

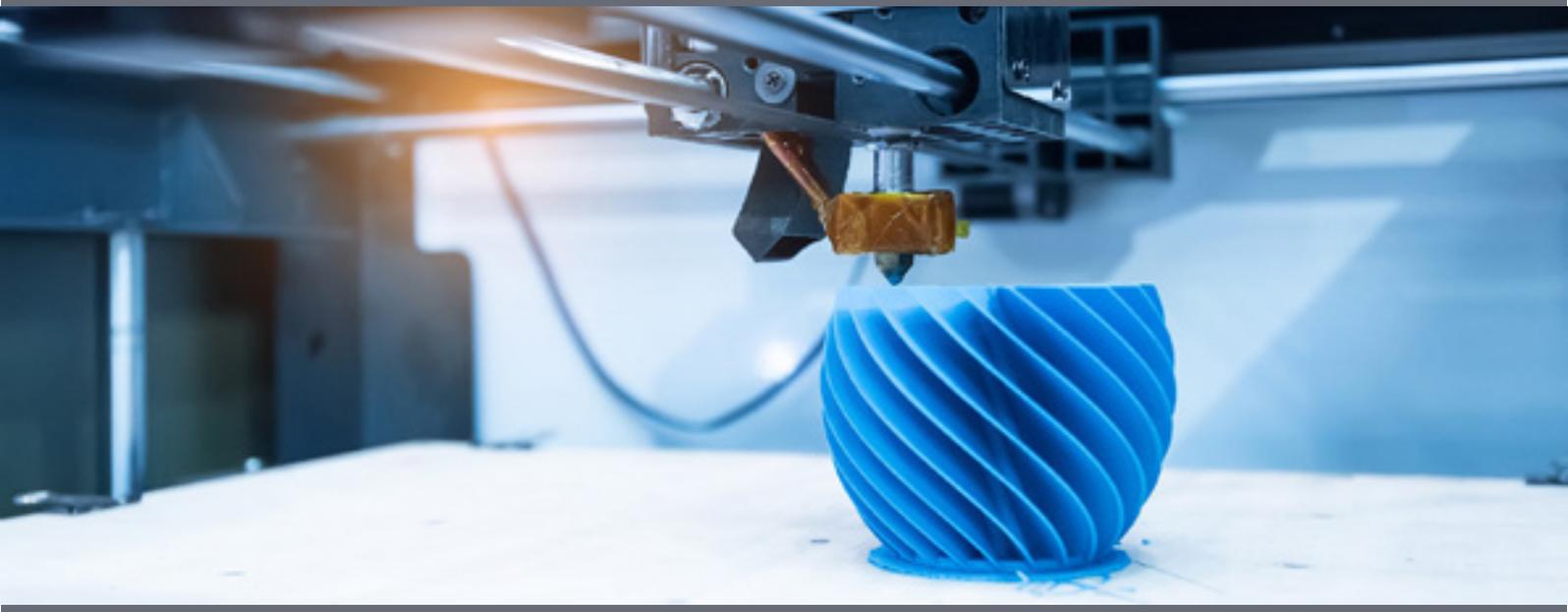


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3D4VET
3D FOR VET SCHOOLS

3D PRINTING COURSE. Module I



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INTRODUCTION TO 3D PRINTING

HISTORY OF 3D PRINTING

The computerized numerical control system (CNC), whose first machines were built in 1940, led to the creation of the technology that ended up setting the bases of nowadays 3D printing.



But, what is computerized numerical control, what does its acronym, CNC, mean ?

CNC is a system that allows us to control the position of a physical element by coordinates of the position of a certain point. This permits fast and accurate machining processes. In a few words, it let us control and monitor

the movements accurately through a computer, for instance milling machine, lathe, grinding machine, water cutting machine, laser ...

The main parts of a CNC are the following:

- Input device
- Control unit
- Machine tool
- Drive system
- Feedback devices (only in systems with servomotors)
- Monitor

All these components are part of the hardware but they are useless without a software system linked to our machine. The computer programme (software) is written in G and M low level code, standardized by 6983 ISO regulations and RS274 from EIA. The G code describes those functions dealing with movements of the machine (for instance, fast movements, progresses, radial progresses, pauses, cycles), whereas the M code describes those miscellaneous required functions needed for the machining of the part, but not linked to the movements of the machine (for example start-up and stop of the spindle, tool change, coolant, stop of the program).



THE FIRST 3D PRINTER



It is in 1984 when Charles Hull, inventor of stereolithography, begins 3D printing. (Stereolithography (SLA or SL; also known as optical manufacturing, photo-solidification, among others) is a kind of manufacturing technology (or 3D printing) used to produce models, prototypes, patterns or final shape).

In 1986 Charles Hull obtains the patent that allows him to create 3D Systems Inc. Company.

Since then, new technologies emerge like the one developed by Carl Deckard, the selective laser synthesizer (SLS is a rapid prototyping addition technique which deposits a layer of dust, a few tenths of a millimeter, in a vat previously heated to slightly below the melting point of the dust. Right after, a CO2 laser synthesizes the dust in the selected points (making the particles merge and solidify). However, it is Scott Crump who manages to get the SLS patent and who creates one of the most important companies in 3D printing sector, Stratasys, which in 1992 patents his FDM (Fused Deposition Modelling) technology.



3D PRINTING TECHNOLOGY

3D FDM

Fused Deposition Modeling, its acronym FDM (MDF in Spanish)

It is a process of manufacturing dealing with the prototyping and production model that uses an additive function from meltable material which is deposited layer by layer till composing a final and finished product. This method creates the resulting model bottom - up and if some parts protrude, support structures able to be removed will be needed once the printing process is finished.

A plastic or metallic filament kept in rolls or reels is gradually inserted through a nozzle heated above the temperature of the needed fusion temperature of the material used. It can be moved on three electronically controlled axes. This nozzle is normally moved by stepper motors or servomotors. The material we obtain coming out of the nozzles is quickly solidified.

TYPES OF FDM PRINTERS

1. Cartesians
2. Delta
3. Polar
4. Robotic arm

Cartesians: The most common FDM printers in the market, they receive this name as they use a spatial coordinates system- axes X, Y and Z - which is used to determine their movement in a three-dimensional space.

The support where the items are printed, commonly called bed, moves only in the Z axis placing the molten system on axes X and Y.

Delta: These printers work with cartesian coordinates and their main features are their circular printing bed together with their cast system fixed on its upper place in a triangular configuration shape which is the reason of its name "Delta". Each of the three items can move up and down which allows the printing head to move in three dimensions.

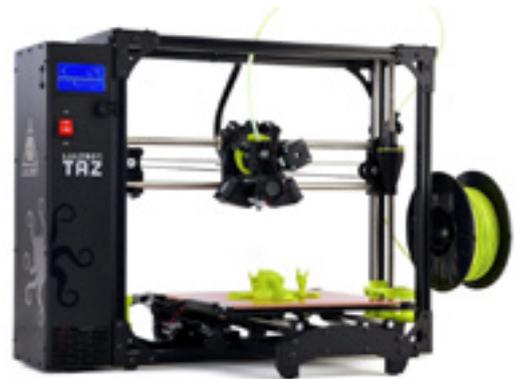
3D Delta printers were designed to increase the printing speed using a printing bed without movement, which might be useful for certain projects. Nevertheless, sometimes this type of printers are considered not to be as accurate as cartesians.

Polar: These printers receive this name due to the fact they use the polar coordinates in 3D printing. The sets of coordinates are described with angle and length. This means the printing bed rotates and the extruder can move up and down, left and right.



Just like delta printers, the printing surface is circular. As they have a bottom that keeps rotating, it is perfect to print items following a spiral. That is, copying objects done with clay winches, for example.

The main problem of these printers are their accuracy. When moving the printing surface in a circular way, the centre is more precise than the edge. Therefore enlarging these types of printers to get higher scales is not at all recommended.





Robotic arm: Mechanical arm, usually programmable, with similar functions to those of a human arm. The molten system is placed on the tip which deposits the material but, unlike the other systems, it does not have to be layer by layer.

The problem of this system is its programming, which is more complex.

FIELDS OF APPLICATION FOR 3D PRINTING

Although the applications of the 3D printing in the industry is really wide, we describe the most significant ones below.

1. Education system
2. Medicine
3. Clothing
4. Building industry
5. Design and prototyping

Education system

At an educational level, this new technology offers new setting up and fulfillment processes for model designs, both decorative and functional, providing a new tool for creativity in the educational area.

On the other hand, getting to know how a 3D printer works implies understanding two major groups, the hardware (physical parts of the printer and all its items) and software (computer program to create printable models and to configure the behaviour of the printer). All this has made it an excellent pedagogical tool in the last years. We are facing a technology that let us see and touch items impossible otherwise. Abstract and three-dimensional mathematical concepts, ancient monuments reproduction, fossil models, bones, organs, etc.



Medicine

In the medical sector we find examples of the use of 3D printing in fields so different like creation of prosthesis, moulds for dental use or recreation of bones diseases.

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Such a significant progress in these areas has been a real medical revolution to the extent of replacing the plastic reels used in FDM printing with biological material. This has led to the creation of 3D printed living tissue and although this procedure is still in its embryonic stage, hopeful possibilities are foreseen in biomedicine.



Clothing

Thanks to the study of flexible filaments by different brands in FDM printing, fashion designers have access nowadays to a technology that let them create from dresses, bags or shoes to endless accessories to be used together with current textile products.

This implies a previous study of a specialized software for creation of patterns, able to take advantage of the benefits of 3D printing. As an example of the use of this technology in fashion we find the Israeli designer Danit Peleg (<https://danitpeleg.com/>), and her amazing designs fully printed in 3D.



Building industry

The Chinese company WinSun was one of the pioneers in using 3D printing in house construction. Making use of a huge 7 meters high, 10 meters wide and 40 meters long printer, they managed to build a housing complex up to 1000 square meters. This complex was made manufacturing macro parts in the factory and taking them to their final destination afterwards, which becomes a complementary system to modular manufacturing.

But the most interesting thing is the possibility of creating habitable houses in just over 24 hours. In the event of a disaster, hundreds of people who have just lost their houses due to a



hurricane, a fire, heavy rains, etc, could be accomodated almost immediately.

Another good example is the popular the 3D printed bridge in Amsterdam, a stainless steel bridge printed by MX3D startup and designed by Joris Laarman Lab. In this procedure a large

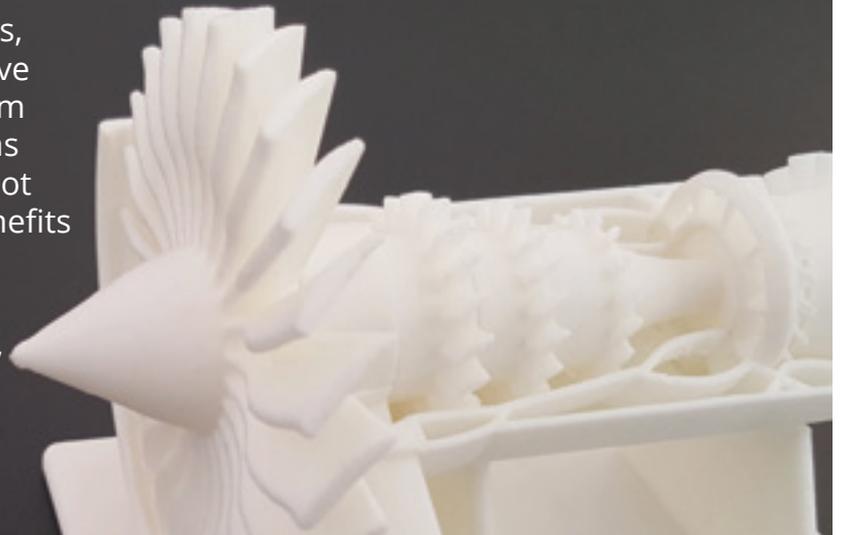
sized robotic arm is used which has been modified to weld in stainless steel allowing the printing of 3D metals at architectural scales

Design and prototyping

One of the sectors where 3D printing is more relevant is in the development of prototyping in the industrial sector, car industry, sports ...

The minuaturization and costs reduction in the 3D printers for SMEs, have alowed these companies to have access to a technology that help them reduce the designing working time as well as the small-scale production, not only making them increase their benefits but also their runtimes.

Brands like Ultimaker, Makerbot, Luzbot or Raise3D have made efforts to create high quality printers at competitive prices and providing professional finishings.



Not only SMEs benefit from technological advances 3D printing is providing to production but also large companies as Airbus, BMV, Boeing... are directly implementing in their products items completely designed by 3D printing processes, obtaining a reduction in manufacturing costs and speed.



3D PRINTING MATERIALS

THERMOPLASTIC FILAMENTS

ABS: acrylonitrile butadiene styrene

Although it is widely used in 3D printing, it is nonbiodegradable, but its tenacity, hardness or rigidity as well as its both chemical and abrasion resistance makes it a very good candidate for the prototyping of models. However, it suffers with long exposure to UV rays, it is soluble in acetone and its density makes its extrusion head to be around 240°C and its “bed” or printing tray to be about 100°C.

It is not an easy material to be used in 3D printing without a closed system with a stable temperature of about 50°C or 60°C due to the dilatation and contraction of this material with respect to temperature fluctuations

PLA: polylactic acid

It is biodegradable and one of the most used ones due to its properties: easier to print and less energy cost. For PLA printing we do not need higher temperature than 215°C in its head and about 60°C in its printing tray.

As it does not suffer much from contraction due to temperature variation, it becomes an ideal candidate for those initiating in 3D printing. It releases a much pleasant smell and it is not toxic.

However, it also has its cons as low mechanical strength. It is a sturdy material but also fragile and it loses resistance and hardness at temperatures around 60-70°C.

This thermoplastic is very much used for decoration and for items which do not have to bear great stress.

HIPS: high impact polystyrene

Very similar to ABS, it is used as a support material in ABS or PLA printings because it is easy to be erased using D-limonene, as it has no effect on neither ABS or PLA. It is indicated to create light and high-quality items. Its flexibility is very low and its hardness very high.

PETG: polyethylene terephthalate glycol

Although PET is the most used plastic in the world as it is used in plastic bottles, food containment, clothing fibers ... PETG is a derivative material used in 3D printing with a change from PET in its chemical structure that makes it more transparent, less fragile and easier to process.

It is a transparent material, with a very good chemical resistance and suitable for food use. It is also easy to recycle and it does not smell when printing.

ASA: acrylonitrile styrene acrylate

A more recent thermoplastic than the previous ones and with improved properties of those of ABS. It combines mechanical robustness, UV and water resistant. Its finishing does not turn yellow over time.

Considered useful to create final pieces of machinery and durable prototypes even when used outdoors as it maintains shape and color over time.

As a counterpart, just like ABS, ASA filament generates toxic fumes when printed, so it is very important to print them in a place with good ventilation.

Although it does not present the same problem as ABS with the issue of contraction due to temperature variation, it still needs a hot base between 80° 110° C and an extruder temperature between 250 and 260°C

Nylon: polyamide

With surprising features and a smooth and silky finish it produces a very pleasant touch. Nylon is extremely resistant, but it has the particularity that it is also flexible when printing thin pieces. It is ideal for moving parts due to its low coefficient of friction.

On the other hand, it is a hygroscopic material, which means that it easily absorbs moisture from the environment and can ruin a print. If the nylon spool is poorly preserved and has absorbed water before printing, it will lead to bad finishes with loss of detail in the item.

The optimal printing temperature of nylon is usually around 240C-260C, depending on the brand.

The base should be about 80°C or more, and beware of abrupt changes since Nylon is sensitive to cooling too fast, and that causes deformation.

To facilitate adhesion it is advisable to use an adhesive.

The layer fans should be turned off, and you should be careful and be in a dry environment without drafts.

PROCESSES AND STEPS IN 3D PRINTING

The 3D printing process is composed of two major groups, the first one is carried out by software and it consists of computer programs developed to create a digital model for its later 3D printing. The second group comprises hardware which is composed of the 3D printer and the material to be printed (filament, resin, dust...).

THE SOFTWARE

CAD software: CAD or CADD tools (Computer Aided Design and Drafting) allow us to make use of the computing technology for design and design documentation. The design process replaces hand drawings with automated processes.

We can find both free of charge and pay software, some of the most used programs below.

- OpenSCAD (free): <http://www.openscad.org/>
- FreeCad (free): <https://www.freecadweb.org/>
- Blender (free): <https://www.blender.org/>
- MeshMixer (free): <http://www.meshmixer.com/>
- Thinkercad (free): <https://www.tinkercad.com/>
- Autodesk Fusion360 (3 years free of charge for students): <https://www.autodesk.com>
- SolidWorks (priced): <https://www.solidworks.com/es>
- Catia (priced): <https://www.3ds.com/es/productos-y-servicios/catia/>

These computer programs allow us to create designs of parts or 3D models that can be later printed using 3D printing technology. The first step is to design an item using some of the previously mentioned softwares, then we must take our 3D model to a slicer program. This program will cut our model layer by layer transferring that information to a file our 3D printer can interpret.

SLICER SOFTWARE

Computer program in charge of dividing the 3D model into layers and also of generating the G-code batch file. This file contains the commands to be executed by the 3D printer so that while it successively deposits the previously defined layers, it manufactures the physical part.

Some of the most common slicers below.

- Cura (free): <https://ultimaker.com/en/products/ultimaker-cura-software>
- Slic3r (free): <https://slic3r.org/>
- Simplify3d (priced): <https://www.simplify3d.com/>



Slicers are a main part of the 3D process as they allow us to convert the 3D models to a language that can be interpreted by the printer. These programs also allow us to configure the behaviour of the printer through the configuration of options that is specified to the resulting file, so it is important to understand the printing parameters that give us the ability to modify the laminar model.

Although we are able to create a digital object from scratch to later on obtain a 3D printed copy of it, we must not forget the possibility we have to create a digital copy of real models. We have both specific hardware and specialized software for this process:

3D scanner

Device that collects the geometry and colour of an object and translates them into a 3D digital model. It let us create a copy of a real object in a virtual version that we could later operate with specific software.

There are two types of 3D scanners: Contact and Non-contact.

- **Contact scanner**

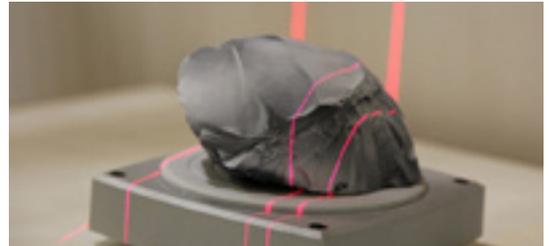
This scanner works with a touch sensor that passes over the work piece acquiring its geometry by contact, generating xyz three-dimensional coordinates. They are mainly used to manufacture models in which the dimensional control is the main focus.



- **Non-contact scanner**

There are various types of non-contact laser technology, but the most used ones nowadays are two.

- **Laser based scanner** uses a process called triangulation by projecting a laser line onto an object, and a camera, which in turn, analyses the position of the laser projection on the object as xyz coordinates.
- **Structured white light scanner** projects a light pattern (usually parallel lines) onto the object and a camera analyses, real-time, the deformation of the pattern on the surface of the object, translating that deformation in three-dimensional xyz coordinates.



Photogrammetry

It is the technology of achieving a digital version of an object determining its geometric properties by using a set of photographs at different positions and angles.

This technique consists of generating a digital copy of an object with just a photo camera, just like 3D scanning. A specific software is needed to interpret each of the photographs as geometric data of three-dimensional coordinates. Among the most well known softwares, we find :

Among the most famous of these softwares are:

Agisoft PhotoScan: <http://www.agisoft.com/>

3DF Zephyr: <https://www.3dflow.net/3df-zephyr-pro-3d-models-from-photos/>

Autodesk ReCap Pro: <https://www.autodesk.com/products/recap/overview>

Visual SFM: <http://ccwu.me/vsfm/>



3D GRAPHIC DESIGN STANDARDS

The first format of digital 3D models was .DWG created in 1982 with the first version of nowadays Autocad from Autodesk trademark. Its use has been so wide that it is still the native format of this programme. However, sometimes it presents difficulty when migrating a file from a programme to a 3D design one.

STL is, with no doubt, the most widespread file used in 3D printing. Its acronym stands for "Standard Triangle Language" and it defines the geometry of 3D objects, excluding information of colour, textures and the rest of physical properties that other CAD formats do include. Created by 3D System company, since 2011-2012 it is one of formats most used by millions of users of 3D printers.

Nevertheless, STL format has some inconveniences that are making new formats to be taking over in the last years. One of the key constraints of this format is the repair of defects in the models such as holes, triangles that are upside down, overlapping faces ...

OBJ, old but reliable, was created by Wavefront and it has been used for decades in 3D design. One of its most important advantages is, unlike STL format, the fact that OBJ supports the use of colour and UV mapping (assignment of coordinates for each vertex of a 3D model to facilitate the placement of a two-dimensional texture on the model)

AMF 'Additive Manufacturing File' format, based in XML and open source is used as a bridge between CAD applications and 3D printers, and offering more features than STL format.

This format supports multimaterials, multicolour including gradient, complex structures, units of measure ... and with a 50% more effective compression than STL format.

3MF created a few years ago, mainly by Microsoft and with the support of companies like HP, Dassault System, netfabb, is one of the most complete formats in the list. It is based, just like AMF, in XML and it presents the essential data needed for additive manufacturing processes. It is an improved format from AMF which includes even more information than this one.

It is a "unified" file format which means it is useful from the design phase to the printing itself without having to perform conversions or lose or sacrifice anything in the way. This means the whole information of the three-dimensional model will be stored in this kind of file.

One of its most important characteristics is the amount of information it contains. All this information condenses the data of the models, materials and properties of the designed object.

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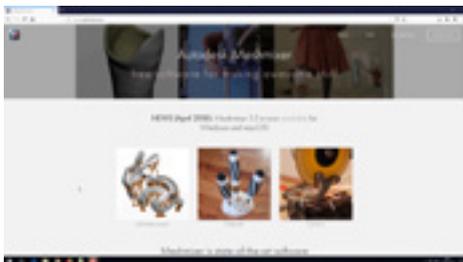
DOWNLOAD AND AMENDMENT OF A 3D DESIGN (PRACTICAL EXAMPLE)

This section consists of five practical videos in mp4 format. Please access the video folder to view each practical example.



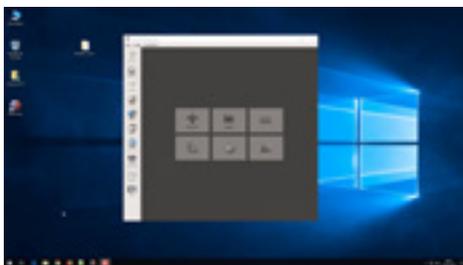
VIDEO 1

Example file Thingiverse



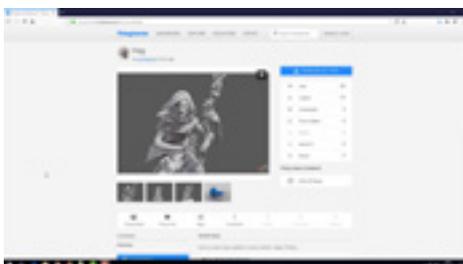
VIDEO 2

Download and installation of Meshmixer



VIDEO 3

Starting with Meshmixer



VIDEO 4

Error correction in Meshmixer



VIDEO 5

Modifying a model in Meshmixer



Sapere utile

