ISTITUTO ITALIANO DI TECNOLOGIA
CENTER FOR SPACE HUMANROBOTICS

Introduzione all’Additive Manufacturing

“Making things with a 3D printer changes the rules of Manufacturing’’ - *The Economist*

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TO ACHIEVE THESE TWO GOALS, THE IIT WILL COOPERATE WITH BOTH **ACADEMIC INSTITUTIONS AND PRIVATE ORGANIZATIONS**, FOSTERING THROUGH THESE PARTNERSHIPS **SCIENTIFIC DEVELOPMENT, TECHNOLOGICAL ADVANCES AND TRAINING IN HIGH TECHNOLOGY.**

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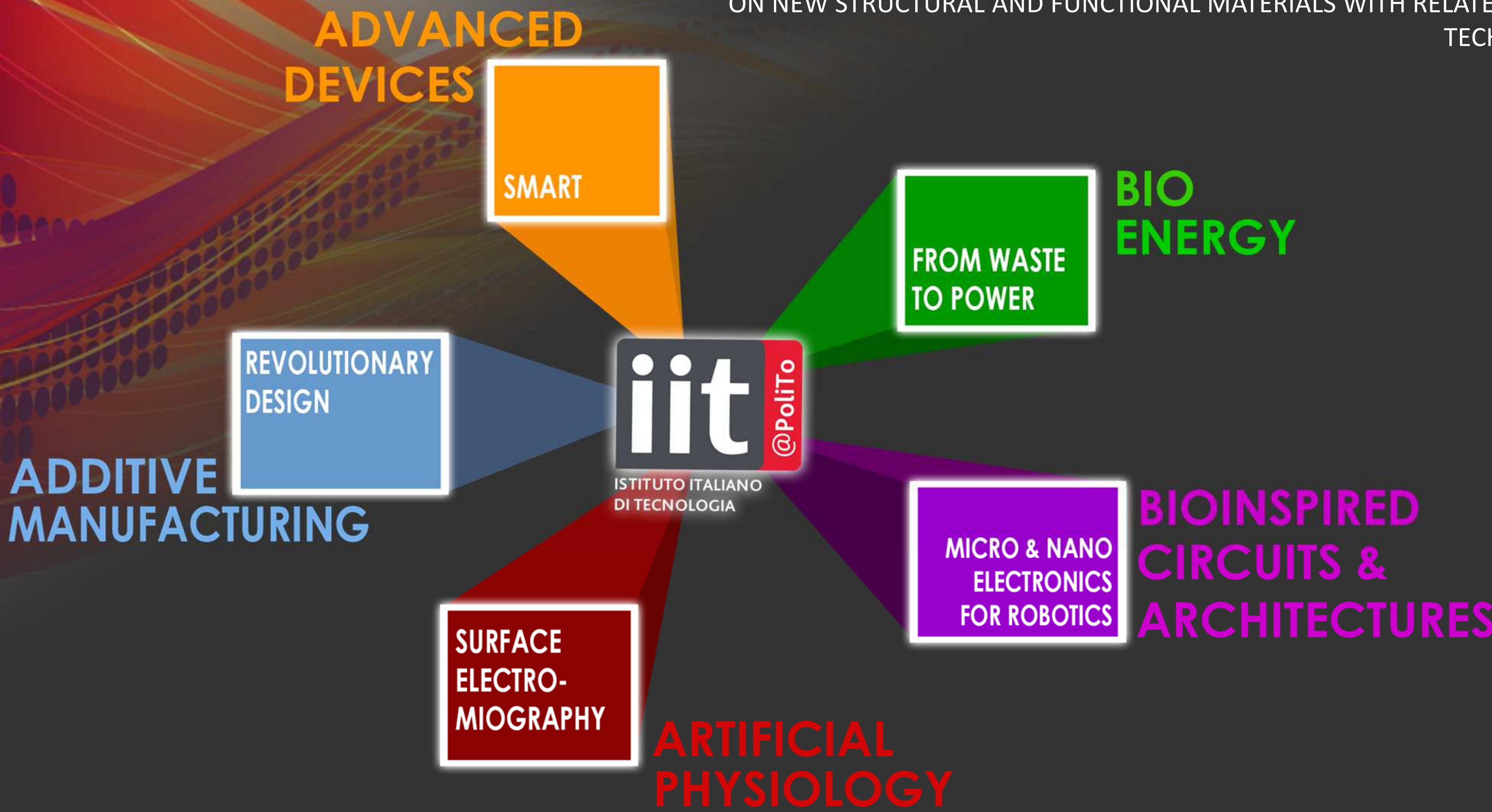
MISSION OF THE CENTER: **TO STUDY, DESIGN AND REALIZE/ASSEMBLE DEMONSTRATORS** FOR THE **FUTURE GENERATION OF MATERIALS, PROCESSES AND COMPONENTS** FOR SEVERAL APPLICATIONS.

THE DEVELOPMENT OF THESE BASIC FUNCTIONS DEMANDS SEVERAL **TECHNOLOGIES AND STRUCTURAL/FUNCTIONAL COMPONENTS, SENSOR/ACTUATOR, MEMS AND NEMS DEVICES**.

IT ALSO REQUIRES **COMPACT AND FLEXIBLE ENERGY SUPPLY SYSTEMS**, ALL BASED ON NEW STRUCTURAL AND FUNCTIONAL MATERIALS WITH RELATED PROCESS TECHNOLOGIES



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OUTLINE

- WHAT'S ADDITIVE MANUFATURING?
- STATE OF THE ART, MARKET FORECAST AND BRIEF HISTORY
- PROCESSES, TECHNOLOGIES AND MATERIALS
- APPLICATIONS

ADDITIVE MANUFACTURING

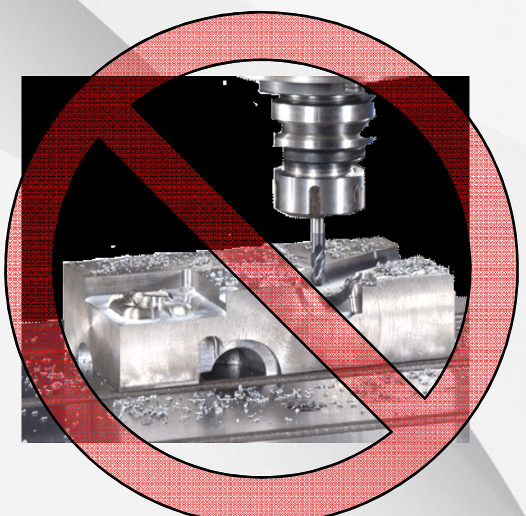
WHAT IS ADDITIVE MANUFACTURING?

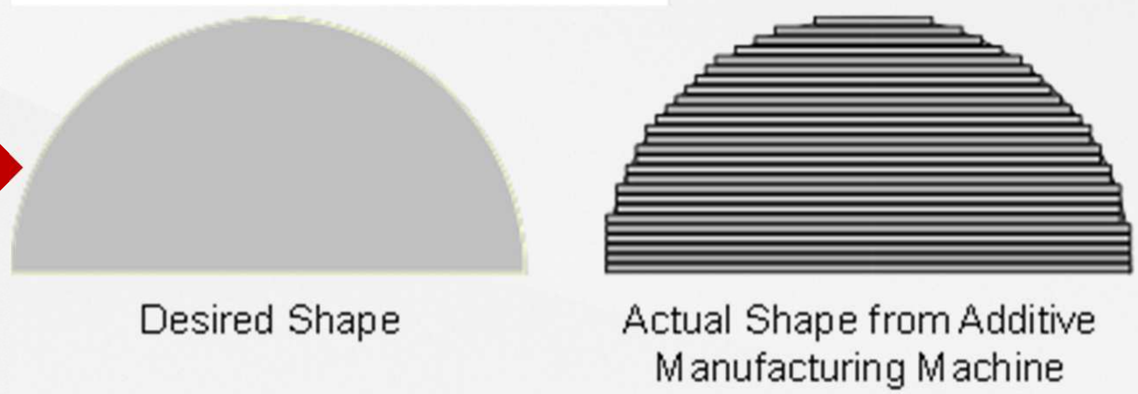
Source: Terry Wohlers Report 2013 - Annual Worldwide Progress Report

ADDITIVE MANUFACTURING: Process of joining materials to make objects from **3D model data**, usually layer upon layer, as opposed to subtractive manufacturing methods

Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, freefrom fabrication, (3D Printing-associated with machines lower in price/capability)

3D PRINTING: Fabrication of objects through the deposition of a material using a print head, nozzle or other printer technology





ADDITIVE MANUFACTURING

WHAT IS ADDITIVE MANUFACTURING?

- **Additive Manufacturing** refers to a process that **builds up a component in layers**, as opposed to a subtractive operation, which removes matter from a block of material to form a product.
- This approach permits to extend the **freedom of design** and manufacture by allowing, for example, to create an object with **desired shape** and **internal structure** in a single fabrication step
- The design of the part can be **tailored** to meet specific functions and properties (e.g. physical, mechanical, chemical, etc.) using **different materials** (titanium, nickel based superalloys, cobalt-chromium, aluminum)

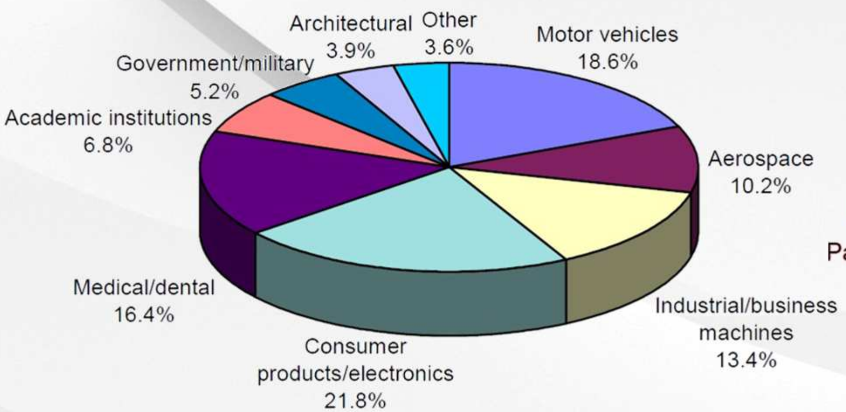
KEY DATES

Fine anni Settanta: gli americani Herbert e Hull e il giapponese Kodama sviluppano indipendentemente un sistema di solidificazione selettiva di un fotopolimero per costruire un oggetto tridimensionale per strati successivi

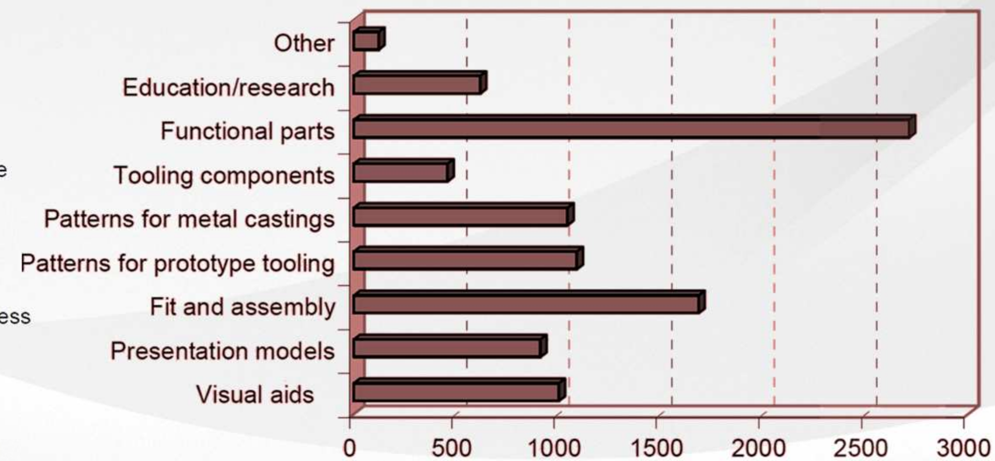
- **1986: Hull** brevetta un sistema che chiama "stereolitografia"
- **1986-87:** si sviluppa la maggior parte dei sistemi alternativi di prototipazione rapida
- **1987:** la **3D System** presenta la prima macchina (SLA1)
- **1989:** la macchina SLA 250 viene posta in commercio dalla **3D System**
- **1991-93:** vengono commercializzate le macchine della **Cubital**, **DTM**, **EOS**, **Helysys**, **Stratasys** con tecnologie alternative alla stereolitografia per la costruzione di prototipi
- **1994:** la **Sanders** commercializza la prima macchina avente un costo inferiore ai 100.000$
- **1996:** la **3D System** e la **Stratasys** introducono sul mercato i modellatori concettuali da destinare all'ufficio tecnico
- **1996-TODAY:** implementazione e diffusione in tutto il mondo di nuove tecniche

State of the Art

INDUSTRIAL SECTORS

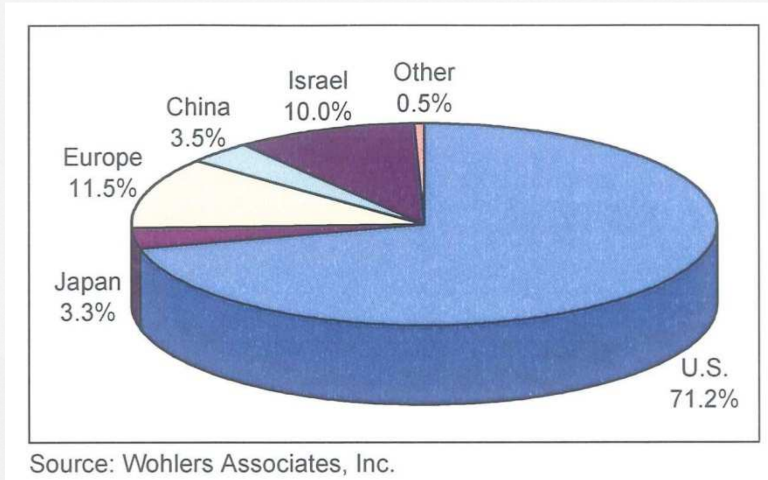


HOW COMPANIES ARE APPLYING AM PROCESSES



MARKET OPPORTUNITY AND FORECAST

WORLD INSTALLATIONS



Source: Terry Wohlers Report 2013 - Annual Worldwide Progress Report

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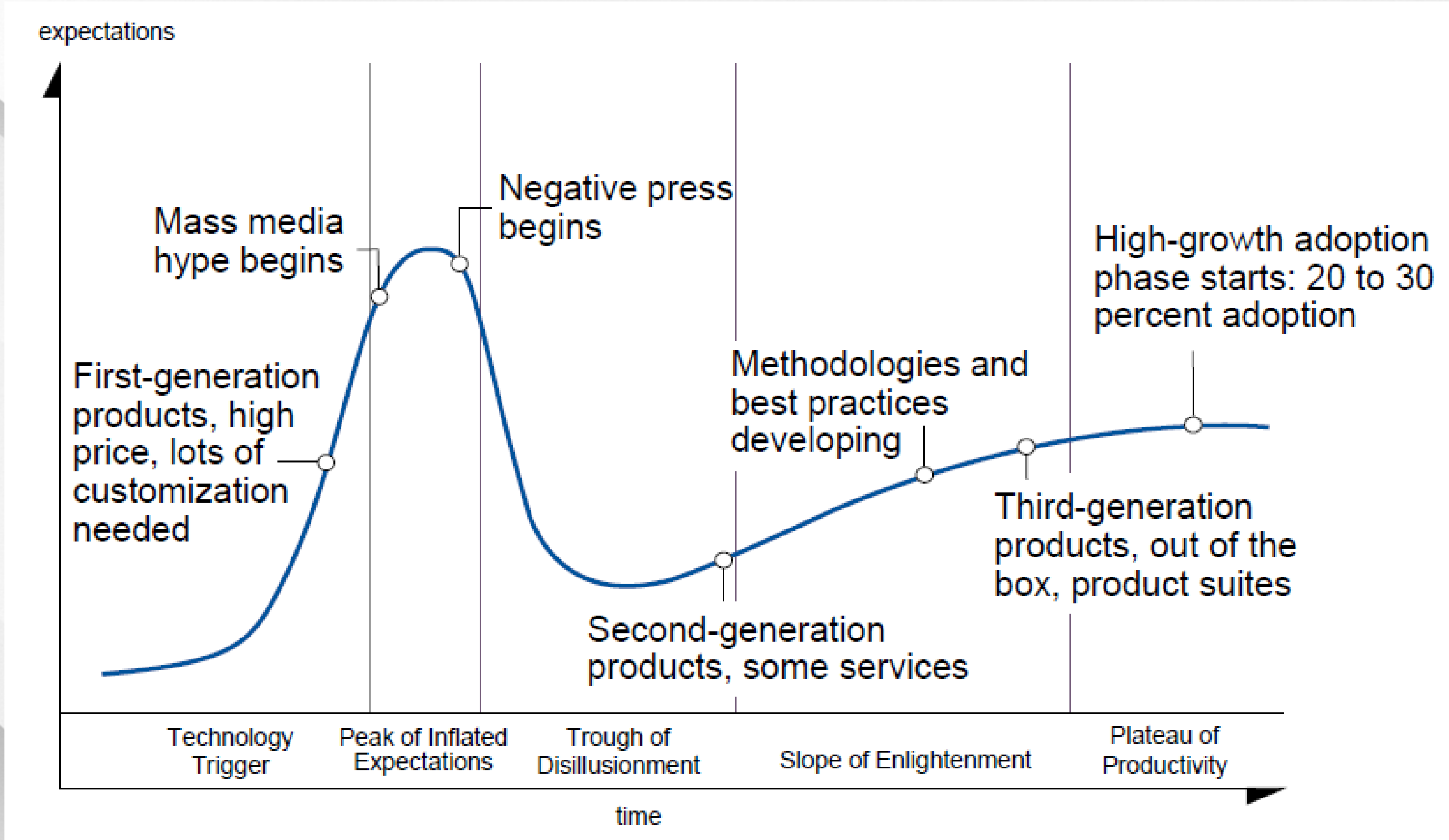
State of the Art



Gartner propone un andamento tipico delle aspettative riposte in una certa tecnologia, in funzione del tempo. Tendenzialmente si osservano almeno 3 macro fasi: **sovra-entusiasmo**, **disillusione**, **realismo**.

DOVE STA OGGI L'ADDITIVE MANUFACTURING?

Source: Gartner Inc.'s 2012 Hype Cycle for Emerging Technologies

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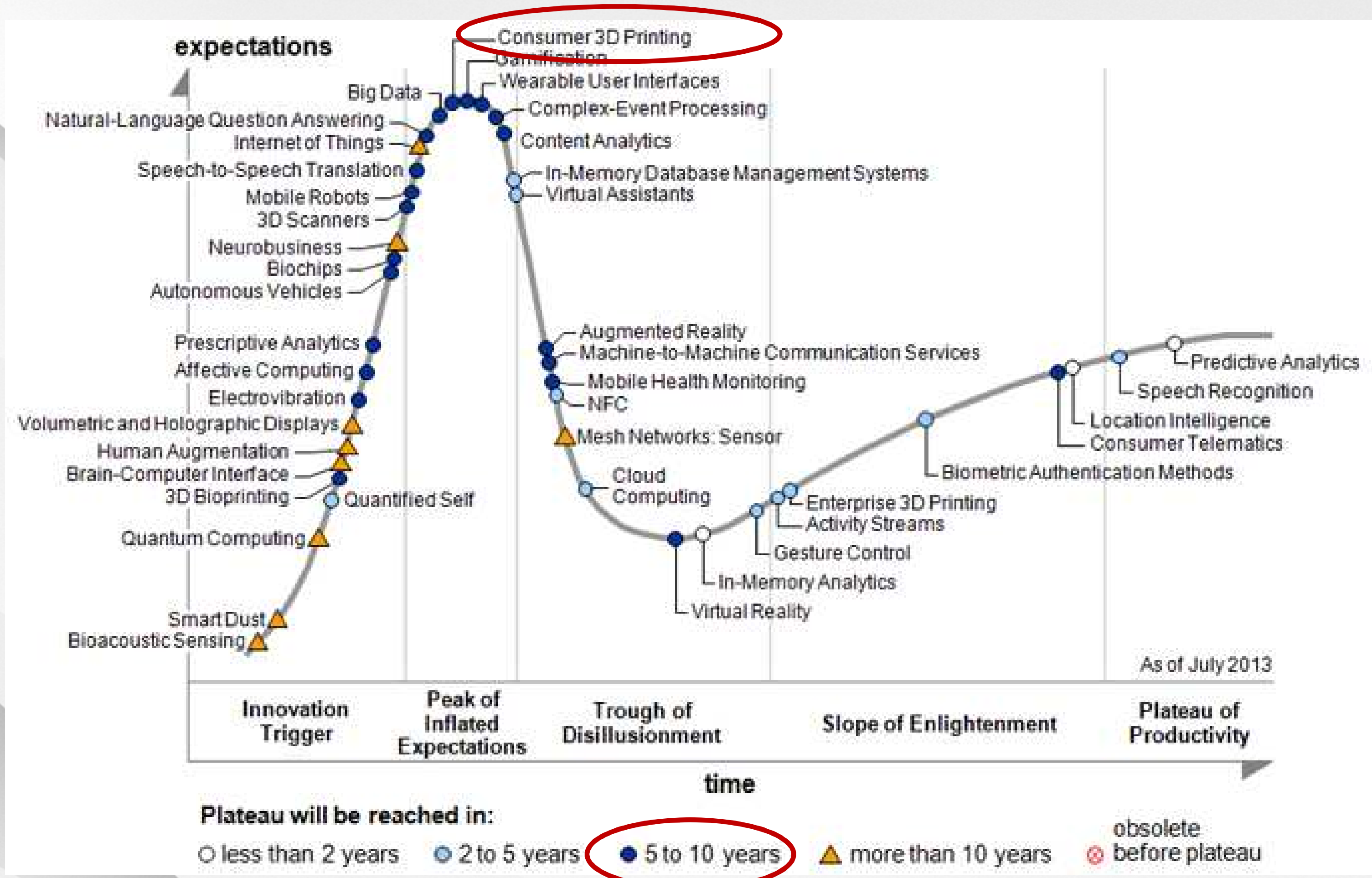

L’ **Additive Manufacturing** si trova ora sul picco del ciclo di evoluzione delle tecnologie emergenti

- Argomento di moda, con ampi spazi sui mass media
- Le aspettative sono molto rilevanti e potenzialmente dirompenti, ma l’impatto sarà ridimensionato nei prossimi anni (disillusione)
- La tecnologia sarà matura nel medio-lungo periodo: 5-10 anni

Source: Gartner Inc.'s 2012 Hype Cycle for Emerging Technologies

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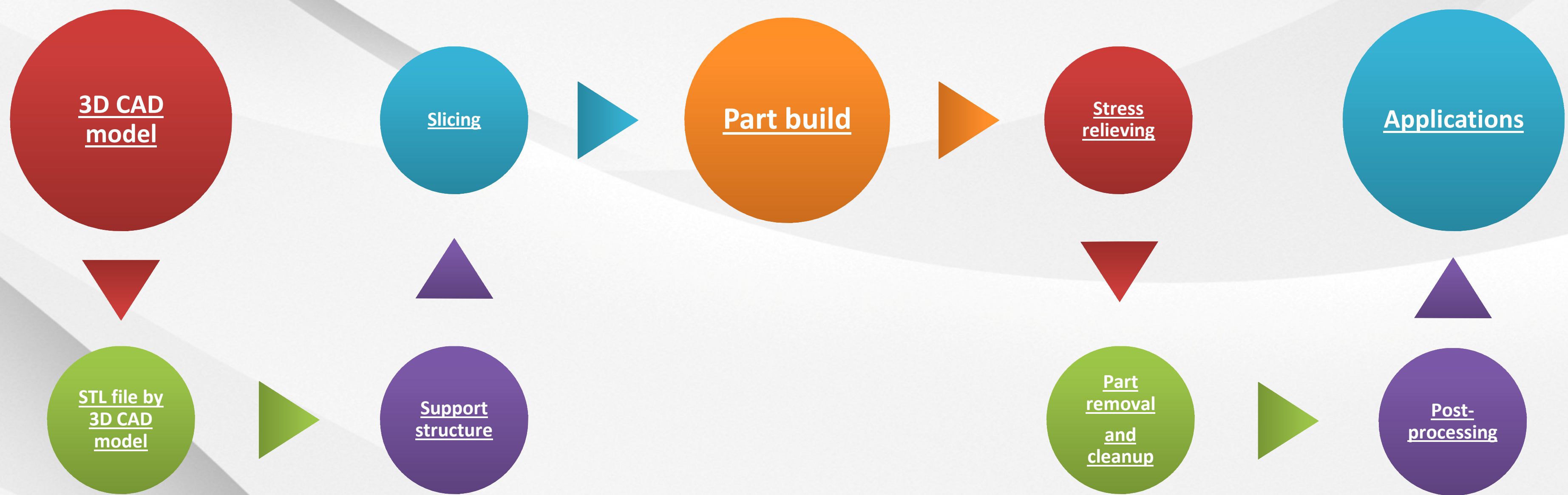
Generalized AM Process



Different AM technologies need to be handled differently with regards to this process sequence

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3D CAD (Computer Aided Design) model

3D CAD model

CAD software builds solid geometry for manufacture as 3D objects based on parametric constraints

To be able to optimize the shape, a set of parameters must be defined in order to respect the specifications as well as the manufacturing constraints (thicknesses, hole's diameter, filled radii, ...)

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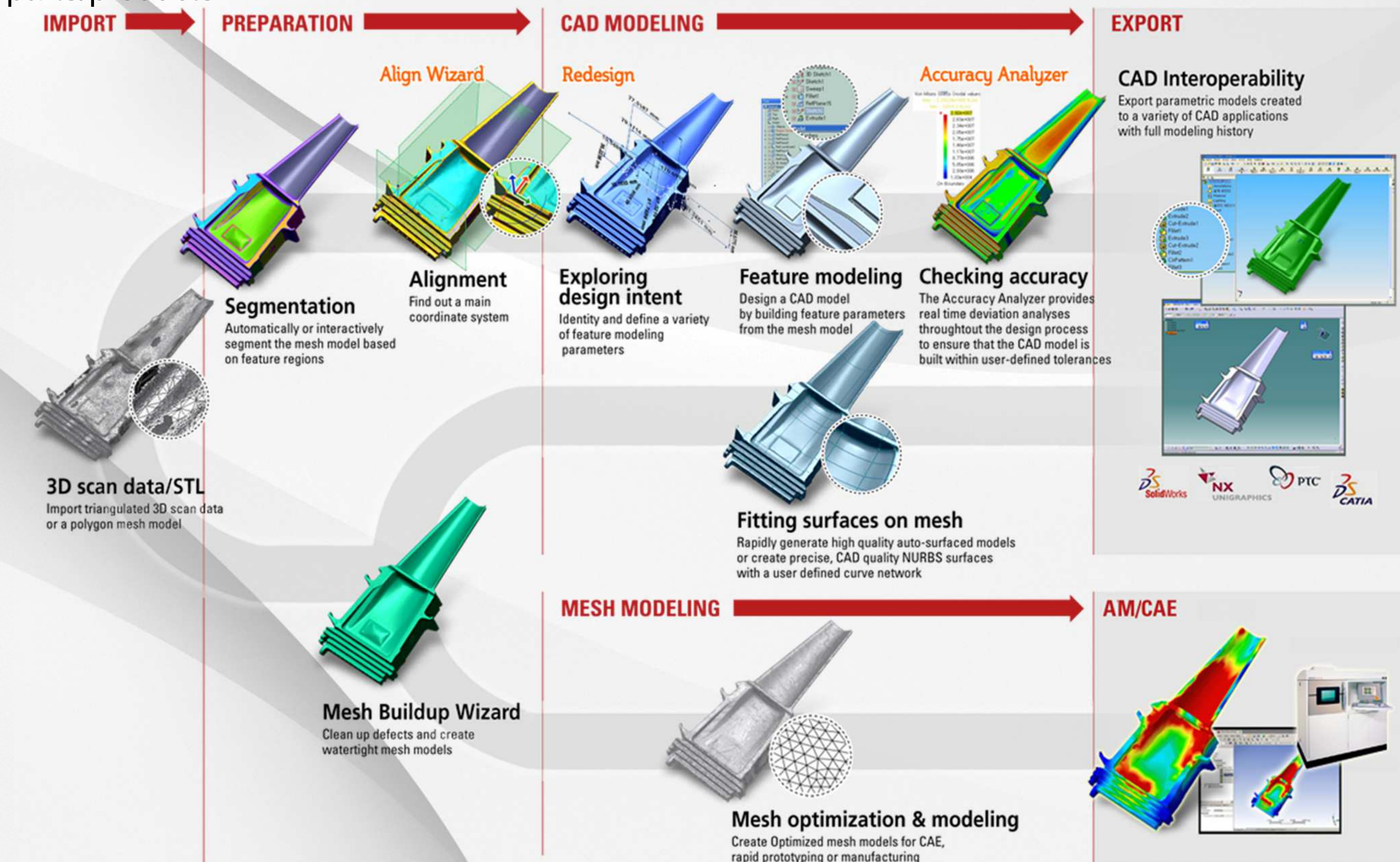
3D CAD model

Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/digitizing existing parts/products.



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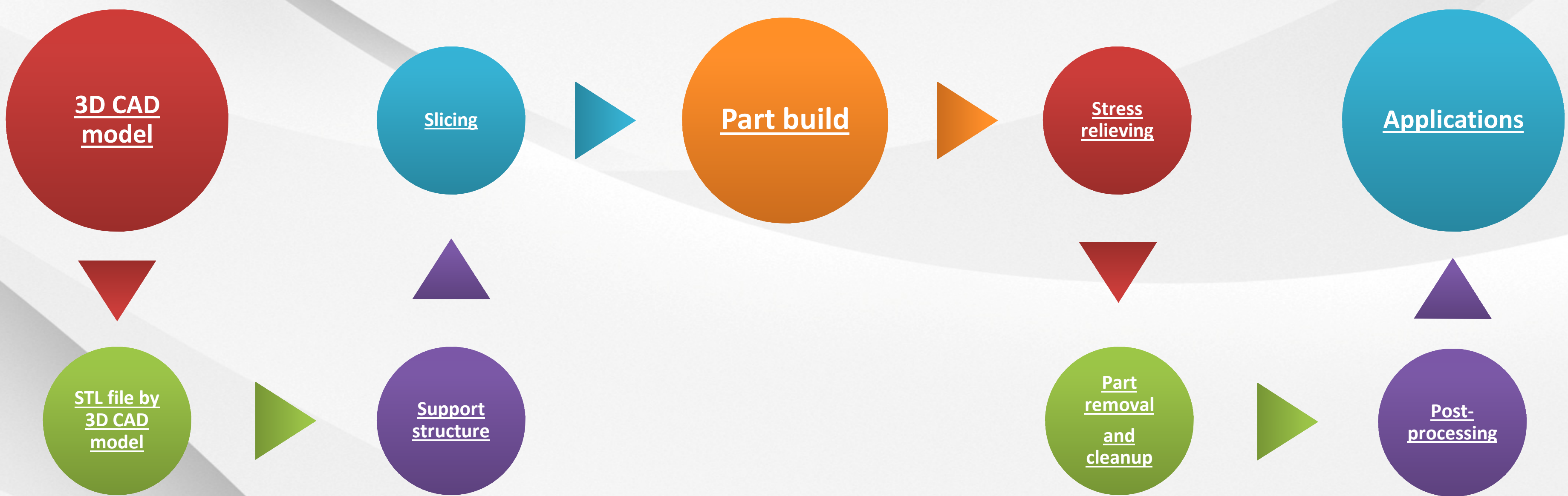

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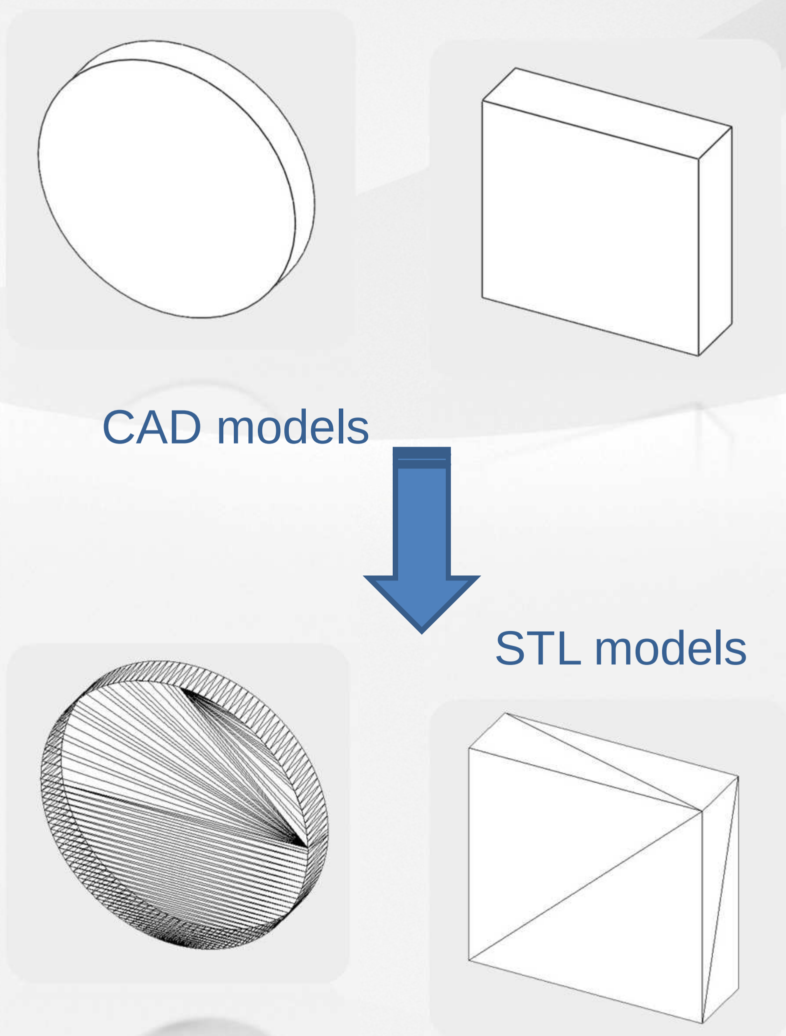
STL file by 3D CAD model

- STL (3–D, 1989) file is a *defacto standard input file for many* AM processes. It is a tessellated of objects, wherein the surfaces of the objects are represented by triangular facets, thus introducing error in the representation of the surfaces.

STL file by 3D CAD model

- For higher number of facets the surface is smoother. So, the accuracy of CAD represented surface increases as the number of facets increases.



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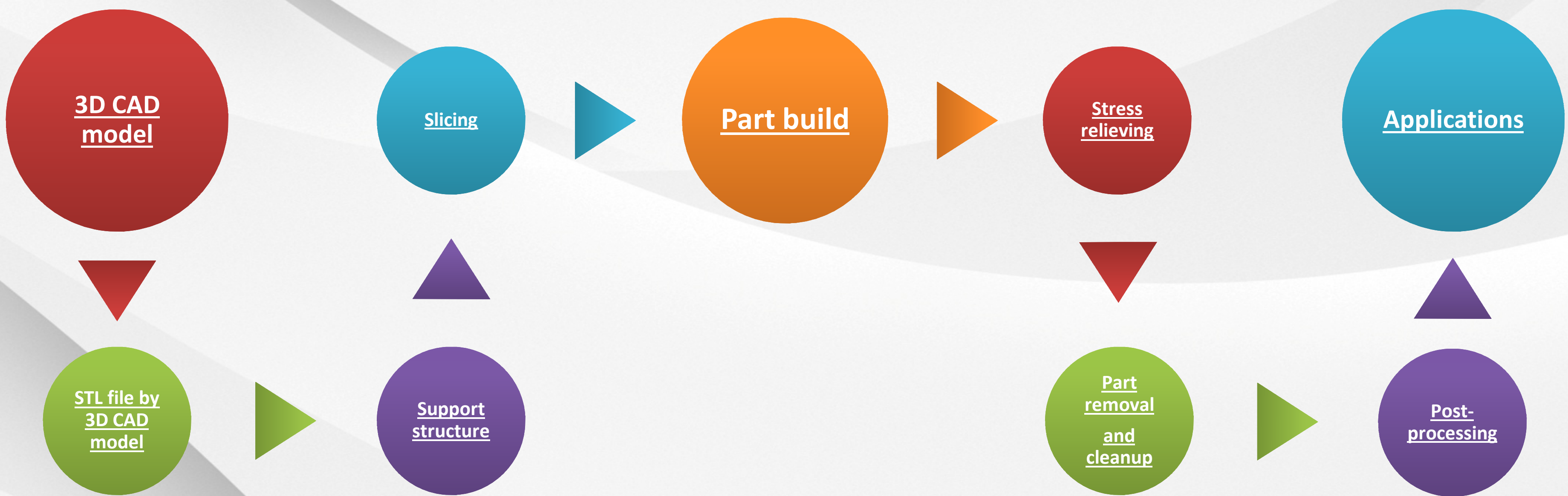

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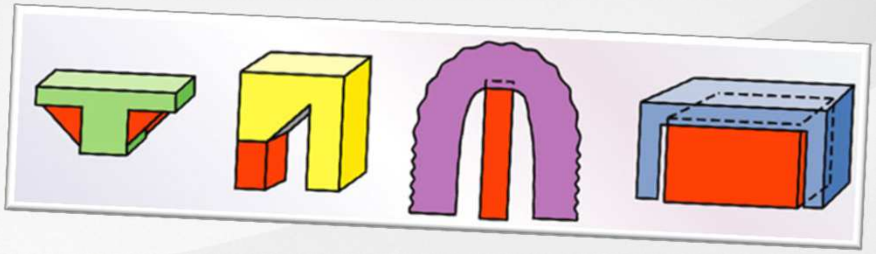
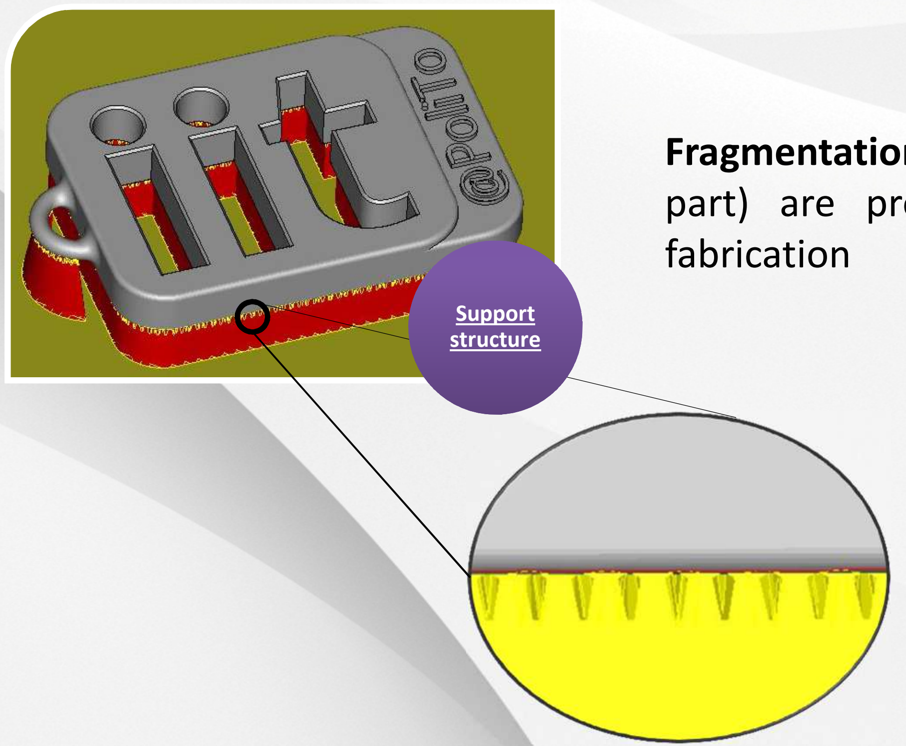
Support structure

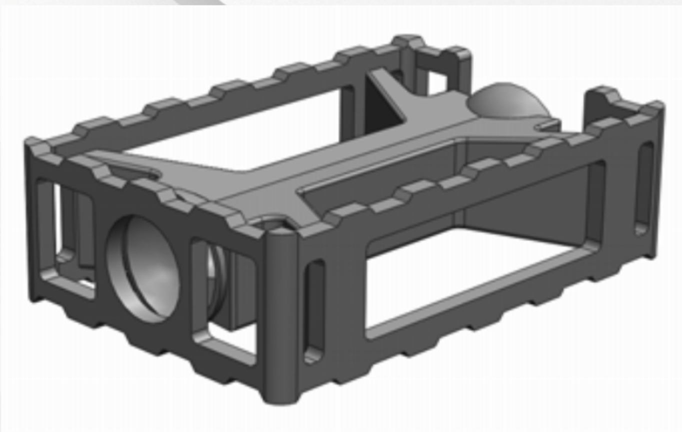
The main functions of the supports are to **fix the part** to building platform and **conduct excess heat** away from the part.

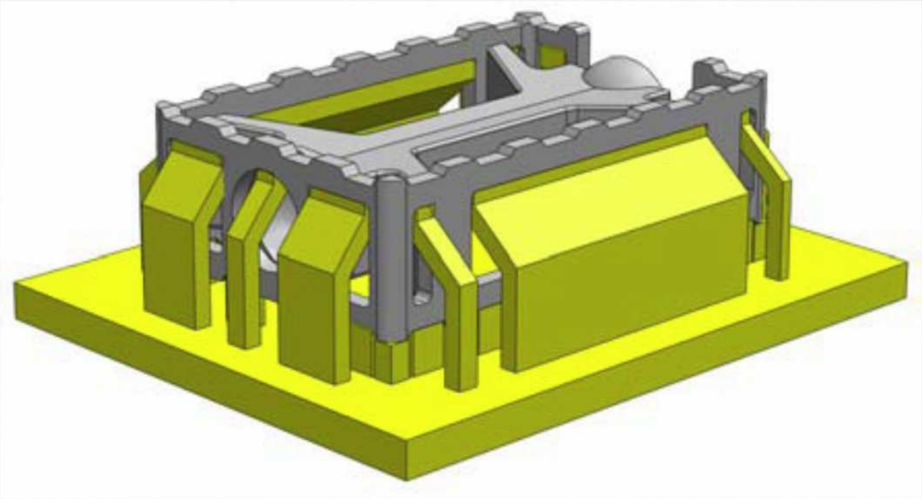




Fragmentation and tooth (in the interface of support and part) are provided for detaching the part easily after fabrication

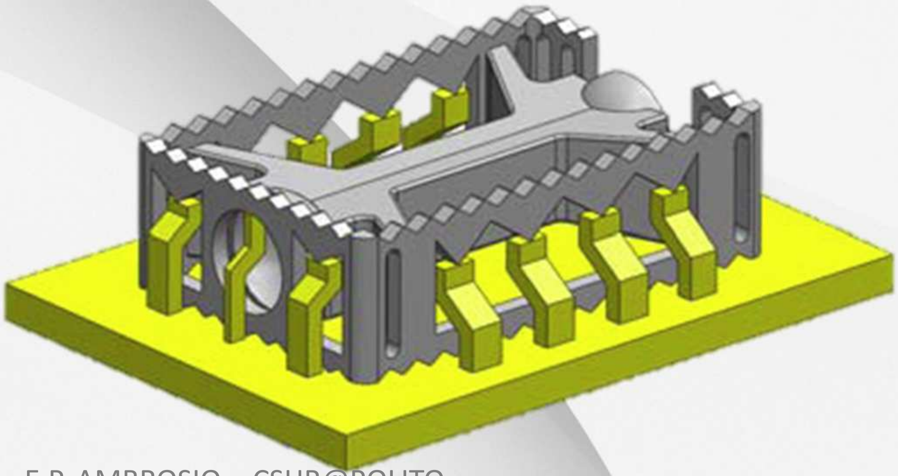
Support structure

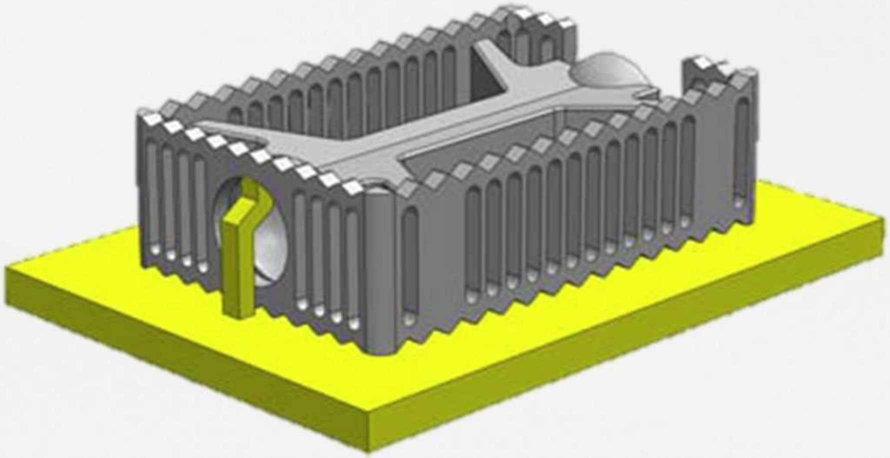




OK for prototyping work but not for manufacturing

Minor design changes can reduce the level of supports required





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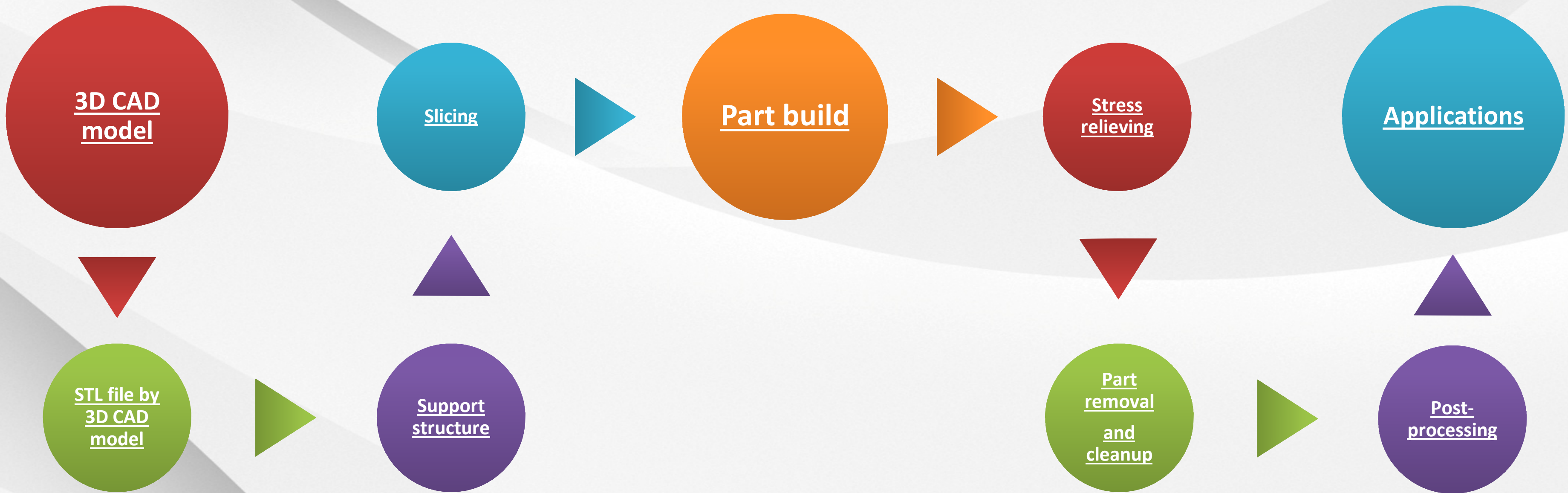
Generalized AM Process



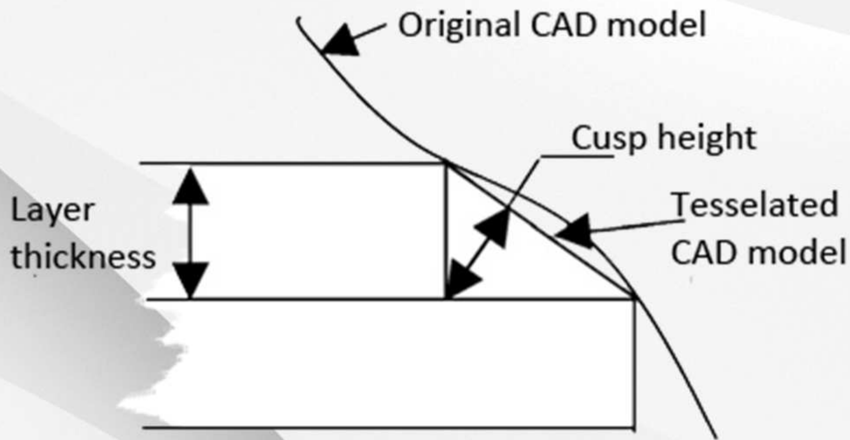
Slicing

A key enabling principle of AM part manufacture is the use of layers as finete 2D cross-sections of the 3D model.

Deposition of sliced layers leads to **staircase effect.**

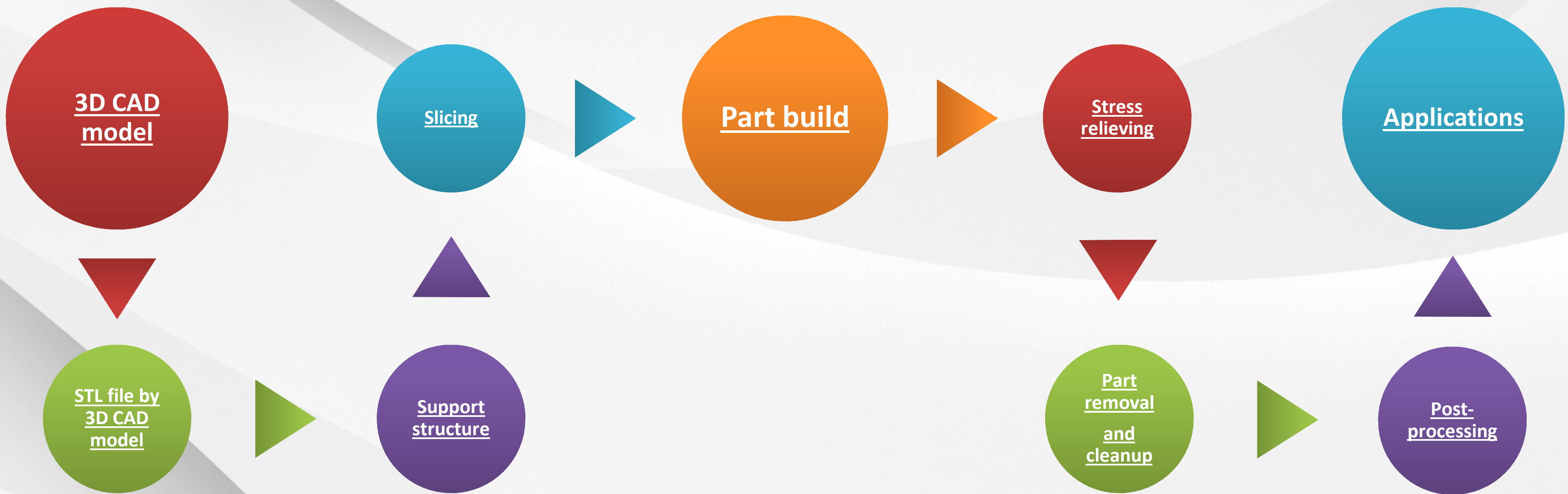
Quantifying the geometry distortion error is the main factor in determining the right value for layer thickness in both uniform and **adaptive slicing**.

Dolenc and Makela (1994) introduced one of the widely used errors: **cusp height.**



uniform slicing adaptive slicing

Generalized AM Process



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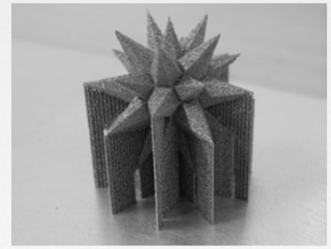
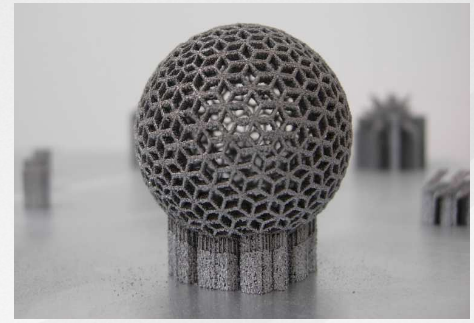
3D printing
No support
(Source: 3DSystem)

Part build

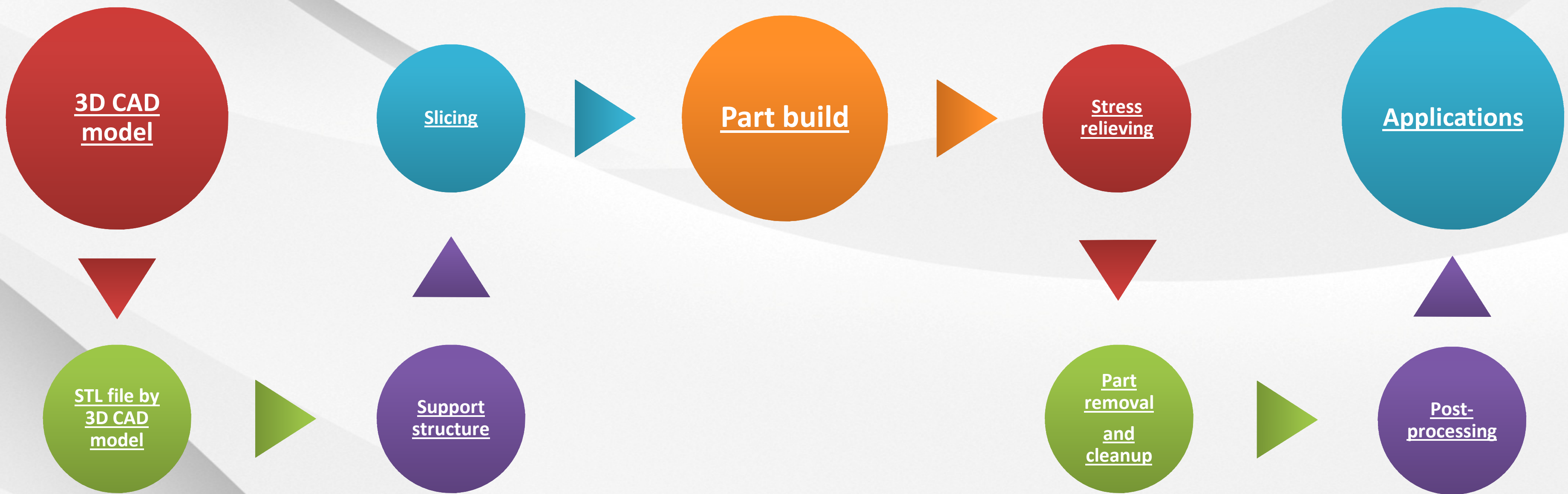
DMLS
With support
(Source: IIT@Polito)





FDM - With support
(Source: Xeos 3D)

Generalized AM Process



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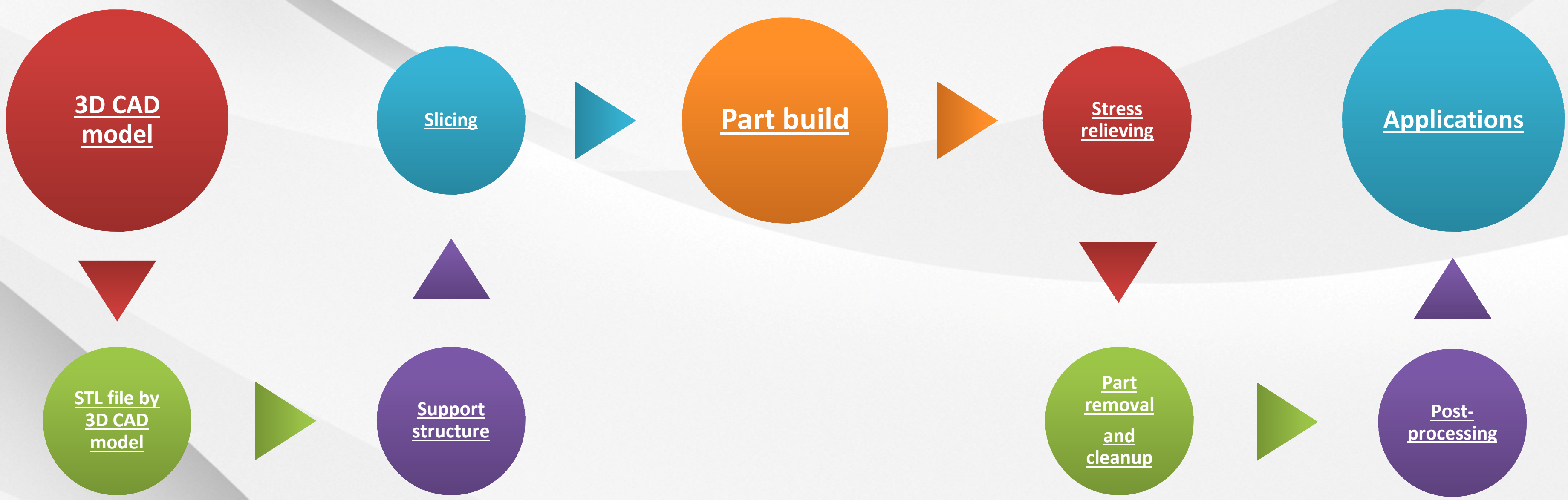
Stress Relieving

Stress relieving is used to remove residual stresses which have accumulated from manufacturing processes.

Stress relief is performed by heating to a temperature to achieve the desired reduction in residual stresses and then the material is cooled at a rate to sufficiently slow to avoid formation of excessive thermal stresses.

Generalized AM Process

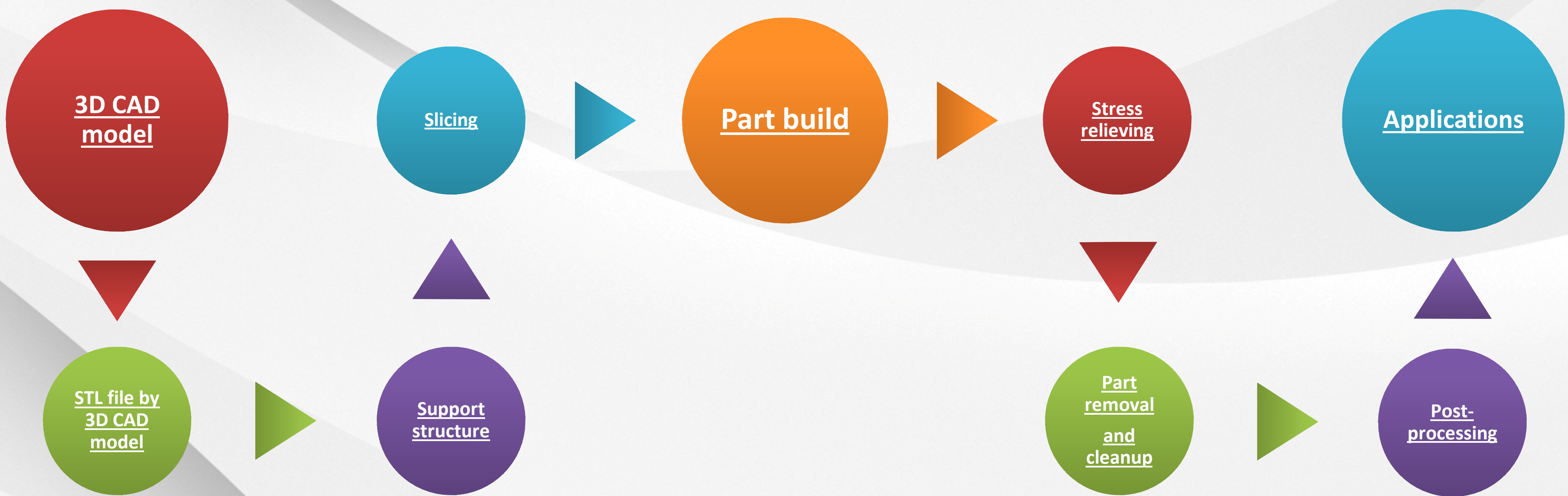


Part removal and cleanup

- Ideally, by this stage the output from the AM machine should be ready for use.
- While sometimes this may be the case, more often than not parts will still require a significant amount of manual finishing before they are ready for use. In all case, the part must be either separated from a build platform on which the part was produced or removal from excess build material surrounding the part.
- While some processes have been developed to produce easy-to-remove supports, there is still often a significant amount of manual work required at this stage. There is also a degree of manual skill required since mishandling of parts and poor technique in support removal can result in a low quality output.

Different AM parts have different cleanup requirements, but suffice it to say that all processes have some requirement at this stage. The cleanup stage may also be considered as the initial part of the post-processing stage.

Generalized AM Process



Post-processing

- Post processing refers to the (usually manual) stages of finishing the parts for application purposes.
- This may involve abrasive finishing, like shot-peening, polishing and sandpapering, or application of coatings.
- This stage in the process is very specific of the applications. Some applications may only require a minimum of post-processing; taking advantage of the speed at which the parts are made. Other applications may require very careful handling of the parts to maintain good precision and finish.
- Different AM processes have different results in terms of accuracy and material properties.

As built

After

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STANDARD TERMINOLOGY FOR ADDITIVE MANUFACTURING TECHNOLOGIES

(ASTM F2792-08)

Sheet Lamination

An AM process in which sheets of material are bonded to form an object

LOM, UAM

Directed Energy Deposition

An AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited

Vat Photopolymerization

An AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

SLA

Material Extrusion

An AM process in which material is selectively dispensed through a nozzle or orifice

FDM

Material Jetting

An AM process in which droplets of build material are selectively deposited

Polyjet

Powder Bed Fusion

An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

SLS, SLM, DMLS, EBM

Binder Jetting

An AM process in which a liquid bonding agent is selectively deposited to join powder materials

3DP

Source: Terry Wohlers Report 2013 - Annual Worldwide Progress Report

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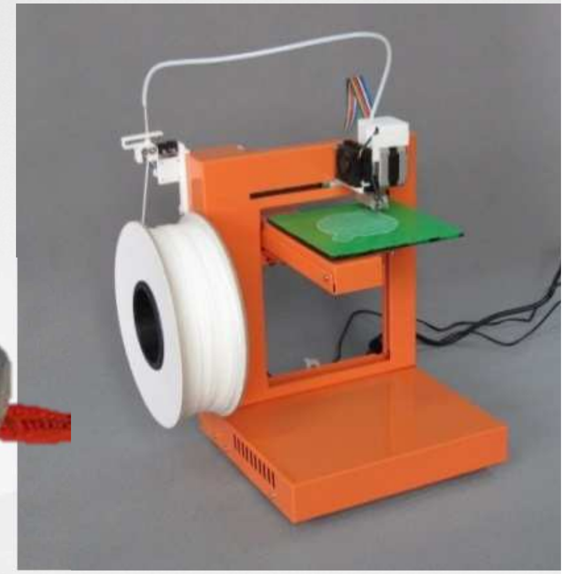
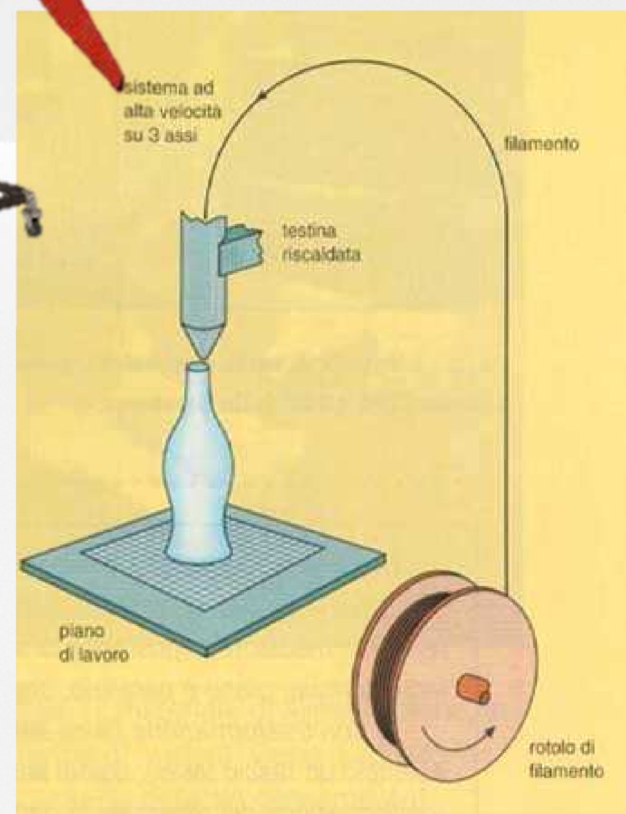
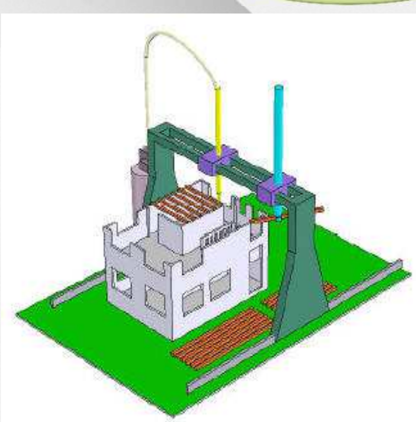


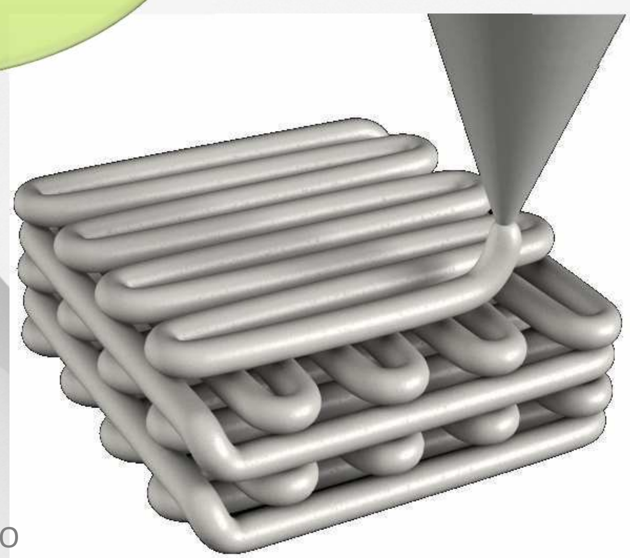
Material Extrusion

An AM process in which material is selectively dispensed through a nozzle or orifice

FDM







Fused Deposition Modelling

Material Extrusion

An AM process in which material is selectively dispensed through a nozzle or orifice

FDM

https://www.youtube.com/watch?v=WHO6G67GJbM

Unico sistema che impiega fili e barrette di materiali differenti per costruire il prototipo

Il cuore del sistema è la testa di estrusione che fonde il materiale e lo deposita in strati sottili tramite un ugello calibrato. La testa si muove nel piano per generare il contorno della sezione

La prima sezione viene realizzata su un supporto che si muove verticalmente

La testa di estrusione dopo aver realizzato i perimetri interno ed esterno riempie lo spazio compreso (incremento le proprietà meccaniche)

Non sono richiesti post-trattamenti

Il controllo della temperatura della testa e della zona di lavoro sono fondamentali

Processo “pulito” e la stazione di lavoro può esser installa vicino a un CAD

Vengono impiegati materiali a basso punto di fusione (cera, ABS, lega ABS-metacrilato)

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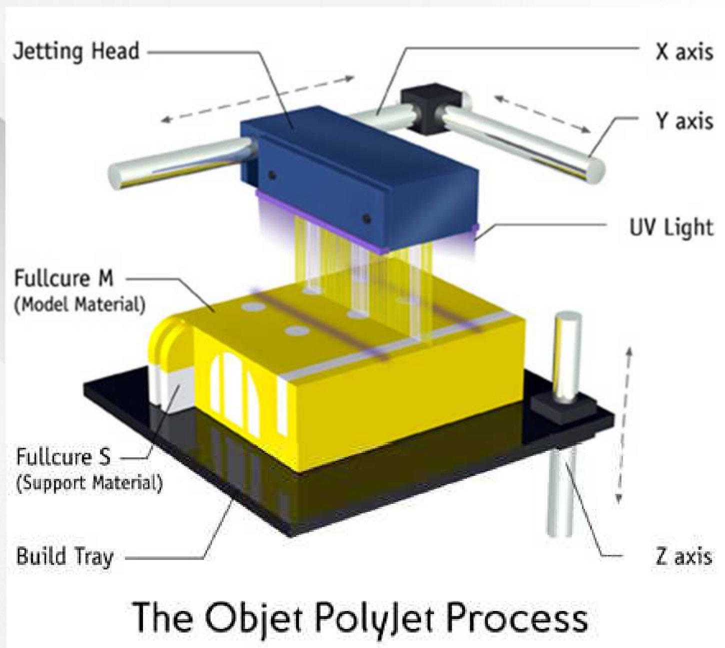

http://www.feminnova.it/tecnologia-polyjet/

Material Jetting

An AM process in which droplets of build material are selectively deposited

Polyjet

Material Jetting Process

Uses ink-jet printig heads to deposit droplets of build material (photopolymers, wax-like materials)

One ore more print heads move across the build area

Often use multi-nozzle print heads to increase printing speed or to print different materials

One material is used to create support, the second as build material

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3DP

A liquid bonding agent is selectively deposited through inkjet print head nozzles to join powder materials in a powder bed

Originally developed by MIT and called 3D printing

Materials of the powders: (plaster-based, metal, sand)

Binder Jetting

An AM process in which a liquid bonding agent is selectively deposited to join powder materials

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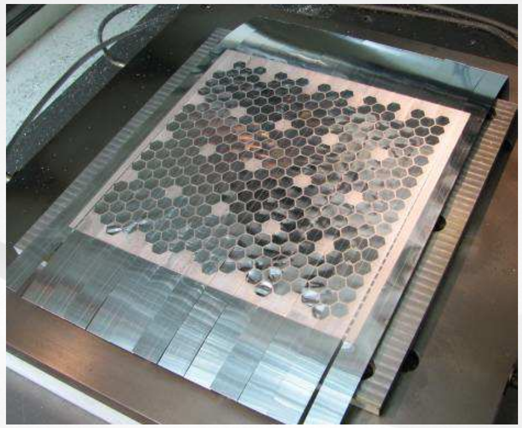

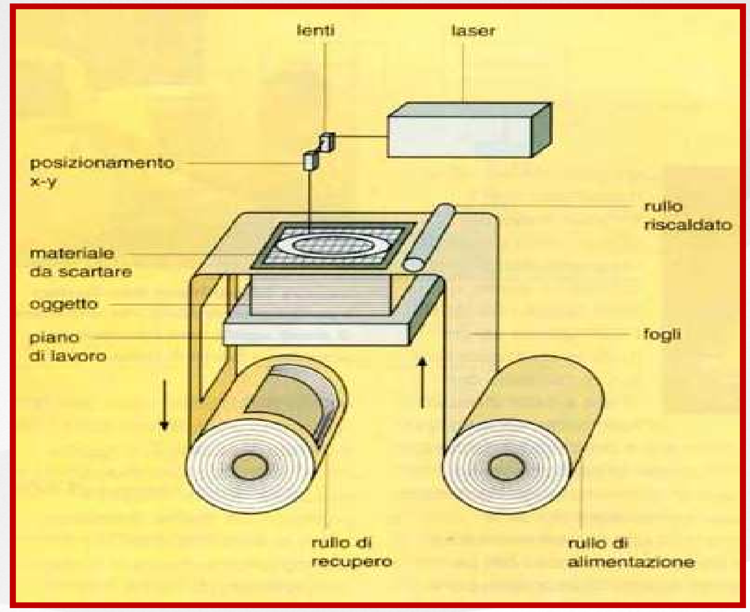

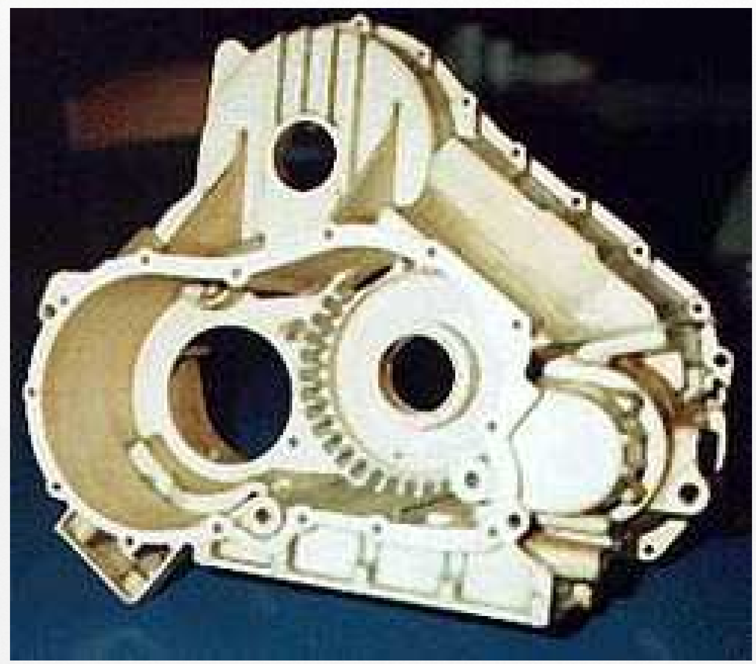

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Sheet Lamination

An AM process in which sheets of material are bonded to form an object

LOM, UAM

Materials: adhesive-coated papers forming a plywood-like solid when laminated into a 3D object or metal tapes and foils that form metal parts

Laminated Object Manufacturing (**LOM**)

Helysis

A roll of craft paper coated with adhesive on one side and a heated roller to laminate successive layers

Mcor Technologies

Uses standard sheets of paper as build material, selective dispensing a water-soluble adhesive that bonds the layers

Ultrasonic Additive Manufacturing (**UAM**) – Fabrisonic

Uses ultrasonic welding to bond layers of thin metal tapes and folis. Layers are welded togheter by a combination of ultrasonic energy supplied by twin, high-frequency tranducers and the compressive forse created by the system's rolling sonotrobe

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STANDARD TERMINOLOGY FOR ADDITIVE MANUFACTURING TECHNOLOGIES

(ASTM)

Sheet Lamination

An AM process in which sheets of material are bonded to form an object

LOM, UAM

Directed Energy Deposition

An AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited

Vat Photopolymerization

An AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

Stereolithography

Material Extrusion

An AM process in which material is selectively dispensed through a nozzle or orifice

Fused Deposition Modelling

Material Jetting

An AM process in which droplets of build material are selectively deposited

Wax or Photopolymers

Powder Bed Fusion

An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

SLS, SLM, DMLS, EBM, etc.

Polymers, metals & ceramics

Binder Jetting

An AM process in which a liquid bonding agent is selectively deposited to join powder materials

3DP

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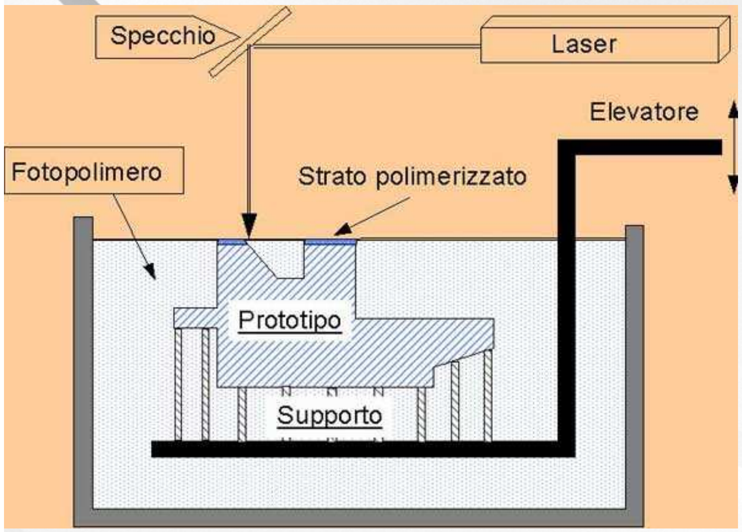
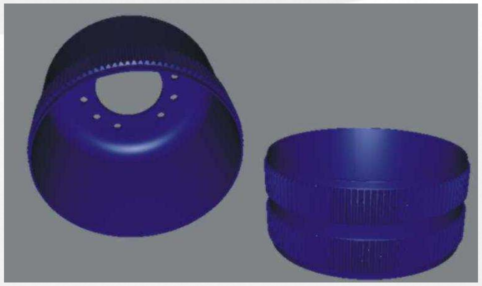
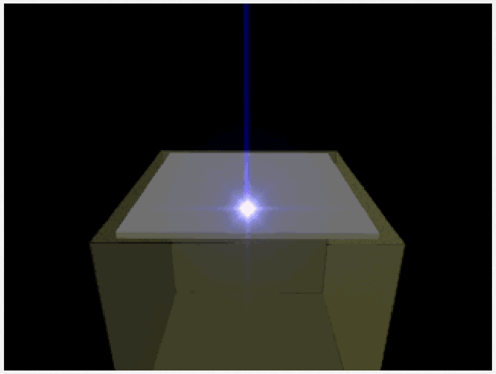


Vat Photopolymerization

An AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

SLA





Stereolitoghrapy (SLA)

Uses un ultraviolet laser and x-y scanning mirrors on computer-controlled galvanometers to scan the top surface of a liquid photopolymer in a vat.

4 main steps: Job Preparation, Building of the part, Cleaning , Post processing (UV curing and surface finishing)

https://www.youtube.com/watch?v=BUfh5wxj3qA

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STANDARD TERMINOLOGY FOR ADDITIVE MANUFACTURING TECHNOLOGIES

(ASTM F2792-08)

Sheet Lamination

An AM process in which sheets of material are bonded to form an object

LOM, UAM

Directed Energy Deposition

An AM process in which focused thermal energy is used to fuse materials by melting as they are being deposited

Vat Photopolymerization

An AM process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization

SLA

Material Extrusion

An AM process in which material is selectively dispensed through a nozzle or orifice

FDM

Material Jetting

An AM process in which droplets of build material are selectively deposited

Polyjet

Powder Bed Fusion

An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

SLS, SLM, DMLS, EBM

Binder Jetting

An AM process in which a liquid bonding agent is selectively deposited to join powder materials

3DP

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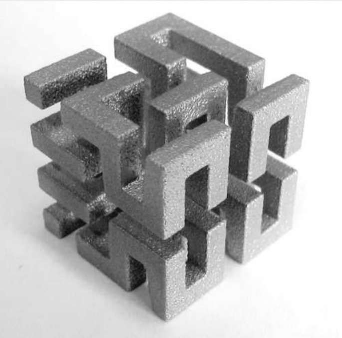
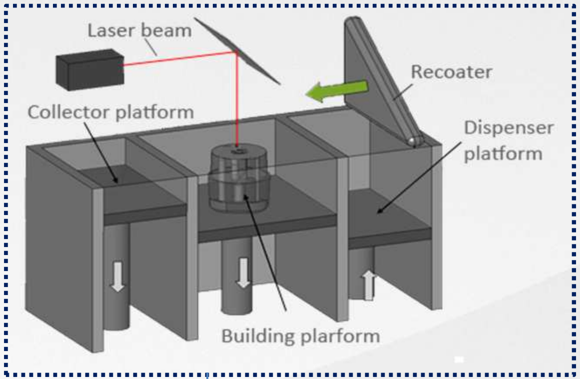
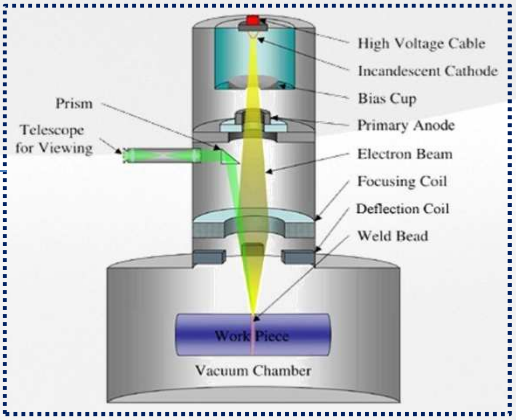




Laser

Powder Bed

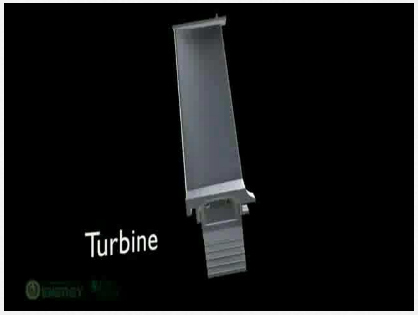
EBM



Powder Bed Fusion

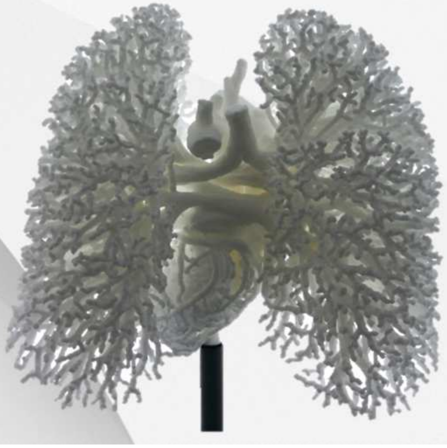
An additive manufacturing process in which thermal energy selectively fuses regions of a powder bed

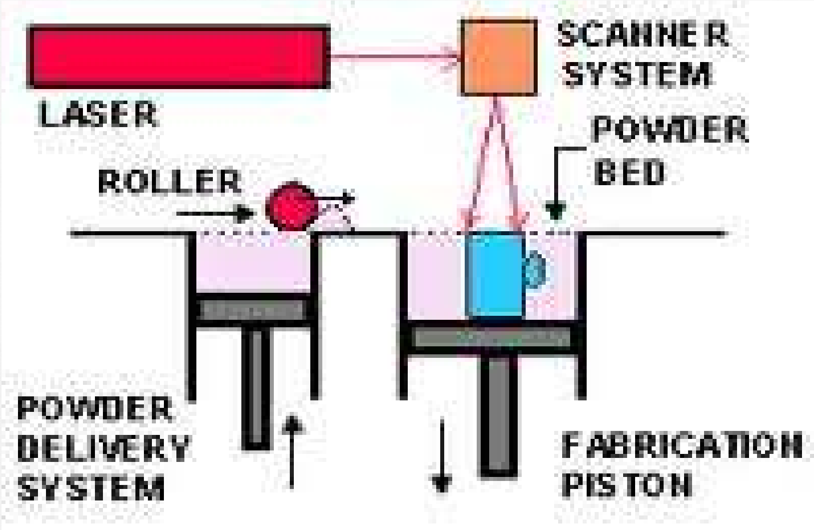
SLS, SLM, DMLS, EBM



SLS - EOS


EOSINT P 700




SCANNER SYSTEM
LASER
POWDER BED
ROLLER
POWDER DELIVERY SYSTEM
FABRICATION PISTON

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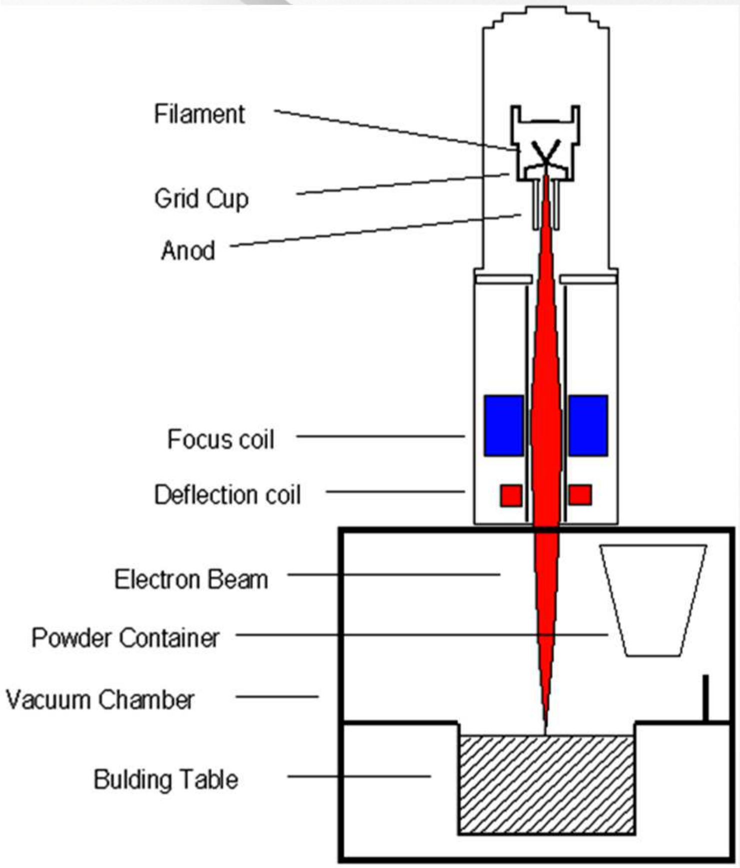
EBM - ARCAM



- A high energy beam is generated in the Electron Beam Gun
- The beam melts each layer of metal powder to the desired geometry
- Extremely fast beam translation with no moving parts
- Vacuum process eliminates impurities and yields excellent material properties
- High build temperature gives form stability and low residual stress
- Low operating costs

EBM - ARCAM

DMLS - EOS

- EOS M280
- Key characteristics
  - Build volume: up to 250x250x300mm
  - Up to 400W Yb fibre laser
  - Spot size: 100µm
  - Layer thickness: 20µm to 80µm
  - Build speed Up to 32.4 cm^3/h
- Surface finish
  - As built: Ra~4-10µm
  - After polishing: Ra~0.04-0.5µm
- Minimum wall thickness / feature size
  - 0.04mm
- Accuracy
  - +/- 0.2mm

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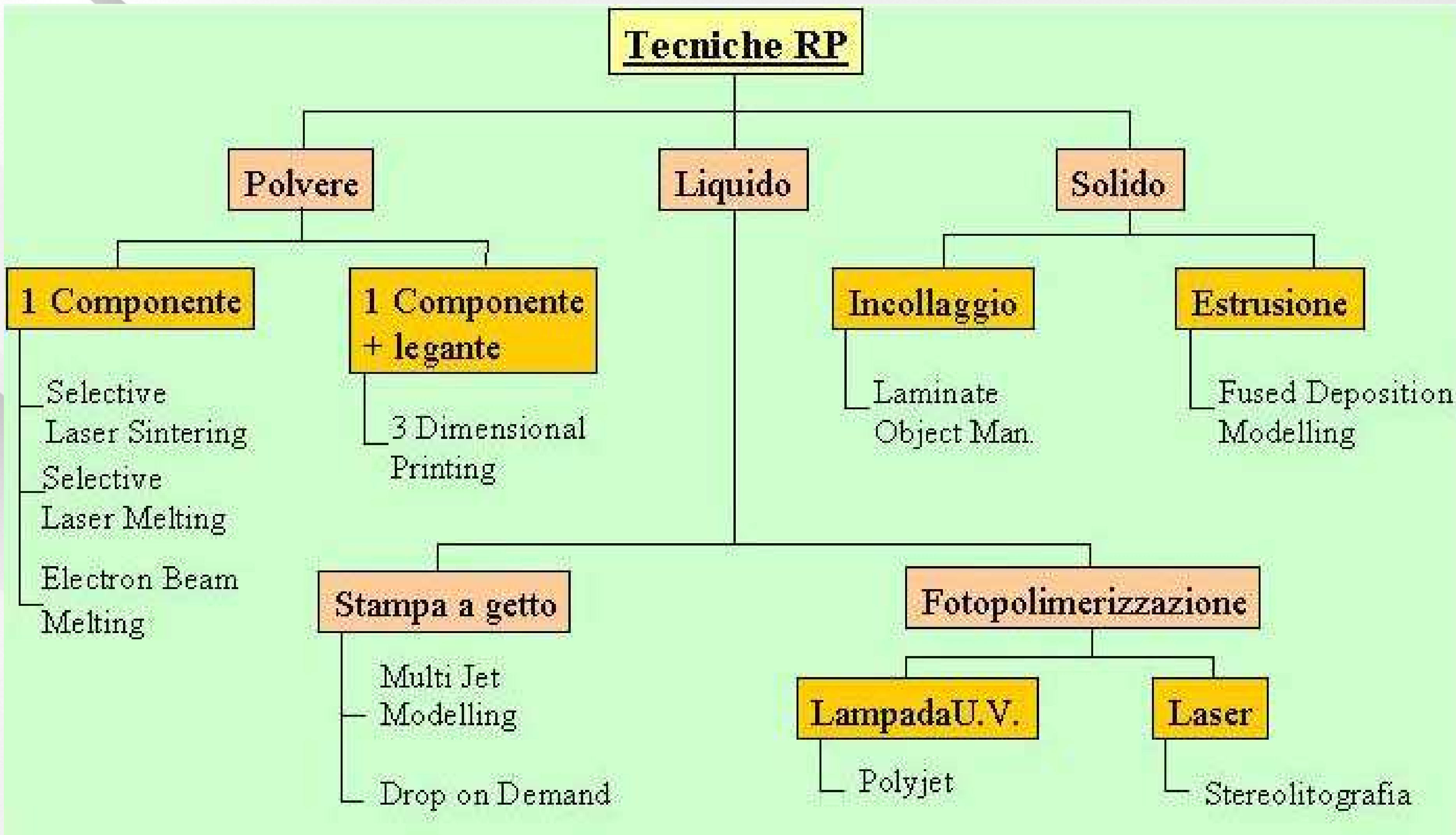
DMLS - EOS

PROCESSES


Tecniche RP
Polvere
Liquido
Solido
1 Componente
1 Componente + legante
Incollaggio
Estrusione
Selective Laser Sintering
Selective Laser Melting
Electron Beam Melting
3 Dimensional Printing
Laminate Object Man.
Fused Deposition Modelling
Stampa a getto
Fotopolimerizzazione
Multi Jet Modelling
Drop on Demand
LampadaU.V.
Laser
Polyjet
Stereolitografia

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PROCESSES

Technology	Manufacturer	Country
Selective **L**aser **S**intering	3D Systems EOS Trump	USA Germany China
Direct **M**etal **L**aser **S**intering	EOS	Germany
Selective **L**aser **M**elting	MTT (now 3D systems) Phenix System Concept Laser Realizer SLM Solutions Wuhan Binhu	UK France Germany Germany Germany China
Electron **B**eam **M**elting	Arcam	Sweden
Direct **M**etal **D**eposition	Optomec POM IREPA Laser Accufusion	USA USA France Canada

PROCESSES


3D PRINTING TECHNOLOGIES
Material extrusion
Vat photopolymerization
Material jetting
Binder jetting
Powder bed fusion
Sheet lamination
Directed energy deposition
ASTM Active Standard F2792, June 2012

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Costs

POWDER BED FUSION
3D systems: 350.000 $ - 850.000$
EOS (polymer): 129.000 $ – 905.000 $
EOS (sand): 690.000 $
Realizer's (lowest for metals): 120.000 $
Concept Laser's (metals): 1.4 million $

VAT PHOTOPOLYMERIZATION
CeraFab7500 (LED light source): 220.000 $
Asiga's Pico: 9.000 $
MediTech Gmbh: 240.000 $ – 350.000 $

BINDER JETTING
ExOne (large build boxes): 125.000 $ - 1.4 million $
Voxelijet: 120.000 $ – 1.4 million $
Projet (3D Systems): 16.500 $ – 113.900 $

MATERIAL EXTRUSION
Most: 500 $ - 4.000 $
FDM (Stratasys): 9.500 $ – 500.000 $

MATERIAL JETTING
Solidscape: 26.000 $ - 46.000 $
Stratasys (single build material): 20.000 $ – 173.000 $
Connex (multimateryal): 160.000 $ – 600.000 $
Projet (3D Systems): 60.000 $ – 160.000 $

SHEET LAMINATION
LOM: 36.400 $ - 47.600 $

DIRECTED ENERGY DEPOSITION
350.000 $ - 1.5 million $

Applications

PROTOTYPING

TOOLING

METAL CASTING

ARCHITECTURAL

MEDICAL

DENTAL

DIRECT PART PRODUCTION

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DIRECT PART PRODUCTION

Aerospace

Automotive& Motorsports

Gifts, trophies & memorials

Museum Displays

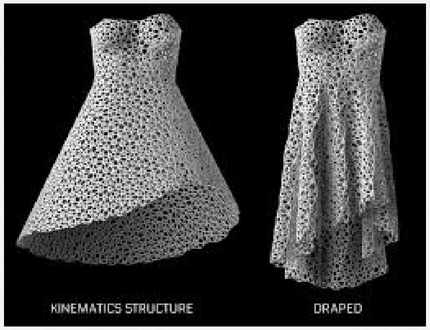
Consumer created products

Music applications

Medical

Furniture, home&office accessories

Art & jewelry



Fashion& High performance products

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Applications

Examples

Electron Beam Melting (EBM)

Industry	Application
Medical	Canine knee implants Hip replacements
Aerospace	Landing gear components Impellers
Automotive	Turbocharger compressor wheels

3D printing

Industry	Application
Power tools	Functioning model for ergonomic testing
Architecture	Scale model of facilities Functional model of furniture designs
Motorcycle	Functional model of accessories for mock-up
Pumping	Functional model of pump housing
Underwater exploration	Modeling of redesigned diving equipment

Selective Laser Sintering (SLS)/ Selective Laser Melting (SLM)

Industry	Application
Medical	Customized knee implants Customized dental implants Humeral mount for prosthesis
Aerospace	Engine components
Automotive	Gearbox housing components
Racing	Prototype fuel vent manifold Prototype air intake Production of race car exterior components
Athletic Wear	Functional prototype of running shoe
Mechanical	Functional prototype for riveting system
Architecture	3D scale model of building
Lawn care	Functional mower deck prototype
Electronic surveillance	Production of radar housing and components

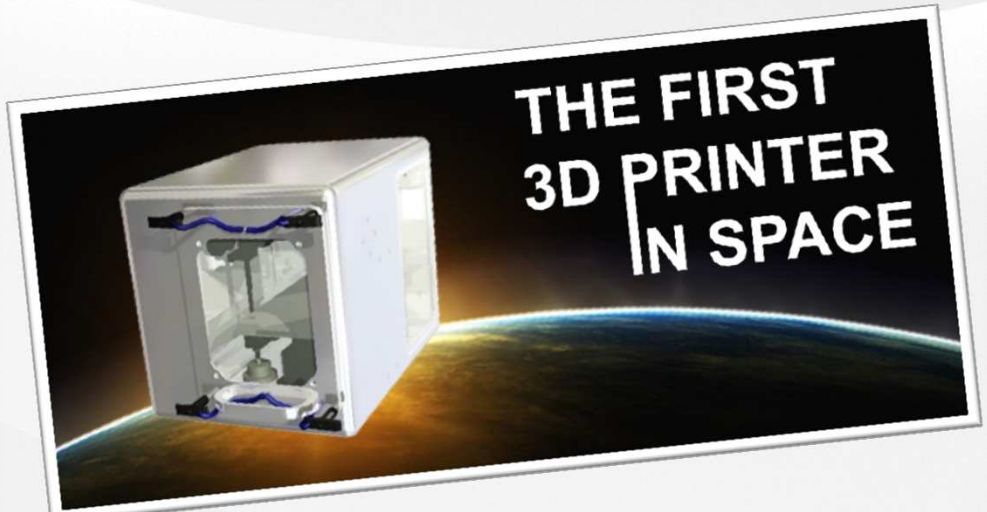
Space Applications

3D PRINTERS TO BE ABLE TO WORK IN **MICROGRAVITY**

http://www.madeinspace.us

NASA – Made In Space
Planning to launch the world's first zero-gravity-capable 3-D printer into space as early as June 2014

Like many of us here on Earth, it's fairly common for astronauts in orbit to lose or break important tools and products. However, instead of making a quick trip to the hardware store for new tools, astronauts living on the International Space Station must often wait several months before receiving any replacement parts.



CSHR INVOLVED IN THE FINANCED ASI PROJECT POP-3D (WITH ALTRAN)

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Questions?

http://www.allanalytics.com

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