POLITECNICO DI TORINO

Faculty of Engineering and Management

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MASTER'S DEGREE THESIS

ADDITIVE MANUFACTURING IN THE GOLDSMITH INDUSTRY. TECHNOLOGICAL ISSUES, ECONOMIC BENEFITS AND FIRMS' ACTUAL ADOPTION

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ABSTRACT

For more than a decade now, in the world of technology has been undermined a new and powerful concept for the industrial production, it is the Additive Manufacturing (AM) which is often naively mistaken for 3D printing.
In this paper will be analyzed the most common technologies of the AM family, with a specific focus on the goldsmith industry for the production of jewels. In fact, as part of the Fourth Industrial Revolution, direct printing of precious metal jewelry deserves a continuous analysis of the state of the art to understand if and when a jeweler should prefer a new technology to the classic technique of lost wax casting. This practical and operational study aims to look at the technological evolution, giving an analysis of the merits and defects of AM jewelry printing, trying to define when and why it is convenient to print a jewel with the additive manufacturing technology.

This study aims primarily to provide an overview of additive technologies, so that the reader can begin to become familiar with the topic. In the first chapter the technologies are explained and grouped by family according to the starting base, whether solid, liquid or powdery.

The second chapter no longer focuses on the general aspect of the AM, instead focuses on the goldsmith industry. In fact, the main changes that the AM has caused in the classic and millenary production cycle of the goldsmith's art are explained. Then are described step by step the various stages of the more traditional technology of classic microfusion and those of the more innovative selective laser melting (SLM). Subsequently, an overview of the materials adopted in the goldsmith's field has been given and the importance of using the right software has been mentioned.

In order to clarify the reason why the world of the goldsmith has decided to approach the AM has been reported a list of pros and cons. The third chapter is divided by macro advantages and disadvantages, each of which is further divided and deepened.

An analysis of the goldsmith sector is dealt with in the fourth chapter. After a general introduction on the effect that the additive manufacturing can have on companies from a competitive point of view, the study moved on to the analysis of the Italian goldsmith sector. Specifically, the geographical distribution and the number of national companies, some economic values, data related to demand, import and export have been analyzed. Finally, given the particular historical period, a brief overview of what will be the future scenario was given.

The fifth chapter enters into the specifics of research, the three most adopted technologies in the goldsmith world have been compared, emphasizing those that are the most critical aspects in the industrial reality. Therefore, classic, direct microfusion and selective laser melting have been analyzed both from a technical-structural point of view, such as the problems of fusion or geometric limits, and from an economic-managerial point of view, such as time and production capacity. Moreover, it has been introduced a topic that has been very much felt so far, that of the environmental impact.

As a final analysis in the light of the assessments made in chapter four, it was decided to demonstrate how in the Vicenza market - one of the best Italian districts in the production of jewelry in the jewelry industry - these technologies have been adopted by local firms. Then this final part aims to give a practical answer to a suspended question: when and why does direct printing in precious metal jewels make sense and not?

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CHAPTER I - ADDITIVE MANUFACTURING TECHNOLOGIES

1.1 Introduction

Additive Manufacturing is an arising topic that is going to lead the manufacturing approach to a future revolution: it is able to change dramatically the way to design new products, reshape the manufacturing process and supply chains. The turning point for this revolution would be the introduction of a fast e reliable process also for metal parts.

Here follows a series of inputs, useful for understanding the various technologies illustrated. At first it is important to define what is meant by "additive technologies". In the face of some initial confusion, a standard of worldwide validity has been published, developed jointly by the regulatory bodies of various countries. According to this document (called ISO/ASTM52921-1 “Standard Terminology for Additive Manufacturing-Coordinate Systems and Test Methodologies”), additive technologies should be understood as “those processes that aggregate materials in order to create objects starting from their three-dimensional mathematical models, usually by superimposition of layers and proceeding in the opposite way to what happens in subtractive (or chip removal) processes” [1]. As a synonym of this term, is often adopted the 3D printing one, very popular in the world of makers and personal manufacture conducted with low-cost machines. The committee identifies as "3D printing" those additive processes that make products by deposition of material using a printhead, nozzles or other printing technologies. In the past, many of these applications were characterized by the definition of "rapid prototyping", now obsolete since with additive technologies functional parts and not only prototype/demonstration parts are increasingly being made.

For simplicity in the following research we will refer to the term 3D printing as a synonym of additive printing to indicate the set of technologies belonging to the additive family.

The application areas of AM are many, indeed in the last decades many are the sectors to have adopted these technologies, in Figure 1.1 it is possible to see the level of adoption.

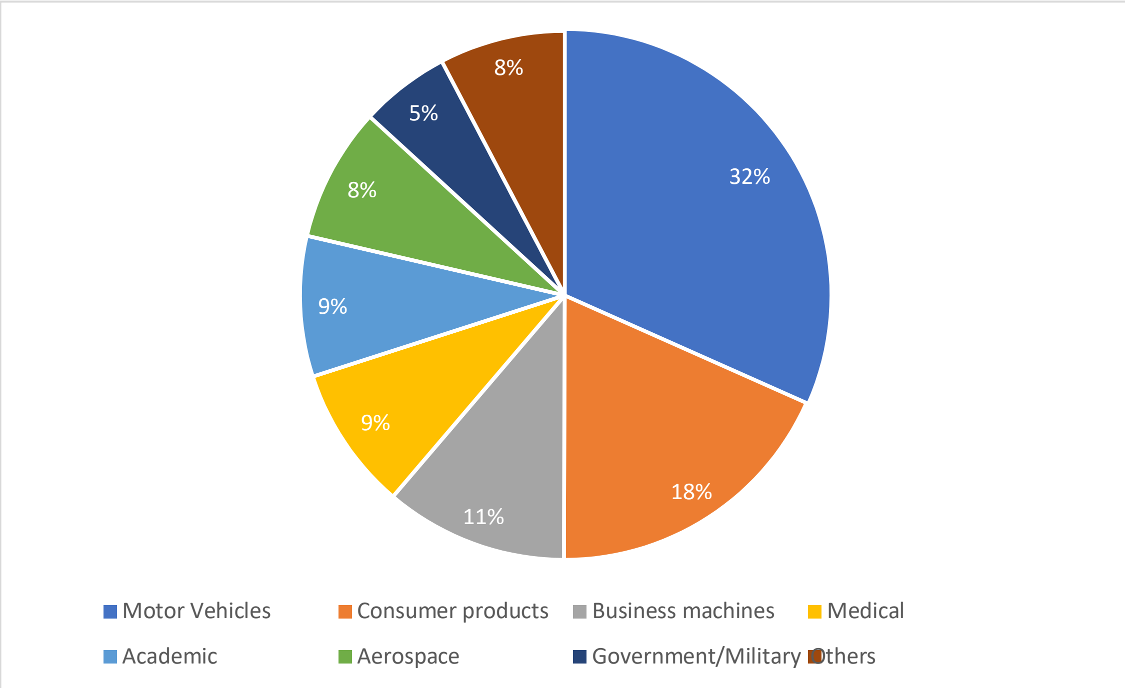


Figure 1.1 *–Industry distribution in the use of AM [2]*

As indicated in the 2018 annual report of SmarTech Publishing - the leading analytical company in the additive manufacturing market - the global additive manufacturing market generated sales of € 7.9 billion. In addition, growth in the industry has increased by 18% over the previous year, a trend that is reflected in future forecasts, which predict that by 2027 the AM printing market could exceed €35 billion.

1.2 Basic aspects of additive manufacturing

In addition to the technologies mentioned in the next paragraph, first of all there are some fundamental aspects related to additive production to be discussed, hereinafter the crucial steps in the adoption of additive manufacturing:

- Design techniques: the manufacturing process using additive manufacturing processes originates from a 3D mathematical model, theoretically generated from any three-dimensional CAD. However, the ability to generate parts with geometries virtually unrelated to the constraints of "design for manufacturing" allows the generation of geometric features "atypical" for traditional software such as, for example, trabecular structures, foam-like, honeycomb, etc., which neither traditional design nor most modeling tools are able to handle efficiently. However, software tools begin to be available that, on the one hand, allow to manage these problems and, on the other hand, to govern the design phases by integrating the definition of the geometries with the simulation. Traditional design approaches need to be revised in order to take advantage of the degrees of freedom offered by the new technology. A difficulty that is found in industrial realities is the ability to make the 3D drawing actually feasible in the production process, here lies the ability of the designer to focus not only on the aesthetic aspect but also on the operational and practical one.

- Post-processing: metal parts made using technology have levels of finish and geometric and dimensional tolerances comparable to those achievable using traditional foundry techniques. This requires machine tool rework that must be carried out considering, on the one hand, the characteristics of the machined materials (often difficult to chip) and, on the other hand the non-conventional geometries allowed by additive technologies. Moreover, in some applications it is necessary to carry out post-treatments to improve the metallographic and mechanical characteristics of the part.
- Process characterization: it is necessary both for "in-process" activities that guarantee a qualitative constancy of the generated products and to characterize the incoming and outgoing materials from the process.
- Generation of raw materials: cost, availability and quality can influence the technological and economic performance of the processes. Cost, availability and quality can greatly influence the technological and economic performance of processes. The application of additive technologies indeed must reckon not only with the success of the finished product, but also with the ability to find at a reasonable price the material for example necessary for the printing of the prototype.

1.3 Technologies description

The technologies for Additive Manufacturing (AM) make it possible to produce in a few hours and without the use of tools - objects of complex geometry, directly from the mathematical model of the object created on a three-dimensional CAD system.

There are requirements and conditions in favor of the application of AM:

- 3D CAD model of the product;
- product with shape and/or material too complex to be economically realized with conventional technologies;
- product to be made in a single piece or in a very limited series.

The additive manufacturing technologies are many and differ according to the method of prototyping and the materials used, as shown in Figure 1.2.

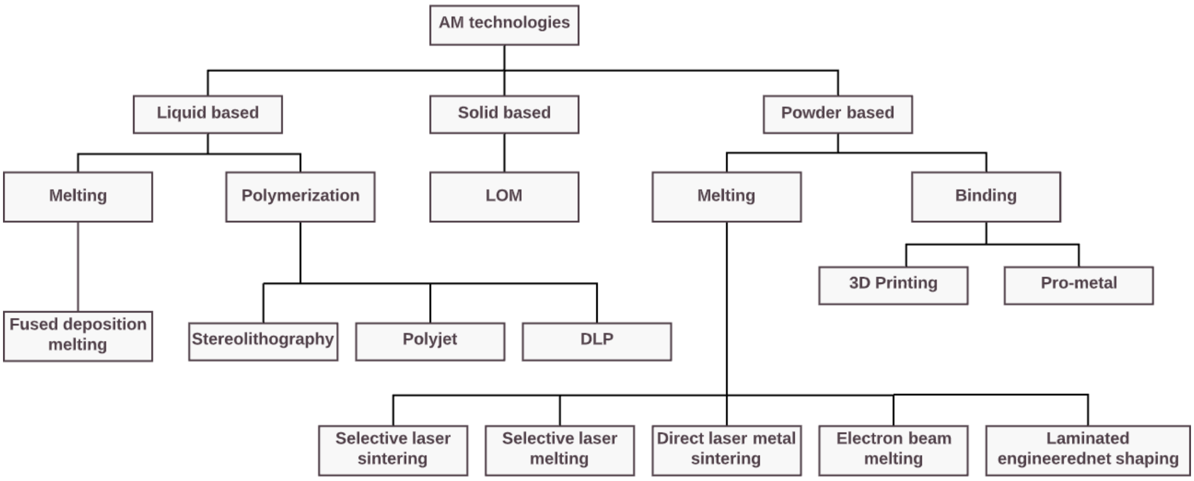


***Figure 1.2** – Summary table of macro technologies [3]*

Below - among the technologies based on the use of powder or liquid or solid, as reported in Figure 1.2 - are described some of the most common techniques.

1.3.1 LIQUID BASED TECHNOLOGIES

Stereolithography – SLA

It is the most diffused process in the category of photopolymerization. SLA is based on the selective solidification of a liquid polymer by electromagnetic radiation provided by a laser or similar.

This technology uses epoxy resins that allow the production of extremely detailed models even with perfectly transparent resins. Materials adopted have a high modulus of elasticity and are suitable for functional prototypes and mechanical tests.

SLA technology is particularly suitable for the production of models with high surface detail, useful for coupling tests, dimensional checks and ergonomic tests.

Stereolithographic processes produce 3D solid objects in a multi-layer procedure through the selective photo-initiated cure reaction of a polymer. These processes usually employ two distinct methods of irradiation, either a mask-based method (in which an image is transferred to a liquid polymer by irradiating through a patterned mask) or by direct writing (using a focused UV beam). The photopolymerization causes the material to cure and solidify, subsequent layers are built up by recoating and curing over the previous layers. This allows for the highest accuracy a resolution. Different resins have been processed using SLA, such as biodegradable resins but the technique is mostly limited to the use of a single resin at a time.

Ideal applications for stereolithography:

- Aesthetic parts with smooth surface;
- Rapid prototyping of small and very detailed parts;
- Prototypes for short functional tests;
- Aesthetic prototypes/concept models for exposure;
- Lost wax casting models.

If the prototype is small in size and requires high accuracy and smooth surface finish, SLA printing is the most suitable technology.

The SLA rapid prototyping technique has the following principle of operation:

1. The construction platform is first placed in the liquid photopolymer tank, at a distance from the bottom equal to one layer.
2. Then a UV laser accurately cures and solidifies the liquid resin.
3. At the end of a layer, the platform is lifted and the process is repeated until the part is completed.
4. Once the prototype is dried, a process is performed to increase the mechanical properties.
5. Finally, the support structures are removed manually and finished on request.

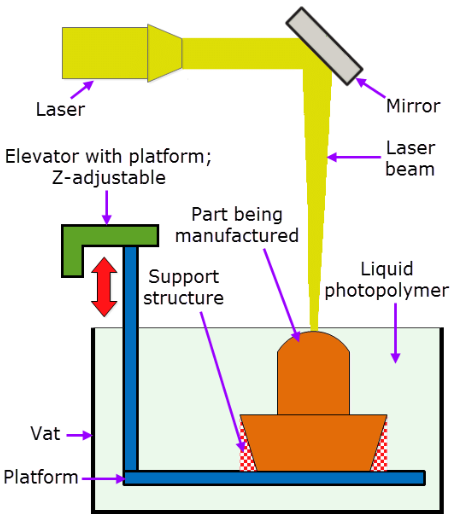


Figure 1.3 *– Schematic representation of the SLA process*

Fused Deposition Molding - FDM

This process is the most diffused technology of the extrusion category, FDM is the traditional example of extrusion-based processes. The material (usually polymer), brought to the pasty state, is selectively distributed through an orifice which through two extruders deposits the material layer by layer.

FDM technology produces products in the final plastic material; the possibility to create large models using materials with exceptional mechanical properties is a great advantage in terms of prototyping.

A wide range of materials can be used, each with different thermal and mechanical properties, such as self-extinguishing or fireproof materials. FDM is restricted to the use of thermoplastic materials with good melt viscosity properties and, therefore, cells cannot be encapsulated into due to the harsh processing conditions some dispensing equipment variations have been registered, using lower production temperatures, multi-material deposition devices and/or crosslinking/ solidification/curing techniques.

In the fused-deposition modeling (FDM) process, an extrusion head controlled by a gantry robot moves on a table along two main directions. The table can be raised and lowered as required. A thermoplastic filament is extruded through a small opening in the heated die. The initial layer is placed on a foam support extruding the filament at a constant speed while the extrusion head follows a predetermined path. When the first layer is completed, the board is lowered so that the subsequent layers can be overlapped. Usually the backing material is extruded with a larger deposition step, so that it is weaker than the model material and can then be broken after completion of the workpiece. In the FDM process, the thickness of the extruded layer is determined by the diameter of the extrusion die and is typically between 0.35 and 0.12 mm.

This thickness represents the best dimensional tolerance obtainable in the vertical direction. In the x-y plane, however, the dimensional accuracy can reach a value of 0.025 mm, as long as a filament can be extruded within the geometric characteristic. A close examination of a workpiece using FDM can indicate the existence of a stepped surface in the outer oblique planes. If the roughness of this surface is unacceptable, chemical vapor polishing or a hot tool can be used to smooth the surface; in addition, a coating, often in the form of polishing wax, can be applied. Overall dimensional tolerances can be compromised by not paying particular attention to the execution of these finishing operations.

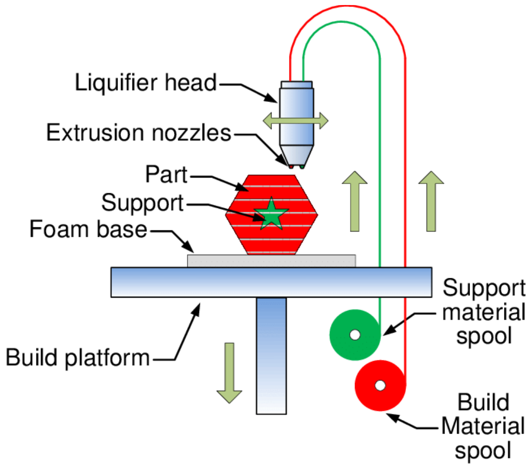


Figure 1.4 *– Schematic representation of the FDM process*

<u>*Polyjet - PJ*</u>

The polyjet process is similar to inkjet printing, where many print heads deposit the photopolymer on the construction plate.

UV lamps, positioned laterally with respect to the jets, cross-link and harden each layer immediately, thus eliminating the need to conduct that cross-linking operation after the typical stereolithography modeling. The result is a smooth surface consisting of thin layers up to 16 micro-m, which can be manipulated immediately after completion of the process. Two different materials are adopted in rapid prototyping: one material is used for the model, while a second polymer, similar to a gel, is used for the substrate. Each material is deposited and cross-linked simultaneously, layer after layer. When the model is complete, the substrate is removed with an aqueous solution. The polyjet process has similar capabilities to stereolithography and uses similar polymers. The main advantages are the ability to avoid time-consuming cleaning and especially post-process cross-linking and the much thinner layer thickness, which allows better resolution.

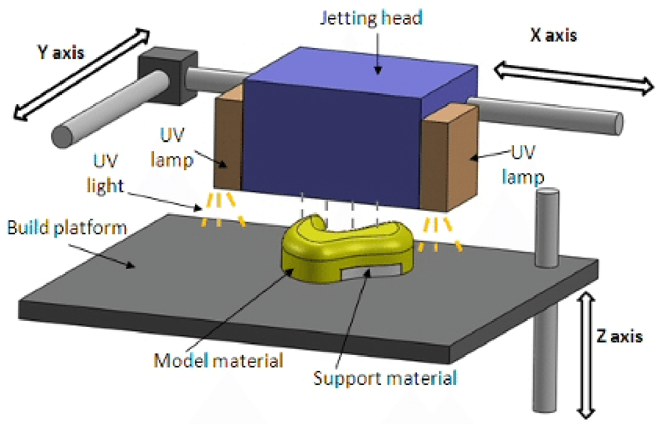


Figure 1.5 *– Schematic representation of the Polyjet process*

1.3.2 POWDER BASED TECHNOLOGIES

Selective Laser Sintering – SLS

The SLS is the ideal technology for the production of small batches or for the construction of large models, whose components will be subsequently assembled and finished in our post-production department. With SLS technology, functional and aesthetic prototypes can be produced with the desired surface finish.

A wide variety of materials can be used in this process, including polymers (ABS, PVC, nylon, polyester, polystyrene and epoxy resin), waxes and metals, as well as ceramics together with appropriate binders. The adoption of polymers is much more common, due to the smaller, less expensive and less complicated lasers these materials require. With ceramics and metals, it is common practice to sinter only a mixture of polymer binder and ceramic or metal powders; the sintering is then completed in the furnace.

(SLS, selective laser sintering) is a process based on the sintering of a polymeric (or metallic) powder to obtain a finished object. The bottom of the process chamber is fitted with two cylinders: a workpiece construction cylinder, which is lowered incrementally as the sintered part is formed, and a powder feed cylinder, which is stressed incrementally to supply the powder to the other cylinder through a roller mechanism.

A thin layer of powder is initially deposited into the construction cylinder. A laser beam, guided by microprocessor control (using the instructions generated from the 3D CAD model of the part), is then focused on that layer, tracing and melting (or, for metals, sintering) a particular section, which will then quickly solidify into a solid mass (after the laser beam has moved to another section). The powder in the other areas remains inconsistent, but it is still able to support the solid portion. Another layer of powder is then deposited and this cycle is repeated continuously until the three-dimensional part is completely produced. Particles that have not been melted (or sintered) can then be removed and recovered.

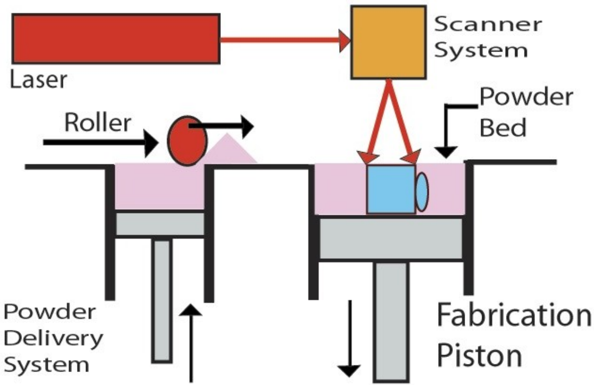


Figure 1.6 *– Schematic representation of the SLS process*

<u>Electron Beam Melting - EBM</u>

Electron beam melting: Electron beam melting (EBM, electron-beam melting) is a process similar to SLS and electron beam welding and uses an energy source associated with an electron beam to melt titanium powders and make metal prototypes. The part is produced under vacuum and its dimensions are limited. From an energy point of view, this process has an efficiency of 95% (compared to 10-20% laser sintering efficiency) and this means that the titanium powder is actually melted and full density parts can be produced.

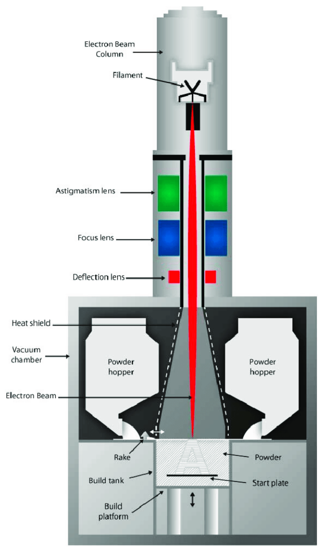


Figure 1.7 *– Schematic representation of the EBM*

Three-dimensional Printing – 3DP

In the three-dimensional printing process (3DP, three-dimensional printing), a printhead deposits an inorganic binder on a layer of non-metallic or metallic powder. A piston, which supports the powder bed, is lowered incrementally and, at each step, a layer is deposited and then melted by the binder. Three-dimensional printing provides considerable flexibility in the choice of materials and binders. The most commonly used materials are polymer and fiber blends and even metals. In addition, since multiple heads can be incorporated into a single machine, it is possible to produce color prototypes with different colored binders. The effect is a three-dimensional analogue to photos printed using inkjet printers with three colored inks. The components produced through the 3DP process are a bit porous and therefore may not be strong enough. Three-dimensional printing of metal powders can be combined with sintering and metal infiltration to produce components with full density. In this sequence, the part is constructed as described above, directing the binder onto the powders. However, the construction sequence is followed by sintering to volatilize the binder and partially melt the metal powders, just as is done in metal injection molding. Among the metals commonly adopted in the 3DP process are stainless steels, aluminum and titanium. Infiltration materials are typically copper and bronze, which give good heat transmission characteristics and wear resistance.

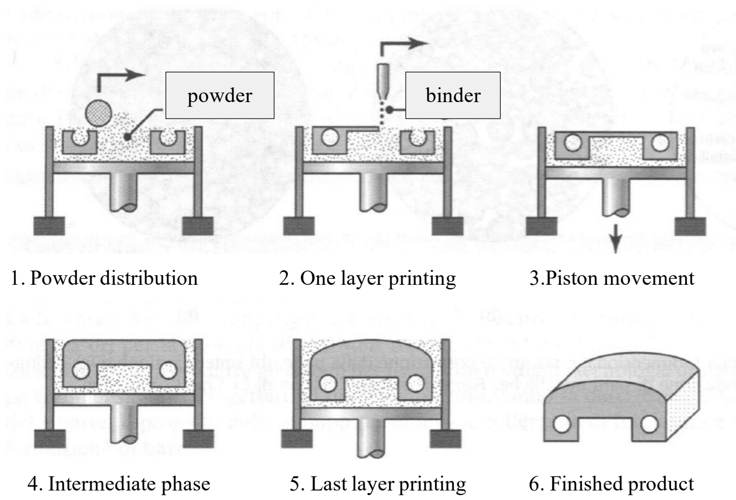


Figure 1.8 *– Schematic representation of the 3DP process*

Direct Metal Deposition Laser Sintering – DMD/SLM

DMLS and SLM are processes that allow the construction of metal parts directly from fine metallic powder, suitable for the production of parts that need a finishing process to be used as finished products.

- DMLS (Direct Metal Laser Sintering) uses a laser system that draws on the surface of atomized metal powder, melting the part that subsequently solidifies. After each layer, a blade adds a new layer of powder and repeats the process until the final metal parts are formed.
  The DMLS allows to produce parts with mechanical properties equal or superior to those built with traditional techniques, with a high degree of precision and a good level of detail. With aluminum, titanium, silver and titanium alloys it is possible to build prototypes, final components and series production up to a hundred pieces.
  The high precision and accuracy of details allow to produce parts for the goldsmith industry and the adoption of materials such as titanium makes DMLS technology suitable for the production of medical and dental prosthesis.
- SLM (Selective Laser Melting) melts metal powders into a homogeneous mass instead of sintering them, the SLM technique differs from SLS in that it involves complete fusion of the particles by the laser beam instead of surface welding due to temperature. The materials that can be used are the same as DMLS and the layers that can be obtained have thicknesses from 20 to 10 µm; the products obtained, in terms of finish and performance, are similar to those of other laser beam technologies.

The two technologies allow the realization of prototypes directly in metal, ready to be tested or already usable as final elements.

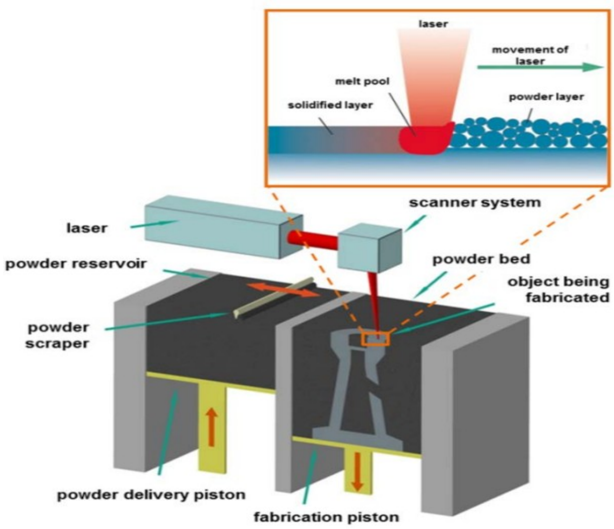


***Figure 1.9** – Schematic representation of the SLM proces*

1.3.3 SOLID BASED TECHNOLOGIES

Laminated Object Manufacturing - LOM

Details are created on a building platform (1), which is supplied with thin construction material from a feed roller (2). The material usually adopted are paper, plastic or metal foil. After each layer, the building platform is lowered and it is fed with new layer of material. The building material is usually provided with heat-activated glue and a heated lamination roller (3) is passed over the building platform to join each new layer.

A laser cutter (4) or knife, cuts a cross section of the model as well as a grid patternt in the excess material to makte it easier to remove as a post process.

Some machines have an integrated color printer which allows printing of full color models.

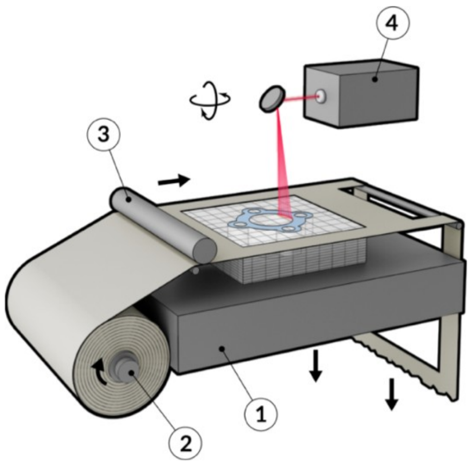


***Figure 1.10** – Schematic representation of the LOM process*

1.4 Software

The large software houses have shown interesting progress both on the modeling side of particular geometries and on the CAM optimization side.

Modern software not only allows the creation of the 3D model but also incorporates many support functions to ensure high quality of the printed product.

Among the first tools there is the topological optimization strategy that allows to create an optimized geometry characterized by high quality surfaces thanks to an integrated module for Finite Elements Analysis (FEM) analysis, a topological optimization tool through the use of customizable reticular structures.

On the other hand, there are software that implement the compensation of distortions due to printing processes to support the most complex geometries. CAD programs, as well as most digital images from television to computers, are based on a grid of square pixels, while some 3D printers use diamond-shaped pixels, presumably to circumvent existing patents; however, for 3D printing, the square shape of pixels is considered by many to be crucial to provide high resolution and sharp details on jewelry-specific miniaturized textures, such as micro settings.

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.

CHAPTER II - ADDITIVE MANUFACTURING IN THE GOLDSMITH INDUSTRY

2.1 Introduction

The production processes of the goldsmith and jewelry industry have remained substantially unchanged for hundreds of years, without real revolutions in the way jewelry is made. Only in last decades some of the technological inventions of the twentieth century, including electroforming, CNC machining, rapid prototyping, laser welding and metal injection molding, have been taken over by the goldsmith world and integrated into the production chain, leading to incisive innovations.
Sometimes these innovations have been introduced to improve old manufacturing processes consolidated over time, still widely used for their undoubted effectiveness, without opening new production paths. In other cases, instead, the adopted of technological innovations has led to total revolutions of the production process, through the use of manufacturing mechanisms completely different from the methods already existing and unthinkable until a few decades ago.
It is among these last techniques, able to completely change the production rules known until now, that the selective laser fusion is placed.

The workshop of a goldsmith is certainly a very fascinating place, full of small tools and instruments, special sparkling objects and precious gems. The traditional design of jewelry, however, is changing, moving towards digital creation.
For more than ten years rapid prototyping has been used for the development of new projects, for about five years now, thanks to the evolution of technology, the AM is used directly for the mass production of entire product lines. Another of the pioneering sectors is undoubtedly the automotive industry, but every day we meet new customers who deal with different products that adopt AM in the industry, design, dental, modeling, etc.
The resolution of AM is fundamental because the final products – precisely jewelry - are often small objects with a high level of detail, smooth surfaces are also required when using AM to create for example molds for casting.

2.2 The planning for the goldsmith's industry

Jewelry has always been a middle ground between art, craftsmanship, fashion and design, tight on the one hand, by the typical authoritativeness of the artist, on the other hand, by the fugacity of fashion. To this is added the tradition of a craftsmanship often closed in the defense of precious materials as the main guarantee of eternity. Jewelry design, in Italy, has therefore suffered from commonplaces, linked to the idea of the necessity of the unique piece, of the aesthetics of tradition, of precious and expensive materials, until the '70s and '80s of the last century when great Italian designers and architects tried, on several occasions, in the creation of jewelry. But already in the late '50s a new generation of goldsmiths began to treat jewelry as a work of art, challenging its role in society and rejecting the conventions in which it was contained.

Today, in the shared idea of modern jewelry, the richness of the idea prevails over the preciousness of the object. This means that from the design point of view a great possibility of innovation has been created by welcoming the most advanced technology, in a new vision that aims to express a high emotional and communicative content and not material richness.

Three possible futures for jewelry: precious tradition, wearable technologies and collective creativity. This last hypothesis represents the scenario in which a territorial design can be expressed because it concerns the rethinking of creative and productive processes offering new opportunities for innovation. Among these, of particular interest is the application of additive manufacturing, which encompasses a wide and multiple family of technologies united by a process of additive material called layer by layer [4]. Available in outsourcing these processes are also changing the jewelry production industry, with the possibility of creating new shapes and finishes, otherwise not possible, allowing to print in a single construction process parts made of heterogeneous materials, and paving the way to the customization.

This technology can be used to print a high-resolution wax model from which a 'lost wax' casting can be subsequently obtained, but it can also be adopted to make the finished jewel. In the latter case there may be limitations due to the types of materials that can be used that affect both the mechanical and aesthetic properties of the finished pieces. The desire to transform this criticality into a new opportunity for innovation is the basis of this research work. In fact, experimentation, diversification and contamination between traditional and innovative materials and techniques are the watchwords to strengthen the ability to successfully oversee the complex and changing global market, generating products that are always new and highly creative.

2.3 Purposes of the AM introduction in the supply chain

The most prestigious brands in jewelry and goldsmiths, from the goldsmith's workshop to the big company, are using a 3D printer to design, prototype, quickly verify the jewel and decide whether or not to produce it.

Some of the AM technologies are ideal for the realization of small prototypes in high resolution to obtain the finest details. Among these, the stereolithography laser printer is the ideal tool to create 3D models for jewelry, thanks to the possibility to print in three dimensions with specific materials for jewelry applications.
The AM has the unique feature of testing the technical feasibility of jewelry, the printer technology is an important tool to speed up the process of product design and development.
The choice of 3D printing is driven by the desire to overcome the limits of manual production and the desire to experiment with innovative techniques. Being able to maintain a perfect balance in the game of full and empty spaces and to achieve minimum thicknesses.

The ability to successfully introduce this new technology coherently and efficiently into a business, whether it be jewelry design, manufacture, retail or e-commerce is key to the AM supply chain but it will inevitably provoke change and adaption at the organizational level. Obviously for customized items all data collection and design methods will need to be re-assessed and tailored. Depending on the supply chain variant adopted, many key decisions will need to be made such as to whether to purchase AM technology and operate it 'in house', or to purchase AM production from a third-party supplier. Both options impact on logistics and distribution but quite possibly the largest and to date unknown impact could well be on a company's culture and how, or if, it changes to accommodate AM. Those considering adopting AM principles either fully or in part should also consider the following tactical business strategies and paths as part of their business model or supply chain conundrum.

2.4 Traditional Process – Lost wax casting

Since the dawn of the lost wax casting, the realization of the artefacts has always required the presence of a model to be reproduced, created separately in manually moldable material, establishing already in origin the impossibility of a direct construction of the objects conceived by the artist or the craftsman.
The lost wax casting involves a considerable complexity of process, due to the production of rubber molds, the assembly of trees and the firing of refractory molds for the casting of the alloy, as well as a considerable environmental impact due to the combustion gases of waxes and the disposal of refractory materials, in the Chapter V there is a deepening on this issue. [5]

In the traditional production process – also called classic microfusion - there are a series of crucial stages, each of which requires technical knowledge:

2.4.1 Design creation

In order to produce a unique piece, the very initial step is to create a design. It is a stage wherein the designer develops an idea for the shape, evaluates the idea and translates it into reality following the next steps.

2.4.2 Creation of a primary model

Once the design sketch is ready, the craftsman with excellent manufacturing skills makes the first wax prototype by hand. It is handmade and is a unique piece that requires the highest precision and meticulousness as well as creative ability for the realization.

2.4.3 Production of a silver master

The wax model is then converted into the silver model using the casting process. The silver model is a master design that is copied to make many similar jewelries. The silver pattern is used to create the rubber mold with which all subsequent pieces are made.

2.4.4 Creation of a silicone / rubber mold, for wax injection to make mass-produced products

In order to be able to reproduce the desired model several times, it is first necessary to make a matrix in a material that ensures high reproduction fidelity, good elasticity, good memory and long life. There are different types of materials adopted for mold making like natural rubber and silicone.

For this purpose, a special rubber is used which, after being applied around the model, undergoes a heat treatment, called vulcanization, which first causes it to soften and then harden. The matrices obtained by vulcanization can be of two types: tear or whole.

Hot rubberizing phases:

- To produce a "tear-off" matrix, the two layers of rubber between which the model is closed are sprinkled with a layer of talcum powder or spray to prevent the surfaces from adhering to form a single block. In order to ensure the perfect re-closing of the matrix, together with the model, some reference pins are also incorporated in the rubber.
- In order to produce a "whole" matrix, in this case, the complete model of the column that will form the sprue is simply inserted between two layers of rubber.
    - The rubber "sandwich" containing the model and well compressed between the plates of the bracket is ready to be vulcanized.

- The bracket is inserted into the vulcanizer for heat treatment. The vulcanization temperature is generally between 140 °C and 180 °C and depends on many factors such as: the type of rubber, the thickness of the matrix and the vulcanization time (30 ÷ 75 minutes).

Once cooled, the matrix is opened and the model is extracted. In the case of tear-off dies it is sufficient to open the two halves of the die, while in the case of whole dies it is necessary to use a scalpel. The cut is specially made in a zig-zag pattern in order to facilitate the correct re-closure of the two parts when the wax is injected.

Figure 2.1 *– Wax models extracted from the mold*

In case the jewel needs the setting of stones, between the exit of the wax ring and the assemblage of it on the tree, the stones are set by hand.

Figure 2.2 *– Stones assembled on the wax model*

2.4.5 Waxing /Wax tree

This phase involves the production of wax pieces from rubber molds made with the silver master. The rubber mold is placed on the commercial wax injecting machine. First the machine creates the vacuum in the mold, and then inject the molten wax into the mold cavity by pressure to create wax models for casting.

Once the wax mold creation process is iterated through the rubber mold, the process of welding the wax pieces onto a wax stem which is called "treeing" takes place. A sprue is attached to each piece, which in turn is attached to the stem. The shaft is such that the heavier pieces are at the bottom of the shaft and the lighter pieces at the top. To avoid the formation of air bubbles during injection, the most modern injectors are equipped with an air suction device that allows to obtain perfect "waxes", improving productivity.

Figure 2.2 *– Assembled wax tree of wax rings*

Source: see [5]

2.4.6 Casting of cylinders

The shaft created in the previous phase is inserted in a cylinder that is filled with plaster, once solidified this cylinder is transferred to a special oven called "wax stove" in which the bunch of wax is melted and through a hole placed at the bottom of the cylinder comes out of the plaster. The temperatures reached by the machinery vary depending on the type of alloy, the object to be made and many other factors, indicatively the temperature reaches 700 degrees.

Casting is a very complex process and requires utmost skilled and experienced casters.

Figure 2.3 *– Cylinder baking machinery for wax leakage and cylinders inside the machinery*

Once the wax is emptied, the still hot cylinder goes directly into a second furnace where it is fired so that the coating acquires the necessary hardness to resist the impact and heat of the molten metal. Again through the same machinery, the metal is melted and then poured into the cylinder, left to cool, then melted to reveal the jewelry in the form of fusion.

Figure 2.4 *– Metal casting machinery in the cylinder emptied of wax*

2.4.7 Grinding

Once the raw casting is clipped off from the casting tree, it has a tiny nub leftover at a place where the gold piece was attached to the sprue. The polisher grinds off this nub using the motorized grinding machine, which acts as an abrasive to smooth the surface of the gold piece/jewelry. A final polishing is then done by holding the piece against a spinning grinding wheel to achieve a smooth surface.

2.4.8 Filing/Assembly

Filing is a technique that helps in removing excess metal or solder from a piece that is being worked on. It is a process wherein the casting layer is removed by using different tools like files and burrs. It gives a smooth finish to the piece. Assembly is the process where two or more component of the same design are joint with the help of solder or laser technique.

2.4.9 Polishing

Polishing offers a neat finish and enhances the value of a piece. Polishing involves three steps, tumbling, pre polishing, and ultra-cleaning. Jewelry pieces with diamonds require pre polishing before the diamond is set. In polishing, the idea is to add shine to the entire piece of jewelry. Polishing is done after setting of stones and it can be done either by hand or by machine.

2.5 Process evolution through AM – Direct Microfusion

This new technique differs from the previous one only in the initial phases. Due to the introduction of new techniques in the market, such as AM, even the traditional goldsmith industry has caught up with the times. Rather than trusting in the craftsmanship of the master model maker, the help of AM printers has allowed the elimination of two steps in the initial phase of the production process.

2.5.1 Design creation

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.5.2 Creation of a primary model

The CAD software is used to increase the productivity of the designer, improve the quality and dimensional accuracy of design, and to create a database for manufacturing. Once a design is conceptualized in the mind of the jewelry designer, it is drawn on paper and then into the system. This process of constructing a design into the system is facilitated through Computer Aided Designing technology.

2.5.3 Creation of a model

Once the CAD design file is ready, it is transferred to the preferred system for prototype printing. The technologies adopted vary depending on the accuracy requirements and the type of material used, be it resin or wax.

2.5.4 Waxing /Wax tree

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

Nowadays with the new technology, instead of printing a mat of pieces that should then be assembled on the tree, now it is possible to directly print the tree skipping a further process. In terms of time, however, it would not see great advantages when printing a size similar to the tree in Figure 2.2 requires more time if not to do it by hand.

Figure 2.5 *– Palette with newly printed jewelry with the SLA technology*

2.5.5 Casting of cylinders

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.5.6 Grinding

As what described in paragraph 2.4, with the difference that the product has to be cleaned from supports required during the printing process.

2.5.7 Filing/Assembly

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.5.8 Polishing

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.6 Fully AM Process – Selective Laser Melting

The emerging process, not yet fully adopted by goldsmith companies, upsets the traditional process in jewelry creation.

Only the two initial stages of CAD/CAM design and the final stages of surface finishing remain unchanged, what completely changes is the central process. Indeed the multiple intermediate steps that characterize the traditional production process are replaced by a single step performed by the SLM machine. Metals that can be used for the jewel creation mostly are 18K gold alloys (Au-Ag-Cu), Platinum alloys (950 Pt/Ru, PtIr20, Pt-Au) or Palladium alloys.

2.6.1 Design creation

This step of the production process is equivalent to the traditional process, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.6.2 Creation of a primary model

This step of the production process is equivalent to the traditional process, so please refer to what described in Paragraph 2.5 to avoid repetitions.

2.6.3 Printing of the final product

In selective laser melting (SLM) - illustrated in Figure 1.9 and explained in Chapter I - there is an increase in temperature required to melt the gold powder to exceed the liquidus point of the alloy. Due to the interaction between the radiation of a thin laser beam and the material to be melted, the melting in a given instant is very localized and affects only a narrow area around the beam radiation point. The solidification of the alloy is extremely rapid as the laser continues to scan and therefore the amount of material that instant by instant is involved in the melting process is minimal. Objects grow through the addition of solid material, without macroscopic movement of molten metal masses.

Figure 2.6 *– Sample of finished products on the plate just released from SLM printing*

2.6.4 Grinding

As in paragraph 2.4, with the difference that the product has to be cleaned from supports fundamental for the printing process.

2.6.5 Filing/Assembly

This step of the production process is equivalent to the traditional process, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.6.6 Polishing

This step of the production process is equivalent to the traditional one, so please refer to what described in Paragraph 2.4 to avoid repetitions.

2.7 Materials

Additive technologies are used to produce physical models, prototypes, components, equipment and products of various kinds, made of polymers, metals, ceramics and composite materials, but the range is rapidly expanding to other sectors.

The current panorama of the goldsmith industry is undoubtedly focused on materials with surprising aesthetic and mechanical characteristics. The materials adopted for the AM printing of jewelry are mainly high performances resins and waxes, sometimes also ceramics: from 100% wax for a perfect bonding to resin bonding to realize geometries unthinkable with traditional methods, to rubber resin to make silicone molds.

Therefore, the traditional production process for the realization of the prototype proceeded to make the model in wax and then to plate it in silver, bronze, brass or other metals of low quality but good resistance and hardness. Now AM printers replace these two processes and make it unique, also eliminating the need to buy rubber, silicone for the molds. The printers can realize the prototypes with the following materials.

- **WAXES**

  Among the class of waxes can be distinguished:

  - A 100% wax ideal for the mass production of high definition microcasting waxes. Thanks to the printing speed it is possible to realize hundreds of perfect models in a short time.
  - A non-toxic wax ideal to obtain high quality castings with any level of geometric complexity. This type of wax does not need to be disposed of in special waste. The wax-like compound is released in the form of micro-droplets to form an object with the highest precision, ideal to obtain an high quality castings with any level of geometric complexity.

***Figure 2.7** – Samples of wax printed jewels (the purple wax is the jewel itself and the white one is the support)*

- **RESINS**

  Resins enable to reliably reproduce sharp settings, defined jaws, smooth stems and refined surface details. Different companies offer their customized resins, each with different heat deflection tension, tensile modulus and strength and others**.**

  - The standard resins, the realization of jewelry prototypes must be quick and economical. Standard resins are ideal for 3D printing test and master models for cold stamping. 3D molded models are robust enough to be handled, worn, shipped to a customer, or for inexpensive custom assembly.
  - The castable wax resin is a photopolymer containing 20% reliable cast wax with zero ash and clean combustion. It allows you to render processed details with great accuracy and offers smooth surfaces that are characteristic of the best SLA printing. The printed parts are durable and do not require post-print photopolymerization, making the work process easier and leaner. For jewelry it is ideal for printing models to be tested by the customer and for the final production by microfusion. It has a print resolution that varies from 50 to 25 micron. [5]
  - The high temp resin offers a thermal distortion temperature (HDT) of 238 °C, this is the maximum temperature between the resins. It is used to print precise, detailed, high-temperature resistant prototypes, supported print resolutions range from 100, 50 to 25 microns. However, this type of resin requires post-printing photopolymerization. This resin is therefore ideal for the creation of master models to be used in vulcanized rubber molding at medium temperature.
  - The grey resin is suitable for the printing of conceptual models and robust and precise prototypes able to give shape to ideas in CAD. With a matte surface finish and precise details, the prints are ready to use directly after printing with the printer. Their neutral hue

makes them perfect for parts that will later be subjected to other finishing processes. This resin is perfect for prototyping and standard design and is excellent for reproducing small details, in fact the supported print resolutions range from 160, 100, 50, to 25 microns.

The design of the jewelry according to the particular material of the 3D models used for the realization is an important aspect to be considered for the success of the fusion.
The various materials described above, are exchanged by the companies - if the availability of the machinery allows it - in order to better manage the good output of the prototype and consequent correct expansion of the material. For example, if you consider products with refined details such as embossed letters, grooves, delicate meshes, paved, set and polished surfaces, it is clear that the selection of the material for the model is crucial for good product output.
Referring to the above, the wax adopted for additive production is made of 100% pure castable wax and can have various colors and properties. The printers indeed - usually FDM, with multi nozzle - have two print heads and use two waxes depending on whether they have to make the object or the substrate. Nowadays the use of wax is the preferred one because it allows to obtain really detailed molds for products with an intricate geometry. The resins instead have a good degree of detail and excellent resistance but give more problems in the production process as they require the adoption of materials different from those that would normally be used with wax models. [6]

2.8 Software

The very first phase is CAD modeling, which can be done with the most common software or with others more specialized for the jewelry industry. Here are reported few examples of the most used software in the goldsmith industry:

- McNeel Rhinoceros is one of the most adopted 3D modeling tools by goldsmiths. With its versatility it allows the creation of any kind of goldsmithing standard, from solitary to cobblestone. It also has many plug-ins that allows an easier insert of the stones' bezels.
- Pixologic Zbrush is the solution if the jewelry designer approach is oriented to organic modeling. It is in fact a software that allows to sculpt digital matter, creating animal and vegetable shapes.
- Autodesk Fusion 360, to constantly modify the parameters of creations then this software is the right solution. Creates from a solid, changes the measurements at any time depending on the customer, runs fillets on rings with a unique simplicity.

CHAPTER III - ADVANTAGES AND DISADVANTAGES OF THE AM TECHNOLOGY IN THE GOLDSMITH INDUSTRY

3.1 Introduction

The capabilities of AM are evolving rapidly. They can build larger components and achieve greater precision and finer resolution at higher speeds and lower costs. Together, these advances have brought the technology to a tipping point: it became a viable alternative to conventional manufacturing processes in an increasing number of applications. Should this happen, the technology would transform manufacturing flexibility—for example, by allowing companies to slash development time, eliminate tooling costs, and simplify production runs—while making it possible to create complex shapes and structures that weren't feasible before. Moreover, additive manufacturing would help companies improve the productivity of materials by eliminating the waste that accrues in traditional manufacturing and would thus spur the formation of a beneficial circular economy. The economic implications of 3D printing are significant: McKinsey Global Institute research suggests that it could have an impact of up to $550 billion a year by 2025. [7]

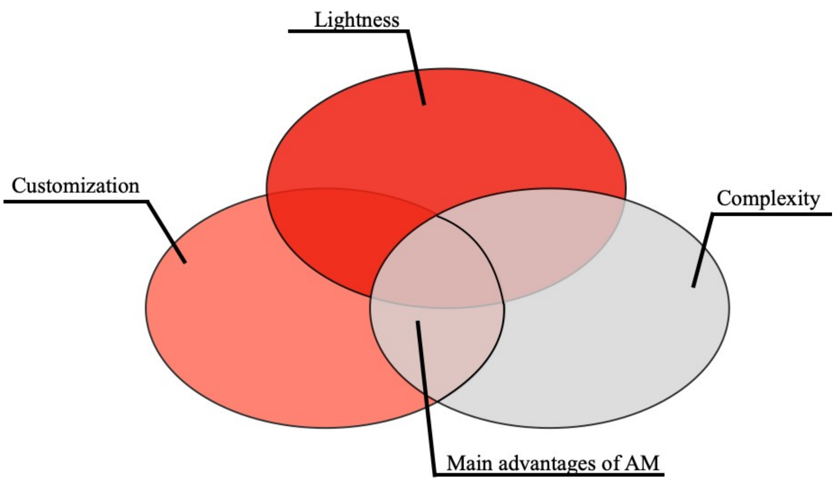


Figure 3.1 *– Main advantages of Additive Manufacturing*

3.2 Advantages

Below are reported some of most important benefits that companies may gain from the adoption of AM technologies, divided into macro-categories and then each described in detail. The main advantages of AM include saving time, managing complex projects efficiently and optimizing costs by seizing the innovations of technological progress.

3.2.1 TIME AND COST SAVING

- Reduction of costs and time from the drawing to the in-house prototype: AM technology allows goldsmith designers to quickly create highly detailed prototypes, saving time and money. Goldsmiths 4.0 are now able to make multiple models directly in their laboratory, verifying their appearance and accuracy. Thanks to the ability to print multiple 3D versions of a jewel in a few hours, the transition between conceptual idea and reality is reduced to one day. It is possible to modify the entire geometry of a jewel, at a low cost; taking full advantage of the printing plan, it is possible to make many jewels, even different ones, at the same time, increasing the production efficiency of each goldsmith.
- The combination of modern technology with traditional craftsmanship makes it possible to shorten production cycles, allowing collections to be published faster and thus have a significant influence on new trends.
- Significant reductions in product-development time cycle. For example, 3D printing makes some aspects of day-to-day R&D work, such as producing prototypes. Over time, 3D printing will begin to affect how companies think about R&D.
- The freedom of not depending on a silicone mold and therefore produce even small series saving time and going straight into production, even for just one piece.
- Saving time in post-melting manufacturing by making all the empty parts in one piece that otherwise would have to be made in several parts and then assembled later with additional manufacturing costs.
- Delivery times and production costs are reduced compared to traditional techniques, see chapter V for more insights.

3.2.2 CUSTOMIZATION

The realization of custom jewelry demonstrates the important integration of AM in mass production and the great potential of AM in series production of custom parts. The final product is made with precious materials, but it is possible to use AM in the initial phase, to create molds or casts, in order to obtain reduced times and costs.

- Most goldsmiths argue that in the future, success will lie in the possibility of creating jewelry designed specifically for each person. Providing a prototype made with 3D printing is an added value that allows customers to control comfort, stone size, weight and shape. Jewelers are thus able to create unique jewelry that differentiates them from competitors.
- One of the strengths of 3D printing technology in the jewelry industry is that 3D models of jewelry can be sent to customers' homes so that they can wear and approve them before the actual metal jewelry is created. In doing so, people feel part of the creation of their custom jewelry and are confident of the final result.
- AM can improve the workflow for custom jewelry production. Jewelry retailers offering custom products have the opportunity to increase sales, especially with the spread of online shopping.
- The direct manufacturing of end products greatly simplifies and reduces the work of a designer who would only have to take products from the computer screen to commercial viability.
- Reducing the reliance on hard tooling (which facilitates the manufacture of thousands of identical items) creates an opportunity to offer customized or bespoke designs at lower cost - and to a far broader range of customers. AM makes customizations at low production volumes possible at a competitive cost.
- AM in customized jewels operates where consumers are willing to pay a premium for a bespoke design, complex geometry, or rapid delivery. Over the longer term, however, they could transform industries in unexpected ways, moving the source of competitive advantage away from the ability to manufacture in high volumes at low cost and toward other areas of the value chain, such as design or even the knowledge of customers' taste.

3.2.3 DETAILS

- Extremely clean aesthetics, for shape and engravings of the jewels, possibility to work even on minimum thicknesses, lightness and unparalleled wearability of the jewel.
- The complexity of the geometries is not a limit, it allows maximum freedom in the design phase and it is therefore indifferent that an AM printer realizes a very complex shape instead of a simple one. Thanks to some technologies such as selective laser melting, the creation of hollow shapes, for example, leads to considerable material savings.

- Some non-contact printing techniques minimize development time, resulting in high speed, smoother side profiles and optimal resolution for jewelry applications.
- The adoption of resins instead of waxes in the printing process allows for more resistant iterations even for perforated patterns. The possibility to print a single piece instead of single pieces to be assembled later guarantees considerable advantages in terms of stability and precision of the piece.

3.2.4 PRE AND POST CONTROL

- To meet the increasingly demand of customers, jewelers use AM to test how a certain piece of jewelry looks to the touch. Rather than focusing heavily on a virtual project, hoping that the final result is perfect for the person who will wear it, producing the 3D model makes easier the verification of size and proportions. This way assures that the jewel is perfect, even before it is made in gold.
- For some printing technologies, the designer has the ability to control the entire production process, from the creative phase to the verification of the powder, from melting to post-processing.
- A key challenge in traditional aftermarket supply chains, for example, is managing appropriate inventories of spare parts, particularly for older, legacy products. The ability to manufacture replacement parts on demand using AM printers is able to transform the economics of aftermarket service and the structure of industries.

3.2.5 STREAMLINING THE PRODUCTION PROCESS

- AM allows the elimination of the necessary steps in the traditional process, where 3D printing is adopted to directly create a molded piece, resin or wax, ready for casting, eliminating some of the longer steps in the traditional process.
- AM technologies have the ability to reduce the minimum scale of production efficiency, shorten the traditional supply chain and reduce working capital requirements (WIP and stock), this could lead to improved performance in terms of profit, cost, risk and reduced time to market, giving companies the ability to deliver their products faster. In the long run, such changes in supply chain structure can be a key growth vector as companies large and small seek to capitalize on the ability to deliver faster, cheaper and more accurately than their competitors.
- Through AM, the design verification process is improved and gives the possibility to easily test with the customer.

3.2.6 MAINTENANCE and TOOLS

- The ability to make prototypes without tooling lets companies quickly test multiple configurations to determine customer preferences, thus reducing product-launch risk and time to market.
- Thanks to the simplicity of operation and the reduced number of moving parts, some printers are characterized by high reliability and low maintenance. Certain technologies have great flexibility thanks to the quick material change system and the absence of calibration and preheating times.
- There are no costs for the realization of molds and production equipment, the cost of waxes would be required even without the adoption of AM techniques.

3.2.7 FLEXIBILITY

- With AM printers it is easy to increase or decrease production according to market demand.
- AM printers allows to produce pieces even outside the working day, thus recovering the "downtime" as the printer can work at any time without the constant supervision of an employee.

3.2.8 EFFICIENCY

- Another important advantage of AM technology is the possibility to make different jewelry models within the same 3D printing process. The advice is therefore to fill the printing plan as much as possible in order to increase the efficiency of the process. It is possible to realize a number of highly accurate models quickly and at a lower cost.
- Reducing production waste and protecting the environment by reducing the energy consumption. In traditional processing, an example is the casting, the steps to make an object are multiple with waste related to waxes, gums and plaster. The time of the entire production process is radically reduced and with it the waste.

3.3 Disadvantages

Where precision and reliability are needed AM technologies are not yet so "low cost". Behind the many advantages however there are some aspects that stand against additive technologies, the main ones are listed below.

3.3.1 ADDITIONAL COSTS

- Customized products on the one hand offer excellent performance and make the customer more satisfied, on the other hand they make the production of those parts expensive. Due to the expensive collection of personal data and then the realization of customized products all followed by a unique management of the entire process makes the procedure more complex and expensive.

- Personnel training is necessary to prepare new technicians for the use of the machine.
- The need for supports during the printing process needs to be balanced with the cost of such structures. Those can be solid, cables that are removed after the build/print cycle has been completed. Therefore supports - despite their necessity for the right output of the jewel - represent a considerable waste in terms of material, time needed for their realization and then removal, and energy consumption. From a cost point of view, supports should be as low in volume as possible, using the minimum amount of precious materials and be relatively easy to remove. These almost contradictory requirements for strength and thinning make automated solutions for the creation of supports very challenging.
- The cost of future materials is uncertain, nowadays given the delicacy of the printers - to avoid breakage and expensive damages - the manufacturers launch together with printers their waxes, resins selling them at a price anything but competitive.

3.3.2 DEFECTS CREATION

- Using materials other than those commonly used by the classical method upstream of the production process, all the materials present in following steps must be modified. The components must therefore be adapted in such a way as to avoid the creation of defects due to undesired chemical reactions.
- Getting the most out of additive manufacturing techniques also involves technical challenges, including setting environmental parameters to prevent shape distortion, optimizing printing speed and adjusting the properties of new materials. In fact, fine-tuning materials is a real challenge.
- To build complex geometries with protruding surfaces and undercuts, support structures are required to help control defects such as bending failure, cracks, shrinkage and/or other deformations of the workpiece. In the case of selective laser melting technology, these defects can be caused by typical thermal stresses or by being dragged and disturbed by the covering or blade of the screed applying the next layer of powder.

CHAPTER IV – THE ITALIAN GOLDSMITH INDUSTRY

4.1 Introduction, a worldwide perspective

The European Union (EU) is traditionally an important supplier of high quality jewelry for the world market. Global economic and financial crises have had an impact on the EU jewelry manufacturing industry and recent price fluctuations of all precious metals have somewhat weakened jewelry sales. Adding to the situation is the reduction in consumer spending on jewelry, who are now looking for personalized pieces with a higher associated personal value. The World Gold Council estimated that jewelry consumption plummeted in the first quarter of 2020, when local gold prices in several countries skyrocketed and markets were closed in an attempt to contain the current pandemic. Global jewelry demand hit the quarterly total, falling 39% year-on-year to 325.8 tons - 42% below the five-year quarterly average of 558.1 tons. The value of global demand fell 26% year-on-year to a 10-year low of $16.6 billion [8].

Within the EU and other developed economies, consumers have adapted to the online digital revolution and now expect a continuous choice of new and innovative products. In addition, there is a growing consumer focus on shopping, there is a growing tiredness towards "fast-moving fashions" and many consumers now increasingly have the opportunity to favor personalized products other than the intrinsic value of that piece of jewelry.

Global economic uncertainty makes it difficult to accurately predict future trends in the jewelry industry, but the EU jewelry market is set to grow in the near future. In particular, the market will increasingly demand higher quality products combined with original designs and statement jewelry with perceived added value, customization or new production technologies. [9]

4.2 Likely impact of AM in the goldsmith industry

From a general point of view, the process of innovation in a company assumes a fundamental importance for the increase of performance, growth, sustainability of competitive advantage, and survival of companies. In doing so, innovative companies have the ability to enter - or even create - new markets thus satisfying customer demand. [10]

To obtain a competitive advantage, a company must be able to distinguish product innovation from process innovation. Product innovations refer to new products and services introduced on the market, with the aim of satisfying latent consumer needs [11]; process innovations refer to new elements

introduced in the company's operation and production processes, such as new materials and machinery.
Once the 3D printer has been introduced in the production process, incremental innovations will have to be introduced within the company deriving from information provided by subjects outside the company, such as the implementation of software [12]. To better contextualize, companies in the manufacturing sector have always focused more on product innovation than on process innovation, in fact the study of Becheikh [13] confirms that most of the literature analyzes exclusively product innovations. Studies have shown that one or two types of innovation are interdependent and closely related, such that a company that neglects process innovations could weaken its ability to make product innovations and compromise the entire innovation process. [14]
In summary, process innovation increases the productivity of companies, determines the achievement of a competitive advantage - especially by reducing production costs and increasing the flexibility of the production apparatus - promotes product innovation.

3D Printing is a process innovation for goldsmith firms, as shown in Figure 4.1 it has a triple effect on the company: it affects their profits, cost impact, customer value and revenues. These effects affect the generation of profits and, consequently, the company's competitive advantage.

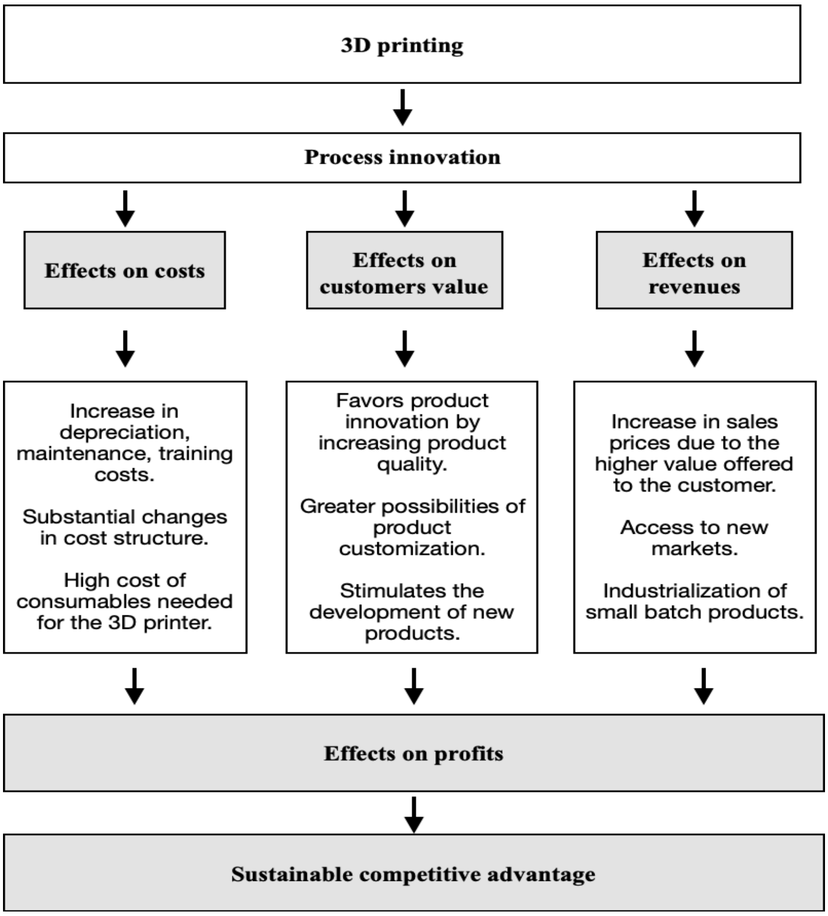


Figure 4.1 *– 3D printing and business competitiveness in goldsmith industries*

Source: see [10]

With regard to costs, for goldsmith companies that use 3D printing there is no substantial reduction in costs, on the contrary there is a slight increase caused by depreciation, maintenance costs, personnel training costs and above all costs for raw materials - the latter generally purchased from manufacturers as a result of contractual formulas. In order to preserve the sustainability of costs, the production process must be continuously activated (7/24) because the machine is not used for long periods of time and there is a possible loss due to non-depreciation.

3D Printing brings fundamental customer service advantages. First of all, it favors product innovation, as it allows to realize new products with better aesthetics and quality. Secondly, there is an improvement in customer service in terms of time to market and customization. Directly related to the previous conceptual theme, there is the effect on revenues as 3D Printing has influenced through three main effects. Revenues are subject to increase mainly due to the increase in sales prices resulting from the higher value offered to the customer. Secondly, the creation of new products has allowed access to new market segments - 3D Printing allows the penetration of previously unreachable customer segments, consisting of high-end customers with high willingness to pay for customized objects with innovative design. Finally, 3D Printing has affected sales prices, made possible by improving product quality.

3D printing is an imitable innovation, creating a sustainable advantage especially for first mover companies. In the case of the goldsmith industry, once introduced by the first competitors this technology has become a necessary factor for survival as today the market requires products with a higher level of design and customized, which can be realized exclusively through 3D Printing. [10]

4.3 **Definition of the sector**

The goldsmith industry is composed of a group of companies and craftsmen who perform the activity of transforming gold, silver and platinum, precious stones for the production of objects such as rings, necklaces, earrings, trays, cutlery and other decorative objects. From this definition are excluded the activities of transformation of gold and silver for industrial and medical use. This industry is strongly characterized by the multiple techniques of metalworking for the realization of the most varied geometries of a wide range of products, to enhance the product also the use of precious stones increases the creation of authentic products.

The goldsmith industry is therefore a sector in which differentiation and flexibility can be strategic elements for the companies that operate there, on the contrary it is impossible to distinguish a clear classification between the different product categories realized. For these reasons it can be affirmed that a simple definition of such an economic system is difficult to formulate because the amplitude of the characteristics that compose it is such that only analyzing them one by one it is possible to obtain a detailed picture of the situation and the appropriate definitions for an in-depth analysis in every aspect. [15]

According to the ATECO 2007 classification, code 32.1 is representative of the handicraft sector of "Jewelry, costumery and connectional articles and working of priced stones". Specifically, the subcategories that would be of interest to the analysis are 32.12.1 and refer to “Jewelry and goldsmith's items in precious metals or coated with precious metals” [16]. For the reasons given above, the data analyzed below is only available for ATECO code 32.1, so no further breakdown is possible.

4.4 **Overview of the Italian goldsmith industry**

4.4.1 Introduction

The reason why the focus of this sector analysis is on the Italian market is due to the fact that in 2018 62.0% of the tons of gold processed in the world came from China and India - respectively with 688.2 and 632.2 tons - due to the numerous and low labor costs that characterize these countries. In third place is instead Italy, with a total of 74,9 tons processed, a merit probably attributed to the millenary knowledge of production techniques and the high quality always accredited to the national craftsmanship. [17, 18]

Moreover, if we look only at the European market, as shown in Figure 4.2 Italy is ranked in first place as the country with the highest rate of employment in the jewelry industry. [19]

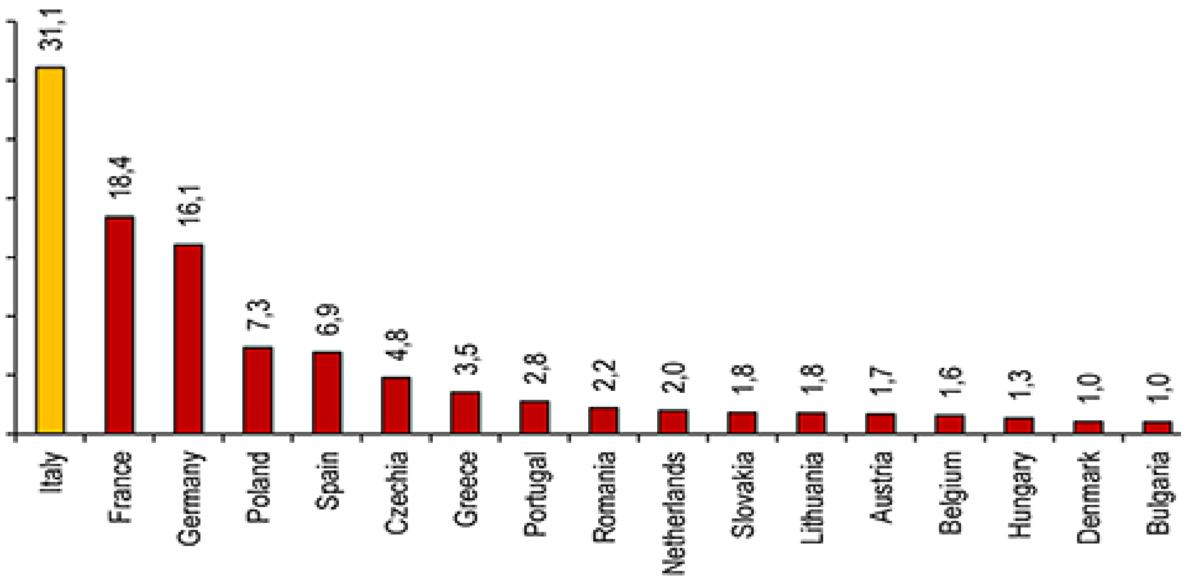


***Figure 4.2** – Level of occupation in goldsmith industries in EU countries (thousands of employees)*

Source: Elaboration of Confartigianato Studies Office on Eurostat data, 2017

In order to define a sectoral picture of the goldsmith industry on Italian soil, it is important to identify the number of companies that are part of it. The Study Centre of Confindustria Moda - based on data from ISTAT Movimprese and Eurostat - has developed studies that show the industry has 7,500 companies capable of employing over 31,300 people. If during 2018 the number of active companies decreased overall (-1.5%), the number of employees was affected by a positive trend (+0.7%).

4.4.2 Geographical distribution

In order to better clarify the distribution on the national soil, the geographical distribution in the country of districts with the largest number of companies dedicated to the gold sector has been reported. The first three classified are respectively Arezzo, Alessandria (specifically Valenza Po) and Vicenza, to follow the remaining districts. The information in Figure 4.3 represent the main 30 Italian districts illustrating the percentage of companies out of a total of 7.500 goldsmith companies present on the national soil.

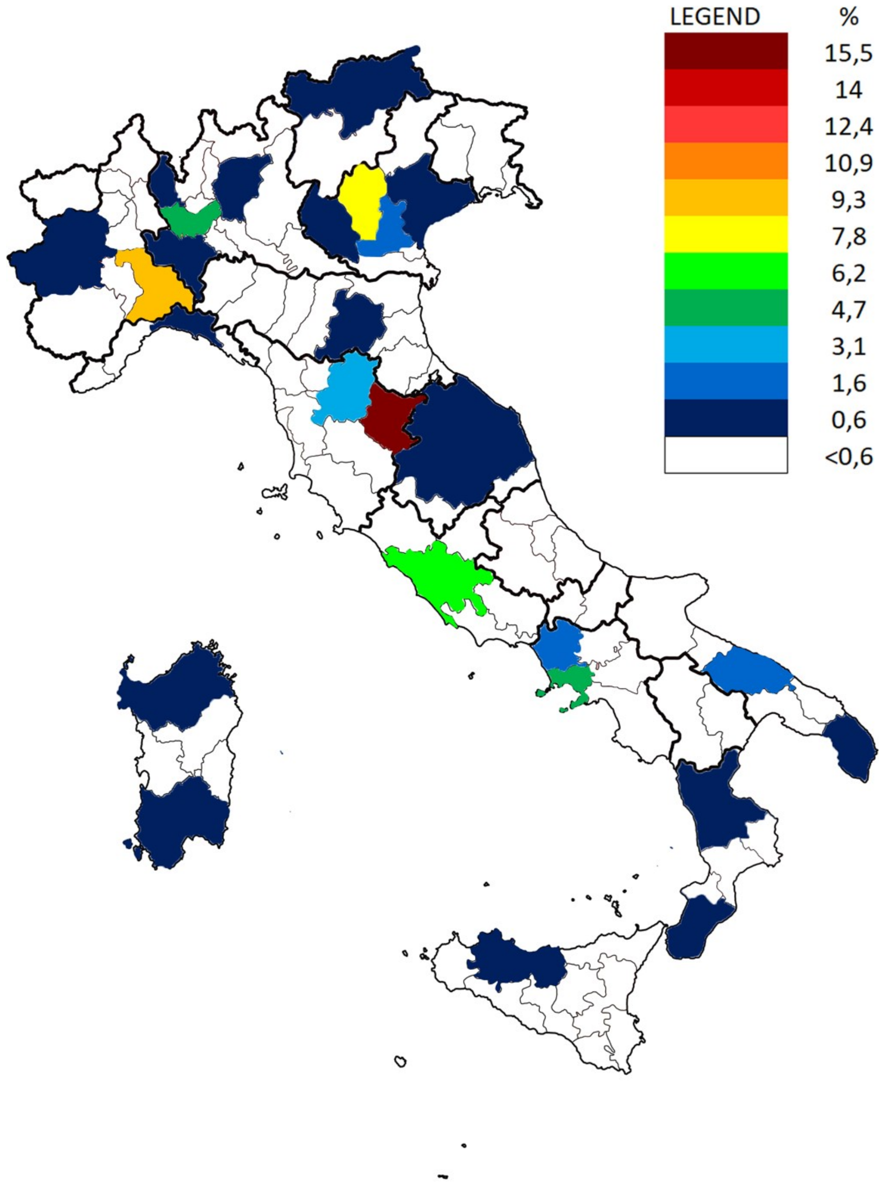


***Figure 4.3** –Geographical distribution of goldsmith industries in Italy*

Source: personal elaboration by processing information from INFOCAMERE– see Appendix A for values

4.4.3 Economic results

In order to better introduce the complex goldsmith industry, an analysis has been proposed below in order to clarify the type of companies present in the territory.

The turnover of the entire industry, to be attributed in particular to the manufacturing or processing companies, in 2018 is equal to €7.4 billion. [17]

This value is given from the sum of the turnover of 7500 enterprises, value that tends to decrease of a percentage point in the last two years, opposite trend owes instead the number of employees involved in the industry that increases year after year. This makes to guess together with the trend of the turnover as the industry is stable and operating despite all the factors of contour that influence the trend of the market, as for example the price of the gold. Values concerning import and export will be discussed in more detail below.

	2015	2016	2017	2018
TURNOVER	7 133	6 850	7 596	7 390
Var.%	-	-4.0	10.9	-2.7
EXPORT	6 168	5 942	6 610	6 451
Var.%	-	-3.7	11.2	-2.4
IMPORT	1 741	1 717	2 035	1 987
Var.%	-	-1.4	18.5	-2.3
TRADE BALANCE	**4 427**	**4 225**	**4 575**	**4 464**
Var.%	-	-4.6	8.3	-2.4
EXPORT PROPENSITY (%)	86.5	86.7	87.0	87.3
N. COMPANIES	7 714	7 698	7 611	7 500
Var.%	-	-0.2	-1.1	-1.5
N. EMPLOYEES	30 658	31 062	31 088	31 306
Var.%	-	1.3	0.1	0.7

***Table 4.1** – The goldsmith-silver-jewelry industry at a glance, 2015-2018 (in million Euros)*

Source: Confindustria Moda estimates on ISTAT, Movimprese, Eurostat data, 2019

To make more clarity and make sure data are accurate, the AIDA database has been analyzed and some results have been obtained. After an initial cleaning of the data, eliminating companies in liquidation or with unreliable values, the clustering of the sample was carried out in various size ranges of each company, it was then evaluated companies from 1 to 5 employees, from 6 to 10, from 11 to 50, and over 50 employees. In order to identify the distribution by company size of goldsmith companies, it was decided to include also companies with 0 employees as it can be assumed that for small companies the definition of the number of employees is not easily detectable.

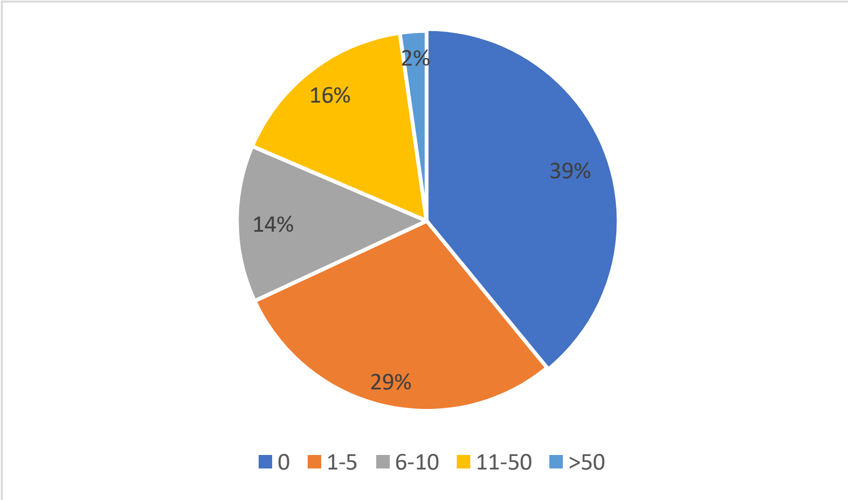


Figure 4.4 *– Companies size expressed in number of employees*
Source: Personal elaboration from AIDA dataset ATECO 32.1

Analyzing the dataset, it was found that the market is mostly composed of micro and small enterprises, 82 % of companies have less than 10 employees. The values of turnover and EBITDA are affected by the size of the company, which is why there is a big gap between values of small and large companies.

From the moment in which analyzed data have been drawn from different sources, it is interesting and reassuring to notice how the relationship between EBITDA and turnover is constant and parts to 5-7%, valid values beyond that in the subdivision for business size also for the values of the three districts (reference to Figure 4.5 and Figure 4.6).

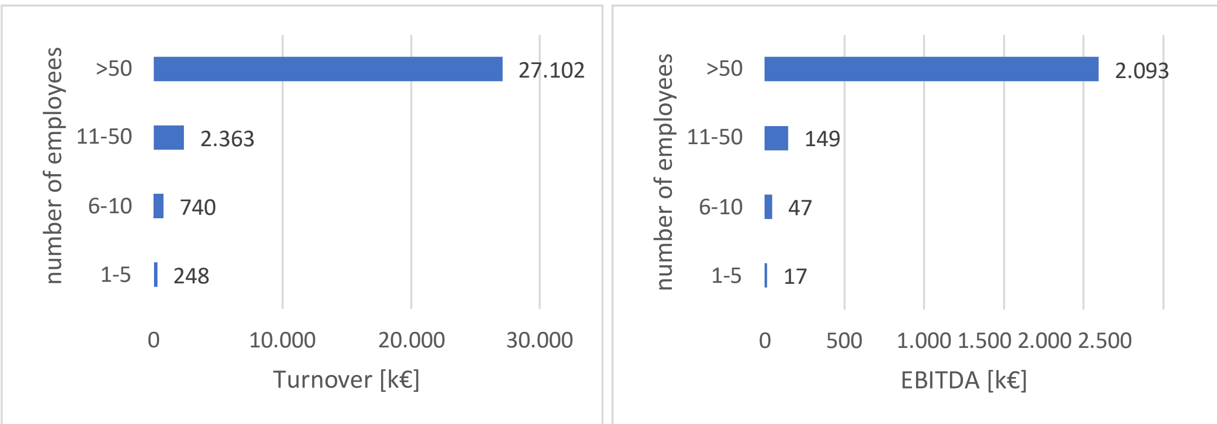


Figure 4.5 *– Turnover and EBITDA values according to company size (thousand Euros)*
Source: personal elaboration from AIDA dataset

The goldsmith industry is a varied market, depending on the size of the companies, the values of turnover vary greatly; the range goes from €248 thousand to €27 millions. The values shown in Figure

4.5 refer to the median values calculated on the initial sample of 1536 companies, dividing them into clusters according to the number of employees.
One of the reasons why EBITDA values are so low can be attributed to the high cost of raw material, to which processing and labor costs must be added. In fact, the goldsmith industry is a typical craft sector where handmade work is still unsurpassed by machinery. In the specific case of the use of 3D printing machinery it can be concluded that the decision to invest in such machinery is not a decision that small companies can take very easily, unlike more structured companies.

After having proposed a global vision of the Italian goldsmith industry, here follows a more specific analysis of the values related to the three main districts of the industry, whose industrial activities make up 33% of those present throughout the country. Of continuation it is brought back a short analysis of the sector made in 2019 by the Vicenza Chamber of Commerce where are compared the three districts according to three indicators of the income statement, two profitability indexes, a solidity and a liquidity index related to the business year 2017.

- Average Production Value, Value Added, EBITDA

  The value of the average production is a data that, unlike the turnover, indicates the quantity of goods destined to the sale, i.e. it includes revenues from sales and the stocks of the production of the year (while the turnover indicates the quantity of goods actually sold net of the stocks).

  The calculation of the value added is obtained by subtracting from the value of production the cost of the raw material and the costs of services consumed. These low values are synonymous with a high cost of raw material - about 15% of the selling price - due to the high but variable price of gold.

  EBITDA is nothing more than the Earnings Before Interests, Taxes, Depreciation and Amortization and reports the result of ordinary operations, meaning revenues minus costs, thus excluding interest income and expenses (financial management), taxes (tax management), depreciation and amortization, provisions, write-downs of fixed assets and current assets. This is an important parameter because it signals the operating cash flow of a company and therefore the available financial resources: in short, it allows to evaluate whether or not the operating management generates wealth. In general, considering - from how much emerged from the AIDA data - a sector composed mainly from small enterprises concentrated in only 3 districts, the values of profitability equal approximately the 5-6% of the value of the production have to be considered like a positive result.

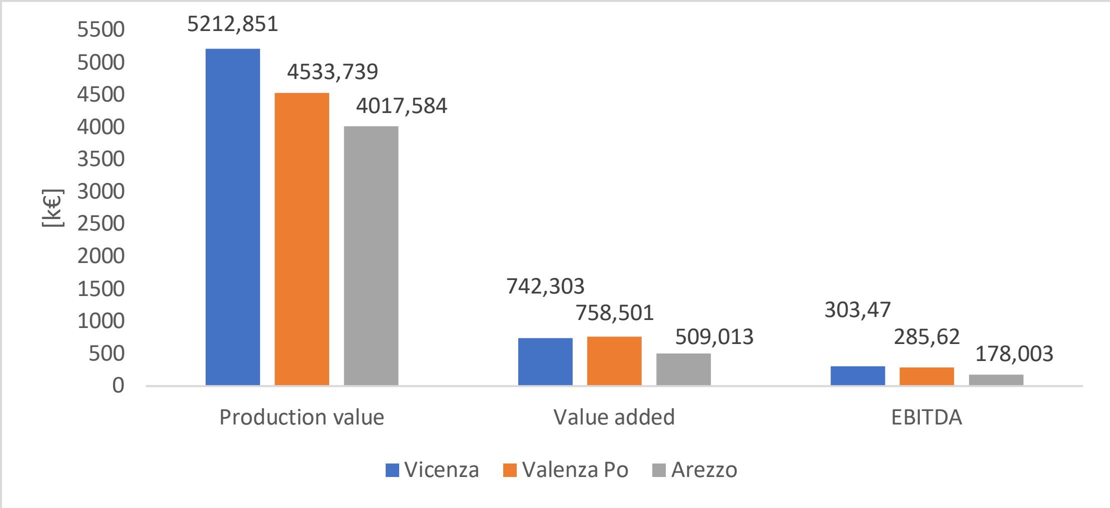


***Figure 4.6** – Some indicators of the income statement of the three main Italian districts (thousand Euros)*

Source: personal elaboration

- ROE, ROI

The R.O.E. (Return On Equity) is the most important indicator of company performance and expresses the potential remuneration of risk capital. The R.O.E. (Return On Equity) expresses the efficiency and effectiveness of the overall management of the company including the choices that can be traced back to the characteristic management and the decisions regarding financial, patrimonial, accessory and fiscal management.

An analogous situation for the R.O.I. which expresses the profitability of the capital invested in the company including both the risk capital and the resources acquired in debt.

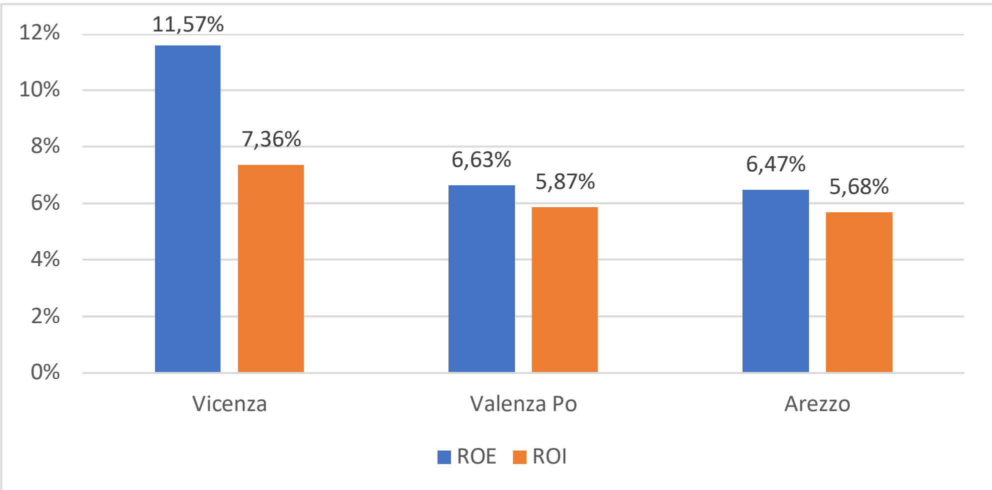


***Figure 4.7** – Profitability indexes of the three main Italian districts*

Source: personal elaboration

- Financial Independence index and Quick Ratio

The financial independence index is an indicator of solidity (given by the ratio of shareholders' equity to total internal and external financing) the higher the value of the index, the more the company is able to finance itself and does not resort to external sources of financing. The data of the three districts are not fully satisfactory, being around a little more than 30% for Vicenza and Arezzo, Valenza Po instead reaches the 44,57%.

Finally, the quick ratio (given by the ratio between the sum of receivables and cash and cash equivalents on the one hand and current liabilities on the other) expresses the ability to meet current liabilities using short-term availability. If the value is less than 1, this means that the company's liquidity situation is unsatisfactory because the future income connected with the realization of the more liquid items of current assets cannot be quantified to such an extent as to cover future expenditure connected with the extinction of short-term liabilities. The quick ratio value of the Vicenza and Arezzo jewelry production is 0.91, while the liquidity situation of the Alexandria jewelry companies is much better (1.17).

4.4.4 Demand

The demand curve of luxury goods is substantially rigid compared to most common goods. Contrary to the norm, up to a certain level of price the demanded quantity increases to the increase of the price. The value of the price in the field of the luxury assumes a double meaning: the highest part of the curve looks like the classical relationship price/quantity in which to the increase of the price a decrease of the demanded quantity is verified. The flexion point represents the moment in which the consumer perceives a disequilibrium between price and effective quality, underneath this point the price assumes the connotation of quality indicator, if the price is too much low the luxury product comes perceived from the consumer like a cheap product and therefore the demand diminishes to the decrease of the price.

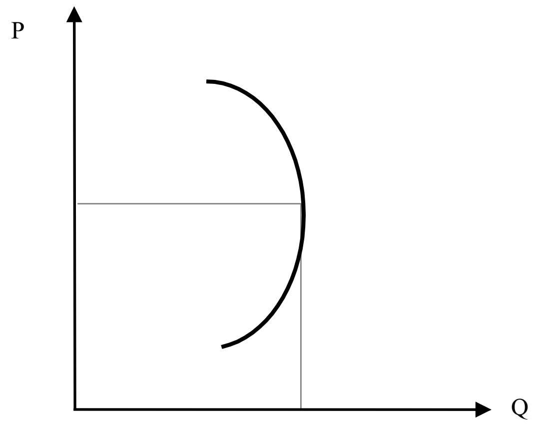


Figure 4.8 *– Rigid demand curve*

Source: see [20]

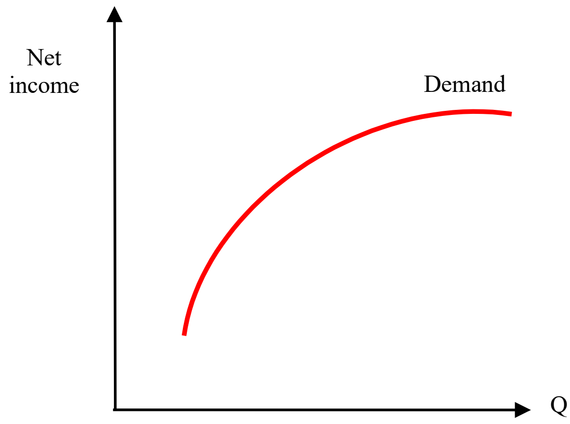


Figure 4.9 *– Demand elasticity*

Source: personal elaboration

The elasticity of demand with respect to income is elastic in a positive way, which means that the increasing economic availability of the consumer will have less and less weight on the choice of purchasing expensive items.

Since the demand in the industry was once based on the uniqueness of the product and today is based on mass production dictated by Fashion Jewelry, it makes for a gradual "elasticization" of the jewelry demand curve. [21, 22]

In Figure 4.10 is shown the trend among years of the jewelry demand form a worldwide perspective, whole trend is not constant at all thus unpredictable; however, it can be said that the Italian demand is decreasing also as a consequence of the decreasing GDP value.

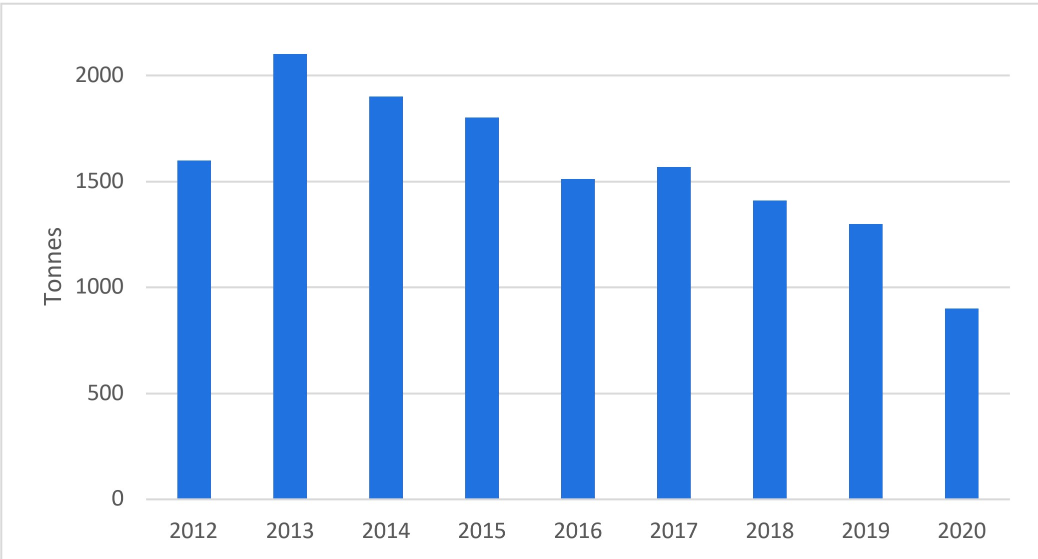


Figure 4.10 *– Global jewelry demand from 2012 to 2020*

Source: Metals Focus, Refinitiv GFMS, World Gold Council

Particularly for the Italian demand it has to be considered that over the years, between one generation and another, the internal demand for jewelry has been the victim of a "break" in the traditional reasons for buying jewelry.

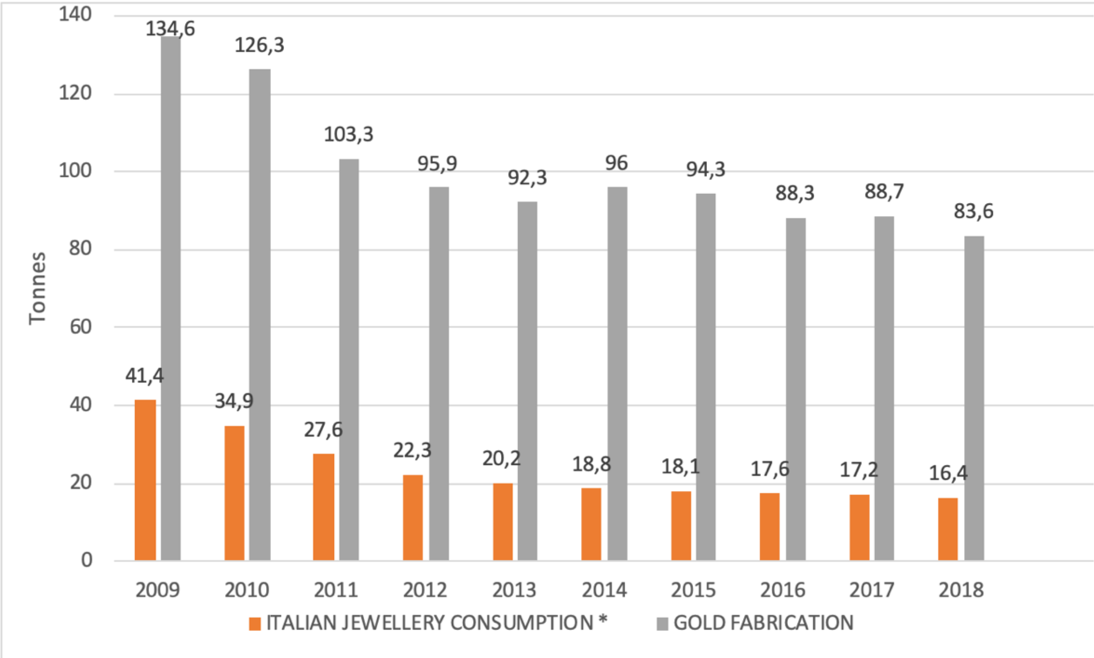


***Figure 4.11** – Italian jewelry consumption and fabrication including scraps**

Source: Personal production from Refinitiv GFMS data, 2019

**Fine gold content of all new jewelry sold at the retail level (excluding the exchange of old for new jewelry), calculated by taking jewelry fabrication, plus imports less exports and adjusting for retail stock movements.*

With great uncertainty surrounding the countries future position in the EU aiding to countries problems, jewelry fabrication in the country declined in 2018 in the entire year falling by 6% to its lowest level this century of 75 tones. The key drivers behind the fall came from weakness in exports, with either domestic economic concerns (in regions such as Asia), tighter fiscal policies (in countries such as the UAE - historically Italy's largest exporting partner), unfavourable payment contracts (USA) or aggressive commercial policies from foreign competitors (Turkey), negatively impacting demand abroad. [23]

Meanwhile the internal demand suffered the differentiation in the scale of purchasing priorities due to the emergence of new products and services (such as travel, digital technology products, mobile phones and more). Hence a slowdown in internal demand, documented by numerous statistical sociological surveys. Among the various cases of penalization appears the significant competition

also exerted by the progressive affirmation of the luxury fashion jewelry and e-commerce. The progressive import penetration has then put in condition the buyers, in addition to having a wider offer, to make more comparisons in terms of sales prices and quality of the goldsmith product offered: a set of conditions that has been combined with the increased propensity of consumers.
Future demand for Italian jewelry looks bleak this year, both on an international and domestic basis. It can be expected, as already has been recorded, an increase in gold instead as an investment asset in the short term.

4.4.4 Import and Export values

With reference to the data collected in 2017, the world trade on the export side in jewelry has almost reached €96 billion. In that year, on a global scale, the main exporters were the Arab Emirates (13.5% of the world total), India (11.9%) and Switzerland (10.4%), the main international hub also for Italian products, in addition to China (10.1%). Italy is the sixth largest exporter in the world with an incidence of 6.5%. [17]

Analyzing the Italian import and export values, firstly it is necessary to distinguish values that refer only to the raw materials or the finished product of precious metal jewelry or costume jewelry. From the analysis made by ISTAT data for ATECO code 32.1 the import and export values are those reported in Table 4.1.
With reference to the export row of Table 4.1 it is pointed out that in 2018 there was a reversal of the trend with respect to the growth (+11.2%) of 2017; in fact exports recorded a decrease of 2.4% to 6.45 billion euros. With regard to the import line, however, it should be noted that in 2018, imports fell by -2.3% year-on-year to just under €2 billion. Therefore, in light of the decrease in imports and exports, the industry has a trade surplus of almost €4.5 billion (-€111 million compared to 2017).

For this analysis, the more specific data of major interest for this research are also reported, which refer to jewelry and goldsmith's items made of precious metals or coated with precious metals (ATECO 32.12.1) whose data related to the national territory are shown in Figure 4.12. It should be noted that the value of import is about one fifth of that of export, a value that is constantly repeated over the years.

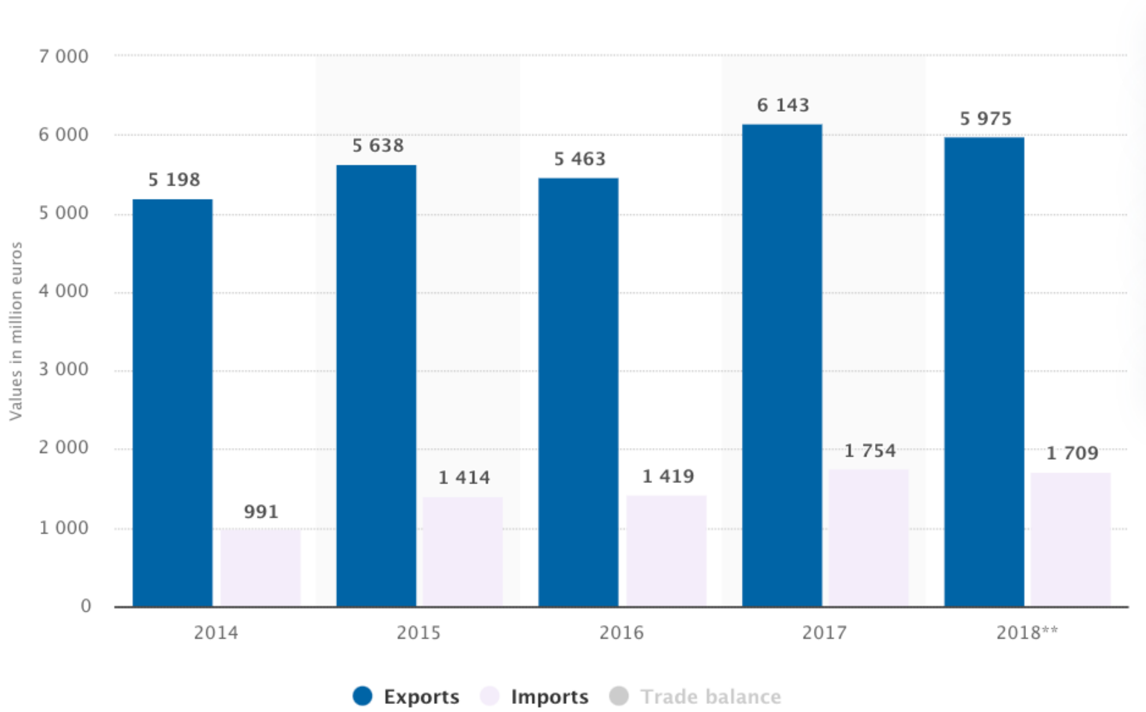


Figure 4.12 *– Export and Import values of the Italian jewelry industry from 2014 to 2018 (in million Euros)*

Source: Statista 2020, ISTAT, Intesa Sanpaolo, Club degli Orafi

Export values have slowed down, also due to the dynamics of the exchange rate and the price of valuables: on average in 2018, foreign sales fell in value 1.7% for the aggregate which also includes costume jewelry and 2.7% for precious metal jewelry. [24]

According to a study conducted by Thomson Reuters, the initial weakness of the year was largely due to the 5% increase in value added tax (VAT) on non-essential luxury goods in the Gulf Cooperation Council countries, which reduced foreign trade statistics for the United Arab Emirates (Italy's main trade hub to India, the Middle East and North Africa) to double digits. The decrease in exports has also been recorded for several European countries as a lack of extra money from middle-class families, as well as a change in lifestyle, labeled as unbranded jewelry as undesirable.

While Eastern markets remain the most desirable for Italian jewelry, there has been a countercurrent change in the dynamics from Chinese buyers that has seen a decrease in exported quantities. To compensate for these losses, however, was the United States, which recorded an increase in Italian jewelry imports of 2% compared to the previous year, data that can be explained by the improvement in the country's economic prospects and the growth in employment and the increase in disposable income. [25]

4.5 Future forecast

The Italian gold jewelry industry, one of the pillars of Made in Italy with almost €8 billion in turnover (2019), opened this year with a first two months growth of +13.1% on the export front, despite the early closure of the Chinese market and the high levels reached by the record price of gold. The expansion of the pandemic and the consequent containment measures led to a real collapse in sales in the industry. In fact, the first four months of 2020 were recorded with a record drop in exports of -30.6% compared to the same period in 2019. [26]

In particular, according to data processed for Federorafi by the Study Center of Confindustria Moda, the month of March fell by -45.0% compared to March 2019, while the month of April even reached -92.1%.

With reference to the main districts of the industry (for which data are available only for the ATECO code 32.1 for the first three months and therefore without the month of total block of April), there is a drop in sales of -15.6% for Arezzo, -27.1% for Alessandria/Valenza and -14.7% for Vicenza.

The return to the levels (in absolute value) of 2019 is expected for 2022 or 2023. By 2025 the market should reach €320-330 billion: this would represent a growth rate of +2/+3% in 2019-2025. [27]

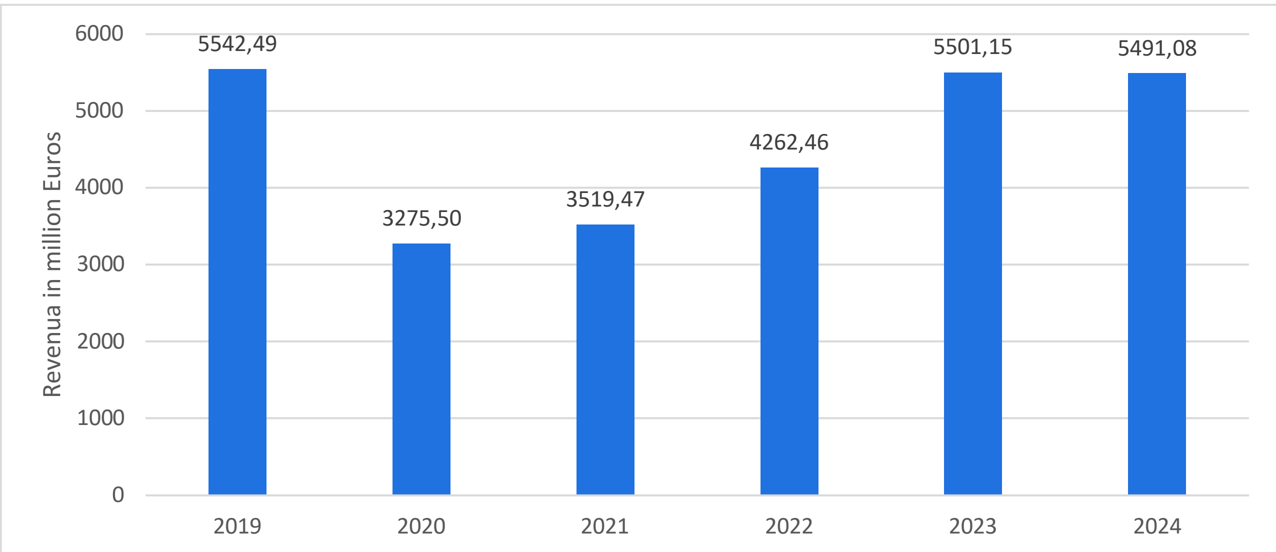


***Figure 4.13** – Industry revenue of "manufacture of jewelry and related articles"*
in Italy from 2019 to 2024
(in million Euros)

Source: Statista, Eurostat

CHAPTER V - COMPARISON AMONG THE MOST ADOPTED TECHNOLOGIES

5.1 Introduction

Among the many AM processes, the most suitable for the goldsmith industry are those that produce parts with tighter tolerances and higher resolutions such as Stereolithography technology or Multi Jet Printing. Referring to a study conducted by the company Progold S.p.A. specialized in the production of alloys and mother alloys for jewelry, the three production techniques adopted in the goldsmith industry were compared below [28]. The comparison was carried out both on the economic and practical side; in the evaluation of lead time, production capacity and emission level, scenarios were defined in order to make an analysis as precise as possible.

5.2 Fusion and modeling

The analysis carried out to delineate which between casting and selective laser melting is the preferred technology, it is impossible not to go through a clear and immediate understanding of the respective modes through which both provide the phase of melting the material and modeling in the desired form.

Taking up the concepts outlined in the paragraph on technologies, it is clear how the characteristics of the material used to create the jewel can be crucial in casting and not in selective laser melting or vice versa.

a. Classic and Direct Microfusion

In the case of casting, both traditional and direct, the temperature of the liquid of the alloys adopted plays a fundamental role in the feasibility and costs of the process. The type of material used for the realization of the prototype binds all the subsequent phases of the production process. Depending on the use of waxes or resins, the crucibles and molds must be adapted accordingly to avoid the risk of contamination of the alloy to be melted and the risk of creating defects in the parts produced, such as inclusions and hard points.

In any case, in the mere process of melting the gold alloy, there are still problems related to the need to significantly increase the temperature of a consistent mass of material and bring it to the correct temperature. This is a shrewdness that allows to avoid thermal inhomogeneity of the melting and to control the heterogeneity due to solid state segregations, the vaporization of some elements or their reaction with residual oxygen.

b. Selective Laser Melting

In the case of SLM, the temperature required to melt the alloy is reached through the localized interaction between the laser radiation and the material. The alloy absorbs the photons emitted by a laser source, whose energy is then converted almost instantly into heat. The first fundamental parameter to estimate the efficiency of the melting process will therefore be the absorbance of the material to be melted at the particular wavelength of the laser used. The main obstacle to laser melting in metals is their high reflectivity, so the radiation is reflected by the surface of the material rather than being absorbed. This effect, directly related to the high electrical conductivity of the materials under examination, is particularly pronounced in the case of gold, silver and copper.

A second discriminating parameter for the efficiency of the selective laser melting process is the thermal conductivity of the material, elements such as gold, silver and copper are disadvantaged compared to other metals because of their high reflectivity, which means that overall high laser energy is required to melt their alloys.

One of the strategies adopted to increase the absorption efficiency of the laser in the selective melting of gold alloys has been to add small amounts of semiconductor elements, such as germanium or silicon, which can lower the electrical conductivity of the material. [29, 30]

With selective laser melting it is therefore possible to see a reversal in the energy efficiency of alloy casting compared to microfusion, the printing of platinum and titanium jewelry is more energy efficient than that of gold or silver objects. This represents one of the great peculiarities that make the technique a real revolution. In fact, it is not trivial for any jewelry manufacturer to have the opportunity to diversify its product offer on the market with collections reproduced in metals that are difficult to work with traditional techniques.

The differences caused by localized melting typical of SLM and lost wax melting affect the microstructure. The extremely thin size of the metal layers melted by the laser and the high solidification rate of the metal result in an average size of the crystalline grains that is small and generally smaller in the case of selective casting than that achievable in casting with the same metal alloy, resulting in improved mechanical strength. [31]

5.3 Geometric limitations

5.3.1 For cable products

In addition to the differences dictated by the different metallurgical processes, the presence of the refractory mold in the casting process with the entire chain of operations necessary for its manufacture and filling by the metal is a source of geometric limitations of the jewel, which can be overcome with selective laser casting. An example is the impossibility to produce a unique piece jewelry with a hollow interior almost insulated from the outside.

a. Classic and Direct Microfusion

One of the biggest limitations of classical microfusion is the impossibility to create hollow objects with minimal thicknesses. Even in direct casting the problem of the production of hollow items persists, despite the fact that resins can be built with cavities almost insulated from the outside - because they are obtained with an additive printing technique - it is necessary to equip the model with numerous holes. These are essential in the next phase of cylinder production the coating where the liquid is not able to penetrate into the internal cavity except through the holes.

A typical practical solution to circumvent the limitations imposed by casting hollow jewelry from combustible material models (wax, resin) is the separate casting of the partitions of the object, which will then be soldered. However, soldering involves the appearance of additional problems, in addition to the presence of an additional production step. The problems generated in this case are related to the need to mask the joint area, often of a color not corresponding to the adjacent material. In addition, the heating caused by the welding operation can lead to deformation and breakage of the parts. Finally, there is a real risk that in the case of thin thicknesses, welding will cause the accidental fusion of a large area of the jewel.

b. Selective Laser Melting

In SLM the problems of microcasting decay and in the construction of hollow items the only need is to drill a limited number of tiny holes to allow the escape of the dust trapped inside the object obtaining without particular production problems almost totally closed hollow forms, such as the rings in Figure 5.1 and the ring in Figure 5.2, which shows the internal cavity that can be filled or not with reticular support structures to increase the mechanical strength. The ability to produce items with occluded cavities is a recognized strength in laser printing because it offers the possibility to reduce the final weight of the jewel with the same overall size.

Figure 5.1 *– Example of hollow faith made by SLM with a small hole (3D model on the left and printed object on the right)*
Source: see [28]

Figure 5.2 *– White gold ring with hollow inside, cross-section with and without reticular support structure.*
Source: see [28]

5.3.2 For thicknesses

The presence of the phases of making the model in wax or resin, the production of ceramic coatings and the casting of the molten alloy inside them also leads to a further limitation in the design of the jewel, which are the thicknesses.

a. Classic and Direct Microfusion

The production of jewelry with thin thicknesses using the classic method makes the production of the model problematic because its filling requires conditions of high wax compression, so the rubber tends to swell and produce thicker or deformed models. In order to overcome this problem, rubber moulds have been designed to facilitate filling, which combined with the adoption of waxes with filling properties make the process more feasible [32]. However, the presence of thin thicknesses always leads to a considerable difficulty in extracting the model from the molds, with frequent and irreparable distortions and dimensional changes.

In the case of direct casting the adoption of additive manufacturing makes the production phase of the model much less critical, with a correct choice of polymeric materials and printing technique, high quality castings are obtained without resin residues that can obstruct the thin cavities then to be filled. [33]

b. Selective Laser Melting

In the case of laser selective casting, thin thicknesses and complex structures are not a limiting factor, as a wax model and refractory mold filling are not required. The limit of the metal walls is given by the thickness of the single trace of laser melting, compatible with the preservation of the adequate strength required by a jewel and the type of metal powder.

SLM not only revolutionizes the way to design and conceive shapes, but also to optimize the investment of the precious metal present in the jewel.

In microfusion it is therefore necessary to renounce a priori certain jewelry geometries because the risk of failure and therefore waste is very high: the number of incomplete pieces can increase drastically within a casting containing many dozens of pieces and the success in the production of a single jewel cannot be translated into the success of mass production.
With the new laser technology, on the other hand, there is no dimensional constraint other than that dictated by the precision of the laser, a problem that is destined to be extinguished with the perfection of the technology.

5.3.3 For supports

In both classic/direct casting and SLM, the presence of supports and power supplies necessary for the success of the jewel cannot be ignored. These elements are indispensable to fix the growth position of the jewelry and send the metal alloy into the hollow shapes mounted on the shaft.
However, it is important to note that particular jewelry geometries may require such a support that the relationship between the volume of the pieces and the volume of the supports is disadvantageous. Like casting feeders, support scaffolds are a valuable part that must be removed from the jewelry and therefore their quantity is a factor that must be considered in the overall economy of the production process as an integral part of production waste.

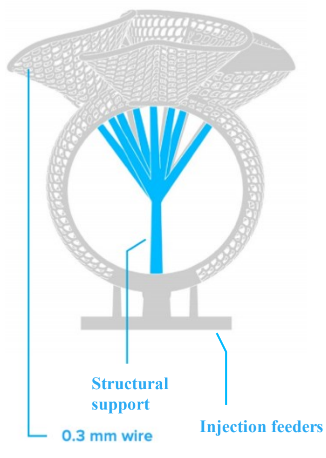


Figure 5.3 *– Sample of a ring with structure support and injection feeders*

Source: see [5]

a. Classic and Direct Microfusion

Unlike classic casting, the media is generally also required in direct casting for printing the model in wax or resin. In this case the supports are removed before the production of the plaster molds and are therefore not present in the assembled shaft, thus influencing the production process only in terms of the time needed for their removal and not on the quality of the workpiece and of the processing waste.

b. Selective Laser Melting

In laser printing, the size and number of media is only related to the surface area of the objects and is necessary to support the cantilevered parts of the object, which otherwise could be easily knocked out by the movement of the metal dust distribution brush. The shape of the supports and their position is designed to make it easy and economical to remove the parts from the construction platform. Their shape mainly takes the appearance of three-dimensional grids, with very thin contact points on the workpiece.

In this case, production waste in the form of supports does not increase as the mass of the object increases, since it is related to the overall surface of the workpiece instead of its volume. The main disadvantage related to the presence of supports in selective casting is due to their removal phase. A residue of their presence may in fact remain attached to the printed jewel or may remain tiny craters. The extent of these defects can be eliminated during the finishing phase (Figure 5.4).

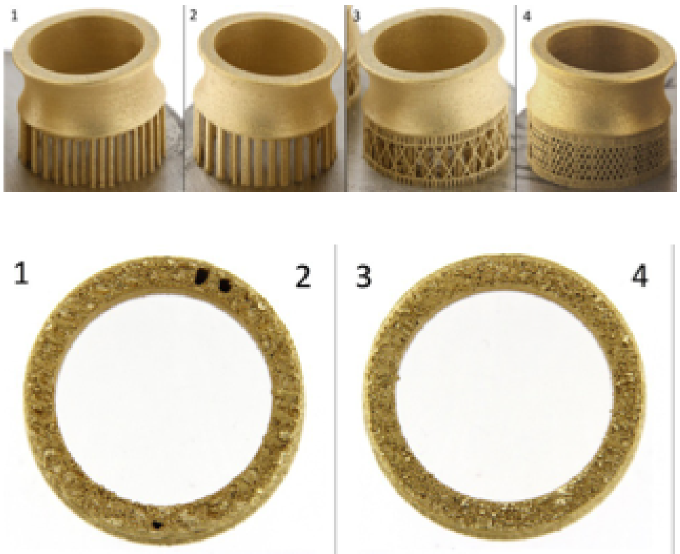


Figure 5.4 *– Surface of the bottom surface of rings - printed with different types of support - after manual removal of the media. Holes left by media removal are visible in zones 1 and 2*

Source: see [28]

Further drawbacks occur when the support is too far away or too thin, landslides, displacements and overheating of the piece may occur with compromise of the final quality of the jewel, if instead the support is too much the roughness of the affected surfaces may be high and its removal difficult.

5.4 Production Lead Time

The time required for the delivery of an order to the customer depends on the number and type of pieces to be produced. Comparing different production techniques the production time for a given number of pieces will result different, moreover considering lots of different size the production time calculated for one technique will result different from the others.
The three techniques under analysis are classical, direct microfusion and selective laser melting.

5.4.1 Scenario

The analysis reported involves three cases, namely: the production of 1, 10 and 100 gold reference rings.
The pieces used for the comparison of production times have the same alloy, a volume and consequently an identical mass around 10 grams, while the shape considered changes according to the technique adopted. The shapes are chosen using a typical geometry among those generally produced with each of the techniques under examination, specifically: a band ring for classic and direct microcasting and a hollow ring for selective laser melting. In this way the simulation of the production time is carried out on jewels that for their shape characteristics would really be produced with one technique rather than another among those examined.
The design and design times of the starting model have not been considered for calculation purposes, as they are a common step of the three techniques considered.
The availability of production machinery has been considered unitary for each type, so the calculation of production time and process productivity has been carried out considering only one machine for each processing phase per company, therefore: one wax injector, one wax jet printer, one cylinder preparation machine, one annealing oven, one casting machine, one laser printer and so on.
The production capacity for each equipment corresponds to the average one present in the goldsmith market, therefore in the summary of the differences between the various techniques exceptional performance machines are excluded to take into account the various purchasing powers of the companies in operation.

5.4.2 Calculations and analysis

The lead time calculation and the analysis of the production capacity have been carried out considering the typical production times of the high jewelry market segment so that the production by selective laser melting is particularly suitable due to its innovative potential.

As shown in Appendix B, for each of the three techniques under examination the time needed to complete each production phase has been calculated.

As described in paragraph 2.4, the procedure for the realization of the prototype in classic microfusion involves the realization of the wax model, its casting in non-precious metal and the surface finishing phase. The injection times in the wax preparation phase, the wax cooling and extraction times and the times for part inspection have been added up to a total of about one minute for a form of low complexity; on the other hand, much longer preparation times are required for complex or massive forms.

It should be borne in mind that the wax preparation time can be further reduced if a second rubber mold is made to be used during the wax cooling time in the first mold. However, in the present case, even for the production of 100 parts, the time saved in wax preparation is more than consumed by the preparation of a second rubber mold, which has therefore been excluded from the production time calculation.

Production Technique	**1 piece [hour]**	**10 pieces [hour]**	**100 pieces [hour]**
CLASSIC MICROFUSION	34.0	34.5	37.5
DIRECT MICROFUSION	18.5	18.5	28.5
SELECTIVE LASER MELTING	2.0	8.0	78.5

***Table 5.1** – Overall production time for the three production techniques*

A comparison of production times showed that the SLM technique, for the production of about 10 units of parts, is clearly advantageous in terms of production times compared to casting.

In the machining of a few parts, the longest times are found with classic microfusion, as the production of the prototype has a very important impact on the overall working hours. It is therefore evident why in reality the production of a single piece in classical microfusion is a rare event, justifiable only for jewelry of enormous artistic importance.

Since the figure of the goldsmith artisan is disappearing, thanks to laser printing the same service is guaranteed but in a faster time. The SLM unlike direct microfusion, allows to directly realize a unique jewel without starting an entire production cycle.

In order to contextualize a reasonable business reality, in the case of resumption of an old mass production for which there are already prototypes and rubber molds, the times of realization of one or ten pieces for the classic microfusion are considerably shorter, resulting inferior to those of the direct microfusion but always higher compared to the case of adoption of SLM because of the long annealing times of the refractory coatings.

Considering the production of a larger number of pieces (about 100), the ranking among the three technologies changes. In this case, the time taken for laser printing is longer than the time needed for the production of prototypes plus ceramic coating firing plus wax printing. Even in the production of about one hundred pieces, direct casting is faster than classic casting, due to the long time required for the preparation of the prototype.
As the number of parts produced increases, the relationship between the times is reversed, i.e.: the production time of the prototype in classic casting is amortized and the wax printing times, which are longer than the injection, are to the disadvantage of direct casting.

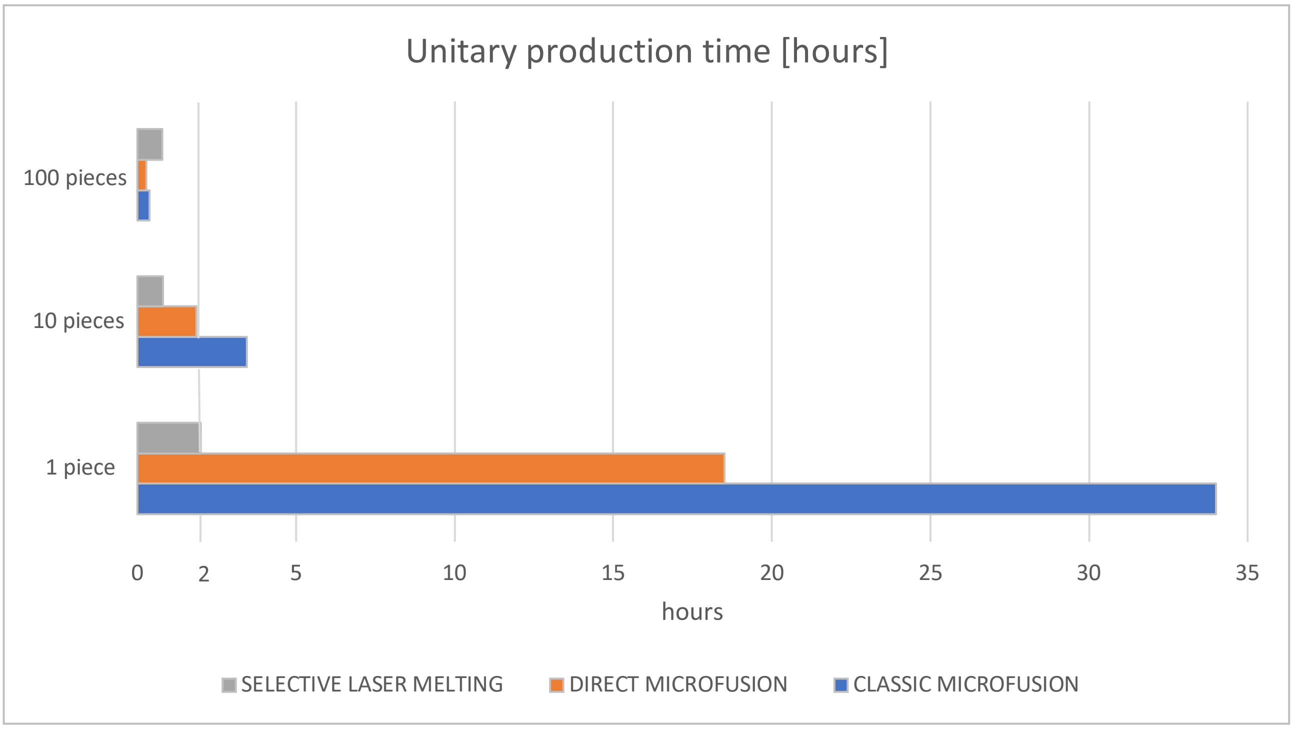


***Figure 5.5** – Production times per single item depending on the production technique and number of pieces to be produced*

Source: personal production, see [28]

Considering the case in which we want to simulate the realization of a large series of jewels for the production of 225 pieces, equal to nine complete cylinders, the production times are 43,5 hours for the classic microfusion and 45 hours for the direct microfusion; this difference increases proportionally to the increase of the number of pieces, visible trend in Figure 5.6. In case instead of using the SLM technique in a series production (more than 100 pieces), it is not at all convenient both in terms of time and cost. Its use can be justified in the case of production of critical part geometries (e.g. thin walls, extended grids, cavities) or problematic materials in microfusion, such as platinum and titanium, or in the case of particular economic advantages, such as the emptying of jewelry for weight reduction or the possibility to keep the weight constant by changing the size of rings and bracelets.

SLM is therefore a surprising technology for the realization of collections characterized by a limited number of pieces, unique and niche pieces, the selective laser casting upsets any traditional lead time cycle, considerably shortening the most time-consuming production phase.

5.5 Production Capacity

In order to conduct an appropriate benchmark, it is good to analyze the production capacities of individual processes. With production capacity is meant the amount of jewelry produced every day and then corresponds to the mass of pieces produced daily (in grams units).

5.5.1 Scenario

Likewise to the previous scenario, also in this case the tools used are considered unitary for each type and average production capacity. The daily work shift has been fixed at eight hours for a single operator for each production department (i.e. in the case of the classic microfusion, the cerist will be able to prepare both the waxes and the castings; at the same time the foundry will be able to start the firing of the castings and make the castings). In the case of operations involving the adoption of automatic machines, these have been considered capable of working until the end of a production cycle even outside regular working hours.

5.5.2 Calculations and analysis

In the case of classic investment casting, a single firing cycle can be completed in one working day for each annealing furnace due to the time-consuming dewaxing process of the coating.

The estimated time for the injection of a single wax into the rubber mold is 30 seconds, however, consider that in a realistic case of mass production several identical rubber molds are generally used. To this is added 10 minutes for the assembly of each shaft with a total weight of 500g, of which 50% is a production waste due to the supports and feeders. On average an oven has the necessary capacity to bake about 15 cylinders and this results in a significant recovery of productivity.
With these times in 8 working hours it is possible to realize the maximum number of cylinders that can be housed in the annealing oven considered. At the same time, the foundry is able to melt, pickling and extract the 15 spindles made the previous day. In short, 3750 g of jewelry can be obtained every working day.
As far as direct microfusion is concerned, the limiting phase of the process is the printing phase of the wax model. Assuming that the printer is able to produce about 220 pieces of 10 g each per day and considering that at the same time of printing the castings can be assembled with the waxes already prepared, the estimated potential production capacity is about 2200 g per day of jewelry. Consider that this value is strictly related to the type of printer adopted.
Finally, in the case of laser printing, productivity is closely related to the printing time and therefore to the type of printer. If we consider the production in 24 hours of rings weighing about 10 g in a single printing table with 7 pieces per level and a total of 5 overlapping levels, the production capacity reached is 350 g of jewelry per day.

Production Technique	Classic microfusion [kg/day]	Direct microfusion [kg/day]	Selective Laser Melting [kg/day]
Daily productivity	3.75	2.2	0.35

Table 5.2 *– Production capacity in kg/day of the three examined techniques*

In table 5.2 are summarized and highlighted the production capacities of the three production techniques and it is clear that the two traditional ones are even more effective to the new SLM. However, it should be stressed that in the jewelry field, the high potential of the production capacity of classic and direct casting is not fully exploited, in fact in the most realistic scenario casting machines are often underutilized.
To date, the production of large batches of items in hundreds and thousands of pieces by laser printing is not convenient if one looks at the purely economic side in terms of cost. Therefore, for the moment, laser printing is adopted to create unique pieces and niche collections, or to create special shapes that would otherwise not be possible with other processes.

5.6 Market Prices

In order to make the scenario as practical and realistic as possible, it is important to provide an economic analysis of the problem, considering the impact and incidence of the new SLM technology on a gold company. Before adopting any new technology to improve the production process, it is of fundamental importance for the operator of the industry to conduct an analysis of market prices and economic convenience, all to ensure effective implementation and investment at medium-low risk. It is also true that this choice of investment depends on many factors, but certainly the attention to capital expenditure and company budget is relevant.

It is also true that this choice depends on many factors that will not be analyzed here, but it is certainly important to pay attention to investments and the company balance sheet.

5.6.1 Scenario

For a correct evaluation of market prices it is important to consider how some factors that influence prices, for example the hourly cost of operators and the electricity used to power the plants, vary depending on the geographical area considered. For this reason the following analysis refers to the Italian market, whose prices are among the lowest in Europe (mainly due to low labor costs compared to other European markets such as France or Germany).

For each technique a price range has been identified that depends on the final value of the production yield (meaning the occupation of the cylinders in the case of microfusion and the capacity of the printing table in the case of laser printing) which in turn depends on the type of object to be made and the production waste (that is given by the damaged parts, of microfusion feeders and supports in the case of SLM.

5.6.2 Calculations and analysis

Since it uses less expensive machines compared to AM printers, and the costs of some phases are reduced thanks to the high number of pieces treated at the same time, the classic microfusion is at the first place in the ranking of the most convenient techniques. The costs and market prices of direct casting, on the other hand, are much closer to those of SLM.

Production Technique	**Market price [€/g]**
CLASSIC MICROFUSION	0.2 - 1
DIRECT MICROFUSION	2 - 6

SELECTIVE LASER MELTING	4 - 12

Table 5.3 *–Comparison among ranges of market price for the jewelry production*

The costs and market prices of direct casting on the contrary are much closer to those of SLM. Analyzing contemporarily the data shown in the tables in Appendix B in Table 5.2 and Table 5.3 - which correspond respectively to execution time, production capacity and market prices - it is possible to see the strengths of the SLM. They correspond to the realization of unique pieces or limited series, whose production time compared to micro casting is substantially shorter, and to the realization of objects that due to geometry or material adopted cannot be produced with classic casting techniques, such as hollow pieces, with extremely reduced thicknesses or with three-dimensional grids.

5.7 Emissions and environmental impact

Nowadays, interest in environmental impact is increasingly one of the areas of interest for every company.

It is now well known that leading edge companies recognize the importance of investing in sustainability by monitoring their impacts while trying to limit emissions as much as possible. One of the universally recognized parameters for assessing 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 in question expressed in terms of mass CO2 equivalent.

5.7.1 Scenario

For the comparison of GHG emitted by the three techniques under analysis, all the production steps and materials needed to complete the production of 1 kg of jewelry were taken into account, referring to the same steps and production times used for the calculation of lead times in the tables of Appendix B.

From the EcoInvent 2.2 database the data needed to calculate the emission caused by the production and disposal of the materials adopted have been obtained, while for electricity the data used refer to the Italian electricity grid. [34]

The comparison does not include the processes considered common to the three techniques (it is the fusion of the mother alloy for the casting and the pre-melting of materials). In addition, the emissions caused by the production of metal raw materials and the emissions caused by the construction and maintenance of machinery and ancillary equipment (such as water and suction systems) have not been taken into account in the calculation, but only the emissions caused by their productive use.

5.7.2 Calculations and analysis

For the annealing phases of the cylinders in classic and direct casting, the emissions have been calculated considering the most advantageous process: full furnace and scaling the emission of the phase for the number of cylinders necessary to make 1 kg of product (that is 4 cylinders out of 15).

CARBON FOOTPRINT OF CLASSIC MICROFUSION	
Production phase	**kg CO_{2eq}/kg**
Prototype realization	7.39
Rubber mold preparation	1.62
Waxes injection	0.31
Stake assembly	0.07
Cylinder preparation	0.72
Cylinder firing	15.90
Alloy pre casting	0.44
Melting and casting	1.85
Pickling	0.42
Release from the stake	0.06
TOTAL (approx)	**28.8**

Table 5.4 *– Carbon footprint of classic microfusion for each step of the production process*

CARBON FOOTPRINT OF DIRECT MICROFUSION	
Production phase	**kg CO_{2eq}/kg**
Waxes printing	3.70
Support removal	0.64
Stake assembly	0.07
Cylinder preparation	0.72
Cylinder firing	15.90
Alloy pre casting	0.44
Melting and casting	1.85
Pickling	0.42
Release from the stake	0.06
TOTAL (approx)	**23.80**

Table 5.5 *– Carbon footprint of direct microfusion for each step of the production process*

CARBON FOOTPRINT OF SELECTIVE LASER MELTING	
Production phase	**kg CO_{2eq}/kg**
Atomization [35]	1.64
Printing	13.2
Support and jewel removal	0.03
TOTAL (approx)	**14.70**

Table 5.6 *– Carbon footprint of SLM for each step of the production process*

Estimates of carbon footprint gases emitted by the three different production techniques show that the values of emissions caused by SLM are lower than those of the other two techniques. The data show that most of the GHG emissions are attributable for all three techniques to the production steps that use electricity over a long period of time: the annealing of classic and direct investment casting coatings, and the printing step for selective laser melting.

In case the furnace is not used at full load, the increase in greenhouse gas production per kg of jewelry is mainly due to the annealing phase of the plasters. In this case the emissions are no longer distributed over the maximum number of cylinders that can be treated, but over a smaller quantity. Generally the CO2 equivalent produced in selective laser melting is significantly lower, being more than half of that of classic and direct microfusion in the case of these have low production efficiency, with ovens strongly underused. On the whole it is therefore possible to conclude that the SLM technique is advantageous compared to micro castings with regard to the impact

5.8 Conclusions

In order to summarize as clearly as possible everything discussed above, a summary table has been created in which the three different technologies are taken and evaluated qualitatively, using a multi-criteria method. The score has been subjectively assigned from 1=* to 5=*****, the higher the number of * the more the technique is winning in the considered aspect. [36]

PRODUCTION TECHNIQUE	CLASSIC MICROFUSION	DIRECT MICROFUSION	SELECTIVE LASER MELTING
Material versatility	**	**	****
Geometries flexibility	**	***	***
Superficial quality	****	***	**
Definition	****	*****	***
Defects	**	***	*****
Finishing drop	**	**	****
Production capacity	*****	***	*
Market price	*****	***	**

Lead time – low volume	*	***	*****
Lead time – mass production	*****	****	*
Level of ecology	**	**	***

Table 5.7 *– Comparison of the general performance of the three manufacturing techniques.*

To more easily select one technology rather than another according to the necessary characteristics, a radar graph referring to the values in Table 5.7 is shown in Figure 5.6.

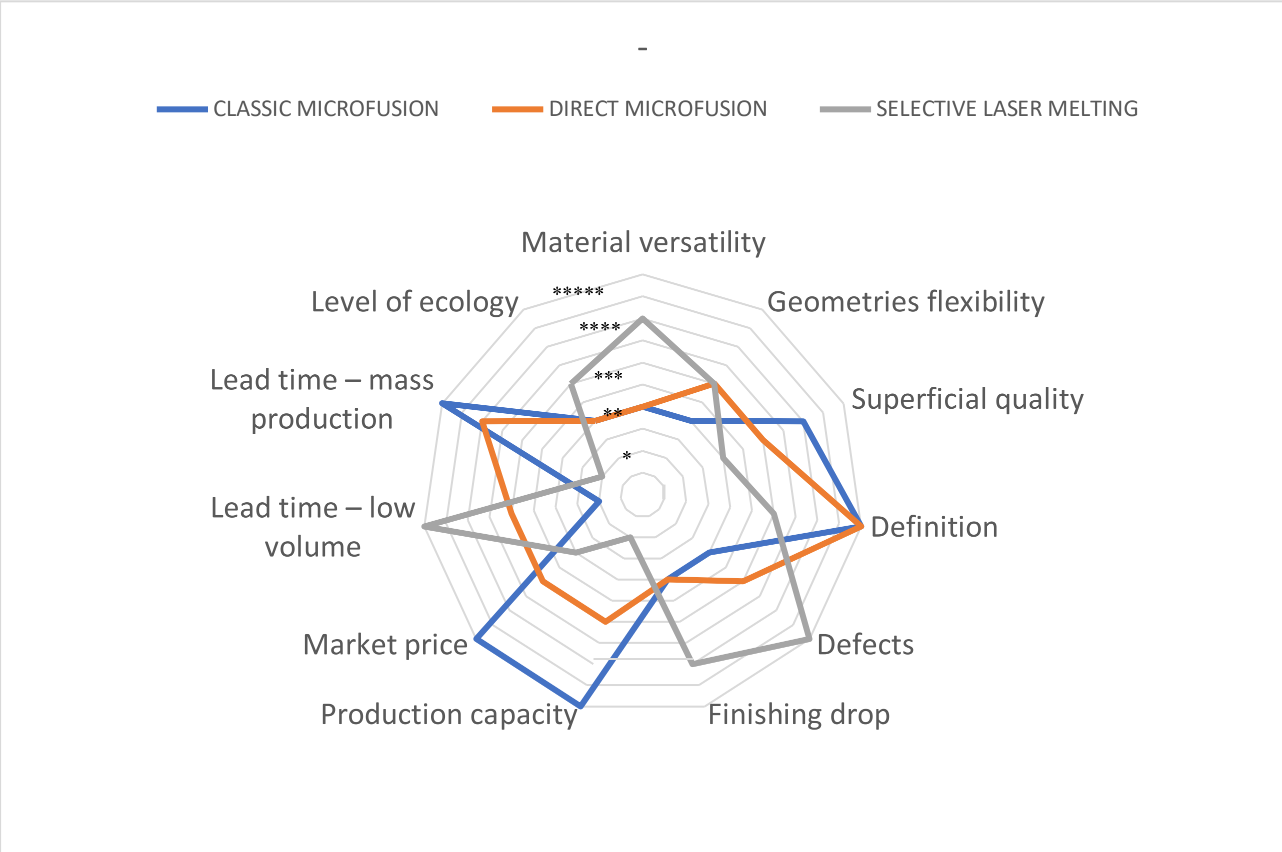


Figure 5.6 *–Comparison among technologies*

Source: see [28]

As can be seen from the graph, it is clear that in terms of production and speed for the production of a few pieces SLM is preferable to casting, while moving to mass production the higher production capacity makes casting, especially classic casting, more competitive in terms of time.

Market prices are also much lower with SLM, while direct casting and laser printing have almost comparable values. SLM can however be advantageous, even in the case of series production, for the

realization of particularly complex geometries or in the case of difficult or impossible materials to use in microfusion, thanks to its greater versatility.
The SLM production cost is the highest, but as already discussed in the previous paragraphs, it can be compensated by the possibility of emptying the objects, in this case bringing the final price of the jewelry to levels that can be even lower than those of classic casting. Ultimately without entering into a particular geometry or production requirement, SLM is currently a technique that offers a potentially higher versatility than other more traditional techniques.

What remains objective, however, is the importance of distinguishing the right technique according to the type of production: not in all cases, production through SLM is the most convenient technique. If at the moment the SLM technique is still seen as experimental and limited to large signatures, in the future the total diffusion of this technology cannot be excluded.
In fact, to suggest such an insinuation is precisely the need to solve the problems related to the cost of the jewel and the long production time, which could be overcome thanks to the greater geometrical possibilities of SLM compared to classical microfusion.
For the comparison with direct casting instead, its versatility in terms of geometries compared to the classic technique is already surpassed by the potential of SLM. Moreover, SLM does not have negative implications with respect to direct casting such as to be disadvantageous with respect to the latter, so it is not utopian to think that in the near future it could progressively replace it.

CHAPTER VI - TECHNOLOGY DIFFUSION IN VICENZA'S INDUSTRIES

6.1 Introduction

After having discussed the possibility that AM technologies offers to goldsmith industry for jewels production, in this last chapter the actual situation regarding the adoption of Additive technologies will be analyzed. The purpose of this survey is to assess the current and effective adoption of additive technology in the jewelry industry, as well as to collect further information and comments from the relevant companies.

The analysis was made on the province of Vicenza, one of the 3 most specialized Italian districts in the goldsmith industry. First of all, in order to obtain a list of valid names of the companies and goldsmith workshops in the province, a contact was sought with Confindustria FederOrafi [37] - Italian association representing more than five hundred national companies in the goldsmith industry – and with Confartigianato Vicenza [38] - national association for the protection and promotion of the values of craftsmanship and small businesses - but the attempt was unsuccessful. In the second instance, it was consulted the producers exhibitors section of the official website of Vicenzaoro, one of the most important gold fair in the world. [39, 40]. In order to verify the correctness of the contacts obtained, to avoid sending the questionnaire to simple jewelry stores, a web check has been carried out with a consequent cleaning of the database.

In the second instance, a call was made to each company on the list to present the initiative and request the availability to participate in the questionnaire by providing a valid email address.
Once the questionnaires were sent and the necessary data were collected, these were analyzed to draw conclusions to support or not the research conducted.

6.2 The sample

The decision to first contact companies by telephone and only then to send the survey electronically depended on the size of the sample. Since the it was not very large, in order to obtain a satisfactory number of responses, it was necessary to verify the availability of the companies by asking for direct contacts. In this way it was possible to accurately track responses and ensure the effectiveness ofthe survey.

	Absolute frequencies	% of total sample
Disabled phone number	3	5,7%
Only commercial activity*	5	9,4%
Not interested to participate (a)	12	22,6%
Email addresses collected (b)	33	62,3%
Total sample	**53**	**100%**
Total goldsmith industries contacted (a) + (b)	45	
Survey responses	18	
Response rate	**40%**	

Table 6.1 *– Details of the sample*

**those companies present in the list of manufacturers but in practice they only carry out commercial activity and do not manufacture*

Although the database was dated to 2019, some contacts were no longer available. Out of the 33 companies that provided the address, some already during the call have stated the potential impossibility to respond to questionnaires of any kind due to company policy.

The data *Not interested to participate* is intrinsic to two types of responses, in fact, on the phone some of the 12 companies besides indicating their unavailability they added not to make use of AM technology, specifically 4 of them.

Out of the 45 contact attempts, the response rate was 40%; in the evaluation of the response rate, companies that were no longer active in the gold industry and that were not relevant to the survey were not considered.

6.3 The survey and its structure

The questionnaire administered to companies, including goldsmith laboratories, is given in Appendix C. Its structure consists of a first part in which companies are asked to identify themselves and to enter the number of employees, necessary to understand whether or not there is a trend in the adoption of the additive according to the size of the company (in terms of number of employees). In the first phase was also asked whether the company makes use of the AM for the production of jewelry or not, this allowed to select the respondents and not to administer them the internal questionnaire dedicated to the actual adoption of the AM.

The second part instead - the companies that have declared to adopt AM technology - are asked a series of questions that get to the heart of the matter and aim to touch respectively the following concepts:
- understand if the company has invested directly and how much in AM;
- understand the actual adoption of AM technologies in the production process, to confirm whether they bring added value to the finished product or if they are only of marginal utility.
The last part instead - administered both to those who make and do not use AM - tries to understand the future trend of adoption of AM in the jewelry industry, especially for the most innovative technology: Selective Laser Melting (SLM).

6.4 Answers analysis

In the first section of the survey, some general questions were asked to better identify the companies under examination. It can be noticed that the proportion of companies in the sample is half from that of the entire Italian jewelry sector, in fact the data reported in Chapter IV referring to the AIDA database confirm that 82% of the companies under examination have less than 10 employees. But it should also be borne in mind that many of the micro enterprises contacted did not provide an answer to the questionnaire due to the fact that they are not structured and have few personnel and time available.

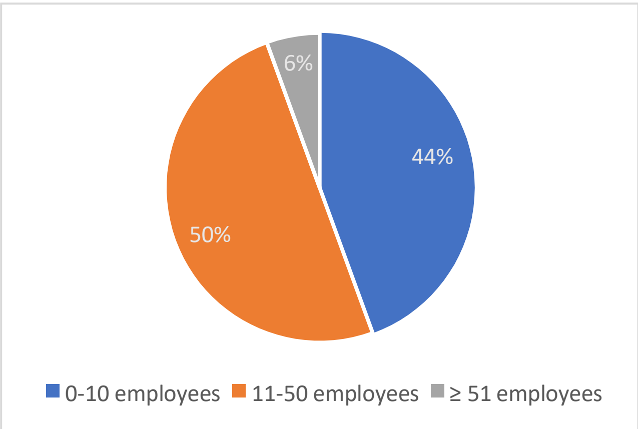


Figure 6.1 *– Q2: How many employees does your company have?*

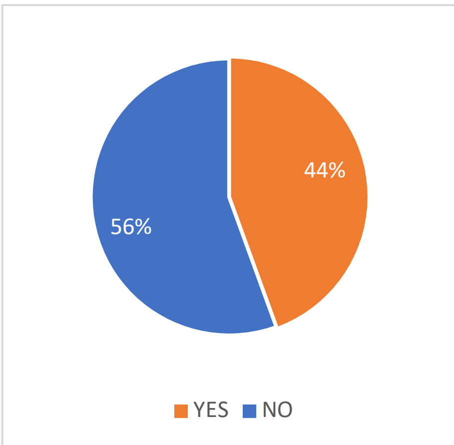


Figure 6.2 *– Q3: In your company, do you use additive technologies (3D printing) in the production of your jewelry?*

The sample analyzed, however, emphasizes what is a phenomenon that characterizes the entire gold manufacturing industry: more than 2/3 of companies do not exceed 50 employees, half of them are micro (1-10 employees) and small (up to 50 employees) enterprises. Only one respondent declared to have more than 50 employees - a possible value but really rare - in fact a industry research declares that only the 3,9% of companies is related to the range >50 employees. [41]
The market is divided into two groups, over half of the companies say they do not use 3D printing in the production of jewelry, the remaining half already adopted it. This data confirms how the traditional technique of lost wax casting continues to be competitive in the market, making 3D printing not yet essential for survival in the market. In addition, the Figure 6.2 excludes the 4 companies to which reference was made just above that did not respond to the questionnaire but declared by telephone not to use the additive. Therefore this data can be updated in this sense: out of a total of 22 companies 64% do not use 3D printers while the remaining 36% have already adopted them. The rate of adoption has therefore been lowered further, this denotes the high cost of the technology and the novelty of the technology itself in a traditional industry.

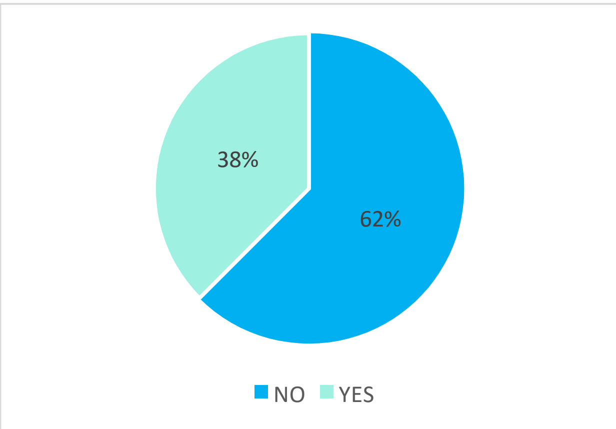


***Figure 6.3** – Rate of adoption of AM in companies with ≤10 employees*

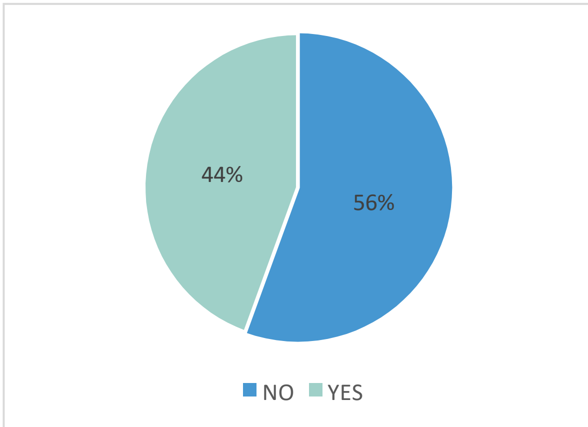


***Figure 6.4** – Rate of adoption of AM in companies with >10 employees*

The data collected did not show a correlation between the number of employees and the actual adoption of 3D printing (see Figure 6.3 and 6.4). In fact, the literature shows that SMEs generally differ from large companies for the investments made in support of innovation. While in large companies R&D investments prevail, in SMEs the main expenses consist in the purchase of new machinery, equipment and facilities to promote innovation [42].

From the end of the first general questions, the sample is divided according to whether the company has declared to use 3D printing or not, those who answered "yes" to question 3 were directed to the next section dedicated to 3D printing. Those who answered "no" were redirected to the last general questions of the questionnaire.

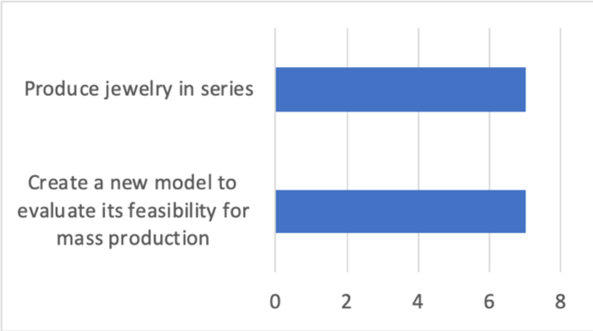


Figure 6.5 *– Q8: 3D technologies in your company, are used for*

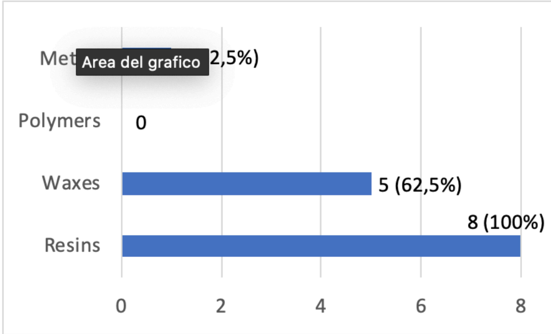


Figure 6.6 *– Q9: Within your company, 3D printers use materials in*

These data are a confirmation of the versatility of 3D printing. Almost everyone has declared to use the technology both in the testing phase of new products to be launched on the market and then to exploit the same machine in production. Also in this case there is no close correlation between the number of machineries owned by the company and its the actual adoption, this suggests that machines are actually multi-purpose and there is no need to invest in two different machines: by investing in a printer the user can obtain multiple adoption within the supply chain.
Depending on the model to be made there are two types of materials available, between the two the resin is the most popular because it is more performing. Many companies, however, have not completely abandoned the traditional waxes, in fact 60% still use it, in parallel with the resins.
The number of machines declared by the companies is also consistent with the specificity of the machine, those who use both waxes and resins have at least 2 printers, one that makes wax models does not work with resins and vice versa, because these are in fact two different technologies (respectively multi jet printer and stereolithography).

Among companies interviewed only one indicated that it uses metals, which means gold alloys, and as expected none of them uses polymers, a material that in other sectors is the most adopted in the prototype stamping process.

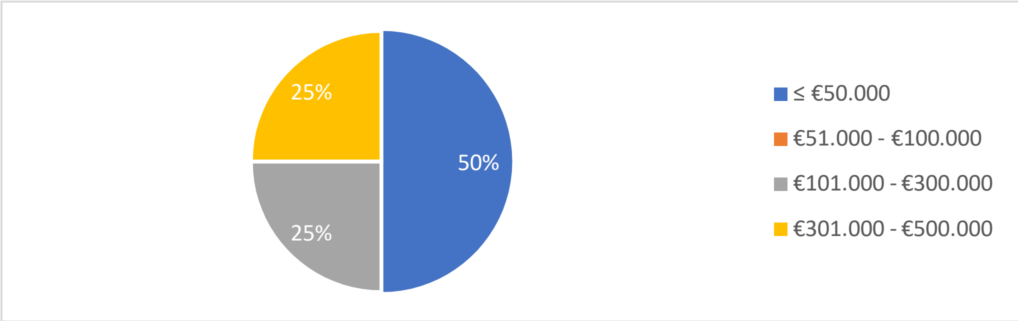


***Figure 6.7** – Q10: How much is the total investment your company has made in 3D printers?*

Since prices for industry-specific 3D printers had not yet been discussed, the following question was asked directly to companies. By comparing the price ranges of investments and the number of 3D printers in the company with the types of materials adopted, it is clear that the printed material makes the difference. These kinds of technologies have a high cost, considering that the market consists mostly of small companies if a firm wanted to buy additive machinery it would be a considerable investment. Thanks to the data collected regarding the number of machines owned, the type of material used and the total investment made for the purchase of additive machinery, it was possible to estimate that: the cost of resin printers is around €30 thousand instead for wax printers the price rises up to a maximum of €100 thousand.

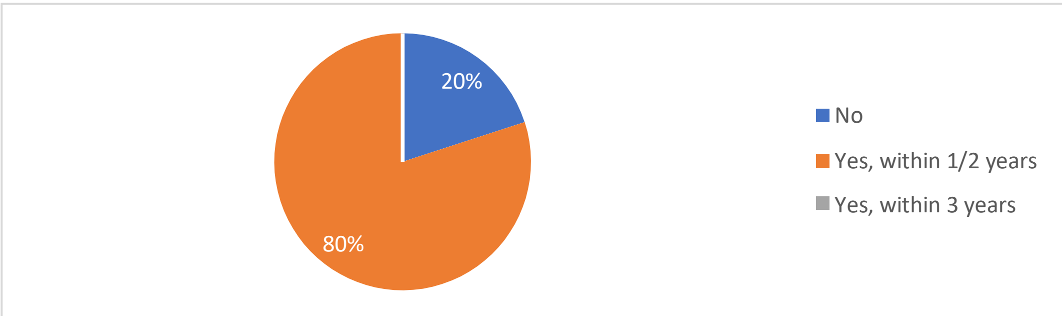


***Figure 6.8** – Q15: Does your company intend to invest in additive manufacturing technologies?*

Taking the market as it is it seems that within the innovation diffusion curve the late majority has already been reached, and according to the data, those who have not yet decided to adopt 3D printing in their production process will never adopt it. Only 1/5 of the companies said they will adopt the technology in the short term, the rest probably due to the price of the machinery and the price of materials for printing desist from upgrading. A direct testimony has confirmed how the goldsmith industry is inertial and very faithful to tradition, not at all pushed towards change and innovation. In support of this there is also the difficulty of adapting the production process to the introduction of the additive as temperatures, plasters and other more specific aspects of the production process must be modified and adapted to the type of wax/resin used upstream.

Since the innovative technology of the SLM has yet to actually land on the market, we wanted to collect opinions on some aspects of this technology through a concordance scale.
The SLM technology is not yet fully known, the sample splits in two in this case, there are those who claim to be fully aware of it and those who have never heard of it, which indicates a strong lack of interest in this technology.
Since the answers of those who do not know the technology at all would be purely subjective and lacking basic knowledge, it was decided to sample the answers of those who know the SLM well enough.

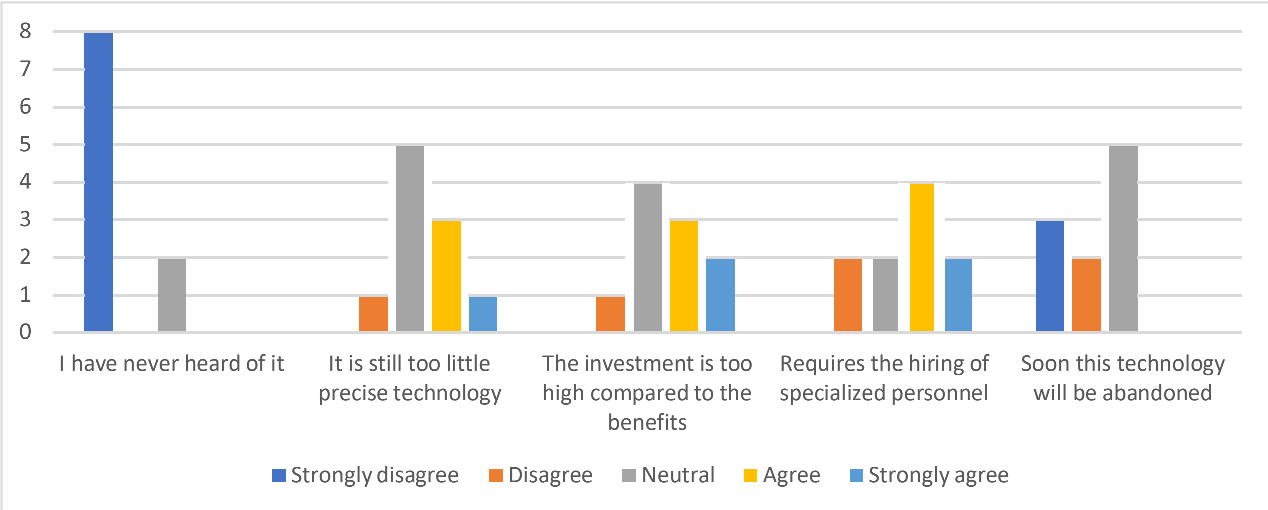


***Figure 6.9** – Q16: Please indicate your impressions about the adoption of Selective Laser Melting Technology (SLM) in jewelry production*

From these data it is clear that the general opinion about the accuracy of the machinery has not yet been the object of interest of companies, 50% of respondents declared themselves neutral while only 40% expressed their opinion by defining the technology as still too immature for the jewelry industry. Probably such disinterest derives from the impression, which all entrepreneurs have in common, that the SLM machinery is still too expensive compared to the benefits it can actually bring in the production process and also to the need to invest in qualified personnel - as the need for new figures would seem essential for a proper functioning of the machinery - thus declaring the investment unsatisfactory.
To conclude, looking at all the answers provided by the companies, it emerges what has been said about the innovation diffusion curve: we are still at the beginning of the evolutionary process, very few innovative companies have approached the SLM but the common thought is projected towards

the evolution and the future adoption of this technology that would upset what is the traditional millenary production technique.

Among the additional comments some companies have given their contribution, a company that based on the request for quotes from a supplier believes that "*the SLM is very valid if referred to objects with high value added by the use of precious stones, while for the jewelry by weight is still too expensive*."

Another one instead declares to have "[…] *tested two SLM machines, the first machine for about a year then replaced with a more advanced one. The results were not very satisfactory, especially as far as the finishing of the final piece was concerned. At the level of test we had never considered the price of the alloy, as it was very expensive, we were talking about 1000 euro of manufacture per kg*."

6.4.1 Clustering by company size

To perform a more in-depth analysis it has been decided to divide according to the size the companies from 1-10 employees (which in the analysis are called small companies, SE) and from 11-50 employees (which below are called medium-sized companies, ME) being these two significant clusters of the sample under examination.

Regardless of the size of the company, in both cases the majority have not yet adopted 3D printing in their production process, but both an SE and an ME have stated that they plan to adopt it in the short term.

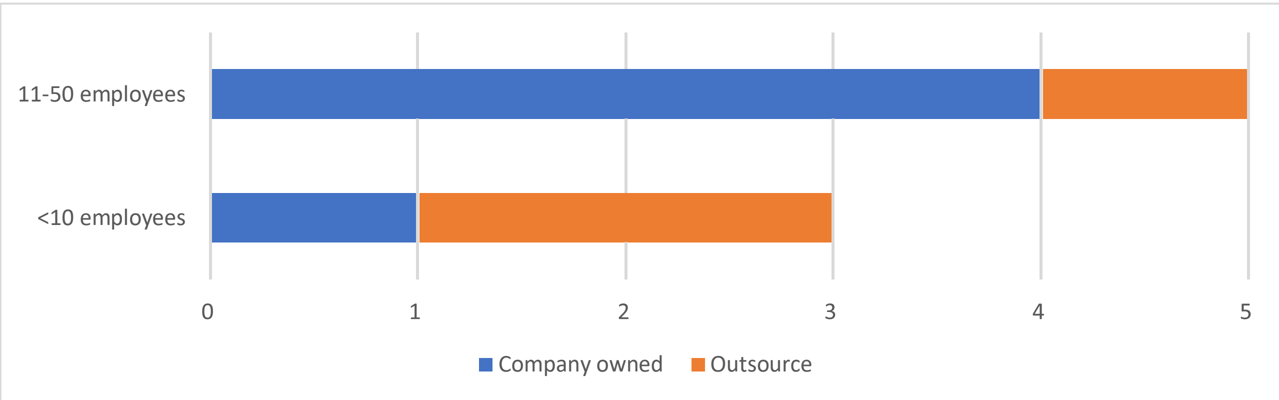


Figure 6.10 *– Q4: If your company uses 3D printers, they are*

Only one of the three SE possesses 3 machineries of property while the remaining two outsourcing the working of additive. The ME have all at least 2 own machinery, only one in case of high production lots outsources part of the production.

It emerged that the SEs that adopt additives rely on third party companies for 3D printing processing, probably due to the cost of the machinery and low production capacity. On the other hand, MEs that have declared to make use of 3D printing have directly invested in technology, only one of the companies has declared to own machinery but also to exploit outsourcing. This explains the factthat manufacturing SMEs need to continuously improve their manufacturing processes to maintain their long-term competitive advantage.

***Figure 6.11** – Q6: How often does your company use the 3D printer? (multiple choice)*

The running time of the machine is not modifiable, larger companies use printers more frequently, especially having them in house it can be managed the timing at will. Moreover, having more than one machine it would seem sensible to think about using one machine always in production and the other one in R&D if necessary.

One of the respondents justified a low level of adoption of the machinery because of the global production decline due to the pandemic.

At this point of the survey a section dedicated to the production process is opened that involves all three technologies that can be used – such as classical and direct microfusion and selective laser melting - as it was intended to verify that the data analyzed in the previous chapter and reported in Appendix B had a fund of truth. Unanimously all companies, whether SE or ME, continue to adopt the classic method for jewelry production, justified by the fact that for large batches the process is still the most convenient, as has already been discussed in detail in the previous chapter.

As was to be expected, the sector being based on a century-old production technique, consolidated and making a higher finished product quality, none of the companies felt the need to completely abandon this technique. At the same time, however, having invested in 3D printing, the companies have also adopted the direct microfusion method, converting the first steps of the production process from the classic method to the digital one.

CONCLUSIONS

By collecting what has been said in the previous chapters together with the information that emerged from the data analysis of the survey it is possible to draw some conclusions.

Firstly it is important to identify that the industry of goldsmith firms is mainly composed of micro and small enterprises concentrated in three Italian districts, whose manufacturing and quality of the finished product is recognized and appreciated all over the world. To realize such jewels, however, there are three main production methods that require high craftsmanship and high precision.
Types of processes compete as production methods: there is the traditional technique of lost wax casting and its variant with the introduction of additive in the early stages of the process (such as Stereolithography or Multi Jet Printing) and finally the innovative, but less feasible, technology that manufacture a jewel entirely in additive (the SLM).

Given this preliminary contextualization, the first point to be underlined is the actual level of adoption of the additive. If at first impact the degree of adoption of the additive may seem low in reality it is not. Considering the type of industry, the high upfront investment that the company has to bear for the purchase of the machine, no substantial reduction in costs, having just under half of additive adoption by goldsmith companies is a good result.

Another aspect to consider, that could justify the choice of those who have already adopted additive technologies, is that the industry is sensitive to the introduction of new machines within the traditional production process, because in this case it talks about process innovation but also intrinsically about product innovation. Thanks to technology, manufacturers are able to make products that previously would not have been possible, or convenient, to put on the market, sometimes even simplifying the process by making unique pieces that would otherwise have needed additional manpower. In this sense the main disadvantages of the additive such as the level of resoluteness fall in the background and are actually solved by the advanced stage of technology and the type of material used.

It can be concluded that the near future will see a period of stalemate in which those who have already adopted the additive will continue to use it and progress along with technological advances.
The companies that have not yet adopted the additive will not do so because they are linked to tradition and unable to see the benefits that can give overall. What does not yet seem to be clear to

these companies is the potential of additive manufacturing: the innovation of the product, the greater value created for the customer, the improvement of time to market, the customization of the product leads to improve the company's competitiveness, however, acting more on revenues and profits rather than on cost reduction.
As regards the SLM will be discussed in the future, since the technology is still not very accurate and the market is not yet ready to change its production process.

The last fundamental consideration is that differently as one might commonly think AM printing tools does not cause a loss of craftsmanship, but rather increases the creative potential of entrepreneurs and designers. Although manual craftsmanship is lost at one stage of the production process, it is important to highlight that in general the artisan approach and creativity are enhanced by this new technological tool.

Appendix A

Elaboration of the Chamber of Commerce of Vicenza on data taken from analysis carried out by Info Camere values reporting the percentage of the 30 districts with the highest presence of goldsmith companies on a national total of 7,500.

LOCAL UNITS in JELWELRY % of each province on the national total of the industry TOP 30 DISTRICTS - 1ST QUARTER 2019					
	PROVINCE	**%**		**PROVINCE**	**%**
1	AREZZO	15,5%	**16**	VENEZIA	1,1%
2	ALESSANDRIA	9,8%	**17**	SASSARI	1,0%
3	VICENZA	7,8%	**18**	ANCONA	1,0%
4	ROMA	6,2%	**19**	MACERATA	1,0%
5	NAPOLI	6,1%	**20**	REGGIO CALABRIA	1,0%
6	MILANO	5,8%	**21**	BOLOGNA	0,9%
7	FIRENZE	4,2%	**22**	BOLZANO	0,9%
8	CASERTA	2,6%	**23**	COSENZA	0,9%
9	PADOVA	1,8%	**24**	PERUGIA	0,9%
10	BARI	1,8%	**25**	GENOVA	0,9%
11	TORINO	1,3%	**26**	TREVISO	0,9%
12	PALERMO	1,2%	**27**	VERONA	0,8%
13	CAGLIARI	1,1%	**28**	LECCE	0,7%
14	PAVIA	1,1%	**29**	BERGAMO	0,7%
15	VARESE	1,1%	**30**	PESARO E URBINO	0,6%

Appendix B

Estimation of production time in classical microfusion, direct microfusion and in selective laser melting.

CLASSIC MICROFUSION			
Production phase	**Working time of 1 piece [min]**	**Working time of 10 pieces [min]**	**Working time of 100 pieces [min]**
Prototype realization	1150	1150	1150
Rubber mold preparation	120	120	120
Waxes injection	1	10	100
Stake assembly	1	3	33
Cylinder preparation	30	30	45
Cylinder firing	720	720	720
Alloy pre casting	15	15	15
Melting and casting	15	15	60
Pickling	5	5	20
Release from the stake	0.25	1	10
TOTAL (approx)	**2050 (34.0 h)**	**2070 (34.5 h)**	**2270 (37.5 h)**

Table B.1 *– Estimation of classic microfusion production time*

DIRECT MICROFUSION			
Production phase	**Working time of 1 piece [min]**	**Working time of 10 pieces [min]**	**Working time of 100 pieces [min]**
Waxes printing	260	270	710
Support removal	60	60	90
Stake assembly	1	3	33
Cylinder preparation	30	30	45
Cylinder firing	720	720	720
Alloy pre casting	15	15	15

Melting and casting	15	15	60
Pickling	5	5	20
Release from the stake	0.25	1	10
TOTAL (approx)	**1100 (18.5 h)**	**1120 (18.5 h)**	**1700 (28.5h)**

***Table B.2** – Estimation of direct microfusion production time*

SELECTIVE LASER MELTING			
Production phase	**Working time of 1 piece [min]**	**Working time of 10 pieces [min]**	**Working time of 100 pieces [min]**
Digital model support	15	15	15
Printing and machine cleaning	110	440	4400
Support and jewel removal	3	30	300
TOTAL (approx)	**130 (2.0 h)**	**480(8.0 h)**	**4700 (78.5 h)**

***Table B.3** – Estimation of SLM production time*

Appendix C

In the following pages is reported the survey that has been administered to the companies of the goldsmith industry.

Additive Manufacturing (3D printing) in the goldsmith industry

I am Eng. Giacomin and I collaborate with the Department of Management and Production Engineering (DIGEP) of the Politecnico di Torino for a research on the use of Additive Manufacturing in the goldsmith sector.
I kindly ask you to answer the following questions, the completion of the questionnaire will take you 3/4 minutes.
The data collected will absolutely not be provided to third parties and will have only scientific and non-commercial purposes.
* Required

Company information

1. Enter company name (the data will not be made public, it only serves to identify which of the companies contacted responded to the survey)

____

2. How many employees does your company have? *

   Mark only one oval.

   - 0-10 people
   - 11-50 people
   - ≥ 51 people

3. In your company, do you use additive technologies (3D printing) in the production of your jewelry? *

   Mark only one oval.

   - Yes
   - No *Skip to question 15*

4. If your company uses 3D printers, they are:

If you chose "No" in the previous question skip this question and select "Next".

Check all that apply.

- [ ] Owned by the company
- [ ] We rely on third party companies

3D printers

5. How many 3D printers are there in your company? *

Mark only one oval.

- ( ) none
- ( ) 1
- ( ) 2
- ( ) 3
- ( ) ≥ 4

6. How often do you use the 3D printer? (multiple choice) *

Check all that apply.

- [ ] never
- [ ] daily
- [ ] more than 3 times a week
- [ ] more than 5 times per month

7. If you have chosen more than one option in the previous question, please justify your answer

____

____

____

____

____

8. 3D technologies in your company, are used for: *

Check all that apply.

- [ ] Create a new model to evaluate its feasibility for mass production
- [ ] Produce jewelry in series

9. Within your company, 3D printers use materials in: *

Check all that apply.

- [ ] Resin
- [ ] Wax
- [ ] Polymers
- [ ] Metal

Other: [ ] ______________________

10. How much is the total investment your company has made in 3D printers? *

Mark only one oval.

- ( ) ≤ €50.000
- ( ) €51.000 - €100.000
- ( ) €101.000 - €300.000
- ( ) €301.000 - €500.000
- ( ) ≥ €501.000

Production process

11. The production process of your jewelry includes: *

Check all that apply.

- [ ] Classic Microfusion - means the process including rubberizing and manufacturing of a master
- [ ] Direct Microfusion - means the process of gumming directly on the prototype created by the 3D printer
- [ ] Selective laser melting (SLM) - means the sintering of gold powder from which the semi-finished product is directly obtained

12. If your company uses the classic microfusion, can you confirm that the production process (from prototype realization to the spiantonatura) for 1 piece (consider a band ring) lasts between 30 and 40 hours? *

Mark only one oval.

- ◯ Confirm
- ◯ No, it lasts less than 30 hours
- ◯ No, lasts more than 40 hours
- ◯ We do not use this technique

13. If your company uses direct casting, can you confirm that the production process (from the wax printing to the levelling) for 1 piece (consider a band ring) lasts between 20 and 30 hours? *

Mark only one oval.

- ◯ I confirm
- ◯ No, it lasts less than 20 hours
- ◯ No, lasts more than 30 hours
- ◯ We do not use this technique

14. If your company uses selective laser melting (SLM), it confirms to us that the production process (from the beginning of the machine path to the detachment of the part/supports) for 1 part (consider a hollow ring) lasts between 1 and 3 hours? *

Mark only one oval.

- I confirm
- No, it lasts less than 1 hour
- No, lasts more than 3 hours
- We do not use this technique

Skip to question 16

Additive Manufacturing: no

15. Does your company intend to invest in additive manufacturing technologies? *

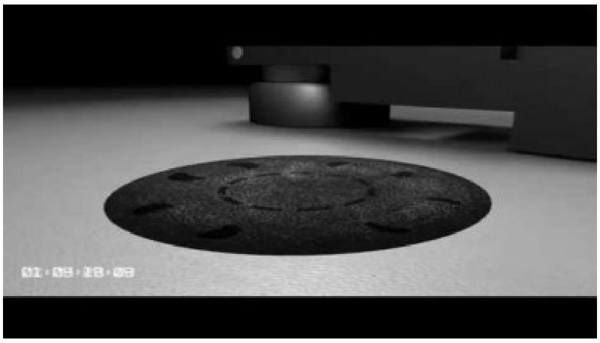
Mark only one oval.

- No
- Yes, within 1/2 year
- Yes, within 3 years

Skip to question 16

Final Considerations - Selective Laser Melting (SLM)

As you may already know, there is a new technology on the market for the creation of jewelry, it is the selective laser fusion technology (SLM) that allows you to create a jewel directly through the printing machine. Below you will find a video representing the Selective Laser Melting Technology (SLM) in operation. The video is an advertisement of the printer manufacturer, we recommend that the audio is turned off.



http://youtube.com/watch?v=jTUp810yOiQ

16. Please indicate your impressions about the adoption of Selective Laser Melting Technology (SLM) in jewelry production

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I have never heard of it					
It is still too little precise technology					
The investment is too high compared to the benefits					
Requires the hiring of specialized personnel					
Soon this technology will be abandoned					

Additional comments

17. The survey has come to an end, if you like you can provide below some additional comments on the use of Additive Manufacturing in the jewelry field.

____

____

____

____

____

Skip to section 8 (Survey concluded)

Survey concluded

The questionnaire has been completed.
Thank you for your answers and for your time. The data provided will be used for research purposes only and without any commercial purpose.

I renew my thanks,
Eng. Giacomin

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