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3D Printing Technologies and Applications: An Overview

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INTRODUCTION IN 3D PRINTING

- Initial concept invented in the late 70s.

Main Idea ⇨

Join different layers of material using a digital model input from a CAD software to create a 3D object

⇧

Definition of Additive Manufacturing (AM)

- This research is a first step in assuring the quality of the printed models with regard to their geometry.

Future ⇨

- Identification of geometrical issues that occur in certain printing technologies
- Characterization of the corresponding frequency of occurrence

[9],[14],[20]

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3D PRINTING TECHNOLOGIES (1/7)

- Categorization based on the adopted process for material deposition
- Basic 3D Printing Processes [22]

Material Extrusion	Vat Photopolymerization
Creates layers by mechanically extruding molten thermoplastic material on a building platform	An ultraviolet laser is used to polymerize the UV resins and create a layer of solidified material
Powder bed Fusion	**Sheet Lamination**
An electron beam is used to melt the spread material on a powder bed	A controlled laser is used to cut the coated material on a building platform

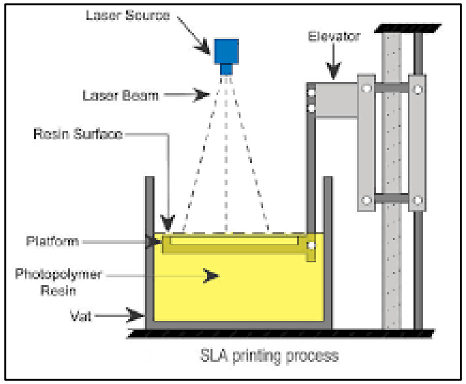
3D PRINTING TECHNOLOGIES (2/7)

3D Printing Processes	3D Printing Technologies
Material Extrusion	Fused Deposition Modeling (FDM)
Powder bed Fusion	Powder bed and Binder Jetting 3D printing (3DP) Electron Beam Melting (EBM) Selective Laser Melting (SLM) Selective Heat Sintering (SHS) Selective Laser Sintering (SLS)
Vat Photopolymerization	Stereolithography (SLA) Digital Light Processing (DLP) Continuous Liquid Interface Production (CLIP)
Sheet Lamination	Laminated Object Manufacturing (LOM)

[14],[20],[22]

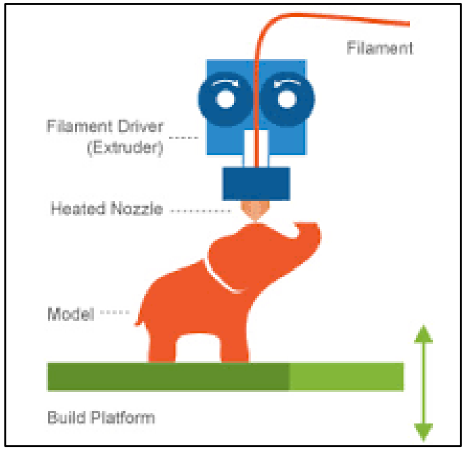
3D PRINTING TECHNOLOGIES (3/7)

SLA uses an ultraviolet (UV) laser which is focused on the top surface of the resin which hardens precisely where the laser hits its surface. Support structures.



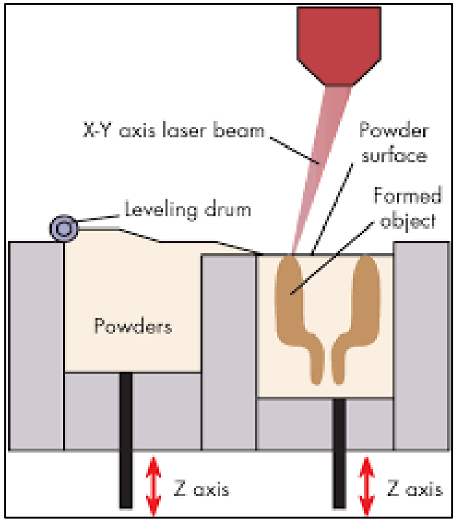
FDM uses a continuous filament of a thermoplastic material and builds a part by heating and extruding this thermoplastic filament through a moving, heated extrusion print head one layer each time. Support structures.

[13],[7]

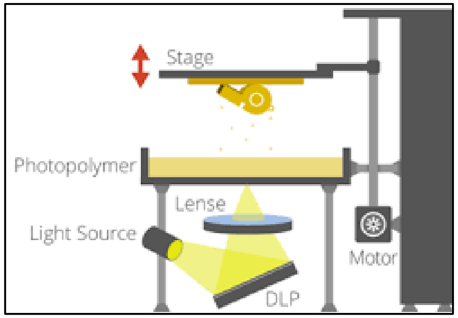


3D PRINTING TECHNOLOGIES (4/7)

SLS uses a high power laser to sinter small parts of powdered material aiming at specific points across a powder bed



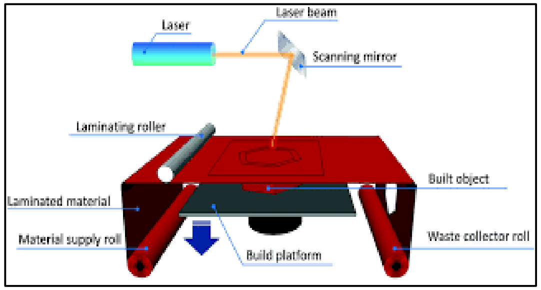
DLP uses a digital projector screen to flash a single image of each layer across the entire platform at once



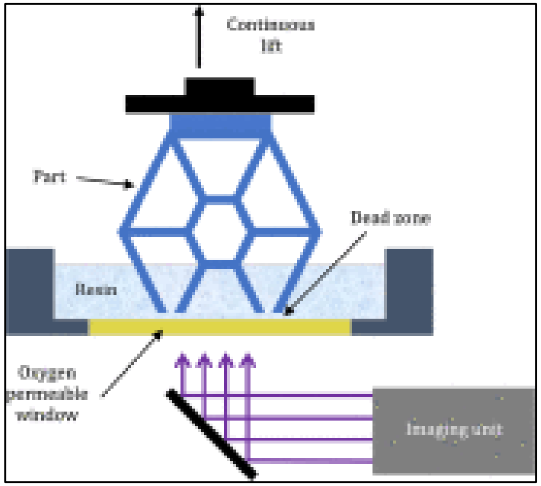
[13],[7],[14],[12],[18]

3D PRINTING TECHNOLOGIES (5/7)

LOM, a laminated sheet of material is spread through a roller mechanism. A computer controlled laser (or other technology) cuts the coated material to form the desired shape of the object



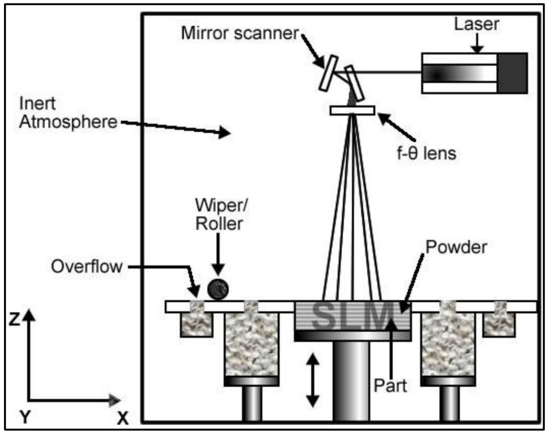
CLIP, a beam of ultraviolet light is projected through an oxygen-permeable window into the vat of liquid resin, illuminating the precise cross-section of the object



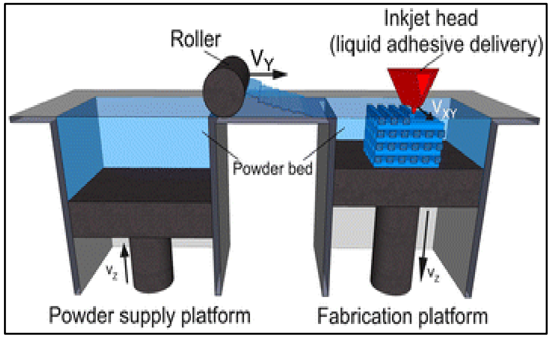
[7],[13],[17],[19]

3D PRINTING TECHNOLOGIES (6/7)

SLM, (DMLS) the powdered material is spread over the fabrication bed and melted or sintered by a high powdered optic laser. In this process the metal material can be fully melted



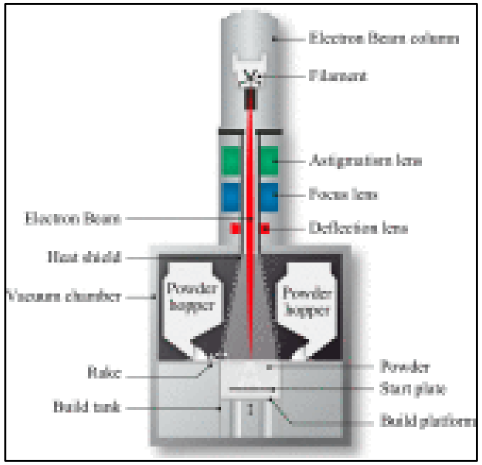
3DP, a thin layer of the powder material is spread onto the fabrication platform and an inkjet print head moves across the powder bed depositing a liquid binding material that joins the powders



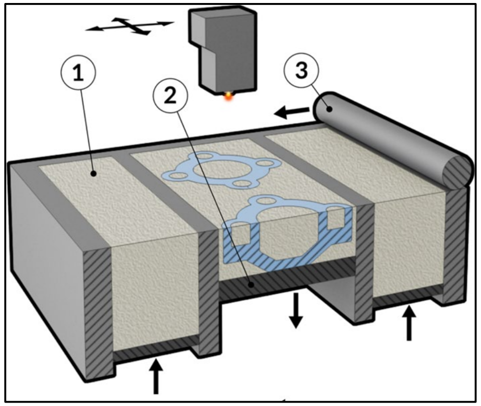
[15],[16],[8],[17]

3D PRINTING TECHNOLOGIES (7/7)

EBM is mainly based on a melting process which uses a metal powder and an electron beam. The material is spread on the building platform and heated by an electron beam



SHS, the material is fed from the powder deposition tanks (1), heated to just below its melting point, spread out into a thin layer over the movable building platform (2) and flattened using a roller (3)



[4],[2],[10]

CRITICAL PARAMETERS OF 3D PRINTING TECHNOLOGIES

Processes	Accuracy	Surface quality finish	Material variety	Model resistance	Cost
Material Extrusion	**	Poor	Wide	Good	*
Powder bed Fusion	**	Powdery/ Porosity	Wide	High	** ***
Vat Photopolymerization	***	Smooth	Wide	Moderate	**
Sheet Lamination	*	High	Laminated	Good	*

[5],[7],[22]

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ADVANTAGES VS DISADVANTAGES OF 3D PRINTING TECHNOLOGIES (1/2)

Technologies		
	Advantages	**Disadvantages**
SLA	Less time consuming - Detailed large prints - High quality - Fine resolution	Limited materials - Possible brittle components - Expensive process (getting cheaper_- Some support structures needed
FDM	Various colors – Simplicity – Multi-materials - High speed for simple structures	Support structures needed - Weak mechanical properties - Limited resolution - Poor surface finish
SLS	Large part size - Variety of materials - Fast procedure - High strength and stiffness	Post processing required - Expensive process
DLP	High accuracy - Fine resolution - Material variety - Fast process	Costly process - Post processing required
LOM	Variety of materials - Larger structures - Post processing required - Reducted tooling cost	Inferior surface quality - Post processing required - Limitations for very complex shapes

ADVANTAGES VS DISADVANTAGES OF 3D PRINTING TECHNOLOGIES (2/2)

Technologies		
	Advantages	**Disadvantages**
CLIP	High quality - Fine details - Improved surface finish - Improved visual quality - High stiffness	No high end accuracy, expensive
SLM	Parts with excellent mechanical and thermal properties – High stiffness	Poor surface finish - Poor visual quality - Post processing required
3DP	Wide range of materials - Complex objects - Moderate speed- Low cost	Porous surface - Post processing required
EBM	High density - High strength - Satisfactory mechanical properties	Lack of accuracy - Poor surface finish - Poor visual quality - Post processing required
SHS	High-complex geometry - High stiffness - Excellent mechanical properties	Porous surface - Poor visual quality

[13],[21],[7],[11],[22],[3],[1],[6],[38],[41],[37],[43],[25],[45],[39],[40],[42],[44],[23]

3D PRINTING APPLICATIONS (1/4)

Technologies	Applications
SLA	Biomedical - Excellent for form testing - Best process for water resistant material - Prototyping
FDM	Prototyping – Biomedical – Toys - Advanced composite parts - Home use applications Food technology – Buildings - Construction
SLS	Biomedical – Dentistry - Aerospace – Lightweight structures – Heat exchangers – prototyping models with mechanical properties – Personalized manufacturing
DLP	Rapid prototyping – Fit and function models – Molds for tooling and metal casting – Hearing aids and medical implants – Dental applications – Jewelry casting – Automotive parts – Aerospace components
LOM	Paper manufacturing - Foundry industries - Electronics Biomedical - Ideal for nonfunctional prototypes - Smart structures

3D PRINTING APPLICATIONS (1/4)

Technologies	Applications
CLIP	Prototyping – End user product manufacturing with smooth surfaces and finish, with no visible layers
SLM	Aerospace – Manufacturing – Medical Biomedical – Fully functional Prototypes – Electronics – Lightweight structures – Heat exchangers and heatsinks – Parts with cavities, undercuts, draft angles – Rotors and impellers – Complex bracketing
3DP	Biomedical applications – Electronics – Aerospace – Lightweight structures – Heat exchangers – Dentistry– Custom design applications – Aesthetic design implementation
EBM	Manufacturing small parts – Biomedical applications – Aeronautics industry – Motor sports industry
SHS	Prototyping

[13],[7],[5],[11],[31],[24],[35],[36],[19],[32],[26],[33],[27]

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3D PRINTING APPLICATIONS (3/4)

Fig.1: SLA technology: Foundry pattern

Fig.2: FDM technology: Airbus space panel (interior view)

Fig.3: SLS technology: Adidas shoe

Fig.4: DLP technology: Pelvis

Fig.5: LOM technology

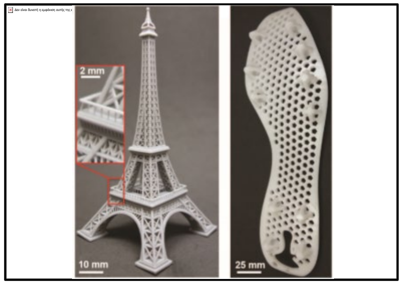

Fig.6: CLIP technology

3D PRINTING APPLICATIONS (4/4)

Fig.7: SLM technology: Food processing nozzle [49]

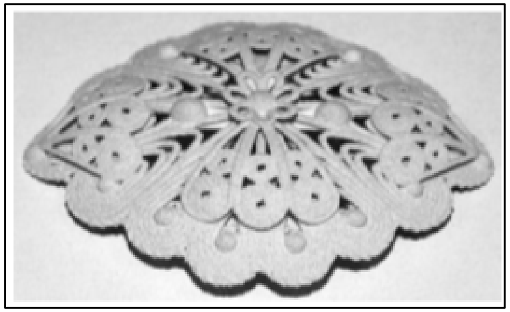

Fig.8: 3DP technology: Fligree Jewelry [28]

Fig.7: EBM technology [50]

Fig.8: SHS technology [44]

[29],[30],[31],[36],[34],[19],[32],[26],[33],[28]

DESIGN RULES FOR 3D PRINTING

Printer Model:
Zprinter450

Methodology:
Powder Bed and Binder Jetting

Technology:
3DP

	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm

[46]

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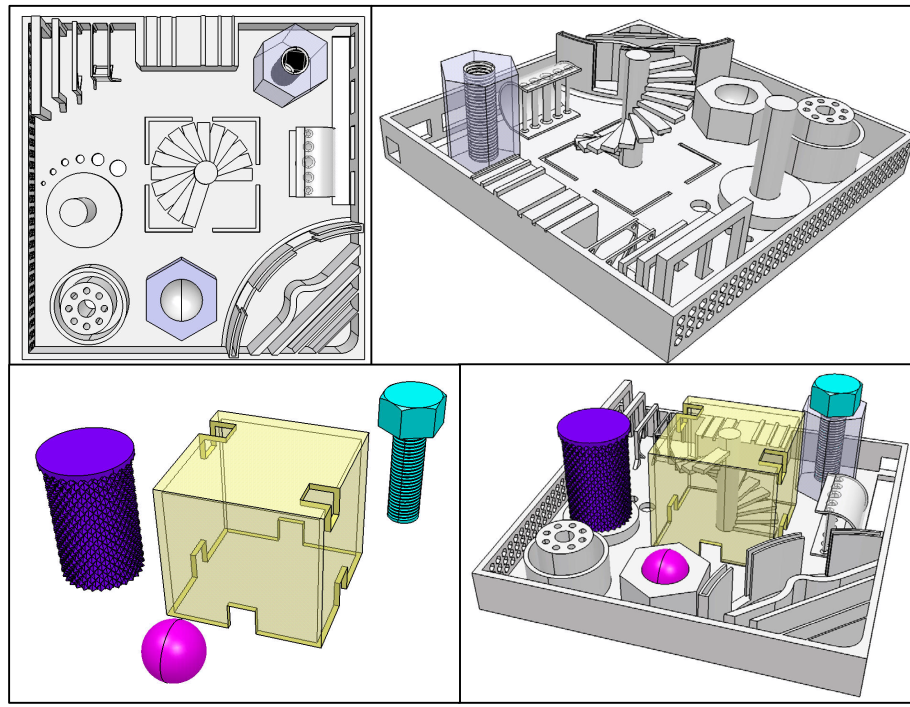
CAD MODEL 1

Design Rules:

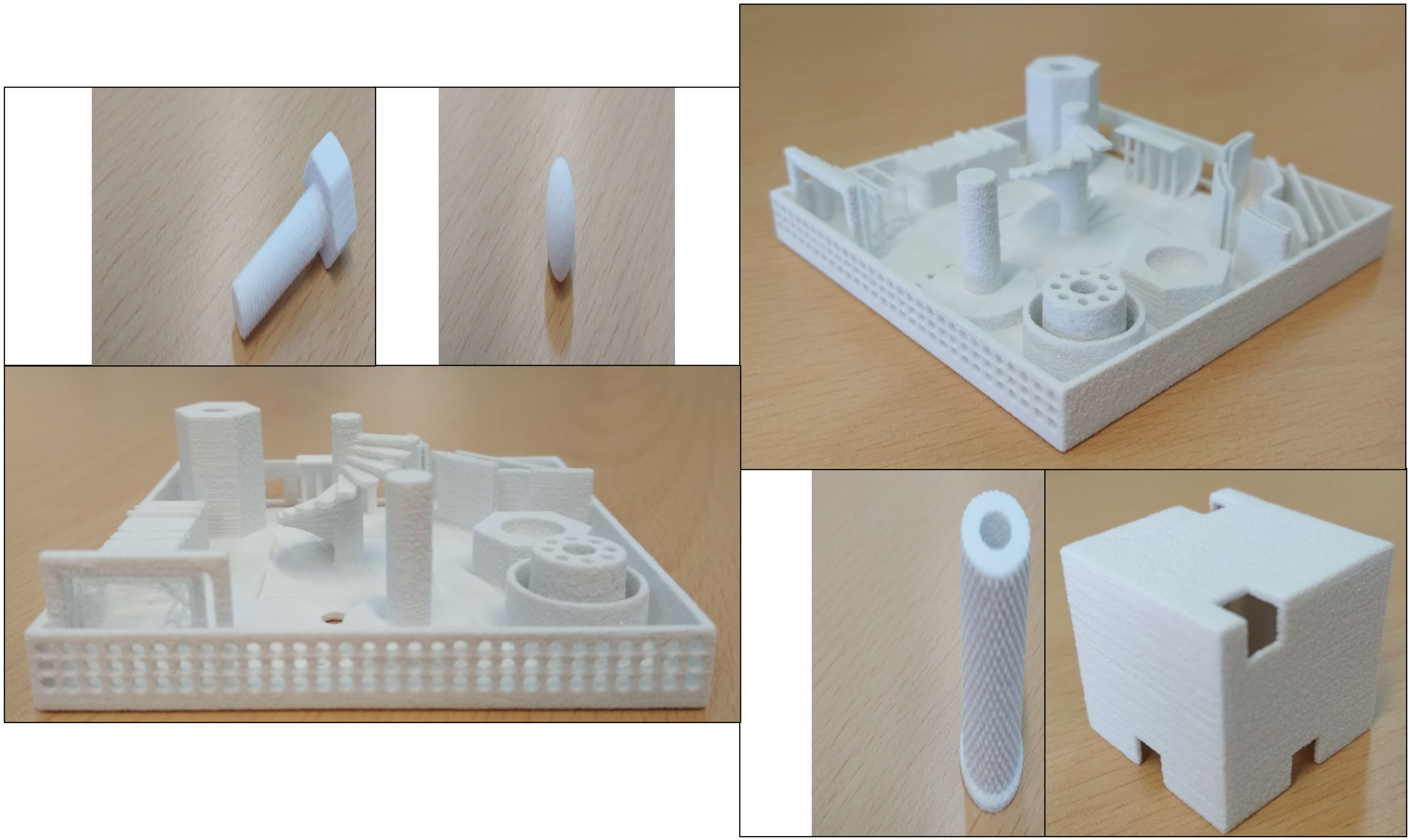
- Supported Walls (values:0.3mm-2mm)
- Embossed and Engraved Details (values:0.3mm-0.75mm)
- Horizontal Bridges (values:0.5mm-2.0mm)
- Connecting Parts
- Escape Holes
- Pin Diameter (values:0.5mm-2.0mm)



Assemble Features:

- Base
- Diamond Knurligs
- Screw
- Sphere
- Cover

PRINTED MODEL 1



CAD MODEL 2

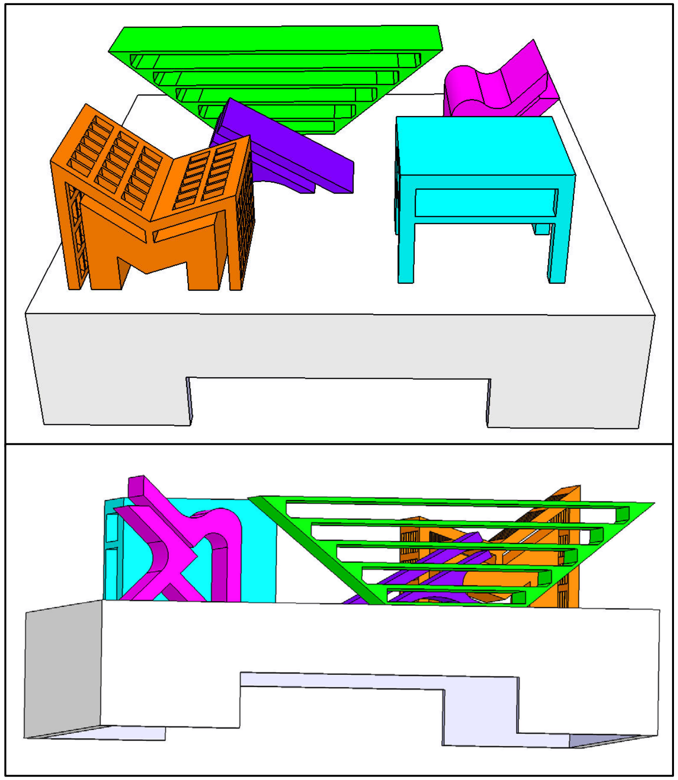
Design Rules/ Special Features:

- Minimum Features (value:0.5mm-2.00mm)

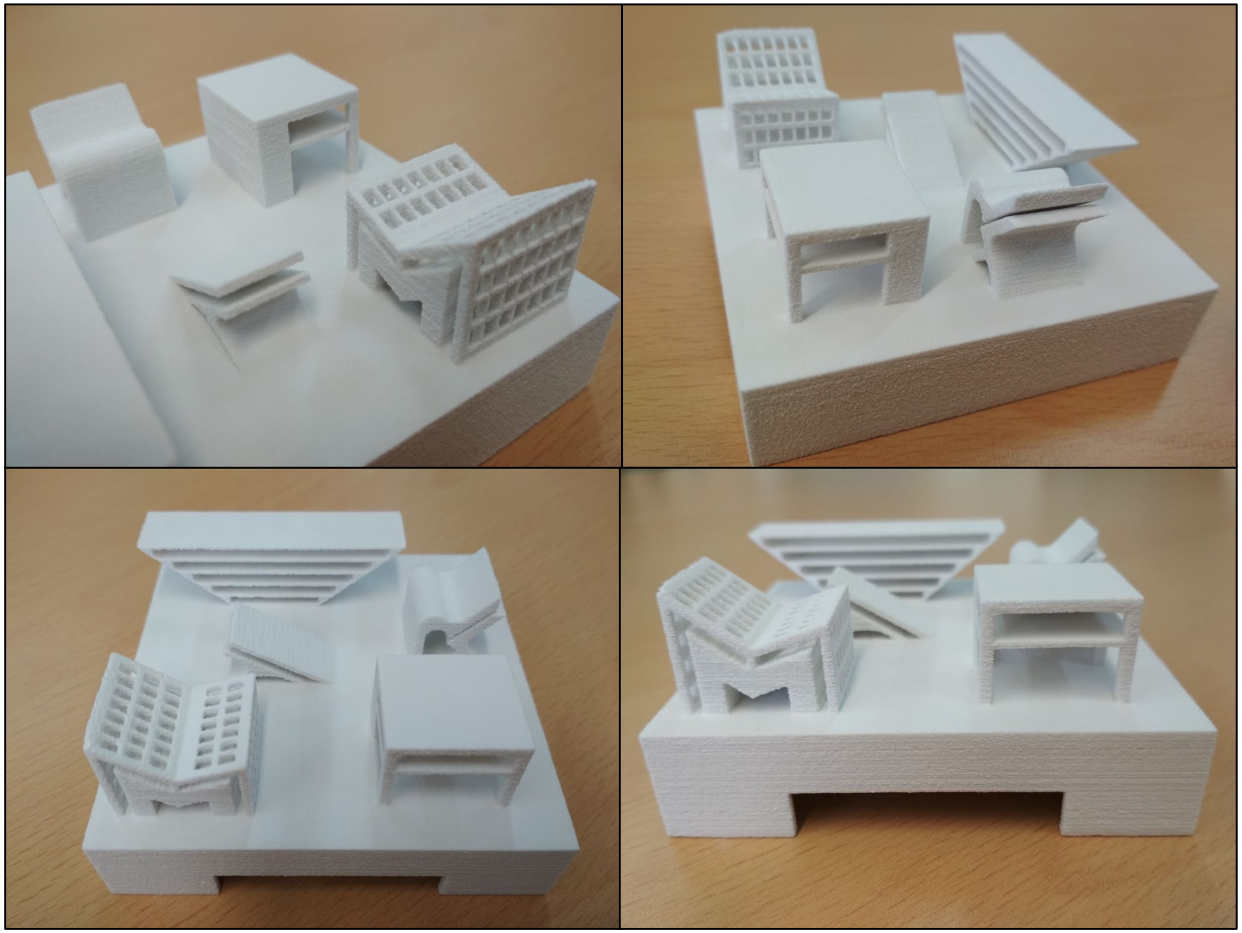
- Bridge creation
- Thin Grid creation

⇒ Stability (need for support structures in other technologies)

- Tested angles =< 30^o



PRINTED MODEL 2



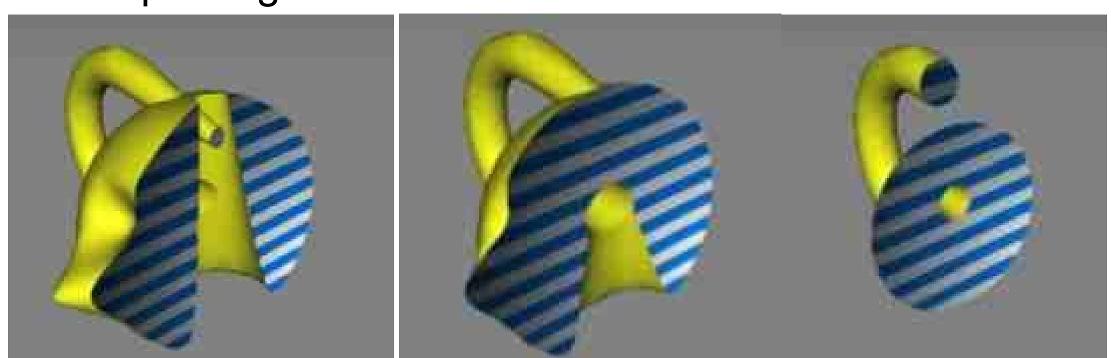
Representations

STEP and IGES files contain information in several formats: wireframes, surfaces, CSG, BREP etc. Needs complicated algorithms to be converted to a representation appropriate for AM (robustness is a mojor issue here)

G-code intermediate language for CNC used now for FDM and other AM technologies. G-code is not machine neutral.

STL: a very primitive triangle based representations, has only face information and repeats vertex information per face. May contain normal information (or encoded in the order of vertices) to determine inside outside. Color is not standard.

Need for a better representation for 3D printing.



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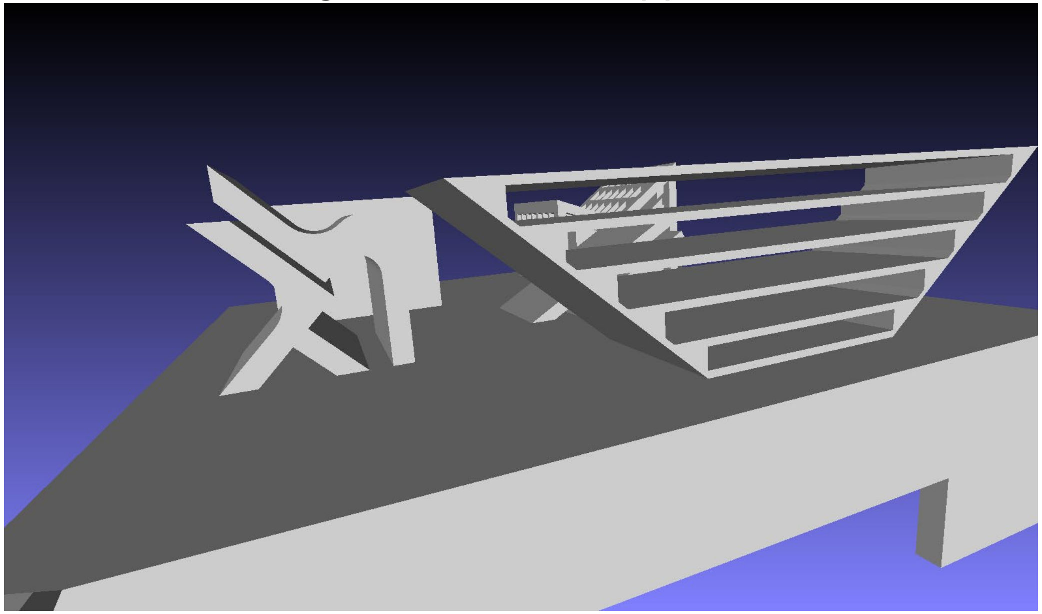
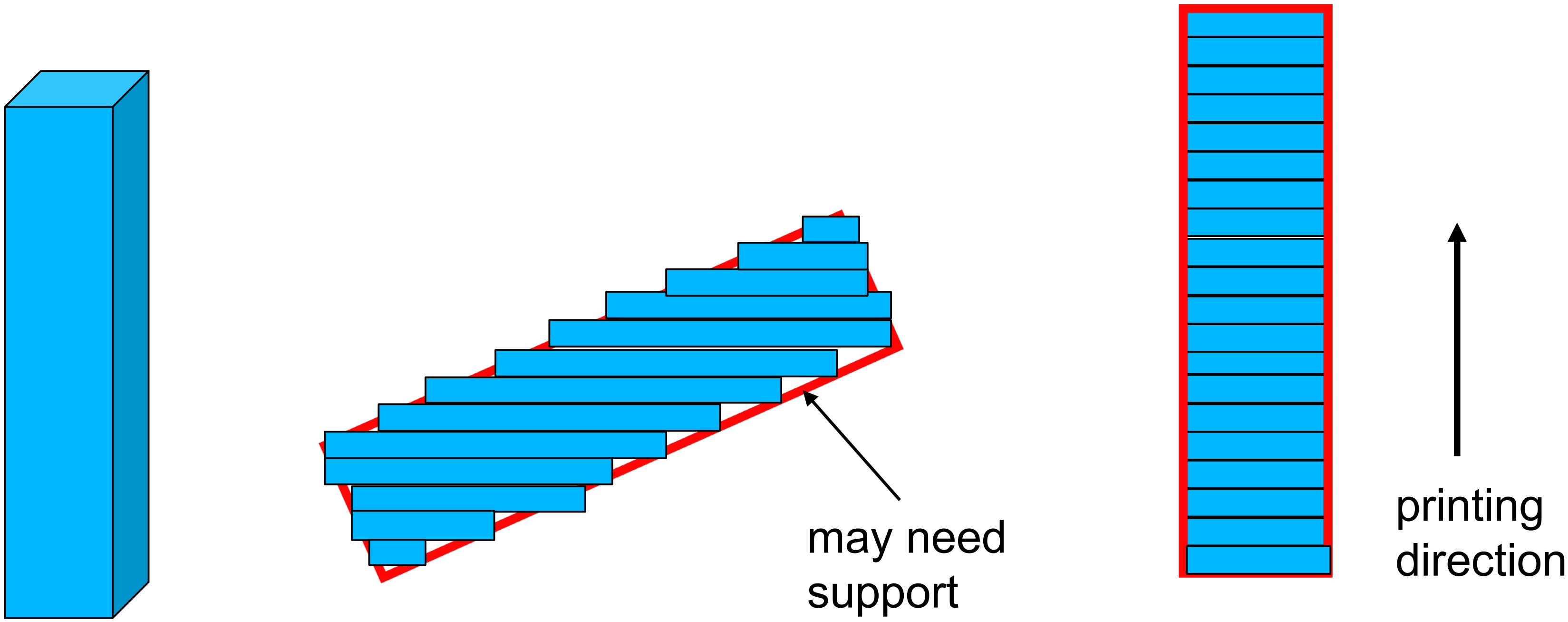
Algorithms (1)

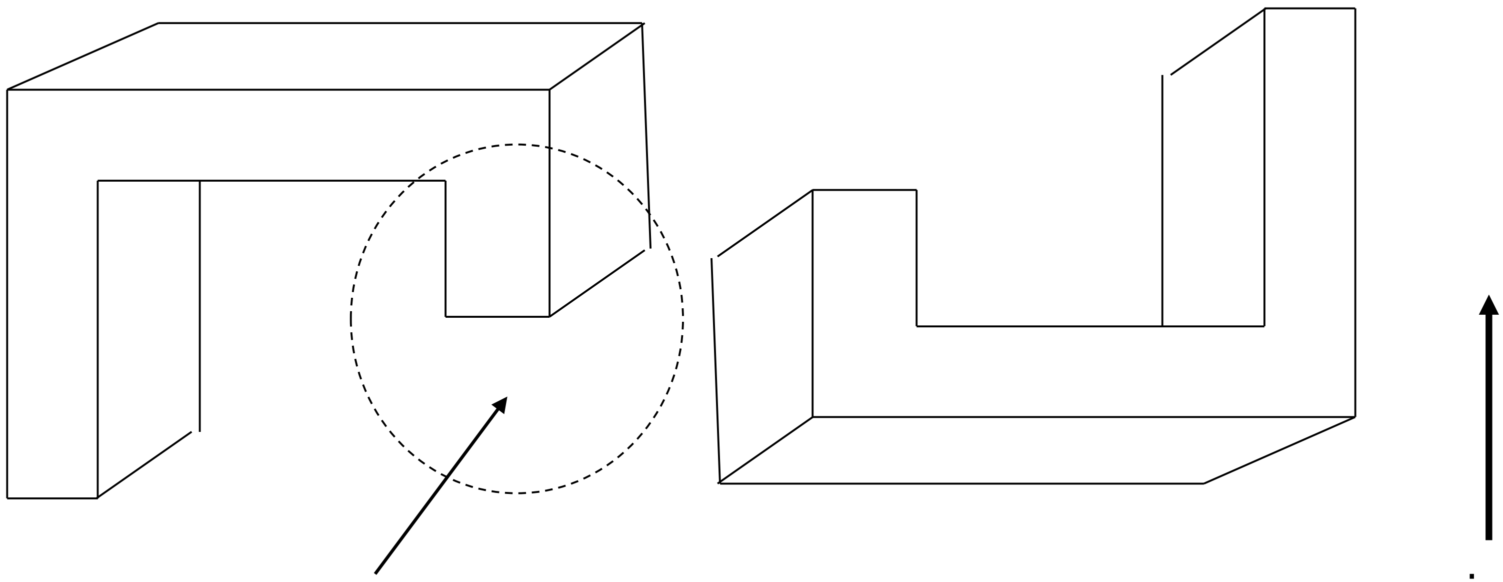
- Orientation algorithms: find layering orientation that minimizes support structures: a problem that has been studied extensively
- Support structures needed are different for each technology
- A benchmark for technologies that need support:



Algorithms (2)



Algorithms (3)



will need support unless the technology is powder based

No need for support

printing direction

Algorithms (4)

Naïve algorithm to find best orientation to minimize support:

For every possible orientation and every triangle determine what support is needed:

Orientation can be modeled with three parameters: two for placing an object diameter in space and one for rotating the object around the diameter: three angles.

We can use rendering passes to compute supports for each orientation direction.

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Algorithms (5)

- Detect problems while printing and correct in the next layers or abort to save consumables.

- Analyze points or layers that are likely to be affected from erroneous behavior. Such robustness issues occur from accuracy errors due to:

    1. step motor errors, material malfunctioning due to humidity or temperature, other external reasons

    2. badly designed 3D printing software that slices the solid object and sends slices to 3D printer as 2D images

- Input ranges from high end sensors to inexpensive cameras

Quality Assurance in 3D Printing

The objective of the Q3D project is the development of the most appropriate digital tools, aiming to provide surveillance and improvement services of the 3D printing procedure, in order to ensure the quality of the final 3D object.

These objectives will be achieved by utilizing the existing technical know-how and the available infrastructures, while introducing pioneering technological methods through the collaboration of the partners of the CERTH, the Department of Computer Science & Engineering/ University of Ioannina, and the 3DLife company.

More info: https://q3d.iti.gr/

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CONCLUSIONS

3D printing

- Simplifies complicated procedures
- Reduces the production time and cost
- Sufficient percentage of accuracy
- Designs almost every complicated model
- Facilitates a wide range of improved designs
- Requires an innovative pipeline and algorithms for quality assurance

More: http://cgrg.cs.uoi.gr

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