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INFLUENCES OF ADDITIVE MANUFACTURING (3D PRINTERS) ON THE PRODUCTION COST AND FUTURE OF JEWELRY INDUSTRY

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the golden feather

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Parisa Sepahvani

Italy, Milan. Dec.2015

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1. Abstract

Putting three dimension printers (3D printers) as the core study of jewelry industry, problems calculating the cost of production and also the role of 3D printers in the jewelry industry seem a vague point.

In this study first, it has been tried to go through the history of Additive Manufacturing with an intensive focus on the metal and jewelry 3D printing, different methodologies. The second step was defining the important factors which influence the cost of the production and establish a simplified formula for calculating the cost of printing jewelries with precious metals.

In the third step the laser additive manufacturing formula (LAM) is modeled in Excel to analyze the influences of different precious metals (Platinum, Gold and silver) on the cost of a 3D printed object based on the results. After that you will study the effects of 3D scanner in the jewelry industry and how the copyright law can protect the designer patents.

Afterward, by comparing the traditional supply chain model and AM SC model you will see the reasons which 3D printers reduce the SC costs.

This study will explain that, how a 3D scanner can be a source of inspiration for the designer to create his or her own creative design without exceeding the copyright law. We will see how we can boost the industry in different occasions by using 3d printers.

We will have a glance over the future of jewelry industry benefited from AM.

Keywords : Additive Manufacturing (AM), Three dimensions (3D) , supply chain(SC) , Computer Aided Design (CAD)

2. Introduction to fashion jewelry

Fashion jewelry can refer to many different definitions with different images, many people consider it as a newly designed products made of precious materials. There are some retailers that call their low-cost stores as jewelry shop even without having any style. However, usually jewelry shops are considered as a place where its' products decorated with diamonds and other precious materials.

In the last years, ideas about jewelries are changing and people nowadays consider fashion and jewelry linked to each other. Since the major buyers of jewelries are women, hence designers describe a jewelry as a piece that women will buy or she will be received as a gift. The other group is the buyers of wedding rings and anniversary gifts

Figure 1, Bulgari , Italian Fine Jeweler

Figure 3, sample of fashion jewelry made by Cartier

Figure 2, Carp Bouquet Ring by Cavalli features gold plated brass with carp and flower detail encircling beautiful moonstone, embellished with crystal accents and emerald eye. Signature dust bag included. Made in Italy.

2.2. Fashion importance

Fashion is more important than what many people think, annually 50 million Americans buy jewelry that can be categorized in fashionable product, considering the national level purchase it will go beyond ½ of all jewelry sales measured by value, also 1/3 of annual total income of jewelry stores are in fashion category. Some important challenges that influence fashion industry can be divided into three different sectors:

- Merchandising

  It can refer to the challenges of choosing materials and style that if more common if fashion and luxury in jewelry industry, and it makes it hard to plan for inventory level, regarding to high price of product and fashion ability (perishable) of it.
- Competition

  However, there are still many people that they prefer to buy their products at a jewelry shops, but still there are many others that they are willing to buy it at gift shops, clothing boutiques, mass merchandisers, internet websites, and other sources.
- Externals

  There are many external reasons that can influence the fashion industry, like political, geographical, economic situation and many other reasons.

  Nowadays the concept of being hand-made jewelry is becoming less important as it used to be before due to changes in customer's behavior. the customers of future will be more price sensitive, more smart with giving more importance to sustainability (Diamond Council of America © 2010, 2010) .

2.3. Introduction to additive manufacturing

Additive manufacturing (AM) is a process of making objects by using 3D models, usually the process of printing is by putting materials layer by layer upon each other. AM is usable in many complex geometrics that is very accurate hence it

needs minimum post-processing work. It can be made from a big variety of materials (metals, plastic, glass, ceramic…) with near-zero material waste.

It enables to make creative, difficult and unique products in a single structure that which is not possible with the current manufacturing process, it is convenient for producing in low volume.

AM which being environmentally and ecologically friendly is improving constantly regarding to producing lower cost, variety of material usage, spreading in different technologies like (jewelry, automotive, medical and aerospace and other industries (Dissertation, 2011) (metal AM, n.d.).

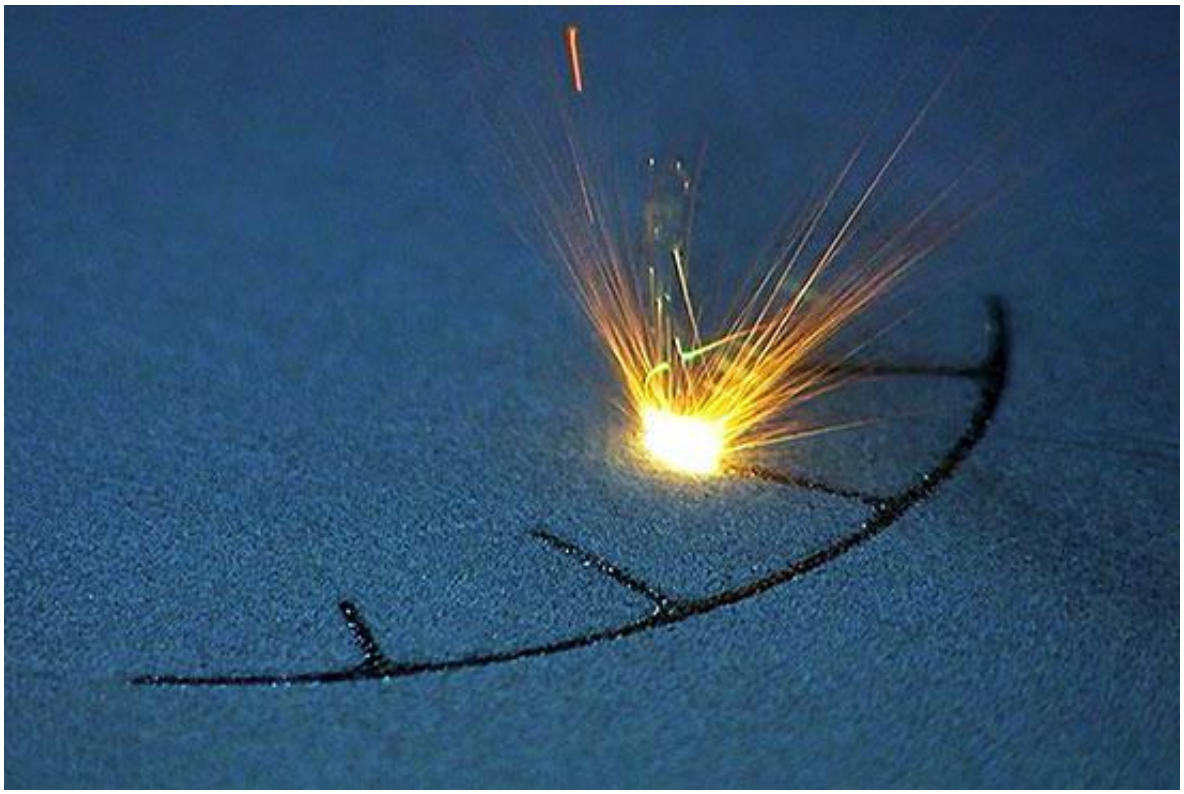

Figure 4, metal AM technique, the laser is melting metal powder over each other based on the 3D model

3. Jewelry 3D printed samples

To help the reader put all of the findings of this report in perspective, the following images illustrate the potential for jewelry made by 3D-PMP

Feather Pendant

- 18k Gold: hand-polished to a beautiful smooth sheen
- About this Product: 0.954 cm WIDTH, 3.76 cm HEIGHT, 0.304 cm DEPTH
- Weight: 5 g
- Cost: $699.99 (shapeways, 2015)

Celtic Knot Heart Bracelet

- Platinum: Solid Platinum hand-polished to a beautiful smooth sheen
- About this Product: In:1.935 x / 0.706 y / 1.78 z
- Cost: $6,354.85
- Resource: (shapeways, 2015)

Trous Ring

- 18k Gold: Solid 18k Gold hand-polished to a beautiful smooth sheen
- About this Product: 2.588 cm WIDTH, 0.8 cm 2 HEIGHT 2.656 cm DEPTH
- cost: $479.99
- Resource: (shapeways, 2015)

Erasmo Pendant Necklace

- Polished Silver: Smooth and slightly textured sterling silver hand-polished to a mild sheen.
- Cost: $262.40
- Resource: (shapeways, 2015)

Wings Earrings

- Stainless Steel: Bronze-infused stainless steel with visible print lines and rough feel.
- About this Product: 4.892 cm WIDTH, 4.526 cm HEIGHT, 0.626 cm DEPTH
- Cost: $75.00
- Resource: (shapeways, 2015)

3D-Rex

- Yellow Gold Plated Polished
- About this Product: MM 88.07 mm X 33.25 mm Y 54.38mm Z
- Cost: $ 183.07

Other Examples of 3D-Printed Jewelry

4. Research Scope and Goal

the goal of this research is to understand how we can Benefit of using 3D printers over conventional Jewelry manufacturing processes, to figure out the pros and cons we can categorize the research goals as below:

1. What are the areas in jewelry industry that influence positively or negatively regarding to usage of 3D printers?
2. Understanding how is the cost of an additive manufactured product is calculated?
3. How does the AM cost of production change due to different precious metal used?
4. what are the affects and outcomes of copyright low on additive manufacturing?

In order to be able to answer the questions above first we need to go through description of some key concepts.

5. Methodology of this Study

Two different methodology used in this research study, the information given collected through, first literature reviews and second, through interviews with authors, researchers, 3d printer owners and designers the pioneer companies like "Shapeways"', and also the and also people working for in the same industries.

5.2. literature reviews

The additive manufacturing history goes back to 1987, since then many different methodology, machinery and also materials introduced to the world. It enabled many different industries to produce many things that sounds almost impossible to do. One of the biggest achievements of 3D printers was Organ printing with the usage of

computer aided programs that Vladimir Mironov, Thomas Boland, Thomas Trusk, Gabor Forgacs and Roger R. Markwald1 all mentioned in their article published in April 2003 (Vladimir Mironov, 2003). In this article they study how 3D printers can be useful in Biological, Anatomy and medical area. In 2006 Sharif University of Technology of, Tehran, Iran in an article explain how does the mechanism of Direct laser sintering of metal powders works and shows the microstructural evolution during direct laser sintering of metal powders (Simchi, Direct laser sintering of metal powders Direct laser sintering of metal powders:, 2006)

Seung Hwan Ko, Jaewon Chung, Nico Hotz, Koo Hyun Nam and Costas Grigoropoulos in 2010 published their article about Ltd Inkjet printing of functional materials which can be a key technology toward ultra-low-cost, large-area electronics. (Seung Hwan Ko1, 2010)

In 2011 the Frank G. Zarb studied producing customized goods with a relatively low price (Frank G. Zarb School of Business, 2011) which can be widely used in the jewelry industry.

In 2013 the societal impact of AM studied by Samuel H. Huang, Peng Liu, Abhiram Mokasdar and Liang Hou. (Samuel H. Huang, 2013). In the same year Hoskins, S. published his book for artists and designers in which he explains how the creative industries are directly interfacing with this new technology and how it is changing the practices of many artists and designers across the globe. (Hoskins, 2013)

Robbert Janssen, Iris Blankers, Ewoud Moolenburgh and Bineke Posthumus analyzed the AM industry from supply chain point of view and focused on the impact of the 3D printers on supply chain management with a focus on influences on orthopedic products (Robbert Janssen, 2014). In the same year Douglas S. Thomas and Stanley W. Gilbert also compared the traditional SC and the 3d printer SC in an article named Costs and Cost Effectiveness of Additive Manufacturing. Sebastian Mohr and Omera Khan in 2015 published their study on the Current and Future Impacts of 3DP on SCM (Khan, 2015).

Finally, in 2015 an article published by Heidi Piili, Ari Happonensome and some other collogues (Heidi Piili*a, 2015) in which they explain what are the important factors in defining the production cost of 3D printers and publish a formula to generate information out of the raw data.

In 2016 Andrew C. Nyce, PhD Andrew Nyce Associates put the US jewelry market by 2026 under investigation and predict its possible outcome in that year. they analyze the opportunities and threats of the industry and the different methodology and precious metal alloys (Andrew C. Nyce, 2016).

Due to the articles that I have gone through, I realized that there is not an exact information about the future of jewelry industry and the fact how the industry can benefit from 3d printers, hence I decided to proceed my study with covering this gap.

5.2.1. History of additive manufacturing (3d Printers)

1987: Using of additive manufacturing started in this year with using UV (Ultra Violet), it used polymer as the material. The first generation of additive manufacturing was SLA-1(Stereo Lithography apparatus) that it was available also for customers. Later the SLA 250 started to work as a replace with the previous one (Gornet, 2014).

1988: the models with the usage of Acrylate resins introduced by Ciba-Geigy. Some other models like DuPont's Somos stereo lithography and Loctite started to work in the same year.

1990: was the year of Electro Optical Systems (EOS), Quadrax to produce Mark 1000 SL system the model that as one of its characteristics we can refer to its visible light resin. One year later since ICI realized some problem related to legal 3d system avoid selling more products of the same model.

1991: the year of non-SL systems.

In this year three different AM technologies introduced, such as fused deposition modeling (FDM)with using thermoplastic materials and produce layer by layer, solid

ground curing (SGC) with UV-sensitive liquid polymer usage with solidifying full layers in one pass by flooding UV light through masks created with electrostatic toner on a glass plate, and the last introduced technology is laminated object manufacturing (LOM) that bonded and cut sheet material using a digitally guided laser. (Gornet, 2014)

1992: the usage of SLS powder materials started in this year which uses heat in order to melt the materials.

1993: direct shell production casting (DSPC) became more popular and commercialized, this technology uses the injecting mechanism.

1994: in this year ModelMaker used inkjet print head instead of using wax materials. Also a small stereo lithography that can be used mainly in the jewelry industry introduced to the market by a Japanese company.

1994 was the year for Fockele & Schwarze (F&S) of Germany to use the technology of stereo lithography machine but on a limited basis it became commercialized with a German company EOS, they named it EOSINT due to laser-sintering technology.

1995: the technology of selective laser melting(SLM) started in Germany. In this year also the international standard group decided to group different to group different selective laser melting into “laser sintering” group however there are different methodologies like selective laser sintering (SLS) and direct metal laser sintering (DMLS) and electron beam melting (EBM)which is different and uses electron beam as the source of its energy.

1996: the first 3D printer (Actua 2100) has been sold in this year after 8 years working on it technology that it used was mechanism of injecting materials layer

by layer. In the same year another company named Z Corp. launched its new machine based on the MIT’s 3DP technology and named it as Z402.

In the same year base on the extrusion process Stratasys introduced a new machine that used the new technology developed at IBM's Watson Research Center that is similar to FDM and named it Genisys machine.

1997: laser additive manufacturing(LAM) developed in this year by AeroMet as subsidiary of MTS system, it started to use the technology with a high power laser and powdered titanium alloys.

1998: many different companies introduced their new products in this year, such as such as Beijing Yinhua that showed up Laser Rapid Prototypes Making & Mould Technology that was similar to FDM, another company was Autostrade that commercialized and introduced its new laser-engineered net shaping (LENS) metal powder system in Japan.

1999: In this year Motorola started to use MIT's 3DP inject-printing technology for building its metal parts.

Later in the same year steel powder-based selective laser-melting system introduced by Fockele & Schwarze with corporation of Fraunhofer Institute. (Gornet, 2014)

Another important event that happened in the same year was the fact that Röders started to sell its new system called controlled metal buildup (CMB) machine.

Machines

2000: this year started with many new technologies introduction such as Objet Geometries of Israel announced Quadra, a 3D inkjet printer that deposited and hardened photopolymer using 1,536 nozzles and a UV light source. Sanders Prototype (now Solidscape) introduced PatternMaster, a machine designed to produce precision wax patterns (Wohlers Report 2014).

Precision Optical Manufacturing (POM) announced direct metal deposition (DMD), a laser-cladding process that produces and repairs parts using metal powder. POM began system sales in early 2002 and continues to offer DMD as a service. Z Corp.

introduced its Z402C machine, the world's first commercially available multi-color 3D printer (Wohlers Report 2014).

2001: the desktop model introduced to the world by Soldimension which is an Israeli technology which uses the PVC plastic as the material and it laminates it in small sheets, however they were planning to tell the product in 2002 but they didn't accomplish to do it till 2004 that they sold some machines to Japanese company.

The direct steel-based powder machine introduced by EOS in the current year consist of particles 20 microns (0.0008 inch) in size.

2002: the company named POM started to use CO2 laser for the usage of direct metal deposition in 3-axis.

2003:3D Systems began to sell and ship machines that jets and hardens photopolymer, similar to Objet's machines with the price around $39,900.

Later the new model that named HR (high resolution) introduced with the price of $59,900. Chubunippon introduced its new low-cost model which the machine can make objects with the size that can fits a 100 x 100 x 100 mm with a price around $10,184.

EuroMold introduces its new machine that works with direct metal laser sintering wich uses fiber laser instead of CO2 laser.

2004: ProMetal with considering the educational and researchers as its customers introduced machine with ability to make objects with max size 40 x 60 x 25 mm and named it RX-1.

In July 2004 a high resolution(HR) 3D printer formed by Bluestone nanocomposite SL resin introduced for usage in the jewelry industry.

In this year EuroMold introduced its new machine that was able to produce thinner layer rather than its previous model named the EOSINT P with the usage of plastic

materials and also all the different kind of metals, but it is not compatible laser marking and laser erosion.

2005: in this year Spectrum Z510 that was a colored 3DP introduced to the world by, Z Corp, it was able to build, however it had a better quality comparing with Z Corp previous model (Z510) but it had a lower price at $49,900, and Stratasys reduced this price from $34,900 to $29,900 only in one month. In April a large-frame with the ability of recycling and also powder handling introduced.

2006: an agreement signed among Stratasys and Arcam that made the stratasys able to distribute EBM (electron beam melting) in the North of America, hence it tried to reduce the price from $24,900 to $18,900 and from $29,900 to $19,900. In same year on February an InVison DP (dental professional) introduced to the market that was also able to 3D scan for dental usage.

2007: A large scale volume came to the market by Arcam which used the electron beam melting (EBM) In April.

2008: the stratasys bought all the Tangible Express's Equipment by $5.3 million since the Tangible Express shot down its operation in January. The agreement that Stratasys and Arcam signed terminated since Acram decided to start distribution in U.S by itself.

In 2008 the Shapeways started to give services to customers to and it enabled them to design their own 3Ds objects and then produce their products. Shapeways which is a part of Philips Electronics, incubator program with providing some useful tools made it easier for customers to make their own designs and products.

In January, Shapeways decided to open its own shop that provide a good place for designers to upload their 3D models and make their products. The products can be manufactured in a high number of variety of products and shapes include sculptures, jewelry, figurines, etc.

2009: In this year, Steven Adler organized a Solidscape group for jewelry designer and all the people that use the same technology(Solidscape) which they published it on

their website named: solidscapeusergroup.com. another website that formed in the same year was maqet.com made by Keith Cottingham.

2010: was the year of agreement between two companies named Stratasys and HP they decided to produce a 3D printer with the brand name HP, this contract enabled the Stratasys to introduce its new machine with a higher volume regarding to its previous models under the HP brand name. the improvement in the amount of smartness of new machines were eye catching which decreased the support needed for materials by 40%.

In February 2010. Due to constant improvements of Optomec they awarded it to work for the Navy in order to use its technology for repair the engine of aircrafts.

A new laser-sintering material introduced in March 2010 by CRP Technology (Italy) which named WindForm LX 2.0.

In July two other low cost machines released by Z Corp the first one that named ZPrinter 150 with a price lower than $15,000, and other one which was also a color printer named ZPrinter 250 with a price lower than $25,000, hence it leads the industry toward low cost 3D printers. Regarding to this fact in September the price of the Alaris30 made by (Rehovot, Israel) decreased to $24,900.

2011: in this year there were many companies that they were planning to use AM as their core methods, the first pioneers were in-the-ear hearing aids that they used AM in their core part of manufacturing. Another pioneer was the dental industry.

In the same year an Italian technology (CRP) revealed its new generation machine that it uses carbon-fiber as the material to be filled with which named it Windform XT 2.0.

In April 2011, due to the necessity of accurate measurement Renishaw plc was have to buy a software developer for 3D printers so that they acquired MTT Technologies, which they bought it from Marcam Engineering (Germany).

Another company that started to invest on using wax patterns was Stratasys so it acquired another company named Solidscape to enable it to make 3D printing with high resolution so that they can enter the jewelry and dental markets they organized a website named: The3dStudo.com to upload 3D models, art gallery and stock photos.

3D printing industry obtained an Amsterdam based company FOC (Freedom of Creation) that enables it to print 3d contents.

2012: a color 3D printed photo initiated by BumpyPhoto in which they input the photo and then it prints the photo in 24-bit color with ZPrinter.

In September a midrange build volume introduced that was faster around 10 times comparing to its forerunners.

Another technology that provides a better elongation comparing with Windform XT carbon fiber-filled material introduced by Italian technology (CRP)

In this year Shapeways (a Netherlands base company) made “Factory of the Future” and it was planning to facilitate the manufactioring in New York with around 50 AM machined that enables to produce around five million pieces of product per year.

Solidoodle (Brooklyn, New York) started a revolutionary market with selling its 3d printer for $499.

2013: Envisiontec in order to satisfy the dental market revealed its 3Dent printer. In the same year the Fabulonia (Estonia)provided a useful online service for designers and artists that could protect their designs for different levels of copyright laws.

2014: in this year the IMTS revealed its 8-13 in Chicago. In a show the first large scale 3D car printed. (figure 5) In the printing that took 6 days long many different companies participated like (Local Motors, Oak Ridge National Laboratory, and Cincinnati).

during the running competition which was mostly based on the design 207 different competitors were presented their models. Michele Anoe who is an Italian designer was the winner of this competition with designing “strati “car which means layers in Italian. The importance of its design was the fact that it needed only 44 hours to be printed completely, it was made of the hard plastic that uses for Lego® called carbon. The other parts such as wheels and hubcaps 3D printed as well with direct metal technology (www.IMTS.com, 2014).

Figure 5 The first 3d printed car

2015: was the year of many different achievements in variety of industries one of the most important ones was to make the words first surgery with using 3D printed sternum and a rib cage (figure 6) for a patient that he was suffering from cancer, another achievement was to make a face transplant for Patrick Hardison that he was a firefighter, the success in this surgery considered as a great achievement (http://www.bioprinting.ru/, 2015) (Vladimir Mironov1, 2003).

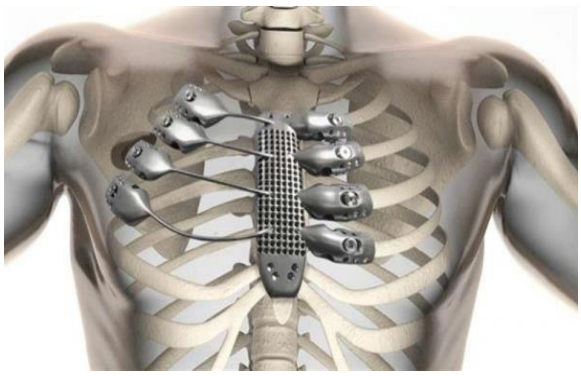

Figure 6 The world’s first 3D printed sternum and a rib cage

In this year 3D printers being a center of industrial manufacturing, selling the industrial metal 3D printers worldwide for the usage in most advanced industries like aerospace, automobile, and defense industries increased up to 45%. Different companies like EOS, Concept Laser, 3D Systems, Optomec were market leader in this year. Some other companies revealed their new products in this year like Toshiba with a very high performance metal 3d printer, Xjet from Israel with inject printing technology.

Also many other materials for 3D printing introduced like glass, ceramics, conductive copper ink and many others.

Nike, Adidas and many other brands entered in this path, for example Nike patened its 3D printing shoes.

Some other companies also entered in this industries like Toshiba, Autodesk, Apple, Lenovo, Toshiba, Lenovo, Michelin and HP.

3D Printed Gun (figure 7) is another sample of the huge variety of using 3d printers in different industries the accuracy of printing with 3d printers enables to make a gun without controversy, however printing such these objects can lead you to the jail and the US state is fighting against those who share models for creating guns online. (http://www.bioprinting.ru/, 2015)

Figure 7 the world's first 3D printed gun

2016:3D printing went another step beyond and introduced the first 4D technology with adding another dimension (time), this product which is bendable change the shape with heating means that it snap back to its initial shape (figure8).

Massachusetts Institute of Technology (MIT) with co-working of Singapore University designed a new material that with the usage of a specific fabrication process and using ultraviolet (UV) a material that can remember their shape (http://www.bioprinting.ru/, 2015).

A 3D-printed mini gripper, consisting of shape-memory hinges and adaptive touching tips, grasps a cap screw.

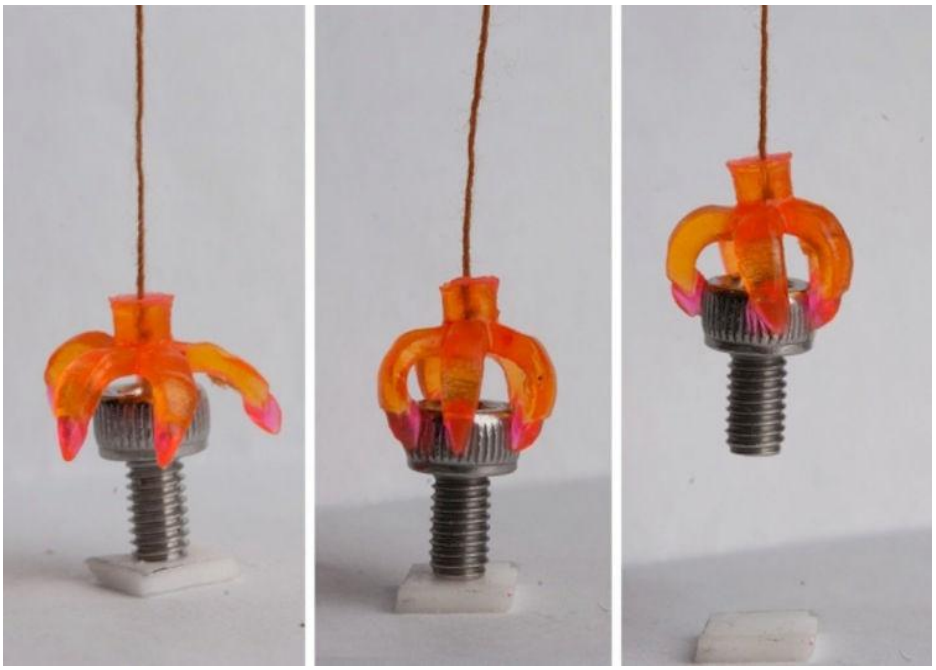

Figure 8 a sample of 4Dprinted published on (www.livescience.com), with the usage of a specific fabrication process and using ultraviolet (UV) a material that can remember their shape

5.2.2. The 3D printing Process

3d Modeling

3D printed models which creates with a computer aided design (CAD) (figure 9) or with the help of 3D scanner, or by a plain digital camera and photogrammetry software. The important factor about 3D printers is that it gives the designers and producers to in reduced errors and find them in order to eliminate them. before printing. The manual part of modeling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning announced to the process printing the received data into an organized shape with the highest similarity to the design. (Jacobs, 1992)

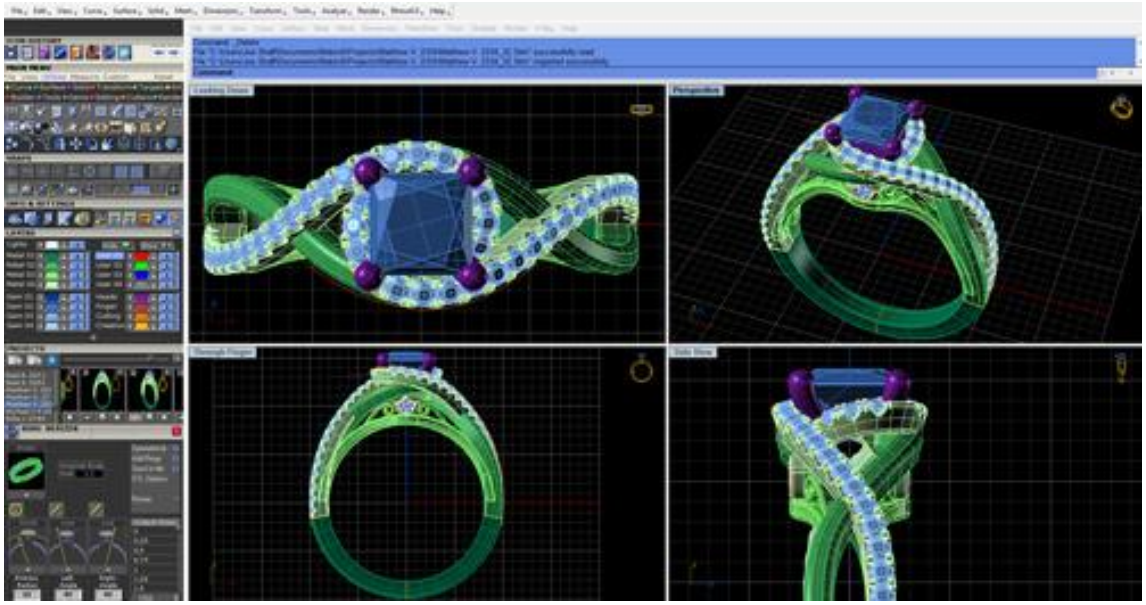

Figure 9, Joseph jewelry 3D model which can be printed directly or can be printed in wax first for to be tested by customers for higher satisfaction

3D Printing

Before printing a 3D model the first step is to examine the model for errors. Most of the CAD software produce some small errors in output STL files: like holes, noise shells or some other errors like manifold. There is a step in STL generation that they call it as "repair" that it fixes such problems in the original model. Generally, STLs model that they are created with 3D scanners have more errors that should be corrected, the reasons why are elated to haw 3D scanners work since they usually scan point to point acquisition. (Fausto Bernardini, 2002)

Once the basic print completed, the STL file needs to be processed by a specific of software called a "slicer," which converts the model into a series of thin layers and produces a G-code file containing instructions tailored to a specific type of 3D printer (FDM printers). This G-code file can then be printed with 3D printing client software (which loads the G-code, and uses it to instruct the 3D printer during the 3D printing process). (Yarlagadda Eswar 2015)

The resolution of the printers means the amount of layer thickness that a print can have and also the X-Y resolution in dots per inch (dpi) or micrometers (µm). usually

each layer thickness is around 100 µm (250 DPI), although some machines can print layers as thin as 16 µm (1,600 DPI). X-Y resolution is comparable to that of laser printers. The particles (3D dots) are around 50 to 100 µm (510 to 250 DPI) in diameter. (Yarlagadda Eswar 2015) (wikipedia, n.d.)

Constructing a model from a 3d designed can takes some hours to some days regarding to the model, the size, complexity and also the method and the type of machine used of additive systems.

Traditional techniques for making polymer objects in large scale so far are less expensive but AM is more flexible regarding to design and faster in time to market and lower price while we have less small quantities. An advantage of 3D printers to the other traditional ways is that it provides a desktop size of the models for designers and concept developers.

3D printing Finishing processes

Though the printer-produced resolution is sufficient for many applications, printing a slightly oversized version of the desired object in standard resolution and then removing material with a higher-resolution subtractive process can achieve greater precision.

Some techniques in AM are capable to work with a variety of materials with into different colors without the need to be painted after finishing. Some printing techniques require internal supports to be built for overhanging features during construction. These supports must be mechanically removed or dissolved upon completion of the print.

All of the metal printed for the commercial purposed needed to be cut from the surface that they have been printed, nowadays a new process which is called GMAW allows the steel and aluminum materials to be removed with using some modification.

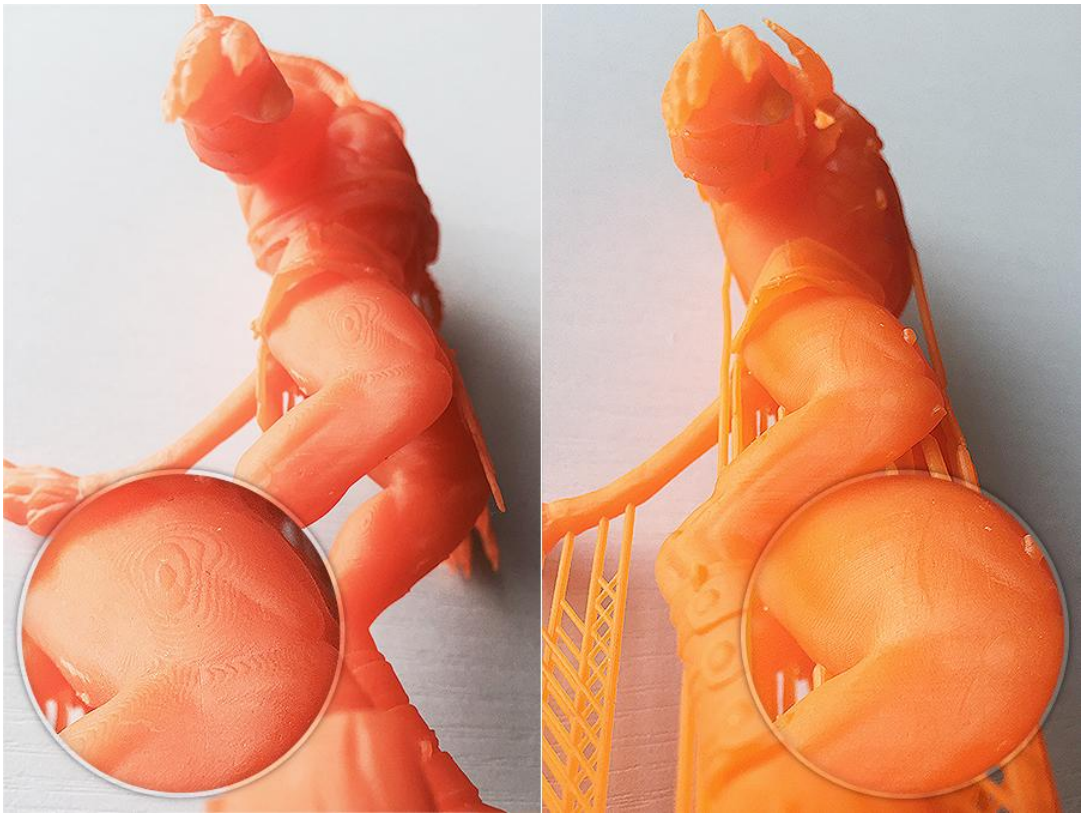

Figure 10, polishing as a step to finalize the product

3d printing Processes

Since 1970 3D many different 3D printing introduces which they were massive, with few production abilities with a high price. Nowadays many different models are available with high variety of material usage that makes them different from each other, another important factor is the technology usage and the way that they melt different layer of material over another layer, which means all the machines like: filament fabrication (FFF), laminated object manufacturing (LOM), fused deposition modeling (FDM), selective laser melting (SLM), selective laser sintering(SLS) and many other models uses different technologies, which any of the methods has some prose and cones that we will go through explanation in next chapters. The main reasons why that we chose one method or machine prior to another model are speed and cost.

The machines that work directly with metals usually are costlier than other models that first make a mold or a wax model and then they make metal parts. (H. Bikas1, 2015)

5.2.3. Different methods of metal additive manufacturing

5.2.3.1. Metal clay method

Japan was the first country that started to make 3d printer with the Metal clay in 1990 (figure 11). Its main reason was to produce jewelry, one of the most important motivation for them was to produce fine jewelry without having years of experience in this industry.

The metals which can be gold, silver, bronze is a crafting is mixed with some other materials like water and organic binder, the result of this printing is a soft sculpture that needed more post processing to make it hard. After the piece is printed and dried the object should be fired which it is possible through different ways, such as: using a binder that burn away till it leaves the pure metal or the other way is using a kiln, with a handheld gas torch. You should consider the fact after the burning process the object will shrink a little around 8% to 30% (H. Bikas1, 2015).

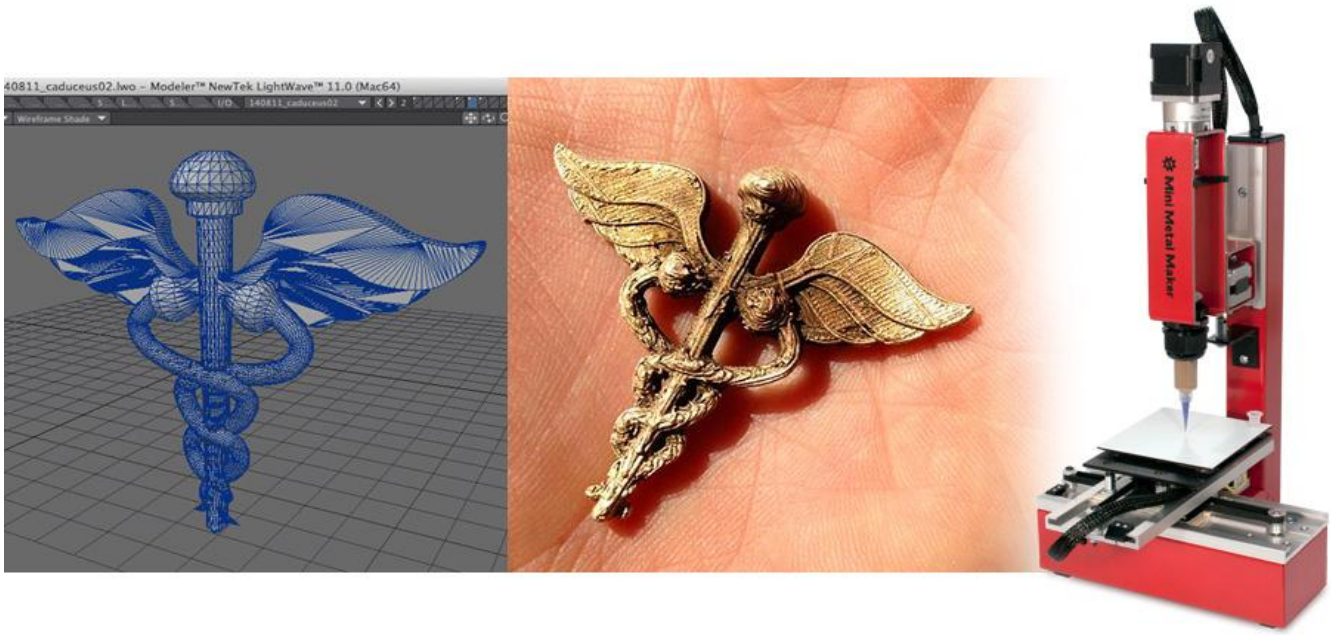

Figure 11 Metal clay 3D printer and a printed object published on(https://3dprint.com)

5.2.3.1.1. Precious Metal Clay (PMC) method

PMC which developed by Masaki Morikawa in Japan started to use precious powder of different, the powder which was a fine and microscopic can be consist of pure gold or silver. They become very successful due to usage of gold, and then achieved more success regarding to silver usage. The PMC can use the following products:

The standard formula of PMC: it fired for 2 hours at 900 °C (1,650 °F), it approximately shrinks around 30%.

PMC+ & PMCflex: this model fired at 900 °C (1,650 °F) for 10 minutes or 800 °C (1,470 °F) for 30 minutes; the possible size that the objects will get smaller is about 15%. PMC+ can be used in some situations that a sheet is needed like origami.

PMC3: it heated at 599 °C (1,110 °F) around 45 minutes or heated at 699 °C (1,290 °F) for 10 minutes; at the end it shrinks by 10%. In this model we can also heat it by a torch to orange heat minimum for 2 minutes, this method needs a longer working hour regarding to other methods.

Aura 22: a 22 k gilding material, which is a gold paste that is used for coating the surface of the silver.

PMC Pro: this material that has only few silver inside (0.900) considers as hard metal, it needs a kiln firing at 760 °C (1,400 °F) for 1 hour.

PMC Sterling: in this method metal gets fired at 815 °C (1500 °F) in this process it shrinks by 10-15%. Since it has copper its formula hence the process of firing should occur into two steps. The first step which is called open-shelf doesn't need any shelter against the second step which needs a firing pan which is activated with carbon media. Because of the copper content in this formula, firing is a two-step process. (H. Bikas1, 2015)

5.2.3.1.2. Art Clay Silver (ACS) method

ACS was developed by another Japanese Chemical Industries. This technology helped the users to fire the object by a handle torch, this technology that followed the PMC Standard has a lower percentage of clay shrinking around (8% to 10%).

Later another model of ACS introduced named Art Clay Slow Dry which needed more working time, that had a slower Further developments introduced the Art Clay Slow Dry, a clay with a longer working time. Both model AC 650 and AC Slow should be fired at 650 °C (1,202 °F), this characteristic enabled the users to combine glass and sterling silver together. The Japanese company AIDA introduced a product named Oil Paste that can be used for drawing on glass.

In 2006 Art Clay Gold Paste introduced by the same Japanese company AIDA, this technique which was an economic way to use 22 K gold, in this method the gold covered the surface of the fired silver printed.

5.2.3.1.3. Metal clay powders method

Metal clays powder are easy to find which in the process of printing water needs to be added in order to hydrate the attain the clay consistency .in 2006 the first powder of silver introduced to the world in the same year many other powders like gold, copper, steel and brass released.

5.2.3.2. Metal alloy method

•Titanium alloy: Titanium alloys (figure 12) which are metals that consist of some other chemical elements, lending properties as very high strength and toughness even if they are heated at a very high temperature. Its special characteristics such as its incredible low weight, super corrosion resistance and the capability to tolerate high

temperatures, making it the elected material for producing highly stressed components such as connecting rods and electronic devices, aircraft, super sport cars, military equipment. however, its high cost is a limitation for it to be used in all the industries because it has a high processing cost as well as high material cost. Since “commercially pure" titanium, alloying with small amounts of aluminum (6%), and vanadium (4%), by weight, is already use or its mechanical properties for producing orthopedic and dental implants. A heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, giving to the product a high-strength durability.

Figure 12 Titanium metal alloy

5.2.3.2.1. 960 Silver Alloy method

The willing to have silver metal clay which can be used with only one process of firing hence with mixing equally the PMC Sterling clay and PMC fine silver clay and firing them around two hours with 898 °C (1650 °F) they could reach their goal only in one process.

5.2.3.3. Robocasting method

Robocasting or Direct Ink Writing (DIW) is an AM technique, first developed in U.S in 1996 (figure 13). In this technique, first a 3D CAD model is divided up into layers, then a small nozzle extrudes a fluid, referred to as an 'ink', (typically a ceramic slurry), drawing out the shape of each layer of the CAD model. The ink exits the nozzle in a liquid-like state but retains its shape immediately, exploiting the rheological property

of shear thinning. differentiating from fused deposition modelling technique that rely on the solidification or drying the extruded ink. (Yang, 2013)

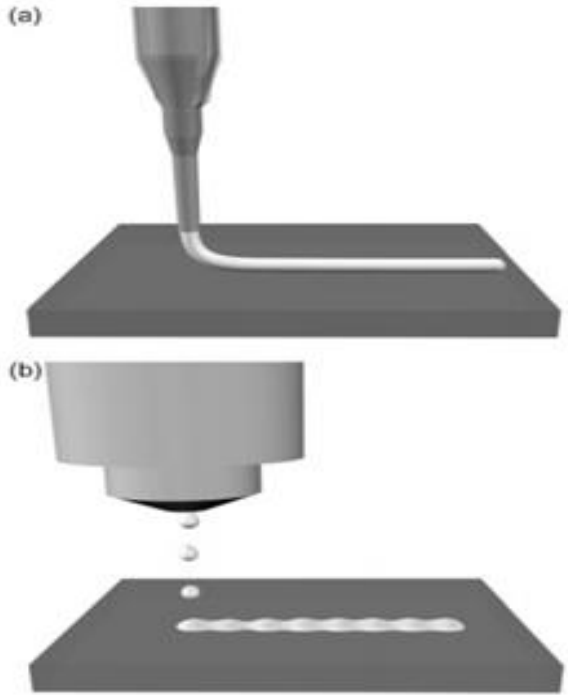

Figure 13 schematic illustration of Robocasting or Direct Ink Writing a)continues filament writing and b)droplet jetting adopted . copyright 2004(Elsevier)

5.2.3.4. Selective laser melting method

It is another way of an AM process for creating 3D metal parts by fusing fine metal powders together with the help of a high-power laser beam, using 3D CAD software to create the model. This technique was developed by Carl Deckard, a student of Texas University, and his professor Joe Beaman in 1980s. The high amount of time and energy for producing one piece, relegate its application mostly in aerospace and medical fields, making it convenient in a production chain only if very few parts are to be produced, for examples in the industries that they have a high setup cost and thy need to make a mold first this technology can be useful because 3D printing has a high price per unit but not a setup cost (figure 14) (f. Abe, 2001).

As robocasting, the process starts by slicing the 3D CAD file data into layers, usually each slice is 20 to 100 micrometers thick, creating a 2D image of each layer (industry standard file format). This file is then loaded into a file preparation software package.

that assigns parameters, values and physical supports that allow different types manufacturing machine to treat optimally the material.

Thin layers of atomized fine metal powder (stainless steel, tool steel, cobalt chrome, titanium and aluminum) are evenly distributed using a coating mechanism, indexing the support table on vertical plane (Z): this first process take place inside a chamber (250 mm X-Y, 350-500 mm Z) containing a tightly controlled atmosphere of inert gas, either argon or nitrogen at oxygen levels below 500 parts per million. After that each 2D slice of the part geometry is fused by the use of a high-power laser beam, usually an ytterbium fiber laser with hundreds of watts. Directing this beam on the X and Y directions with two high frequency scanning mirrors, it is possible to give shape to the wanted piece, by melting in solid metal each layers, one by one (top Max technology Magazine , n.d.).

5.2.3.5. Selective laser sintering method

Similar to direct metal laser sintering (DMLS), selective laser sintering (SLS) uses a laser as the power source that bind the material (typically metal) together to create a solid structure, defined by a 3D model. These two techniques differ in technical details: with selective laser melting (SLM) the material is fully melted rather than sintered, allowing different properties (crystal structure, porosity, etc.) to the product; SLS, instead, is a relatively new technology that so far has mainly been used for rapid prototyping and for low-volume production of component parts.

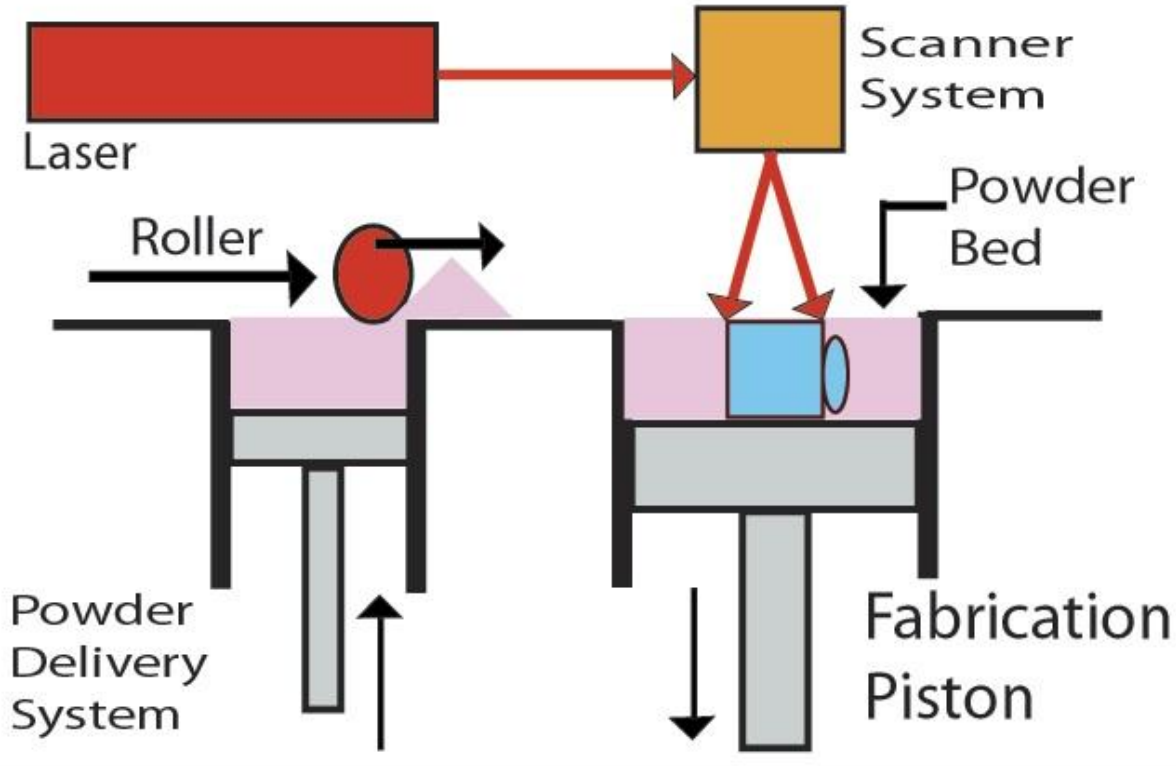

Figure 14, Selective Laser Sintering (SLS) is a technique that uses laser as power source to form solid 3D objects.

5.2.3.5.1. Technology used in SLS method

SLS involves the use of a high power laser (carbon dioxide laser) to fuse different kinds of materials powders (plastic, metal, ceramic, glass) into a desired three-dimensional shape; a 3-D digital description of the part (for example from a CAD file or scan data) define cross-sections on the surface of a powder bed, the laser selectively fuses it: after each one of them are scanned, a new layer of material is applied on top, and the process is repeated until the part is completed.

Density of ultimate product depends on peak laser power, rather than laser duration, so a SLS machine typically uses a pulsed laser; furthermore, for facilitate laser to reach the melting point of the applied material, the SLS machine preheats the powder bed somewhat below the predicted temperature. (H. Bikas1, 2015)

In contrast with some other additive manufacturing processes, such as stereo lithography (SLA) and fused deposition modeling (FDM), which most often require special support structures to fabricate overhanging designs, SLS does not need a separate feeder for support material because the part being constructed is surrounded by non-sintered powder at all times: this particularity not only allows construction of geometries that were impossible to define with others AM, but also to fabricate multiple parts has a far lower impact on the overall difficulty and price of the design. In many cases large numbers of parts can be packed within the powder bed, allowing very high productivity. However, it should be considered that with SLS it is 'impossible' to fabricate a hollow but fully enclosed element, because of the impossibility to drain the non-sintered powder.

In this last years, lower prices of these instruments, since patents have started to expire, makes this technique affordable for home printers: while it began as a way to build prototype parts early in the design cycle, it is increasingly being used in limited-run manufacturing to produce end-use parts. One less expected and rapidly growing application of SLS is its use in art. However, the heating process remains an obstacle, both for power consumption (5 kW/h) and managing heating temperatures, that have to be stable within a range of 2 °C for all the three stages of preheating, melting and storing before removal.

5.2.3.5.2. Materials and applications used in SLS method

Some SLS machines use single component powder, such as direct metal laser sintering, produced by ball milling: the laser melts only the outer surface of the particles (surface melting), fusing the solid non-melted cores to each other and to the previous layer. However, most SLS machines use two-component powders, typically either coated powder or a powder mixture. (Jessica M. Williams, 2005)

Unlike others AM previously described, SLS can produce parts from a relatively wide range of materials, thanks to commercially available powder materials. These include polymers such as nylon (neat, glass-filled, or with other fillers) or polystyrene, metals (steel, titanium, alloy mixtures) and green sand.

The laser can operate full melting, partial melting, or liquid-phase sintering, depending on the material or density level wanted. (H. Bikas1, 2015)

5.2.3.6. Direct metal laser sintering(DMLS) method

This model uses micro-weld powdered metals, it directly prints the shape that designed from CAD data. It eliminates the time wasting tooling. I this AM technique Yb (Ytterbium) fiber laser fired over a bed of powdered. In this technique the process of melting occurs instead of welding the metals.

The process of melting the powder continuous until the whole design is printed in a solid structure (figure 15).This method which was developed first in Munich, Germany read the model from a 3D CAD file and start to prints it, when the “built file” is file is over it is “sliced” into the thickness of the layer that the machine is able to build, then another part will be downloaded and starts to build another layer again (Simchi, Direct laser sintering of metal powders, 2006).

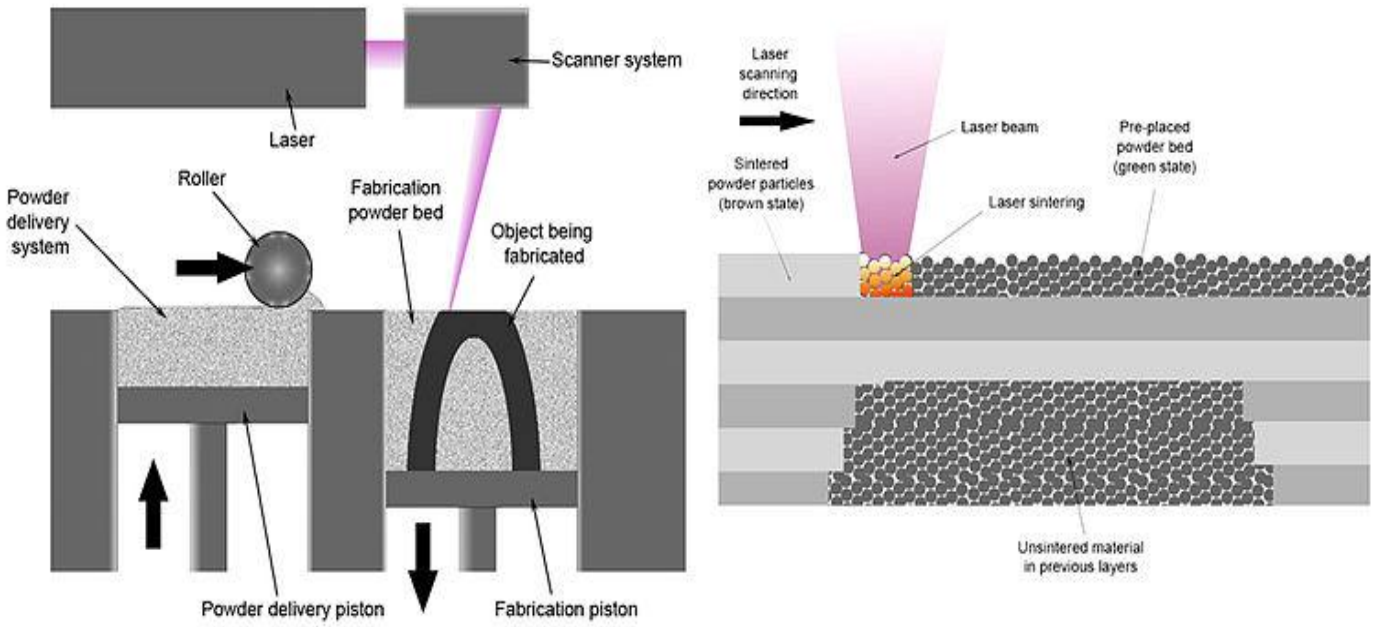

Figure 15 . Direct Metal Laser Sintering(DMLS) process

The DMLS which has a 200 watt Yb-fiber optic that uses a high powered 200 watt lase. Inside it there is a platform and a blade recoated, the usage of the blade is to put a thin layer of powder over the platform to be sintered and melted locally by laser beam, usually the thickness of each layer is 20 micrometers.

The China Polytechnic University is working on a project to make a 3D printing machine for aircraft to use titanium as the material, they believe that it can helps this industry to have a remarkable positive effect on material saving.

the first fully additive manufactured rocket engine printed with direct metal laser sintering On September 2013, Using Inconel, an alloy of nickel and iron. They tested the engine at a very high temperature to prevent any failure in it and, in 2004 it overcome all the qualifications and it is predicted to start its first space flight in 2017.

5.2.3.6.1. Benefits of DMLS method

DMLS Tanique has lots of advantages comparing with traditional one, for example the fact that you do not need any special tool to produce a unique object provides a fast production. It is much easier to solve the possible errors in this method.

Nowadays DMLS is one of the most important techniques used in many AM productions, since the process of printing is layer by layer it gives us also the ability to design the internal features as well as the outer parts.it enables to simplify very complex designs with the minimum components. In DMLS we do not need so many tools for casting hence it is also more suitable for short production runs (H. Bikas1, 2015).

5.2.3.6.2. Constraints of DMLS method

This technology can be used for important industries that have small and medium size parts like (e.g. for EOS's EOSINT M280) of 250 x 250 x 325 mm, those the parts with high complexity, or the ability to make different parts into one unique shape. DMLS which is a cost effective as long as cost effective helps to decrease the production time and cost. It is a useful method for simplifying assemblies and complex geometrics. The printed surface needed to be polished if a very smooth surface is needed. One way for smoothing is laser polishing in which the surface of the object heats by DMLS and the roughness fades with a fast moving laser beam (H. Bikas1, 2015).

5.2.3.7. Laminated object manufacturing method

The technique of LOM which introduced by Helisys Inc. is a rapid prototyping system that uses adhesive-coated paper, plastic, or metals as the material and laminates them over each other and cut to the shape with a knife or a laser. The printed object maybe needs to be modified by different tools like drilling or machining. Usually the resolution

of the product depends on material and also the thickness of it. In this method it is possible to make larger object since no chemical process is needed (figure 16). Here in the figure below we can explain the LOM process as (Harris L. Marcus, 1996) (Wikipedia, the free encyclopedia, n.d.).

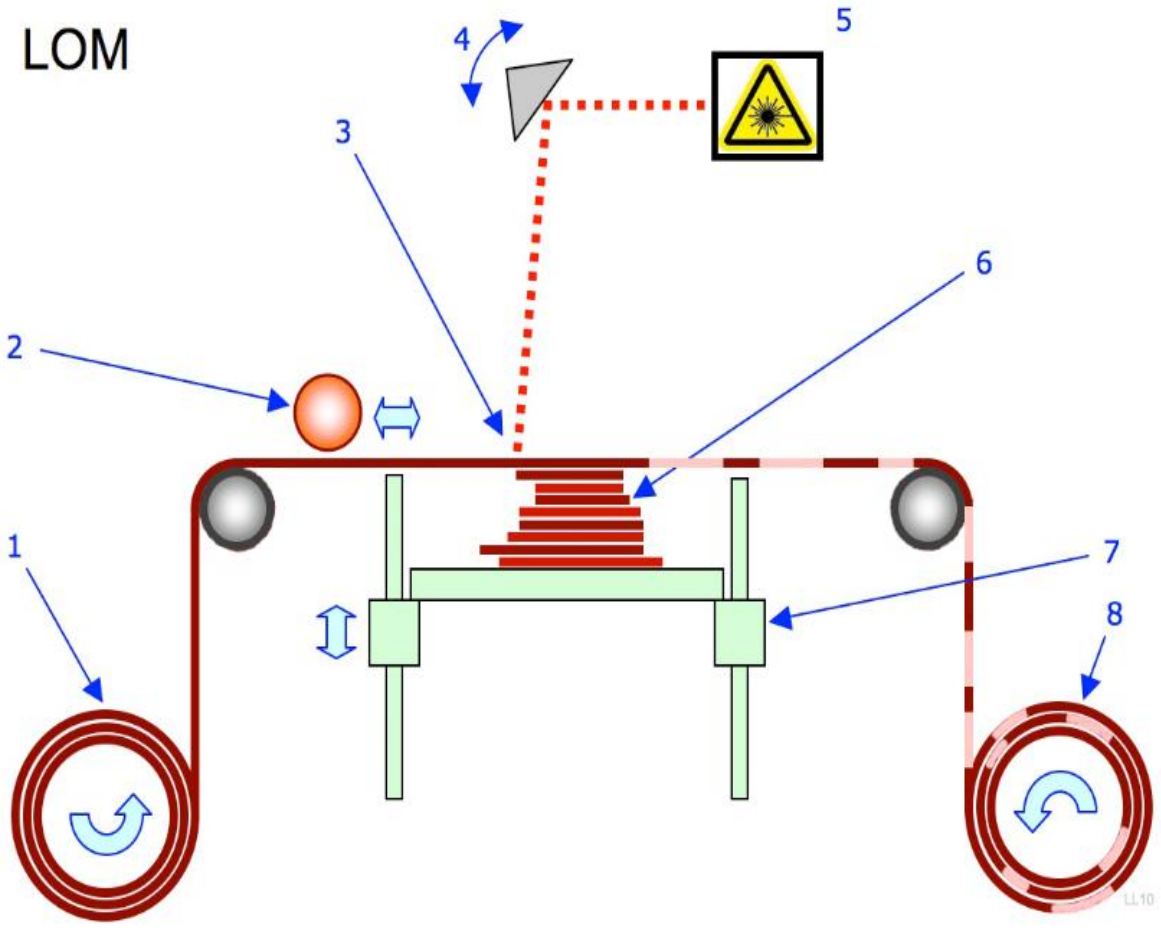

Figure 16. Laminated object manufacturing process1 Foil supply. 2 Heated rollers. 3 Laser beam. 4. Scanning prism. 5 Laser unit. 6 Layers. 7 Moving platform for entering new layer. 8 Waste

5.2.3.8. Electron beam freeform fabrication method

This method (EBF3) which developed by NASA mostly uses the high reflectance alloys like aluminum and titanium. this technology can be very useful in aerospace industry by reducing the cost and time, it also simplifies the model for assembling.

The EBF3 process inject the wire feedstock in a molten pool that it creates and sustained using aa electron beam is a high vacuum environment, then the electron beam couples effectively with any electrically conductive material, including highly reflective alloys such as aluminum and copper (figure 17). This technology enables of bulk metal deposition at deposition rates in excess of 2500 cm3 /hr (150 in3 /hr). (Hafley, 2015)

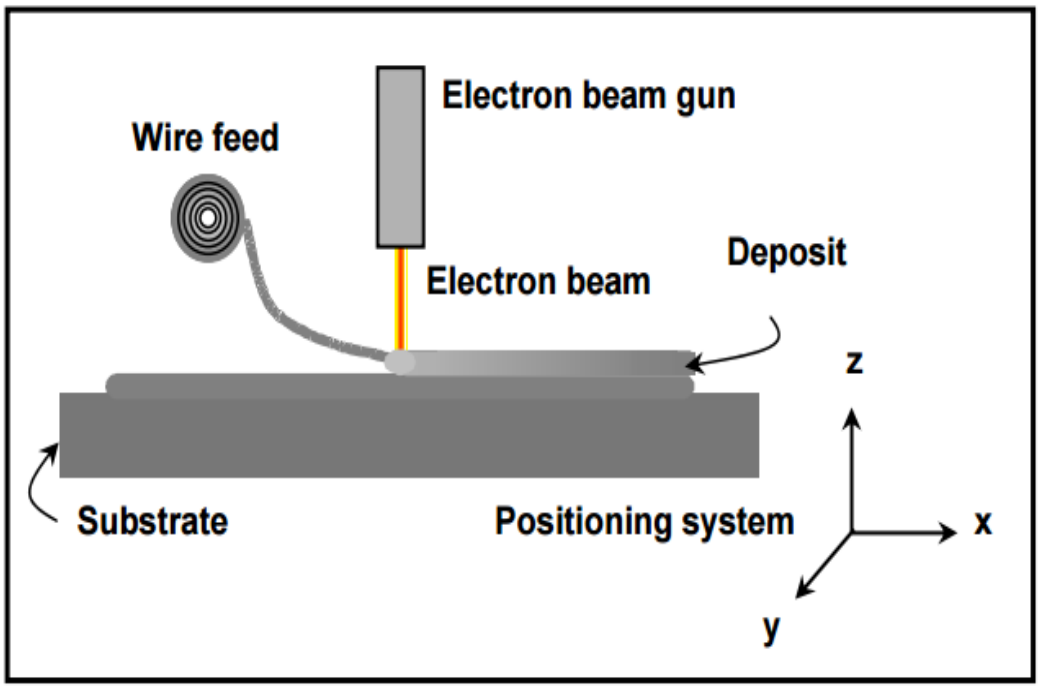

Figure 17 Electron beam free form fabrication process

5.2.3.9. Powder Feed Systems method

A generic illustration of AM powder feed systems is shown in Fig. 2. The build volumes of these systems are generally larger (e.g., >1.2 m3 for the Optomec LENS 850-R unit). Further, the powder feed systems lend themselves more readily to build volume scale up than do the powder bed units. In these systems, powders are conveyed through a nozzle onto the build surface. A laser is used to melt a monolayer or more, of the powder into the desired shape (figure 18). This process is repeated to create a solid three dimensional components. There are two dominate types of systems in the market. 1. The work piece remains stationary, and deposition head moves. 2. The

deposition head remains stationary, and the work piece is moved. The advantages of this type of system include its larger build volume and its ability to be used to refurbish worn or damaged components. (H. Bikas1, 2015)

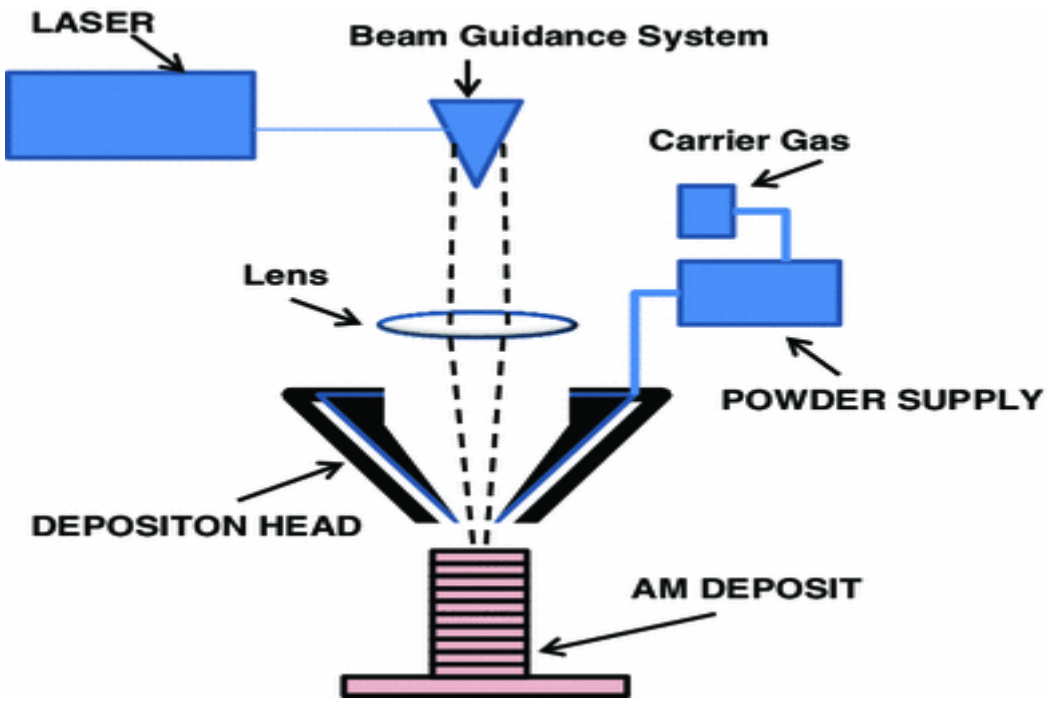

Figure 18 generic illustration of an AM powder feed system

5.2.4. Literature review Problem description

Answering to the study purposes related the cost comparison between different metals like (gold, platinum, silver) did not fully covered during the literature reviews due to lack of published articles. Also in the research studies made by (Heidi Piili, Ari Happonen and Tapio in 2014) some formulas related to calculating the production cost forlaser additive manufacturing(LAM) published, in another publication of Douglas S. Thomas and Stanley W. Gilbert in 2014 some other cost models introduced, which in none of the articles the price comparison is covered. Hence in order to figure out the answer of the question the needed of interviewing with the people in this industry seems avoidable.

There are some other parts that needs to be covered in the research study which I can mention as below:

How is going to be the future of jewelry factory or a jewelry production line? Which I have answered to this question based on my own assumptions and observations.

5.3. Interview questions

The technique of this interview questionnaire is based on an open ended question in order to avoid putting any kind of limitation for the interviewees and give them enough freedom to answer.

Beside the questionnaire that spread among different companies, employers, designers or the 3D printer different viral connection such as skype, LinkedIn and Email has been used as well in order to give the interviewees the flexibility of answering to find a unique and simple formula to calculate the cost of production base on different materials to enables the cost comparison.

*Note: the questionnaire table is attached at the end of this study.

5.3.1. Interviewees for this research

Marc Weiland: 3D Modeler, Designer of Shapeways company. (www.shapeways.com)

(Shapeways which is a part of Philips Electronics, incubator program with providing some useful tools made it easier for customers to make their own designs and products)

John Hornick: Author: 3D Printing Will Rock the World, (United States).

- author of the award-winning book, 3D Printing Will Rock the World (Silver award, Nonfiction Authors Association; 4.5 stars, IndieReader).

- Founded Finnegan's 3D Printing Working Grou

Alberto Costa: Luxottica senior technician Artist and Lead 3D printing Dep. 3D modeler, (Italy).

MD Jamsher: 3D Printing Specialist and 3D Designer at 3DVinci Creations, (United Arab Emirates)

Alessandro Tassinari: 3D Printing Specialist, (Turin, Italy)

6. Why additive manufacturing in Jewelry?

For answering to this question and the reasons why that 3D printing in this industry can be effective first we need to cover some topics

6.1.1. Brief overview to supply chain management

What is the definition of supply chain management?

The integration of activities taking place among a network of facilities that produce raw materials, transform them into intermediate goods and then final products, and deliver products to customers through a distribution system. (Lee & Billington)

Managing supply and demand, sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, and delivery to the customer. (The Supply Chain Council)

After knowing the definition, we should understand the reasons why that the SC is important hence we can include to the description of "(Forrester 1958, p. 37)" that we will include here:

“Management is on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, materials, money, manpower, and capital equipment. The way these five flow systems interlock to amplify one another and to cause change and fluctuation will form the basis for anticipating the effects of decisions, policies, organizational forms, and investment choices. “

6.1.2. Why SC is so relevant?

Since there is so many uncertainty and unpredictability in the fashion industry's supply chain, hence crating a smart SC which reduces the uncertainty can be very useful. Specially a quick response (QR) is an important factor uses by many different companies to maintain an efficient supply chain management (SCM).

Regarding to the fact that a firm is not a standalone entity but it consists of many other parts that they are interconnected and knowing that optimizing the internal process of the plant is doesn’t assure the success of the company lead us to go beyond the boundaries, and start to manage our supply chain. In order to analyze our SC better, we should consider two important factors:

1. Evolution / problems "upstream"

- Outsourcing
- Offshoring

2. Evolution / problems "downstream"

- Explosion and volatility in customer requirements
- New products and process technologies
- Request for faster processes
- Internationalization and market globalization

However, outsourcing and offshoring can play an important role in the SC but on the other hand they increase the SC complexity, considering the fact that in there are some

limitation in export and import of the precious metal all over the word in case that we can prevent it without losing the quality or increasing the price we would better prevent it.

With taking into account the downstream problems, with 3D printing we can have a faster response to our customers' needs with the usage of the new technology, minimize the delivery time with initiating the 3D printers as near as possible to the market and specialization our products based on market demands.

6.1.3. supply chain in model of luxury industry

Barons" or "Global Sellers of made in…" is a SC model which uses in most of luxury industries the reasons why of using is to get benefit from the Strong global brand from strong local roots that they know how to make Competitive advantage of local sourcing and local manufacturing. Hence they can benefit from the "Made in" products.

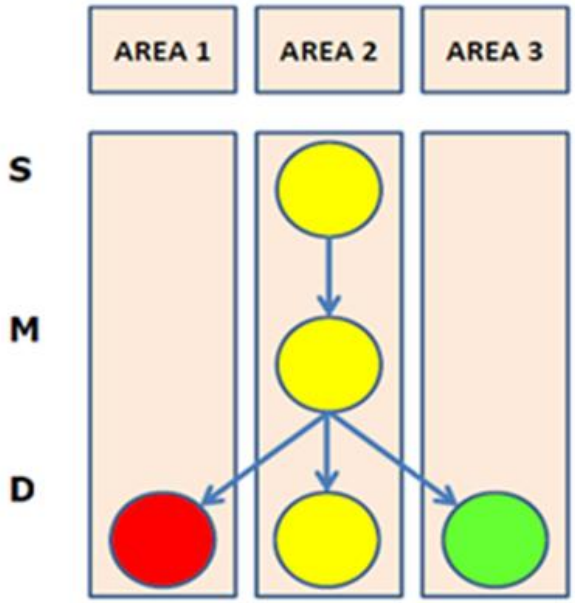

Figure 19. Barons" or "Global Sellers of made in". in this figure S=Source, M=Make, D=Deliver

6.1.4. luxury critical success factors in luxury success factors

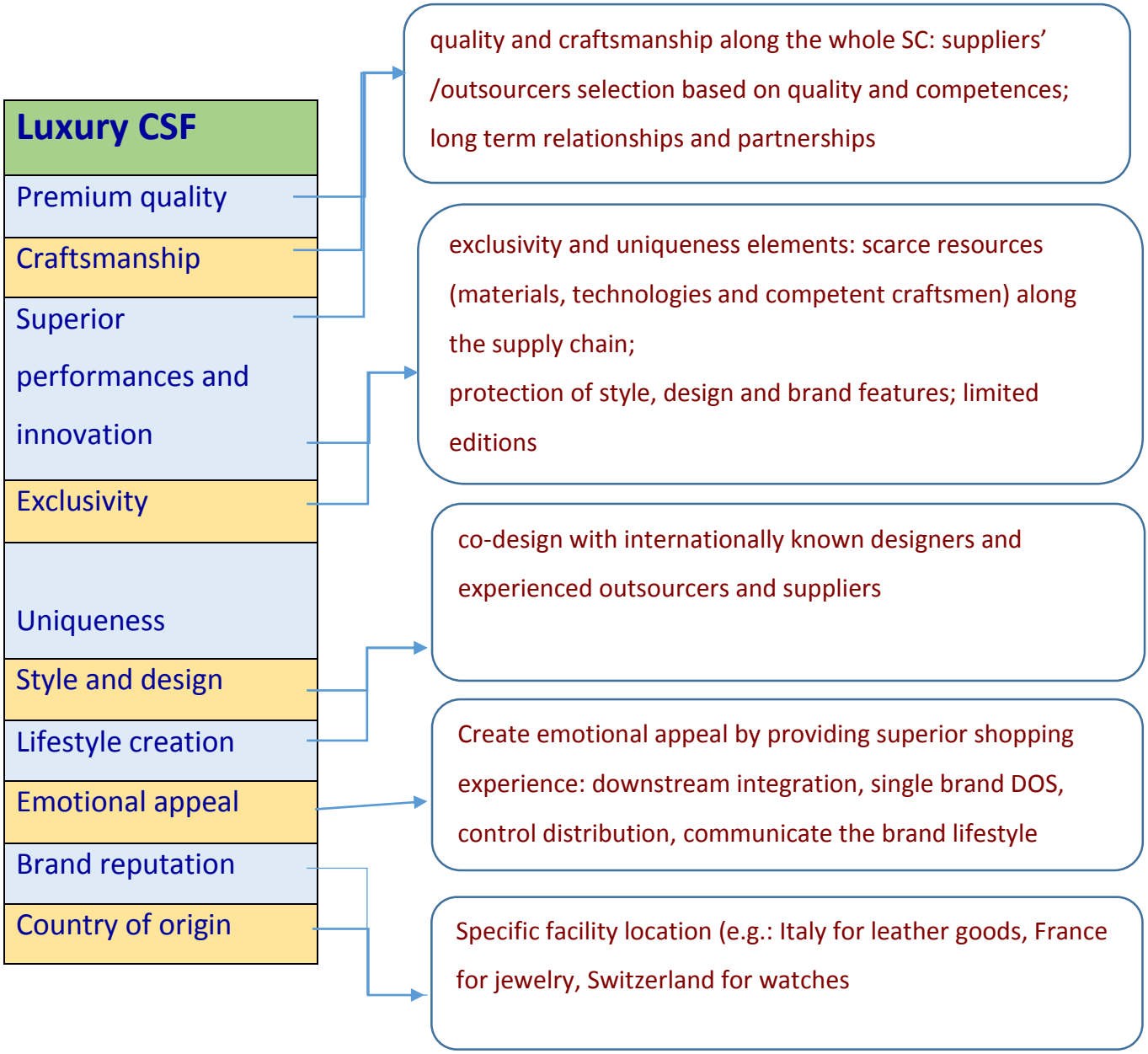

Table 1 critical success factors in luxury industry interfered from Prof. Andrea Sianesi lecture.

6.1.5. Comparison between traditional supply chain and AM Supply chain

The production with additive manufacturing leads to reducing the links in the SC hence the production therefore the business will face less interrupts and it will be closer to customers, it leads to lower labor, lower inventory. Additionally, the more the production line get close to the customer, decentralization will be more visible.

In the (figure 20) you can see the differences in a general tradition supply chain model and an additive manufacturing SC. (Gilbert, 2014)

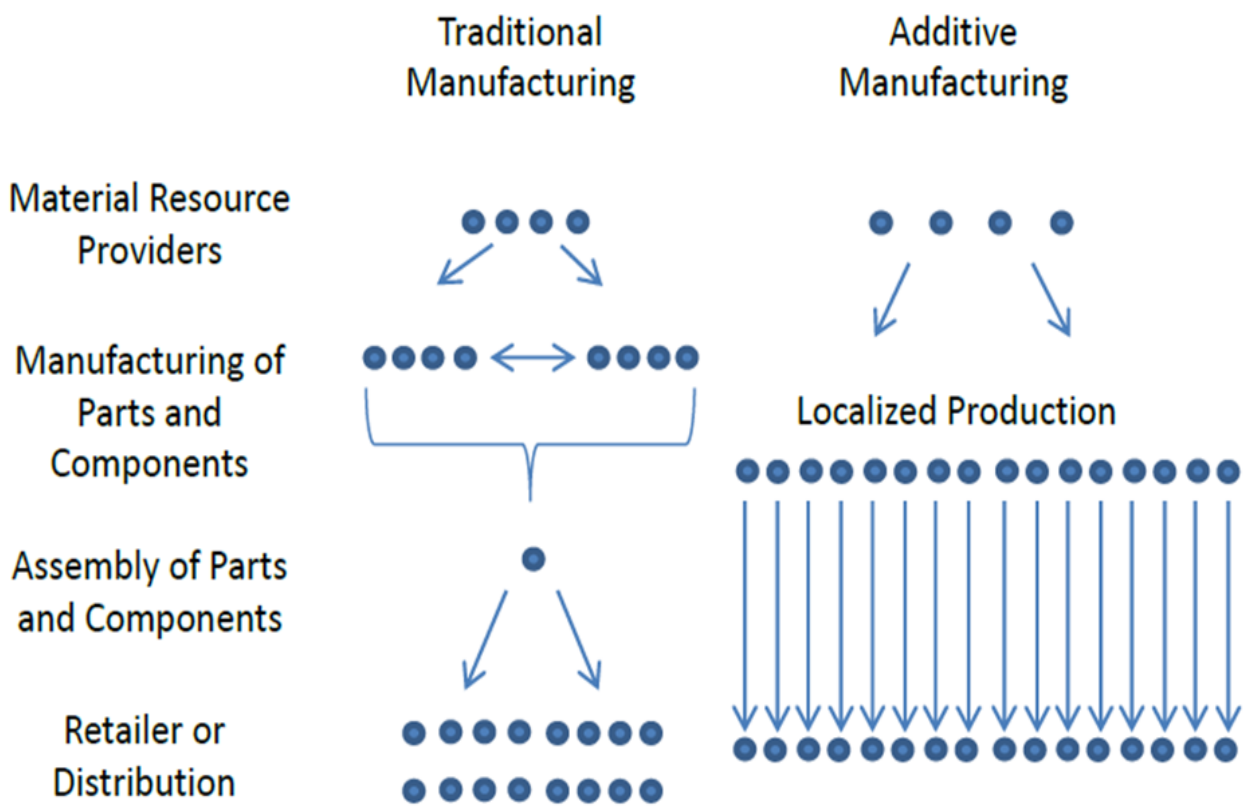

Figure 20 schematic of comparing traditional supply chain and AM SC published by Douglas S. Thomas and Stanley W. Gilbert. It shows how AM can reduce the intermediate numbers and thus the SC cost.

6.1.6. Comparison between traditional jewelry manufacture and a possible AM plant

We are expanding in new dimensions in a visionary manner and presenting the additive series manufacturing of “Industry 4.0”: digitally networked and automated.

The 3D metal printing factory of tomorrow integrates three essential requirements: Clever digital networking of machines among themselves, automation of processes, and integration into the production environment. Regional print centers can arise around the globe on a distributed basis. Production-on-demand will fundamentally change spare parts logistics. In the fully automated process, metal parts meeting the highest standards are produced with the same level of documentation everywhere in the world.

Holistic Laser CUSING® system concepts already bring about industrial mass production solutions today – with greater speed and cost-effectiveness. A major contribution to value creation, growth, and competitive advantage.

1. **Reducing labor cost and supply chain cost**

3D printing is a path from traditional way of jewelry making with using a large amount of labors to a technological manufacturing with minimizing the labor usage and eliminating many unnecessary costs. Avoid outsource and offshore of production in order to increase the response time (figure 21).

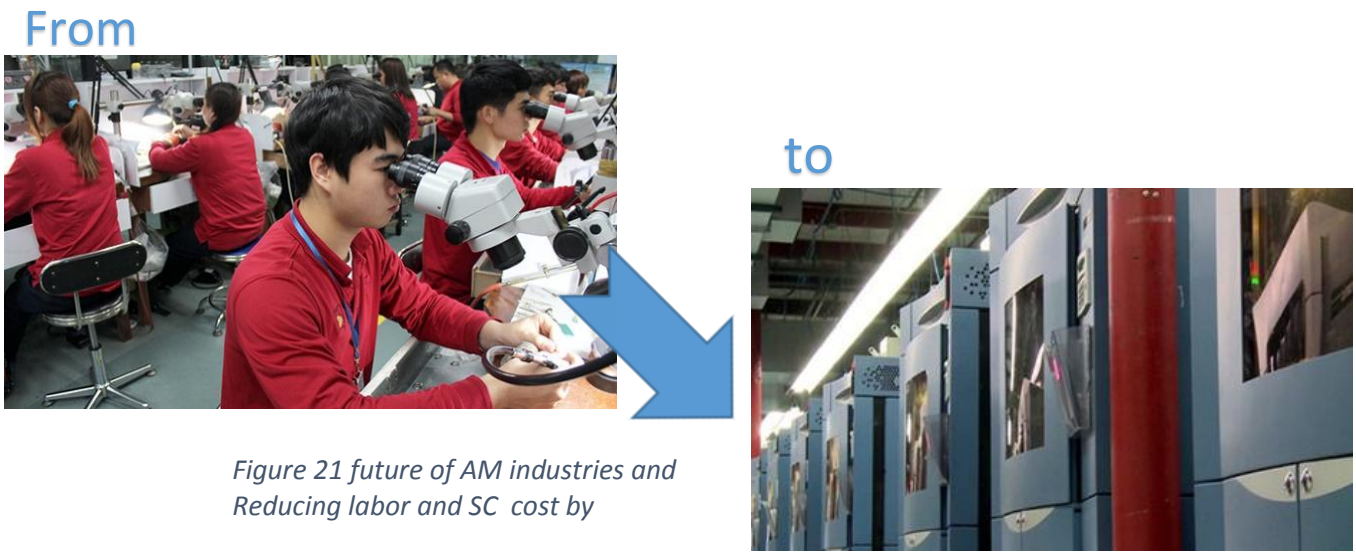

Figure 21 future of AM industries and Reducing labor and SC cost by

2. **Freedom of Design**: There is a huge remarkable different of the freedom of creativity and design that the 3D printing process offers you with the CNC. It Enabling the company to produce the complex design with the highest specialization and satisfying global needs (Figure 22).

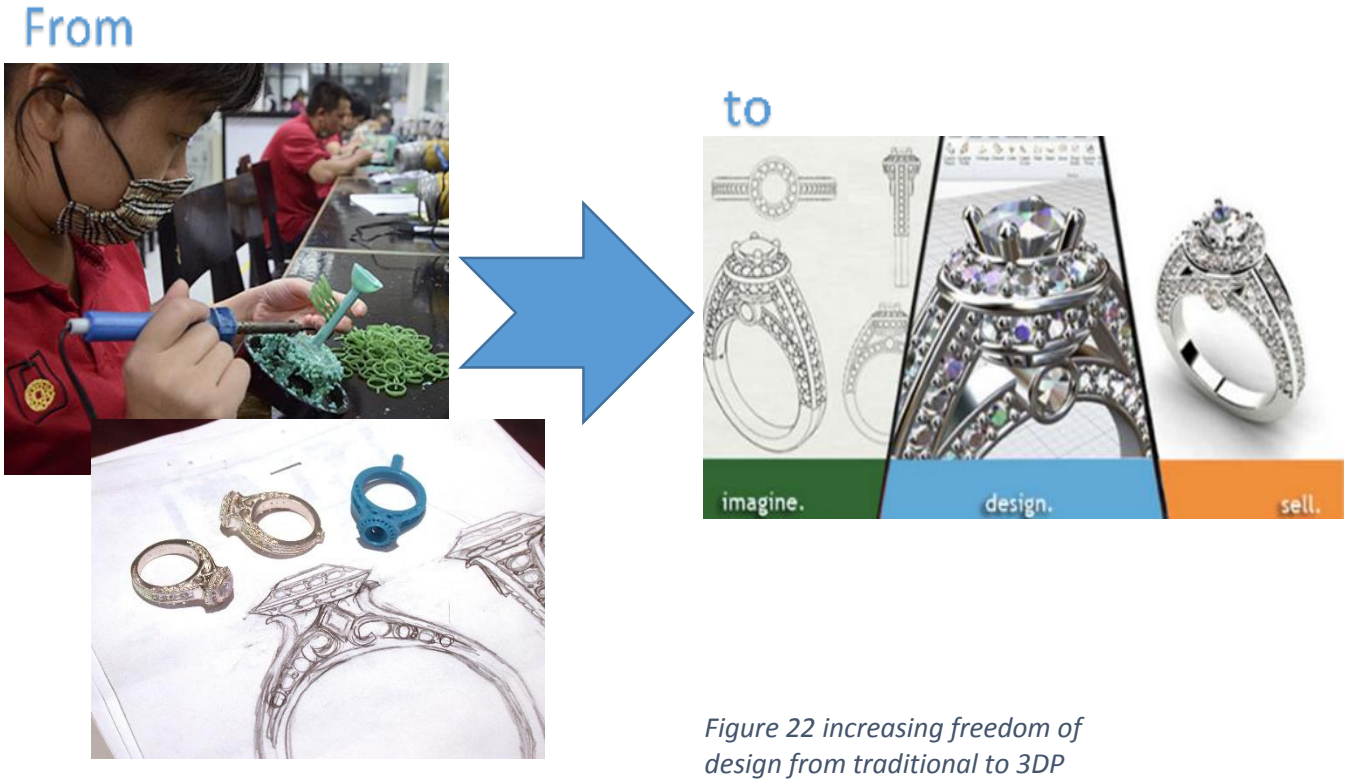

Figure 22 increasing freedom of design from traditional to 3DP

3. **Reduction of time to market:** The time to bring a new product to the market can be reduced drastically if a manufacturer uses faster prototyping and manufacturing methods such as 3D printing. In the fast moving IP theft scenarios, it is of paramount importance that the designs are innovated faster than they are copied. The machines are always ready to print immediately and there is no need of molding and time consuming preparations (figure 23).

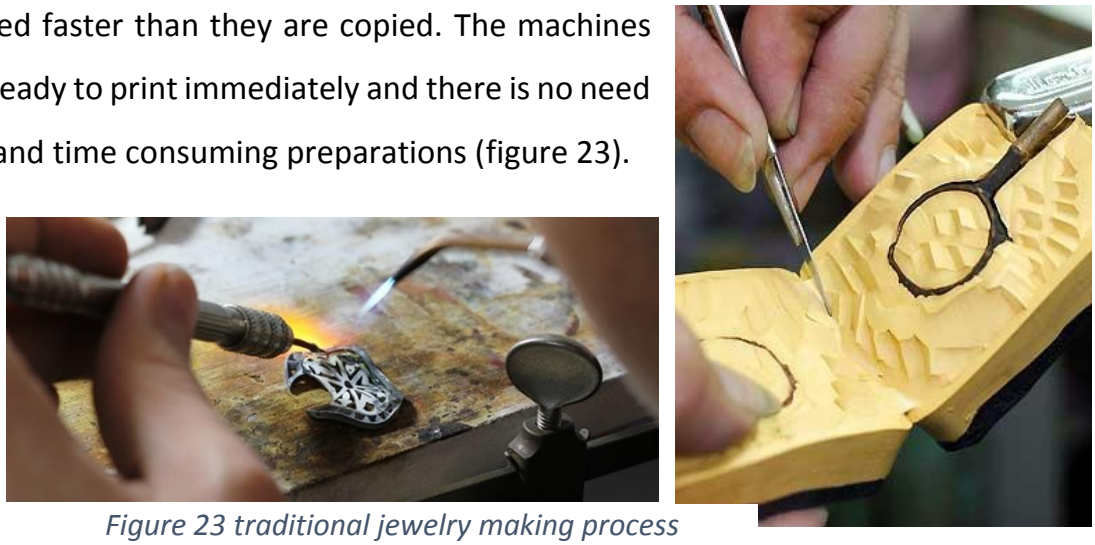

Figure 23 traditional jewelry making process

4. **Using the advantages of being a "made IN" product.** (figure 24 and 25)

Figure 24 Luxury jeweler Bulgari is about to celebrate 125 years as one of the world's most sought-after jewelry brands. Made in Italy

Figure 25 Cartier French luxury goods conglomerate company. The company designs, manufactures, distributes and sells jewelry and watches. Founded in Paris, France in 1847 by Louis-François Cartier

5. **being up to date**

   by Using the new technology in order to be ready for fast improvements so it increase the company flexibility.

6.1.7. The important factors in defining jewelry price

There are some key factors that defines the final price of each jewelry product which we can have a glance over theme here:

- Metals
- Gems
- Handwork
- refining cost
- seller profit

6.1.7.1. Metals factors in defining the cost of Jewelry

On the top of fashion jewelry metal is metal that has the highest interest among people as both category total gold and gem-set. The interest between two different color of gold is 50-50 and many of women prefer to have a combination of the colors. Also other precious metals like Platinum and silver have many fans however there are some limitation regarding to marketing strategies. Platinum which is expensive and considered mostly as bridal fashionable metal found its fan regardless to its high price. Affordability of silver enabled many self-purchasing women to buy it hence it became so much popular. (Diamond Council of America © 2010, 2010)

The formula used to calculate the price is the metal price (the daily spot price) multiplied by purity (the true noble metal content) times weight (can be in ounces, pennyweights or grams). The purity is the karat of gold or percentage of noble metal (gold, platinum, silver). 24 karats are pure. 10 karats are 10/24 or .410 gold and the balance of weight is the alloys. 14 karats are 14/24 or .583 gold and 18 karat is 18/24 or .750 gold. Platinum most of the time is 90% pure and 10% alloy. Silver jewelry is usually sterling, which is .925 pure. The three units of weight used with precious metals are troy ounces, pennyweights, and grams. The troy ounce is equal to 20 pennyweights (DWT) or 31.15 grams (learn more about measure precious metal weights). So here is an example; say the spot price of gold is $300 and a 14K ring weighing 10 grams would work out like this. $300 (spot price) X .583 (the fineness of gold) equals $174.90 per ounce divided by 31.15 (troy ounce to gram) equals $5.63 per gram times our ring of 10 grams equals $56.30. Just remember to subtract some refining cost and profit for

the dealer and you can find out the intrinsic metal value for your jewelry. (www.mygemologist.com, n.d.)(www.scribd.com)

6.1.7.2. Gems factors in defining the cost of Jewelry

Gems which are one of the most important parts of jewelry pay an important role in the estate jewelry value as well they can influence the value more than 75% in units to 95% by value. Diamonds are one of the leaders in gem's category however there is also a strong demand for colored gemstones, like, emerald, Blue sapphire, ruby, and tanzanite are consistently best-sellers. Amethyst, cultured pearls, tourmaline, various garnets, topaz and fancy sapphire (especially pink and yellow). (Diamond Council of America © 2010, 2010)

6.1.7.3. Influence of Handwork on jewelry cost

some homework and note taking can lead a jewel to much higher price as a low handwork jewel.

6.1.7.4. refining cost description

means that the more the jewel needs post processing the higher will goes the cost.

6.1.7.5. What is the seller profit?

the profit that the seller or the producers define as the net profit is another cost that should be added to the price of jewelry.

In order to calculate the price of a jewel there are some steps that we should go through:

- Calculating Your Initial Price
- Record the time you spent on each design
- Calculate labor costs
- Calculate wholesale prices
- Calculate retail price

the most important areas that 3D printing can help us to improve our business are as below:

Cheaper: It is much cheaper to use a 3D printer for prototyping and testing compared to a CNC machine. However, this is on a case by case basis.

7. Production cost calculation of 3d printers

An important part in this study is the calculation of the production cost to understand what are the important factors influencing the 3D printer's costs and to figure out what is the accurate formula to calculate the build cost. Hence first we will go through some simplified models and then through scientific models.

7.2. Simplify explanation of, how is the cost of a 3d printed product is calculated?

the costs of a 3D-printed product is based on multiple factors that first will explain in a very simplified model and then we will explain as with a professional calculation:

-the volume of the piece:

-the cost of the material per mm^3

-the machine space

-basic price per file

The volume of the piece:

the volume of the piece is the amount of material needed to print the piece. A solid piece will have a greater volume and will thus use more material.
A hollow piece will be cheaper to produce. (designer), 2016)

The material-cost is the price of the material per mm³:

This price changes a lot regarding the following factors:
-the same material is sold for different prices from different producers
-the material itself, e.g. it is clear that plastic is cheaper than gold
-the value of the material on the market, e.g. the values of gold and silver change over time

The machine space:

The machine space refers to the needed space in the printer that each object will occupies inside the machine (the larger space that the object needs in the machine, the fewer items from other costumers can be printed in the same print-run, resulting in a higher price for our piece).
This calculation is based on this:
Say we have a print bed of 10cm x 10cm x 10cm, we then have a capacity of printing a volume of 1000000 mm³.

Say that the cost to print a cube that fills the entire print volume will be 100€ in electricity and the wear of the printer, an item with the dimensions of 10 cm x 1 cm x 1 cm has a machine space price of 1€. This is just an example; the actual price differs from machine to machine.
Note that to calculate the machine space, the volume is irrelevant, only the different dimension is counted, a hollow and a solid object will need the same machine space.

The basic price per file:

The basic price per file which is also called handling costs is the price for the work that a human being has to do in order to print the piece. This can be to load and check the file or to take the piece out of the printer.

Materials like gold based on the machine method may have more production steps:

-The model is printed in cast able wax

-A mold is produced from the wax-model

-The item is casted in gold in traditional ways from a gold-smith

-The item is hand-polished afterwards

You can see that there is a lot of handwork here, so the handling costs will be much higher than with plastics. (designer), 2016)
at the end on top of this you need to add the margin for the company so they can make a profit.

7.3. Cost Calculation Formula of Laser Additive Manufacturing(LAM)

The most important factors influencing manufacturing costs in LAM is related to the machine cost, the energy consumption of it has a small part. Printing simultaneous objects at the same time in one run of printing has a huge influence on reducing the cost (Rickendacher et al. 2012, Väistö et al. 2013). So it means that in order to have a higher cost reduction we should minimize the printing time and also to find optimum number to reduce the consumption per part.

Many studies have done to estimate the optimum building time (Angelo & Stefano 2011, Byun & Lee 2005, Munguia et al 2009, Pham & Wang 2000, Zhang & Benard 2013).

The first model to minimize the build time introduced by Pham and Wang which consist of powder additional time and also the time that uses for scanning. It is better to set the object in such a direction it has lesser height, (Pham & Wang 2000).

For getting the best result the total volume that should be arranged must be as the lowest amount that minimize the total traveling distance of laser head (Pham & Wang 2000) (Heidi Piili*a, 2015).

In the calculation below you can find useful formula in order to figure out the minimum build time by using geometric parameters like height and area of cross section that suits for best orientation to build a part. Equation 1 shows the relationship between build time and parameters considered (Byun &Lee 2005).

Nomenclature

$\bar{A}_p$	Average cross section area of part [mm^2]	l_d	laser beam spot diameter [mm]
A_{psr}	Area rate scanning the interior of the part [mm^2/s]	l_t	Layer thickness [mm]
A_{phr}	Area rate hatching the interior of the part [mm^2/s]	$m_{material}$	Mass of material [kg]
$\bar{A}_s$	Average cross section area of support [mm^2]	N	Number of layers
A_{sr}	Area rate scanning the support [mm^2/s]	$Price_{energy}$	Price of the energy [€/ J]
C_{build}	Cost of build [€]	$Price_{material}$	Price of material [€/ kg]
$C_{indirect}$	Machine costs [€/ h]	S_A	Surface area of part [m^2]
$C_{material}$	Cost of material [€/ kg]	T_{Build}	Total build time [h]
d_p	Density of part [kg/m^3]	T_p	Idle time between layers[s]
d_s	Density of support structure [kg/m^3]	V_P	Process velocity [mm^3/s]
E_{build}	Energy consumed during build [J]	w	Mass of the piece [kg]

Figure 26 data table for calculating the AM cost

Equation 1

$$T_{build} = N\left(T_p + d_p\left(\frac{\bar{A}_p}{A_{phr}} + \frac{\bar{A}_p}{A_{psr}}\right)\right) + d_s\frac{\bar{A}_s}{A_{sr}}$$

Equation 2

$$\bar{A}_s = S_A.l_d/(N.l_t)$$

Equation 3

$$\bar{A}_p = V_p/(N.l_t)$$

From Equation 1, it is noticeable that the build time is calculated from summation of idle time between layers, time for fusing the powder layer and time for support structure generation, (Byun & Lee 2005). Basic cost calculation for laser additive manufacturing was discussed by Baumers et al. The approach calculates the cost of LAM process.

The post processing cost is not calculated in this formula as it can vary from different models and metal and the labor costs in different places. The total cost can be calculated using Equation 4 (Baumers et al. 2012).

$$C_{build} = m_{material} \cdot C_{material} + T_{build} \cdot C_{indirect}$$

Equation 4

The direct costs are product of the part mass and raw material cost. The indirect costs are product of whole platform build time and machine cost rate. Cost per part, is obtained dividing Cbuild with number of parts built simultaneously (Baumers et al. 2012). With interest in environmental considerations, it was decided to calculate the electricity consumption separately. For this Baumers et al., proposed a more detailed model for the expenses, as Equation 5 illustrates (Baumers et al. 2012) (Heidi Piili*a, 2015).

$$C_{build} = C_{indirect} \cdot T_{build} + w \cdot Price_{material} + E_{build} \cdot Price_{energy}$$

Equation 5

Equation 5 which refers to the energy consumption separated from the machine upkeep and overheads. These overheads are found to be less than 10% (Baumers et al. 2012). This equation also applies to production of multiple instances of same part. The cost of gas usage such as nitrogen gas generator that can be needed in some LAM techniques is included. Other casts that are mostly variables costs such as material and energy costs calculated based on the literature of (Baumers et al. 2011, Baumers et al. 2012, EOS GmbH 2012, Officer et al. 2013, Ruffo & Hague 2007) (Heidi Piili*a, 2015).

7.4. Comparing the weight of different metals

Comparing the weight of Gold to Platinum.

Considering the fact that Precious metals due to their different by composition and density have different weight, thus for calculating the exact weight of different products in different materials need some easy calculation which is so much important. Because it will also influence the cost of material. There is a guide below which compares weight of different golds comparing with platinum. (serendipity diamonds, n.d.)

- Platinum is approx 88% heavier than 9ct Gold.
- Platinum is approx 59% heavier than 14ct Gold
- Platinum is approx 34% heavier than 18ct Gold.
- Platinum is approx 21% heavier than 22ct Gold
- Platinum is approx 11% heavier than Fine Gold.

As a rule of thumb, Platinum tends to be one third heavier than 18ct Gold.

Precious Metal Weight Conversion

Converting the weight of one precious metal to another can be a very critical factor. The chart shows you some important reference, to calculate an approximate weight for most of the precious metals. The chart below will show you a simple and useful way to convert the weight of a metal to another.

The chart below can be applied to a range of metals including Platinum, Palladium, Gold, Silver and wax. (serendipity diamonds, n.d.)

	Wax	Sterling Silver	9ct Gold	14ct Gold	18ct Gold	22ct Gold	Fine Gold	Platinum	Palladium
Wax	1.00	10.30	11.20	14.10	15.70	17.80	19.50	20.60	12.00
Sterling Silver	0.097	1.00	1.11	1.31	1.50	1.73	1.87	2.08	1.15
9ct Gold	0.089	0.90	1.00	1.18	1.36	1.59	1.72	1.88	1.04
14ct Gold	0.071	0.76	0.85	1.00	1.14	1.29	1.40	1.59	0.88
18ct Gold	0.064	0.67	0.74	0.88	1.00	1.15	1.25	1.34	0.77
22ct Gold	0.056	0.58	0.63	0.78	0.90	1.00	1.08	1.21	0.67
Fine Gold	0.051	0.53	0.58	0.72	0.83	0.94	1.00	1.11	0.62
Platinum	0.049	0.48	0.53	0.63	0.72	0.83	0.90	1.00	0.58
950 Palladium	0.083	0.87	0.96	1.14	1.30	1.49	1.62	1.74	1.00

Figure 27, Converting chart the weight of one precious metal to another

Step by Step Conversion

Example: Item in 18ct White Gold weighing 5g we wish to find out the equivalent weight in Platinum.

Step 1. Choose the metal for your item. e.g. 18ct Gold down the left hand side.

Step 2. Find the metal you wish to convert the weight to along the top of the chart. e.g Platinum.

Step 3. Multiply your known weight of the item by the figure in the box. 1.34 for this example.

An item weighing 5g in 18ct White Gold would therefore equal (5 x 1.34) = 6.70g in Platinum. (serendipity diamonds, n.d.)

Density of Gold & Other Metals

Density of Gold, Silver, Copper, Platinum & Other Jewelry Metals with the same volume is different so that it raises up many questions t like “What does a cubic meter / foot / inch / centimeter of gold weigh

Density and Specific Gravity

For most practical purposes, density and specific gravity are the same, however there are slight differences between them, as most scientists would appreciate.

Density

Definition of Density is calculated from the mass of material to the volume. But those who are unsure about "mass" definition they can consider it as the same as "weight" and it is not a very concept (https://24carat.co.uk, n.d.).

Specific Gravity

Specific gravity is defined in Webster's dictionary as the ratio of the weight or mass of a given volume of a substance to that of another substance (usually water for solids and liquids) used as a standard.
(https://24carat.co.uk, n.d.)

Specific Gravity Table

Note that there might be slightly differences due to the exact density (table 2) (Gilbert, 2014)

Metal	Density
Gold	19.3
Silver	10.5
Platinum	21.4
Palladium	12.0
Copper	9.0
9ct	10.9 to 12.7
14ct	12.9 to 14.6
18ct Yellow	15.2 to 15.9
18ct White	14.7 to 16.9
22ct	17.7 to 17.8
Sterling Silver	10.2 to 10.3
950 Platinum	20.1

Table 2 specific Gravity table for different materials.

7.5. comparing the production cost of different precious metals

In previous chapter we find out that how the Build cost of Laser 3D printers calculates. Based on the formula given in the chapter (7.3.) we stablished an excel model that you can see below (Table 4).

Before calculation we need some general information, Precious metal price. In the sample we are calculating Base on the prices in Italy (Euro) (table3). (livepriceofgold, 2016) (www.daily-gold-price.com, 2016)

Platinum Price	Platinum Ounce	Platinum Gram	Platinum Kilogram
EUR	869.81	27.97	27,968.32
USD	925.93	29.77	27.29

GRAMS Italy	Gold Price per Gram [EUR] in Euro
1 GRAM GOLD 24K	35.22
GRAM 22K	32.33
GRAM 21K	30.82
GRAM 18K	26.42
GRAM 14K	20.61
GRAM 10K	14.69
GRAM 6K	8.81

Silver Prices Italy	Silver Prices [EUR] in Euro
(999) Fine, Pure Silver Price per Gram	0.5006
(958) Britannian Silver Price per Gram	0.4798
(925) Sterling Silver Price per Gram	0.4631
(916) 22K Silver Price per Gram	0.4586
(875) 21K Silver Price per Gram	0.4380
(800) Jewellery Silver Price per Gram	0.4005
(585) 14K Silver Price per Gram	0.2929

Table 3 Platinum, Gold and Silver prices in 04/12/2016

NOTE: The given information is based on calculation on a specific type of machine named" 3D FUSION™ "(NANO POWDER DIRECT METAL SINTERING SYSTEMS)

C_{build}	$C_{indirect}$	T_{build}	w (mass of pieces)	$Price_{material}$	E_{build}	$Price_{energy}$
601.3769	0.6008	0.0614	21.4000	28.1000	0.2369	0.1170
685.1832	0.6008	0.0553	19.3000	35.5000	0.2136	0.1170
576.8954	0.6008	0.0508	17.7000	32.5900	0.1869	0.1170
404.6708	0.6008	0.0444	15.2000	26.6200	0.1716	0.1170
5.1786	0.6008	0.0301	10.2000	0.5046	0.1163	0.1170
0.0421	0.6008	0.0214	7.8000	0.0025	0.0828	0.1170

Table 4, data chart expressing calculated cost of Build in Laser 3D printers with considering influencing factors

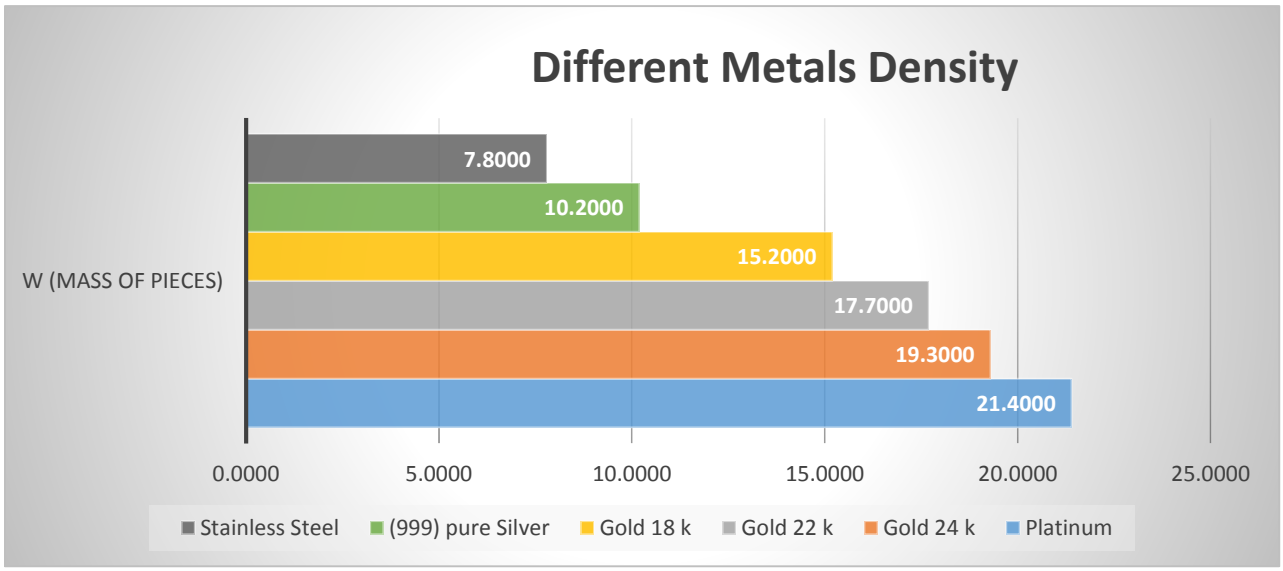

Table 5 material price comparison in 4/12/2016 (Italy)

Density is calculated from the mass of material to the volume that is different in different materials. As you can see below for different metals (table 6). (www.coolmagnetman.com, 2016)

Table 6 comparison chart of different metal densities which uses in jewelry industry

Result conclusion:

The result below (table 7) is extracted from the build cost formula for laser 3D printers that shows the cost for making one cube cm of each material. It this formula electricity consumption, cost of material, machine cost and also all the influencing factors are considered. However, we should remember that the material price, energy consumption, machine cost and many other factors can be different from a place to another and also regarding to the time.

The factors that it is not mentioned here and could not be included due to high volatility and uncertainty are" the company benefit" and the "Post processing cost". Considering the fact that the post processing for different material can be different and some materials like gold and platinum need more post processing changes the final cost.

And on the top of all the costs is the company benefit which can be remarkable.

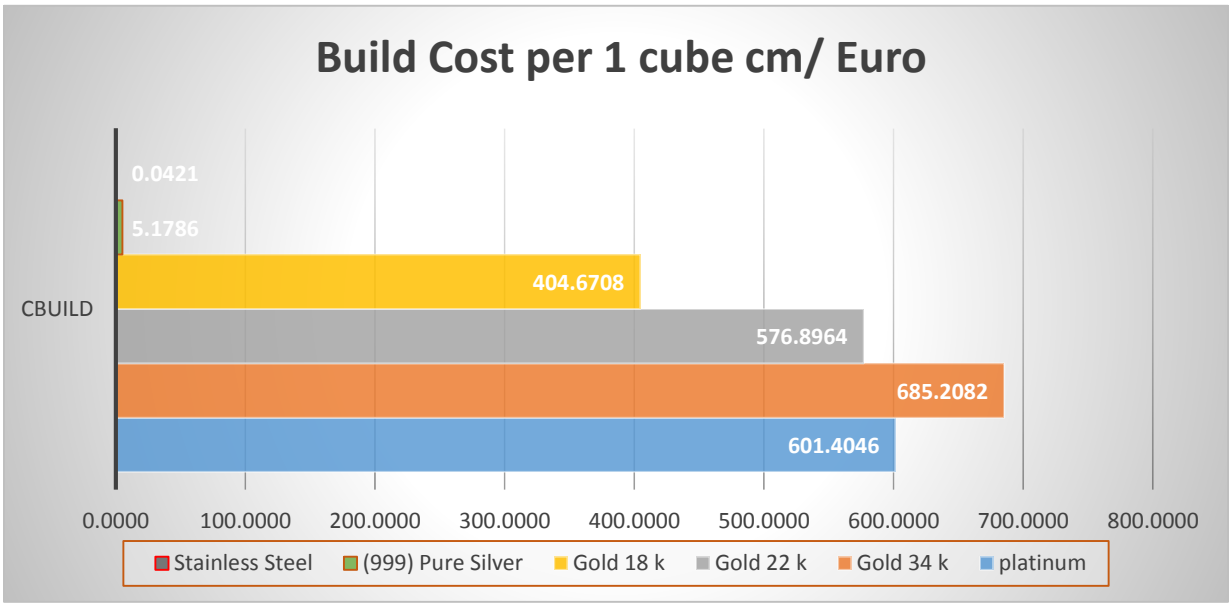

Table 7 ,The chart shows the result received from the Build cost formulas on chapter(7.3.) which present the cost of laser 3D printing 1 cube centimeter.

8. The influences of 3D scanners on Additive manufacturing

The 3d scanning and 3d printing can be so much inter-connected. Means that you can scan every possible object with 3d scanner and then easily print it with 3d printers.

A 3d scanner is a device that gives the possibility to the users to make a digital 3D image out of any physical objects. The transferability through internet is one of its important factors that makes it very useable. There are different areas that you can use it like:

- Creating Art
- Scanning 3D Objects
- making Portraits

nowadays with improving the technologies, you can easily use your cellphone as 3d scanner and have it with you anytime you want (figure 28 and 29) (steves digicams , n.d.).

Figure 28, notepad 3D scanner

Figure 29 cellphone usage as a 3D scanner

The easiness accessibility of this facts will raise a number of questions:

- which objects can be scanned and printed by 3d printers?
- Does it mean that we can simply scan a TIFFANY&CO., Bulgari or Gucci jewelry and print it?
- Will the future be full of fake products made by jewelry printers?
- how to treat 3D scans in the context of existing intellectual property law, specifically copyright law.
- What are the possible positive influences of 3d scanning and printing for future?

For answering to these questions we should consider some rules and predictions like Copyright to get the answer which we will go through them below.

8.2. How the copyright law implemented on the 3d printers design?

The fact that 3D Scanning is a world without Copyright scares many people they want to know who will be the owner of the patent. The fact that copyright doesn't protect the 3D scanning means that it is possible to scan any physical object into a digital 3D Model which sounds scary for the designers and producers also famous brands but we should also consider the fact that 3d scanning itself consist of different phases that needs some technical requirements and knowledge which is not so easy to obtain.

The different process that we can mention are mainly divided into 3 phases:

- preparing the scan
- making the scan
- processing the data generated by the scan

In the first step the light, background and the position of the object should set be considered. For avoiding any problems with copyright the products that have been

designed and produced in virtual reality once, cannot be reproduced again, unless they ask for the permission from the original designer (Michael Weinberg, 2016).

The copyright law is stricter for some special industries like jewelry. In some products that they can be freely replicate after 25 years can be even more difficult to be copied, means that or the company should be legally allowed to produce the product by editing it or otherwise the copy process should be stopped.

We should consider that not all the aspects of 3D scanning and printing are scary, however there are some challenges but in many cases it can open a new door to the world of creativity and novelty in in many industries. also fashion industries. 3D printers already found a way in the fashion industry which is considerable (figure 30 and 31). One useful method of 3D scanning which can be a source of creativity is Expressive Scans that we will explain in the next chapter.

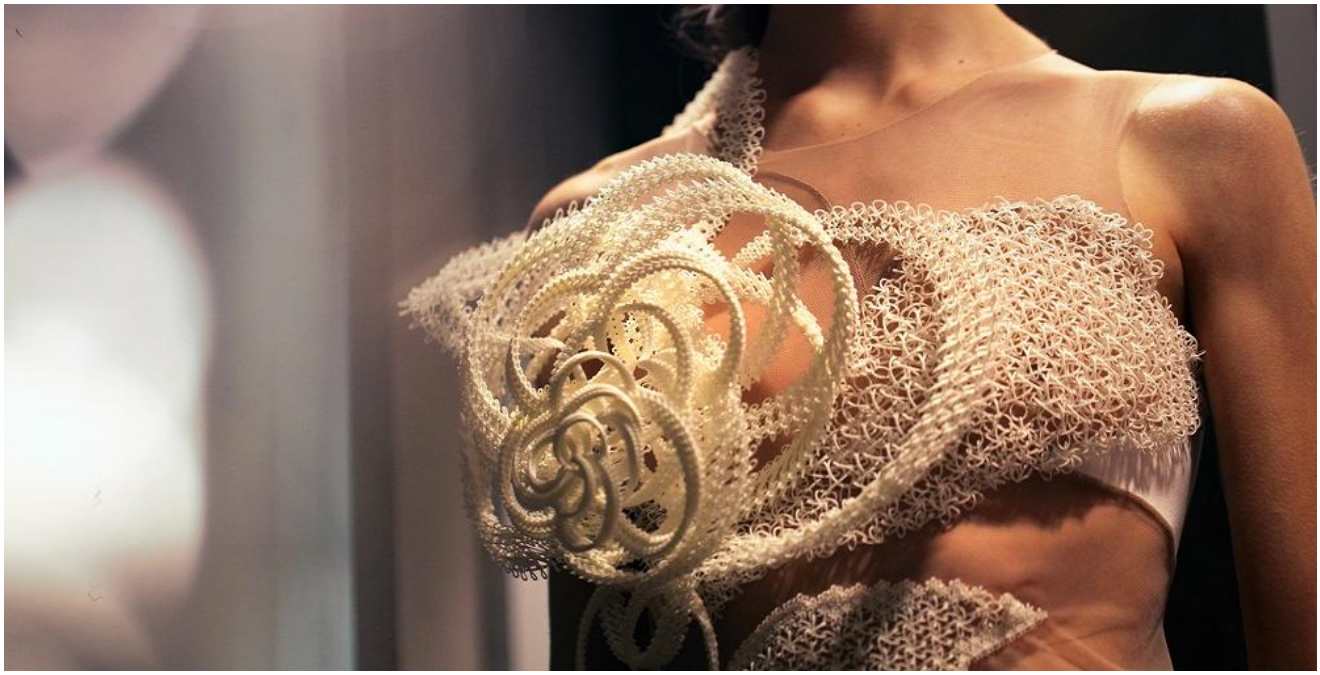

Figure 30 3D printed dress, used in the fashion show

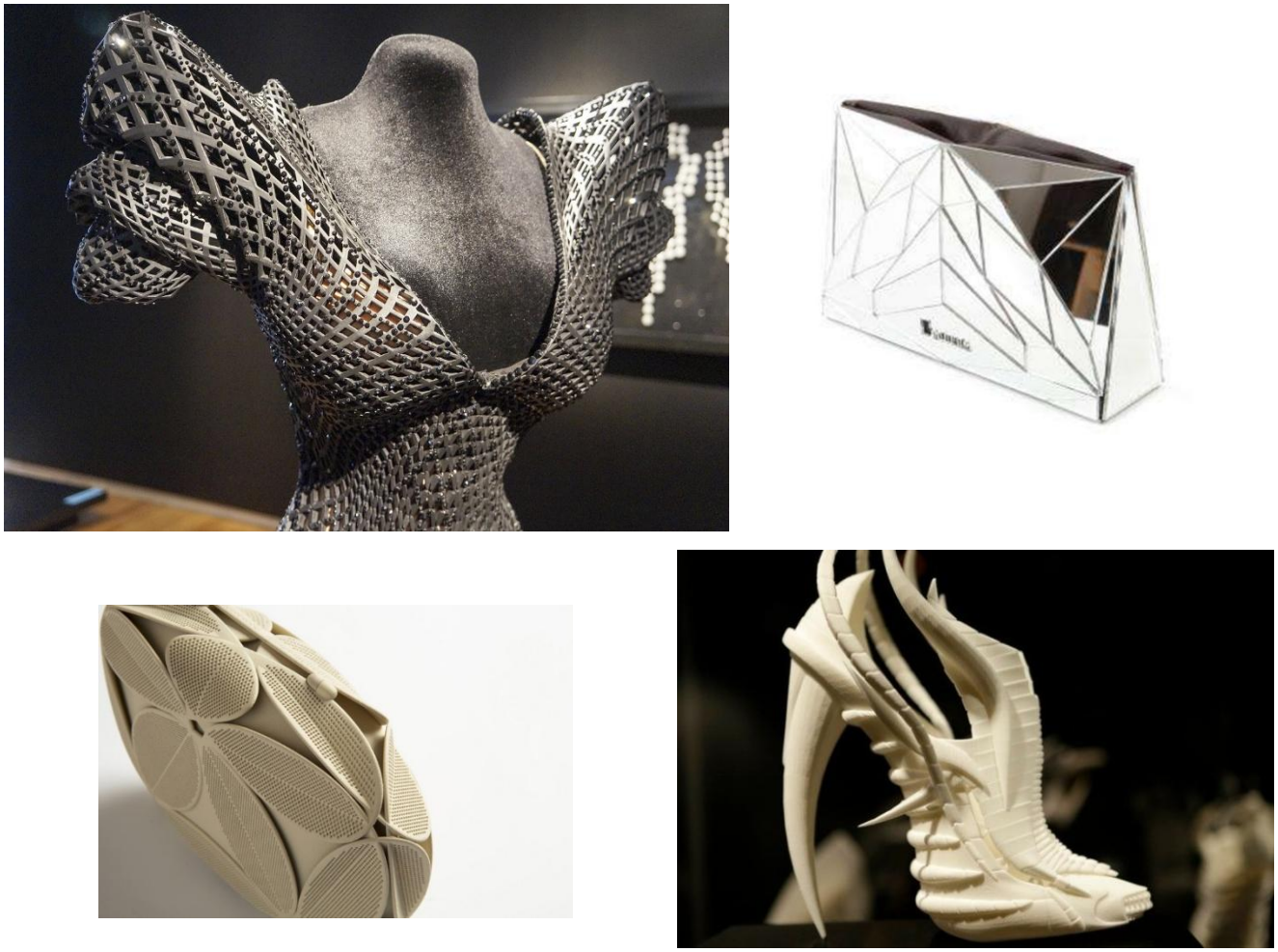

Figure 31.some samples of 3D printed designs used in fashion industries

8.3. what is Expressive Scans?

Expressive scan which is 3d scan method that can be totally from another without facing any problem with copyright. It can be a work to satisfy its audience in which the scan is not a reference but it is a creative work which can be the scan of a person, an object in order to create a unique work.

For instance, Sophie Kahn which is an artist used this method to reconstruct a historical monument but she didn't make it as a complete sculpture intentionally to create her own work (figure 32). (sophie kahn, 2015) (Michael Weinberg, 2016).

Figure 32 *Sophie Kahn's L: Gold (2012) uses intentionally imprecise scanning as the basis of an expressive work. Image courtesy Sophie Kahn under a CC-BY-SA 4.0 International License.*

8.4. How Expressive Scan can boost the 3D printing in jewelry industry?

When you want to design a jewelry there are some other important factors except the material and the brand that we should take into account. We should decide how to put everything together, see if it is comfortable why wearing and other factors which defines the success factor which I will explain below.

➢ ***The wearer's personal life and tastes***

- we should consider that people may be interested in different colors.
- What is the lifestyle or interests of the customer?
- Considering if they have any allergy or sensitivity or no?
- Do they have any personal taste? For instance, maybe a person likes bright jewelry while the other prefer something small and discreet.

- ***Practicalities of the design and affordability***

Before starting to design a jewel you should already have an image about the product that how it will look like when it finishes and some other factor like:

- To see of you have all the requirements and the needed tools or not.
- How much the final work will cost? will the design cost to make? The cost of a making a design could impact on whether you can make it at all.
- How easy are the materials to source? Difficult to obtain materials may be costlier and also take more time to find.

Expressive Scan can be a used as a source of creativity and novel ideas without facing any problems with copyright.

Here I will explain some examples note that these are my personal opinions which can be a small part out of hundreds or thousands other samples that each person individually can have.

1. Object scanning:

this method can conclude many different things that you can scan to use as a source of your design.

You do not need to copy the work of other producers you can create your own patent without any difficulties and then print it by the right material and into the right shape. With this technology you can have your custom design.

Figure 33

You can simply scan objects, animals, flowers, statues any other possible physical object and merge it with the base of your

jewelry which van be a ring, a neckless, an earring or any other jewels to thing else (figure 33).

In the first example you can see a snail which is 3d scanning (figure 34) that can be used as a part of your jewelry and do not need to be designed with complex software with difficulties that needs a very high digital knowledge to design it.

After scanning you can create your own patent or you can even go beyond this and mix two different pattern to create more unique model (figure 35).

Figure 34 3D scanning a snail to use as the main pattern of the jewel design

Figure 35 jewels using snail and skull patent

This technique enables you to scan your favorite physical objects and creates jewelries out of it, for example if you are the owner of MASQUE PERFUME and you want to have its symbol on your jacket in some special occasions you can simply do it. There is no need to necessarily produce a high volume, or wait long days for your product to get ready. Just scan it and print in your favorite material. (Figure 36)

Or if you bought a nice mask from Venice and you wish to have a piece of jewel like it you can scan it and mix it with any basic pattern and then print it as neckless, a bracelet or whatever you want. (figure 37 and 38)

Figure 36 Masque 3d scanned and printed in Gold

Figure 37 different masks which can be used as an object for 3d scanning

Figure 38 3D printed jewelries inspired with mask design

2. Difficult design, minimum afford:

the nature of 3d scan can enables the jewelry industry to benefit from using difficult design with a very low afford. you may ask how it is possible?

Let us imagine that we want to use the shape of flowers as the source of inspiration and obviously designing it so delicate and with so many details can be though job, hence with using 3d scanner you can easily scan it and have a 3d image of a flower which can be expanded into any jewel (Figure26). the nature of the flower beauty leads many different producers to use it in their designs Dior can be a good example that uses flowers in their designs (figure 39).

You can see some more sample of flower used in jewelry industry below (figures 40-41).

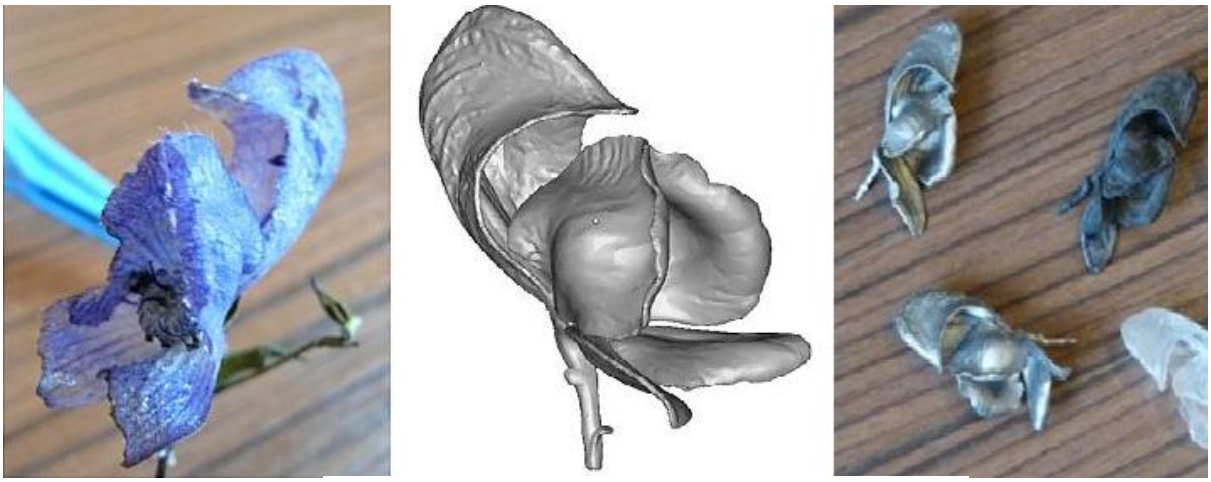

Figure 39, sample of 3D scanning of flowers(orchid)

Figure 40 the usage of flower shape in Dior jewelry

Figure 41 samples of Orchid usage in jewelry industry

3. **Customers satisfaction**:

each customer based on its lifestyle can have different interests, many people due to their position or personal will, can be interested to do some particular stuff, maybe they like to have jewel which is made due to a design of his face (figure 42), his family members or they may like to have his/her partner finger prints on their wedding (figure 43). Doing such these work with the traditional ways can be do much time consuming, costly which needs a high level of expertise to do it

Figure 42 expressive scan on cuff clips and ring

Figure 43, family expressive scan and finger print scan on the ring

8.5. Other roles of 3D printing in the future of jewelry industry

The role in the start-up companies: One of the roles of 3d printers which can be remarkable is for start-up companies, those that want to produce some product but they are not sure if there will be the market for that or no. and on the other hand the initial cost for producing the first samples is so high. The company should buy the needed equipment which can be so costly and if the market won't be successful they will lose a big fortune of money. Considering all these facts, 3D printing can be so much useful in order to test your market and see if there will be demand or no. If you realize that the response to your product is remarkable then you can buy the needed equipment and start the mass production.

The nature of 3D printers enables the industry to response the demand so fast, this characteristic highly reduces the time to market. The question is that how we can benefit from it?

8.5.1. How to use the fast response of 3d printers in jewelry industry?

3D printing can be used in many different situations due to its fast response that some samples will be explained here:

- **reduce the inventory costs by production postponement:**

regarding to the high material cost of jewelries, producers should be very careful about the right amount of production. Since predicting the demand is always different from what we have predicted (always the real demand is higher or lower than our prediction), it can be upper forecast or lower forecast that in each two scenarios we will face different problems (figure 44).

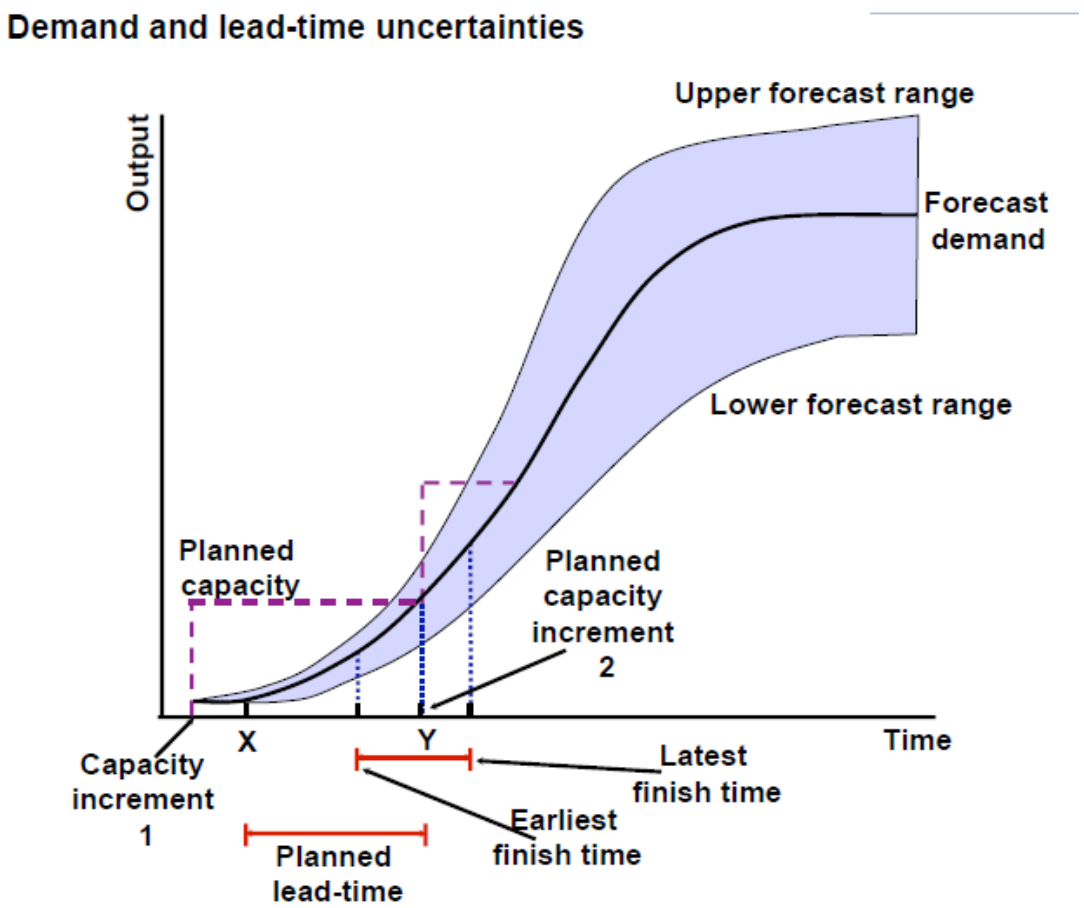

Figure 44 the demand prediction curve which shows that there is always errors in predicting demands correctly

If we forecasted higher than demand means that we have produced more than needed hence we had a higher production cost and though higher inventory cost, higher labor cost and etc.

If we forecasted lower means that we lose some market share and we did not benefit from the potential of the market.

What is the solution to this fact?

The best solution is to postpone the production and wait till the demand arrives, the 3D printers enables the industry to have a fast response to the demand without losing market share, the right amount at the right time.

- **Response to an event:**

Any year in all over the word people face some important event that it may means a lot to them. It can be a football or a tennis championship, it can be a Golden Globe event, a heat song of a singer, an important match in Olympic, an important political or economic revolution etc. (figure 45). For example, if it is a football championship and Real Madrid win the tournament the fast response for the fans can be some symbolic products as jewels.

Figure 45 symbolic jewels referring to some occasions

If you still remember the football world cup 2006 you can imagine how the industry can be boosted by the fast production and minimizing the time to market. (figure 46)

Figure 46, fast response to a sportive event

In these situations, usually the fast response to this event can lead to a big success for the company. But many times it happens that companies cannot response to this situation in proper it may cause not even a benefit but also a loss.

3D printers help the producer to benefit from the fast production not to lose any opportunities.

9. Conclusion

Due to this study on the influences of 3D printers in Jewelry industry and after going through history of Additive manufacturing, we realized that every day more variety of 3D printers comes to the market with wider range of materials. This fact enables the designers to have as much more freedom to create their unique design. Considering the machinery cost which is highly reducing during the last years gives the opportunity to the industrial plants to use it in a broader area. Even very low cost 3D printers that they are convenient for home usage, attracts many customers to use it as a source of production for themselves, their families or even beyond, to become little entrepreneurs.

Since there are some worries about the increasing number of fake (not-original) products, we frequently think about the future of 3D printers in jewelry industry?

However, it also can be a hypothesis, but there are more hope and prediction to face many creative designs with a very unique patent. This characteristic may lead famous designers a big brand to have a more challenging life and go far beyond what they have been so far, to create less imitate able jewels. They may use a higher variety of different Materials (metals, crystals, precious stones, ceramics and etc.) in one piece to make it more though to be imitated by only one 3D printer, and with the non-professional designers.

Considering all these facts, the Future with 3D printers can be a world full of innovative Ideas in which designers are more cautious to create a piece of art which provides a higher value for the customers.

10. References

References

(2016, 12 04). Retrieved from livepriceofgold: http://www.livepriceofgold.com/italy-gold-price.html

(2016, 12 04). Retrieved from www.daily-gold-price.com: http://www.daily-gold-price.com/gold-price-in-italy.php

(2016 , december 4). Retrieved from www.coolmagnetman.com: http://www.coolmagnetman.com/magconda.htm

Andrew C. Nyce, P. A. (2016). An Assessment of the 2026 U.S. Markets and Technology for Jewelry Manufactured by 3D-Precious Metal Printing. 37.

designer), M. W. (2016, august 30). Calculating 3d printers cost. (P. Sepahvani, Interviewer)

Diamond Council of America © 2010. (2010). Advanced Jewelry Sales. *Diamond Council of America*, 37.

Dissertation, g. (2011). An advanced prototyping process for highly accurate models in biomedical applications . 162.

f. Abe, k. M. (2001). The manufacturing of hard tools from metallic powders by selective laser melting. 4.

Fausto Bernardini, H. E. (2002). The 3D Model Acquisition Pipeline. p. 24.

Frank G. Zarb School of Business, H. U. (2011). *3-D printing: The new industrial revolution.*

Gilbert, D. S. (2014). Costs and Cost Effectiveness of Additive Manufacturing. 89.

Gornet, T. W. (2014). History of Additive Manufacturing. p. 34.

H. Bikas1, P. S. (2015). Additive manufacturing methods and modelling approaches. 405.

Hafley, M. K. (2015). Electron Beam Freeform Fabrication for Cost Effective Near-Net Shape. *NASA Langley Research Center*.

Harris L. Marcus, J. J. (1996). Solid Freeform Fabrication Proceedings. In *Solid Freeform Fabrication Proceedings* (p. 439). The University of Texas at Austin.

Heidi Piili*a, A. H. (2015). Cost Estimation of Laser Additive Manufacturing of Stainless Steel. *ScienceDirect*, 396.

Hoskins, S. (2013). *3D Printing for Artists, Designers and Makers.*

http://www.bioprinting.ru/. (2015). *http://www.bioprinting.ru/*. Retrieved from 3Dbio : http://www.bioprinting.ru/en/press-center/publications/3d-printing-year-in-review-the-biggest-3d-printing-news-stories-of-2015/

https://24carat.co.uk. (n.d.). *chard website*. Retrieved from www.24carat.co.uk: https://24carat.co.uk/frame.php?url=densityofgoldandothermetals.html

Jacobs, P. F. (1992). *Rapid Prototyping & Manufacturing: Fundamentals of Stereolithography.* Retrieved from wikipedia: https://en.wikipedia.org/wiki/3D_printing

Jessica M. Williams, A. A. (2005). Bone tissue engineering using polycaprolactone scaffolds fabricated via selective laser sintering. 11.

Khan, S. M. (2015). 3D Printing and Supply Chains of the Future. 29.

metal AM. (n.d.). Retrieved from http://www.metal-am.com/introduction-to-metal-additive-manufacturing-and-3d-printing/

Michael Weinberg. (2016). 3D SCANNING a world withoud copyright . *shapeways*, 18.

Robbert Janssen, I. B. (2014). TNO: THE IMPACT OF 3-D PRINTING ON SUPPLY CHAIN MANAGEMENT. 24.

Samuel H. Huang, P. L. (2013). *Additive manufacturing and its societal impact.*

serendipity diamonds. (n.d.). Retrieved from https://www.serendipitydiamonds.com/uk/education/precious-metal-weight-conversion-chart

Seung Hwan Ko1, 4. J. (2010). Metal nanoparticle direct inkjet printing for low-temperature 3D micro metal structure fabrication.

shapeways. (2015). Retrieved from www.shapeways.com: https://www.shapeways.com/marketplace/jewelry/

Simchi, A. (2006). Direct laser sintering of metal powders. 11.

Simchi, A. (2006). Direct laser sintering of metal powders Direct laser sintering of metal powders:. *Department of Materials Science and Engineering and Institute for Nanoscience and Nanotechnology Sharif University of Technology, P.O. Box 11365-9466, Azadi Avenue, Tehran, Iran* , 178.

sophie kahn. (2015). *http://www.sophiekahn.net/*. Retrieved from http://www.sophiekahn.net/

steves digicams . (n.d.). Retrieved from www.steves-digicams.com: http://www.steves-digicams.com/knowledge-center/how-tos/photo-accessories/3-creative-uses-for-a-flatbed-scanner.html#b

top Max technology Magazine . (n.d.). *top Max technology Magazine* . Retrieved from http://en.topmaxtech.net/reviews/2015/12/27/types-of-3d-printers-or-3d-printing-technologies-overview/279.html

Vladimir Mironov, T. B. (2003). Organ printing: computer-aided jet-based 3D tissue engineering. 160.

Vladimir Mironov1, T. B. (2003). Organ printing: computer-aided jet-based 3d tissue engineering. p. 161.

wikipedia, t. f. (n.d.). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/3D_printing

Wikipedia, the free encyclopedia. (n.d.). *Laminated object manufacturing*. Retrieved from Wikipedia, the free encyclopedia: https://en.wikipedia.org/wiki/Laminated_object_manufacturing

www.IMTS.com. (2014). *IMTS*. Retrieved from www.IMTS.com: https://www.imts.com/show/history2014.html

www.mygemologist.com. (n.d.). *mygemologist*. Retrieved from www.mygemologist.com: https://www.mygemologist.com/learn/selling-jewelry/how-to-sell-your-jewelry/

Yang, M. V. (2013). A review on 3D micro-additive manufacturing technologies. 34.

Questionnaire for 3D printers' production cost

Here there is a voluntary questionnaire provided by Parisa Sepahvani in order to participate in my study research to analyses the production cost of 3D printers and the influencing factors, which I kindly invite you to participate in.

Questions	Answers
1) Name:	
2) Family:	
3) Company:	
4) Your Position in the company:	
5) What is the area that your company works in?(e.g. fashion luxury, industrial, medical)	
6) Does your company have mass production with 3d printers?	
7) Which technology (machine) does your company use?	
8) How big is the machine that your company uses?	
9) Do you have technical information about 3d printers production?	
10) do you know what are the influencing factors in the 3d printing Production cost? (if yes mention them)	
11) do you know how the production cost calculates?	
12) Do you have a 3D printer?	
13) * if yes. what do you do with it?	
14) What is your favorite area to work?	
15) How do you see the 3D printers position in future?	
16) Do you think in the future we will see many fake products made by 3D printers or no?	
17) Does the material consistency have an influence over the printing speed?	
18) In your opinion What are the positive effects of 3d printers in future?	