# 3D Printing

**MARCO CALLIERI**

**ISTI-CNR**

# Chi sono?

## Marco Callieri

- Master degree & PhD in computer science

- Researcher at the Visual Computing Lab, ISTI-CNR, in Pisa
- I work on 3D data manipulation and rendering... lot of experience in 3D scanning and data processing
- Most of my activities are in the field of cultural heritage

## http://vcg.isti.cnr.it/~callieri
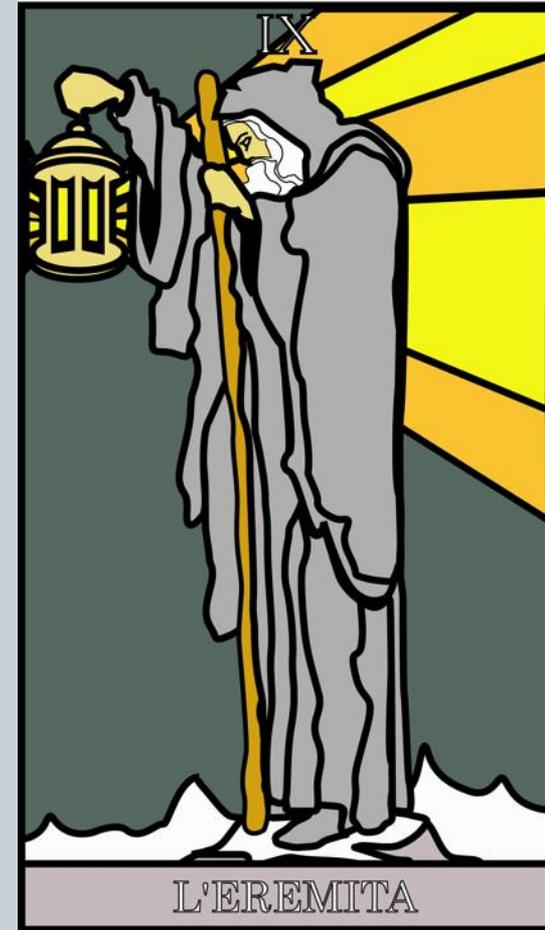
Beside this:

an eclectic artisan, an avid gamer, a former biker, a good cook, an incorrigible geek... and much more

# Visual Computing Lab

Gruppo di ricerca dell'ISTI (Istituto di Scienza e Tecnologie dell'Informazione), istituto del CNR...

Siamo nell'area di ricerca di Pisa; siamo circa 20 persone, che lavorano su diversi aspetti della Computer Graphics

**http://vcg.isti.cnr.it**
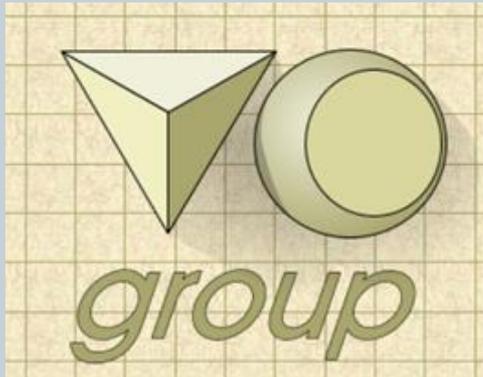
# Buzzword

3D Printing is a "buzzword"

**buzz·word** (bŭz'wûrd)

*n.*

**1.** A word or phrase connected with a specialized field or group that usually sounds important or technical and is used primarily to impress laypersons

Everyone is talking about 3D printing, and seems everything may be solved with 3D printing... (just like "drones", "social media", "3D"...)

# The story so far

The problem is…

**3D PRINTING IS NOT A NEW TECHNOLOGY**

3D printing derives from a much *wider* and *older* family of technologies, called RAPID PROTOTYPING which, in turn, is a subset of of an even wider one, called CAM (Computer Aided Manufacturing)

# Ancient Concepts

**Subtractive**

**Additive**
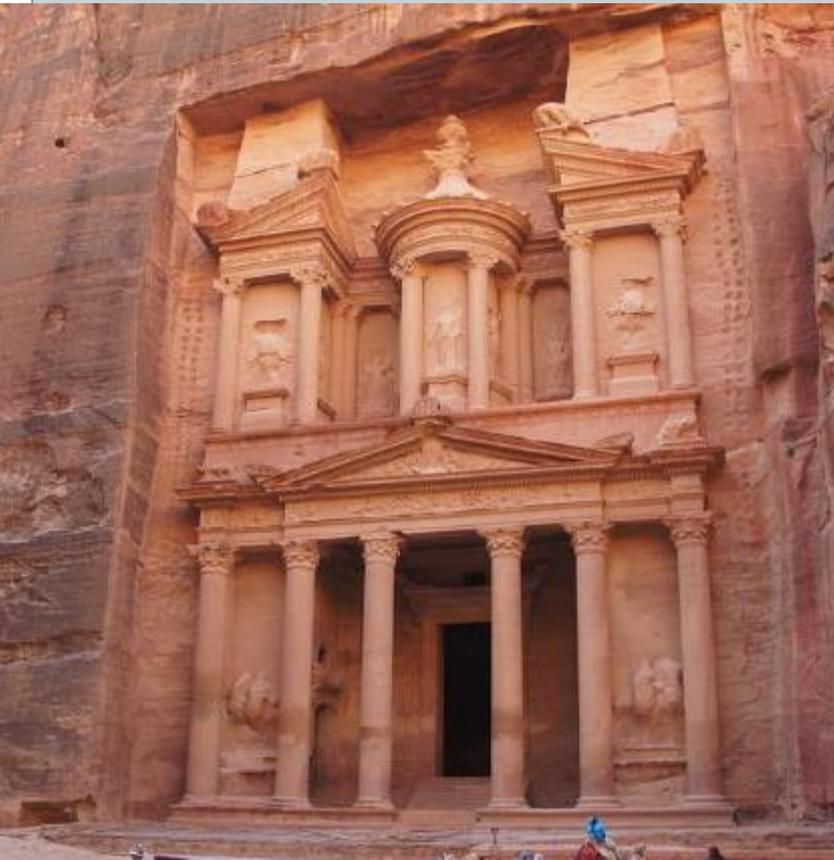
# The story so far

The oldest CAM tools are simply a series of milling / cutting / drilling heads, controlled by a PC.

CNC machines are still used a lot today, and they can be considered the origin of the Rapid Prototyping…
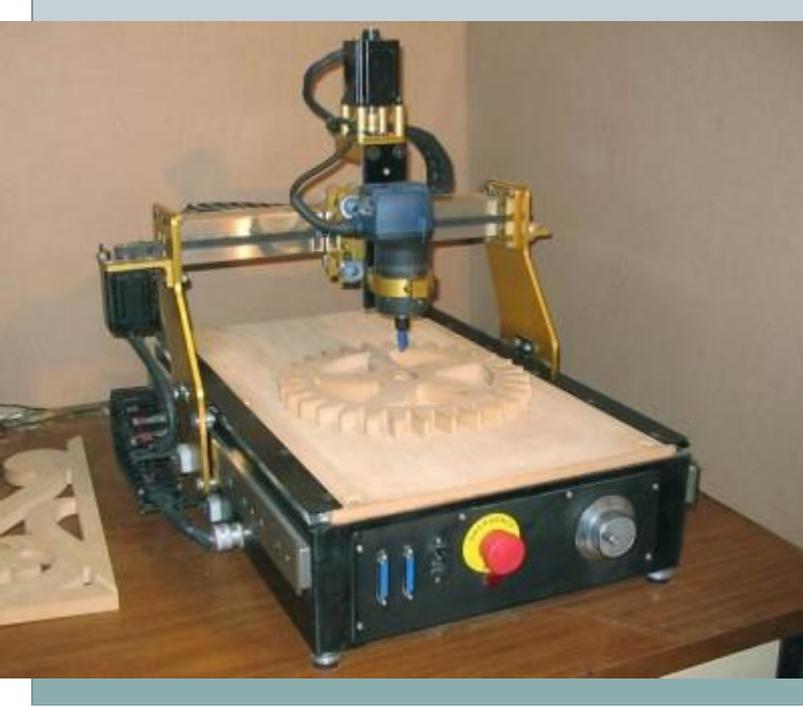
# The story so far

CNC machines, however, may only build a limited subset of geometries, depending on their working tools…

New machine could carve increasingly more complex objects

- 2.5 D drill/router (only produces a "height field")
- 3-4-5-…N axis carving machines (tuttotondo)

# The story so far

Many different milling / carving  techs.

Size and shape of the carving tool affect the quality of the results

- Bigger/rougher means faster
- Smaller and more precise means slower

Milling paths:

How to move the carving head

Over the surface of the object is THE problem.
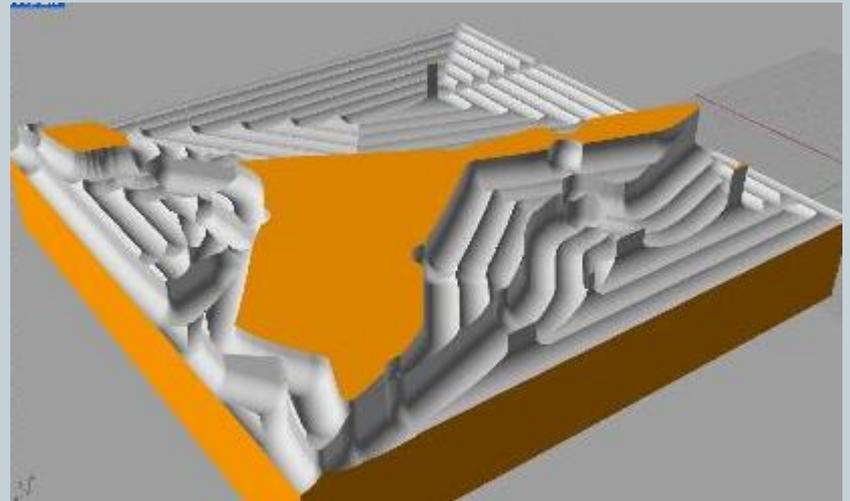
Up to a certain point, only SUBTRACTIVE technologies were available… then, along came Stereolithography

# Stereolithography (SLA)

The most famous old-school (1986) **additive** method for rapid prototyping: a liquid resin is solidified, layer by layer, using a laser.

Really costly, but creates incredibly detailed, sturdy objects

Used **a lot** in automotive!

# Stereolithography

# Stereolithography

http://www.materialise.com/
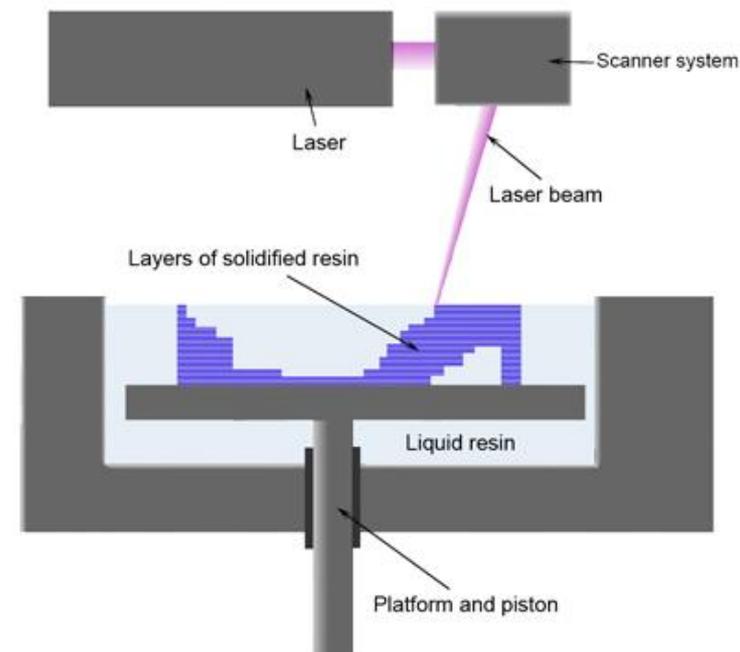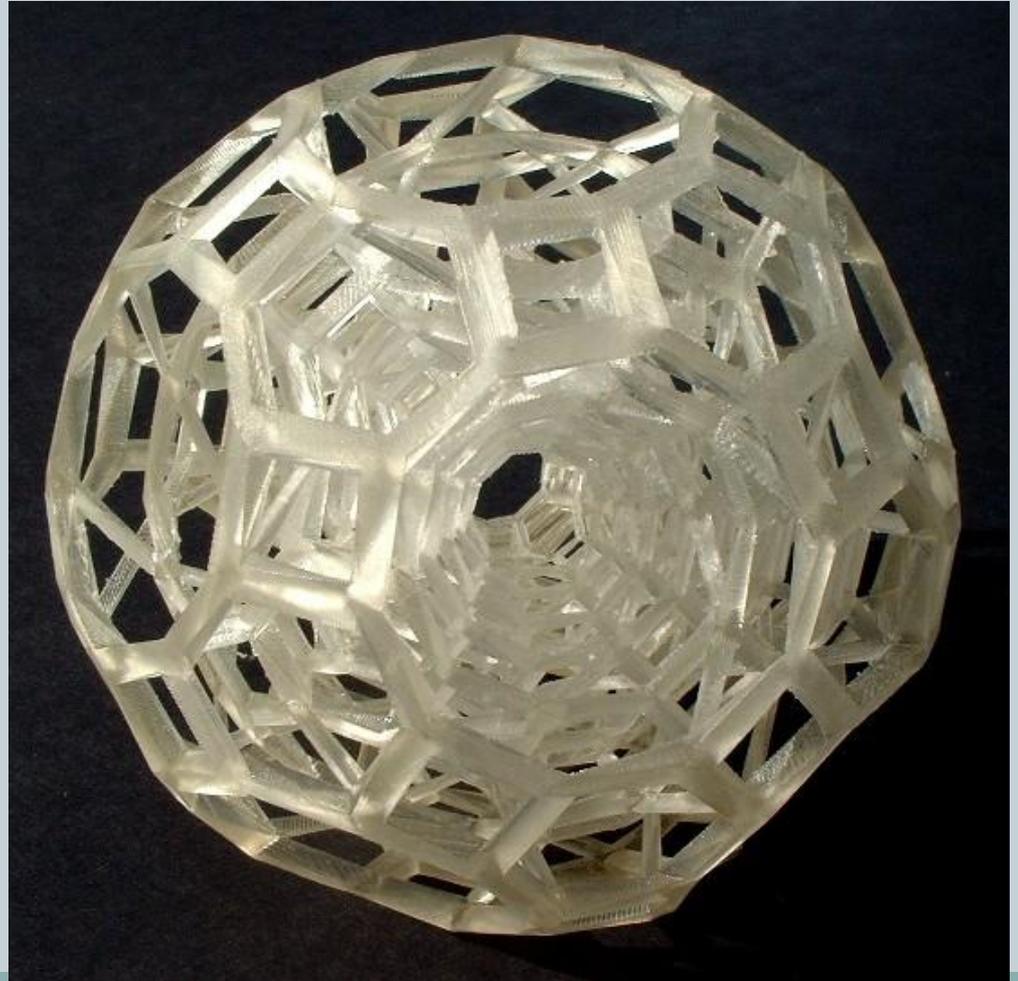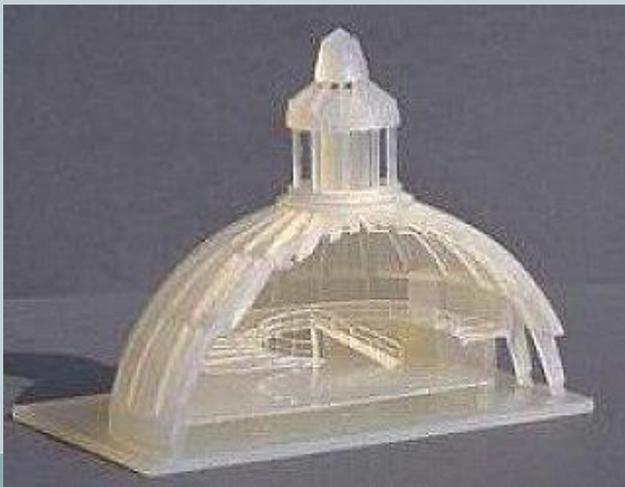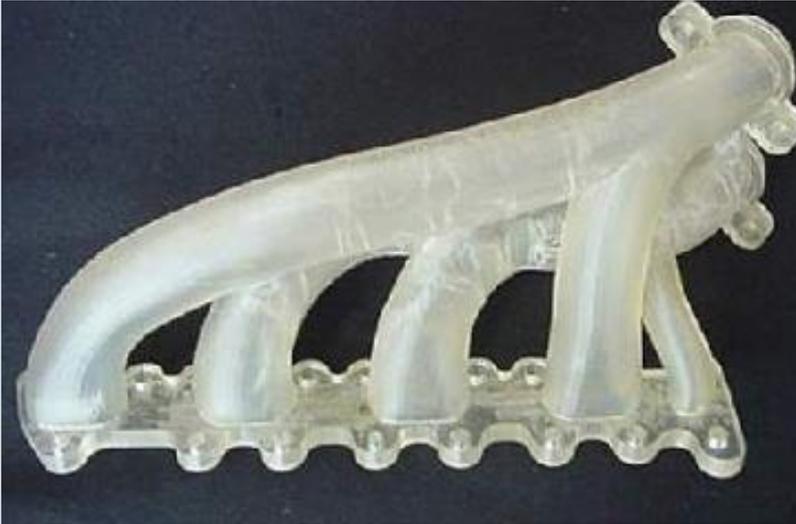
One of the oldest and biggest companies providing additive rapid prototyping as a service (you provide the 3D model, they print it).

We used them years ago to make a David head.
They have the largest printing vats in the market !!

# "almost" at home

Difficult to use at home… it uses laser, a vat full of resin, and require a lot of maintenance…

BUT

There are some experiments and new commercial printers to do "desktop" stereolithography…
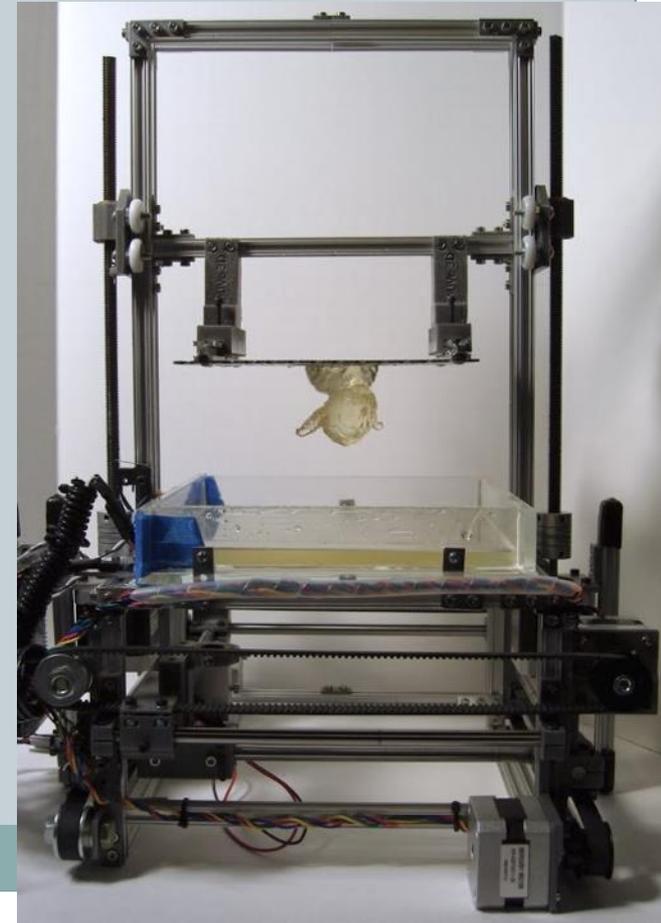
# Now, at home

"resin 3D printers"

Formlabs form2-3

Elegoo Mars

Anycubic photon

Still need lots of additional work: cleaning and maintenance, washing stations, more difficult the model preparation

# Other technologies

CHALK/powder printers

The printer deposits a layer of powder in a vat, then an inkjet head sprays glue on the "surface" of the object… Layer after layer the vat is filled, the object, now solid, is dug out from the powder…
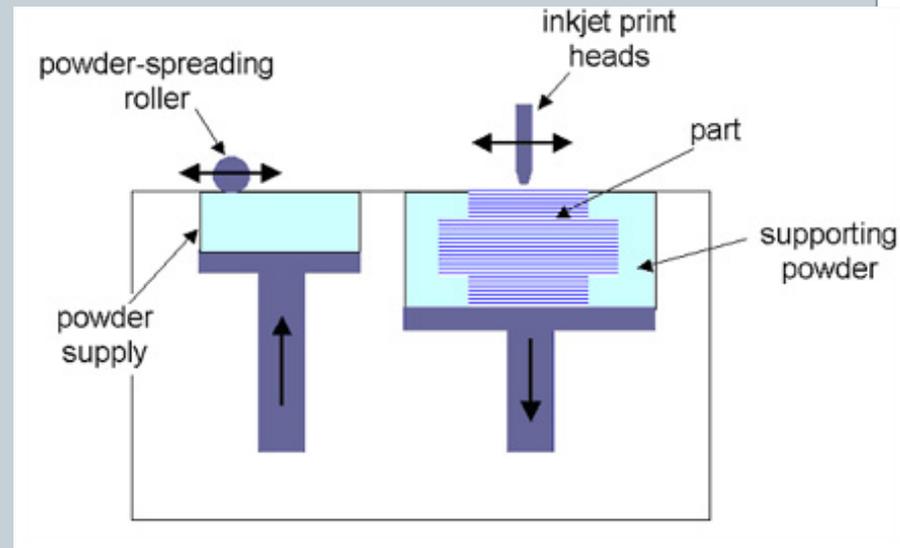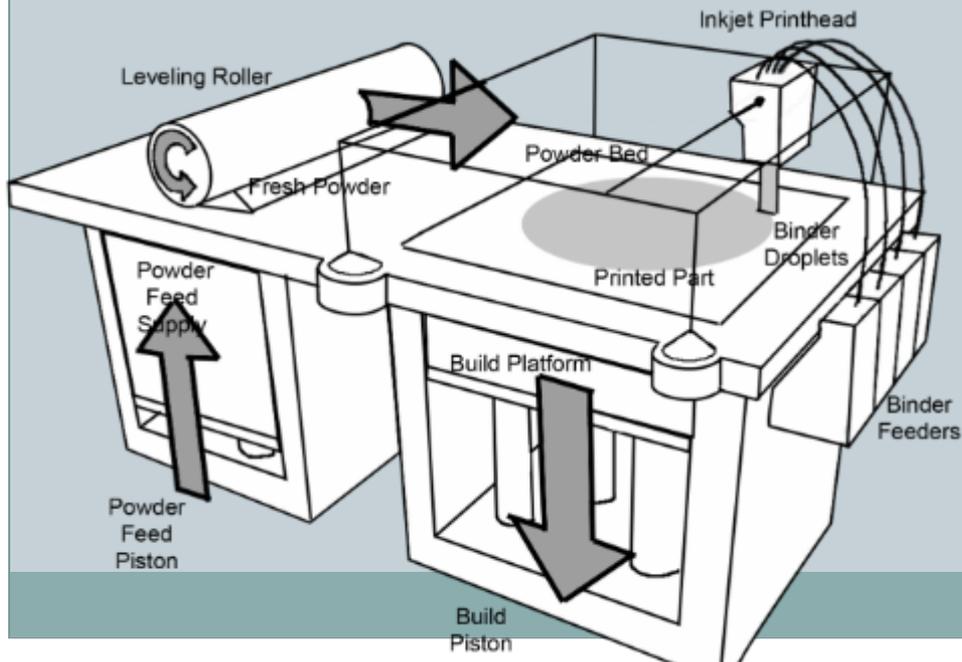
# Other technologies

- No desktop use: industrial machine requiring maintenance

- Slow and high cost

- Fragile



+ High detail

+ Can do color prints

+ No problems with overhangs (I'll expalin later)

+ The "feel" of the object is good for some markets

# Other technologies
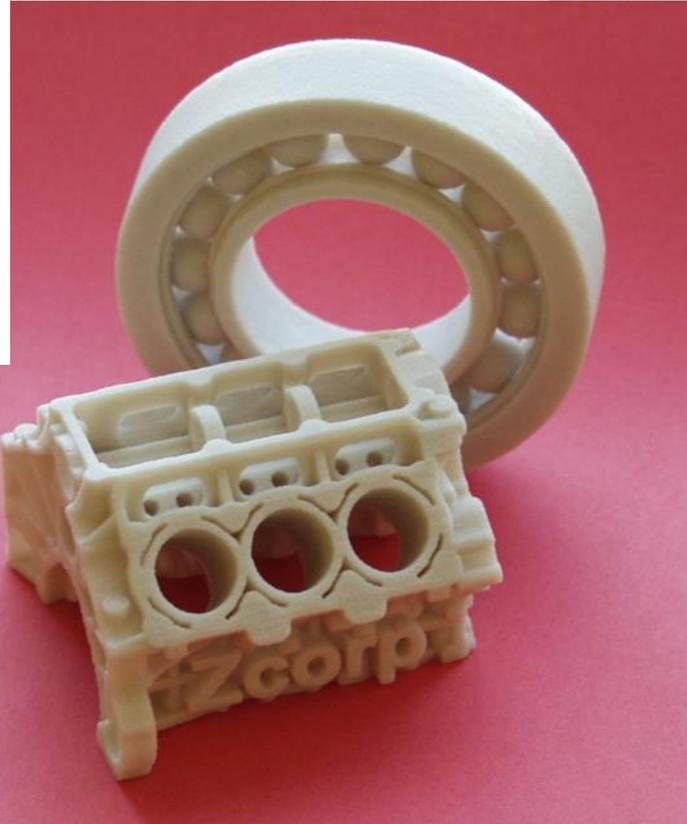
# What happened, then

The current 3D printing trend is the result of different factors

- Industry developer new technologies for the creation of physica objecs from 3D models

- Huge increase in the use of 3D models

- Cheaper hardware

- Popularization of the technology thanks to independent people aiming at developing open-hardware for 3D printing

# 3D Printing as we know it

3D printing, even if is used for any technology, is the name for all those technologies using an additive, layer by layer strategy, akin to "standard" 2D printing…

More specifically, with 3D printing, we generally indicate:

- Desktop, Do-It-Yourself, Home-safe printers

- Low cost approach (w.r.t. industrial solutions)

- ???

# The "open" approach

A group of enthusiasts, technicians and researchers started designing a machine able to print itself (!!)

So... simple mechanism for depositing material, and simple architecture.

The project was called **RepRap**
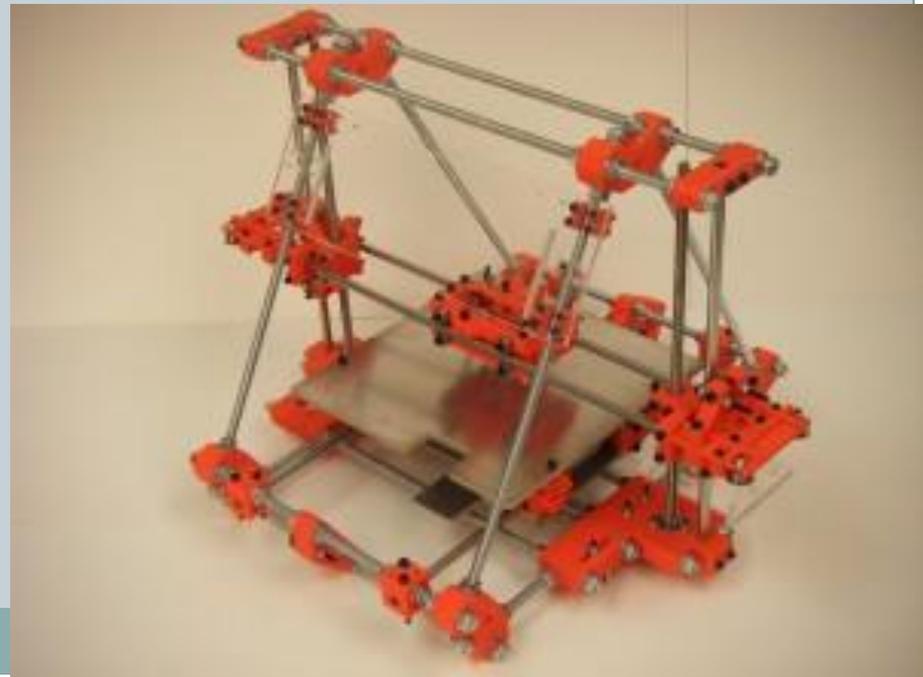
# The "Fused Filament" method

It was necessary to find a printing method which was simple, easy to do with common hardware, suitable for a "desktop environment"... **fused deposition modeling** (under copyright) or **fused filament fabrication**

Now expired!

- The printing material is plastic, stored as filament on a spool
- The material is heated to its melting point, and deposited in layers

(this method was also used in industrial printers)
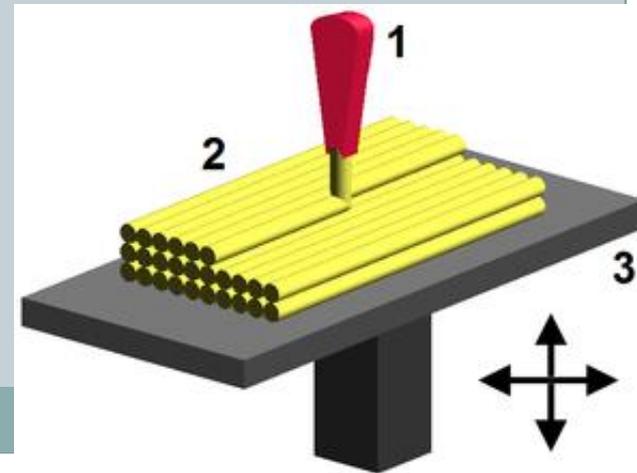
# FDM
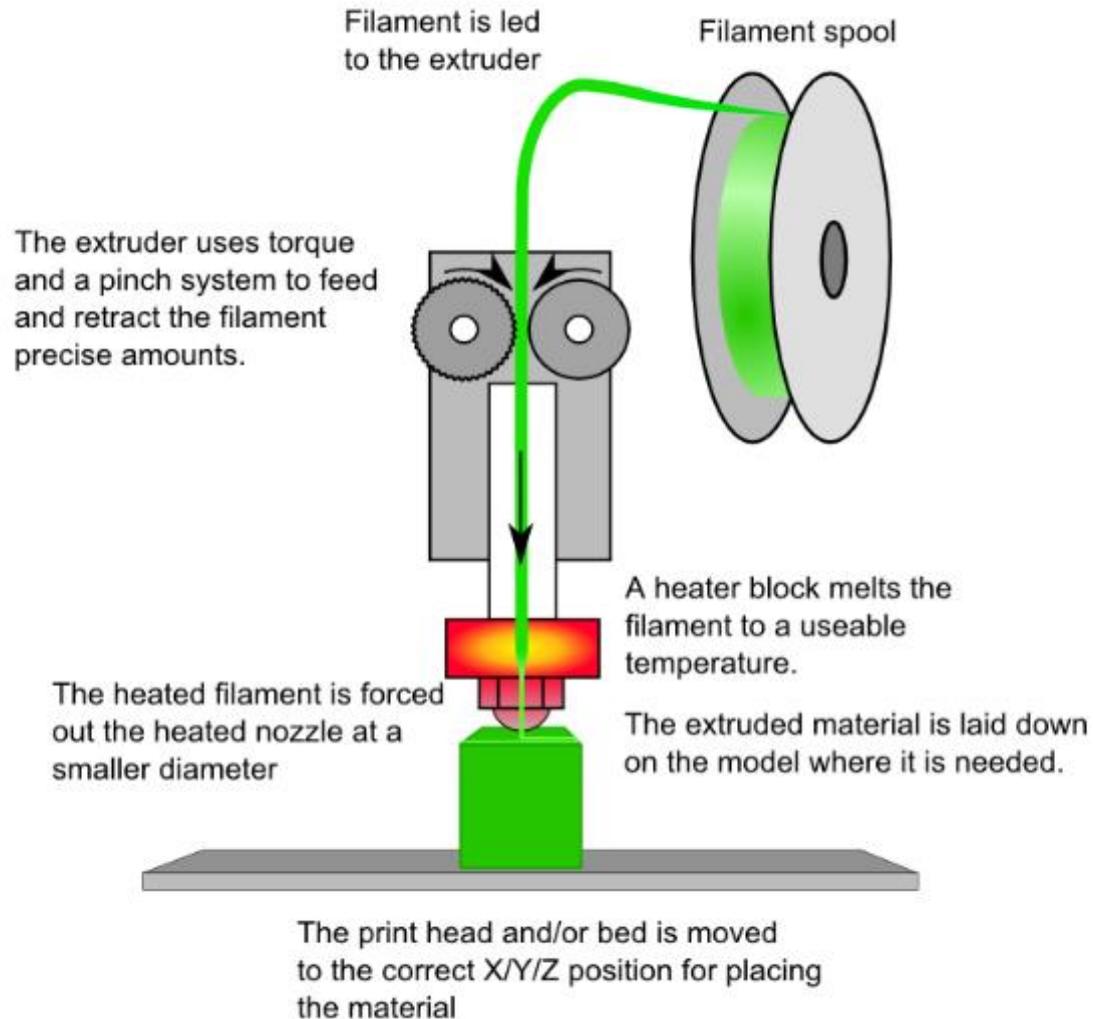
# The "open" approach

The RepRap project evolved a lot in the years, now there are different "blueprints" for whole printers, electronic components for printers, extruders... There are many "derived" models, kits on sale, and companies/fablabs helping you build your own DIY printer...

# A Do-It-Yourself Printer

Prusa i3

# A Do-It-Yourself Printer

Prusa i3

# A Do-It-Yourself Printer

## Prusa i3

# An entire ecosystem

Directly forking from RepRap, or inspired by it, a number of other 3D printers have sprouted…

Open, close, semi-open, open projects with closed parts, free software, open source software…

It is a **mess** just to understand what is available on the market
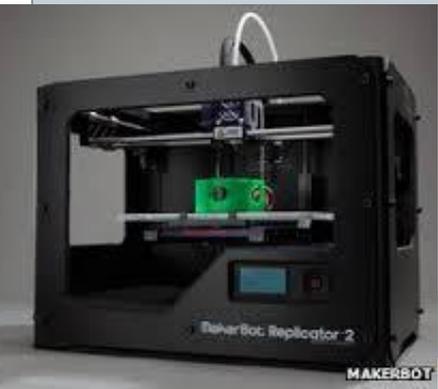
# An entire ecosystem

Beside the cost/print size/resolution…. Things to look for:

- Is the hardware open? Is it possible to open/dismantle the parts to clean/repair them?

- Which material can I use? Can I use third part material?

- Is the software included? Is it open? Can I use third-part software?

- Can I manage the build/operation/maintenance ?

READ REVIEWS!!! Ask on forums… Internet is good to find reliable feedback

# 3D model

A printer needs a "printable" 3D model…

The requirements for the 3D models are many, we will describe them in detail in the next days.

Some are related to the shape and detail…

Some are more "basic":

- Triangulated

- Closed (mostly)

- Shelled (maybe)

- Topologically clean (as much as possible)

# 3D model

- Not all 3 models are "directly printable", but may require conversion/resampling/heavy edit

- When hand-modeling, there are strategies to create printer-friendly geometries

I will try to cover these points, but…

- There will ALWAYS be unprintable 3D Models

# Before printing

The printer cannot directly handle a 3D model, but needs clear instruction on how to print it.

A conversion from a 3D Model to instructions is ALWAYS necessary. This processi is called **slicing.**
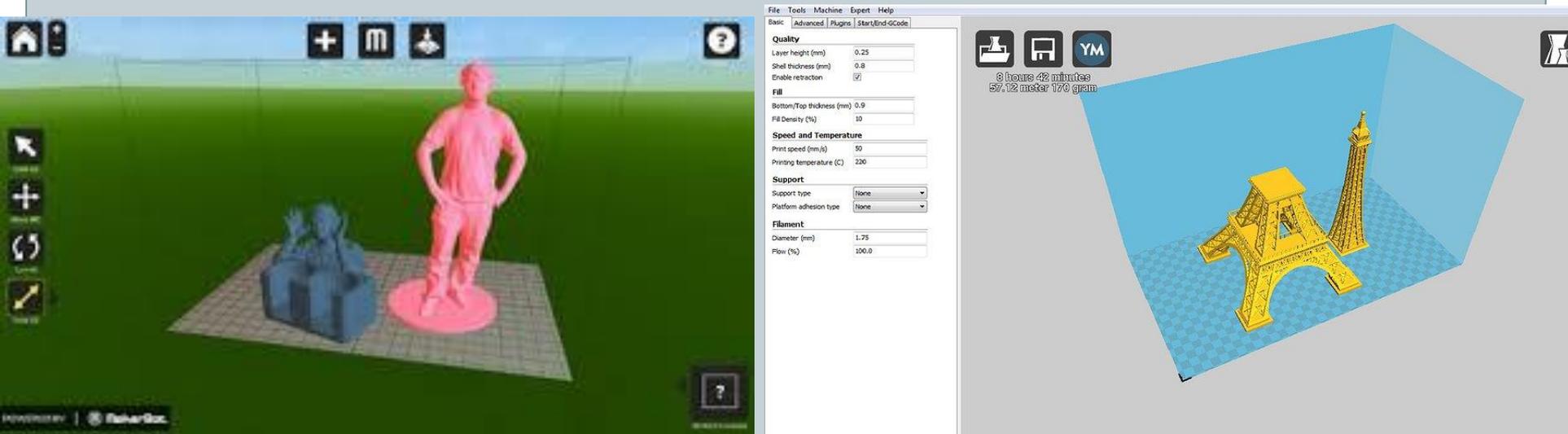
# Before printing

- Many slicing tools, from "single button" to extremely complex

- Different slicing tools will produce different results, some will not even be able to manage certain geometries

- Orientation of the 3D model DOES matter

- Knowing what happens in the slicing software helps a lot

- There will ALWAYS be unprintable geometries

# Toolpath Generation

# Toolpath Generation



Shells

Infill

Perimeter

Cover
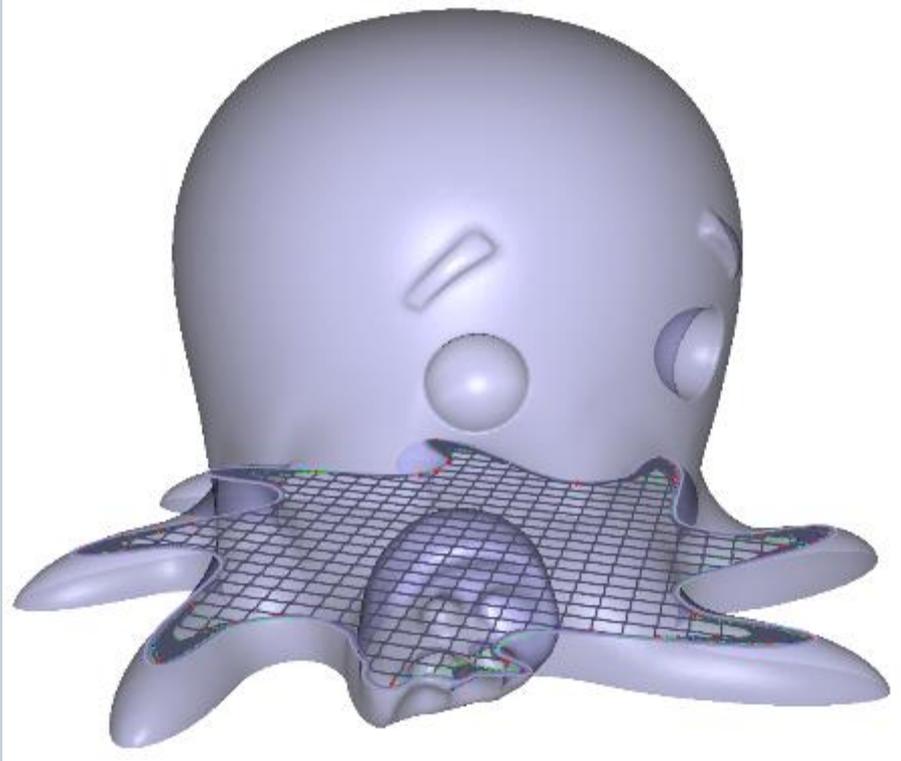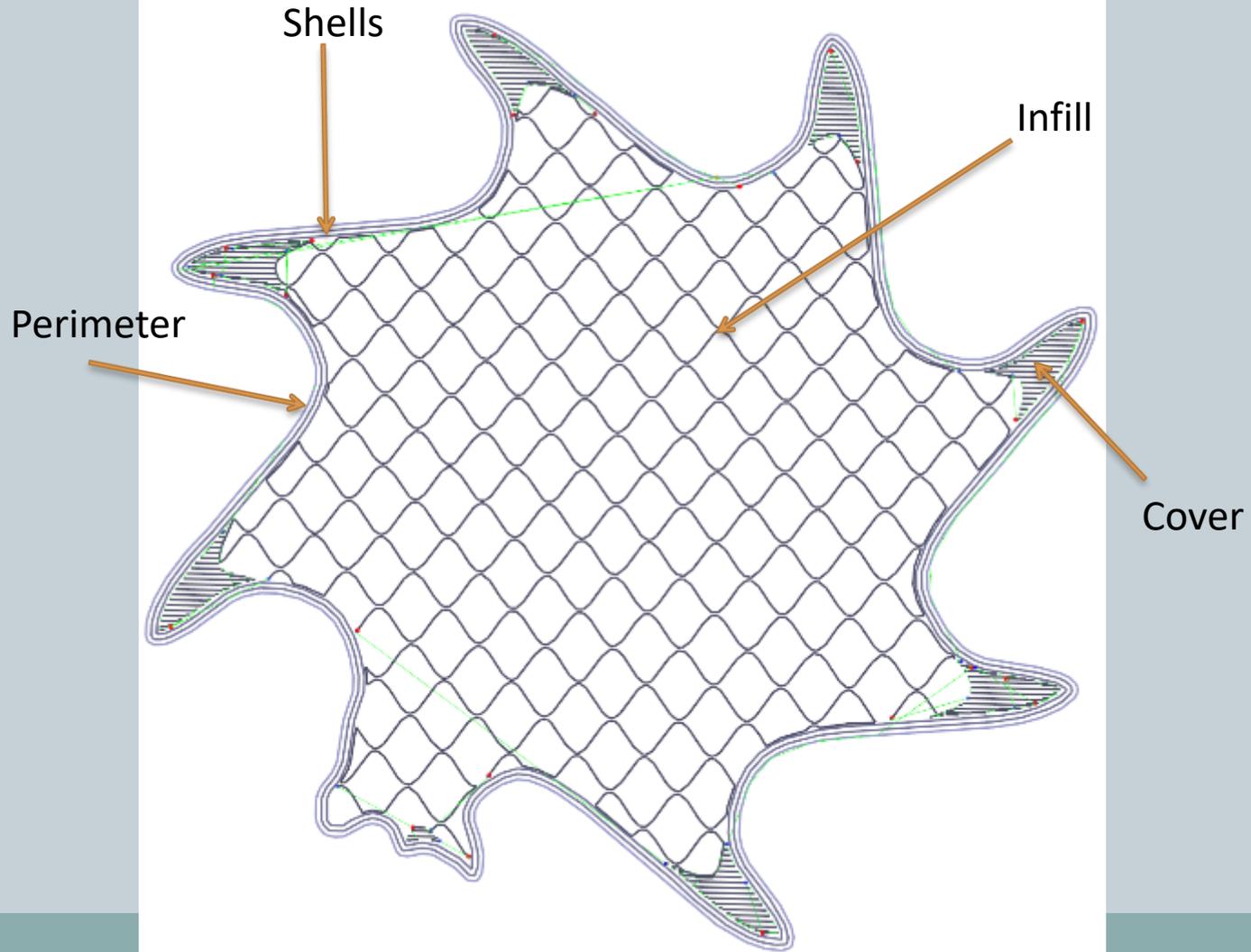
# Infill



MAKERWARE 2.2.0: Infill Patterns
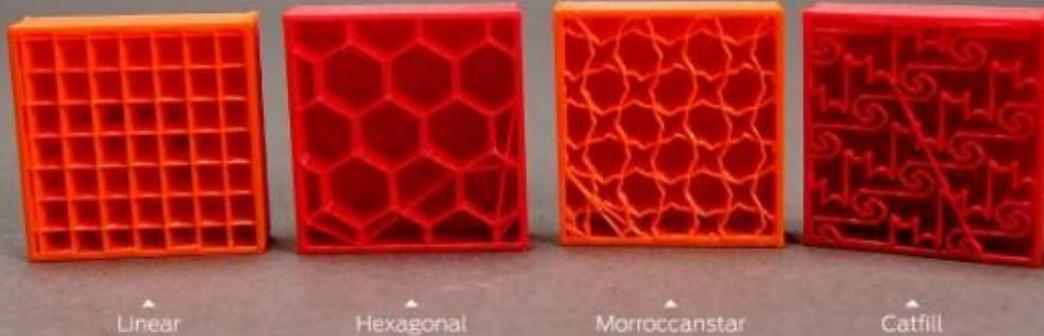
Linear   Hexagonal   Morroccanstar   Catfill

**Objective:** save material inside
the object volume
(and preserve strength)
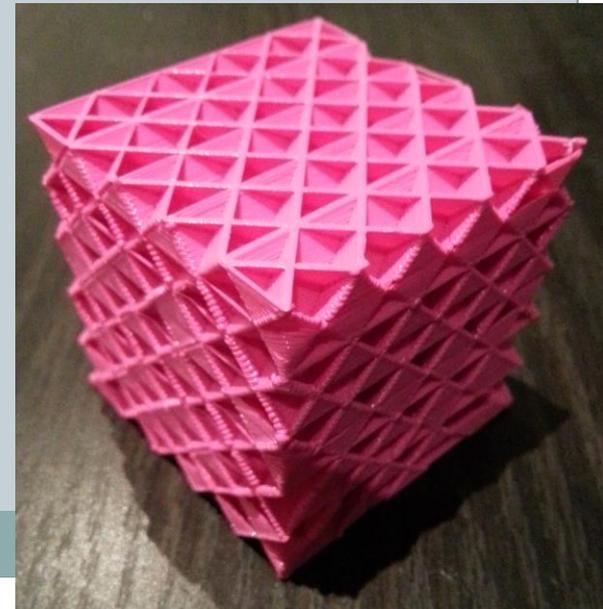
# Infill
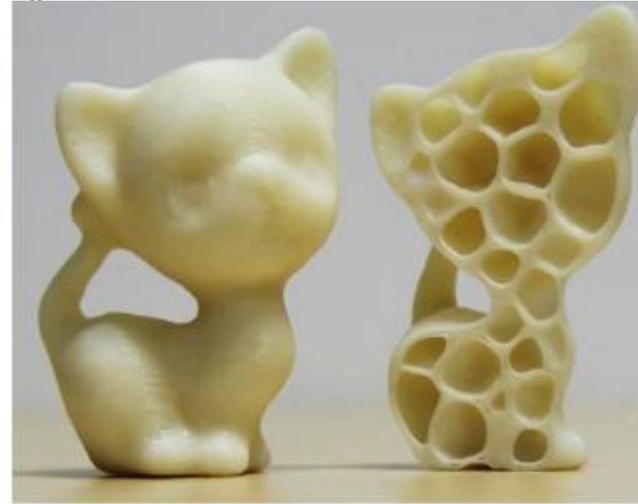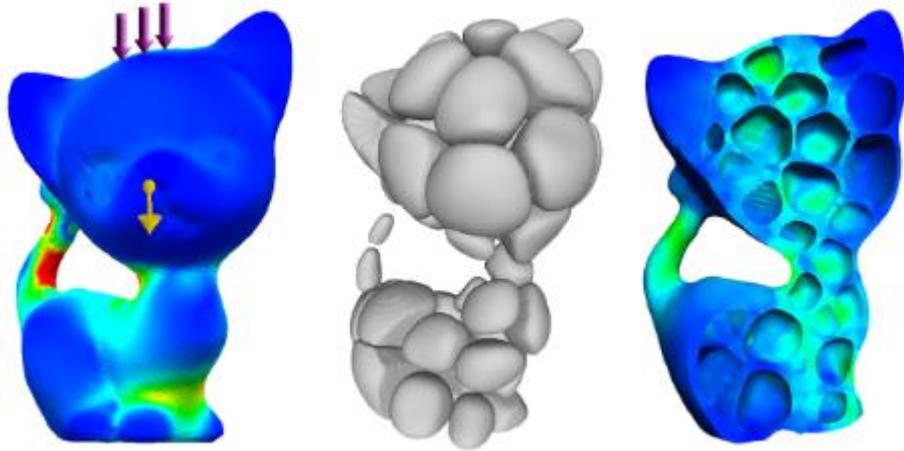


[Lu et al. 2014]

☐ **Inserting rods**
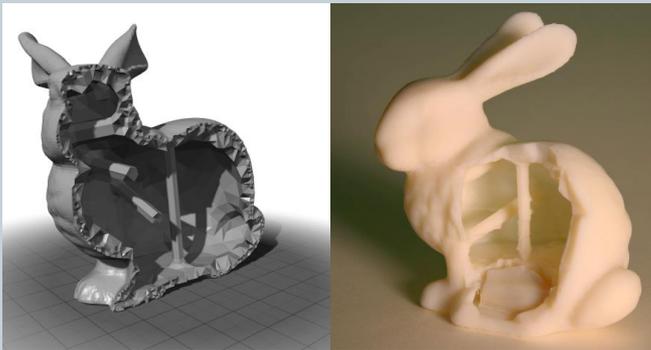


[Stava et al. 2012]

☐ **Optimize the internal structure**



[Wang et al. 2012]

# Support Structures

**Deposited material is not self supporting!**

☐ Automatic support generation done by most sofware tools

☐ Supports must be manually removed

☐ Some FDM's use a different support material (soluble)

☐ **In general: FDM and SLA need supports**!
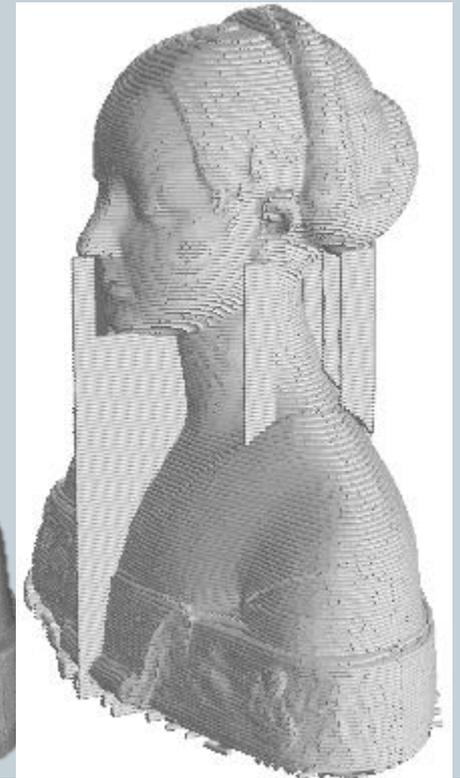
# Support Structures



[Dumas et al. 2014]



[MakerWare software]



[Vanek et al. 2014]



[Autodesk MeshMixer]

# Problems

- Overhangs

Layer by layer building has problems when geoemtry has outstanding parts, steep surfaces, undercuts

- Temperature

Plastic shrinks when cooling, curling/cracking the object. Too low temperature will not stick, too high will "bubble"

- Details/thickness

Even if the resolution of printer should handle them, most small details will disappear

# Slicing

Layering is unavoidable
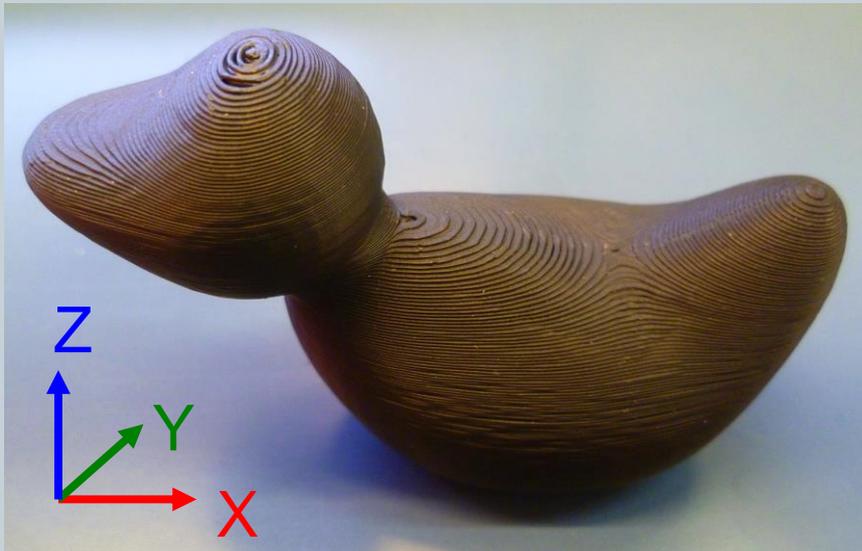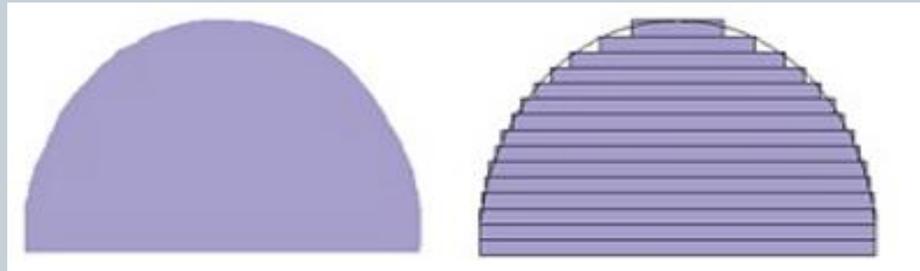


The precision is different between <X,Y> and <Z> axis

# Slicing
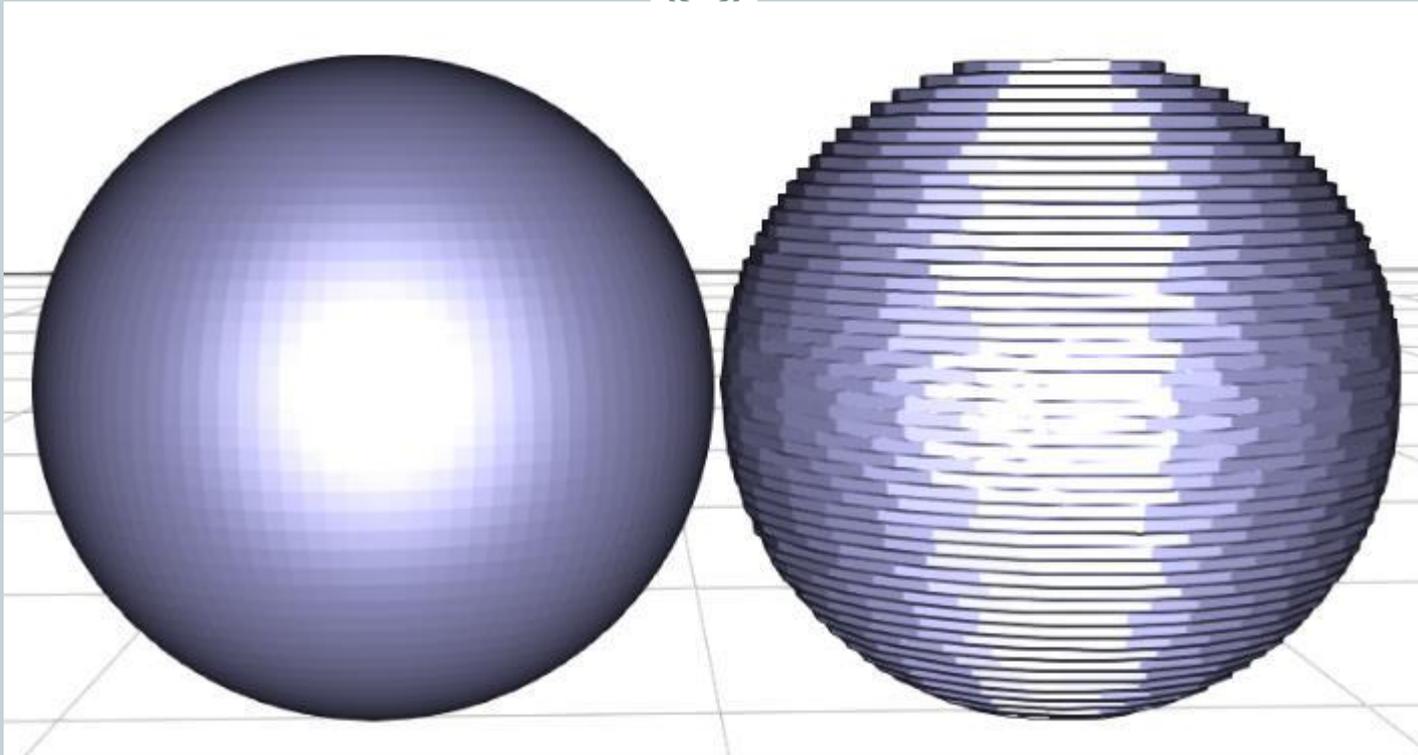


Lower layer thickness => Higher quality => Higher printing time

- 0.4 mm -> 1h
- 0.2 mm -> 3h
- …

# Problems

- Overhangs



Smart
Break Away
Support



MakerBot
MakerWare 2.3
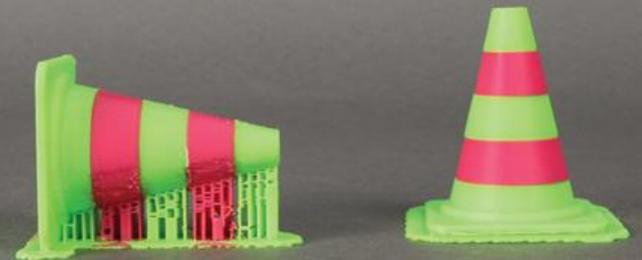
# Problems

- Temperature
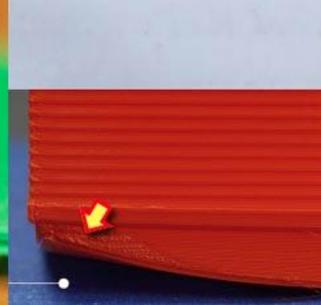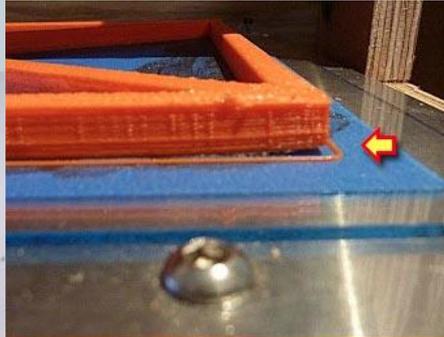


Photos from inte

# Not for home

We already saw 2 technologies not good for home/desktop printing…

- StereoLithography

- Powder printer

They are not the only ones…


All of them, however, are generally available through servicing…

# Other technologies

## LOM printers

Laminated Object Manufacturing. Roll/sheets of material are cut and stacked. (Again, layer-based)
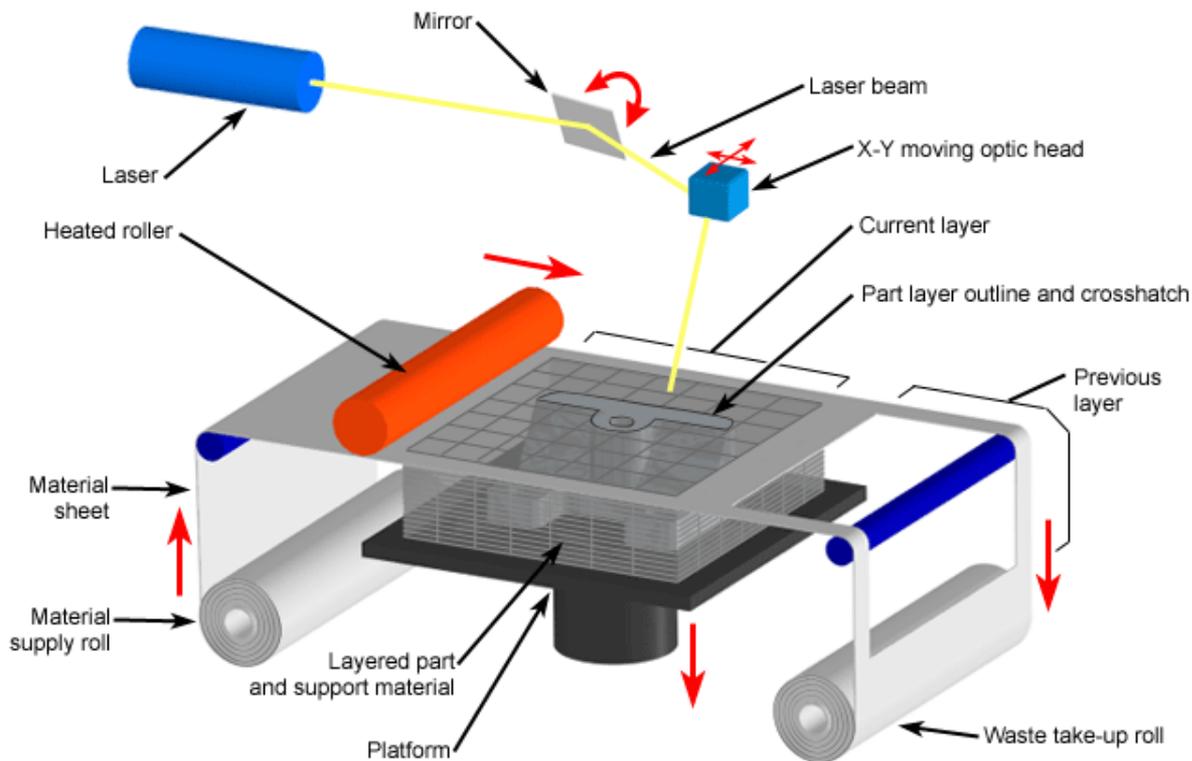
# Other technologies

**Paper** printers

A sheet of paper at a time is cut, color printed and glued to the underlying one.

Good, solid results, no problem with overhangs, colored output, wastes a lot of material, but is fully recyclable

# Other technologies

**Laser cutter**

Not strictly 3D printing, but still in the family.. 2D technique, but can be used for 3d objects
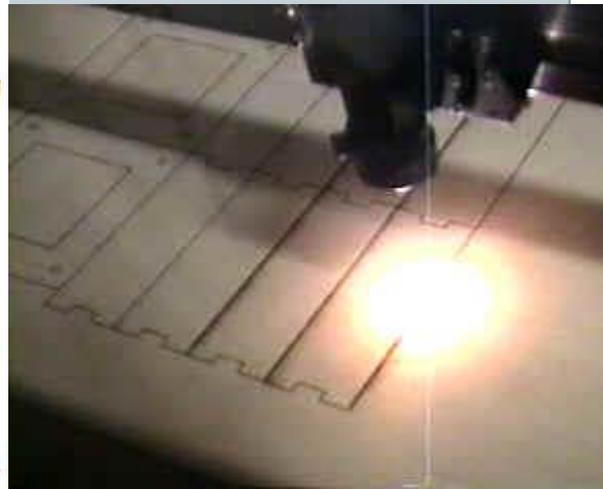
# Other technologies
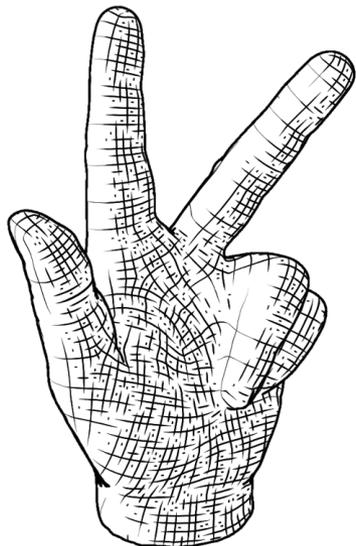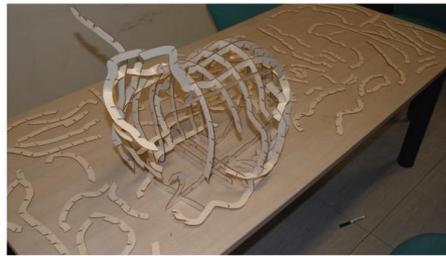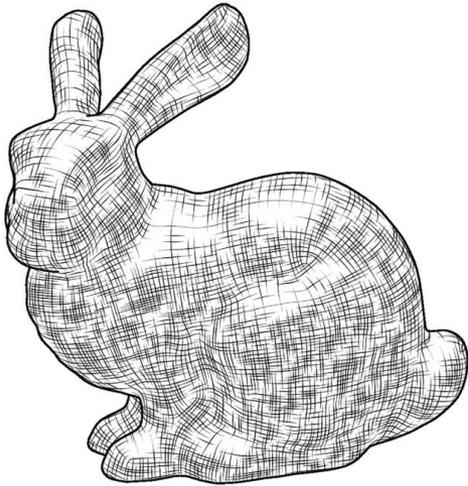
# Other technologies

**Ceramic** printers

The printer works more or less like a FF plastic printer, but deposit CLAY, that is then fired in a kiln

# Other technologies

**METAL** printers

The printer works more or less like a FF plastic printer, but deposit metal powder+resin, that is then fired in a kiln… OR a porouse substrate, which is then infiltrated with molten metal… OR it works like the powder printer, but the top layer is fused on the underlying one (see next slide).
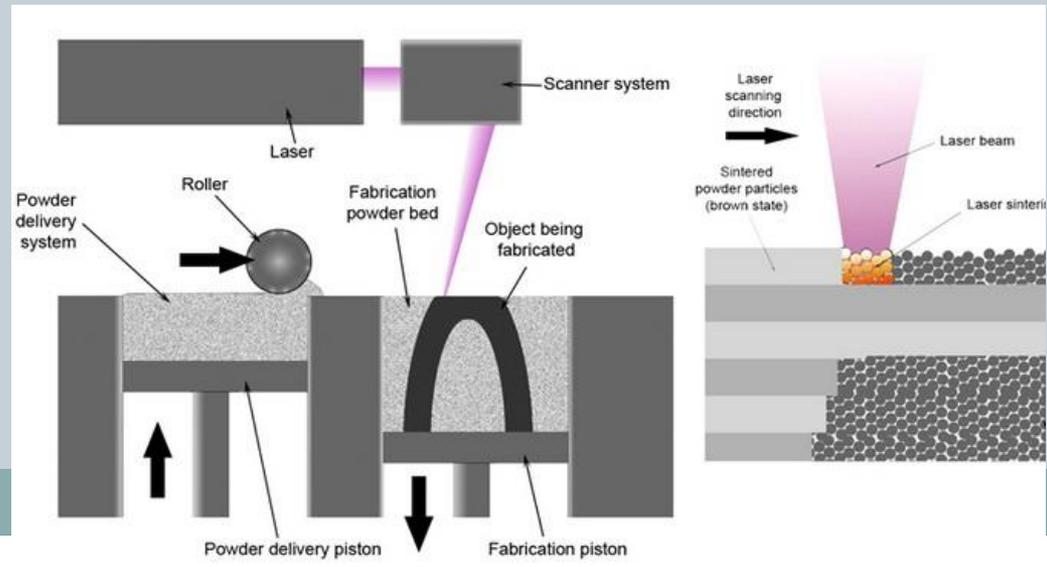
# Other technologies

**SINTERING** printers

Metals, plastics, hybrid materials… a laser "almost" melt a layer of material on top of another

# And so on…

Printing using many kind of **resins**

**Sugar**/**chocolate**/**food** printing

**Gold**/**Silver** printing

In most case, however, they use a variant of one of these techniques…

# Materials

Lot of research & experimntation with mixed materials

Plastic (mostly PLA variants) +

- Wood pulp
- Stone powder
- Metal powder

You get a printed object with a «fake material», with a texture, weight and finishing that resemble the real substance.

But with a higher wear on nozzle, and lots of trial/error…

# Controversy

Despite all the good things 3D printer can do, one thing was all over the newspapers last year:

**THE 3D PRINTED GUN**

Mostly, it was media stunt AND a Provocation of makers…
Anyone with a drill press / lathe may build a gun (much better than this one)
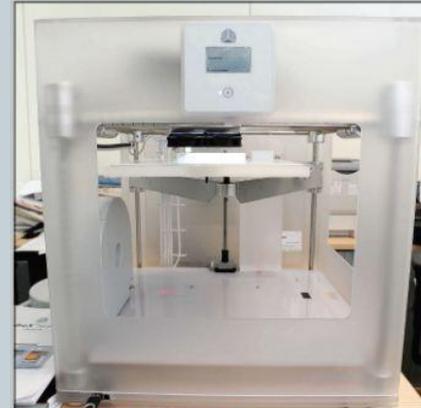


**1 THE £1,700 PLASTIC PRINTER**
WE purchased a £1,700 printer from the internet. The gun's blueprint was downloaded on to a computer, and then a memory stick was inserted into the 3D printer. It built up the design from layers of quick-setting plastic.

**3 THE SIMPLE ASSEMBLY**
USING simple DIY tools, each piece was filed and sanded to remove excess plastic, then the pistol's parts were assembled in just a matter of minutes.

**2 THE DEADLY, PRECISION-MADE PARTS**
IN LESS than 36 hours we had printed 15 plastic components. The final piece – a common nail which acts as a firing pin – was bought from a hardware shop. It is the only metal part of the finished gun.

HAMMER
HAMMER BODY
FRAME
BARREL
2 SPRINGS
TRIGGER SPRING
GRIP
WASHER
TRIGGER
FRAME PINS
FIRING PIN
HAMMER PIN
GRIP PIN

© daily mail
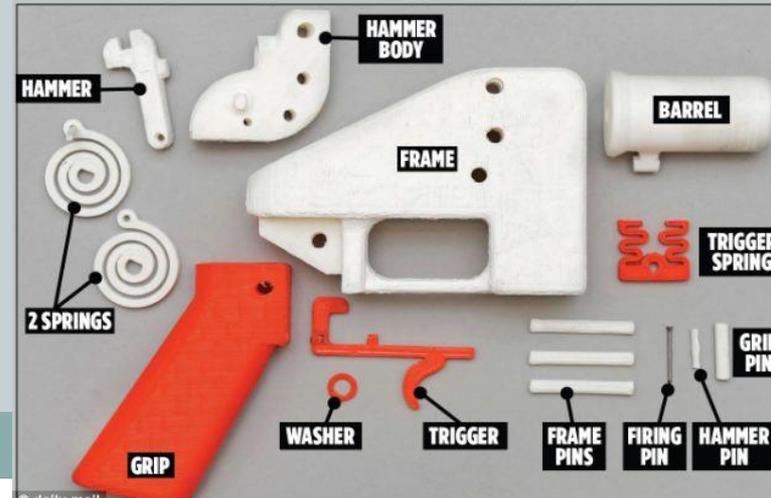
# Things to see

The internet is full of resources for people interested in 3D printing, I will try to point out some basic resources lesson by lesson...

- RepRapWiki

    http://reprap.org/wiki/RepRap/it

- Make magazine

    http://makezine.com/

- Instructables

    http://www.instructables.com/

# Thingverse

http://www.thingverse.com/

Free repository of printable objects, great resource for ideas, advices on printing, examples, reviews

Not so influential as it was before…

# Myminifactory

https://www.myminifactory.com/

Free repository of printable objects. The best place for geek gadgets.

Lots of good quality **CH** objects
(some "stolen" from museums)
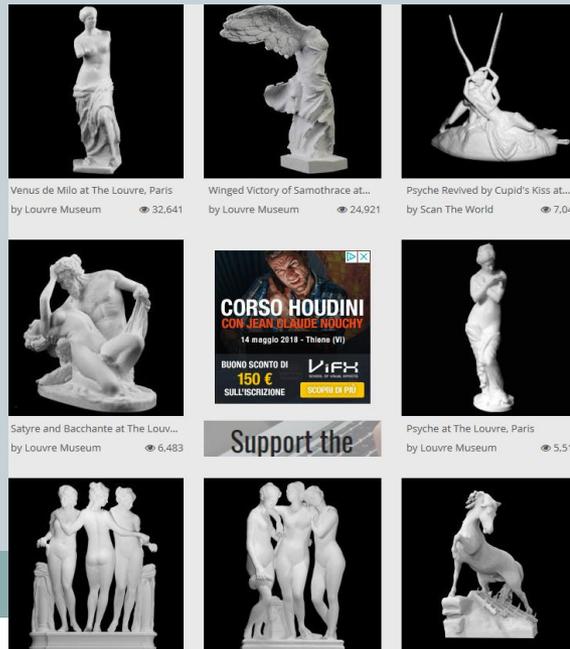
# Shapeways

http://www.shapeways.com/

Online service for 3D printing… you upload the model, choose the material, and order it

Not super cheap, but fast and reliable

# What about subtractive ?

Require much "harder" hardware, and it is not usable in a desktop environment. May go larger in size, but this require even costlier hardware

However, it is still widely used... the advantage is that it is possible to use different material... e.g. it is possible to carve STONE to replicate shape & material of a statue in the Cultural Heritage field, or metal for industrial applications

# Robot sculpting

You will be surprised to know how many sculpting robots are active in the Carrara area... most of them just for the initial steps, but some for the complete sculpting process...

# Robot sculpting
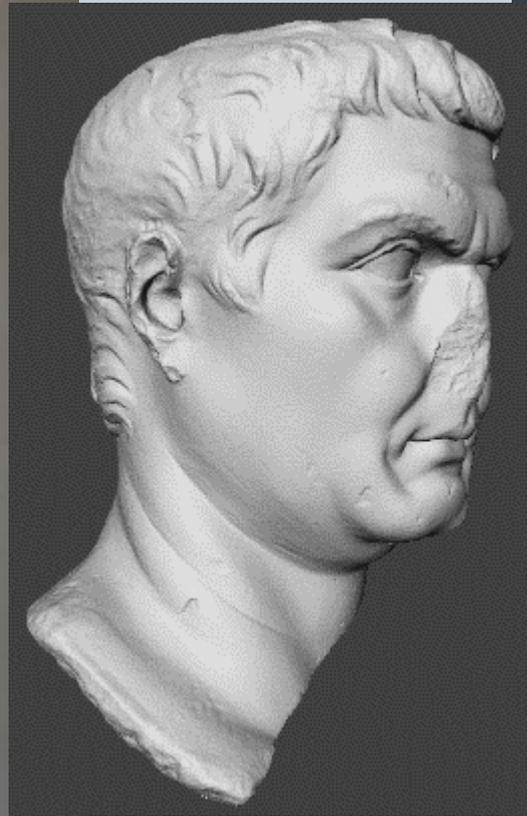
# At home ?

Some cheap do-it-yourself CNC, a couple of commercial products… however, still much more messy than FF printing
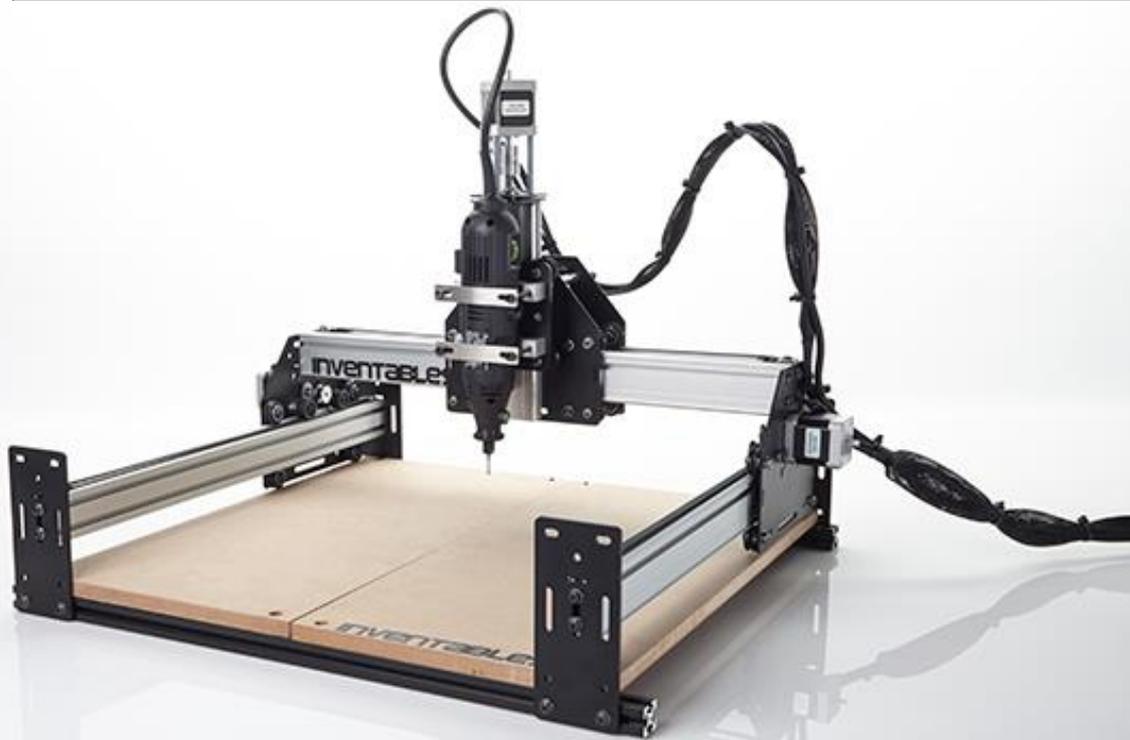
# Question Time

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`http://vcg.isti.cnr.it`

`http://vcg.isti.cnr.it/~callieri`