POLITECNICO DI TORINO

Master's degree in Engineering and Management

Master of Science Thesis

Additive Manufacturing adoption in Dental Practices

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Ai miei amati genitori.

Abstract

Additive Manufacturing is an innovative production technology belonging to the latest Industrial Revolution, the era of digitalization, also known as Industry 4.0.

The diffusion of 3D printing is moving fast, and it is already considered a viable manufacturing technology across industries such as aerospace, biomedical and manufacturing.

The aim of this thesis is to describe the actual economical and technical scenario of Additive Manufacturing with particular attention to the Dental sector. The crucial part of the paper concerns an analysis conducted in the Palermo area to understand the level of diffusion of additive manufacturing technologies in dental offices. For these purposes, a detailed questionnaire was developed and then submitted to a sample of dentists. To have a clear general picture, the technician sector was also investigated to understand the level of adherence to the new production technology in these laboratories. The analysis of the collected data provided interesting considerations on the future opportunities of additive manufacturing in this sector.

The first chapter provides a general description of the AM technology, explaining its discovery, the 3d printing process starting from its discovery, the different phases that make up the generic 3d printing process and the technologies currently in use.

The second chapter deals with the economic aspects of Additive technology, highlighting the advantages and the limits that characterize it with reference to the different field of application.

The third chapter analyzes additive manufacturing from the point of view of technological innovation with particular attention to its destructive nature and the level of diffusion in the market by examining historical data and estimating future forecasts.

The fourth focuses on the specific dental sector. The economic features are introduced to give an idea about the size of the market and subsequently the transformation that the phenomenon of digitization has brought on the traditional workflow and on the relationships between Labs and Practices. At the end, the main benefits and limitations that 3d printing has in the dental industry will be discussed.

The last chapter deals with the market analysis carried out through the submission of a questionnaire to a sample of Palermo dentists. the results obtained will be analyzed and compared with the analysis carried out by colleague Stefano Conte in the Turin area. To get a clearer picture, the interviews conducted with dental technicians will be discussed. This will allow us to advance important conclusions on the diffusion of 3D printing in the dental sector in relation to the area under examination.

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Chapter 1: The Additive Manufacturing technology

Introduction

Additive Manufacturing is an innovative industrial process that starting from digital 3D models produces solid objects by depositing material one layer at a time. Differently from the traditional subtractive method, which starting from a block of material removes mechanically the shaving, with AM the material is added layer upon layer until the object is completed.

3D printing, the more common name by which the new technology is known, is a tool that simplifies and expedites the product development process, also allowing significant material savings and greater freedom in the design of the component compared to traditional production technologies.

AM has already been adopted in different industrial sectors, such as Aerospace, Biomedical and Automotive mainly for rapid prototyping and for the production of small series but is a rapidly developing technology that in a short time could really change the way companies produce.

The invention of Additive Manufacturing

The origins of 3D printing date back to the 1980s when Charles Hull, in 1983, patented Stereolithography becoming the pioneer of the 3D Printing revolution.

In the early 1980s, Charles Hull was an engineer for a small furniture manufacturing company who used UV light to apply thin layers of plastic to artifacts. This process was time consuming and made Hull's work uninspiring. It was precisely from this dissatisfaction that his invention, Stereolithography, was born, a process by which thin layers of material were overlapped until the creation of a three-dimensional object. Each layer is made by means of a laser source capable of selectively triggering the thermosetting reaction of a liquid photopolymer. This technology was patented in 1986 with the name of "*Apparatus for Production of Three-dimensional Objects by Stereolithography*" and in 1988 the 3D System company, founded by Hull in California and still today leader in the sector, released the first commercial printer, the SLA-1.

In 1986 Carl Deckard and other researchers at the University of Texas, starting from Chuck Hull's ideas, invented the *Selective Laser Sintering* (SLS), a new 3D printing technology that involved a process similar to Stereolithography in which, however, the liquid photopolymer was replaced by a powder thermoplastic that did not require supports and therefore brought advantages from a practical point of view.

In 1988 Scott Crump patented the *Fused Deposition Modeling* (FDM), the simplest and most common technique that involves the use of molten material to be spread layer by layer, eliminating the use of lasers. Crump founded Stratasys, currently one of the most important companies in the 3D printing industry.

In 1995 the Fraunhofer Institute conceived the *Selective Laser Melting* (SLM), for the first time it was possible to melt metal powders and create objects with a density comparable to that obtainable with traditional methods. The process is similar to Selective Laser Sintering with the addition of some precautions due to the nature of the metal material.

In 2002, the *Electron Beam Melting* (EBM) was developed, a technology that allows the complete melting of a metal powder using an electron beam, suitably focused and accelerated, ensuring an even greater density than Selective Laser Melting.

In 2005, the mechanical engineer Adrian Bowyer of Bath University founded the *RepRap* (Rapid Replicating Prototyper) project, determining the real turning point in the world of 3D printers. Bowyer's goal was to create low cost solutions for the hobby and home 3D printing, without having to resort to expensive industrial infrastructure.

A further boost to the spread of home 3D printers was given in 2009 by *MakerBot*, a company founded by Bre Pettis, Adam Mayer and Zach Smith, who following the success of RepRap provided an open source do-it-yourself (DIY) kit for people wishing to build own printers and print products at home. The company also created Thingiverse, a library of downloadable and 3D printable online files that has now become the largest file repository in the world. The year 2009 è also the year in which the ASTM F42 Committee was formed, which published a document containing the standard terminology on additive manufacturing, officially making AM an industrial production technology.

In 2011, three MIT Media Lab students, Maxim Lobovsky, Natan Linder and David Cranor, founded *Formlabs* with the intention of developing an easy-to-use, low-cost 3D printer. Only thanks to a gigantic fundraiser on Kickstarter, worth 3 million dollars, the company was able to start the production and marketing of its first 3D printer model, FORM 1, which uses stereolithography technology.

The AM Process

The production process of Additive Manufacturing consists of several successive phases, which starting from a 3D CAD model, allow the creation of the final 3D object (*fig.1*).

1) 3D CAD model generation

The production of an object using a 3D printer requires as input a virtual model that faithfully reproduces its structure and shape. The first step in the additive manufacturing process is therefore the creation of a digital file through the use of a *Computer Aided Design* (CAD) software or digitalizing an existing object through 3D scanning.

2) CAD File conversions

After creating the CAD file, you need to convert it into a specific format that makes it readable by the printer. There are various reading formats depending on the technology used by the machine, for example if it is stereolithography, the CAD file must be converted into a STL.

3) STL File manipulation

In this phase the 3D model is split into thousands of horizontal layers through a slicing software that instructs the printer on exactly what to do. To do this, the program converts the STL file into G-code, which is a numerical control programming language used to control automated machines tools, as indeed a 3D printer.

STL file is transferred to the machine.

4) Preparing the printer

At this point we need to set up the machine, that is to properly install the polymers, binders and other materials which are necessary to perform the printing operation.

5) The Building Up

At this point the 3D printer proceeds with the realization of the product by generating and overlapping layers of material.

Depending on the size of the object, the machine and the materials used, the whole procedure could take hours or even days, so you just have to wait and run random checks to make sure there are no errors.

6) Removal of prints

This phase can be extremely easy or complicated depending on the AM technology used. In fact, it may be a question of simply removing the printed part from the construction platform, or it may require more sophisticated extraction operations, which can only be performed by highly qualified operators.

7) Post Processing

Once the processing is completed, post-processing activities are required such as cleaning, supports removal, UV curing and others. The necessity and the complexity of these procedures depends on the 3D printing technology used and on the use for which the piece is intended.

Fig. 1.Generalized Additive Manufacturing process

AM technologies

In the previous paragraph the general 3D printing process was described, highlighting the main phases that compose it, now we shift the attention to the specific printing phase.

In these years, the growing innovation in the AM sector has led to the invention of different technologies, with names arbitrarily assigned by the respective owner. This caused no little confusion in the minds of users in differentiating processes, sometimes similar technologies had totally different names.

To solve this problem, a collaboration between ISO and ASTM standard organizations gave birth to the *ISO/ASTM 52900 Standard* in order to have a common terminology and a clear classification of the processes. AM technologies were classified in seven different process categories, whose detailed description are presented in the following section. This categorization will certainly require future revisions given the strong rate of innovation that characterizes the AM production technology.

Material Extrusion

The invention of this process is attributed to Scott Crump, that in 1988 deposited a patent for the *Fuse Deposition Modelling* (FDM). Nowadays, it represents a widespread technology used on many cheap and hobby printer.

According to the ISO/ASTM 52900 Standard the Material Extrusion technology is defined as "Additive Manufacturing process in which material is selectively dispensed through a nozzle or orifice".

The material is added to the machine in spool form and drawn through a nozzle, an element that can move horizontally along x and y, here it is heated and deposited in a first layer. Once the latter is finished, the platform will move down or the extrusion head moves up, allowing the nozzle to extrude a new layer over the previous one. The layers are fused together upon deposition as the material is in a melted state. Supports are required for bottom surfaces and overhanging features, which are easy to remove manually when the component is completely built. In the *fig.2* is possible to see a schematic representation of the process.

Point in favor of the material extrusion process are:

- the easiness to use
- the low cost of the printer
- the low operating costs
- the wide range of usable materials.

It is possible to use the ABS plastic, an easily accessible material with good structural properties.

The main disadvantage of this technology is that the quality of the final product is influenced by many factors:

- extrusion temperature
- layer thickness
- print bed temperature
- print speed

All of these must be kept under control to assure a high-quality level.

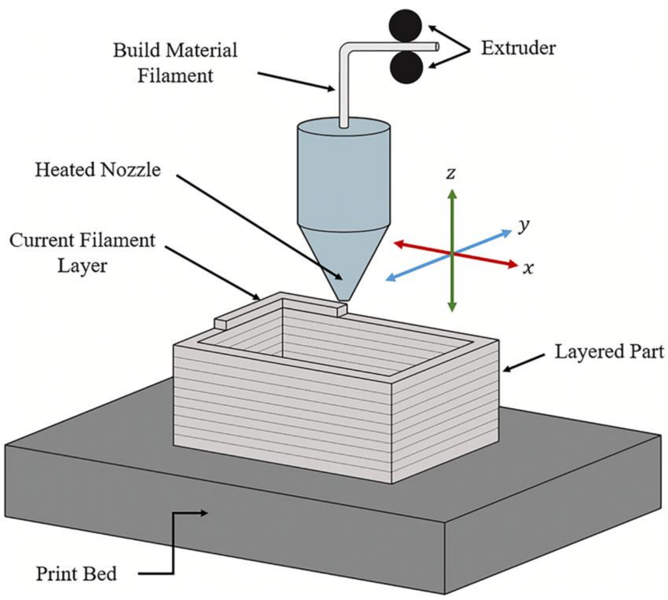


Fig. 2. Material Extrusion process

Material Jetting

Defined as "Additive Manufacturing process in which droplets of build material are selectively deposited", this technology creates objects in a similar way to a two-dimensional ink jet printer. As shown in *Fig.3*, droplets of material are selectively deposited onto a build platform via a horizontally moving nozzle, using a continuous or a DOD (Drop on Demand) approach. When the first layer is solidified, through a UV light, the printer deposits the next, until the whole object is completed. This technology often uses multi-nozzle print heads to increase speed and to allow the use of different colors and materials. DOD printers have two nozzles, one deposits the build material while the other is used for the support material.

Since the material must be deposited in drops, this technology allows the use of a limited number of materials. Among those commonly used, we find polymers and waxes, materials suitable for this process thanks to their viscous nature and the ability to form drops. The process often requires supports which, at the end of processing, can be removed using a sodium hydroxide solution or a jet of water.

The main advantages of this kind of process are:

- High accuracy and homogeneity of the final product
- Low waste of material thanks to the high accuracy of droplets deposition
- Possibility to use multiple materials and colors in the same process

The drawbacks are:

- Expensive 3D printing technology
- Low mechanical properties
- Limited number of materials (polymers and waxes)
- Supports are often required.

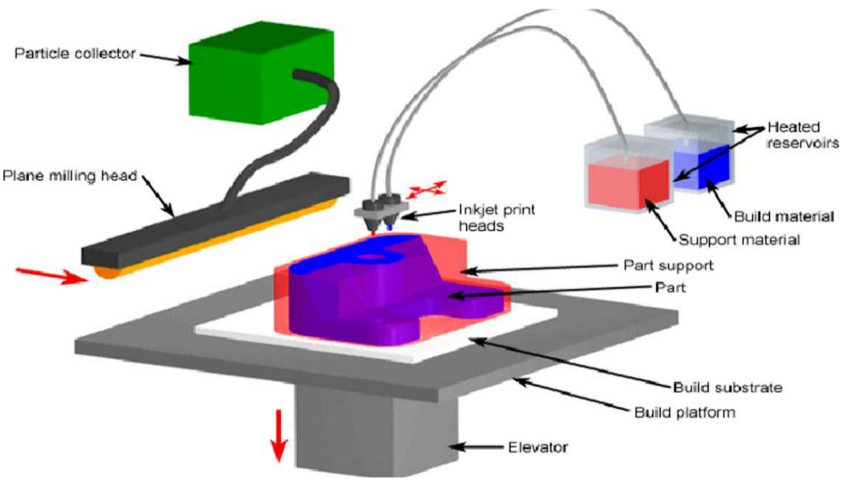


Fig. 3. Material Jetting process

Binder Jetting

Defined as "Additive Manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials", the Binder jetting process is similar to the material jetting one in its use of inkjet printing, the only difference regards the liquid material, that in the first case is a bonding agent acting as an adhesive between powder layers, while in the other one is the building material.

The process starts with a print head that moves horizontally along the x and y directions depositing the first layer of powder material, spread over the build platform using a roller. At this point the print head deposits the liquid binding agent to fix the powder material where required. Then, the build platform is lowered to allow the overlap of the next layer of powder until the object is completed.

Post-operation treatments are required to make the piece more resistant and with a high-quality finish. In fact, once the printing is finished, the component is left in the powder bed to cool and solidify completely. No support structures are needed, the object is self-supported within the powder bed.

The Binder jetting process allows the creation of complex geometries but does not guarantee good mechanical properties to the piece produced, it is therefore suitable to print presentation models and sand-casting cores or molds.

The main advantages of this AM technology are:

- Complex geometry allowed
- No supports structure needed
- Unused powder is 100% recyclable
- No heat involved, so no risk of distortion

The drawbacks are:

- Low mechanical properties
- Post-processing activity adds time to the overall process

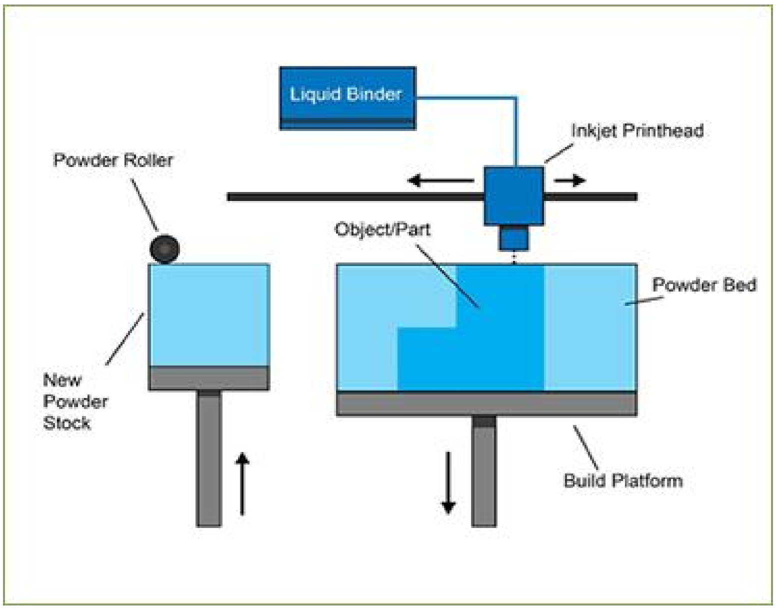


Fig. 4. Binder Jetting process

Sheet Lamination

The Sheet Lamination category, defined as "Additive Manufacturing process in which sheets of material are bonded to form a part", includes two types of technology that differ for the sheet material used:

- *Laminated Object Manufacturing* (LOM) uses sheets of paper which are bounded together using an adhesive, creating aesthetic and visual models not suitable for functional use.
- *Ultrasonic Additive Manufacturing* (UAM) uses ultrasonic welding to join sheets or ribbons of metal, using materials such as aluminum, copper, stainless steel and titanium. The metals used are not melted so the process is conducted at low temperatures with low energy consumption and allows the creation of internal geometries.

These processes require post-processing activities to cut the excess material, if in LOM machining this can be easily done manually, the second case requires CNC machining to remove the unwanted material.

The main advantages are:

- Low cost and speed process

- Fast and easy cutting technology

Disadvantages are:

- Low range of usable materials
- Post-processing often required to achieve the desired finishes.

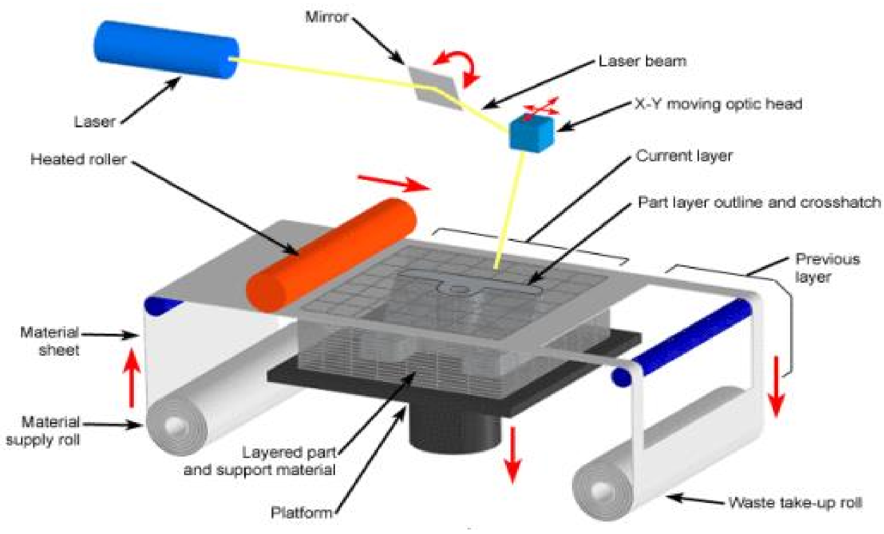


Fig. 5. Laminated object manufacturing

Vat Photopolymerization

The ISO/ASTM 52900 Standard defines this process category as "Additive Manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization".

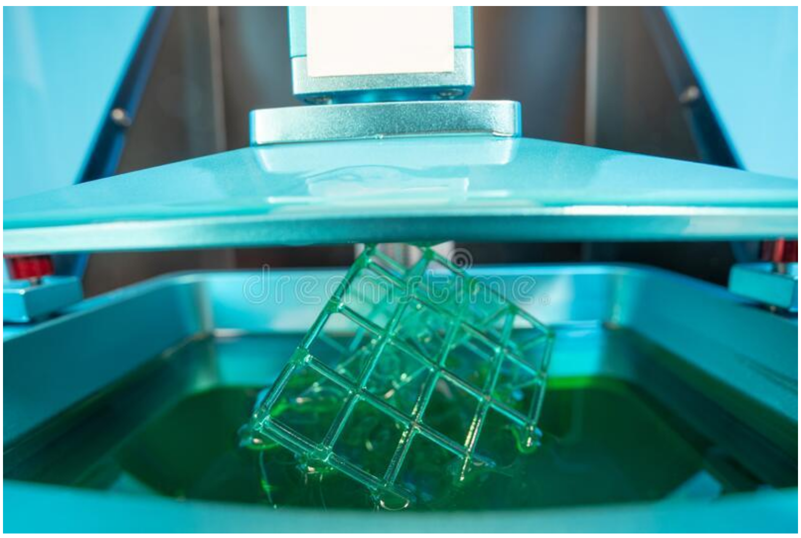


Fig. 6. Vat Photopolymerization process

The invention of this technology represented the beginning of the era of 3D printers. Patented as *Stereolithography* (SLA) by Charles Hull in 1983, it still represents a valid printing method in many fields like jewelry, dental applications and prototyping. In addition to Stereolithography, this category of AM technology includes Digital Light Processing (DLP) and Continuous Liquid Interface Production (CLIP).

Although these vat photopolymerization processes have been identified as three different technologies, the main differences in the printing process are limited. All three create 3D objects by selectively curing a liquid resin, called a photopolymer, through a targeted ultraviolet (UV) light that emits certain wavelengths that can quickly bond photopolymer molecules to create the solid state.

Stereolithography (SLA) is the oldest and most widespread technology which uses mirrors, called galvanometers, to direct a laser beam toward the layer to be solidified: through the tank for bottom-up printers; directly on the first layer for top-down ones (*fig.7*).

Digital light processing (DPL) uses a different light source than SLA, a digital projector screen that flashes a single image of each layer across the entire platform at once. This way DLP can achieve faster print times, as each entire layer is exposed all at once, rather than being pulled out with a laser (*fig.8).*

Continuous Liquid Interface Production (CLIP) works continuously, so the build platform has a continuous upward movement. In addition, to prevent the part from sticking to the tank, the printer creates a "dead zone" of uncured resin by means of an oxygen permeable window. This results in a faster build time.

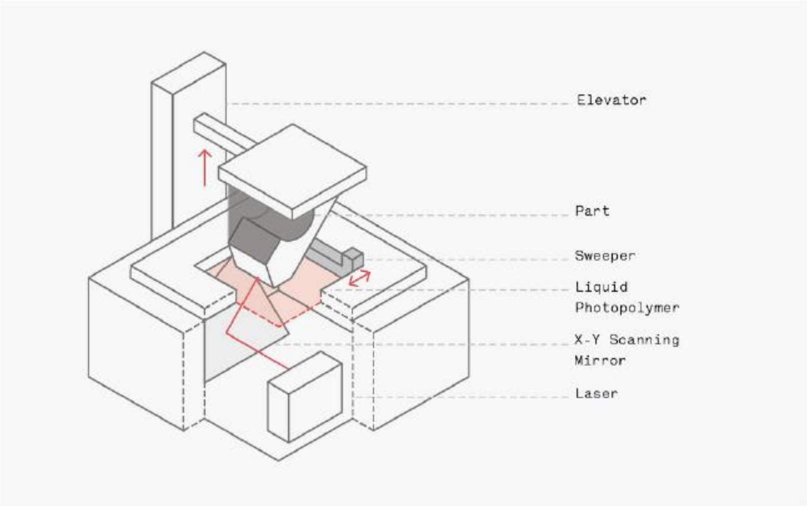


Fig. 7. Schematic of SLA printer

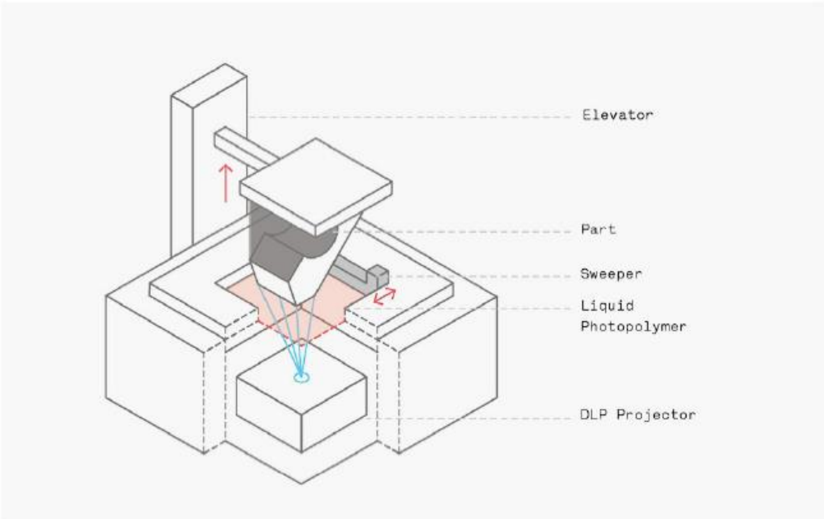


Fig. 8. Schematic of DPL printer

The Vat Photopolymerization process starts lowering the printing platform into the tank containing the liquid photopolymer based on the thickness to be created, a laser directs an ultraviolet light to selectively cure the resin in a liquid layer according to the information provided by the CAD file . In some printers, a blade is used after each layer is created to provide a smooth base on which to build the next. The platform is again immersed in the liquid and the photopolymerization process described above is repeated until the object is completed. During the printing phase it will be necessary to use structural supports because, unlike printers that use powdered material, the uncured resin being in the liquid state is unable to support the object.

Vat photopolymerization is a fast and very accurate AM process that can be used to print quite large models and prototypes. However, photopolymers in general do not have good structural characteristics and the pieces produced are subject to degradation and deformation over time. In addition, printed parts often require post-processing to remove the supports and clean the piece of excess resin via an alcohol rinse followed by a water rinse. To ensure a better quality of the piece, a post-curing with UV light can also be carried out.

An important aspect to underline is that the printers that use the Vat Photopolymerization technology can work in two configurations: Bottom-up and Top-down.

The *Top-down* approach, *fig.9a*, places the light source under the tank and the build platform begins its run near the base, then gradually rises and allow the laser to solidify successive layers of material until the part is completed. A disadvantage of this approach is that the part could remain attached to the tank, altering the normal printing process and causing structural stress to the piece, but this can be solved by applying a special coating to the bottom of the tank that prevents it from sticking.

The *Bottom-up* approach, *fig.9b*, involves positioning the light source above the tub, therefore the build platform will be progressively immersed in the liquid photopolymer as described in the initial presentation of the Vat Photopolymerization process.

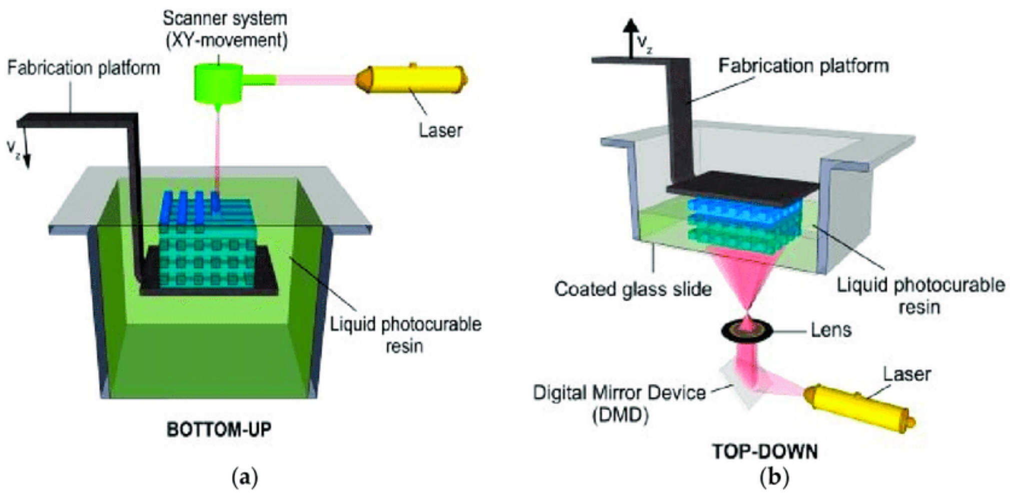


Fig. 9. Bottom-up approach (a) and Top-down approach (b)

The benefits of Vat Photopolymerization processes are:

- High accuracy and good finishes

- Little process time compared with other technologies

There are also some disadvantages, among which:

- Post-processing required
- Low range of materials: photopolymer resins only
- Not suitable for functional part (low mechanical strength and durability)
- Supports needed.

Powder Bed Fusion

Powder bed fusion (PBF) is an "Additive Manufacturing process in which thermal energy selectively fuses regions of a powder bed".

The heat source is applied, by laser or thermal print, in a powder bed consolidating the material layer by layer, like all other AM techniques, for three-dimensional objects. These processes have an important advantage, that of not requiring support structures as this function is performed by the surrounding unfused powder bed This allows to construct complex geometric structures as after the construction of the piece there will be no support structures to remove. The material used are metal and polymeric powders.

The Powder Bed Fusion process includes different printing techniques that differs for the material used. *Selective Laser Sintering* (SLS) is the most used process for polymers, while D*irect metal laser sintering* (DMLS) and *Selective laser melting* (SLM) for metals.

These processes are complex and expensive compared with other AM technologies, especially for those using metal materials.

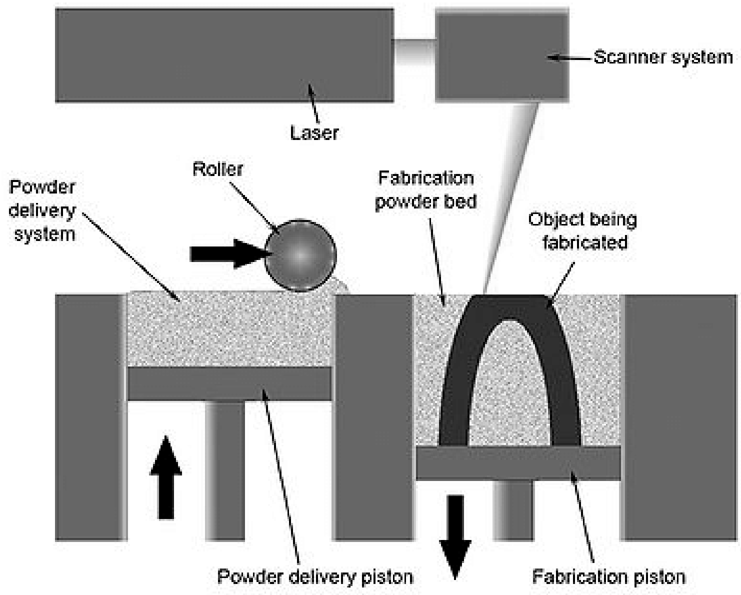


Fig. 10. Powder bed fusion process

Selective Laser Sintering

Selective Laser Sintering (SLS) technology was one of the first additive manufacturing techniques, invented by Carl Deckard in 1984 at the University of Texas.

The build material, polymer powder, before being deposited on the building platform, is heated to a temperature just below the melting point of the material allowing the laser to operate on a non-cold material reducing the likelihood of warping. Once the first layer is spread, the laser fuses together the particles of material according to the digital 3D model. At this point the build platform lowers and the recoating blade deposits a new layer of powder until the part is completed. The unfused material acts as a support for the part under construction eliminating the need for additional structures and allows the slow cooling of the piece, improving its mechanical properties.

At the end of the printing process, the part is extracted and cleaned of excess powder. Unfused material can be recycled for subsequent processing, but as high temperatures degrade it, virgin material must be added. Numerous post-processing activities can be performed to improve the surface finish.

The most common material for SLS is nylon, this lightweight, strong and flexible thermoplastic. It is ideal for both rapid prototyping and manufacturing, used from engineering consumer products to healthcare.

The main benefits from this process are:

- No supports needed
- Recyclable material
- High level of accuracy
- Products with good mechanical properties and complex geometry

The main disadvantages are:

- Significant printer cost
- Skilled operator required
- High power usage
- Finish depends on powder grain size

Direct Metal Laser Sintering and Selective Laser Melting

These two technologies are similar to SLS, the main difference is the material used, DMLS and SLM work on a metal powder rather than on polymers. Furthermore, unlike processes that use a plastic powder, they require support structures to avoid distortions, even though there is residual powder around the piece.

Direct metal laser sintering and Selective laser melting differ in the way of acting on the layer of material, therefore of solidifying it. DMLS heats the powder up to a certain temperature allowing the particles to join at the molecular level, while SLM melts the material using a laser.

The main advantages of these two processes are:

- High level of accuracy
- Parts with complex geometry
- Good mechanical properties

The main drawbacks are:

- Expensive 3D printing technology
- Need support structures
- Skilled operators required
- Relatively slow process

Direct Energy Deposition

Defined as “Additive Manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited”, DED is a complex 3D printing process commonly used to repair or add material to existing components.

A DED printer consists of a nozzle mounted on a multi-axis arm that deposits material, usually in the form of wire or powder, on the surfaces of the object. Then, it will be melted through a laser or an electron beam, allowing it to solidify.

Typically, these kinds of printers have a movable arm that moves around the object, but there are some cases where the opposite occurs, thus the build platform will be movable, while the arm will remain in a fixed position. Mainly metallic materials are used, such as titanium, cobalt and chrome.

The cooling times of the produced part are fast and influence the final grain structure of the deposited material.

The main advantages are:

- Excellent structural properties
- Fast process

The main drawback of this method is the high cost of the machine. In fact, the machine

around $500,000.

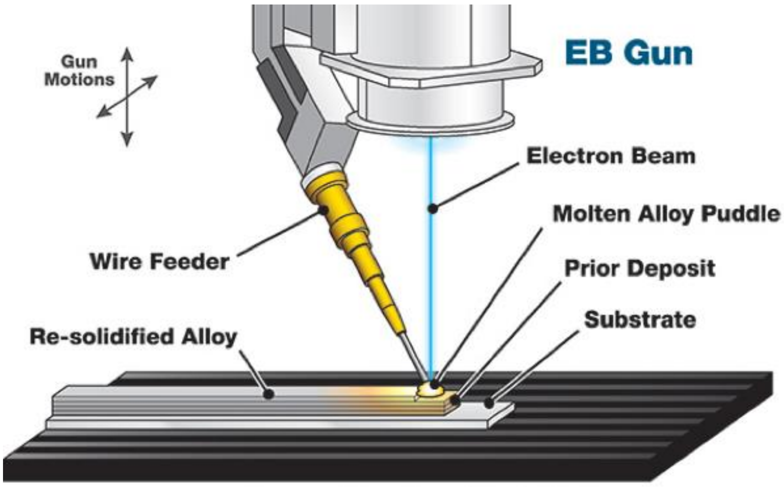


Fig. 11. Direct Energy Deposition

Conclusions

The chapter just illustrated had the objective of describing additive technology from a technical point of view. We have seen what different technologies are currently in use and how they have been classified, but innovation in this field is running fast and this list is set to grow in a short time. Many scholars are working to make improvements to existing technologies and discover new ones, ranging over various fields of application up to what today seems unreachable.

Having delved into the origins, process steps and techniques of 3D printing, we will now turn our attention to the economic aspects of AM.

Chapter 2: AM impact on the production system

Introduction

The use of additive manufacturing technologies in many different industries has increased significantly in recent years, representing a powerful force changing how companies make parts and products. Currently, additive manufacturing allows and facilitates the large-scale production of products that can be individually customized.

Additive manufacturing technologies are opening new opportunities in terms of manufacturing paradigm and manufacturing possibilities. Production times will be substantially reduced, new designs will have a shorter time to market, and customer demand will be met more quickly.

This chapter identifies the implementation benefits and transformation potential of additive manufacturing, highlights the limitations that hinder the transition to a new paradigm that abandons traditional production methods, analyzes the "The economies of One" production model and the differences with economies of scale, and finally explores emerging business models.

AM benefits

The continuous and constant growth of technologies, materials, processes and capabilities has positioned additive manufacturing as the ideal solution for multiple sectors. However, companies are willing to switch to new production processes, abandoning traditional methods, only when these imply a real added value to their products.

Additive manufacturing has a high potential and has numerous advantages that allow companies to respond to customer needs with speed, precision and quality.

The main benefits of additive manufacturing over traditional manufacturing methods will be discussed below.

Complex geometries

Additive manufacturing enables more complex and high performing geometries which are not possible to create with traditional methods, see *fig.12*. These, such as milling, turning or casting do not allow the development of complicated three-dimensional structures or are only possible at disproportionately high costs.

Additive technology allows to create any shape that can be built in a 3D CAD program, giving developers maximum freedom of geometric design. The material is added only where it is needed, allowing material savings and consequently production costs, which unlike traditional production, will not increase with the complexity of the geometry.

AM has strong potential to revolutionize design and manufacturing processes and improve the functionality of parts and products, this supports the creation of products designed for performance rather than manufacturability. AM technologies allow the redesign of products by creating unique pieces that include dozens of sub-components that with traditional technologies are created individually and then assembled, in this way companies are able to create a product of high quality and functionality in less time, also reducing the risk of breakage deriving from the assembly phase. For examples Nasa redesigned an engine fuel injector by reducing the number of components from 115 to 2, obtaining an engine with improved performance. In fact, the redesigned injector was able to fuel an engine that produced 20,000 pounds of thrust of up to 3,300 degrees C while withstanding 1,400 pounds of pressure per square inch.

For sectors such as aeronautics or biomedical, being able to create a finished product with a reduced number of components is very important, this in fact significantly reduces its weight, a crucial element for a component that must be installed on a military aircraft or interior of a patient's body.

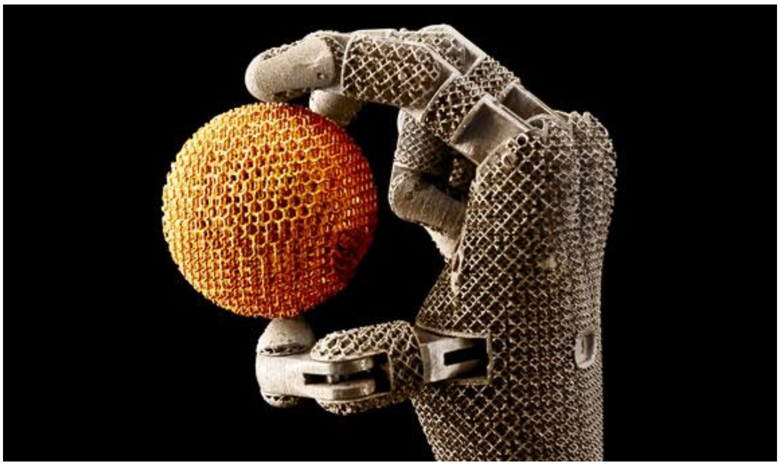


Fig. 12.Complex geometries achievable with AM

Time-to-market

The time to market, defined as the time interval between the conception of a product and its commercialization, is a critical aspect for the success or failure of the launch of a new product and therefore can make the difference in achieving the company objectives set.

AM has the potential to accelerate every part of the product development process, from the idea to the realization of the piece, not requiring time for assembly, tool development, shipping or transportation, thus reducing the time to market from months to days. The idea of brainstorming a project in the morning and printing and sharing a prototype or model in the afternoon is extremely tempting to speed up the innovation process and set the stage for developing a new product.

Thanks to the use of additive technologies for example, an educational laboratory equipment manufacturer can print turbine wax mold models in 18 hours as a single component, in contrast to its traditional 170-hour multi-tool process.

Decentralized manufacturing

The AM allows you to build medium or small production batches without geographical limitations. Using traditional production techniques, this would be unthinkable, in fact in these cases companies are able to maintain good profit margins only by producing large production batches, thus enjoying economies of scale.

AM undermines the idea of traditional centralized production, setting the conditions for decentralized production that allows companies to place themselves in strategic geographic positions closer to the bases of primary consumers. It also enables the speed of delivery and support of new products to consumers, the rapid repair of parts and the reduction of warehouse shelves. The digital files needed for product production can be quickly shared with the team simply by transferring data rather than waiting for shipments. This is particularly interesting if we consider the possibility of producing components or spare parts in remote areas that are difficult to reach in a short time, such as a spaceship. The possibility of producing the parts to be replaced directly in space would drastically reduce the enormous transport costs.

Additive manufacturing realizes and benefits from true just-in-time manufacturing ensuring decentralized manufacturing.

Fig. 13. Decentralized manufacturing

Mass customization

3D printing technology is the cornerstone of a great change in traditional business models, capable of bringing together two opposite concepts of customization and mass production, proposing a production capable of offering customized products to satisfy individual tastes, but which enjoys the low unit costs associated with mass production: Mass customization (*fig.14*). This concept fits perfectly with the need of many customers who would like to have a particular product, different from that of their friend and enriched by a personal touch such as adding their name or changing the color, but not being willing to pay a significant increase in the price.

Traditional production is not able to reap the economic benefits of mass customization. The manual modification of the piece would be very expensive as it would require a significant increase in labor costs, and additional costs related to the change of equipment and the extension of delivery times. All this would result in a significant increase in price, which only a company that refers to a niche market could propose, in fact the mass market would not be willing to pay much more for the customized product than the basic version.

3D printing does not require additional production costs for mass customization, in fact, unlike traditional production, it is not necessary to use different molds or specific tools, simply modify the digital file, an operation that could be performed directly by the customer on the website of the company. The 3D file will automatically update after the changes are made.

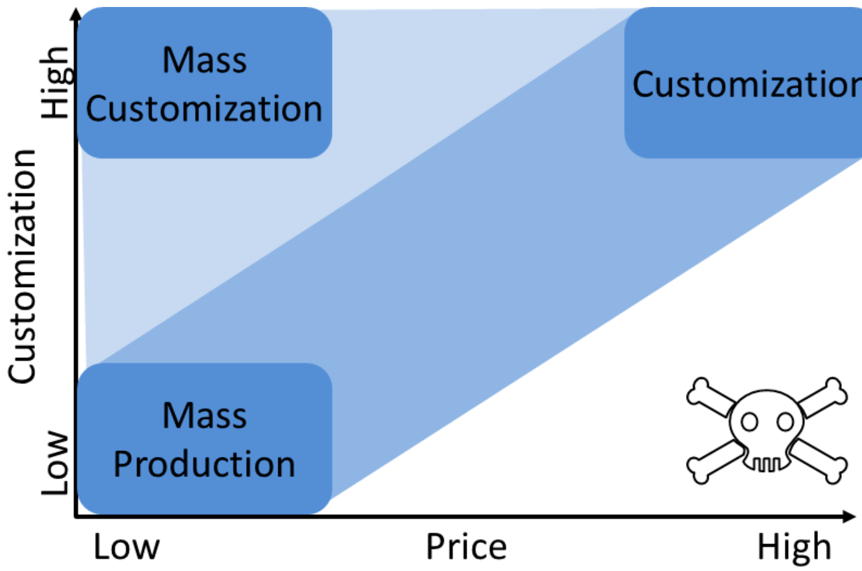


Fig. 14. Mass Customization chart

An example of mass customization is the project promoted by the Normal earphone manufacturer which gives the customer the possibility to customize his 3D printed earphone. Personalization is done in a specific way. The customer needs to download the Normal app, take a picture of his ear and upload it to the network. The company receives a 2d image of the ear but will be able to produce a pair of custom-made earphones in 48 hours, adapted to the size of the ear and comfort preferences.

Fig. 15. 3D printed Normal custom earphones

Eco-friendliness

AM has a lower environmental impact than conventional production, above all thanks to the reduction of the material inside a product. The material is solidified where it is needed, producing much lower production waste than those produced by machining by removing material and alleviating the load of supplying raw materials.

However, totally eliminating the inefficiencies of the process is impossible, small wastes of material persist, such as support material, need for fresh powder, material trapped in the voids and meniscus of liquid resin retained on the surface of the parts. Excess material cannot always be reused, a part will be lost because it cannot be recovered or contaminated.

The selection of materials, the recycling and reuse of waste materials are also important factors for the sustainability of production processes. Under certain circumstances, AM design improvements may present opportunities to replace high-energy materials with low-energy substitutes. For example, using the intelligent AM design, one could replace titanium with a steel powder, this would give less corrosion resistance and less biocompatibility to the part, but would significantly reduce the embodied energy of the part and the resulting carbon footprint of the raw material. .

The AM community is placing greater emphasis on material disposal and recycling. The melting processes of the plastic powder bed produce significant volumes of unusable polyamide material. This unusable powder has generally been treated as a low-quality industrial waste product, but efforts are underway to offer the material to third-party plastic retailers as a clean, recyclable raw material for applications other than laser sintering.

AM barriers

When you think about the adoption of additive manufacturing in your company, you must not only think about the benefits that this would bring in terms of reduction of production costs and added value to the products, but also to some limitations described below. The balance between the benefits and drawbacks of AM will be decisive in deciding whether to adopt additive technologies or remain anchored to conventional production methods.

Cost of machine and materials

The biggest limitation to implementing 3D printers in the enterprise production system is the high purchase price of the machines and the cost of construction materials.

The high cost of AM machines, especially for high-definition ones, can be mainly attributed to the few pieces sold by suppliers who have to recover development costs for production. The spread of additive technology will lead to more pieces to come and therefore to a reduction in prices, in addition the AM sector is experiencing greater competition which should have a favorable impact on product prices for customers. For some years now it has been possible to buy a low-priced 3D printer for home or hobby use, when high mechanical performance and quality are not required.

The high costs of materials make the marginal costs of production higher than traditional technologies. Some materials are very expensive and complex to produce others are artificially inflated just because it is used for additive processing. Manufacturers of AM systems often use warranty clauses or even software lockout to force customers to use only their materials. As with machine prices, material costs will decrease when a competitive market is established and large-scale production economies are realized.

Considering the cost with the same amount of material required, the construction materials for 3D printers are much greater than those used in traditional productions, making evident the convenience in continuing to use the latter by producing in a conventional way. But the key point lies in a comprehensive cost justification for the AM use, considering the reduction of the material used in the entire product life cycle and the added potential benefits that AM could produce. For example, if we consider that building a part with AM costs €1000 compared to the € 500 required to produce it traditionally, the convenience in traditional methods appears clear, but if AM were able to reduce the weight of the piece by 25% and reduce 10-years operating costs of € 5000, then the convenience of one over the other could no longer be so clear. Considering other benefits such as improvement in product function, greater customer satisfaction, lower maintenance costs and reduction in total production costs, the best production alternative might be AM.

Quality obtained

AM can make high quality parts, but the technology is not mature enough to guarantee quality control over an extended production run. This limitation is not present if traditional production technologies are used, in fact the material extrusion processes are able to maintain the internal properties of the piece unaltered after processing, thus obtaining high quality parts for a prolonged production cycle.

This problem limits the spread of AM in the aviation and medical industries, highly regulated sectors, where the qualification of new processes and materials can be time-consuming and very expensive. To be accepted, parts produced with AM must meet the standards of the production solutions currently used, therefore be in line with the standards and regulations governing the level of defects, material properties, traceability and process certification.

This problem also represents a major obstacle to the production of medium batches in sectors where the quality of production is of primary importance and therefore high costs for quality controls should be covered.

To address these issues and regulate the AM industry, ASTM International has since 2009 initiated an international effort to develop specific standards for additive manufacturing. Two primary standards committees have been created: ASTM Committee F42 on Additive Manufacturing and ISO / TC 261 on Additive Manufacturing.

Traditional attitude

"Why change something that works well?". This is the phrase that many manufacturers hold when thinking about the option of making minor or radical changes to the company business. This way of thinking represents a strong obstacle for the spread of AM, especially if it is a question of small companies, fond of conventional methods that have made their company profitable. What is new is often frightening.

Corporate culture is the hardest thing to change, but it can be dangerous, with many examples of market-leading companies that haven't caught the wave of innovation and been cut off from the market. The birth of a new technology in fact opens the doors to new entrants, who manage to gain a slice of the market in a short time, if the incumbents do not keep up with innovation they risk a drop in turnover, if not failure.

For these reasons it is very important to have an open attitude towards new technologies, trying to develop a culture of innovation always looking for new and better ways of doing business.

A new production model: Economies of one

Economies of scale are an important concept for any business in any industry and represent the cost savings i.e. efficient production and competitive advantages that larger companies have over smaller ones.

Companies can achieve economies of scale by increasing production and by lowering costs, in this way the costs are distributed over a greater number of goods, reducing the unit cost of the product and guaranteeing a greater profit margin.

The reduction in unit costs is due to several factors including labor specialization, which increases production volumes, wholesale orders from suppliers and lower capital costs. A further contribution is given by the distribution of internal functions over several units.

Additive manufacturing technology does not allow to exploit the same economies of scale as traditional production as the unit production costs do not decrease as the volumes produced increase: the delivery cost of a 3D printed part will always remain the same regardless of the whether one or 100 are produced. This has severely slowed the adoption of additive manufacturing processes as viable manufacturing tools and explains one of the reasons why AM is still seen as an efficient prototyping tool only.

Since the concept of economies of scale does not meet the characteristics of additive technology, a new business model was born, called "*Economies of One*". The term was defined with the intention of highlighting that, using 3D printing, it is possible to create a batch or even a single piece without incurring fixed costs.

Today additive technology is not a good alternative for large-scale production as it is not able to compete with the cost efficiency guaranteed by economies of scale in traditional production, but in the future things could change. In fact, the rapid acceleration towards strategic automation, the rationalization of workflows and improvements in technologies and materials could allow the diffusion of additive technology as a valid production tool in many sectors.

In a short time, companies will find themselves having to coincide the world of additive with the traditional one, using the two technologies selectively to obtain the maximum benefit from their potential. Traditional methods will be used to produce large batches taking full advantage of the resulting economies of scale, while additive manufacturing can be used for small series of custom parts that would otherwise not be cost-effective. The automotive and aerospace industries would benefit greatly from using hybrid manufacturing processes, as they are used to produce one-off and limited parts alongside large-scale production.

The *Table 1* presents the main differences between economies of scale and economies of one.

	Economies of scale	**Economies of one**
Source of competitive advantage	Low cost, high volume, high variety	End-user customization
Supply chain	Sequential linear handoffs between distributed manufacturers with well-defined roles and responsibilities	Non-linear, localized collaboration with ill-defined roles and responsibilities
Distribution	High volume covers transportation costs	Direct interaction between local consumer/ client and producer
Economic model	Fixed costs + variable costs	Nearly all costs become variable
Design	Simplified designs dictated by manufacturing constraints	Complex and unique designs afford customization
Competition	Well-defined set of competitors	Continuously changing set of competitors

Table 1. Economies of scale vs Economies of one

Sectors of application

3D printing is revolutionizing the industrial world by covering more and more sectors, for some of which until a few years ago the application of these technologies was unthinkable. Engineers, designers, architects, researchers and many other professionals have implemented additive manufacturing techniques taking advantage of reduced production times and costs, along with better design and accuracy. We will see below the main industrial sectors in which AM is used and the wide range of feasible applications.

Aerospace

The aerospace industry was one of the first to adopt 3D printing, representing today one of the most mature sectors and a significant share of the additive manufacturing market. Its use concerns not only prototyping and tooling but also the production of final parts. This sector provides for strict performance standards and the production of lighter but equally resistant complex components is a key factor in reducing costs and the environmental impact due to lower fuel consumption.

The pioneer of the use of AM for the construction of final parts is GE Aviation, which in collaboration with the French company Safran, has produced a LEAP engine inside which there is a very complex 3D printed component.

Fig. 16. 3D printed fuel nozzle

It is a metal fuel nozzle capable of significantly reducing fuel consumption during flight. The LEAP engine, whose first installation took place in 2016 on an Airbus A320 neo aircraft, is now in demand on a global scale.

Airbus and Boing, the two largest companies in the aerospace market, have long since implemented this technology in their productions and today mount various additively built devices on their aircraft.

In 2016 Airbus presented at the Berlin aviation fair "Thor", a 4-meter mini plane made entirely in 3D. Its name stands for “Test of High-tech Objectives in Reality” and is an example of the enormous possibilities that 3D printing may be able to offer in this field.

Fig. 17. "Thor". First 3D printed mini airplane

Additive manufacturing allows the production of several aircraft components, from external coatings to engine components, in a short time and with reduced waste of raw materials. This translates into cheaper aircraft to build but also to use, in fact the reduction in weight implies lower fuel consumption which will benefit both the airline and the environment.

The parts necessary for maintenance can be produced quickly and right where they are needed, without having to wait for the availability of large industrial plants that are often very far away. This feature would be a game changer for aerospace missions where the failed component would be reproduced directly inside the spacecraft and then replaced.

Automotive

The use of 3D printing in the automotive sector is mainly concerned with prototyping and tool production, although lately it is finding space in the other phases such as the production of final parts which seems to mainly concern niche markets such as luxury and racing cars.

Rapid Prototyping has revolutionized the product development process, speeding up what was once a time-consuming and expensive process requiring multiple iterations of a product. This allows designers to turn ideas into compelling Proof-of-Concepts, which are then developed into high-quality prototypes, and ultimately drive products through different validation steps leading to series production. A designer can most effectively present his or her design idea when supported by a scale model showing the shape of a vehicle. These are also often used for aerodynamic testing. SLA and material jetting are used to produce high-detail automotive models.

Fig. 18. 3D printed scale model

Finding spare parts for a vehicle can sometimes be very difficult, 3D printing represents a valid solution to this problem, in fact, thanks to the use of CAD software, the designs of all the parts can be stored in digital format and be produced on customer request. In addition, as regards components that no longer exist like those of vintage cars, the existing parts could be scanned, allowing them to be manufactured on request. Ringbrother reproduced the Cadillac emblem for a custom classic vehicle by 3D printing the shape and casting it in metal.

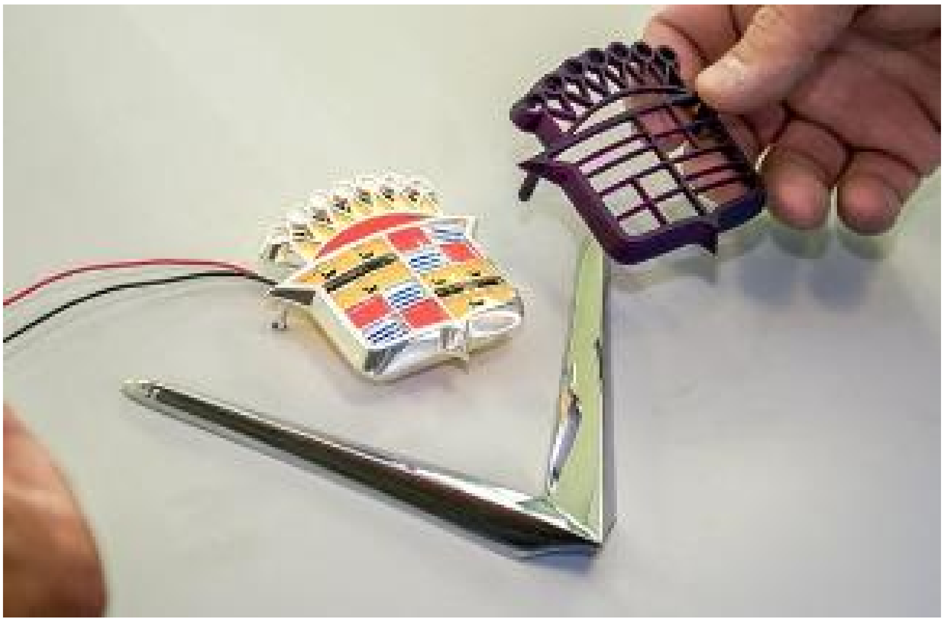


Fig. 19. 3D reproduction of the emblem of a vintage car

The production of cars entirely in 3D is a distant concept, but there are already some very interesting projects that show where this innovation is going.

Medical

3D printing is widely used in the medical sector, able to offer solutions for serious clinical problems. The main fields of application concern orthopedics, personalized surgery and medical and dental devices.

In orthopedics, 3D printing allows the creation of superior quality orthopedic implants, composed of complex mesh structures that allow better bone growth (*fig.20*). It is also possible to create cutting guides that accurately indicate to the surgeon where to intervene during the surgery.

Fig. 20. 3D printed vertebrae

In maxillofacial surgery, 3D printing and digital modeling allow you to align small bone fragments and find the best solution for surgical corrections. The production of pre-surgical 3D models that help to better explain the intervention to the patient or the operating team for its design is also very important.

Another application concerns medical and dental devices such as prostheses, surgical guides, dental restorations and transparent aligners. These will be analyzed in detail in the next chapter.

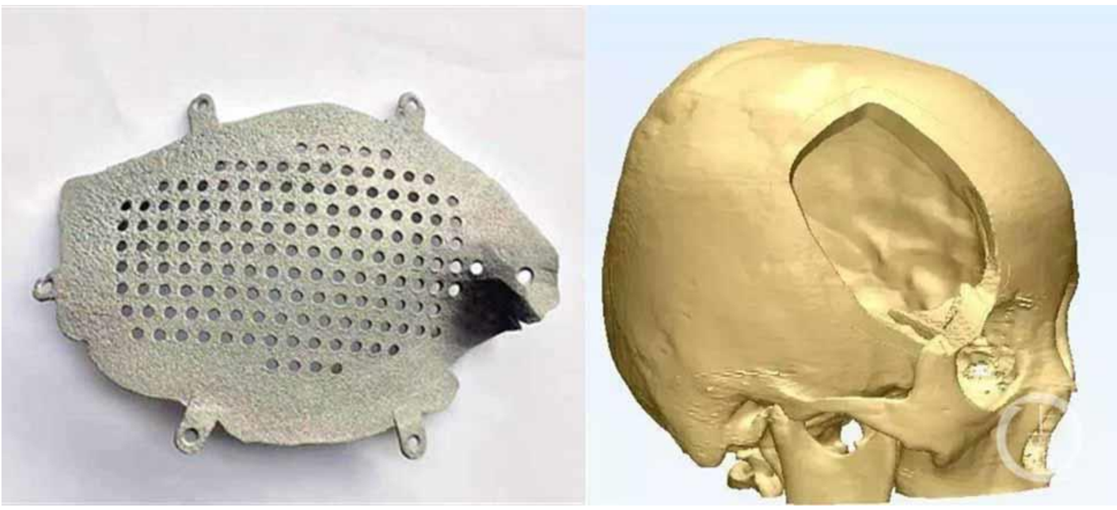


Fig. 21. 3D printed titanium prosthesis

Retail

The retail industry is one of those sectors in closest contact with the consumer. For these reasons it is increasingly important to be able to create the right product for each individual customer. Short delivery times and a high degree of customization are two very important criteria that determine the competitiveness of a company in this sector, and AM can offer excellent results in this direction.

Among the various retail sectors, the clothing sector requires high customization, consumers prefer a unique product rather than a mass-approved one. Many companies are moving towards online manufacturing by transporting the customer's request directly to a digital platform and guaranteeing immediate service and product customization. For example, Nike allows customers to configure their custom shoe directly online, choosing from the many variables present in the configurator.

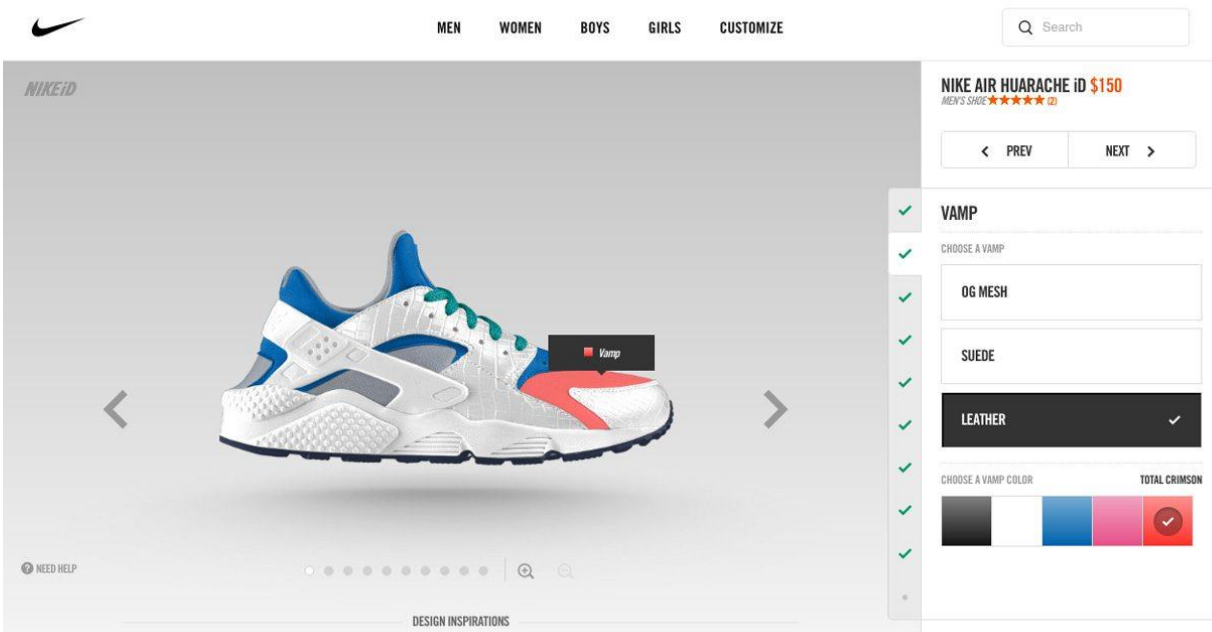


Fig. 22. Nike online configurator for footwear

Chapter 3: AM diffusion

Introduction

Today, Additive Manufacturing represents a technological innovation that has the potential to radically change the manufacturing sector. A new way of producing, in which the use of molds and the removal of material are replaced by the addition of material layer by layer and above all only where necessary, seems to have a prosperous future ahead of it. As described in the previous chapter, this technology, in which speed and efficiency are the keywords, is representing a strong turning point for many areas. The innovation of 3D printing is increasingly attracting the world's largest companies as it is considered the industrial revolution of these times and therefore a great opportunity for those who will know how to ride it but a threat for those who will assume an attitude of distrust. Its history began in the 1980s, began to spread in 2000 and grows steadily until today it has earned the title of *disruptive innovation.* This chapter describes the nature of additive technology and analyzes its development and diffusion through the analysis of s-curves and the hype effect.

A disruptive innovation

Disruptive Innovation is a term coined by Clayton Christensen in 1997 in his *article "*The Innovator's Dilemma" identifying a technology whose application drastically affects the way a market works. Care must be taken not to confuse this term with disruptive Technology, in fact, while the latter refers to the technology itself, disruptive innovation revolutionizes the entire structure of the sector. Technological innovations can be classified differently depending on the context to which it refers. Considering the impact on the industry Christensen identifies the innovation as Sustaining or Disruptive. While the former does not lead to major changes in competitors' positions and market shares, the latter does involve significant ones, representing a powerful way to expand and develop emerging markets at the expense of current ones.

The change in technology and therefore the affirmation of a new paradigm is a critical aspect for *Incumbents*. In fact, new realities albeit small and just founded, the *New entrants*, but with good knowledge of the new technology could enter the market and be able to compete with them. The paradigm shift can represent an opportunity or a great threat. The existing companies that will not evolve could be wiped out of the market, there are not a few cases of industry leaders that have not been able to seize the opportunities offered by the advent of a new technology and have been made out of business.

New companies will enter the sector by investing directly in new technologies, while existing ones will have to invest in change not only the production process but also the skills of employees, providing them with training courses. For incumbents, adapting to innovation will be even more difficult the further they move away from traditional technologies and skills. Another factor that greatly influences the fate of the incumbents concerns their response to innovation, assuming a behavior of inertia both in understanding the new situation (*cognitive inertia*) and in reacting effectively to it (*action inertia*) involves serious repercussions on their competitiveness. Cognitive inertia is very dangerous and resides in what is commonly called corporate culture. This phenomenon represents a great obstacle to change and is due to a series of cognitive traps inherent in the managers mind. The first trap is to look with extreme confidence at the sources of competitive advantage and the strategies that have ensured business success in the past. In fact, their use could be unsuitable and therefore ineffective for maintaining one's market position within the new paradigm. A second trap is the reluctance to abandon an old technology that has caused the company huge investments and whose value would not be recovered. This reasoning is incorrect and tends to underestimate the cost of staying anchored to the old paradigm. In fact, assets related to old technology usually represent a sunk cost only in the short term since, in the medium to long term, they will have to be maintained and then replaced. The last trap is linked to a lack of foresight, and to maintaining the status quo. Incumbents can be deceived by the low performance shown up to that point by the new technology by convincing themselves of the greater efficiency of traditional methods. They do not take into account, however, that while the latter have already reached their limit, the new technology is in a phase of strong development and innovation, and its sudden growth risks catching them unprepared, so they will respond to change when it is too late. .

The main reason that allows AM to fall into this category is that it represents a completely new way of producing, and whose affirmation could completely replace the traditional method of subtractive production, which in this case represents the old technology.

S-curves

The best way to understand the development and diffusion phases of a technology in the market is to define the trend over time of some reference indicators such as performance or sales, tracing the so-called s-curves. As can be seen from fig. 19 below, it is possible to define three main phases in the life of a technology: incubation, diffusion and maturity. In the first phase there is a slow advancement of both performance and sales, values that instead grow significantly in the next phase. The last phase represents a mature technology in which performances have reached the technological limit and sales have saturated the market. Knowing the life stage of technology is very important for companies as it will guide them in deciding the best strategies to undertake. During the incubation phase, it will be very important to invest in research to fine-tune the new technology and be ready for the demand that will soon grow significantly. In the next phase, adoption sales referring to consumers who buy the product for the first time dominate, so companies will have to convince them of its usefulness. While in the last phase, the technology is mature and widely adopted, so it will be necessary to focus on the product replacement rate, convincing consumers to replace the old product with a new one. This phase will be very delicate, companies must prepare for a possible new technology change that will revolutionize again the market.

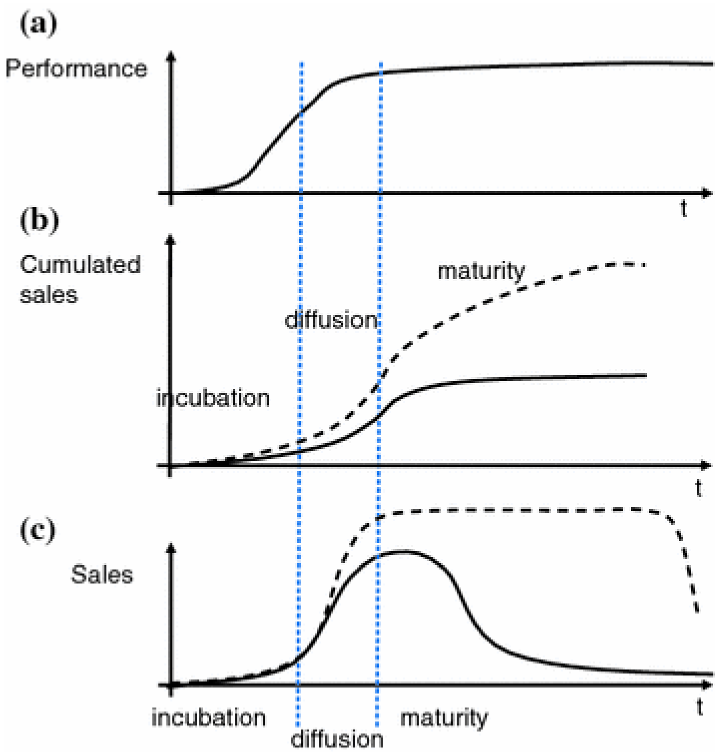


Fig. 23. Performance and diffusion s-curves

Additive manufacturing up to about 2000 experienced an incubation phase followed by strong growth especially in the last decade. The switch from one phase to another is essentially due to a greater knowledge of the new technology, the strong commitment to the study of the processes and materials used has led to improvements in performance and greater diffusion. In fact, in the last decade the level of adoption of 3D printing has grown significantly and involves more and more sectors. Future forecasts indicate a good increase in sales in the short term, identifying the permanence in an intermediate phase for a few more years. Continuous studies into usable materials will allow greater diffusion in sectors that already use this technology, just think of the effect that the availability of certified biocompatible materials in the medical industry will have. Furthermore, the improvement of existing technologies will make it possible to adopt AM in sectors currently excluded. Having entered its maturity stage, the technology will have already explored most of its technological potential and improvements will involve further reductions in production times. 3D printer manufacturers will have to take care of the replacement aspect, convincing customers to buy a new model using excellent marketing strategies.
In the meantime, it will be within the same curve that the insertion of a new technology will be placed ready to take over from the previous one in order to allow continuous technological progress. Innovation is constantly evolving, and it is for this reason that although 3D printing is a relatively recent technology, some are already talking about 4D printing. although apparently science fiction, this new technology could soon become reality already partially reality. The focus will shift to the use of intelligent materials capable of changing, adapting and responding to external stimuli with naturalness.

Hype cycle

As suggested by Wohlers report it is useful to distinguish the diffusion of 3D printers used for rapid prototyping, now in a phase of end diffusion, from those of rapid manufacturing used for the construction of final parts, which are instead in the initial phase of incubation. Their diffusion is very limited compared to the machines used for prototyping and many studies on processes and materials are underway. In this regard, it is useful to introduce the concept of hyper-expectations that often characterizes the first phase of a technology's life.
The consulting company Garter, famous for its analysis of the expectations placed on new technologies, offers a valid tool that can help consumers understand how real the expectations placed on 3D printing are.

As *fig.24* shows, five different phases make up the hype Cycle: innovation trigger, peak of inflated expectations, through of disillusionment, slope of enlightenment and plateau of productivity. In the first phase, *Innovation Trigger*, we witness the appearance of a product on the market with potentialities not yet fully known, the expectations and the enthusiasm associated with it begin to rise until they become unrealistic reaching the *Peak of Inflated Expectations*. Immediately after, a decreasing phase follows, which can be linked to the loss of interest in the, due to the failure to fulfill excessive expectations (*Through of Disillusionment)*. The technology will mature slowly and realistic applications will emerge creating new interest among consumers, who, having become aware of the real potential of the technology, will be more inclined to make investments (*Slope of Enlightenment*). This time we can see a positive and stable return thanks to the maturity reached by the technology, thus passing through the final stage of *Plateau of Productivity.*

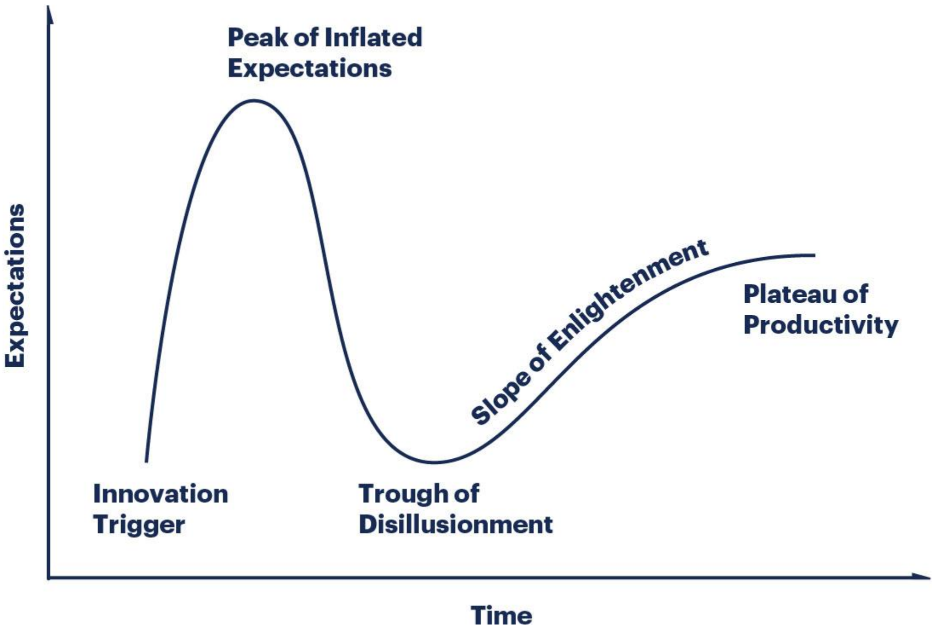


Fig. 24. Hype Cycle phases

Focusing on AM, fig. 21 shows the 2019 Gartner hype cycle which provides us with important insights into 3D printing forecasts. It is possible to see how different AM sectors find different positioning within the curve, for example "3D printing of Consumable Personal Product" being one of the latest applications in which AM is addressing, is in the innovation trigger phase, while the "3D Printing in Automotive ", which we know to be one of the most popular areas of 3D printers for rapid prototyping, is in the slope of enlightenment phase. It is interesting to note that the “3D Printing in Retail” is in the phase of Peak of Inflated expectations. The reasons for this positioning are to be found in the search for personalization of today's customer who wants to differentiate themselves from others. Some companies are creating strong expectations that exceed what is really achievable, in fact at the moment it is not possible to fulfill all the customer requests in retail, which otherwise would lead to a lack of cost effectiveness.

Data of strong interest for the research conducted concerns the positioning of "3D printing of Dental Devices". As we will see in the next chapters, the application of 3D printing in the dental sector is very widespread allowing artisans to print several products using both resins and metals. 3D printers are now an integral part of production among dental technicians but will soon bring strong changes in the balance of this sector, spreading also in dental offices.

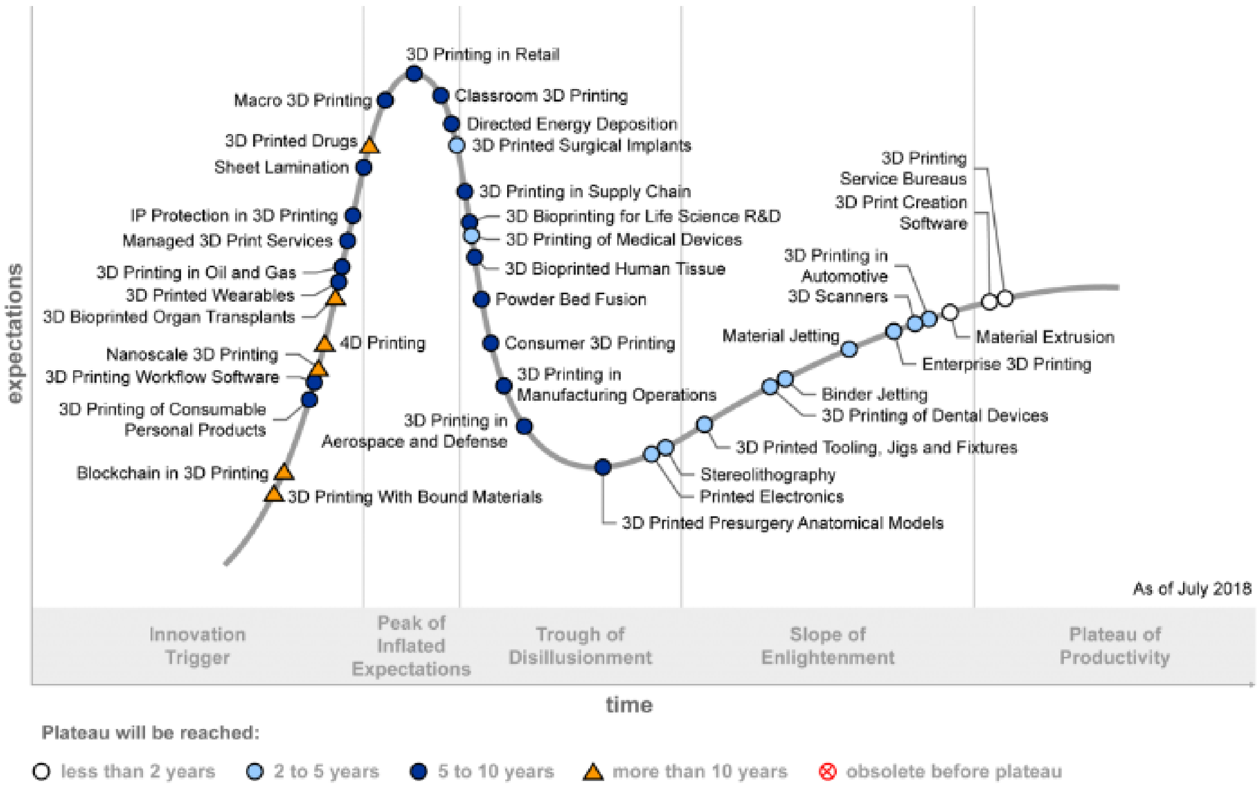


Fig. 25. Gartner Hype Cycle for 3D printing technology

Industry growth

After analyzing additive manufacturing from the point of view of technological innovation, the aspects related to its growth will be examined in detail in the next paragraphs, paying particular attention to the worldwide revenues from the sales of printers and related services, the division of the market among the different application sectors, major competitors and geographic areas. Then, the forecasts for AM will be presented, relating not only to market values but also to future projects already mentioned.

Revenues from AM

AM development is monitored annually by Wohlers reports, which provide detailed information on technologies, materials, economic features and more about 3D printing innovation. According to the latest publication, the additive manufacturing industry in 2019 grew by 21.2% reaching the market value of 12 billion dollars. This increase is slightly lower than in 2018, but it is still a very high figure.

Referring to the *fig.26* below, taken from data from the Wohlers report 2019, global revenues in recent years have experienced an impressive growth, just think that if in 2014 the revenues from sales were equal to $4.103 billion, in 2018 they more than doubled reaching $9.8 billion. The annual values shown in the graph consider both revenues from sales of printing machines, materials, lasers and software, but also those derived from the offer of services related to AM. These are generating a huge turnover that even exceeds the direct sale of products for production, they include revenues generated from parts produced on AM systems by service providers and system manufacturers, system maintenance contracts, training, seminars, conferences, expositions, advertising, publications, contract research, and consulting services.

In 2018, more than 1.42 million 3D printers were sold, which is estimated to reach 8.04 million units by 2027. These data clearly show excellent predictions for the future of 3D printing, which certainly goes to recent initiatives that have shed light on what it can do.

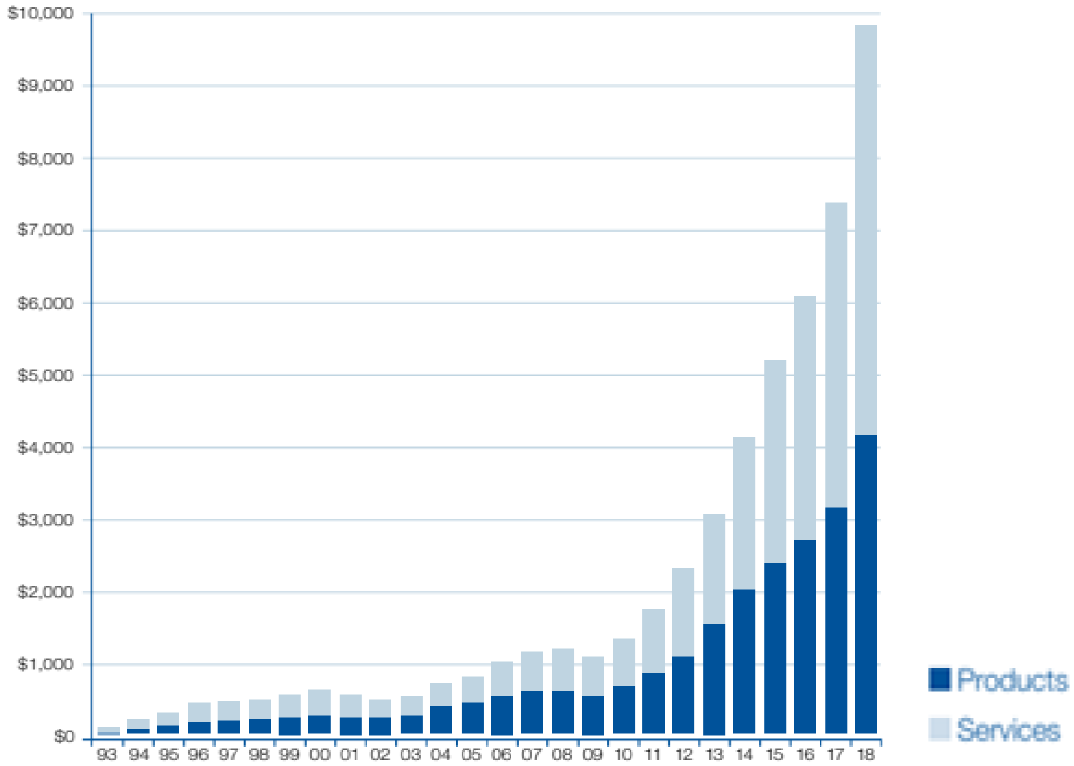


Fig. 26. Global 3D printing revenues (in million $)

A noteworthy figure concerns the sale of metal AM systems which in the last years have recorded an impressive growth in sales, with a jump of about 80% between 2016 and 2017, passing from 983 to 1.768 systems sold. The size of the global metal 3D printing market was valued at $ 772.1 million in 2019 and is projected to grow at a compound annual growth rate (CAGR) of 27.8% from 2020 to 2027. The great production flexibility, waste reduction and cost effectiveness play a key role in the growth of metal 3D printing in the market, attracting more and more manufacturers in the sector.

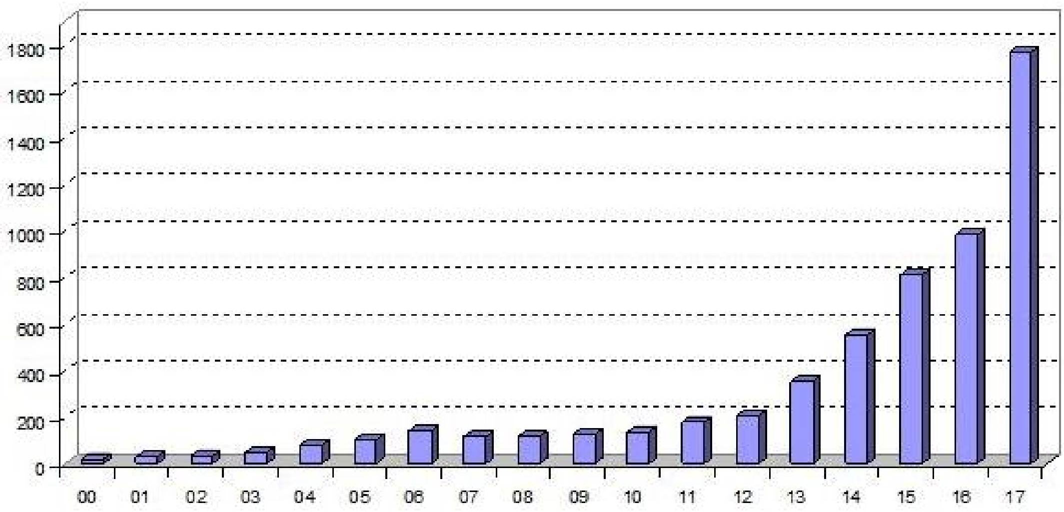


Fig. 27. 80% rise in metal AM system sales between 2016-2017

Industry Sectors

Additive manufacturing finds space in many industrial sectors that are moving towards digitization. As seen in the previous chapter, some of them are in the diffusion phase, while others have just entered this world and are experiencing its potential. For manufacturing applications, aerospace and medical/dental companies are leading the way, while the automotive industry, which has largely implemented AM for prototyping, is moving towards new solutions that see the use of these technologies also for the production of finished parts, the reduction in the prices of printers and materials will play a key role.

The pie chart shown below, describes the sectoral distribution of AM for the year 2017, according to data provided by Wohler Associates. The analysis was conducted by investigating a sample made up of manufacturers of industrial AM systems and service providers from all over the world, who were asked which industrial sectors they supplied and the resulting revenues. The largest shares are awarded to the following sectors: Industrial/business machines, Aerospace, Motor vehicles, Consumer products/electronics and medical/dental. Considering these 5 dominant sectors and making a comparison with the data of previous years, we can see a growth trend in the adoption of AM for Aerospace and Industrial/business machines and a decrease for the other three.

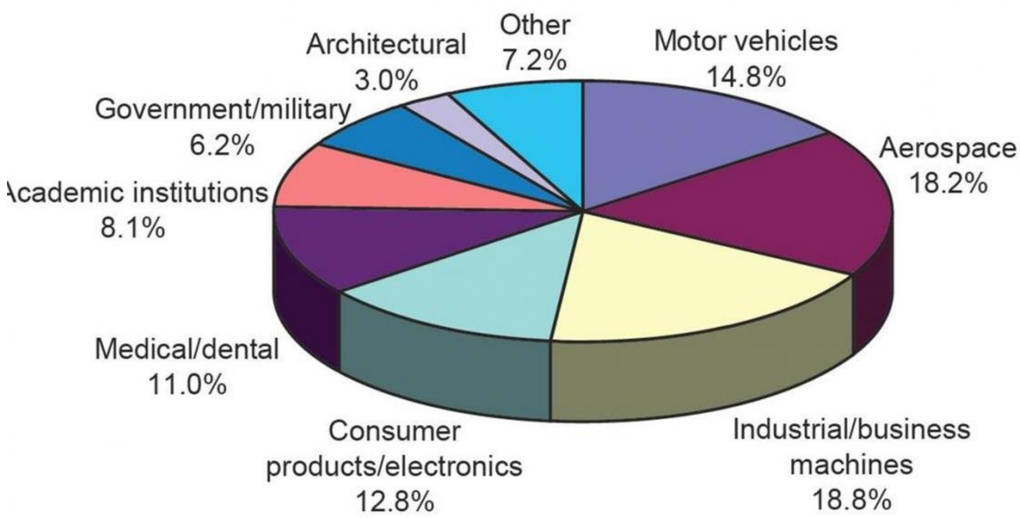


Fig. 28. Sectors of AM application-Wohlers Report 2017

Market shares

The market share is a percentage indicator used to synthetically evaluate the competitive position of companies on the market, relating the sales of the individual company with those of the entire market. The pie chart shows the market percentages for the year 2017 according to the Wohlers report. The Stratasys company has the largest market share of 35.6% and has represented with the largest installed base since 2003. This is followed by the well-known 3D system, whose founder, Charles Hull, was responsible for the discovery of additive manufacturing and Envisiontec. Lately many companies and startups are entering the market causing an increase in competition, this could lead to a rapid change in market percentages and represent a risk for the larger and more established companies that are already seeing their market share decrease.

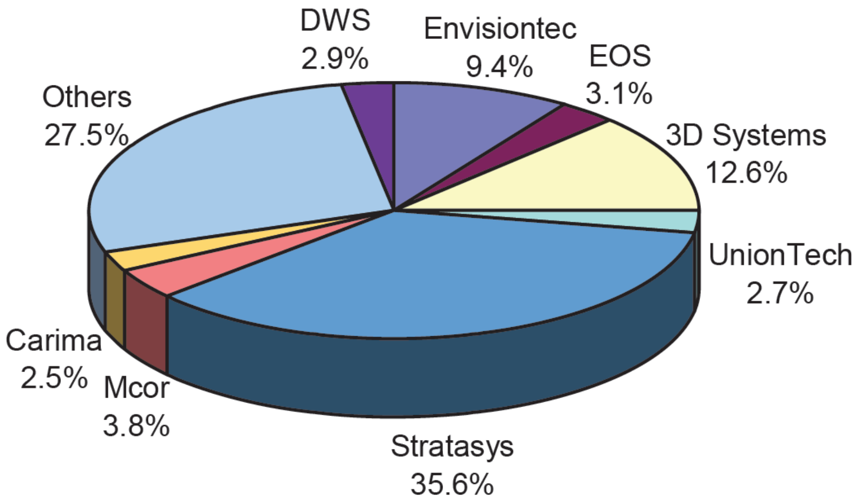


Fig. 29. AM market shares

Due to the growing competition due to the entry of new companies and startups in the AM sector, Stratasys and 3D System have suffered a slight decline in market share going from 51.9% and 16.5% respectively in 2015 to 35.6% and 12.7% in 2017, but they continue to be the largest in the world of AM today. In addition to be pioneer in the sector and having contributed to the 3D printing revolution since its inception, their success is due to the strategies they have undertaken. Both companies invest a good percentage of their turnover in R&D to remain competitive in a rapidly growing sector. Stratasys aims to spread to new application sectors, adopting a market strategy that allows it to grow by not attacking competitors on the traditional prototyping market, but by placing itself first on virgin markets such as design and fashion.

Stratasys was born in America but in 2012 it merged with Objet giving birth to the Stratasys Ltd. company registered in Israel. This move had strong resonance in the geographical distribution of the production and sale of 3D systems, in fact America, which since the birth of this technology has represented the largest production country, has suffered a sharp decline from 60.9% (2013) to 17, 2% (2014) also being overtaken by Israel which in 2014 reached 51.9% of market share. The data for the year 2017 still see changes, in fact Europe has grown considerably, going from 19.3% in 2013 to 32.7%, Israel drops to 35.8% while the US and Asia divide the rest part.

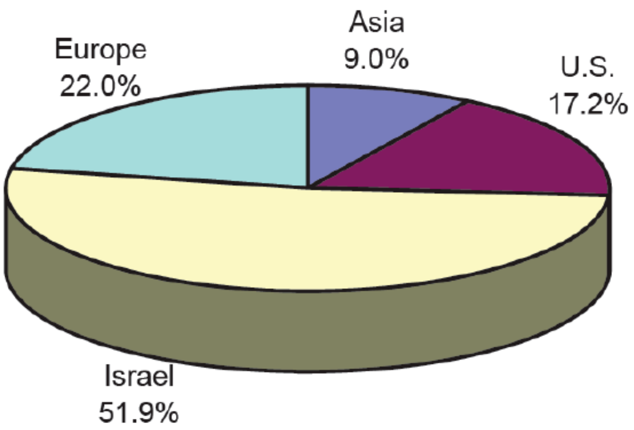


Fig. 30. Geographical distribution of 3D system production and distribution in 2014 (after Stratasys merging)

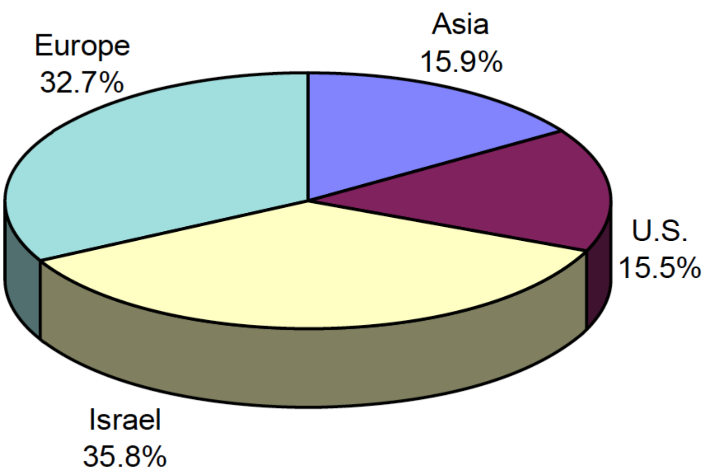


Fig. 31. Geographical distribution of 3D system production and distribution in 2017

Market forecast

The Wohlers Report 2019 forecasts for 2020 amount to $ 15.8 billion for all AM products and services worldwide, which will rise to $ 23.9 billion in 2022 and $ 35.6 billion in 2024, leaving assume strong growth in 3D printing.
3DHUBS in its "3D printing trends 2020" report provides a detailed analysis of the current dimensions and future predictions for 3D printing over a 5-year time frame, combining data from the publications of ten reliable industry analysts. It is important to note that the historic market size (2014-2018) was calculated by averaging the values reported by Wohlers Associates, EY and SmarTech , while the forecasted one from the combination of data reported by all ten analysts.
As shown by the graph, the 2019 global market value was estimated at $ 12.1 billion, recording a growth of 25% compared to 2014. An average annual growth of 24% has been estimated for the next 5 years (CAGR) which will bring the value of the AM industry to $35 billion and a doubling in size approximately every 3 years.
The data provided is an estimate between the assessments of the various analysts, since these are forecasts and not certain data, it is appropriate to consider some margins of variability. In this regard, two extreme cases of *Compound Annual Growth Rate* values were generated. The worst case predicts a CAGR of 20% and a market value of $24 billion in 2024, while the best case a CAGR of 28% and a market of $45 billion.
Different factors can affect these numbers, both internal to the AM industry such as the adoption rate for mass production, the reduction of total costs, material or external developments such as customer requests and the general economic climate.

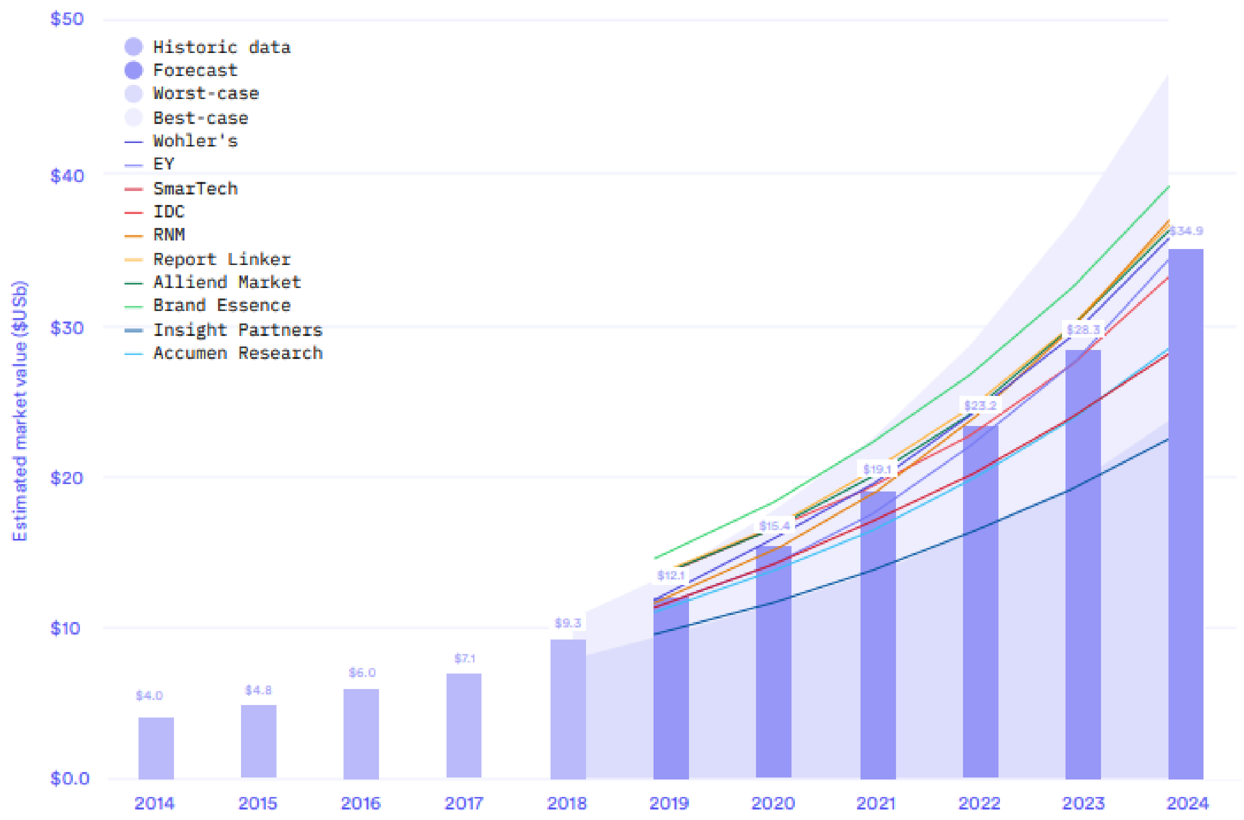


Fig. 32. 3D printing Market Forecast-3DHUBS

The 3DHUBS article reports two important market research conducted in 2019 by companies EY and Ultimaker, questioning a sample of companies in the field of additive manufacturing. The first study, carried out on 900 companies, shows that 65% use 3D printing and 18% are considering a possible investment. Comparing these percentages with the values recorded in 2016, respectively of 24% and 12%, there is a strong increase in the diffusion of this technology. Additionally, 18% of respondents say they use AM in series production. This data is very important, it testifies to the increase in the adoption of 3D printing for final parts production and therefore the opening to other uses in addition to prototyping. At this rate, the use of AM for series productions is expected to be adopted by the first majority (50% of all companies) by 2022, which means a significant increase in production volumes and market size.

The analysis performed by Ultimaker highlights a different result, in fact out of 2500 companies interviewed, 67% know what is referred to with "3D printing" and "AM", while only 35% use additive technologies, a figure that is growing if it compares with 10% in 2014 but much lower than in the first study. Both surveys found evidence that supports the accelerated adoption rate of 3D printing, but also plenty of room for growth, which is likely to have a very positive effect on the market in the coming years.

Chapter 4: The dental sector

Introduction

The dental sector is one of the most promising for the application of Additive Manufacturing technologies, in fact compared to traditional applications, it offers high customization to products, a focal point for a mainly one-off custom manufacturing industry like this.

The AM allows the creation of dental elements with high precision based on patient data acquired by a 3D scanner and then processed with a CAD software. It finds application for the production of elaborate dental crowns, bridges, orthodontic appliances, but also of removable prostheses, aligners, surgical guides and models for treatment planning.

This technology has the potential to act as a catalyst for radical changes in dental care around the world, increasing access to quality digital care and redefining the role of dental clinics and laboratories in the future.

The chapter will explore the key aspects of the application of AM in the dental sector, starting from some economic data to give an idea of the size of this market and a forecast of future trends. The discussion of the digitization process will follow, highlighting the main differences between the traditional and digital workflow. The following paragraphs deal with the applications of additive manufacturing in the dental industry and the potential changes in the dentist-dental technician relationship. In fact, the diffusion of 3D printing in the studio could represent a strong threat to the laboratories as their customers would start to produce independently the devices they need. This topic was investigated by carrying out interviews with these professionals. The last section will discuss the benefits of additive manufacturing in the dental industry and the current limitations that hinder its rapid spread.

Economic features and future trends

QY Research, a Chinese consulting and market research firm, estimated in its latest report "Global Dental 3D printing Market Analysis, 2014-2025" that the dental 3D printing market will reach $ 930 million by the end of 2025. This value is impressive and when compared with the $ 260 million of 2018 it makes us understand even more how fast this sector is growing and will continue to grow. Furthermore, according to the company, the Dental 3D printing market has grown by 17% in the last 6 years alone.

Such a growth is due to the fact that many companies are focusing on the additive revolution in response to the need to find new technologies that allow for cost reduction and better quality of dental products. The key benefit of additive technology is with no doubts its unique customization ability, but there is no lack of negative aspects, such as the high cost of treatment and maintenance of 3D printing machines, which could play an adverse role in the spread of the additive industry in the dental sector.

3D printing technology is expected to provide 60% of all dental manufacturing needs by 2025. The SmarTech Publishing report highlights that the value of dental applications produced with additive technologies will amount to $ 3.5 billion in 2021 with 22.7% of the revenue deriving from the realization of PFM crown substructures, followed by dental models and surgical guides.

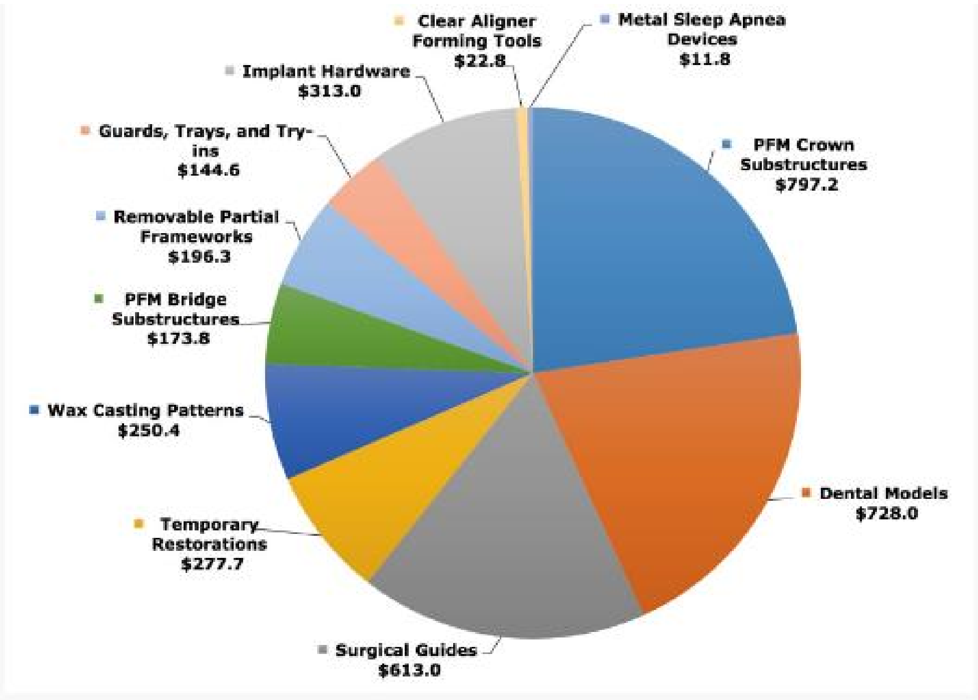


Fig. 33. SmarTech: Total projected dental application market value, by type, 2021 ($US millions)

Printing is done in both the dentist's office and labs and brings a new level of speed and ease to old procedures. This represents a huge opportunity for dentists to avoid the intermediation of the dental technician by in-house printing orthodontic products. For example, the case of a broken tooth or to be replaced could be particularly fast and simple, the dentist will be able to acquire the digital image of the damaged tooth via an intraoral scanner, design the repair in

CAD and start the 3D printing of the new tooth. Likewise, the dentists could use the 3D printer to create dental implants, prostheses, dental models, drill guides, or surgical tools needed to complete certain procedures.

All this could prove to be an excellent business opportunity for dentists, but a serious damage for dental technicians who could lose substantial revenues or even see their professional figure disappear.

From tradition to digitalization

The phenomenon of digitalization, which for most represents the future of dentistry, is significantly transforming dental practices and dental laboratories all over the world. The traditional workflow is completely revolutionized through the introduction of new digital devices, such as digital scanner, CAD/CAM, digital radiography, 3D printer and photography, which optimize activities such as impression taking, treatment planning, design and production, increasing the companies productivity and competitiveness. The adoption of digital can also represent a marketing strategy, the customer will in fact have the perception of an avant-garde facility that focuses heavily on the comfort of his patients.

Fig. 34. Intraoral scanner and 3D printing devices

The Digital Workflow

Dental practices are varied and different, but despite this the digital workflow is the same and consists of three main phases: Scan, Design, and finally Manufacture.

Fig. 35. Dental digital workflow

Scan

The *Scanning* phase allows to digitally obtain the patient's dental impressions through the use of an Intraoral Scanner. This device is equipped with a handpiece, which contains some integrated scanning devices that capture images of the patient's mouth. Once active, the device produces a light beam which, projected onto the surface of the teeth, deforms, detecting their exact positioning. The images obtained are processed by a software that will create a 3D model that the dentist can use as a reference for the treatment to be performed. Despite being a sophisticated device, its use is not complex, just insert the scanner tip into the patient's mouth and move it along the dental arches to identify its position, even the most difficult angles will be captured. The doctor follows the scanning process on the screen and in case the system detects points where the scan was not performed correctly, they can easily remedy by passing the scanner over that part again. The resulting file can be exported in .STL format, the universal language of all CAD/CAM (Computer Aid Design /Computer Aid Manufacturing) software used to produce dental devices.

The intraoral scanner has many advantages over the classic method of taking impressions. It is a less invasive method for the patient, with shorter detection times and which allows to immediately detect the quality of the impression obtained. In addition, it allows for fast data transfer and communication with the dental lab.

Fig. 36. Dental impression via Intraoral Scanner

The traditional method involves the use of an arch-shaped support filled with a special soft paste which, once placed in the patient's mouth, will harden taking the shape of the teeth and gums. This step is extremely annoying for the patient, who often feels a sensation of suffocation and vomiting. The impression obtained will represent the negative reproduction of the dental arch, subsequently cast and finished by the dental technician to obtain the dental model that the doctor can study to design the work to be performed.

Fig. 37. Classic method: negative and positive representation of the oral cavity

The biggest obstacle to the full diffusion of the 3D scanner is certainly represented by the rather high price (around 20,000 euros), whose investment can only be repaid if the machine is inserted in daily use within the dental practice.

Design

After scanning, the detected anatomical data are imported into a CAD software, Computer Aid Design, to plan the treatment and *Design* the restoration. This will be followed by the export of an .STL file for production using subtractive or additive methodologies as *fig.38* shows.

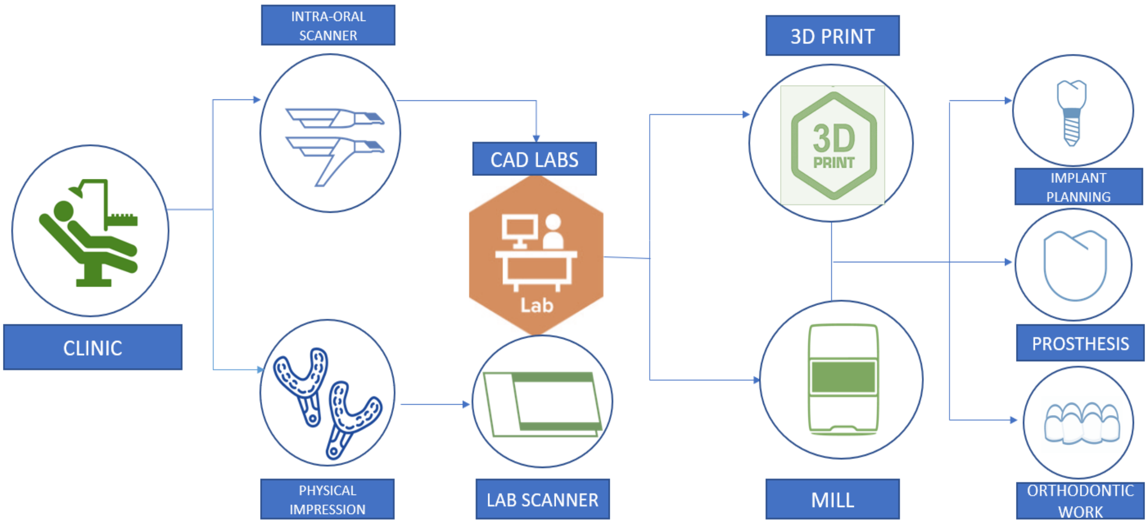


Fig. 38. CAD/CAM Workflow

Manufacture

The last phase, concerning the physical realization of the product, can be performed with both Additive and Subtractive production techniques, in which the digital file will be sent respectively to a 3D printer or a numerically controlled milling machine.

The manufacturing phase has always been the responsibility of dental technicians, highly specialized artisans who return the finished product to the dentist, ready for installation on the patient. While milling machines are more common in dental labs and can offer very limited use in dental practices, 3D printing opens the door to in-office manufacturing, allowing dentists to create a wide range of products including dental models, surgical guides, transparent prostheses and aligners thus avoiding the intermediation of a dental technician.

Subtractive Manufacturing works by removing material, i.e. starting from a raw block it returns the object with the desired shape. The dental sector mainly uses a numerically controlled *Milling machine* to sculpt various raw materials up to the creation of prosthetic restorations. The machine is controlled by an integrated electronic device for coordinating the actions, which after reading the CAD file, provides the machine with information on the tools and functions to be used processed by the CAM software. Once the processing parameters have been set, the operator loads the machine with the raw material and starts processing. The extrusion process takes place gradually, first a large diameter tool is used to remove the more peripheral material, in this way a coarse shape will be obtained which will then be refined in detail with the use of a smaller cutter. Post-production processes will follow for finishing, cleaning and, if necessary, sintering the piece.

The milling machines differ in several characteristics including the number of free axes, a very important aspect for making specific productions. 3, 4 and 5 axis milling machines are available. In 3-axis milling machines, the working tool can only move linearly, i.e. along the x, y and z axes, while 5-axis milling machines also allow rotations. Milling machine with multiple axes of freedom provide higher quality and allow the machining of more complex geometries as they can reach even the most difficult to remove parts.

Fig. 39. Milling machine for dental applications

These machines are very expensive and are generally used in dental laboratories that have specialized figures for the management and control of production operations.

Although it is a very complex machine, there are simplified models on the market whose purchase would be an interesting investment also for the dental practice. This would allow the *Chairside*, the production in-office of specific components that can be immediately applied to the patient. For example, in the event of a fracture of a temporary restoration, the dentist can immediately reproduce it and deliver it to the customer, eliminating the logistical time related to the intervention of the dental technician.

Additive Manufacturing is an innovative method that nowadays finds various applications in the Dental sector. Digital scanning and subsequent design processing via CAD software provide the input for the 3D printer. Once the .STL file has been inserted, the machine will start production by depositing layer by layer until the required part is obtained. Prominent technologies in this industry are Stereolithography (SLA) generally used for aligners fabrication, and Direct Metal Laser Sintering (DMLS), which is capable of high-quality metal dental crowns and appliance frames. To these is added the Selective Laser Melting (SLM), an additive technique belonging to the Powder Bed Fusion category that is well suited to the complex needs of the dental sector.

AM dental applications

3D printing in the dental sector is in constant growth and development and is already widely used in various applications both in the laboratory and in the office as *fig.40* describes, bringing advantages in terms of cost and time. The main uses concern the production of dental models, clear aligners, surgical guides and temporary crowns.

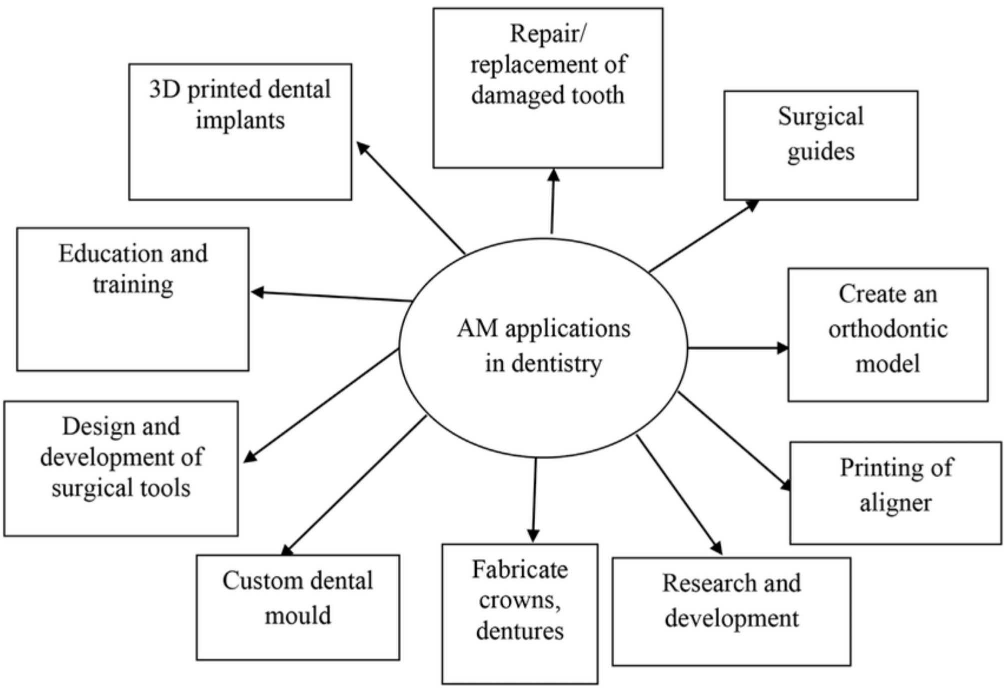


Fig. 40. Major additive manufacturing applications in Dentistry

Dental models are three-dimensional reproduction of the patient's oral anatomy used for planning surgery, to verify that implants, crowns and aligners fit correctly before proceeding with the carving or as educational tools in university courses of dentistry. The printing of these elements is simple and inexpensive, as being not intended for oral use, the models can be built with inexpensive and non-biocompatible resins.

Fig. 41. Dental models

Clear aligners are orthodontic devices used to adjust teeth in cases of moderate misalignment. Not effective in patients with severe crowding, for which it is necessary to intervene with the installation of conventional braces.

The first transparent aligner was Invisalign, launched in 2000 by the American company Align Technology. At first, orthodontists were against the adoption of this product as it was considered unreliable, but the growing popularity of the product forced them to change their mind.

The treatment requires the digital acquisition of the patient's teeth, this can be done quickly using an intraoral scanner or, in the case of a traditional impression, with a desktop scanner that develops the 3D model from the plaster structure. The aligners are modeled using CAD-CAM software and finally printed with the Stereolithography technique, i.e. by polymerizing successive layers of photosensitive liquid resin through a laser.

The aligners exert pressure on the teeth, causing small displacements of the order of 0.25-0.33 mm, so often multiple devices will be required for the treatment of a single case.

Fig. 42. Clear Aligner

Surgical guides are the latest advancement in dental implant technology and enable dentists to perform processing safely and efficiently. This instrument exactly reproduces the intraoral surface to be treated and helps the surgeon to drill the implants into the bone with very high precision. The operation times are reduced and also the trauma for the patient who will have a faster recovery time. The realization of a surgical guide follows the standard stages of additive manufacturing, therefore scan the dental impression, design with CAD software and finally print the piece using a light-curing resin.

Fig. 43. Surgical Guide

The D*ental crown* is a prosthesis created to protect and completely cover a damaged tooth or a dental implant, ensuring the patient both the functionality of chewing and the restoration of aesthetics.

Due to the lack of certified biocompatible material that can be used permanently within the oral cavity, additive manufacturing only allows for the creation of temporary crowns, i.e. ones that can be used for a short period of time, lower than 30 days. Their use is of fundamental importance to cover the time span necessary for the creation and installation of a definitive crown.

Fig. 44. Dental Crowns for temporary installation

Workflow between Lab and Practice

With the traditional workflow, the practice takes the patient's impression and sends it to a dental lab that creates the required models, restorations or other items, which the lab then sends back to the practice for treatment.

The advent of digitalization upsets the balance of traditional workflow, giving dentists the opportunity to develop new skills previously assigned only to dental technicians. The scanning, design and manufacturing steps can alternate between laboratory and dental practice, depending on the complexity of the case, the tools available in a practice, and other conditions.

For example, the digital scan can take place in a dental office using an intraoral scanner or it can be carried out by the laboratory, which receiving a traditional plaster impression can scan it with a desktop scanner obtaining the digital file.

An equipped with 3D scanners can decide to design models, prostheses or other elements internally through CAD software or otherwise entrust the design to a laboratory.

Finally, as far as manufacturing is concerned, a dentist can invest in a 3D printer that will allow him to internally produce simple devices such as surgical guides and rely on a laboratory for the realization of more complex parts.

Another combination could be that in which the dental technician offers the CAD design service, leaving the 3D production in the hands of the dentist to whom he will have sent the file ready to be printed.

The spread of AM in the dental sector brings substantial changes in the traditional relationship between dental practices and laboratories, if for the former this can be seen positively, for the latter it can represent a threat. In fact, if on the one hand dentists would have the freedom to internalize one or more phases according to the clinical case to be treated, optimizing time and costs, on the other hand, dental technicians would use a gradual reduction of orders as their customers would become new "competitors".

According to the last SmarTech Analysis report, dental laboratories should not feel threatened by the spread of AM as a possible cause of their exit from the market, but rather review their business model adapting it to the new needs of their customers.

As dentists move towards the implementation of 3D printers in their doctors' offices, the laboratories of the future could provide design and support services for the production of efficient and effective dental devices thus becoming facilitators of in-office 3D printing.

The next paragraph describes the results of interviews conducted with dental technicians in order to identify the development of 3D technology in their laboratories and draw more conclusions about the future of the dental technician-dentist relationship.

Benefits and limitations of AM in dental sector

Additive manufacturing in the dental industry offers important advantages in terms of productivity, costs, customization and delivery times, resulting in a viable production technology for this sector. The main benefits found are:

1. Cost and time savings

One of the most evident advantages of using AM in dental applications is certainly the saving of time and costs. Unlike traditional techniques in which each product is processed individually, 3D printing allows the simultaneous production of multiple dental devices by exploiting the maximum capacity of the construction platform. In particular, with a DLP production method, the printing time does not vary according to the number of parts to be produced because the system allows to cure an entire layer at the same time. This makes the process very cost effective compared to traditional methods.

3D printing is an automatic process that greatly reduces the intervention of the technician in charge of tool setting, process control and machinery maintenance, further lowering production times and costs of the final devices. Thanks to the automaticity of the production process that does not require particular technical construction skills, dentists can independently produce simple devices such as surgical templates or transparent aligners, eliminating supply times from suppliers and ensuring short delivery times to the patient.

2. Flexible production

3D printing allows for flexible production that plays a fundamental role in the adoption of this technology in the dental sector. Many printers are equipped with a cartridge refill system that allows you to easily change the resin tank, guaranteeing the dentist the possibility of producing dental devices of different materials with the same machine, promptly responding to the specific needs of the case to be treated.

3. High accuracy

3D printing allows the creation of more complex and accurate geometries than traditional subtractive methods, this is very important in the dental sector where the production of very accurate devices is required, which best fit the dental structure of each individual. In this sector we work with very small tolerance margins, of the order of microns. It often happens that the devices created, once tried in the patient's mouth, are found to be non-compliant and need several remodeling before obtaining a perfect fit. 3D printing is able to overcome this problem, being able to reach higher levels of accuracy and dimensional precision.

Many researches demonstrate the high quality of dental devices produced with AM and the superiority of these technologies over traditional ones, especially in the treatment of very small elements such as dental crowns. This does not mean that traditional methods are not able to create excellent quality restorations, but being a manual work the result will strongly depend on the skills of the operator. In general, AM provides excellent quality in much shorter times because it avoids intermediate remodeling.

Being a technology not yet mature and in continuous improvement, there are some disadvantages in terms of available materials, learning curve and regulations that can limit its spread in the dental industry.

1. Biocompatible materials

The major obstacle to the spread of AM is represented by the materials and legislative limits present on dental resins.

Being a medical industry, it is necessary that the materials used respect specific conditions of biocompatibility to ensure a favorable interaction between the foreign body and the host structure. The European legislation identifies in the Council Directive 93/42/EEC 4 risk classes of medical devices based on the invasiveness of the device and the duration of contact between the parts:

- Class I: Low-risk devices
- Class IIa: Medium-risk devices
- Class IIb: Medium to high risk devices
- Class III: High-risk devices

Table 2 shows the European rules specific for each class and the position of different dental applications.

Medical devices belonging to the medium, medium-high and high-risk classes must be certified by a National Body that ensures compliance with existing European regulations. As for the dental devices that can be made with AM, the crowns are identified as long-term invasive devices (Class IIa) therefore the construction resins used must be certified.

Although a lot of research is underway and some companies seem to have found compliant materials, there is currently no certified biocompatible resin that can be used in the long run. For this reason, it is not possible to create permanent restorations, but only temporary crowns that do not exceed the contact time limit of 30 days. Due to this limitation, many industry specialists believe that additive manufacturing cannot completely replace traditional technology that is able to guarantee long-term proven quality. As you can easily guess, this represents a major obstacle to the rapid growth of AM in the dental sector.

	Legislation rules	**Dental applications**
Class I	- Non-Invasive Devices - Invasive devices for transient use - All invasive devices with respect to body orifices, other than surgically invasive devices and which are not intended for connection to an active medical device or which are intended for connection to an active medical device	- Dental impression materials - Handheld mirror for dentistry - Dental patient chairs - Dental curing light
Class IIa	- All non-invasive devices intended for channeling or storing blood, body liquids or tissues, liquids or gases for the purpose of eventual infusion, administration or introduction into the body - All non-invasive devices that may be connected to an Active medical device - All non-invasive devices intended for modifying the biological or chemical composition of blood if the treatment consists of filtration, centrifugation or exchange of gas or heat - All invasive devices intended for short term use with respect to body orifices, other than surgically invasive devices and which are not intended for connection to an active medical device or which are intended for connection to an active medical device in Class I - All invasive devices with respect to body orifices, other than surgically invasive devices, intended for connection to an active medical device in Class IIa or a	- Orthodontic wires - Fixed dental prostheses - Bridges and crowns - Dental alloys, ceramics and polymers - X-ray films

	higher class - All surgically invasive devices intended for short term use - All implantable devices and long-term surgically invasive devices to be placed in the teeth - All active therapeutic devices intended to administer or exchange energy - All active devices intended to administer and/or remove medicines, body liquids or other substances to or from the body - Devices specifically intended for recording of X-ray diagnostic images	
Class IIb	- All non-invasive devices intended for modifying the biological or chemical composition of blood, other body liquids or other liquids intended for infusion into the body - All invasive devices intended for long term use with respect to body orifices, other than surgically invasive devices and which are not intended for connection to an active medical device or which are intended for connection to an active medical device in Class I - All implantable devices and long-term surgically invasive devices - Active devices intended to emit ionizing radiation and intended for diagnostic and therapeutic interventional radiology	- Denture disinfecting products - Invasive dental equipment
Class III	- Surgically invasive devices intended for transient use, specifically to control, diagnose, monitor or correct a defect of the heart or of the central circulatory system through direct contact with these parts of the body or for use in direct contact with the central nervous system - All surgically invasive devices intended for short term intended to have a biological effect or to be wholly or mainly absorbed - All devices manufactured utilizing animal tissues or derivatives rendered nonviable	- Antibiotic bone cement - Maxillo-facial implants

Table 2.European legislation specific for each class and the example in dental industry

2. Legislation

Dental additive manufacturing is not currently regulated by specific European standards. Dental devices printed with AM fall into the category "made-to-measure device" defined by Council Directive 93/42 / EEC as "any device specifically made in accordance with the written prescription of a duly qualified doctor who provides, under his responsibility, characteristics specific designs and is intended for the exclusive use of a particular patient”. In this sense, a custom-made device does not require any certification from the notified body, so the responsibility for correct manufacturing lies entirely with the device manufacturer.

The lack of regulations and the total responsibility of the manufactured products discourages dentists from adopting 3D printing for fear of running into unpleasant situations.

3. Use of CAD software

The difficulty of use in the additive manufacturing process lies not so much in the use of the printer, this in fact provides a completely automatic process, but rather in the programming of the 3D model through a CAD software. While dental technicians are more familiar with the use of this tool as many have already converted to digitalization of processes, dentists are in great difficulty as they have not received any such education and should try their hand at it or take training courses.

A solution to this problem would be the possibility of outsourcing the CAD processing to third parties, in this case the dental technicians, and having the file sent ready to be printed.

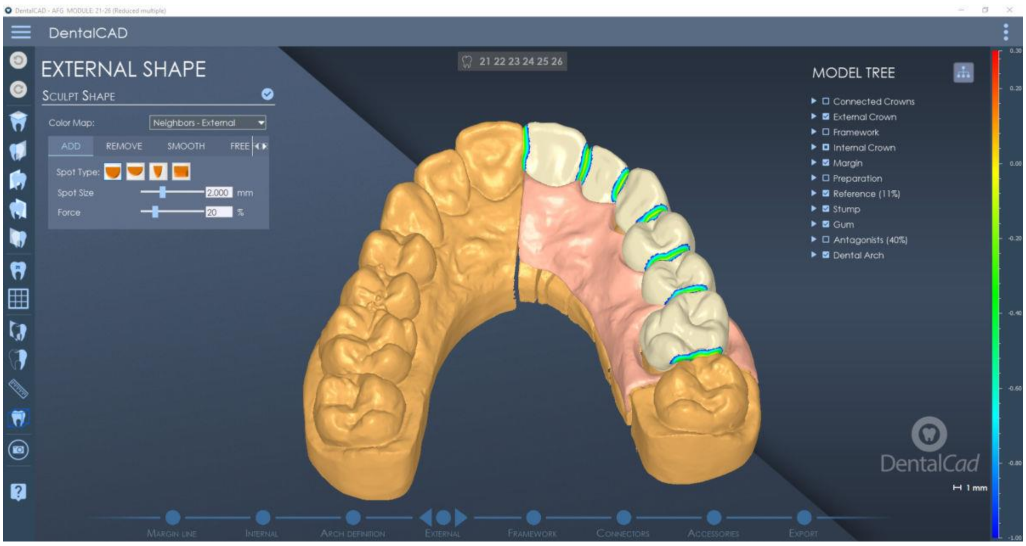


Fig. 45. Dental CAD/CAM software

Chapter 5: AM adoption in dental practices

Introduction

After providing a general overview on dental Additive Manufacturing, this chapter aims to closely examine a sample of dentists, submitting them a detailed questionnaire, to draw important conclusions about the future of additive technologies in this sector. The answers obtained were analyzed and then compared with a study previously done on the Turin area. Finally, the last section was dedicated to interviews with dental technicians who contributed to obtaining a more complete image.

Questionnaire submission

The first phase of the analysis concerns the creation of a questionnaire and the definition of a specific sample to be examined.

The questionnaire, reported in Appendix A, aims to investigate the level of digitization of dental practices, with particular attention to additive technologies. As we have seen, the adoption of a 3D printer by a dental office cannot be separated from the purchase of an intraoral or desktop scanner that allows doctors to obtain a digital image on which to model the final project to be printed. For this reason, a section within the questionnaire is dedicated to the adoption of scanners and one to that of 3D printers. Only those who already have the first device will be asked if they actually use a printer.

The next step concerns the creation of a database of dental practices in the province of Palermo, from which a reference sample comprising 110 contacts was randomly extracted. The database was created from data received from the virgilio.it website.

The target population was contacted by telephone in order to present the ongoing research work and ask for their participation. To those who had provided their availability by sharing their email address, a link was sent to access the survey accompanied by a cover letter signed by the thesis supervisor, prof. Luigi Benfratello. The *Table 3* shows the trend of the call activity, highlighting the different behaviors that have occurred. Of the 110 numbers that were called only 78 answered, despite having made several attempts on different days and times. 19

telephone numbers were found to be non-existent and 13 did not answer. The dentists who showed interest and provided their email address were 41, but only 31 actually took part in the questionnaire. The Adjusted response rate, calculated on the basis of the 78 dentists actually contacted, was 39.7%.

	Absolute frequency	***Relative frequency (%)***
Inexistent phone number	19	17,3%
Missed call	13	11,8%
Not interested	37	33,6%
Email collected	41	37,3%
Total sample	*110*	*100%*
Total dental offices contacted	78	70,9%
Survey responses	31	39,7%
Adjusted response rate	**39,7%**	

Table 3. Some figures about the survey

Analysis of the answers

The survey is made of 3 main sections, the first focuses on the sample characteristics, collecting information about the dental offices. The first question asks about the name of the dentist or the dental office in order to identify which of the contacted offices responded. Thanks to this, another round of calls could be made to solicit those who had not yet participated.

The question 2 asks how many implantology and fixed prosthesis operations are performed on average weekly to understand if and how often, the offices execute practices that may require the implementation of scanners and additive technologies. Many restorations could justify the investment in expensive in-office production machinery. 77.4% of dental offices carry out less than 5 restorations, and only 22.6% more than 5.

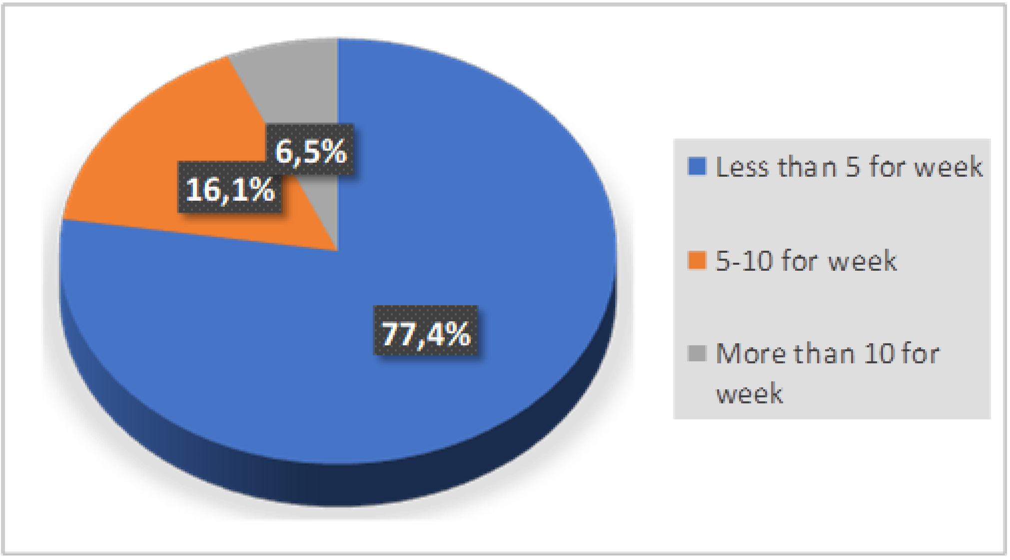


Fig. 46. Question 2: On average, how many implantology and fixed prostheses surgery are carried out in your practice?

The questions 3, 4 and 5 collect information on the age of the dentists working in the practice, as it is more likely that younger dentists, many already born in the digital age, are more inclined to adopt new technologies. The older ones, on the other hand, being accustomed to working traditionally for many years, may be reluctant to experiment with alternative productions such as AM. It appears that in case of only one doctor operating in the office, the age is over 45 for 66,7% while only 13,3% is under 25, resulting in an average age of 49. In case of multiple doctors, the fourth question asks to indicate the age of the first 5 operating in the clinic. The average age is of nearly 41 years and almost all offices have one or more under 25 doctor, in most cases supported by older colleagues.

The second section, dedicated to the adoption of digital scanners, begins with question 6. The answers collected will help us understand the current level of digitalization in dental practices, the propensity to introduce new technologies and investigate the reasons for non-purchases. To begin with, dentists are asked if they use a scanner and, if so, what type it is. 41,9% of the dentists interviewed said they use the digital dispositive, among them all use the intraoral one. This result is very interesting, as it testifies to a strong interest in the digitization of processes and the possible opening to additive technologies.

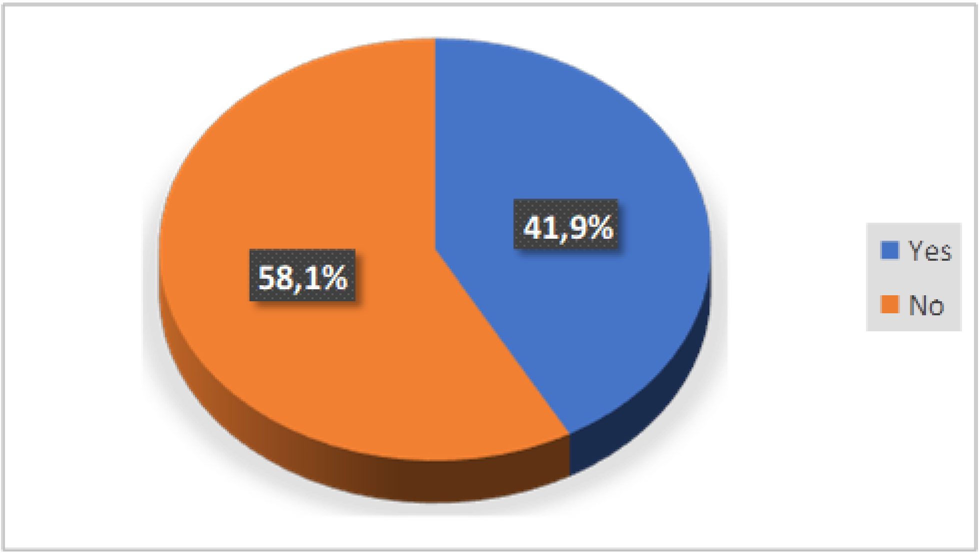


Fig. 47. Question 6: Is at least one intraoral or desktop scanner used in the practice?

From the answers obtained to question 8, it appears that most of the investments, about 77%, took place in the last four years, therefore the diffusion of this device is very recent.

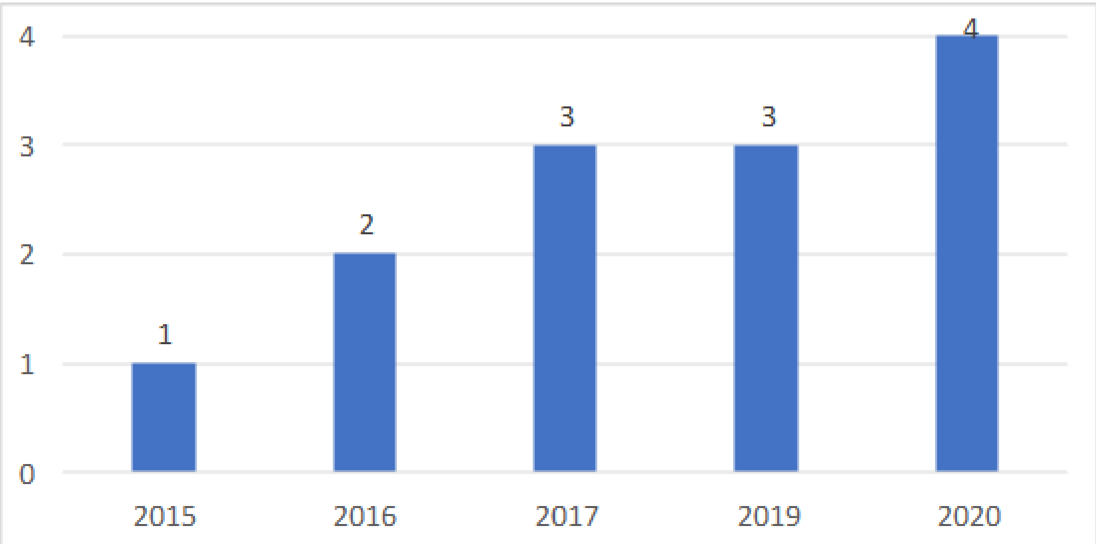


Fig. 48.Question 8: In what year was the first investment in a scanner carried out?

The last question submitted to users of intraoral scanners concerns the benefits it has brought. These mainly concern speed and simplification of the dental impression acquisition process, good quality of the digital format obtained and greater comfort for the patient. In fact, the traditional method used to acquire dental impressions is very annoying and often causes an unpleasant feeling of vomiting.

The reasons for non-compliance with the technology are investigated in question 10, where non-adopters are asked what their degree of agreement is with some phrases designed to highlight what could be the main disadvantages of the device.

The reason many dentists seem to agree is that the price is too high in relation to the benefits. In fact, the purchase of a scanner involves a high initial investment, which could be efficient only if balanced by a high number of practices performed daily. On the other hand, the traditional method, even if it does not allow to enjoy the benefits of the scanner, allows to collect the patient's dental impression with a common dental sponge, implying a very low initial cost.

The general disagreement found in the sentences "It is still an immature technology" and "It will soon become an obsolete technology" highlights a sense of confidence in the future of this technology on the part of dentists. Furthermore, there is no strong evidence relating to learning difficulties in using the device. The answers gathered weigh down the hypothesis of non-adhesion due to the too high price and suggest that a strong reduction could lead many to experiment with the use of a scanner in their dental office.

There seems to be no strong attachment to traditional methodologies, apart from a few interviewees who think there is no reason to change the old for the new. This bodes well for openness to new technologies and the possible spread of additive technologies.

Finally, many seem to have received offers to buy a scanner, suggesting that almost everyone has heard of digital scanners and that the manufacturers are promoting their products by encouraging dentists to buy.

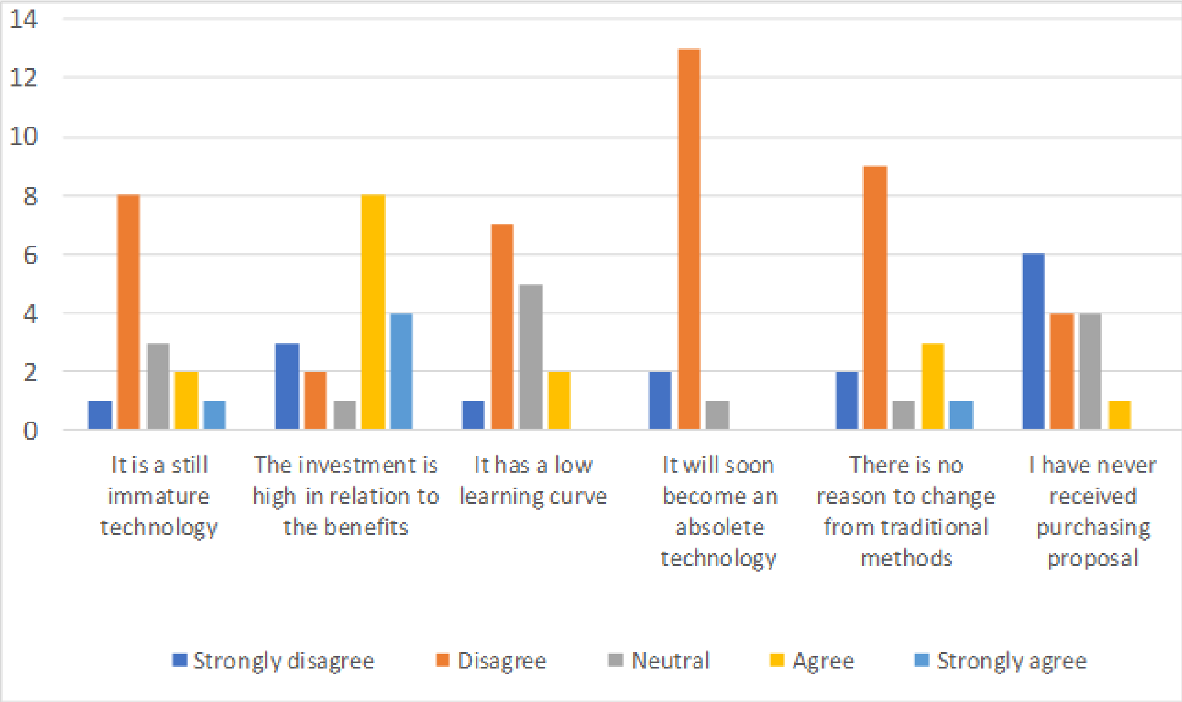


Fig. 49.Question 10: Please indicate the reasons why you did not invest in this technology

Promising data on the increase in scanner diffusion are provided by *fig.50*, which reports that 35,3% of dentists have planned an investment within 5 years. On the other hand, 58,8% of them seem to have no plans to buy an intraoral or desktop scanner in the next few years.

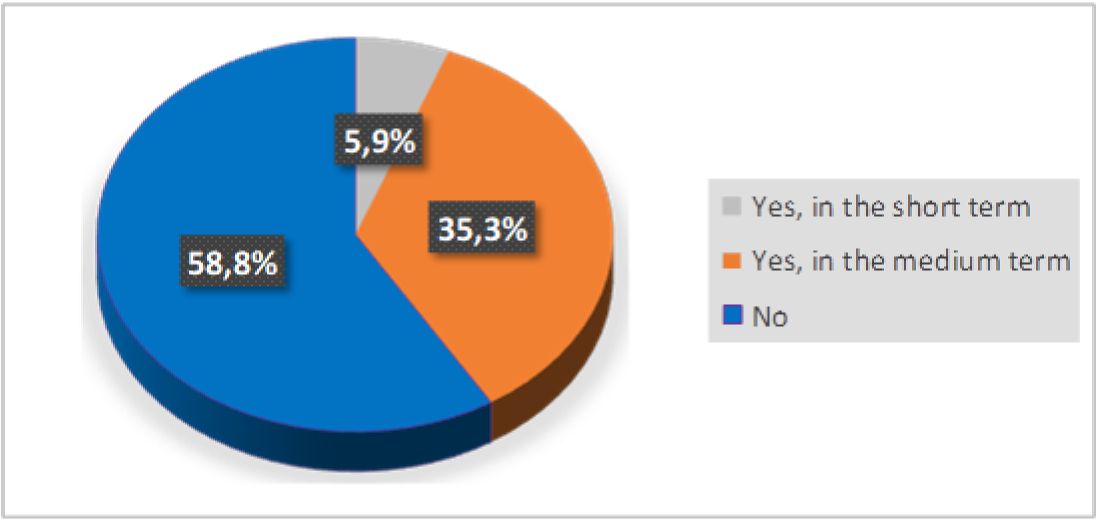


Fig. 50.Question 11: Have you already planned future investments in Intraoral or Desktop scanner?

The last two questions asked of dentists who said they did not use a scanner concern Additive Technologies. More than a quarter of respondents think that in the future they will use a 3D printer in their dental practice, 11,1% think they will never do so and the majority are unable to express themselves clearly on the possibility of a future adoption.

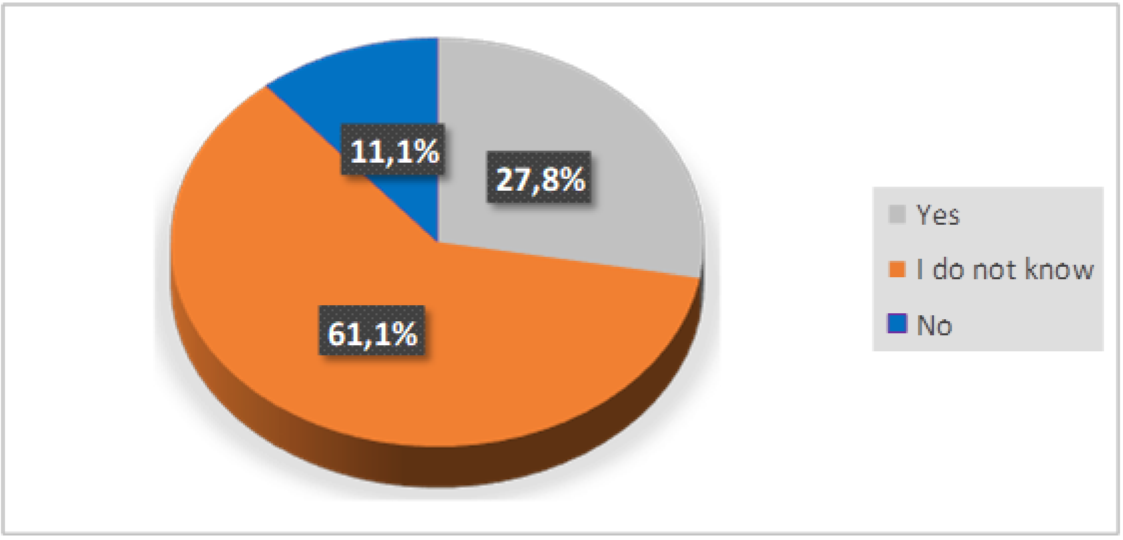


Fig. 51.Question 12: Do you think you will use a 3D printer in your office?

The next question aims to collect the opinions of dentists on the benefits and disadvantages that the introduction of a 3D printer in the office would bring, therefore the possibility of internally creating the parts necessary for the work to be carried out on different patients.

The main advantage that emerges from the comments released is the speed in obtaining prosthetic products and therefore the shortening of delivery times.

Many are those who dwell more on the disadvantages, citing for example higher costs, lower product quality than what the trusted dental technician would be able to provide, reduction of time to devote to "real" dentist work or the need to hire additional employees , i.e. a dental technician, who deals with developing the prostheses directly in the office. Someone drastically writes: "For these treatments there is another figure: Dental Technician".

The last part of the questionnaire is proposed to intraoral scanner adopters. These dentists have already invested in digitization and may be more likely to adopt 3D printers than those who have not yet. As a first question, it was asked if they use additive technologies, among the 13 scanner adopters only one answered positively.

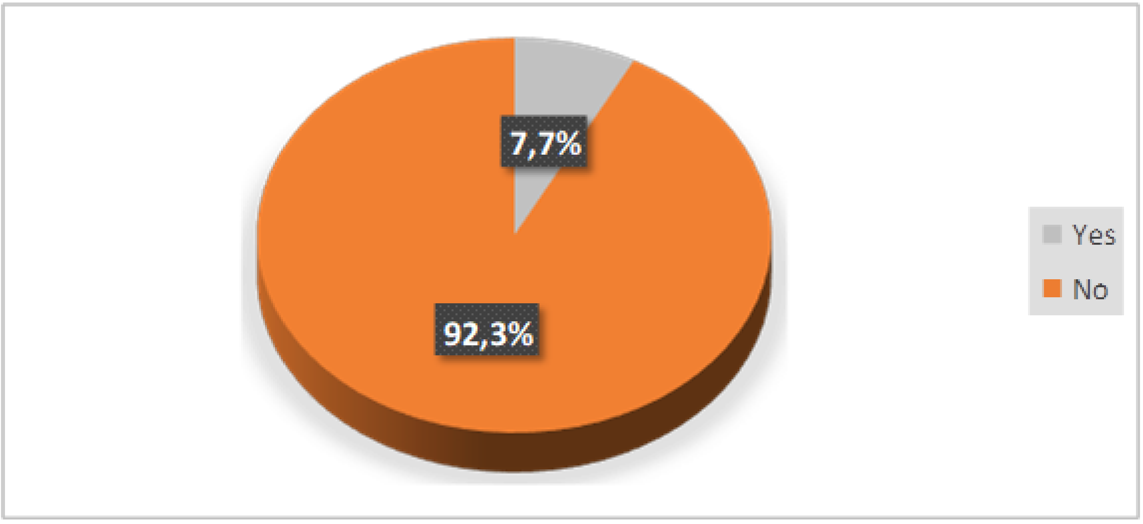


Fig. 52. Question 14: Do you use a 3D printer in your office?

The subsequent questions will deepen the details relating to this recent investment, in fact the interviewee specified that he had purchased the machinery in 2020, therefore a few months ago. The parts produced are surgical guides, temporary crowns and dental models, the investment made amounts to less than €7000 and the main benefit is described as "the possibility of fully managing many clinical situations in the office".

The final questions of the survey aim to investigate the reasons why the investment in 3D printing was not made. In question 20, an accordance scale was again used to demonstrate respondents' degree of agreement with some statements. As *fig.53* shows, many dentists disagree with the phrase "I do not know this technology" which suggests that the AM world is now widely known in the dental industry. A contribution is certainly given by the manufacturers of 3D machines who carry out a constant promotional activity in the dental sector to induce doctors to purchase.

Regarding the maturity of the technology, there are conflicting opinions, even if more are those who consider it a mature technology. Supporters of immaturity think that this technology still has a long way to go and that its diffusion is far away, this thought will certainly push them not to invest in a 3D printer while remaining anchored to traditional methodologies, that is, completely relying on the figure of the dental technician.

Few think that there is a low learning curve, modern machines are in fact equipped with simple interfaces allowing the customer an easy use. Furthermore, the cartage-based system allows to reduce complex charging operations.

Many say they prefer the guarantee of their dental technician, this confirms some comments previously collected according to which the autonomous production of dental parts through a 3D printer in the studio would not allow to obtain a quality equal to that which would result from the work of a dental technician. Surely years of experience in the creation of dental devices make the difference in the perception and identification of very small defects and in their faster elimination, furthermore the resolution of any problems in the printed element would involve post-processing or new prints that would steal too much time from the daily practices to perform. This is confirmed by the results of the phrase "I do not have the skills to design the devices", where some dentists believe they do not have the right skills to replace the work of dental technicians. On the other hand, there are not a few who argue the opposite, showing disagreement. The latter, more confident in their abilities, would probably be less reluctant to experiment with additive technologies.

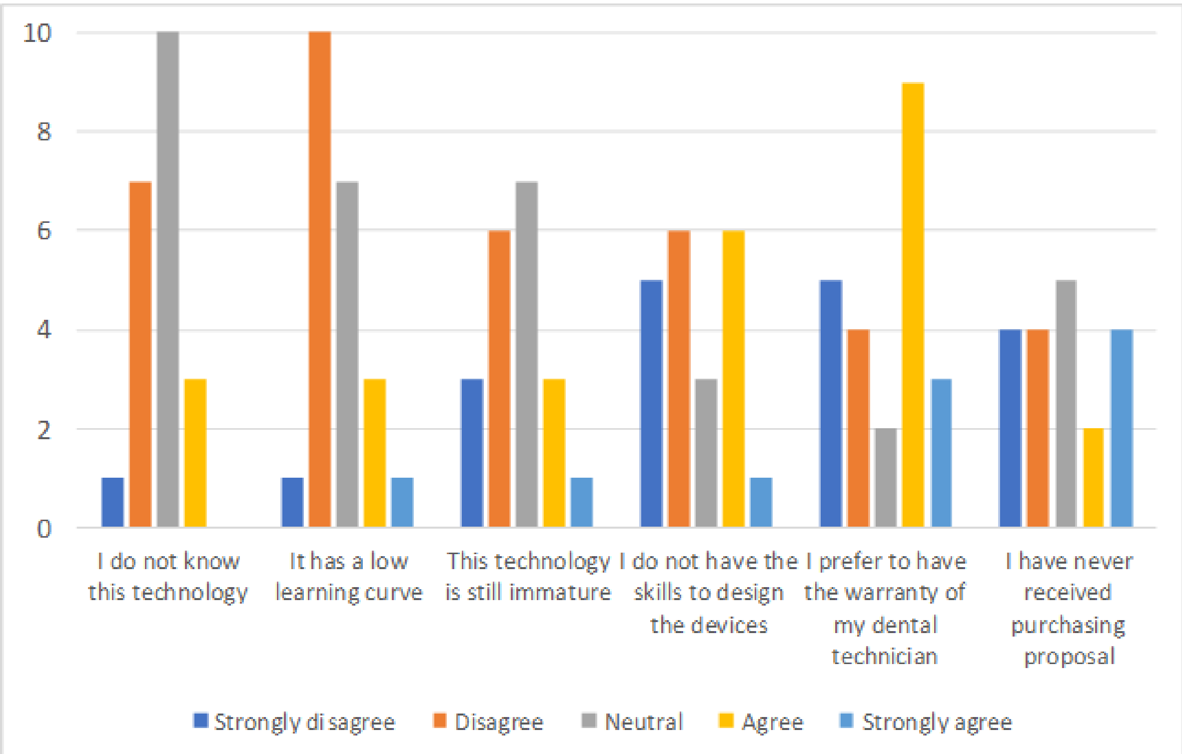


Fig. 53.Question 20: Please indicate the reasons why you did not invest in 3D printing

The answers to question 21 show that 2 dentists, 16,6% of the ones that already use a scanner, have planned future investments in a 3D printer in the medium-short term, while 83,4% did not.

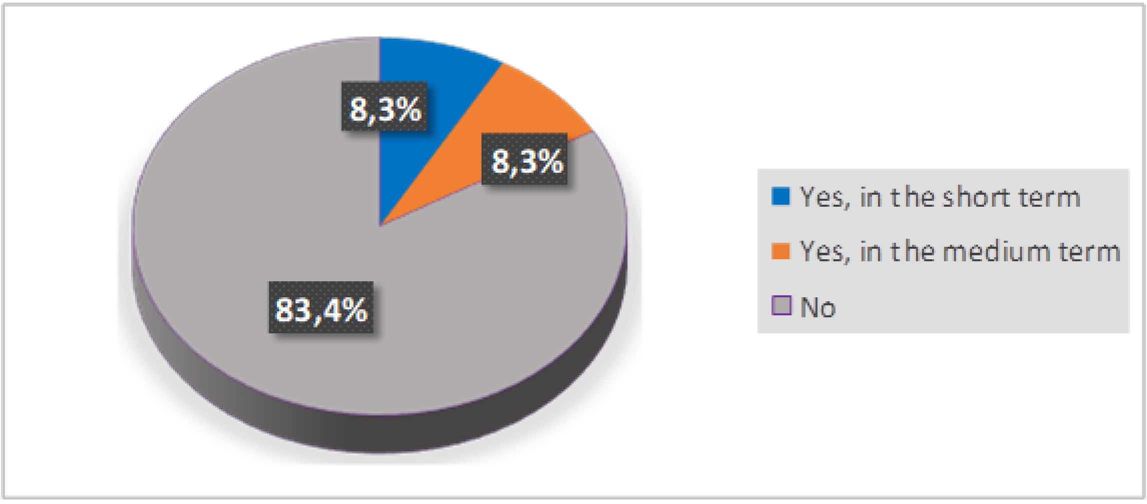


Fig. 54.Question 21: Have you already planned future investments in a 3D printer?

The last question concerns the adoption of the dental milling machine. Although it is a device that uses subtractive production principles, its diffusion in dental offices marks a first step towards in-office production and detachment from the labs. 23% currently use it.

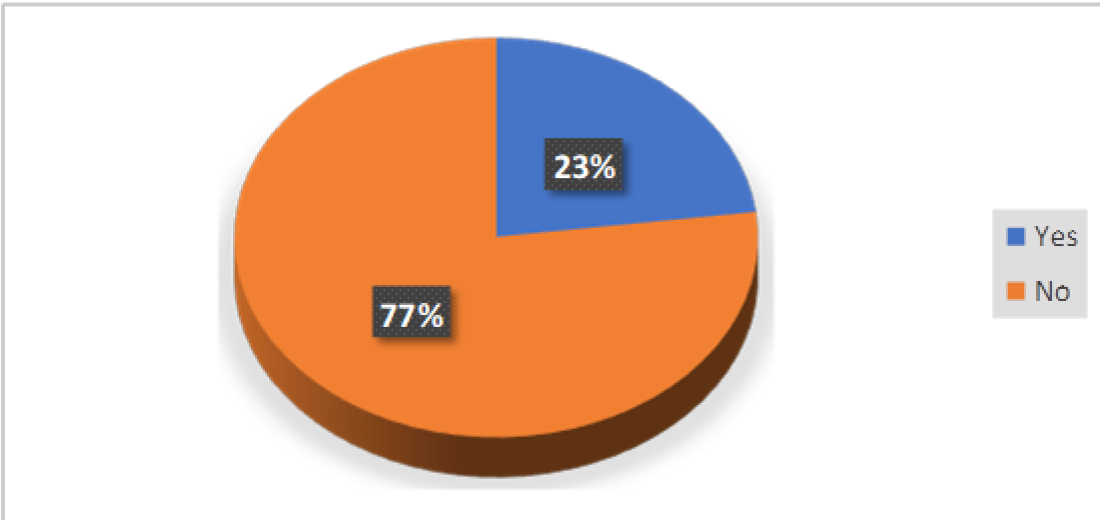


Fig. 55.Question 22: Did you use or use a dental milling machine in your practice?

Few interesting cross-analysis

The cross-analysis of the results can be very useful to highlight some interesting aspects and confirm or deny the hypotheses formulated. The first issue we want to investigate concerns the adoption of the scanner and its relationship with the number of implantology and fixed prosthesis operations performed weekly, the size of the study, intended as the number of operating dentists, and the average age. From the first comparison it appears that both dentists who have declared to carry out more than 10 interventions use a 3D scanner, this seems to confirm the previously advanced hypothesis according to which a higher number of operations stimulates the purchase of the device, whose frequent use will allow to quickly recover the investment, in addition to speeding up processes with better management of the workload. The second deduction that we could make is that adoption depends positively on the size of the office, in fact, among those who declared to have more dentists, 50% are in possession of the scanner, while in the case of a single doctor the value drops to 30%. (4 out of 13). Finally, it appears that among the 13 studies that use the device, there are only 4 over 45 doctors. Three of them work alone and one belongs to a larger studio where operate with two younger colleagues.

Given these results, it seems that the adoption of the scanner depends positively on the high number of restorations performed, the size of the office and the young environment. In fact, among the studies equipped with the device, almost 70% have more doctors, whose average age is less than 45 years and perform 5/10 operations per week. However, there are some exceptions. In fact, the remaining 30% of adopters identify doctors who work alone and with a low frequency of weekly interventions. Three of them are under the age of 35, which could justify the investment as the youngest are certainly the most inclined to technological innovation and therefore to the digitization of the traditional workflow. But what is surprising is the adoption by two doctors over 45 who, despite their age, the small size of the study and the low frequency of interventions, decided to adopt the scanner.

The second analysis is similar to the first but concerns the adoption of 3D printing. As we know, this happens only when a digitization process is already underway and an intraoral scanner is available. According to the outcome of the questionnaire, only one of the respondents uses additive technology, an investment made in 2020 after the purchase of an intraoral scanner a few years earlier. The case is fully part of the trend described above, in fact it is a good-sized study with 4 operating dentists, a young environment with an average age under 35 and performing more than 10 operations per week. As for the future forecasts, 2 of the 3 studies that have planned the purchase of a 3D printer in the medium-short term, in addition to owning a scanner, have large dimensions and a good frequency of weekly interventions.

An interesting consideration comes from the combination of data relating to the use of a dental milling machine in the office and the spread of scanners and printers. In fact, it appears that all three dentists who claim to use a milling machine in the office in question 23 have already embarked on a digitization path by adopting an intraoral scanner, and one of them has planned investments in a 3D printer within a year. There is no exact match, but these data may suggest that dental practice, having already experienced the benefits of in-office production, wants to continue in this direction. 3D printers can replace or support subtractive devices to increase internal production.

A comparison between two cities: Palermo vs Torino

Palermo and Turin are two very different cities in economic, social and cultural aspects. This paragraph aims to highlight, if any, the main differences between the two cities in the diffusion of the digitization process and the implementation of additive manufacturing in dental practices. The data compared derive from the study carried out by colleague Stefano Conte in 2019. The time gap of one year between the two analyzes will be taken into consideration.

The values of the diffusion of the intraoral scanner between the dental offices of the two cities are comparable. If we look at the result of question 2, it would seem that there is a strong advantage of Palermo over Turin, with an adhesion percentage of 41.9% compared to 22.6%, but furthering the analysis we note that 4 of the 13 adopters in Palermo have invested in 2020. The value referred to 2019 will be 29%, therefore perfectly in line with the 22.6% of the other city. In such an innovative context, which is undergoing a strong phase of growth and development, within a year there is a clear change in the data found as seen in the example just reported. There is greater confidence in technology, in fact the perception of immaturity which was one of the main causes of non-adoption of the device is now being downsized, leaving unchanged the accordance on high costs compared to the benefits produced.

As for 3D printing, we see that in both areas there is only one case of adoption, but since the Palermo practice invested in 2020, making the comparison on the same annual basis the Nordic city has an advantage. This is confirmed by the planning of future investments according to which only 16.6% of Palermo offices plan to purchase a 3D printer within 5 years, compared to 66.7% of the Turin. Unlike 23% in the southern city, 50% of Turin scanner adopters are already experimenting with the potential of in-office production using a dental milling machine. If the two cities are running at the same speed as regards the adoption of digital scanners, the situation looks very different for 3D printing where Turin seems to have a distinct advantage.

Interview with dental labs

The previous chapter describes the changes that the adoption of additive manufacturing in the dental sector can cause, including the relationship between dental laboratories and practices. The dental technician has always represented the craftsman of the teeth, the one who received the order from the dentist, starts production in his laboratory and then delivers the finished product ready for application. The world forecasts regarding the application of AM in the dental industry speak of an upheaval in the traditional workflow due to the adoption of 3D printers in dental offices and the shift to in-office work. As shown by the questionnaire results, although a case of AM adoption has been found, widespread diffusion is expected to be very distant.

To get a more complete picture of what the current scenario is, interviews were conducted with Palermo's dental technicians. It seems that they have widely implemented additive technologies in their production, making it not a replacement element but complementary to the traditional subtractive processing. They confirm the main use for production support and therefore in the creation of prototypes. The printers used are mostly for resin and allow various processes such as surgical guides, dental models and temporary crowns. While the creation of metal structures such as bridges is subcontracted to large stamping companies that can afford the much larger investment required to purchase a metal printer.

Investigating the reasons behind the purchase of the first 3D printer for laboratories, the speeding up, accuracy and repeatability of processes were mentioned, but also the need to keep up with innovation and customer requests. Many dentists, converted to intraoral scanners, send the digital file directly to the dental technician to be processed in CAD and in these cases the lack of new technologies would mean the loss of those customers.

To the question "do you think subtractive technology can be totally replaced by AM?" all said no or at least not soon. According to the testimonies collected, there are limits in the application of the 3D printer ranging from costs to the materials used and make it inapplicable for many applications.

With reference to the possible reduction of work caused by the development of AM in dental practices, they do not seem to be worried. It is not as simple as it seems, they say, there are complex post-production processes that only an experienced craftsman is able to do. The dentists can focus on producing simpler applications but will certainly need the support of the laboratory for the creation of longer processes and more complex products. They also add that a dentist still has an office to run, which requires many hours of chair-side work not allowing him to fully internalize the production. The alternative would be to hire a dental technician but at that point the benefits deriving from the possibility of producing internally what is needed, shortening the delivery times to the patient would not be compensated by the high increase in costs to be faced.

Conclusions

The analysis of the survey responses and the interviews with dental technicians allowed a complete view of what is the spread of dental additive manufacturing in Palermo. It seems quite clear that the spread of 3D printers in dental offices is still a long way off. This can be linked to various factors including the high investment costs, the perception of a still immature technology, the considerable limitations in the materials, that for example do not allow the creation of permanent crowns, and the unclear legislature that does not offer great protection to AM dental product manufacturers. But above all, the hard core of adoption seems to be not wanting to give up the dental technician, believing it can offer a better service for the reasons previously discussed. Different situation regarding the 3D scanner, despite being a much more expensive device than some printers. Its diffusion among Palermo dentists is already wide and will grow further in the coming years according to the answers collected.

The comparison between the two cities highlights a substantial difference, in fact if the colleague Conte had identified the high cost of the scanner as the major constraint for the adoption of 3D printing, thus a good future propensity of doctors towards AM, the situation found in this research is different. There is no direct relationship between the purchase of the two devices. The adoption of a scanner should not be intended as a first step towards the complete disintermediation from the laboratory, many adopters have in fact stated that they have no plans for future investments for 3D printing as they believe they do not have the skills suitable for production jobs and prefer rely on the figure of the dental technician. The adoption of the scanner is often undertaken to improve the patient's condition by avoiding the bothers of the traditional impression, to speed up the process and partly also as a marketing strategy. The idea of an innovative dental practice that has cutting-edge technologies can be an excellent business card, important for gaining the trust of patients.

We know that additive technology is in its diffusion phase and has not yet reached maturity, so we expect greater diffusion and lower costs due to increasing competition in the market in the coming years. This could lead to rapid changes in the dental industry and increase the currently low prevalence in dental practices. Laboratories that now seem to be calm, not having accused a reduction in requests from their customers, should keep their guard up, trying to anticipate future trends in order not to be crushed by the dynamics of an innovation that runs quickly.

Appendix A: Questionnaire

Sondaggio sull'uso di tecnologie Additive Manufacturing negli studi dentistici

Gentile Dottore,
La ringrazio per aver scelto di partecipare al sondaggio. Le sue preziose opinioni daranno un contributo fondamentale a questa ricerca. Qualora volesse conoscere di più riguardo allo studio lo indichi nei commenti finali.
Cordiali saluti,
Ing. Serena Ciulla
Politecnico di Torino.
*Campo obbligatorio

1. 1. Indichi il suo nome e cognome o il nome dello studio* *

*(Questa informazione non verrà utilizzata per fini commerciali o pubblicitari ma solo per individuare quali tra gli studi contattati hanno risposto al sondaggio)

____

Informazioni sullo studio dentistico

2. 2. Medimente quanti interventi di implantologia e protesi fissa vengono effettuati presso il suo studio? *

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- Meno di 5 a settimana
- 5-10 a settimana
- Più di 10 a settimana

3. 3. All'interno dello studio operano più dentisti? *

Contrassegni solo un'opzione. Se Sì, passi alla domanda successiva. Se No, passi alla domanda 5.

Contrassegna solo un ovale.

- Si
- No

Più dentisti : Sì

4. 4. Indichi la fascia di età dei dentisti che operano nello studio

Contrassegni solo un valore per riga. Dopo passi alla domanda 6.

Contrassegna solo un ovale per riga.

	25-35 anni	35-45 anni	Più di 45 anni
Dentista 1	◯	◯	◯
Dentista 2	◯	◯	◯
Dentista 3	◯	◯	◯
Dentista 4	◯	◯	◯
Dentista 5	◯	◯	◯

Più dentisti : No

5. 5. Indichi la fascia di età del dentista che opera nello studio

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

◯ 25-35 anni

◯ 35-45 anni

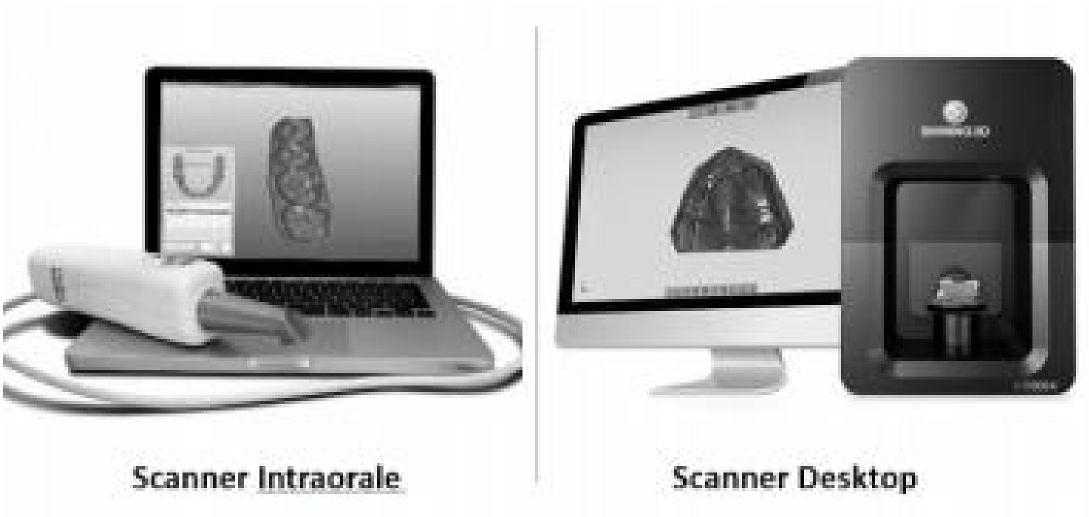
◯ Più di 45 anni

Scanner Intraorale e Scanner Desktop

Lo Scanner Intraorale viene utilizzato per rilevare l'impronta del paziente direttamente in formato digitale mentre lo Scanner Desktop viene usato per convertire un modello in gesso in un formato digitale.

6. 6. All'interno dello studio viene utilizzato almeno uno di questi scanner? *

Contrassegni solo un'opzione. Se Si, passi alla domanda successiva. Se No, passi alla domanda 10.



Contrassegna solo un ovale.

- ◯ Si
- ◯ No

Scanner: Si

7. 7. Quale tipo di Scanner utilizza?

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- ◯ Scanner Intraorale
- ◯ Scanner Desktop

8. 8. Quando è stato effettuato il primo investimento per l'acquisto dello scanner?

(Spefichi l'anno)

____

9. 9. Quali sono i principali benefici introdotti da questa tecnologia?

Dopo passi alla domanda 14.

Scanner: No

10. 10. Indichi i motivi per cui non ha aderito a questa tecnologia

Contrassegni solo un'opzione per riga (indichi il grado di accordo con queste affermazioni).

Contrassegna solo un ovale per riga.

	Molto in disaccordo (1)	In disaccordo (2)	Nè disaccordo nè d'accordo (3)	D'accordo (4)	Molto d'accordo (5)
È una tecnologia ancora immatura	⬭	⬭	⬭	⬭	⬭
L'investimento è elevato in relazione ai benefici	⬭	⬭	⬭	⬭	⬭
Ha una bassa curva di apprendimento	⬭	⬭	⬭	⬭	⬭
Presto diventerà una tecnologia obsoleta	⬭	⬭	⬭	⬭	⬭
Non c'è motivo di abbandonare i metodi tradizionali	⬭	⬭	⬭	⬭	⬭
Non mi è stato mai proposto l'acquisto	⬭	⬭	⬭	⬭	⬭

11. 11. Ha già pianificato investimenti futuri per l'acquisto di uno Scanner Intraorale o Desktop?

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- Sì, a breve termine (entro 1 anno)
- Sì, a medio termine (entro 5 anni)
- No

Tecnologie Additive

Grazie all'uso di una stampante 3D è possibile creare nel proprio studio dispositivi dentali come Corone provvisorie, Dime chirurgiche, Aligners trasparenti e Modelli tridimensionali. Per l'utilizzo della stampante 3D è necessario disporre dell'impronta del paziente in formato digitale e quindi lo scanner intraorale o desktop è strettamente indispensabile.

12. 12. Pensa che in futuro utilizzerà una stampante 3D nel suo studio?

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- Sì
- Non sono sicuro/a
- No

13. 13. Indichi quali vantaggi e svantaggi porterebbe la produzione di dispositivi dentali direttamente nel suo studio.

Dopo passi alla domanda 23.

Stampante 3D

14. 14. Utilizza una stampante 3D nel suo studio?

Contrassegni solo un'opzione. Se Sì, passi alla domanda successiva. Se No, passi alla domanda 20.

Contrassegna solo un ovale.

- Sì
- No

Stampa 3D: Sì

15. 15. Quando è stato effettuato il primo investimento nella stampa 3D?

(specifichi l'anno)

____

16. 16. Cosa produce con la stampante 3D?

Può selezionare più di una risposta.

Seleziona tutte le voci applicabili.

- [ ] Dime chirurgiche
- [ ] Corone provvisorie
- [ ] Aligners trasparenti
- [ ] Modelli dentali

Altro: [ ] ______________________________

17. 17. Qual è l'ammontare del primo investimento da lei effettuato nella stampa 3D?

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- Meno di 7.000€
- 7.000€ - 15.000€
- Più di 15.000€

18. 18. Quali sono i principali benefici introdotti dalla stampante 3D?

19. 19. Ha utilizzato oppure utilizza una fresatrice dentale nel suo studio?

La fresatrice dentale rappresenta il primo esempio di utilizzo di tecnologie innovative per produrre corone dentarie direttamente nello studio dentistico. Contrassegni solo un'opzione. Dopo passi alla domanda 23.

Contrassegna solo un ovale.

- Sì
- No

Stampa 3D: No

20. 20. Indichi i motivi per cui non ha investito nella stampa 3D

Contrassegni solo un'opzione per riga (indichi il grado di accordo con queste affermazioni).

Contrassegna solo un ovale per riga.

	Molto in disaccordo (1)	In disaccordo (2)	Nè disaccordo nè d'accordo (3)	D'accordo (4)	Molto d'accordo (5)
Non conosco questa tecnologia	⬭	⬭	⬭	⬭	⬭
Bassa curva di apprendimento	⬭	⬭	⬭	⬭	⬭
Credo che questa tecnologia non sia ancora matura	⬭	⬭	⬭	⬭	⬭
Non ho le competenze tecniche per progettare i dispositivi dentali	⬭	⬭	⬭	⬭	⬭
Preferisco avere la garanzia del mio odontotecnico	⬭	⬭	⬭	⬭	⬭
Non mi è stato mai proposto l'acquisto	⬭	⬭	⬭	⬭	⬭

21. 21. Ha già pianificato investimenti in una stampante 3D?

Contrassegni solo un'opzione.

Contrassegna solo un ovale.

- ⬭ Sì, a breve termine (entro 1 anno)
- ⬭ Sì, a medio termine (entro 5 anni)
- ⬭ No

22. 22. Ha utilizzato oppure utilizza una fresatrice dentale nel suo studio?

La fresatrice dentale rappresenta il primo esempio di utilizzo di tecnologie innovative per produrre corone dentarie direttamente nello studio dentistico. Contrassegni solo un'opzione. Dopo passi alla domanda 23.

Contrassegna solo un ovale.

- Sì
- No

Commenti

23. 23. Indichi qui ulteriori commenti riguardo alla ricerca e al sondaggio

____
____
____
____
____

Sondaggio concluso

La ringrazio per il tempo da lei dedicato.

Acknowledgments

A conclusione di questo elaborato, desidero dedicare qualche riga a tutti coloro che mi sono stati vicini in questo periodo, contribuendo direttamente o indirettamente alla realizzazione di questo lavoro di tesi.

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