Politecnico di Torino

Department of Management and Production Engineering MsC in Engineering and Management

July 2022

Additive manufacturing in the Italian goldsmith industry.

Analysis on current adoption and economic impact of Additive Manufacturing technology in the district of Arezzo, Valenza and Vicenza

Supervisor:
Luigi Benfratello

Candidate:
279846 Domenico Geraci

A.Y. 2021/2022

Contents

Table of figures

ABSTRACT

The AM technologies have been spreading during last decades as alternative to the traditional subtractive production processes such as turning, milling, and drilling. These technologies are taking hold in all sectors alongside, improving or replacing traditional production techniques.

In the jewelry industry additive manufacturing is beginning to settle as the main prototyping tool and is slowly starting to be used directly for the finished product.

In the chapter 1 a general overview of the AM technologies is presented. After a brief outline of the history, the classification of the techniques available according to the material form (liquid, solid or powder) is accompanied with a brief description of the industry and the application fields.

Chapter 2 presents an overview of the Italian goldsmith sector with a focus on the three main districts of the peninsula (Valenza, Arezzo, Alessandria). The analysis is supported by reports on the goldsmith sector of Intesa San Paolo and an extraction on AIDA on the first thousand companies per turnover with ATECO *code: 321210 - Manufacture of jewellery and precious metal goldsmithery or coated with precious metals.*

The evolution of production processes in goldsmithing up to additive manufacturing adoption is described in Chapter 3. Starting from the traditional lost wax casting, passing through the usage of 3D printers for prototyping in Direct investment casting up to the Selective Laser Melting that directly prints the finished product. In this chapter is also presented a technical comparison among these three techniques.

In chapter 4 the advantages and disadvantages of the adoption of SLM in the goldsmith industry are presented. The lead time, the economic factor and the sustainability are the more important points dealt.

Finally, collecting the surveys carried out to the companies of the three main poles for the goldsmith in Italy (Arezzo, Valenza, Vicenza), in chapter 5 an analysis on the adoption of the additive manufacturing inside the Italian goldsmith landscape is presented.

CHAPTER 1: ADDITIVE MANUFACTURING TECHNOLOGIES.

1. INTRODUCTION

Additive manufacturing is a specific 3D printing process. This process builds parts layer by layer by depositing material according to digital 3D design data. The AM technologies have been spreading during last decades as alternative to the traditional subtractive production processes such as turning, milling, and drilling. This method offers convincing advantages conventional methods cannot achieve and for this reason, despite this is a quite young technology, it has reached a good level of maturity thanks to the large amount of investments made by leading countries. At the beginning of their spread these technologies were characterized by the definition of "rapid prototyping" but, during last years, it is consolidating more and more the idea that it can be the same 3D printing to give the finished product. The AM technologies are expanding into all sectors and according to a recent study by *Dimensional Research*, it is present in 81% of companies.

2. HISTORY

The first attempts to make solid objects using photopolymers date back to the late 1960s and were conducted at the Battelle Memorial Institute in Columbus, Ohio. This initial research activity led to an experimental setup in which two laser beams of different wavelengths, crossed at a point inside a container, filled with photopolymer resins, in order to solidify a certain amount of volume. Below are briefly presented, in chronological order, the patents that have given a fundamental impulse to the development of additive manufacturing technologies.

- *US4575330*: SLA (Stereolithography) technology, presented on August 8 1984 by Chuck Hull (*Figure 1*)

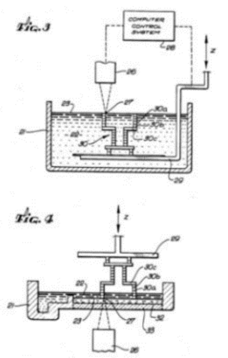

Figure 1 US4575330: SLA (Stereolithography) technology

- US4752352: LOM (Laminated Obiect Modeling) technology, presented in 1986 by Michael Feygin
- US4863538: SLS (Selective Laser Sintering) technology, presented in 1986 by Carl Deckard (*Figure 2*)

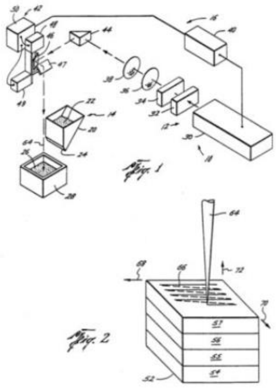

Figure 2- US4863538: SLS (Selective Laser Sintering) technology

- TUS4961154: SGC (Solid Ground Curing) technology, filed in 1986 by Itzchak Pomerantz but immediately found extremely expensive and complex, so it was later abandoned.
- US5121329: FDM (Fused Deposition Modeling) technology, filed in 1989 by Scott Crump (*Figure 3*)

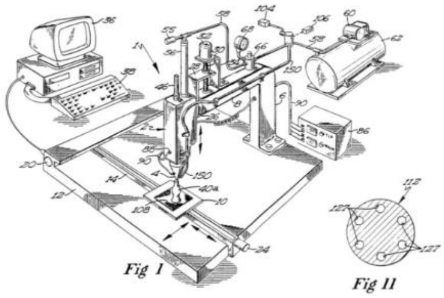

Figure 3- US5121329: FDM (Fused Deposition Modeling) technology

- US5786562: EBM (Electron Beam Melting) technology, presented in 1993 by Ralf Larson.
- US5506607: IJP (Ink Jet Printing) technology, presented in 1991 by Royden Sanders Jr.
- US6259962: Polyjet technology presented, in 1999 by Hanan Gothait (*Figure 4*)

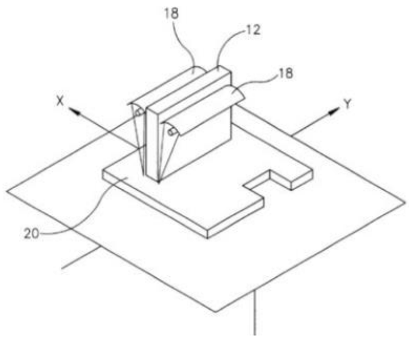

Figure 4- US6259962: Polyjet technology

In the first half of the 2000s, discussions took place about the correct terminology to be used for these technologies: the previous terms (Rapid Prototyping, RP, Rapid Manufacturing, RM and Rapid Tooling, RT) all identify the additive characteristic of the process, consisting in the creation of a component layer by layer, in contrast to the subtractive characteristic of traditional processes carried out on CNC machines, through which a component is made through the gradual removal of material. These discussions led to the definition of the term Additive Manufacturing (AM) as defined in ASTM F2792-12a (Standard Terminology for Additive Manufacturing Technologies).

3. 3D PRINTING PROCESS

Although the AM processes have different characteristics, we can identify four main steps to reach the final product (Figure 5): planning, design, manufacturing, measuring (post process).

Figure 5- 3D printing process

- Planning phase: first it’s important to have clear in mind what to produce. To begin the AM process it’s important to have references like pictures, drawings or measurement doing on the object you want to reproduce.
- Design phase: It is the phase in which the idea becomes a digital artifact. During this stage special software called CAD (computer-aided design) are used, these allow to "draw" the model in three dimensions by using simple geometries (cubes, spheres, pyramids) and a series of operations that can be done on them (union, difference, extrusion, etc...) rather than with a modeling by means of lines that are then processed to realize the three-dimensional object. Common factor of these applications is the possibility to save or export the model made in STL format, the format used as a standard by the software that we will see in the next steps of the workflow.
- Manufacturing phase: the part of the process in which we pass from the digital object to the real physical object. First the STL file is transferred to a slicer software where it is manipulated with respect to the AM technology restrictions and a machine code sequence is generated. These software manipulate the surface that is subject to the “Slicing” process that consists into fractioning it into cross-sectional layers to better improve the accuracy of the geometry represented. At this point it is important to choose the suitable materials for mechanical or aesthetic properties. So, the machine parameters and tools are set up to build both the support structures in case of overhanging components and then the part. After these operations the real manufacturing process and the part is built up layer by layer according to the type of AM technology.
- Measuring phase (post process): the part is removed from the machine platform and the support structures. In this evaluation step, for example, we check whether the object produced corresponds in the measurements to what is expected, rather than having the necessary resistance to stress, or even that the appearance is as expected. In positive case it is continued with the successive actions of post-production, while if there is something to regulate it starts again with the cycle beginning a new planning, design, realization in an iterative process that goes gradually refining the final object to obtain the desired quality Additional operations such as heat treatment, cleaning, finishing could be necessary.

4. ADDITIVE MANUFACTURING TECHNOLOGIES

Additive manufacturing technologies (Figure 6) can be subdivided into three macro-categories: liquid-based technologies, solid-based technologies, powder-based technologies.

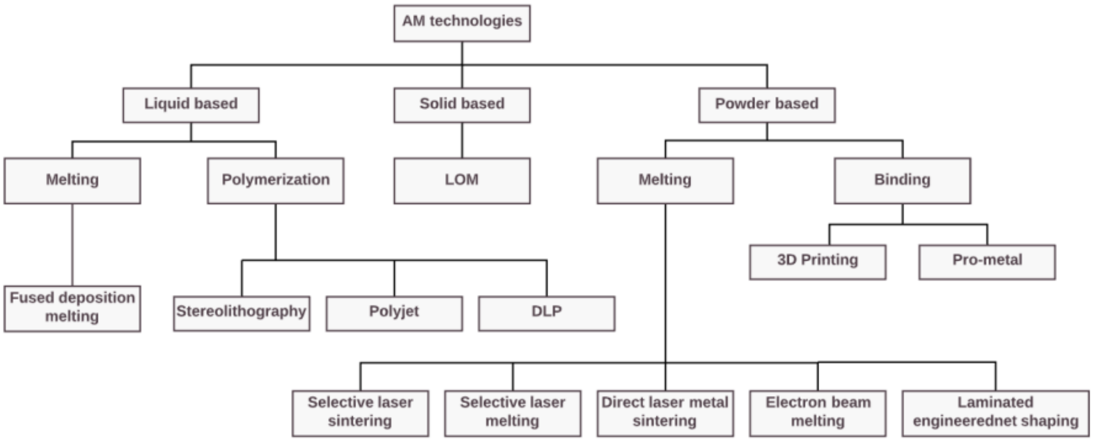

Figure 6 Summary table of macro technologies

Among these three categories there are substantial differences in how the material is laid and solidified. In short: in 3D printing technologies powder polymerization occurs using particular thickeners or a laser beam; in solid 3D printing technologies occurs the deposition of a thermopolymer layer by layer by means of an extruded; Finally, liquid 3D printing technologies solidify photosensitive liquid polymers with a UV or laser beam. Below, among the technologies based on the use of powder or liquid or solid are described some of the most common techniques.

- LIQUID BASED TECHNOLOGIES

Stereolithography – SLA

Stereolithography is considered the technology behind 3D printing, with the first equipment patented in 1984 by Charles Hull and the first commercial machine developed by *3D Systems* in 1988. Stereolithography, also known as SLA (Stereolithography Apparatus), uses the principle of photopolymerization to produce 3D models using UV-sensitive resin. The solidification is caused by the passage of a laser layer after layer. It allows you to get one of the best printed surfaces when compared to existing 3D printing technologies.SLA is the most widespread process of the Vat Photopolymerization family. Stereolithography machines contain a resin holder plate, a movable platform (Z axis), a scraper system (X axis), a UV laser, focusing optics and a mirror galvanometer (X and Y axes). The laser beam treats the liquid resin according to the digital 3D model provided to the printer. After a layer has been solidified, the platform drops one level. The next section is then solidified. There are as many printing cycles as there are layers needed to obtain the full volume of the piece. On some SLA 3D printer models part production is done upside down. The platform is immersed in the resin tray, while the laser acts from the bottom up. Differently from other technologies an additional UV treatment is usually required to finalize the photopolymerization and optimize the strength of the material.

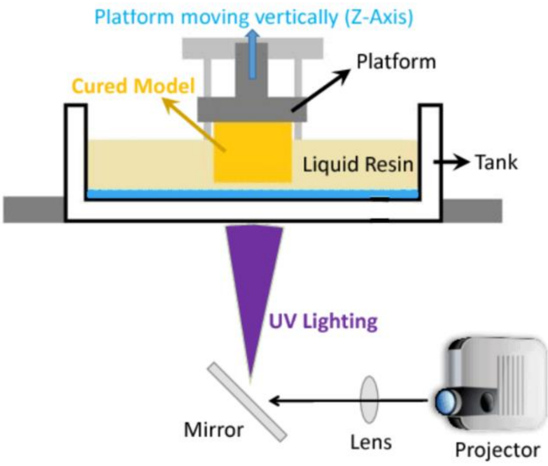

Figure 7- Stereolithography – SLA process

Fused Deposition Molding – FDM

Fused deposition modeling (FDM) is an extrusion-based 3D printing technology. The printing materials used in FDM are thermoplastic polymers and come in the form of filaments. In the FDM, a part is produced by selectively depositing molten material layer upon layer in a path defined by a CAD model. Thanks to its high precision, low cost and wide choice of materials, FDM is one of the most widely used 3D printing technologies in the world. An FDM printer consists of two reels: one for the printing material and the other for the supporting material. The 3D printing process for molten deposition modeling follows these main steps:

Step 1 - After entering the CAD data, the filament of the already loaded solid print material is dissolved with the help of heat in the extruder terminal.

Step 2 - This molten liquid plastic is deposited on the printing bed as a layer through the extrusion nozzle that moves in all directions as defined by the CAD model. This process of adding liquid/semi-solid layers on top of each other is repeated. If the design consists of projections or structures that could potentially deform or bend, supporting elements are used. The support material can be the same as the printing material or any other material.

Step 3 - If support structures are used, they are then removed after printing is complete.

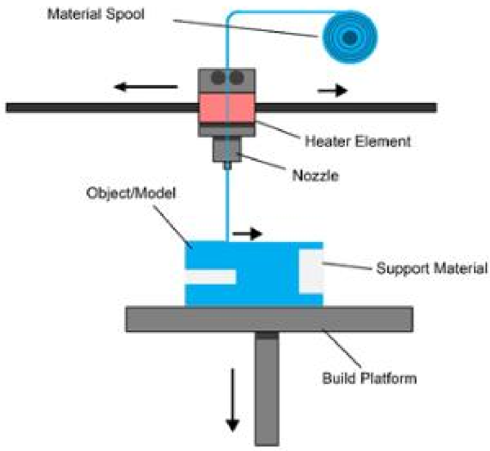

Figure 8 - Fused Deposition Molding – FDM

Polyjet – PJ

PolyJet technology is renowned for its outstanding realism and breathtaking aesthetics. The technology works similarly to traditional inkjet printing, but instead of jetting ink onto paper, a print head jets liquid photopolymers onto a build tray where each droplet cures in a flash of UV light. Polyjet printers instantly cure the droplets of liquid photopolymer using UV. Thin layers accrue onto the build tray to create the 3D part(s). Where support is needed, the printer will jet removable support material. Material is easily removable by hand, with water or in a solution bath. No post-curing is required as the 3D printed part is ready to handle straight off the build tray.

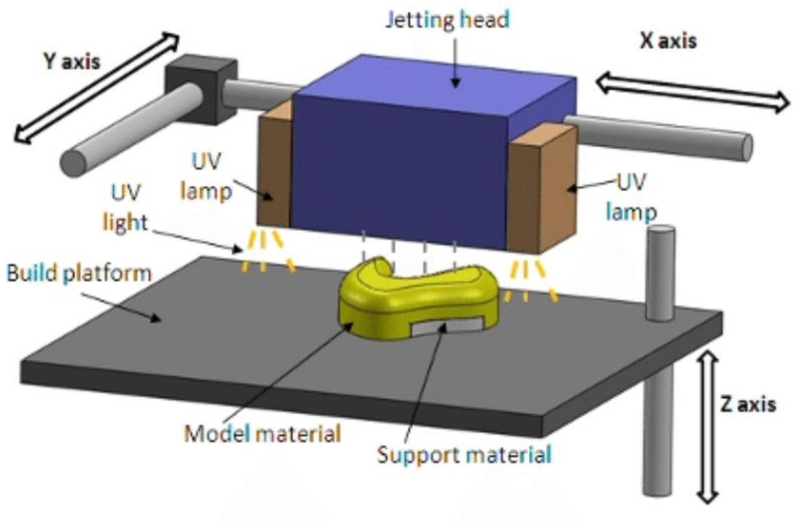

Figure 9 - Polyjet – PJ process

- POWDER BASED TECHNOLOGIES

Selective Laser Sintering – SLS

Selective laser sintering (SLS) 3D printing is trusted by engineers and manufacturers across different industries for its ability to produce strong, functional parts. he powder is dispersed in a thin layer on top of a platform inside of the build chamber. The printer preheats the powder to a temperature somewhat below the melting point of the raw material, which makes it easier for the laser to raise the temperature of specific regions of the powder bed as it traces the model to solidify a part. The laser scans a cross-section of the 3D model, heating the powder to just below or right at the melting point of the material. This fuses the particles together mechanically to create one solid part. The unfused powder supports the part during printing and eliminates the need for dedicated support structures. The platform then lowers by one layer into the build chamber, typically between 50 to 200 microns, and the process repeats for each layer until parts are complete. After printing, the build chamber needs to slightly cool down inside the print enclosure and then outside the printer to ensure optimal mechanical properties and avoid warping in parts. The finished parts need to be removed from the build chamber, separated, and cleaned of excess powder. The powder can be recycled and the printed parts can be further post-processed by media blasting or media tumbling.

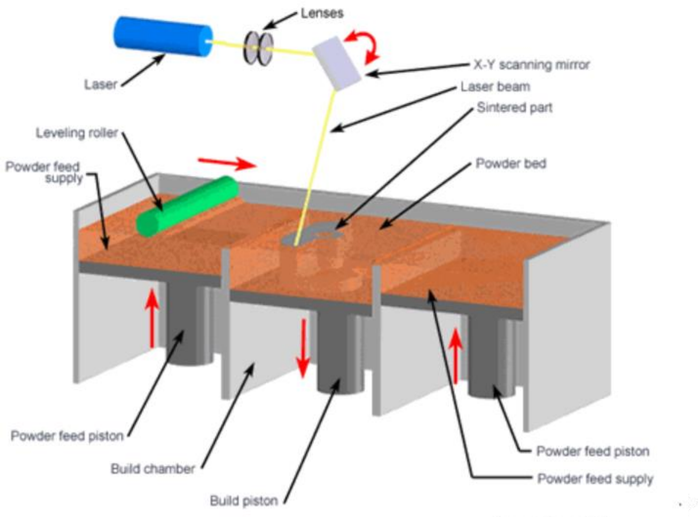

Figure 10 - Selective Laser Sintering – SLS

Electron Beam Melting – EBM

Electron Beam Melting (EBM) is a 3D manufacturing process in which a powdered metal is melted by a high-energy beam of electrons. An electron beam produces a stream of electrons that is guided by a magnetic field, melting layer upon layer of powdered metal to create an object matching the precise specifications defined by a CAD model. Production takes place in a vacuum chamber to guard against oxidation that can compromise highly reactive materials. Electron Beam Melting is similar to Selective Laser Melting (SLM), as they both print from a powder from the 3D printer's powder bed, but EBM uses an electron beam instead of a laser. EBM builds high-strength parts that make the most of the native properties of the metals used in the process, eliminating impurities that may accumulate when using casting metals or using other methods of fabrication. It is used to print components for aerospace, automotive, defense, petrochemical, and medical applications.

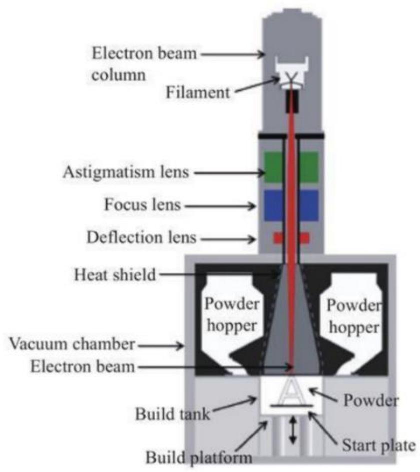

Figure 11 - Electron Beam Melting – EBM

Three-dimensional Printing – 3DP

Three-Dimensional Printing functions by building parts in layers. From a computer (CAD) model of the desired part, a slicing algorithm draws detailed information for every layer. Each layer begins with a thin distribution of powder spread over the surface of a powder bed. Using a technology similar to ink-jet printing, a binder material selectively joins particles where the object is to be formed. A piston that supports the powder bed and the part-in-progress lowers so that the next powder layer can be spread and selectively joined. This layer-by-layer process repeats until the part is completed. Following a heat treatment, unbound powder is removed, leaving the fabricated part. The sequence of operations is depicted below.

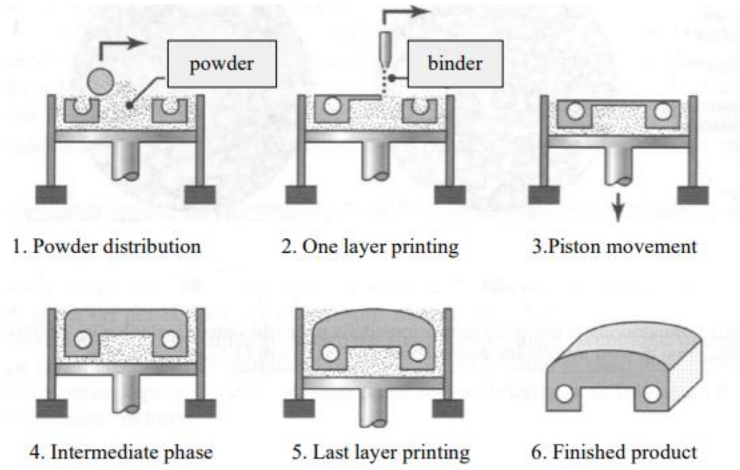

Figure 12 - Three-dimensional Printing – 3DP

Direct Metal Deposition Laser Sintering – DMD/SLM

The DMLS machine begins begins the 3d metal printing process by sintering each layer—first the support structures to the base plate, then the part itself—with a laser aimed onto a bed of metallic powder. After a cross-section layer of powder is micro-welded, the build platform shifts down and a recoater blade moves across the platform to deposit the next layer of powder into an inert build chamber. The process is repeated layer by layer until the build is complete. When the build finishes, an initial brushing is manually administered to parts to remove a majority of loose powder, followed by the appropriate heat-treat cycle while still fixtured in the support systems to relieve any stresses. Parts are removed from the platform and support structures are removed from the parts, then finished with any needed bead blasting and deburring. Final DMLS parts are near 100 percent dense.

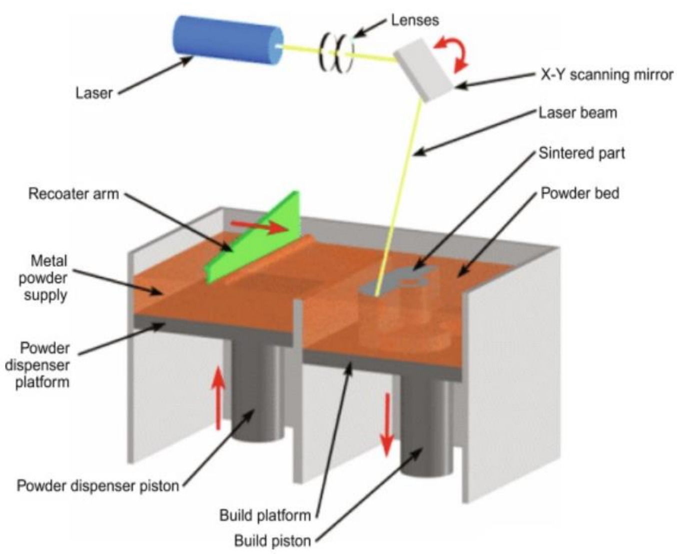

Figure 13 - Direct Metal Deposition Laser Sintering – DMD/SLM

- SOLID BASED TECHNOLOGIES

Laminated Object Manufacturing - LOM

Laminated object manufacturing uses a building platform onto which the sheets of material can be rolled out. The materials are usually coated with an adhesive layer that is heated by a feeding roller to melt the adhesive. In this way, each layer can be glued to the previous one to build up an object. A blade or laser is used to draw out the geometry of the object as well as cross hatching excess material to facilitate the removal of waste. Once a layer has been glued into place and the required dimensions drawn, the build platform moves down so another layer of material can be rolled into position with the heated roller. This process is repeated until the model or prototype is complete. If an object is printed using layers of paper it will take on wood-like properties and so may need sanding to finish. Paper objects are then often sealed with paint or lacquer to prevent moisture getting in.

.

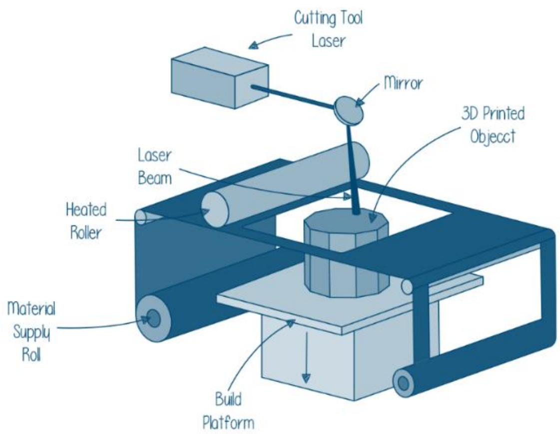

Figure 14 - Laminated Object Manufacturing - LOM

5. MATERIALS

The great adoption in all sectors of 3d printing is not only due to the progress and the introduction of new technologies, but, above all, thanks to the possibility of using materials with very different characteristics. Today it is also possible to print and assemble objects composed of materials with different chemical and physical properties. The cheapest are thermoplastic materials of which the most common are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid). ABS is the cheapest thermoplastic for printing and is used at a temperature ranging from 215 °C to 250 °C. ABS creates fumes that could create problems and is therefore recommended to have good ventilation. PLA is a biodegradable thermoplastic material, easy and safe to use, obtained from corn or potatoes. PLA filaments are used at a temperature of 160 °C - 220 °C. Resins can also be used as materials in 3D printers, but the possibility of using them is limited by the possible need to support objects during the printing process. 3D Printers using this material are more expensive but can provide more sophisticated results. Resin-based printing allows you to print very thin structures. Another type of material widely used are powders. Among powder, there are Nylon and Alumide. Nylon (polyamide) is a durable and flexible material that allows an excellent level of detail. The white and very fine powder is sintered by the laser, then sanded with a mechanical process that makes it shiny and shiny. Nylon is an extremely versatile material, which can be flexible in low thicknesses, but can have a strength such as to make it ideal for 3D printing of structural parts. Alumide is a rigid and resistant material, originating from a mixture of aluminum powder and nylon. The powders are solidified, layer by layer, by a laser (SLS). The appearance is grainy, porous, but the aluminum powder gives brilliance to the surface. It is ideal for printing objects with moving parts such as joints or hinges and for complex objects. The use of ceramic materials, such as aluminosilicate, in 3D printing allows food use and is watertight: objects created with this material can then be used with food and drink. This 3D-printed ceramic is heat resistant up to 500 C. and is recyclable. Because of the process used, the glazing adds a small surface thickness that could change the appearance of some details or distribute them in a not completely uniform way. Different metals are also widely used in industrial 3D printers. For example, titanium powder can be sintered to obtain lightweight products with excellent mechanical properties. The last frontier for 3D printing today is given by molecular engineering and biotechnology with the aim in the future of printing human tissues and organs that can be implanted. Body parts are printed using biological polymers, which can then be inserted into a bioreactor filled with stem cells.

6. SOFTWARE

The large software houses have shown interesting progress both on the modeling side of particular geometries and on the CAM optimization side. The programs you need to control the AM processes are CAD software, CAM software, software to set up the printer, post-process software.

- *CAD software (Computer-Aided Design):* these software have scope to realize the models that, later, will be elaborated by the slicer.
- *CAM software (Computer-Aided Manufacturing):* they are also called slicer software. By "slicing" the software processes the three-dimensional model, cutting it into many layers

and converting it into mechanical controls, which will allow the 3D printer to understand what it must do and how it must move.

- *Software to set up the printer (Figure):* Print management programs are used to communicate directly with the 3D printer. Print management software can send and receive instructions, such as start, shut down, or query commands.
- *Post-process software:* the growing interest in post-processing concerns in the case of SLS or SLM technology in the automatic removal of non-sintered material is well exemplified by an algorithmic powder removal system. The software is therefore able to make the machine perform the best movements to clean the workpiece cavities in the shortest possible time.

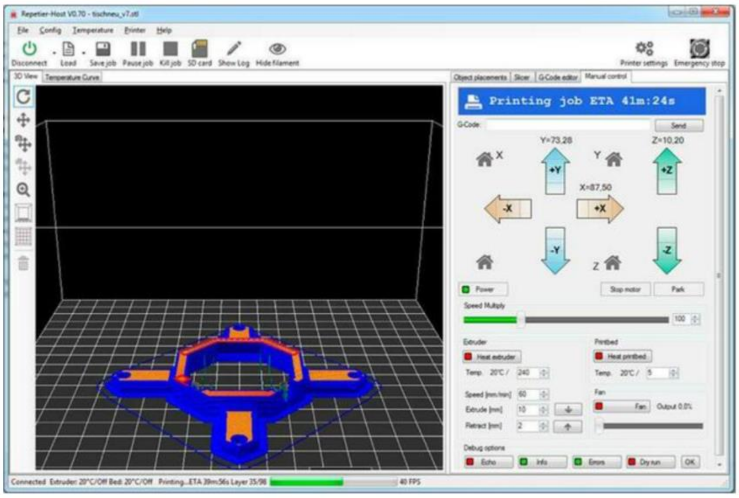

Figure 15 -example of print management program

7. 3D PRINTING INDUSTRY

By the end of 2021, the global AM market was estimated to be worth over $15 billion. Several factors are fuelling the growth of the industry. One is that 3D printing hardware and materials are being developed for industrial applications, as companies across industries continue to find new use cases for the technology. The additive manufacturing market is forecasted to more than double in size over the next five years, reaching a value of $37.2 billion in 2026 as shown in the graph below.

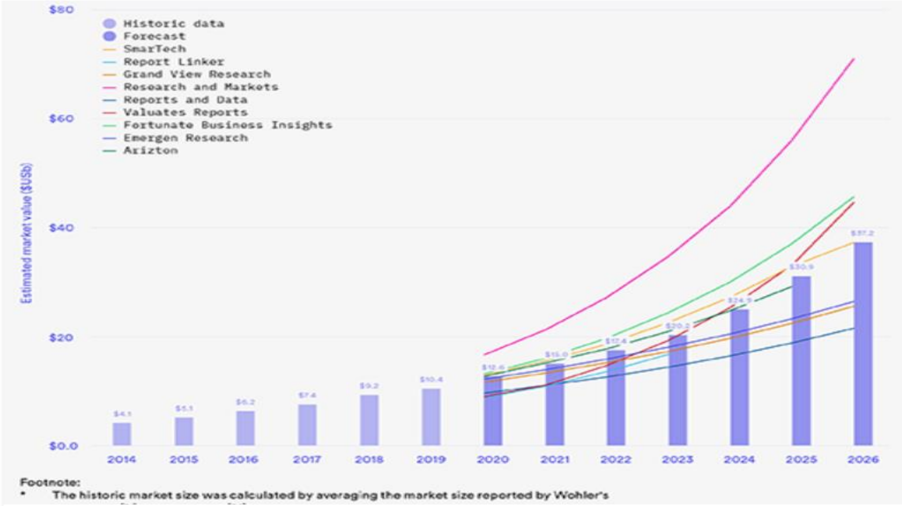

Figure 16 – report of industry growth by "Industry today"

According to the report of AM landscape in 2020 by *AMFG (Autonomous Manufacturing),* the industry can be segmented into 5 categories:

- *Hardware manufacturers* (Polymers, Desktop, Metals, Composites, Ceramics, Electronics)
- *Software vendors* (Design & Simulation, Slicer & Data Preparation,Workflow & MES, Security)
- *Materials suppliers* (Polymers & Composites, Metals)
- *Post-processing system manufacturers*
- *Research institutions*

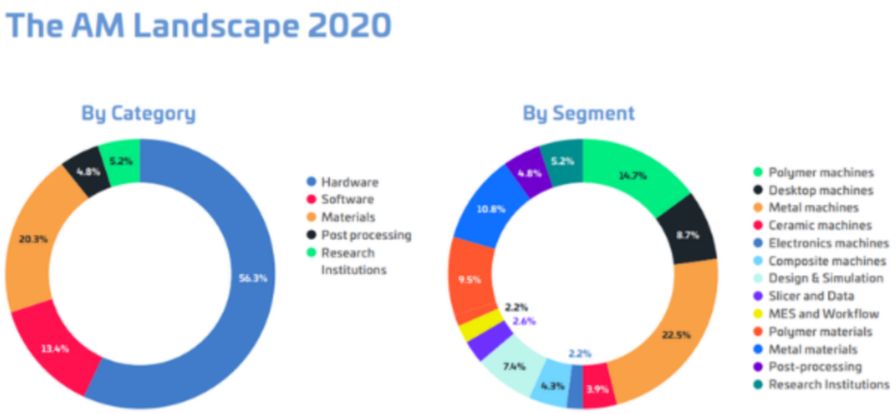

Figure 17 – The AM Landscape 2020 by AMFG (Autonomous Manufacturing)

As showed in *Figure 17* 3D Printers Manufacturing is the dominant sector of the industry. Metal machine manufacturers make up 40% of the hardware category and 22.5% of the overall landscape and they dominate the industrial segment for 3D printing. Desktop 3D printers are another vital part of the AM landscape. Machines in this category are increasingly geared towards industrial applications. At the same time, desktop 3D printers are aimed at democratising 3D printing by lowering the barrier to entry and creating a more user-friendly 3D printing experience. The range of 3D printing materials continues to grow. In 2020, the Senvol Database lists as many as 2245 different AM materials, compared to just over 1700 materials in 2019. The adoption of 3D printing as digital manufacturing technology has created the demand for specialised software that can streamline AM processes, from part design to workflow management. As 3D printing moves to production, there has been a great push to overcome key post-processing challenges like highly manual and time-intensive post-processing steps. Furthermore, the post-processing of 3D-printed parts makes up a considerable part of the overall cost-per-part.

A large proportion of our landscape features start-ups that have emerged in the last five years. They are also receiving a lot of attention from investors. It is estimated that $1.1 billion of investment was made in 77 early-stage AM companies in 2019, with the largest amount of funding going to hardware manufacturers.

8. APPLICATIONS

3D printing is driving a revolution across many industries and a wide range of applications, including markets that until a few years ago would not even have been considered appropriate for this technology. Its first employment was to build prototypes and functional parts for the industrial/business machines sector and the ResearchGate Report (2021) shows that it is still the leader with 20% of share.

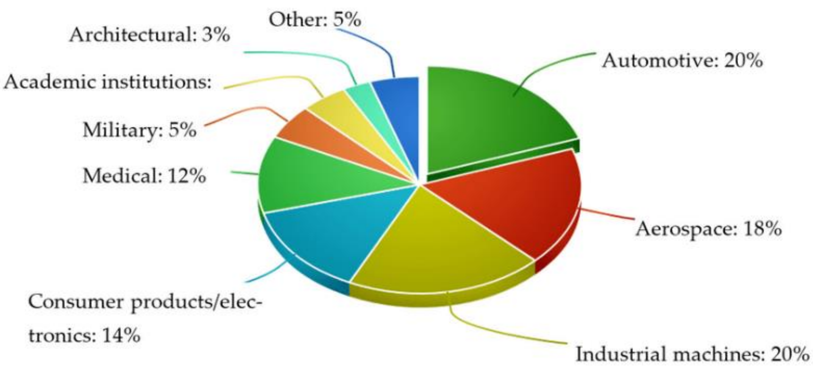

Figure 18 – final customers AM industry by ResearchGate Report (2021)

The other dominant sectors are aerospace, automotive and consumer products/electronics. Aerospace and automotive engineers use 3D printers for fast production of ready-to-use parts significantly reducing uptime and costs, using 3D printing as casting models. The use of AM processes in medical sector is growing significantly during last years. Researchers use 3D solutions for medical and surgical innovation to achieve less invasive procedures and shorter recovery times for patients. Another area in which 3D printing is becoming increasingly popular is that of goldsmith, this will be deepened in the following chapters.

CHAPTER 2: ANALYSIS OF ITALIAN GOLDSMITH INDUSTRY

1. INTRODUCTION

This chapter presents an overview of the Italian goldsmith sector with a focus on the three main districts of the peninsula (Valenza, Arezzo, Alessandria). The analysis is supported by reports on the goldsmith sector of Intesa San Paolo and an extraction on AIDA on the first thousand companies per turnover with ATECO *code: 321210 - Manufacture of jewellery and precious metal goldsmithery or coated with precious metals.*

2. ITALY IN THE GLOBAL LANDSCAPE OF GOLDSMITH

The goldsmith sector is one of the “Made in Italy” sectors with the greatest vocation for export, thanks to the quality of jewelry recognized all over the world. After the 2020 crisis, due to the pandemic of covid 19 and the lockdown period, which has impacted many sectors including the goldsmith, in 2021 the goldsmith industry had a sharp recovery. Italy is an European leader in the jewellery sector. The examination of the latest data made available by Eurostat shows that in Italy the number of employees in the jewellery sector is over 31 thousand, representing over a quarter (27.7%) of employment in the sector throughout the European Union. In the last nine months of 2021, according to the survey by *Federorafi* on *Istat* data, the foreign trade of the goldsmith-silversmith-jeweler sector had an export increase of 70.6% for a total of 5.574 billion euros. The “Made in Italy” of Italian jewellery is mainly sold in non-European markets, accounting for 74.8% of exports in the sector, while the EU markets account for 25.2% of exports. Almost two thirds of gold exports (64.8%) are destined for five markets: the United States with 15.6% is the main Italian jewelry market, followed by the Switzerland with 14.8%, United Arab Emirates with 11.5%, France with 11.1% thanks to a 44.1% increase in exports in 2021 and Hong Kong with 11.0% where there is an increase of 40.9% compared to 2020. Among the Italian districts, the most dynamic is the goldsmith district of Vicenza: its exports amounted to 1.2 billion euros with an increase of over 480 million compared to the corresponding period of 2020. The most important district for the Italian economy however is that of Arezzo, with an export quota that reaches +31% and that grows of 92% for 1,8 billion euros.

3. ITALIAN GEOGRAPHY OF GOLDSMITH PRODUCTION

As mentioned in the previous paragraph, the goldsmith sector is one of the most developed in Italy, so the production and distribution centres are placed along the whole territory so that almost all regions caught up on the goldsmith production processes through time. Analyzing the first 1000 companies in Italy by turnover from AIDA database, the distribution of goldsmith's firms on the territory is not very homogeneous. As shown in *Figure 19*, the province of Arezzo is the most populous from the point of view of companies followed by the districts of Alessandria and Vicenza which are the 3 main poles of the peninsula and which we will cover in more detail in the following paragraphs. Milan, despite being a minor pole in terms of production, boasts ancient origins, dating back to the Middle Ages. However, it remains an excellent international showcase thanks to the international fashion events it hosts every year and the large national and foreign companies present in the territory. Also worth mentioning is the district of Naples where the business is above all the realization of high quality products with precious stones and natural gems, the result in many cases of a processing still strongly artisanal. Each province mainly includes an agglomeration of small-medium firms and few big companies which contribute to different stages of the same supply chain. In fact, the job specialization is their principal strength for manufacturing high-quality pieces of jewellery while achieving globally a good level of competitiveness.

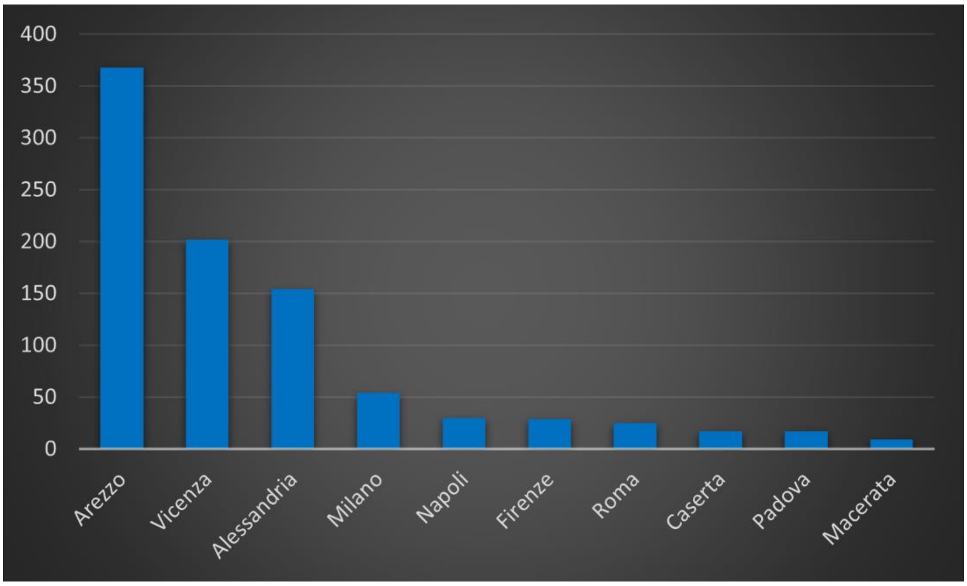

Figure 19 - Top 10 provinces for goldsmiths in Italy among the top 1000 per turnover. AIDA 2020

4. MARKET DEMAND

From the beginning of 21st century the demand for top-quality pieces of jewellery made by hand by Italian artisans has been changed. In the ‘80s the industrial production of jewels in big volumes challenged the perception of goldsmith jewellery as a symbol of uniqueness and luxury. Today, due to the changes in customer’s needs, the perception of jewels has changed. The decline in the consumption of gold goods is determined by many factors. First, it is changed the scale of priority in purchases. Consumers have changed their tastes, if once the jewel represented the achievement of a goal or otherwise the symbol of a certain status, now it is the technological products and travel to convey these messages. This change of vision has led to the birth of a new segment in the jewelry industry called “fashion jewellery” as the expression of the need of making jewels accessible to any customer while the segment of the traditionally handcrafted jewellery continued to live despite its smaller size. Other factors that affect the demand in goldsmith sector are seasonality since jewels sales boost in some periods of the year (Christmas, anniversary) and the fluctuations of gold quotations. The demand for luxury goods is by definition rigid since large price variations induce only slight variations into the quantity demanded although the new segment of fashion jewellery has made the demand more elastic, in particular, growth of 54% was recorded in the first quarter and 60% in the second quarter (*Figure 20*). China, after the strong rebound of the first three months (+216%), tied also to a 1-year-old quarter 2020 already heavily affected by the pandemic and the implementation of drastic containment measures, shows growth in line with the global figure (+62%) and exceeds the values of 1 semester 2019. In the 2nd quarter the rebound is spread to all major markets and stand out in particular the countries of the Middle East (+190%), Russia (+158%) and the United States (+103%) (Fig. 2).

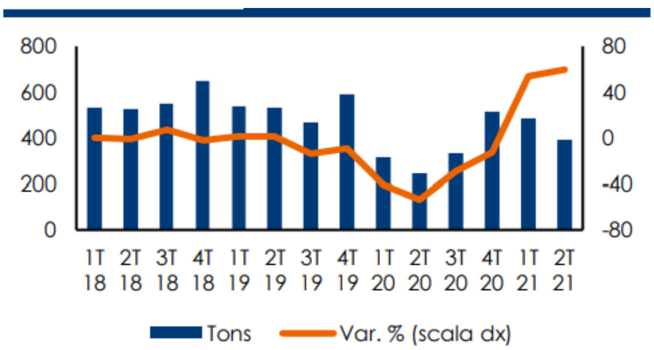

Figure 20 - World Gold Council - Gold Demand Trend

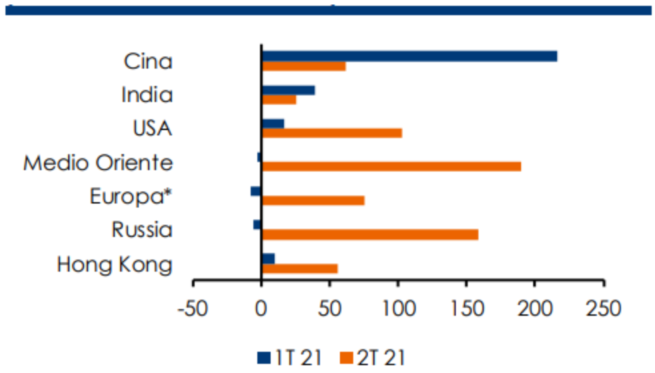

Figure 21 - Figure 22 - World Gold Council - Gold Demand Trend per state

5. SUPPLY CHAIN

The supply chain is the system of activities that companies carry out to transform raw materials into final products. Below are shown the main steps of the supply chain regarding the goldsmith industry. Except for the large enterprises that may have a higher degree of vertical integration, the Italian SMEs are usually specialized just on few steps of the value chain such as design and manufacturing or retailing only.

Figure 23 – Goldsmith supply chain

- *Country regulation*

The first process in the goldsmith supply chain is the government of the country where the gold is located. Each country regulates the ability to mine and mine ownership, as well as the human, environmental, safety and political conditions under which mining can occur. Countries may cooperate in international regulation and guidance or may govern independently. Countries, just like individuals, can be responsible or corrupt, laissez-faire or interventionist, nationalistic or global in their behaviours, and this variability means that some countries are much less effective than others in assuring responsible activities in the gold supply chain. Countries also vary in their permission or prohibition of artisanal mining, individual land ownership, and mining rights.

- *Mining*

Gold in the ground is found in hard rock deposits as a mineral, where the financially minable gold content may be between 1 and 20 grams of gold per tons of ore. Gold is also found in alluvial deposits where gold panning and sluicing can retrieve flakes and small nuggets of gold. To get the gold ore out of the ground requires miners. Estimates say 100 million people depend on artisanal mining. About 7 million people are employed in industrial mining worldwide. Artisanal and Small-Scale Mining (ASM) occurs in approximately 80 countries worldwide. ASM production supply accounts for 20% of mined gold. In some countries, LSM and ASM co-exist, while in others, artisanal miners and large corporations are in competition for the same resource. Though the informal and poorly mechanized nature of ASM may result in low productivity, ASM represents an absolutely vital subsistence activity for local populations. A typical ASM mining process includes digging the gold ore, transporting the ore (carried in bags or by wheelbarrow) to where it is manually crushed, washed, and filtered. The filtered sediment is processed chemically, often with mercury, to yield a gold-mercury amalgam that is then sold to local traders. LSM extraction of gold typically involves machine crushing and milling the rock to a powder or slurry, then vat or heap leaching using sodium cyanide to yield impure gold.

- *Traders/Exporters*

To get the roughly separated gold from the ASM site to a smelter involves traders and exporters. At this step in the supply chain, gold can easily be redirected to illegal hands. Local traders may purchase small quantities of gold amalgam from miners and sell it in turn to large traders. Or miners may act as a cooperative and sell to large traders directly. Large traders may then smelt the gold themselves or may ship the amalgam to a smelter. Local traders may be the first to price the gold coming from individual miners, or pricing may be set by local politicians or chiefs, or in some countries, set by regulation. Each of the participants in the process between the miner and the smelter (mine supervisors, local tribal authority, traders, government officials, police, and others) can perform their work legally or illegally. Assuring fair and responsible sourcing is fraught with challenge when so many hands can be involved in the process.

- *Transporters*

There are a variety of forms of transportation involved in moving gold ore from the mine site to the smelter. Following the manual labour required to transport gold ore to the crusher and flotation equipment, gold amalgam needs to be assembled in sufficient quantity to be exported to smelters. In the case of ASM gold this involves land transport by a variety of means including bicycle, motor scooter, truck and trailer. Road transport may be subject to arbitrary taxation by local government officials or extortion by illegal groups.

- *Smelters and Refiners*

The smelter is considered the midpoint in the mineral supply chain, with processes before mineral arrival at the smelter being ‘upstream’, and distribution and manufacturing processes after metal production being ‘downstream’. Smelters process not only mineral ore from LSM and ASM but also recycled material coming from a variety of sources. In a smelter, gold is released from its natural mineral state by melting and then reacting with chemicals. The resulting doré gold is a semi-pure alloy of gold and silver that can vary in purity, so frequently it is then sent to refineries, where further treatment can bring the purity of the gold to nearly 100%.

- *Metal trader*

The next process in the gold supply chain is the purchase, marketing, and distribution of purified gold. This is done by global traders, many of whom provide logistic services in addition to the raw material in order to assure delivery to the customer. In our case, this customer would be the manufacturer of jewels.

- *Jewels manufacturer*

The metals supplied by global traders are, then, employed by manufacturers to realize jewellery artworks. The manufacturing phase includes, first, the design of the final product by hand or by using a CAD software; after the model building, the effective production of the piece through the assembling and galvanic plating of metals and/or punching and mounting stones; post-processing operations to improve the quality of the part and correct eventually any defects. Finally, the products which have gone successfully through the quality control are ready for being delivered to the distribution centers and then, to the final customer.

6. EMPLOYMENT AND LABOUR COST

The analysis of the data made available by Eurostat in 2020 (*Figure 24*) shows that in Italy there are over 31 thousand employees in the jewellery and jewellery sector, representing over a quarter (27.7%) of employment in the sector throughout the European Union in front of the

18,000 employed in France and the 16,000 in Germany. They follow, at a distance, Poland with 7,300 employees and the Czech Republic with 4,600 employees. Over three-quarters (77.1%) of jewelry employment is concentrated in micro and small businesses. The sector has a high artisan vocation: 6,106 craft enterprises employ 16,633 workers, more than half (53.5%) of the sector, and exceed the number of employees of the entire German jewelry industry. The three provinces of Arezzo, Alessandria - with the district of Valenza Po - and Vicenza alone count 8,488 employees in the goldsmith craft, over half (51%) of the occupation of all the Italian goldsmith crafts.

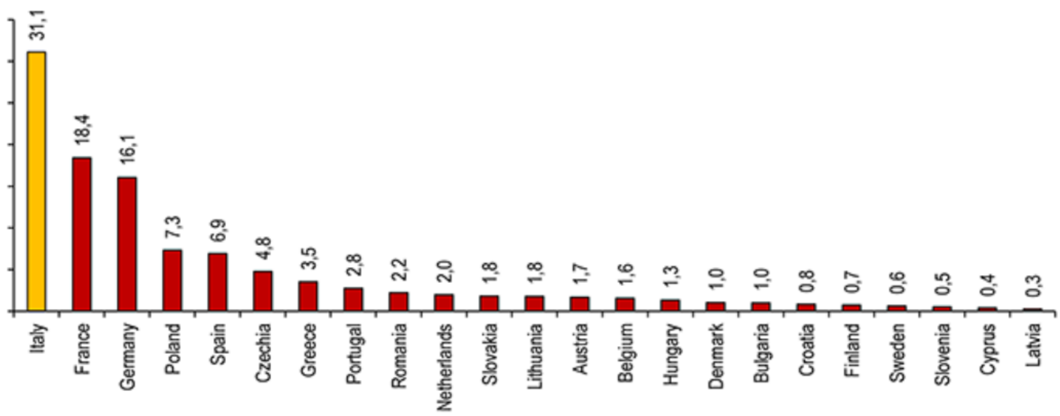

Figure 24 – Employment in Europe; analysis by EUROSTAT 2020

Analyzing the first 200 companies in Italy by turnover from AIDA database we can see that the average annual staff cost per employee is 29.825,22 € with the company *Pomellato S.P.A.* based in Milan with the largest staff cost per employee of 75.350 €. These data are in line with the average salary for goldsmith in Italy that is € 28,000 per year or € 14.36 per hour. The "entry level" positions receive a salary of € 25,000 per year, while the most experienced workers earn up to € 32,000 per year. According to the AIDA database among the top 200 industries in Italy the average *Turnover/Staff Cost ratio* is 14,57 and the highest is the one of *BLS S.P.A. (BERICA LAVORAZIONI SPECIALI)* with a ratio of 58,12.

7. MARKET OF MATERIAL

Goldsmith companies and artisans use mainly precious metals and stones as raw materials. Their procurement cost is affected by the fluctuations of precious metals quotations that cannot be controlled. In fact, the prices of these materials depend on the extraction activities in mines so that companies are price-takers. Considering gold, for example, jewellery was the leading demand sector worldwide. However, in 2020 the jewellery share dropped to 37% equal to 1,400 metric tons while 2,119 metric tons more had been demanded in the previous year. Because of the pandemic and the rising price of gold, Investment with 47% share and 1,774 metric tons became the leading sector asking for gold thanks to an increase in the demand for ingots. Central banks accounted for 8.6% share while Technology sector 8% because the conductive properties of gold are good for electronical devices. According to a study by *Intesa Sanpaolo*, in 2021 the prices of precious metals recorded a decrease (*Figure 25*) explained by the strengthening of the US dollar and expectations of an upcoming tapering by the Federal Reserve.

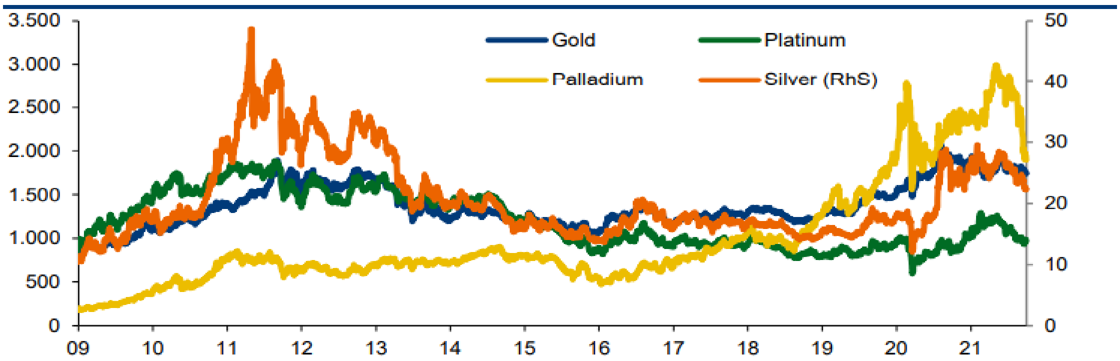

Figure 25 - Intesa Sanpaolo elaborations on Bloomberg data

Focusing on the gold, according to data published in 2021 by the World Gold Council (WGC) in the last year the contribution of ETFs to the demand for gold has collapsed: in the 2nd quarter 2020 accounted for 40% of global demand, while in the 2nd quarter of 2021 it covered just 4% of world consumption, thus absorbing a volume of metal even lower than that of industry, which is usually the least important component. By contrast, all other components of gold demand have increased. in jewelry and technology, the risks of inflation and uncertainty about the trend of the epidemic of coronavirus have fuelled demand for bullion and coins; the renewed push towards the diversification of foreign exchange reserves has supported demand for gold in the official sector. In fact, in the 2nd quarter 2021 purchases of gold by central banks grew by more than 200% and accounted for about 20% of total demand.

	2nd quarter 2020	% of the total	2nd quarter 2021	% of the total	growth % y/y
Total demand for gold(tons.)	961		955		-1
Goldsmith	245	23	391	36	60
Bars and coins	157	15	244	22	56
ETFs	428	40	41	4	-90
Central Banks	64	6	200	18	214
Technology	68	6	80	7	17
Total supply for gold(tons.)	1039		1172		13
Mining production	794	72	924	87	16
Hedging of producers	-37	-3	-29	-3	-22
Recycled gold	282	25	277	26	-2

Figure 26 - Intesa Sanpaolo elaborations on World Gold Council data

According to the data by AIDA among the first 200 firms in goldsmith industry the costs for raw materials impact on total cost for 66,46%, on average, with peaks of 97 %.

8. GOLDSMITH DISTRICTS IN ITALY

In Italy there are three focal points for the goldsmith industry, headquarters of as many important districts: Valenza, Arezzo and Vicenza. In these three provinces 31.5% of local units and 55% of Italian employees are concentrated in manufacture of jewellery and the processing of precious stones. The Goldsmith district of Valenza shows a clear predominance of small local units: 83% employ fewer than ten people and 15% employ 10 to 49 people. In these companies they find work 76% of the goldsmiths in the province of Alessandria. There are also 10 units medium sized premises, employing about 750 people and a large factory that employs about 580 people (11% of the total). Arezzo is highlighted for a more of small local units (19% versus 15% of Valenza), in which 47% find a job employees (versus 42% of Valenza). A large factory is also present in Arezzo but has smaller size (employs just under 300 employees). Vicenza, however, despite not having units large premises has a greater presence of medium local units (2.3% of the total vs about 1% to Valenza and Arezzo), which employ over 1,000 people, about a quarter of the total.

	Goldsmith in Valenza	Goldsmith in Arezzo	Goldsmith in Vicenza
Local units of active enterprises	100	100	100
micro(0-9 employees)	83	80	81
small(10-49 employees)	15	19	17
medium(50-249 employee)	1,2	1	2,3
large(>250 employees)	0,1	0,1	-
Employees of local units of active enterprises	100	100	100
micro(0-9 employees)	34	36	31
small(10-49 employees)	42	47	45
medium(50-249 employee)	14	12	24
large(>250 employees)	11	2	-

Figure 27- Intesa Sanpaolo elaborations on ISTAT data

In the following paragraph this three main district of Italian Goldsmith industry will be deepened to the historical level with a focus on the main company in Italy (*Bulgari Gioielli S.P.A.)* according to the Aida data for turnover. At the end a comparison between the three districts will be presented

9. VALENZA

- *History*

The processing of gold in Valenza is traced back to the initiative of *Vincenzo Morosetti*, who in 1845 opened a laboratory calling to help him two experienced Alexandrian workers: Francesco Zacchetti and Carlo Bigatti. In reality, a statistic from a few years ago already records in Valenza the presence of two goldsmiths, two watchmakers and two sellers of gold objects. Presumably it was of modest activities, both in terms of size and quality, the product, often costume jewelry, was intended for local customers. Morosetti strong experience, it seems acquired through emigration, began a production of a certain value using techniques more refined production. Then Bigatti and Zacchetti left the laboratory and started their own activities. The company of Carlo Bigatti set production on criteria no longer craft, but with a first form of division of labour. The qualifications of its workers, noted by a census, were engravers, goldsmiths, enamellers and cleaners. In 1850 there were three goldsmiths' workshops in Valenza, in 1872 there were added two others and, altogether, gave work to 110 workers. The following year, *Vincenzo Melchiorre*, native of Valenza who had travelled a lot, returned to his native city and opened a goldsmith's workshop bringing you the fruits of the technical experience and taste he had acquired first in Turin in the atelier *Twerembold*, then in the Paris of the Second Empire, then European temple fashion and luxury, at *Vaubourzeix Boucheron*, and then again in the new Italian capitals, in Florence by Marchesini and in Rome. The production of Melchiorre was of higher quality compared to the Valenza average, employed precious stones embedding them in an artistic jewel. In 1911 *Melchiorre & C.* gave work to 86 workers. His example was followed by other firms: Raselli Nicola (1875), Cunioli and Repossi (1880), Marchese and Gaudino (1882). The birth and the process of growth of what will become the gold district was then realized thanks to knowledge employed abroad and for imitation by skilled workers, through a path of qualitative improvement. At the beginning of the new century, in 1902, a *Cooperative of Producers of Goldsmith*, a limited company with unlimited capital, whose members were mainly skilled workers and whose production, on the eve of the First World War, stood at a value of 220,000 lire. At that time there were at least 44 goldsmiths from Valenza, 8 of whom employed more than 25 workers. The raw material, gold, was purchased mainly on the Milanese market, precious stones from Milan, Paris, Amsterdam, Antwerp. As for the machinery, since 1840 was present in Alessandria the company Mino G. B., appreciated factory of machines for goldsmiths. Around 1910, in Valenza began the production of the chains that allowed a greater mechanization, even if the goldsmith work remained to a very large extent manual labor. Male labor was preponderant on women. Women were engaged in non-specialized work, such as cleaning objects gold that required patience, but not particular skill and preparation. Sales were initially directed to the local market, then gradually spread national after the Unity, while the first exports date back to the late nineteenth century and were directed to South America. Sales were made thanks to a traveller, often the owner himself of the laboratory, which visited customers at home. A real boom in production occurred in the years following the end of the Second War worldwide. Subsequently, the sector was strongly affected by the general economic trend. This tendency, moreover, was present from the beginning: since they are voluptuous and luxury goods, the Sales contractions are very evident in periods of economic downturn. The district, as recognized by the Piedmont Region, includes eight municipalities of which three born in Lombardy for "budding". Small and medium-sized companies that often work for subcommissioning, the supply chain is complete and includes jewelry, precious stone processing, trinkets. Today Valenza is a world-renowned goldsmith's center that holds the record of the medium-high and high jewelry packaging, characterized by a combined use of craftsmanship, technological innovation and aesthetic research.

- BULGARI GIOIELLI S.P.A.

According to the database of AIDA Bulgari Gioielli S.P.A. is the company with the highest turnover in Italy in 2020 (412.256.539 €) among those with the ATECO *code: 321210 - Manufacture of jewellery and precious metal goldsmithery or coated with precious metals.* The Bulgarians are descended from an ancient family of Greek silversmiths of Epirus whose founder, Sotirio, performed precious works in silver. In the mid-nineteenth century Sotirio was moved to Italy and in 1884 opened the first store in Rome in Via Sistina, then replaced in 1905 by the store in *Via Condotti* which is still the center of gravity of all Bulgari stores. The brand acquires an international reputation in the 70s encourages the Group to start the first phase of expansion abroad with the opening of stores in New York, Ginevra, Montecarlo and Paris. In 1993 Bulgari chooses to diversify the own product portfolio entering the perfume market with the *Eau Parfumèe au Thè Vert*, followed by other successful fragrances. 1995 marks another milestone fundamental for the Group, which is listed on the Milan Stock Exchange. In 1996 continues the diversification with the first collection in silk, side by side the year next from a wide range of accessories ranging from leather goods to ties, to headscarf, to glasses. The process continues in 2002 with the acquisition of Crova, historical jewelry manufacturer. In 2011, in order to guarantee a bright future to the Company Paolo e Nicola Bulgari, BVLGARI's Chairman and Vice-Chairman respectively, decided to sell their shares to the group LVMH, big French luxury, which has kept the philosophy and strength of the brand, but allowed to increase the investment, and to acquire a well-rounded business vision. In the following years the growth of Bulgari in all sectors continued in which the company has decided to diversify, closing 2014 in strong growth. These positive trends, led to early 2016, Bulgari's CEO, Jean-Christophe Babin, to announce the opening of a new jewelry factory in Valenza, with inauguration on 8 January 2017, the largest in Europe that has allowed to triple production. Today, according to AIDA, Bulgari has 810 employees and the average of wage and salaries is 28.792,59 € per employee with a turnover/employee of 509.090 €. In 2020 Total production costs for Bulgari were 363.989.442 € among which, due to the high quality of its final product, 230.767.077 € in raw materials. EBITDA in 2020 was 30.359.820 € (higher than € 12,567,47 on the second for EBITDA according to AIDA) with a ROA of 5,08 % and a ROI of 20,37 %. One of the most important investments of Bulgari is in the AM in goldsmith sector, in fact, Bulgari was among the first to invest in 3D printing technologies for prototyping and for the final production of their high-end jewelry collections. From the sales chart per year from 2011 to 2020(*Figure 28*) we can see two aspects. The first is the gradual growth from incorporation by LVMH, with an exploit that begins in 2017 (Opening year of the new center in Valenza) and culminates in 2019 with a turnover of almost 620 billion. The second is how the crisis due to the pandemic of covid 19 has impacted even large companies like Bulgari with a sharp stop to the positive trend of previous years with a decrease of 35.5% on turnover between 2019 and 2020.

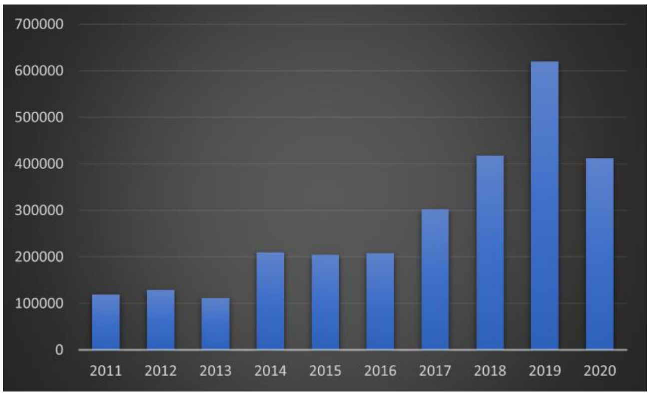

Figure 28 - Turnover per year Bulgari Gioielli S.P.A.- AIDA

10. AREZZO

The history of the processing of precious metal is intertwined with the history of Arezzo itself. It all started with the Etruscans, the mysterious people of the most excellent master goldsmiths of antiquity. Thanks to them, between the ninth and the first century BC, in Etruria goldsmiths were born. The Etruscans had a very refined technique of working gold, granulation, which reduced the metal into tiny grains, then welded on a thin sheet to shape the jewels in every shape. In Arezzo you can admire the Etruscan creations in the National Archaeological Museum Gaio Cilnio Mecenate and in the National Museum of Medieval and Modern Art. Do not miss the MAEC, the Museum of the Etruscan Academy of Cortona, a timeless wonder From the Etruscans onwards, in Arezzo it has always continued to work gold, until the birth of the flourishing goldsmith workshops of the sixteenth century. The jewels that were born here arrived in the Renaissance courts of Florence and Rome. Then, on commission of the papacy, a production of religious jewels also started. In the twentieth century Arezzo was transformed from an agricultural and artisan city into an industrial city and the goldsmith industrial district was born, which now counts more than a thousand companies. The turning point came in 1926 when Carlo Zucchi and Leopoldo Gori created the airport, which will leave a permanent mark on the industrial reality of the territory of Arezzo.

11. VICENZA

The Vicentine goldsmithing, which in Roman times left little appreciable traces, flourished during the Lombard period. The Berian city, which became the seat of a duke, was equipped with a mint which was granted the right to mint gold coins. The processing of gold, however, also declined in the manufacture of a remarkable range of products. Among them, to stand out are certainly the precious, characterized by a refined aesthetic research, and the characteristic golden crosses. In the municipal statutes adopted by the city of Vicenza in 1339 the goldsmiths corporation appears for the first time in the city documentation. Indicated by the specific term of "fraglia", at the time it could already count, as suggested to us also by the matricula (the collection of provisions that goldsmiths provided along the fourteenth century), 150 masters of workshop on an urban population of about 20,000 inhabitants, tangible sign of the diffusion of Vicenza's goldsmith's art during the late medieval climate. The document also demonstrates the social importance of the professional order. The master goldsmiths were granted the opportunity to elect a representative to the "council of the elders" which in the municipal political institutions of the time was one of the highest decision-making bodies of the municipal government. The most flourishing period of the goldsmith's art coincided with the

Renaissance and the Baroque, thanks above all to the fundamental contribution of some personalities who contributed enormously to its development. Among his great performers, to stand out are certainly the figures of Valerio Belli, whose activity was praised by Vasari, Battista della Fede and Giorgio Capobianco, Exponent of a family of ancient tradition that has rightfully written its name in history thanks to the creation of the "gioiello di Vicenza", model of the city that was donated as a votive offering to the Madonna di Monte Berico for the escape of the plague of 1576. Lost during the Napoleonic occupation, the artifact was faithfully rebuilt in 2013 thanks to the action of the "Comitato per il gioiello di Vicenza". The nineteenth century marked a radical turning point in the production horizon of the entire Vicenza gold industry, which, meeting the demands of a constantly expanding market, was able to decline its tradition to the nascent prospects of industrial development. These new challenges were soon accepted by Luigi Merlo, who developed the first machine tools designed exclusively for goldsmith production.

12. DISTRICT ECONOMIC COMPARISON

The province of Alessandria employs 5,494 people (equal to 17.5% of the total Italy) and on the territory operate 802 local units (representing 10% of local Italian goldsmiths). Arezzo employs 7,673 people, which translates into 24.4% of the Italian total, while Vicenza has a percentage of 13.1 with 4,127 employees. Valenza, compared to Arezzo and Vicenza, traditionally specializes in high-end jewelry, thanks to the presence of numerous craft companies highly specialized. All data from Intesa Sanpaolo report are visible below (Figure 29)

	number of employees	weight of local unit employees in total Italy	index of specialization of employees	Number of local unit	weight of local units in total Italy
Italia	**31.393**	**100,0**		**7.903**	**100,0**
Arezzo	7.673	24,4	24,5	1.119	14,2
Alessandria	**5.494**	**17,5**	**19,9**	**802**	**10,1**
Vicenza	4.127	13,1	3,5	565	7,1
Milano	1.893	6,0	1,1	561	7,1
Firenze	1.619	5,2	2,1	398	5,0
Roma	1.094	3,5	1,7	497	6,3
Napoli	770	2,5	1,0	372	4,7
Varese	764	2,4	1,0	108	1,4
Torino	622	2,0	0,4	138	1,7
Padova	493	1,6	0,6	132	1,7

Figure 29 - Intesa Sanpaolo elaborations on ISTAT data

To the three goldsmith districts is attributable about 75% of the Italian export of the sector.

Among all, the Goldsmith's Valenza has been distinguished by the significant growth in exports in the last decade: between 2009 and 2019 exports increased by 1.7 billion, from less than 400 million to 2.1 billions. In the years 2017 and 2018 the district was the largest exporter in Italy, surpassing Arezzo. 2019 saw a substantial parity in terms of exports between the two districts.

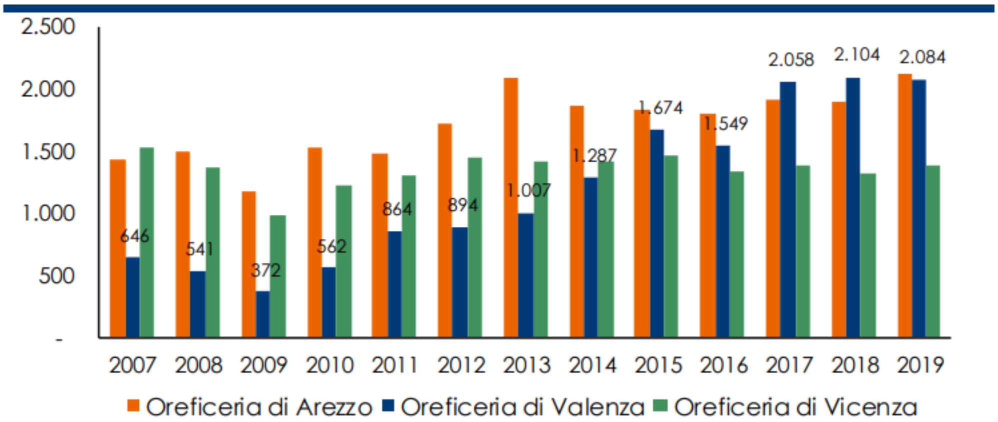

Figure 30 - Intesa Sanpaolo elaborations on ISTAT data

The capital formation in Valenza is high (45.5%) and well above Arezzo (29.8%) and Vicenza (34.5%). Net operating margins as a percentage of turnover were 7.8% for Valenza, 3.4% for Vicenza and 3.3% for Arezzo. The cost of the job in the district of Valenza for employee is slightly higher regarding the other districts (31.500 euros vs approximately 29.000 euros), but the value added per employee is greater than almost 10,000 euros (50,500 euros vs about 41,000).

	Valenza	Vicenza	Arezzo
The main Income Statement items in % turnover			
Net purchases	39,3	54,6	55,8
Costs for services and use of third party goods	25,4	20	21,4
Cost of labour	19,4	14,1	14,1
Depreciation of tangible fixed assets	0,9	1	1,1
Added value	31,7	21,3	20,7
Taxes	1,4	0,7	0,7
EBITDA	9,2	4,9	5,1
Composition of the balance sheet (as % of total assets)			
Total fixed assets of which:	7,8	15,5	15,2
Intangible assets	0,2	0,2	0,2
Tangible assets	5,4	9,2	11,2
Total current assets	92,2	84,5	84,8
Cash flow	4,3	5,7	6,2
Total permanent capital	66,8	56,7	52,5
Current liabilities	33,2	43,3	47,5
Equity	45,5	34,5	29,8
Competitiveness			
Total assets(% var.)	6	3,5	4,5
Turnover(% var.)	4,7	5,7	7,6
MON in % of turnover	7,8	3,4	3,3
Rate of rotation of invested capital	91	153,4	140,1
ROI	7,1	5,7	5,6
Added value per employee(K€)	50,5	41,6	40,4
Cost of labour per employee(k€)	31,5	28,7	28,7
Company size(tunover M€)	1,7	2,2	1,9

Figure 31 - Intesa Sanpaolo elaborations on ISID data

In 2020, the Italian goldsmith industry was severely hit by the crisis, registering one of the worse results within the Italian manufacturing with the production that has contracted 27.6% (against the -11,7% of the manufacturing) and the turnover of 23.6% (against the -11% of manufacturing). Weighs the sharp fall in world demand for gold jewelry (-33.5% in the average of 2020 according to WGC data in tons) which led to a contraction of exports Italian of comparable size (-31.2% in value and -29% in quantity). In this context, exports of the Goldsmith district of Valenza in 2020 have halved (*Figure 32),* with a contraction of 44% (equal to -918 million euros), the most intense among the Piedmonts' districts. The district has suffered the greatest setbacks on foreign markets also compared to the other goldsmith districts: Goldsmith of Arezzo -29,1% and Goldsmith of Vicenza -21,4%.

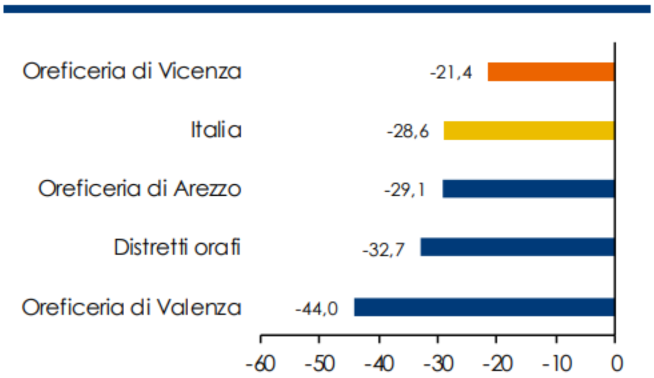

Figure 32 - Intesa Sanpaolo elaborations on ISTAT data

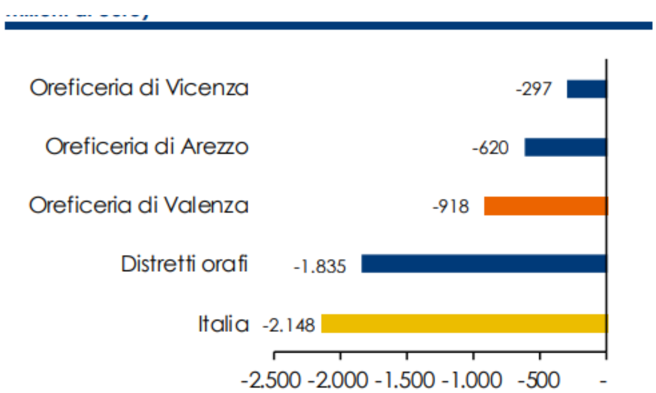

Figure 33 - Intesa Sanpaolo elaborations on ISTAT data

CHAPTER 3: THE EVOLUTION OF PRODUCTION PROCESSES IN GOLDSMITHING UP TO ADDITIVE MANUFACTURING ADOPTION

1. INTRODUCTION

Goldsmithing is the art of working precious metals, such as gold and silver, to make jewelry and other ornaments. The goldsmith has ancient origins and is in close correlation with the jewelry in the creation of artifacts that combine precious metals to gems. The working techniques of goldsmithing boast a long tradition of purely manual activities, still considered of great value, which have been a reason of great prestige throughout the world. Nevertheless, the technological evolution that has occurred in recent years has introduced in the field of goldsmith an increasingly considerable use of machinery and equipment for the processing of precious metals, thanks to which a wide range of jewelry is available for production without the need for human intervention.

2. TRADITIONAL LOST WAX CASTING

The technique of lost wax casting is very ancient: from Egypt to Greece and finally to Rome, there are many masterpieces of bronze sculpture, such as the “Riace Bronzes”, created thanks to its use. During the Renaissance - in the context of the recovery of all aspects of the classical civilization - the Venetian foundry resumed the lost wax casting technique for the realization of the bronze door tiles of the Baptistery of Florence. Benvenuto Cellini - Italian sculptor and goldsmith - described in his "Trattato di Scultura" the technique used for the fusion of his wonderful Perseus, an almost epic undertaking of years of hard work. With the advent of the Second World War, the lost-wax casting process took a different path: the need to supply precision components from complex geometry to the military industry favored its use in advanced technology. Lost wax casting is a process in continuous evolution, from ancient history but always current: art continues to benefit from its use, as well as the goldsmith and design, demonstrating the versatility of a technique of remote origins but of permanent importance.

The Investment Casting process is composed of a sequence of common steps as shown in *Figure 34*.

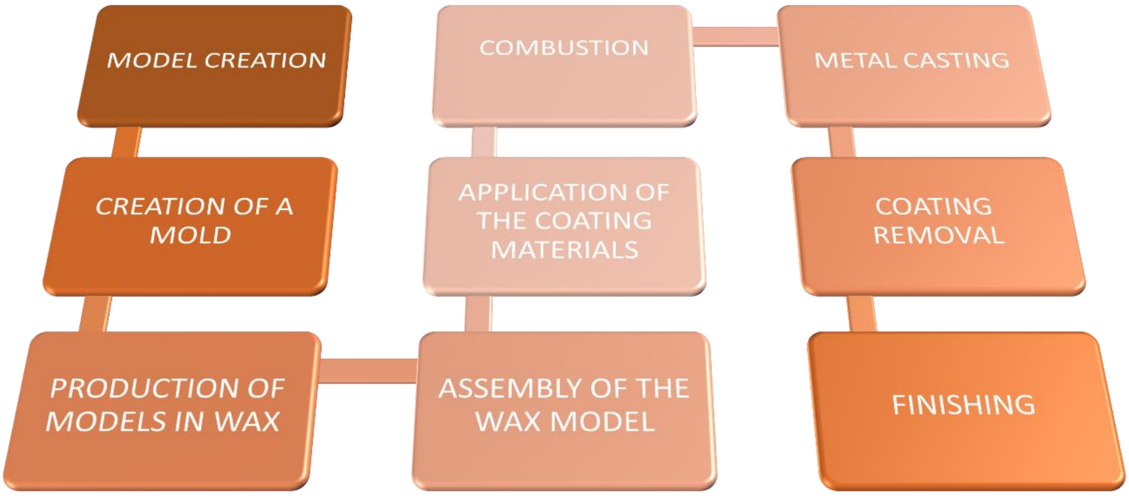

Figure 34 – Traditional lost wax casting steps

- *MODEL CREATION*

The craftsman carves a model in wax. The size and complexity of the wax model will depend on its ability to carve wax and the capacity of the casting equipment.

- *CREATION OF A MOLD*

A foundry then melts the model and smoothes the casting to produce a master model. The master model is used to make a rubber wax mould, which is heated and "vulcanized" around the original casting piece to create a flexible wax mould.

- *PRODUCTION OF MODELS IN WAX*

Melted wax is injected or, sometimes, poured into the rubber mold. This process can be repeated as many times as needed to obtain copies of the original design

- *ASSEMBLY OF THE WAX MODEL*

Are added to wax copies of the casting channels, which are connected to create a kind of tree structure, which defines the path to the leakage of molten wax and the flow of molten metal with which the cavity will be filled later.

Figure 35 – example of wax tree

- *APPLICATION OF THE COATING MATERIALS*

The wax tree is immersed in a mixture of silica or put in a cylinder and surrounded by the coating material in the form of liquid chalk.

- *COMBUSTION*

Once the coating material has dried, the cylinder is turned upside down inside a furnace that melts the wax, leaving a negative cavity with the shape of the original model.

- *METAL CASTING*

The coating material is further heated in a furnace to reduce the thermal difference with the molten metal. The metal is melted and then poured, using gravity or vacuum pressure to push the metal inside the cavity.

- *COATING REMOVAL*

Once the molten metal has cooled, the coating material is cooled in water to dissolve the refractory gypsum and release the raw result of melting. The casting channels are cut and recycled, while the melted parts are cleaned to remove the marks of the melting process.

- *FINISHING*

The cast parts are filed, sanded, machined or sandblasted to obtain the final geometry and surface finish. If necessary, the cast parts are also heat treated to improve the mechanical properties of the material.

Figure 36 – finishing of a jewel

3. DIRECT INVESTMENT CASTING

Today, digital software and 3D printing optimize lost wax casting with the benefits of digital design and manufacturing processes (*Figure 37*).

Figure 37- Direct investment casting steps

With the digital workflow, designers use CAD software to create designs in digital format and a high-resolution 3D printer to produce 3D printed models that can then be cast into the mold. After the positive model has been combusted, the process followed is identical to that of traditional lost wax casting. Thanks to digital techniques it is possible to greatly reduce labor and the design itself is easy to store, modify and recreate as needed. By using this method, it is possible to print hundreds of small to medium-size patterns with exceptional surface finish, dimensional stability and castability. In addition, it is far quicker and cost effective compared to the time and cost of manufacturing with a traditional injection mold.

4. SELECTIVE LASER MELTING

The diffusion of 3D printing in all sectors has led the production process of goldsmith to evolve. The additive manufacturing processes in the jewelry production chain are no longer present only in the initial stages (design and prototyping), they are thinning out until the creation of the finished product. The preferred technology for the treatment of precious materials is Selective Laser Melting (SLM). So, goldsmith production has been turned into a fully 3D-based process, from the digital design until the selective melting of the metal powder directly into the final product. In *Figure 38* are shown the steps to obtain the final product with SLM.

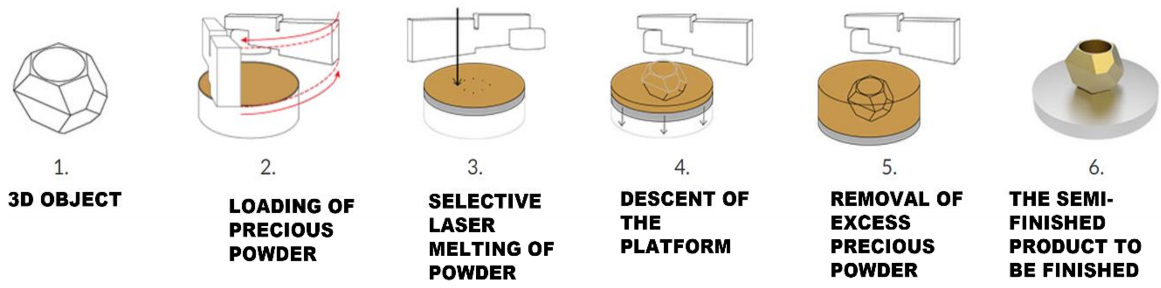

Figure 38 - SLM in goldsmith production

- *3D OBJECT*

The process starts from the 3D file in format .stl, optimized for printing

- *LOADING OF PRECIOUS POWDER*

After the precious powder is loaded into the printer, the arm distributes layers of it over the platform.

- *SELECTIVE LASER MELTING OF POWDER*

In relation to the 3D model, the laser proceeds to melt the metal particles.

- *DESCENT OF THE PLATFORM*

The operation continues as the platform descends simultaneously.

- *REMOVAL OF EXCESS PRECIOUS POWDER*

When the process is completed, the excess precious powder is removed.

- *THE SEMI-FINISHED PRODUCT TO BE FINISHED*

The object obtained is raw, ready to be polished to your needs.

Objects made directly from precious powder melted by laser beam rest and "grow" on standard measuring platforms. To ensure that the jewels develop in an appropriate way, the so-called "supports" are used, real precious metal scaffolds that satisfy multiple needs:

- Make sure that the jewel is well anchored to its platform. When the jewel is then separated from it the supports will be removed
- Make sure that every single point of the surface (internal and external) of the jewel is supported.
- Dissipate the excess heat developed during laser fusion The supports represent a theme strongly connected to the SLM technique because it is essential.

For this reason, there are designs much more suitable for 3D printing (*Figure 39*), whose design has angles greater than 45 and therefore little involved in the need to be supported, and less suitable, because it would require a degree of support so important to distort the design and quality of the jewel.

Figure 39 - example of printability of object

A printing resolution standard for metals is not definable. However, by virtue of the best results collected by polymer printers, the table below (*Figure 40*) shows the resolution in the X-Y-Z axes and expressed in DPI (dots per inch).

	PLATINUM 950‰	YELLOW GOLD 750‰	RED GOLD 750‰	WHITE GOLD 750‰	TITANIUM
xy [DPI]	170	120	120	150	120
z [DPI]	1200	1200	1200	1200	500

Figure 40 -resolution expressed in DPI for SLM. Source: Progol3D

The values indicate that in the X and Y planes the metal direct printers cannot achieve details less than 0.15 - 0.20 mm, while in the Z axis it is possible to reproduce details up to 0.02 mm. In microfusion this is not possible, especially for high melting point alloys such as platinum and titanium. In any case, even for gold alloys it is difficult to melt, or rather fill, thin elements less than 0.25-0.30mm.

5. TECHNICAL COMPARISON OF TECHNIQUES

Below are shown the technical differences between traditional and direct lost wax casting and SLM.

- *EMPTY OBJECTS*

With microfusion it is not possible to create empty monolithic jewelry. In the example shown in *Figure 41*, the ring must be micro-machined into two parts which in turn are assembled to create an internal vacuum. This is a mandatory procedure to have an acceptable weight. It also means generating, after the assembly of the two parts, an unwanted and visible welding line, due to the different color gradation.

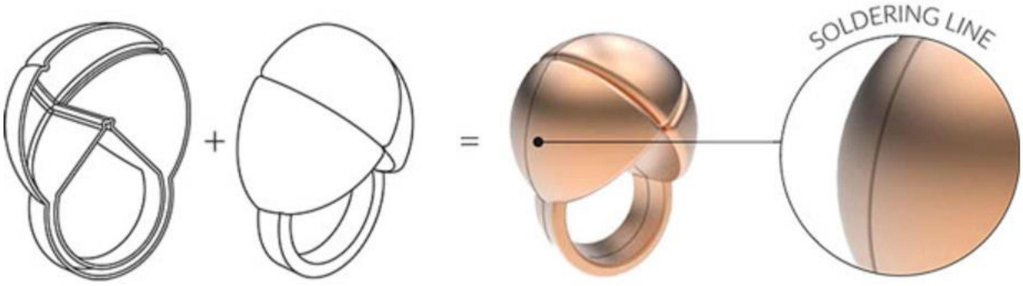

Figure 41 – Empty object with microfusion. Source: Progol3d.

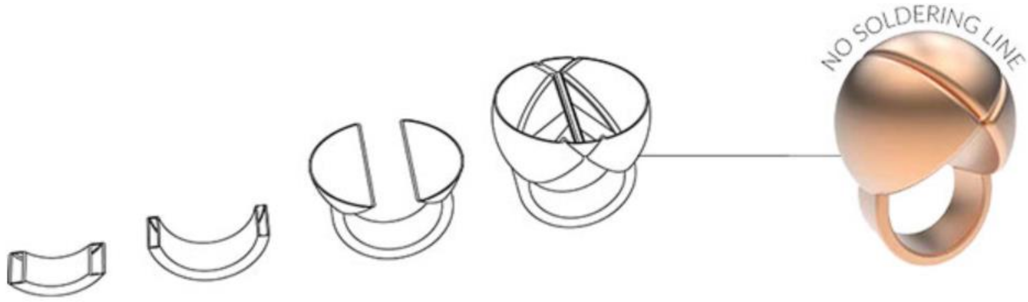

Figure 42 – empty object with SLM. Source: Progol3d.

The 3D printed ring directly on metal shown in *Figure 42* is monolithic and free from any problem of visible welding lines.

- *VOLUME AND WEIGHT*

The direct metal 3D printing offers the possibility to decide, beforehand, what will be the final weight of the jewel, without affecting the desired apparent volume. This is an opportunity for a perfect market positioning as it allows the jewelry to be much more comfortable to wear, such as earrings.

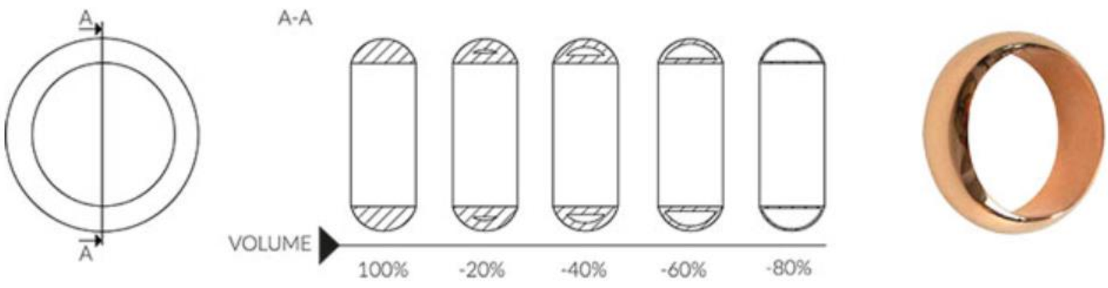

Figure 43 - Volume and Weight with SLM. Source: Progol3d.

- *ROUGHNESS*

The graph below (*Figure 44*) highlights the total roughness of the jewels, called Rt, when compared between traditional microfusion, direct microfusion and direct 3D printing. In the case of microfusion, the high roughness is not as distributed

PROCESS	LOWEST ROUGHNESS [µm]	HIGHEST ROUGHNESS [µm]
TRADITIONAL CASTING	10,8	39,9
DIRECT CASTING	18,6	44,9
DIRECT 3D PRINTING	22,1	59,1

Figure 44 Roughness between techinque in goldsmith. Source: Progol3D

on the surface as in direct 3D printing. It is often located in holes due to some typical defects of the microfusion, such as shrinkage porosity. This will force the goldsmith operator to remove the metal surrounding the hole to make the surface smooth and shiny, without defects. However, the average roughness of jewelry made with direct 3D printing is comparable to that of jewelry produced with direct microfusion.

The advantage of direct 3D printing, in case roughness values are similar, is that the amount of metal to be removed is much smaller. This is in case of any non-local laser repairs for microfuse parts.

PROCESS	LOSS%
TRADITIONAL CASTING	0,8%
DIRECT CASTING	0,9%
DIRECT 3D PRINTING	1,2%

Figure 45 – Amount of metal to be removed between techniques. Source: Progol3d.

- *THICKNESSES AND SURFACES*

Molten metals, during the microfusion process, have the ability to fill thin parts in proportion to the extent of the surface. In microfusion, the larger the surface, the thinner the thicknesses need to be reached and completed. In direct 3D printing this relationship no longer exists,as shown in *Figure 46*. Regardless of the size of the supercifier, whether large or small, the printable thickness is always the same. In absolute terms, 3D printers are capable of constructing parts with a thickness at least 50% less than the microfusion.

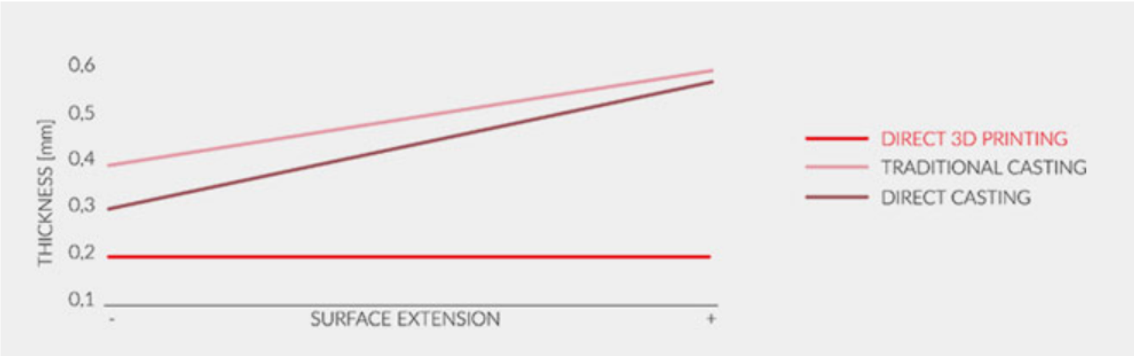

Figure 46 - Thicknesses and surfaces between techniques. Source: Progol3d.

CHAPTER 4: ADVANTAGES AND DISADVANTAGES IN THE ADOPTION OF THE SELECTIVE LASER MELTING IN THE GOLDSMITH INDUSTRY

1. INTRODUCTION

In this chapter, a comparison will be made between the most common technologies used in goldsmith production discussed in the previous chapter. Classic microfusion, direct microfusion and Selective Laser Melting will be compared using the data collected from a report by the company Progold, active in the goldsmith sector and based in Vicenza.

2. SUPPORT AND FEEDERS

A complete comparison between advantages and disadvantages of Selective Laser Melting technique compared to the microfusion cannot disregard the presence of supports in one and feeders in the other. These elements are indispensable for fixing the growth position of the jewelry in SLM and directing the metal alloy in the hollow shapes in microfusion. In laser printing, the presence of supports is also necessary to support the cantilever parts of the object, that otherwise could be easily moved by the movement of the metal powder distribution brush and to dissipate the heat generated during melting. Like the feeders in microfusion, the supports are a valuable part that must be eliminated from the jewel and therefore their quantity is a factor that must be considered in the general economy of the manufacturing process, because it is an integral part of the production waste. Compared to feeders in microfusion, the supports are generally less important parts of the precious metal involved in the production process and therefore the reduction in processing in laser printing is usually lower than that found in microfusion. The supports are generally also needed in direct microfusion for the printing of the model in wax or resin, but in this case they are eliminated before the production of ceramic molds and are therefore not present in the assembled three, influencing the production process only in terms of the time needed to remove them and not on the quality of the workpiece and the processing waste. The main drawback related to the presence of the supports in SLM is due to their removal phase. In fact, a residue may remain attached to the printed jewel or may remain tiny craters, due to the removal of jewel material attached to the ends of the supports. The entity of these defects and the possibility of eliminating them in the finishing phase depends on the type of supports used, the more these will be massive, the more generally they will be expensive to remove, also increasing the decrease in the production process (*Figure 47*).

Figure 47 - Example of defect in a ring due the removal of supports

The mandatory presence of a certain amount of supports obviously affects the design of printable objects. In the presence of decorative details of reduced size or recessed, the residue left by the presence of the supports is often incompatible with the level of definition required by the piece, making the quality of the jewel printed unsatisfactory.

3. LEAD TIME

The time required to deliver an order is of course dependent on the number and type of parts to be produced. From the comparison of different production techniques, however, it is immediately evident that not only the production time for a given number of pieces is different, but considering lots of different sizes the production time calculated for one technique is very different than that of another. The comparison between classical, direct and selective laser casting was carried out by Progold considering three cases, namely the production of one, ten and one hundred gold reference rings. The pieces used for the comparison of the production times have in any case, with the same alloy, a volume and consequently an identical mass around the ten grams, while the considered shape changes according to the technique used. The planning and design times of the initial model were not taken into account for the purposes of the calculation as they were a passage in common to the three techniques considered. The availability of the production machinery was considered unitary for each type. Print times in direct microfusion have been estimated using a multijet printer Projet CPX 3500 plus (3D Systems). The time needed to complete the individual production steps are summarized in the tables given below(Figure 48,49 and 50).

Microfusione classica			
Fase produttiva	Tempo di lavoro 1 pezzo (min)	Tempo di lavoro 10 pezzi (min)	Tempo di lavoro 100 pezzi (min)
Realizzazione prototipo	1150	1150	1150
Preparazione stampo in gomma	120	120	120
Iniezione delle cere	1	10	100
Assemblaggio dell'alberino	1	3	33
Preparazione del cilindro	30	30	45
Cottura cilindro	720	720	720
Prefusione Lega	15	15	15
Fusione e colata	15	15	60
Decapaggio	5	5	20
Spiantonatura	0.25	1	10
TOTALE (approx)	**2050 (34.0 h)**	**2070 (34.5 h)**	**2270 (37.5 h)**

Figure 48- Lead time estimated for classic microfusion- Source: Progold

Microfusione diretta			
Fase produttiva	Tempo di lavoro 1 pezzo (min)	Tempo di lavoro 10 pezzo (min)	Tempo di lavoro 100 pezzo (min)
Stampa delle cere	260	270	710
Rimozione supporti	60	60	90
Assemblaggio dell'alberino	1	3	33
Preparazione del cilindro	30	30	45
Cottura cilindro	720	720	720
Prefusione Lega	15	15	15
Fusione e colata	15	15	60
Decapaggio	5	5	20
Spiantonatura	0.25	1	10
TOTALE (approx)	**1100 (18.5 h)**	**1120 (18.5 h)**	**1700 (28.5h)**

Figure 49 - Lead time estimated for direct microfusion- Source: Progold

Fusione selettiva laser			
Fase produttiva	Tempo di lavoro 1 pezzo (min)	Tempo di lavoro 10 pezzo (min)	Tempo di lavoro 100 pezzo (min)
Supportazione modello digitale	15	15	15
Stampa e pulizia macchina	110	440	4400
Distacco pezzi e supporti	3	30	300
TOTALE (approx)	130 (2.0 h)	480(8.0 h)	4700 (78.5 h)

Figure 50 - Lead time estimated for Selective Laser Melting - Source: Progold

First of all we can see how the steps to be carried out for the production of jewelry is in greater number for the classic microfusion than the other two techniques. This is due to the fact that for direct microfusion via the 3d printer the wax prototype is produced directly. For the SLM the steps to have the finished product are only three. Comparing the production time in the case of classic and direct microfusion and SLM (Figure 51) immediately it can be notice that for productions limited to the order of ten units of pieces, the production time with selective laser melting is significantly shorter than with other techniques.

Tecnica produttiva	1 pezzo (ore)	10 pezzi (ore)	100 pezzi (ore)
MICROFUSIONE CLASSICA	34.0	34.5	37.5
MICROFUSIONE DIRETTA	18.5	18.5	28.5
SLM™	2.0	8.0	78.5

Figure 51 - Lead Time comparison for the three techniques- Source: Progold

For small batches the longer times are found with the classical microfusion, because the production of the prototype has a very important impact in the total working hours. In reality the realization of a single piece in classical microfusion is a rare event, justifiable only for jewels of enormous artistic importance, and generally opt in this case for direct microfusion. In the case of the resumption of an old series production, for which rubber prototypes and moulds are already present, the time of realization of one or ten pieces for the classic microfusion is considerably shorter, resulting lower than those of direct microfusion but increasingly higher than in the case of use of SLM. The situation is opposite in the case of production of a higher number of pieces. In this case, the long time of laser printing becomes greater than the time of realization of the prototype, the firing of ceramic coatings and the printing of the waxes, making the casting in complex a production process faster than selective laser melting. For a hundred pieces, the classic microfusion times are still higher than those of direct microfusion, due to the long preparation times of the prototype. The advantage in production speed detected for a relatively low number of parts can be very useful in a world where the desire for originality and customization of the public has become important for every company, just look at the automotive industry, clothing and watchmaking. This mass phenomenon inevitably also leads to the goldsmith and high jewellery sector. In the past, artisan goldsmiths occasionally created a unique jewel for a single customer, while today with laser printing it's possible constantly offer the same service more quickly. In the case of jewelry to be produced in series the productive advantage of the casting is still evident compared to SLM due to the long stamping times of current 3d printers.

4. PRODUCTION CAPACITY

With production capacity is understood the amount of jewelry produced every day and has been defined equal to the mass of pieces produced daily, as established by traditional industrial canons. The instruments made available are once again considered by Progold to be uniform by type and average production capacity, while the daily working hours have been fixed at eight, without the use of night shifts by human resources. Moreover, it has been considered a single operator for every productive unit. In the case of classic microfusion, only one furnace can complete on average one firing cycle during the working day due to the long life of the coating decryption process. However, a typical furnace in the industry can hold about fifteen cylinders simultaneously, resulting in a significant productivity recovery. Ultimately, every working day you can get 3.75 kg of jewelry with classic microfusion for these conditions. About direct microfusion, the critical step of the process is the wax printing phase. Assuming that the printer is able to produce about 220 pieces of 10 grams per day and considering that at the same time of printing the posts can be assembled with the waxes already prepared, and carried out the castings of the annealed cylinders, the estimated potential production capacity is about 2.2 Kg per day of jewelry. Finally, in the case of SLM, productivity is directly linked to print times. In the case of rings of about 10 g a single printing table with 7 pieces per level and a total of 5 overlapping levels is completed in about 24 hours, for an amount of 350 g of daily jewelry

Tecnica produttiva	Microfusione classica (kg/giorno)	Microfusione diretta (kg/giorno)	SLM™ (kg/giorno)
Produttività giornaliera	3.75	2.2	0.35

Figure 52 - Production capacity for the three techniques - Source: Progold

Figure 52 shows that in terms of production capacity, traditional production techniques are still superior to selective laser melting. However, it should be stressed that this high potential production capacity is not always necessary and fully exploited in the field of fine jewellery, where often microfusion systems are underused.

5. ECONOMIC COMPARISON

For a correct assessment of market prices, it is important to consider how some factors influencing prices, such as the hourly cost of operators and of the electricity used to power the plants, vary according to the geographical area under consideration. For this reason, Progold analysis refers to the Italian market, whose prices are among the lowest in Europe, mainly because of the low cost of labour compared to other European markets such as France or Germany.

Tecnica produttiva	Prezzo di mercato (€/g)
Microfusione classica	0.2-1
Microfusione diretta	2 - 6
SLM™	4 – 12

Figure 53 - Market price for jewellery produced with the three techniques under examination - Source: Progold

As shown in Figure 53, classic microfusion is evidently at the moment the most economical production technique compared to the other two, using machines individually less expensive than laser printers, and reducing the costs of some phases thanks to the high number of pieces treated simultaneously. The costs and market prices of direct casting on the contrary are much closer to those of selective laser melting. From the combined analysis of lead time, productive capacity and market prices it is possible to deduce as the strengths of the selective laser melting are therefore the realization of unique pieces or limited series, whose production times compared to the microfusion are substantially lower, and the realization of objects that due to the geometry or material used are not possible to produce with the classical techniques of microfusion. To compensate for the increased process times due to the use of SLM you could opt for the purchase of more printers to work in series. The purchase and maintenance of a large number of production machinery, however, implies a substantial initial investment and a large, fixed capital. SLM is however able to produce 0.35 Kg per day with average sales prices of 8 €/g. The Selective Laser Melting technique therefore proves to be competitive by guaranteeing the producer high profit margins and a return on capital invested in a very short time.

6. SUSTANAIBILITY

The environmental impact is increasingly one of the areas of interest for each company. Respect for the environment and the territory contribute strongly to a sustainable growth not only of the organization and the sector, but of the whole world system. It is now known how leading companies recognize the importance of investing in sustainability by monitoring their impacts. One of the universally recognized parameters for the assessment of the environmental impact of a production process is the so-called Carbon Footprint (CF), which refers to the amount of greenhouse gases (GHG) emitted during the process under consideration expressed in terms of mass of CO2 equivalent. The comparison of the GHG emitted by the three techniques (Figure) in analysis was carried out by progold considering all the phases and materials present in the company necessary to complete the production of 1 Kg of jewelry, referring to the same steps and productive times used for the calculation of the lead times in paragraph 3.

Carbon footprint microfusione classica

Fase produttiva	kg CO_{2eq}/kg
Realizzazione prototipo	7.39
Preparazione stampo in gomma	1.62
Iniezione delle cere	0.31
Assemblaggio dell'alberino	0.07
Preparazione del cilindro	0.72
Cottura cilindro	15.90
Prefusione Lega	0.44
Fusione e colata	1.85
Decapaggio	0.42
Spiantonatura	0.06
TOTALE (approx)	**28.8**

Figure 54 - CF classic microfusion - Source: Progold

Carbon footprint microfusione diretta

Fase produttiva	kg CO_{2eq}/kg
Stampa delle cere	3.70
Rimozione supporti	0.64
Assemblaggio dell'alberino	0.07
Preparazione del cilindro	0.72
Cottura cilindro	15.90
Prefusione Lega	0.44
Fusione e colata	1.85
Decapaggio	0.42
Spiantonatura	0.06
TOTALE (approx)	**23.80**

Figure 55 - CF direct microfusion - Source: Progold

Carbon footprint fusione laser selettiva	
Fase produttiva	kg CO_{2eq}/kg
Atomizzazione	1.64
Stampa	13.2
Rimozione pezzi e supporti	0.03
TOTALE (approx)	14.70

Figure 56 - CF Selective Laser Melting - Source: Progold

The estimate of greenhouse gas production resulting from the use of the three different production techniques shows that the values of emissions caused by selective laser melting are significantly lower than those caused by the other two techniques. It is also clear that the majority of greenhouse gas emissions are attributable for all three techniques to production steps that use electricity for a long time: the annealing of coatings in classic and direct microfusion, the printing phase for selective laser melting. From the graphic comparison(Figure 57) it is immediate to note that only in the presence of very low print speeds and high production efficiency microfusions the greenhouse gas emission is lower with classical and direct microfusion. Generally, in fact, the CO2 equivalent produced in selective laser melting is much lower, reaching to be more than half compared to traditional and direct microfusion in case these have poor production efficiency, that is with furnaces strongly under used. Overall, therefore, it can be concluded that the SLM technique is advantageous compared to micro-castings in terms of production environmental impact.

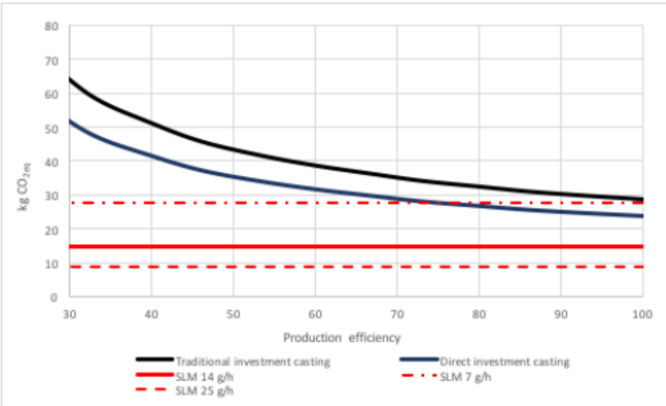

Figure 57 - Evolution of CO2 production equivalent to the variation of production efficiency - Source: Progold

CHAPTER 5: ANALYSIS ON AM TECHNOLOGY ADOPTION IN THE GOLDSMITH DISTRICT OF VICENZA, AREZZO AND VALENZA.

1. INTRODUCTION

To analyze the adoption of Additive Manufacturing in the Italian goldsmith industry, the answers to three questionnaires that had been placed by former students of the Politecnico of Torino to the three main goldsmith districts in Italy were collected and unified. The districts in question that have been deepened in chapter 2 at a historical and economic level are: Arezzo, Valenza and Vicenza. The analysis presented in this chapter is mainly based on:

- the adoption rate among firms of different districts and of different size.
- The reasons which brought to adopt 3d printers and the techniques mainly used.
- The timing of the 3 techniques presented in the previous chapters.
- The materials mainly used in the 3d stamping process.
- The positions about future investments in AM techniques.

2. THE METHODOLOGY

The methodology through which the analysis was conducted is characterized by a sequence of steps.

1) First, the questionnaire replies and all sample data were collected. The data on the companies contacted, the companies willing to reply and the companies that effectively replied to the questionnaire were analysed.
2) Denoted the fact that for the district of Arezzo a few questionnaires had been filled out to carry out the analysis, 15 of the companies that were willing to respond but did not reply were contacted by phone and the link to the questionnaire was sent via Google Forms. Of these 5 companie effectively completed the questionnaire and the answers were added to the existing database.
3) Once the database was complete it has been fixed. Among the answers of the districts of Valenza and Vicenza there were some questionnaires filled out 2 times by the same company and some inconsistent answers. They were thus discarded and the adjusted database is finally composed of 68 companies.
4) The questionnaires, however, had different questions and answers for each district since the survey was conducted by three different students. Thus, only the questions common

to the three questionnaires were considered and the answers were standardized in such a way that a more consistent analysis could be made. Finally, the question considered are 14.

5) Once the three questionnaires have been fully standardized the database has been uploaded to Stata. After fixing the database with the last inconsistencies through the statistical software all the analyses have been carried out.

More information about the database can be found in Appendix A.

3. ANALYSIS ON SAMPLE AND RESPONS RATE

The sample is composed of the companies with ATECO *code: 321210 - Manufacture of jewellery and precious metal goldsmithery or coated with precious metal* from the district of Valenza,Vicenza and Arezzo. Considering the large number of companies located on these districts (almost 2000 in total) they were selected randomly for being reached by phone. Below the sample size is showed for every district (*Figures 58,59,60*) and the response rate is calculated on the "adjusted sample size" which is calculated by the difference in the initial sample and the companies that closed their business or that had an inexistent phone numbers or that declared not to be involved in any manufacturing activities because just jewels retailers.

Valenza(AL)	
Sample size	140
Adjusted sample size	112
Survey response	28
Response rate	25,00%

Figure 58 - Response rate on Vicenza goldsmith district.

Vicenza	
Sample size	53
Adjusted sample size	45
Survey response	18
Response rate	40,00%

Figure 59 - Response rate on Vicenza goldsmith district.

Arezzo	
Sample size	78
Adjusted sample size	70
Survey response	22
Response rate	31,43%

Figure 60 - Response rate on Arezzo goldsmith district.

As you can see the highest response rate is that of the district of Vicenza while the lowest is that of Valenza despite the latter have been collected more answers. This is due to the fact that for the district of Valenza a greater number of companies have been contacted (140) against the 53 contacted for Vicenza and the 78 for Arezzo. Figure 61 shown the response rate in total.

Three main district	
Sample size	271
Adjusted sample size	227
Survey response	68
Response rate	29,96%

Figure 61 - Response rate on the three analysed goldsmith district

At the end the large number of response in the database are from the district of Valenza(28), followed by Arezzo(22) and to end up Vicenza(18) for a total of 68 company. Below is shown the percentage of every district response on the total that is almost balanced(Figure 62).

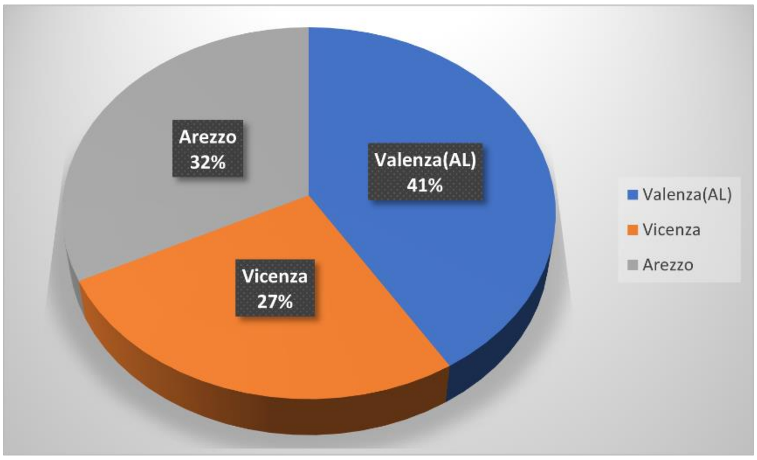

Figure 62- percentage of every district response on the total

4. ANALYSIS OF RESPONSES: COMPANY SIZE, DISTRICTS AND AM ADOPTION

According to Istat data in the three districts micro and small firms are between 96% and 98 % and the survey confirm this result. The chi-square test gives a p-value of 0,531>0,05 and for this reason the null-hypothesis cannot be rejected, there isn't a strong correlation between the company size and the districts.

	District			
n. employees	Valenza	Arezzo	Vicenza	Totale
1--10	18 64,29%	11 50,00%	8 44,44%	37 54,41%
11--50	8 28,57%	8 36,36%	9 50,00%	25 36,76%
>50	2 7,14%	3 13,64%	1 5,56%	6 8,82%
	28	22	18	68

Figure 63 - Company size for district

Figure 63 shows that 37 companies, corresponding to 54,41% of the respondents, are micro firms with the peak for Valenza with 64,29%. This is in line with what was expected since most of the companies in these districts (mainly Vicenza and Valenza) have a long tradition in the goldsmith industry and are mostly family-run. Small companies are the 36,76 % of the total (25) with a peak for Vicenza with 50%. The companies with more of 50 employees are only the 8,82% (6) and the peak is for Arezzo with 13,64%. Probably this is due to the number of companies in the district because Arezzo is the most populous province from the point of view of companies (as shown in chapter 2) with 1202 firms involved in the goldsmith sector (Istat data) and for this reason there is more variety in company size.

The attention was then drawn to 3D printing adoption. 36 companies answered to be currently using AM technology in their production process. Although more than half of the respondents (52,94%) already went for 3D printing, 47.06% still manufacture finished products traditionally by hand (Figure 64).

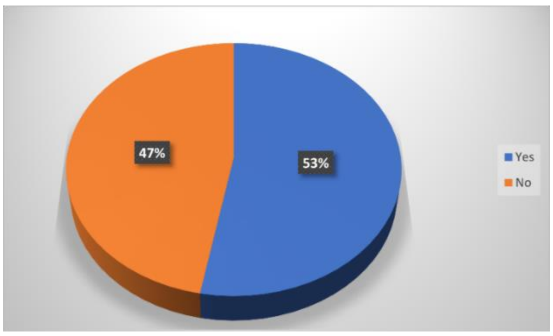

Figure 64 - Percentual adopters among the respondents.

Figure 65 shows the correlation between adoptions and the size of companies.

	n. employees			
AM ADOPTION	1--10	11--50	>50	Totale
Yes	18	14	4	36
	48,65%	56,00%	66,67%	52,94%
No	19	11	2	32
	51,35%	44,00%	33,33%	47,06%
	37	25	6	68

Figure 65 - correlation between adoptions and the size of companies

The chi-square test gives a p-value of 0,663>0,5 and for this reason the null-hypothesis cannot be rejected, there isn't a strong correlation between the company size and the AM adoption. It is possible to see that for micro firms the adopters are almost balanced with no adopters (48,65% versus 51,35%) while for small businesses, 56% of the firms adopted. The peak in adoption is showed by the firms with more of 50 employees (66,67% versus 33,33% of no adopters). This data can probably be explained by the fact that larger companies have more economic availability to invest in expensive technologies such as 3d printing.

	District			
AM ADOPTION	Valenza	Arezzo	Vicenza	Totale
Yes	20	8	8	36
	71,43%	36,36%	44,44%	52,94%
No	8	14	10	32
	28,57%	63,64%	55,56%	47,06%
	28	22	18	68

Figure 66 - correlation between adoptions and the districts

In Figure 66 is shown the adoption rate related to the districts. The chi-square test gives a p-value of 0,036<0,5 and for this reason the null-hypothesis can be rejected, there is a correlation between the adoption and the districts. The respondents from Valenza district adopt in 71,43% of cases (versus 28,57% of no adoption) according to the survey this is the district with the highest number of adoptions in percentage. Following there is Vicenza with

55,56% of no adoption (versus 44,44% of adoption) and finally Arezzo with the lowest adoption rate with only 36,36% adopting.

These data can be explained from the the prevailing orientation of the districts regarding what is produced. Arezzo goldsmith industry is the largest consumer of raw gold in Italy, and the prevailing orientation is towards industrial processing products, generic, aimed at the medium-low end of the market. This means that not being a high-end jewelry manufacturing district, the advantages in terms of 3d printing design are not exploitable in most cases. While the Valenza district, although compared to Arezzo has a more artisanal orientation of production, has as main final customers those who have interests in high jewelry and in this case the design is therefore a fundamental aspect. The district of Vicenza is therefore competing on two fronts, both with Arezzo in the simple processing of gold, both with Valenza for the finest processing and tending to jewelry.

5. ANALYSIS OF RESPONSES: NUMBER OF 3D PRINTERS AND INVESTMENT.

First of all, in figure 67 it is shown the rate of companies that has the 3D printers of property against those who rely on third parties.

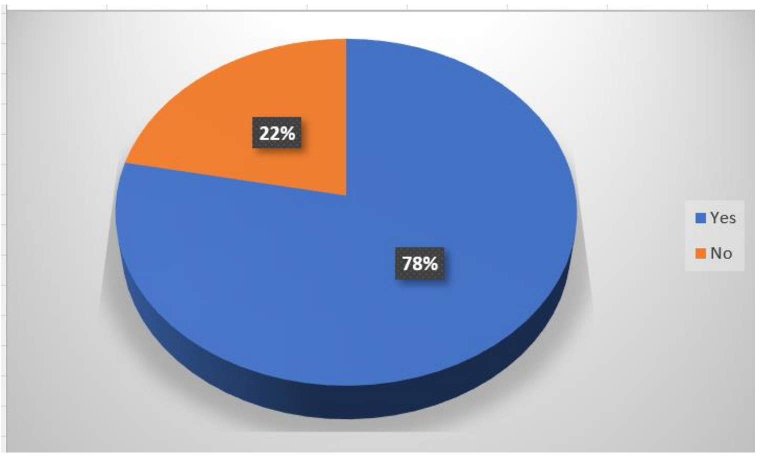

Figure 67 - Percentage of companies that have the 3D printers of property

There are various firms in Italy and abroad, such as Progold (from which data was taken for analysis in chapter 4), which provide a 3D printing service on commission for companies. Their customers send the design of the jewel you want to print and Progold provides the design in CAD and printing in the required material. The semi-finished jewel (to be machined) is then delivered at the end of production with SLM. Probably 22% of respondents who rely on third parties use these services. The majority of respondents in this case has the owned 3d printers

(78%) probably because the production in their factories is a key element of each company and certainly also for a matter of costs that are very high in the case of prints on commissions are for a large amount of jewelry.Companies were asked to provide the number of 3D printers at their disposal.

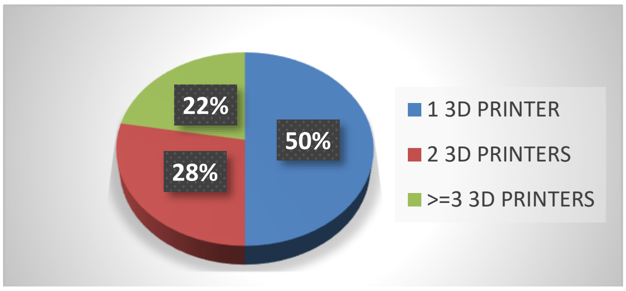

Figure 68 - number of 3D printers owned by companies

As it's shown in Figure 68, the majority of companies (50%) owns only one 3D printer and only 22% owns more than 3 3D printers. This is probably due to two factors: the first is that although the price of 3D printers has been lowered in the last years, many companies are still restrained from purchasing more than one machine because of their cost.In fact, among the 18 companies that have indicated that they only own a 3D printer more than 50 % (10) are micro firms. The second factor is that the technique most used (as we will see in the following paragraphs) does not assume the use of multiple 3D printers in series. Following the investments in 3d printers are analyzed. Companies were asked to select one of the proposed ranges which were shaped to the online prices of the most popular printers and software systems available on the market.

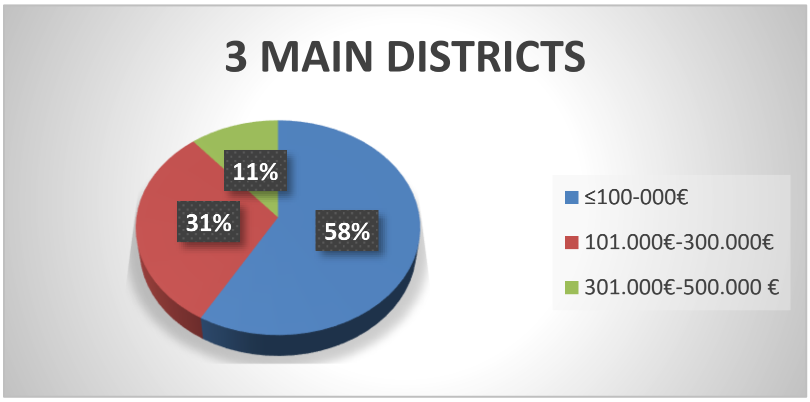

Figure 69 - Range of investements in 3d printers

In Figure 69 it can be see that the majority of companies (58%) have invested less than 100 thousand euros in 3d printers and this is consistent with the fact that most companies own maximum 2 3d printers (78%). Only 11% has invested more than 300 thousand euros and this shows that in the Italian goldsmith sector the AM technologies are not yet seen as totally mature. Below (Figures 70,71,72) investments per district.

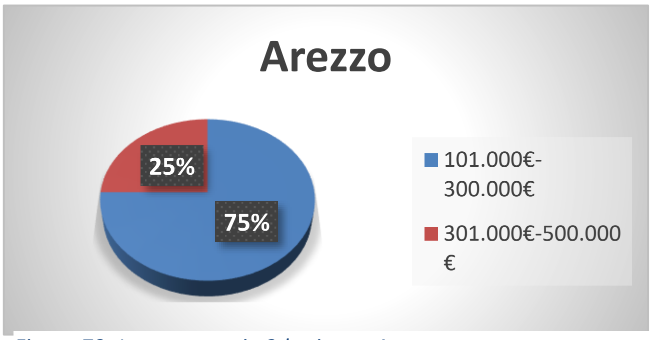

Figure 70- Investments in 3d printers Arezzo

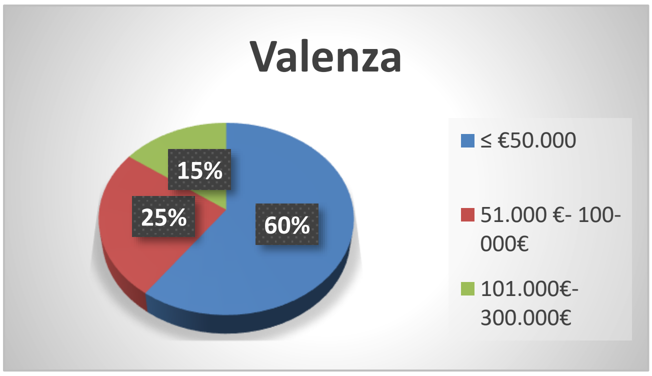

Figure 71 Investments in 3d printers Valenza

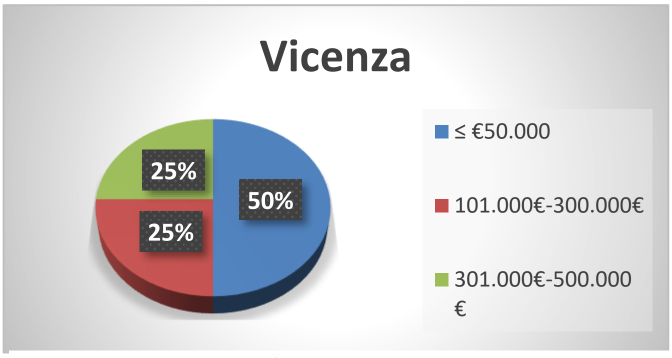

Figure 72 Investments in 3d printers Vicenza

No company in Valenza has stated that it has invested more than 300 thousand euros is this is consistent with the fact that most adopters are micro firms. While the companies of the district of Arezzo have declared to have invested at least 100 thousand euros. This is due to the fact that for what is produced mainly by this Italian segment (as mentioned in the previous paragraph) companies need larger printers that therefore cost more.

6. ANALYSIS OF RESPONSES: TECHNIQUES AND MATERIALS

Following the production process carried out in the 36 goldsmith companies currently using 3D techniques and tools are analysed.

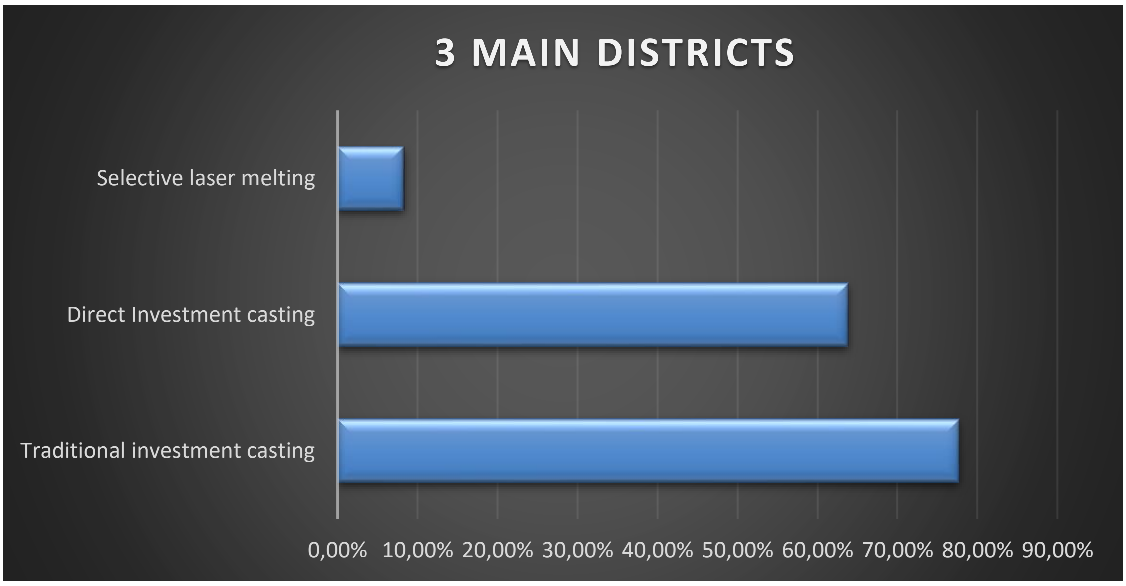

Figure 73 - Techniques used by the companies in goldsmith production

Traditional investment casting is still the most popular since used by 77,78 % of firms. This technique is the traditional technique that has been used since the dawn of goldsmithing and despite the evolution of the tools it remains difficult to abandon it for a market, the Italian one, which boasts a tradition so honored and recognized worldwide. Thanks to modern tools this has certainly been improved in efficiency but the fact remains that it is a laborious technique that requires many steps to obtain the finished product. Even direct investment casting is widely used (63,89% of firms). This technique is considered as the evolution of the traditional one and is already used by many. 3d printers in this case accelerate and improve the prototyping process. Probably, in fact, most companies use 3d printers precisely to produce wax models that are then used to make the casting of the metal and get the finished product. Also for this reason, as it has been evidenced in the previous paragraph, the necessary 3d printers to a company are not many and for this very reason the investments in the technology are inferior in most of the cases to the 100 thousand euros. Are only 3 the companies that use the SLM, in percentage 8,33% of the total. Selective Laser Melting is probably not a mature technology for the jewellery industry. The high costs are surely a factor that affects its lack of diffusion besides the fact that, as it has been previously said, to abandon the traditional techniques is not an easy passage for industry like that goldsmith. Below the percentage of techniques used by every district(Figures 74,75,76).

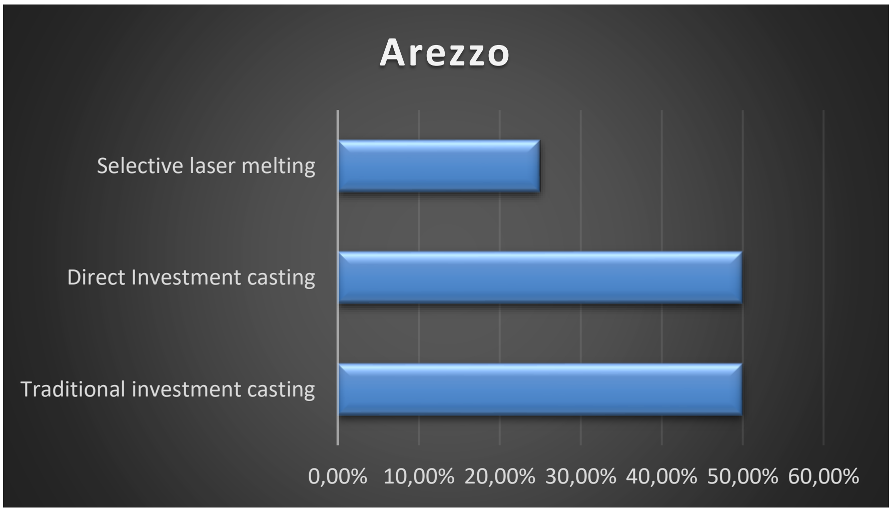

Figure 74 - Techniques used by the companies in goldsmith production Arezzo

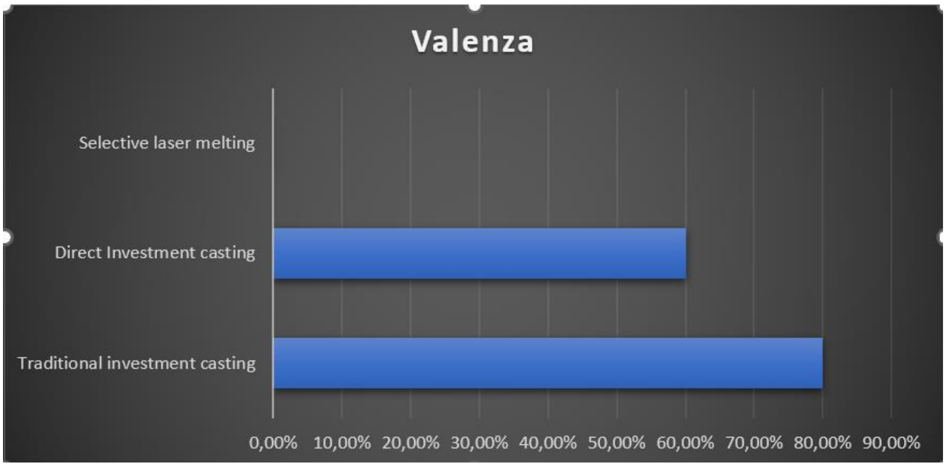

Figure 75 - Techniques used by the companies in goldsmith production Valenza

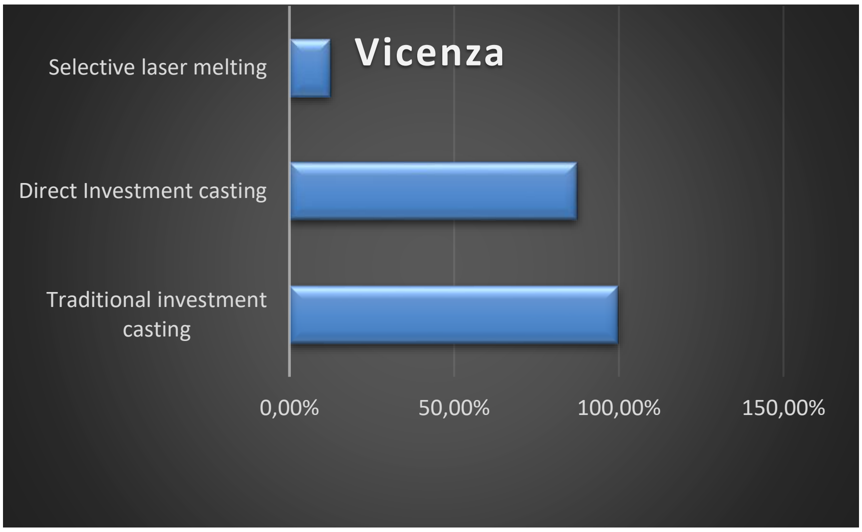

Figure 76 - Techniques used by the companies in goldsmith production Vicenza

The charts shown that in Valenza no companies used the SLM. Another data that emerges from the analysis is that 100% of the companies of respondents in the district of Vicenza use the traditional microfusion technique. This is certainly because the district of Vicenza is the oldest in Italy. Among the 3 industry that use SLM only 2 use it as the only technique for the production process and both are the two of the district of Arezzo while the company of Vicenza district use all the three techniques. Figure 77 shows that the majority of companies use both traditional and direct investment casting(47,22 %) while only 16,67 % only use direct microfusion.

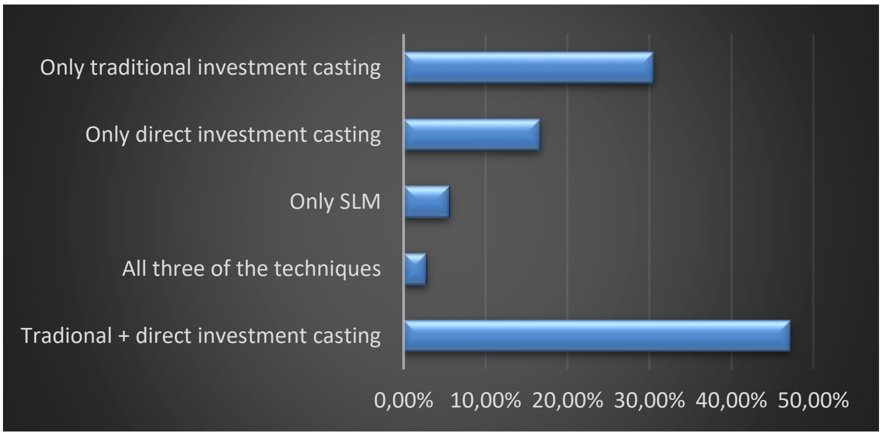

Figure 77 - Combination of techniques used by the companies

The materials mainly used for the printing process are showed in Figure 78 and it is possible to see see how waxes and resins (in order 66,67% and 75%) are the most widely used materials for printing since they have low costs and are the materials used mainly for models and prototypes. Only 13.89% of companies use metals for printing, given their high cost and the fact that they are mainly used for SLM. In fact, among the 5 companies that have declared to use metals for printing 3 are those that use the SLM.

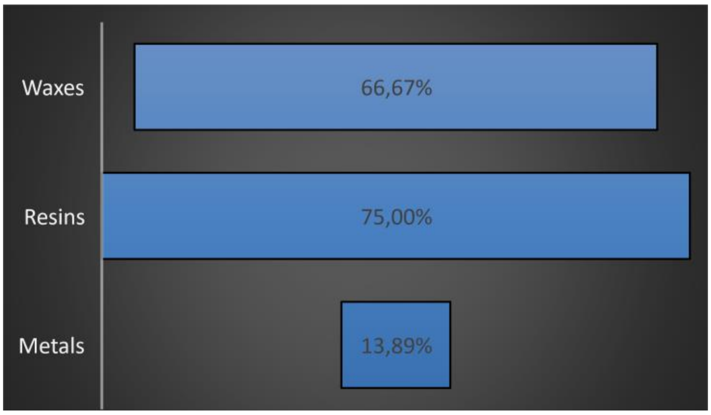

Figure 78 - Materials used for 3d printers

7. ANALYSIS OF RESPONSES: PRODUCTION TIME

This section shows the answers regarding the timing of the various processes that are compared with the data obtained from the analysis of Progold. Below the results (Figures 79,80,81).

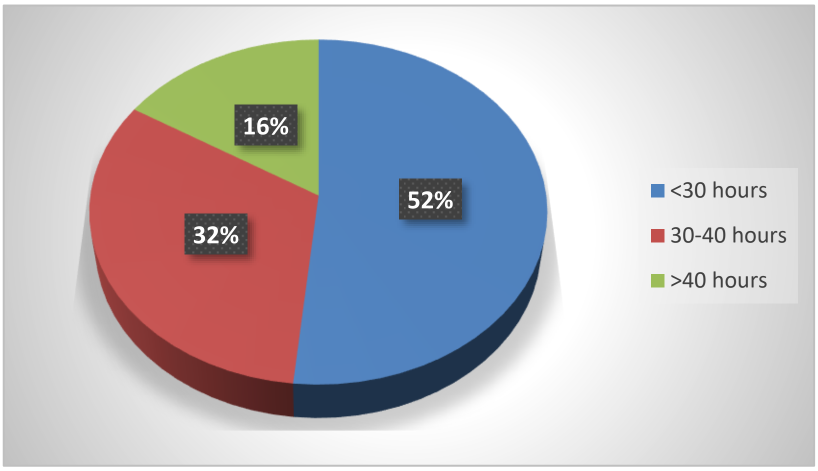

Figure 79 - Timing for traditional investment casting

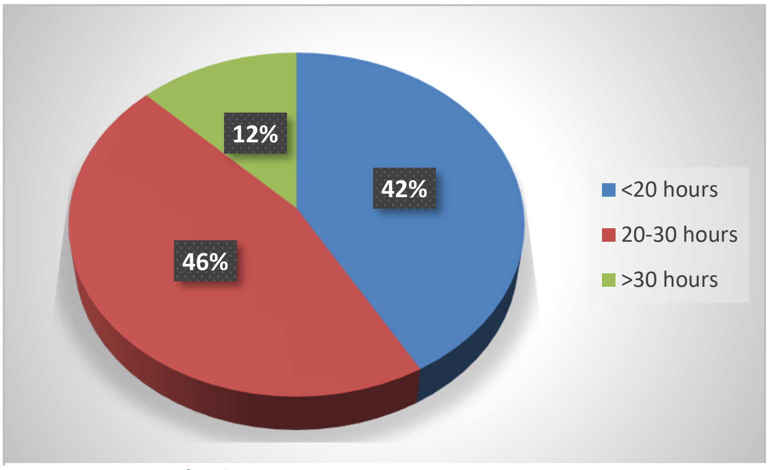

Figure 80- Timing for direct investment casting

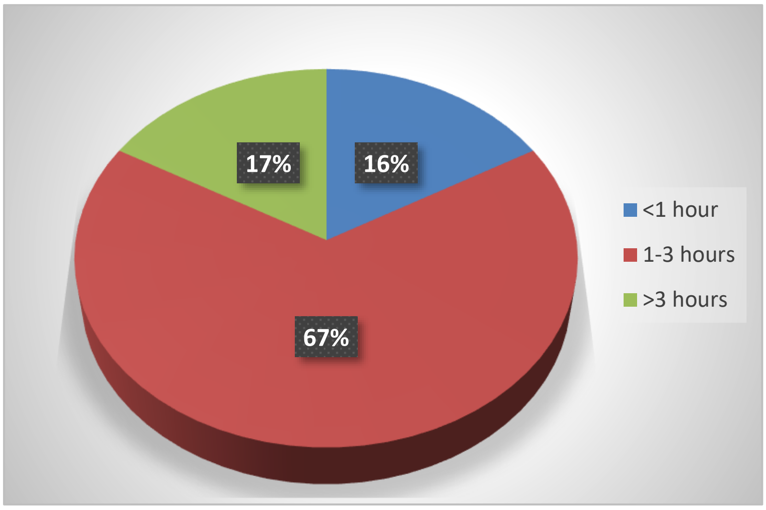

Figure 81- Timing for SLM

While for the SLM the times are more or less those that were proposed by Progold, it is possible to note that for classic and direct microfusion, a good percentage of the companies (in order 52% and 42%) that use them have indicated that the process lasts less than seen in the previous chapter. This, especially in the case of traditional investment casting, is certainly due to the know-how developed over time being techniques used for many years.

8. ANALYSIS OF RESPONSES: FUTURE PERSPECTIVES

In this paragraph the analysis is different for the company who adopt AM and for the other that not adopt. Among the company that does not use 3d printers in their production processes only the 18,75% was interested in investing resources into 3D technology. These figures might be justified by the fact that the majority of which not planning to switch their current production processes were made of micro firms whose brand image rests on handcraft and luxury principles. Among the enterprises using 3d printers 75 % were planning to go on investing resources. This shows how once AM techniques are implemented in the company's processes the benefits are immediately recognized and the innovation brought by this technology has a positive impact on the company.

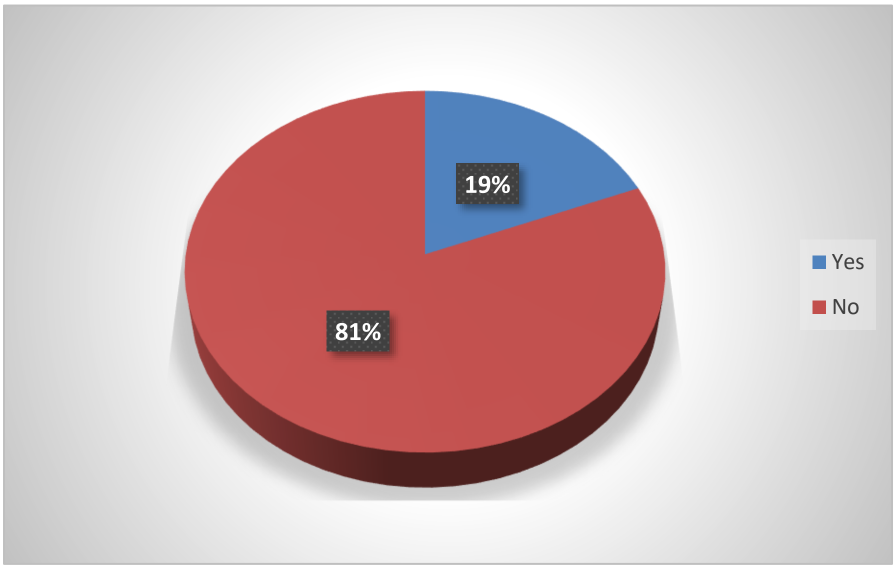

Figure 82 - Future perspectives for the company does not adopt AM technologies

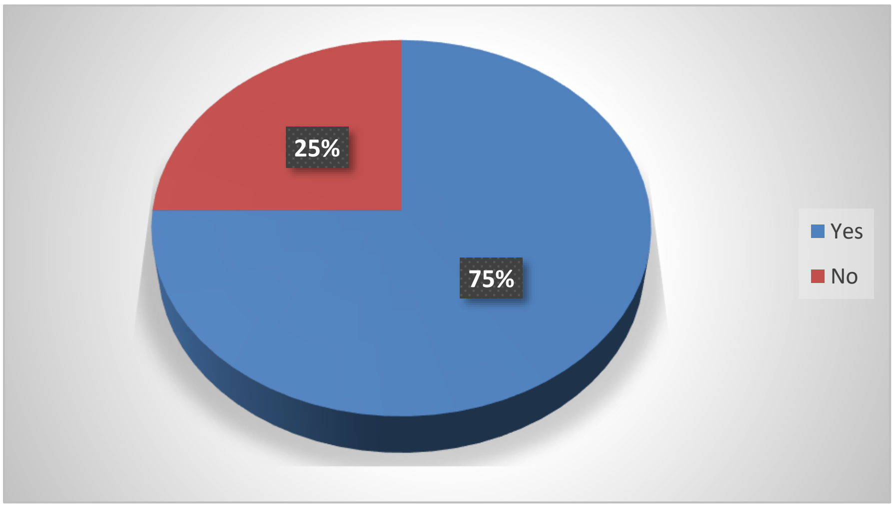

Figure 83 - Future perspectives for the company adopt AM technologies

CONCLUSIONS

AM technologies are now quite mature technologies and you can see that they are also used to produce parts for sensitive sectors such as medical or aerospace. The idea that 3D printing can only be used for prototyping is now outdated and many industries are also taking advantage of the use of this technology to produce the finished product directly. The aim of this thesis was to analyze how much AM technologies have penetrated in the goldsmith sector and more specifically in the Italian goldsmith sector, analyzed through the three main districts of Valenza, Vicenza and Arezzo. The Italian goldsmith industry, analyzed in depth in chapter 2, is known all over the world for its history and for the quality of the finished product. The three main districts of the peninsula, despite the difficulties due to the pandemic covid, have managed to maintain a high level of exports not only in Europe but also in America and Asia. The studies of Progold, analyzed in chapter 4, shows how the advantages of the introduction of the SLM technique within the goldsmith context are evident in spite of disadvantages due to costs and production in series. The SLM compared to the two most widely used techniques in the goldsmith industry, Direct Investment Casting but above all the historical technique of lost wax casting (presented in detail in chapter 3) shows advantages in the production of small batches of jewelry. In a world increasingly marked by the exclusivity of the product, Selective Laser Melting can give a competitive advantage not of little account when used within the production processes. Another important use of 3d printing is to produce models for the direct microfusion process in less time and especially with greater precision. For this reason, Chapter 5 presents the adoption of these techniques in a cutting-edge market in this sector such as the Italian one. The analysis was carried out through questionnaires submitted to companies in the districts of Valenza, Arezzo and Vicenza. Although not so many responses were collected, the data collected give an idea of the current situation of Italian goldsmiths in the field of 3d printing for goldsmith production. The adoption rate is just over 50% within the sample and this shows that the abandonment of traditional techniques, for a market that makes tradition a cornerstone, is not simple. The prevalence of micro and small companies, in addition to affecting adoption, also affects investments, which in a few cases are more than 100 thousand euros. The most widely used technique is that of lost wax casting, flanked in many cases by direct microfusion. A very important data that has emerged is that relating to the use of the SLM technique since only 8.33% of adopters use Selective Laser Melting. Firms, indeed, are still sceptical about the maturity of such technology. Especially micro and small ones are afraid of switching to a new technology that would change their production process radically requiring big capital investments as well. Although companies that have not adopted additive techniques have indicated in large numbers that they do not intend to invest in 3d printing in the coming years, a large percentage of adopters have indicated that they want to invest in technology in the future. This shows how once AM techniques are implemented in the company's processes the benefits are immediately recognized and the innovation brought by this technology has a positive impact on the company.

APPENDIX A

Questions and answers uniformed from the three different questionnaires

*Campo obbligatorio

Informazioni generali sull'azienda

1. Qual è il nome dell'azienda? *

2. Qual è il numero di impiegati dell'azienda? *

Contrassegna solo un ovale.

- 0-10
- 11-50
- >50

3. Attualmente l'azienda utilizza delle tecnologie di Additive Manufacturing (stampa 3D) nel suo processo di produzione? *

Contrassegna solo un ovale.

- Si *Passa alla domanda 4.*
- No *Passa alla domanda 15.*

Additive

4. Le stampanti 3D usate durante il processo produttivo sono di proprietà dell'azienda? *

   Contrassegna solo un ovale.

   - Si
   - No
   - Non usiamo questo tipo di tool

5. Qual è il numero di stampanti 3D di cui dispone l'azienda? *

   Contrassegna solo un ovale.

   - 1
   - 2
   - >=3

6. Con quale frequenza vengono impiegate la/e stampante/i 3D? *

   Contrassegna solo un ovale.

   - Giornalmente
   - Una volta a settimana
   - Due volte a settimana
   - Più di due volte a settimana

7. Il/i motivo/i per cui sono state adottate stampanti 3D per il processo produttivo aziendale è/sono *

   Contrassegna solo un ovale.

   - Creare un nuovo modello per valutarne la fattibilità per la produzione in serie
   - Produrre i gioielli in serie
   - Facilità della customizzazione del prodotto

8. I materiali utilizzati nei processi di stampaggio 3D sono principalmente *

Seleziona tutte le voci applicabili.

- [ ] Resina
- [ ] Cera
- [ ] Metalli
- [ ] Altro: ____________________

9. Qual'è l'ammontare dell'investimento annuo dal 2014 al 2021? *

Contrassegna solo un ovale.

- ( ) <=50.000 €
- ( ) 50.000€-100.000€
- ( ) 100.000€-300.000€
- ( ) Oltre 300.000 €

10. Sono previsti ulteriori investimenti nei prossimi anni? *

Contrassegna solo un ovale.

- ( ) Si
- ( ) No

11. L'attuale processo di produzione su quale tecnologia si basa? *

Seleziona tutte le voci applicabili.

- [ ] Microfusione classica- si intende il procedimento comprensivo di gommatura e realizzazione di un master
- [ ] Microfusione diretta- si intende il processo di gommatura diretta sul prototipo creato dalla stampante 3D
- [ ] Fusione Laser Selettiva SLM- si intende la sintetizzazione di polvere in oro da cui si ottiene il prodotto direttamente semifinito

12. Se la tecnologia aziendale di produzione usata è la Microfusione tradizionale, qual è la durata del processo che va dalla prototipazione alla spiantonatura di 1 pezzo (es. un anello a fascia)?

Contrassegna solo un ovale.

- meno di 30 ore
- tra le 30 e le 40 ore
- più di 40 ore

13. Se la tecnologia aziendale di produzione usata è la Microfusione diretta, qual è la durata del processo che va dalla realizzazione del prototipo a quella di 1 pezzo (es. un anello a fascia)?

Contrassegna solo un ovale.

- meno di 20 ore
- tra le 20 e le tre 30 ore
- più di 30 ore

14. Se la tecnologia aziendale di produzione usata è la Selective Laser Melting, qual è la durata del processo che va dalla preparazione della stampante 3D alla rimozione dei supporti di 1 pezzo (es. un anello cavo)?

Contrassegna solo un ovale.

- meno di un'ora
- tra 1 e 3 ore
- più di 3 ore

Titolo predefinito

NO ADDITIVE

15. L'azienda ha intenzione di investire risorse nelle tecnologie dell'Additive Manufacturing nei prossimi anni? *

Contrassegna solo un ovale.

- Si
- No

REFERENCES AND VISITED WEBSITES

1) Cantamessa, M., & Montagna, F. (2016). Management of Innovation and Product Development. Springer.
2) Gibson, I., Rosen, D. W., & Stucker, B. (2010). Additive Manufacturing Technologies. Rapid Prototyping to Direct Digital Manufacturing. Springer.
3) Allio, R. (2010). L'oro di Valenza. Centro on line Storia e Cultura dell'Industria .
4) Pieraccini, S. (2020, Oct 2). Oro da investimento: il distretto di Arezzo cresce e batte la crisi. Il Sole 24 Ore.
5) Moccia, M. (2018, Sept 10). I distretti della gioielleria italiana . ExportPlanning.
6) Galleri, R. (2021). Il distretto orafo di Valenza: numeri e congiunture. Intesa Sanpaolo - direzione Studi e Ricerche.
7) Zito, D., Allodi, V., Sbornicchia, P., & Rappo, S. (2017). Perchè dovremmo produrre i gioielli con stampa diretta 3D? Un confronto tra due pensieri: l'oggi e il domani. Retrieved from progold.com: https://www.progold.com/PG_Resources/PG_Documents/Innovation/SFS2017_IT.pdf
8) Vinto S. (2020, Sept 1) Additive manufacturing: una storia di brevetti.
9) FabbricaFuturo (2014, Sept 1)Materiali e stampa 3D: una nuova rivoluzione industriale
10) AMFG(2020, May 26) The Additive Manufacturing Industry Landscape 2020: 240 Companies Driving Digital Manufacturing
11) https://www.eos.info/en/industrial-3d-printing/additive-manufacturing-how-it-works?utm_source=google&utm_medium=cpc&utm_campaign=generic_EMEA&utm_content=wyn&gclid=Cj0KCQjw-pCVBhCFARIsAGMxhAdAASII8Qt-v6omoIuTFHDYJ_3Z7Hc-Jav6ElNbCN48wk09bmYAQRsaAvJREALw_wcB
12) https://www.binarioprint.it/produzione-con-la-stampa-3d/
13) https://www.makermiky.com/2020/10/processo-di-stampa-3d/4/
14) https://monza.sharebot.it/prototipazione-sharebot/additive-manufacturing-am/
15) https://www.3dnatives.com/it/stereolitografia-281020219/#!
16) https://www.eos.info/en/industrial-3d-printing/additive-manufacturing-how-it-works/sls-3d-printing?utm_source=google&utm_medium=cpc&utm_campaign=generic_EMEA&utm_content=wyn&gclid=Cj0KCQjw-pCVBhCFARIsAGMxhAc0kyiRzRuA0yUdbIhrw1B27xsZIo9Md44ZFkrA7xwaJR-WWjpQkd4aAlc-EALw_wcB
17) https://www.stampa3d-forum.it/articoli/guide/software-stampa-3d/
18) https://industrytoday.com/additive-manufacturing-trend-report-2021/
19) https://www.selltek.it/settore-stampa-3d/
20) https://www.confartigianato.it/2020/01/studi-mpi-italiane-della-gioielleria-leader-in-ue-in-italia-lartigianato-vale-come-lintera-germania/
21) https://www.almalaboris.com/organismo/blog-lavoro-alma-laboris/67-export-management/3710-oro-gioielleria-italiana-boom-esportazioni.html
22) https://www.repubblica.it/economia/affari-e-finanza/2021/07/12/news/da_usa_e_cina_la_ripartenza_dell_oro_made_in_italy-309635431/

23) https://www.artisticofirenze.edu.it/wp-content/uploads/ANALISI-FABBISOGNI-2021.pdf
24) https://www.minespider.com/blog/exploring-the-gold-supply-chain
25) http://www.storiaindustria.it/repository/fonti_documenti/biblioteca/testi/Testo_Distretto_Valenza.pdf
26) https://formlabs.com/it/blog/fusione-cera-persa/
27) https://www.progol3d.com/it-it/STAMPA-3D-DIRETTA