventX (Fig. 4.13) is highly applicable for mass production of silver jewellery. Due to the perfect size of the metal 3D printer (Fig. 4.14) and post-production the InnoventX is an interesting machine for the AM innovation for the jewellery industry [40].

Figure 4.13: InnoventX [40]

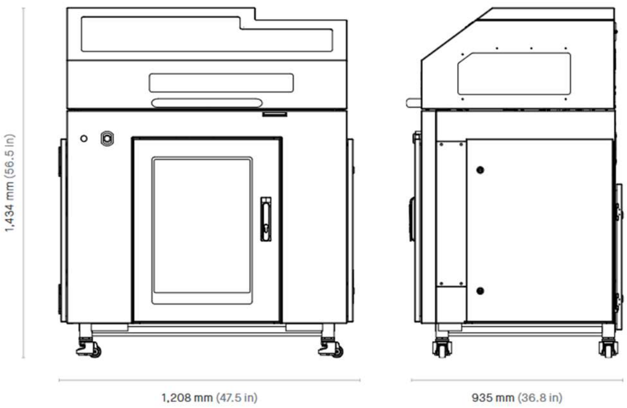


Figure 4.14: InnoventX external dimensions [40]

**III. Stage of analysis**

Another task is to look for a price quotation for a silver pendant made by two technology processes –casting and BJT printing. Two companies were contacted: A jewellery casting company based in Prague and Desktop Metal (using the InnoventX printer). Tab. 4.4 and Tab. 4.5 show the obtained price quotations of one silver jewellery produced. The casting and printing results are shown in Fig. 4.15 and Fig. 4.16.

**Casting:** It is important to note that for the second and other castings the price for the 3D printed model and mold is no longer considered. Price is only estimated for casting and surface finishing. Fig. 4.17 shows the cast silver pendant used for this calculation.

**Direct 3D printing:** For a direct 3D prinitng the InnoventX printer was used. The amount of printed silver jewellery parts per one print is 156 silver pendants. The price consists of printed and sintered part.

Table 4.4: Price quotation for casting and direct 3D printing a silver pendant with a mold included

| **Casting** | **Price quotation for 1 silver piece** | **Direct metal printing** | **Price quotation for 1 silver piece** |
|---|---|---|---|
| 3D printing of a model | €17,80 | Printed and sintered part cost | €14,44 |
| The mold preparation | €121,38 | | |
| Casting and finishing | €17,8 | | |
| **Total** | **€157** | **Total** | **€14,44** |

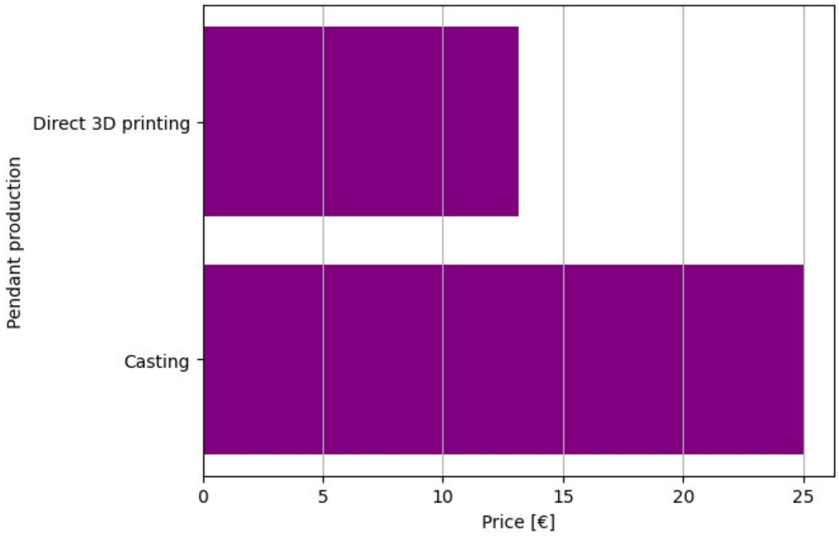


Figure 4.15 Price comparison between casting and BJT with mold included

Table 4.5: Price quotation for casting and direct 3D printing a silver pendant without a mold included

| **Casting** | **Price quotation for 1 silver piece** | **Direct metal printing** | **Price quotation for 1 silver piece** |
|---|---|---|---|
| Casting and finishing | €17,80 | Printed and sintered part cost | €14,44 |
| **Total** | **€17,80** | **Total** | **€14,44** |

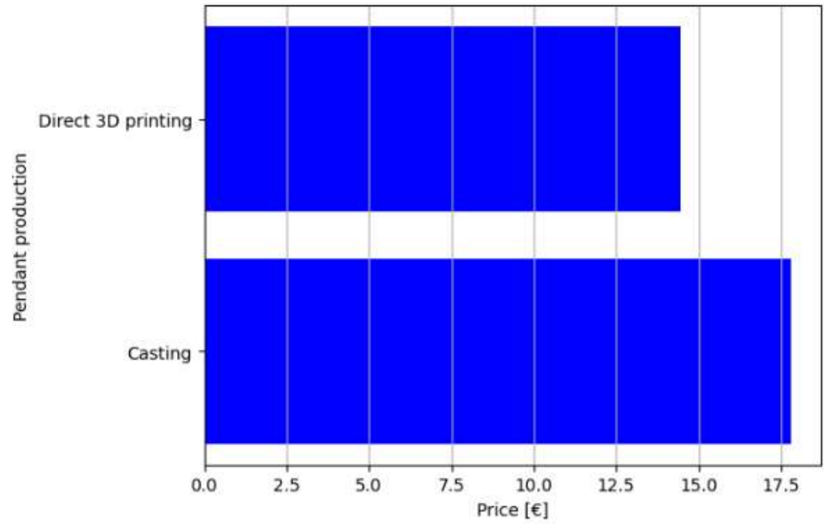


Figure 4.16: Price comparison between casting and BJT with no mold included

The previous calculation was set up to one silver piece. If a jewellery business would adapt to the InnoventX printer the amount of produced silver pendants per a week, month and year is showed in the Tab. 4.6. The calculation was given by Desktop Metal.

Table 4.6: Amount of printed silver pendants per a year

| **InnoventX** | **Printed silver pieces** |
|---|---|
| Printed parts/ build | 156 |
| Printed builds/ week | 6 |
| Printed builds/ month | 25 |
| Printed builds/ year | 294 |
| Sintered parts/ week | 918 |
| Sintered parts/ month | 3,670 |
| Printed builds/ year | 44,042 |

Figure 4.17: Silver pendant made via traditional casting

When determining which metal 3D printer is the most suitable between SLM/DMLS or BJT, a jeweller must assess both the current and future requirements of their business. These metal 3D printers differ in price, post-processing steps and the ability to produce a desired amount of jewellery pieces. Not only do jewellers need to consider the high price of metal 3D printing technology but also how to adapt the metal printers to the workplace. They need to consider which kind of additional equipment is required during the 3D printing process, e.g., vacuum cleaners for cleaning up the left-over metal powder, high electricity for the heat furnace, space for storing the precious powders and other crucial accessories. These all act together to increase the production costs. From this point of view, it is hard to say whether it is a good business decision for smaller jewellery establishments or brands to purchase such 3D printers.

On the other hand, jewellery designers or smaller jewellery brand owners can benefit from adapting to this technology, because casting only one piece of jewellery is inefficient and metal 3D printers can offer a lower price calculation for a single piece of jewellery due to no molds or complex steps required in the production process of traditional casting. From a technical observation the question of whether it is technically possible to construct and operate such metal 3D printers in smaller jewellery establishments is known since there are already smaller metal 3D printers utilized in jewellery production, e. g., Desktop Metal introduced a smaller BJT version the InnoventX from the X-series which fits into smaller spaces and is less costly than the larger P-1 model. Even PBF printers are becoming more ergonomic and reduced in size for small jewellery companies, e.g., the EOS Precious M80 is a compact 3D printer and is used in many small businesses [9]. Metal 3D printers are quite safe to operate, but safety precautions a required, e.g., wearing gloves or eye protection. The electricity consumption is on metal 3D printers is not a big issue as its mostly needed for the thermal furnace for post-processing, so metal 3D printers themselves do not require a large amount of electricity [10].

Another question when considering metal 3D printers is the economic considerations. This additive technology is expensive and requires not only purchasing the metal 3D printer but also post-processing machines, and other equipment in addition, precious metal powders are costly; however, there is a strong argument that these 3D printers hold a significant role for the future of jewellery production

When discussing the further integration of metal 3D printers in the jewellery industry there is still much research and innovation needed to be done. Jewellers should be more open to discussions about this additive technology and reflect on whether it has a place in their production process and offers enough added economic efficiency for jewellery production [9]. Jewellery companies can benefit from metal 3D printers thanks to their high efficiency and reducing the manufacturing steps in the traditional investment casting. Metal 3D printers allow more freedom to produce jewellery in various quantities whereas casting is more suitable for larger production runs of jewellery pieces [23].

**Discussion**

Theoretically, the future of metal 3D printers owned by homebased freelance jewellery designers is an interesting concept idea as they are like desktop SLA printers where the resin model can be directly printed under several minutes or hours. However, the user would have to operate with strict safety measures, count with high cost of precious powders, post-processing which is not suitable for amateurs or purchase additional appliances, e.g., vacuum cleaners for cleaning the powder. Today the application of these 3D printers used by jewellery designers in their households is nonexistent due to their high prices; however, this idea of direct 3D printing jewellery designs at home could help innovative the jewellery industry. The InnoventX is one of the metal 3D printers which could play a part as it’s a great starting point for freelance jewellery designers who want to produce at home.

# 5. CONCLUSION

Jewellery production over many centuries adopted various jewellery production techniques from hand crafting a single piece, to mass producing jewellery via casting which has become highly effective for today's jewellery production, to utilizing 3D printers which enable the direct metal printing of jewellery with precious materials, e.g. silver. Since the adoption of SLA printers in the jewellery industry they have reduced the need for traditional investment casting in the production of jewellery, e. g., wax based resin prints which enabled omitting molds. For faster jewellery production the metal 3D printers became highly beneficial due to their various advantages which displaced traditional investment casting, e.g., direct 3D printing jewellery occurs with lesser CO2 emissions due to lesser need for electricity consumption which traditional investment casting requires because of the longer heating time in furnaces. SLM and BJT offer direct printing of intricate jewellery which is hard to cast and labour intensive. Despite the various advantages of metal 3D printers there are drawbacks which hold jewellers back from using this additive technology, e.g., the prices of these metal 3D printers, and the surface quality is much poorer than from traditional investment casting.

In the theoretical part of this thesis the wide use of SLA printers in jewellery production was introduced. It holds a strong significance in the jewellery industry for reducing production time and manufacturing costs. More advanced 3D printers, e.g., SLM, DMLS and BJT are slowly becoming another source of jewellery production. The difference lays in printing source, e.g., lasers or liquid binder.

The practical part of this thesis was focused on the collection of technical data from various metal 3D printers where price, dimensions and build plate played a large role in the first stage of evaluation. Another very important aspect was the post-processing which is essential to do after direct printing the silver jewellery. Values and results obtained from the graphs; the InnoventX from Desktop Metal proved to be a suitable metal 3D printer for smaller jewellery establishments. Due to its size, build plate and post-processing it is a great technology for mass production of jewellery. However, emphasis was paid to the safety measures when operating such technology.

A price calculation of multiple silver pendants was also presented in the third stage of the practical part and was compared with traditional investment casting. The study provided results that for jewellery business owners it is still economically feasible to produce their jewellery via a traditional casting method despite the large number of equipment used for casting. Direct investment casting was also presented as an alternative way to produce jewellery; however, in terms of mass production and costs traditional investment casting is still much more beneficial.

The practical part of this thesis pays a respect to both traditional casting and direct metal printing stating that neither is superior to the other. Both offer interesting ways of jewellery production for different types of clients. For mass production it is still better to produce the jewellery via traditional casting whereas for more complex designs the metal 3D printers are a better option. In the jewellery industry today, we are seeing more businesses starting to adopt this additive technology; however, the high prices of such 3D printers prohibit jewellery business owners to invest into this technology for now. All in all, an open discussion within the jewellery industry on the benefits of metal 3D printing technology is required to innovate jewellery industry. In time, metal 3D printers will have an essential part to play in the world of jewellery production and bring interesting possibilities of design and innovation to the jewellery business.

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