Introduction to Additive Manufacturing (3D Printing)

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- Introduction to AM
- History and Evolution
- Applications
- Pros and Cons of AM
- Benefits
- Basic step of AM
- Type of AM Process
- Some parts manufactured by AM
- Case study

Additive Manufacturing (3D Printing)

- Additive Manufacturing (AM), also known as 3D Printing technology, refers to processes used to generate a 3D object in which layers-upon-layer deposition of materials are successively formed under a computer controlled program to create a physical object.

- The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication.

- AM application is limitless. Early use of AM in the form of Rapid Prototyping focused on preproduction visualization models. More recently, AM is being used to fabricate end-use products in aircraft, dental restorations, medical implants, automobiles, and even fashion products.

- The objects manufactured through 3D printing processes can be of almost any shape or geometry. They are typically produced using digital model data from a 3D model or another electronic data source such as a STereoLithography (STL) file, one of the most common file types that 3D printers can read.

History and Evolution

- Additive manufacturing invention can be traced back to the 1980's by Japanese, French and American researchers. The very first patent of 3D printing was coined in 1984 by Chuck Hull of 3D Systems Corporation.

- Hull defined the 3D printing process as a system for generating three-dimensional objects by creating a cross-sectional pattern of the object to be formed. His invention consists of a stereolithography fabrication system, in which layers are added by curing photopolymers with ultraviolet light lasers. Stereolithography is still one very popular 3D printing manufacturing technique, also known as SLA.

Evolution

AM applications timeline

This timeline lays out past, present and potential future AM developments and applications. (courtesy of Graham Tromans)

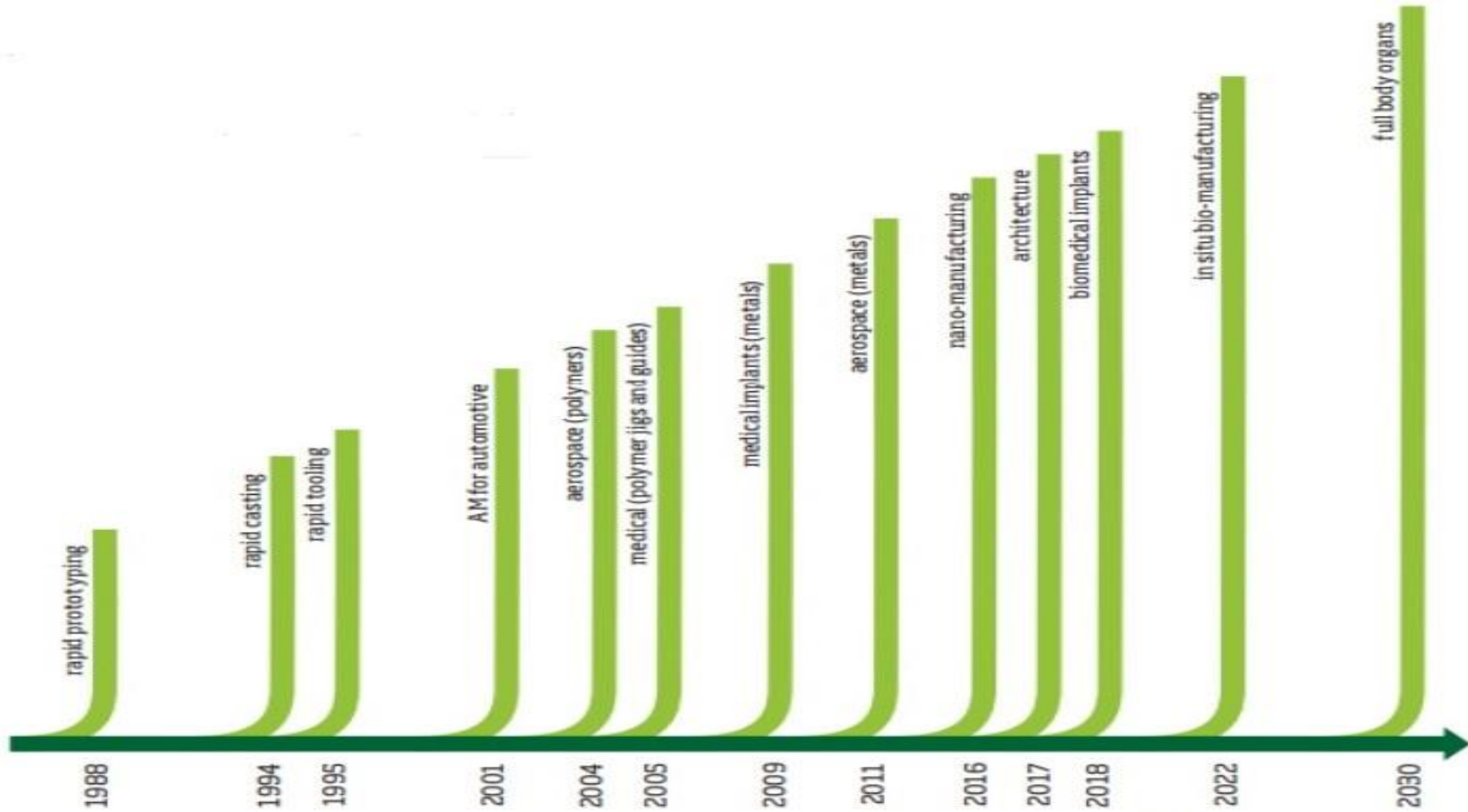|	
1988–1994	rapid prototyping
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013–2016	nano-manufacturing
2013–2017	architecture
2013–2018	biomedical implants
2013–2022	in situ bio-manufacturing
2013–2032	full body organs

CASE STUDY

GE AND MORRIS TECHNOLOGY
Graham Tromans

The automotive and aerospace industries are two of the main beneficiaries of AM. In 2012, GE Aviation bought AM Morris Technologies, one of the biggest metal additive manufacturers in the world. GE is ramping up AM manufacturing of aero engine fuel nozzles. The conventional method of making fuel nozzles requires making 20 separate parts and welding them together, "which is extremely labour-intensive and has a high scrap rate," said Graham Tromans, Principal and President of AM consultancy GP Tromans Associates. AM allows the creation of pre-assembled nozzles. GE predicts that, by late 2015/16, it will make 10–20 fuel nozzles for each engine using AM, or 25,000 a year. The company also envisages that 50% of a jet engine will be additive manufactured within current lifetimes.
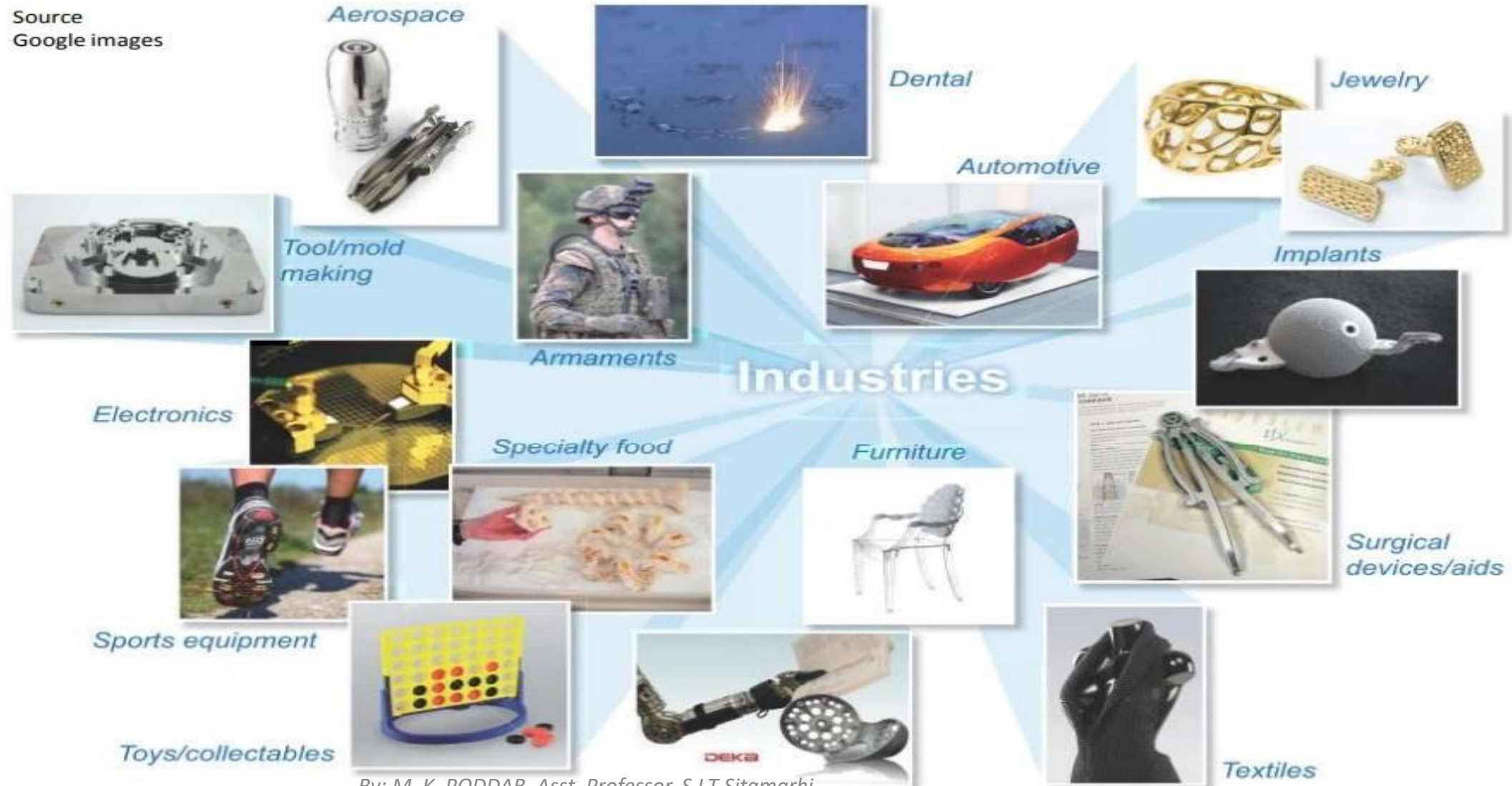
Source: Royal Academy of Engineering

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Evolution

rapid prototyping — 1988

rapid casting — 1994

rapid tooling — 1995

AM for automotive — 2001

aerospace (polymers) — 2004

medical (polymer jigs and guides) — 2005

medical implants (metals) — 2009

aerospace (metals) — 2011

nano-manufacturing — 2016

architecture — 2017

biomedical implants — 2018

in situ bio-manufacturing — 2022

full body organs — 2030

Source: Royal Academy of Engineering

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Current applications and Potential industries for AM

Source Google images

Aerospace · Dental · Jewelry · Automotive · Tool/mold making · Armaments · Implants · Electronics · Specialty food · Industries · Furniture · Surgical devices/aids · Sports equipment · Toys/collectables · Prosthetics/orthotics · Textiles

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Pros and Cons of AM

- Pros and Cons :: advantages and disadvantages

Pros and Cons

Pros	Cons
Freedom to design and innovate without penalties	Unexpected pre- and post-processing requirements
Rapid iteration through design permutations	High process cost
Excellent for mass customization	Lack of industry standards
Elimination of tooling	Low speed, not suitable for mass production
	Inconsistent Materials
Green manufacturing	Limited number of materials
Minimal material waste	High equipment cost for high-end manufacturing
Energy efficient	
Enables personalized manufacturing	

Benefits of AM

- Weight Reduction

- Complexity for free

- Freedom of design

- Customized Medical Products

- Home Manufacturing

- Potential elimination of tooling

Benefits

AM benefits: Weight reduction

TRADITIONAL DESIGN
Source: SAVING project

> A conventional steel buckle weights 155 g[1]
> Weight should be reduced on a like-for-like basis within the SAVING project
> Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN
Source: SAVING project

> Titanium buckle designed with AM weighs 70 g – reduction of 55%
> For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
> Over the airplane's lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime
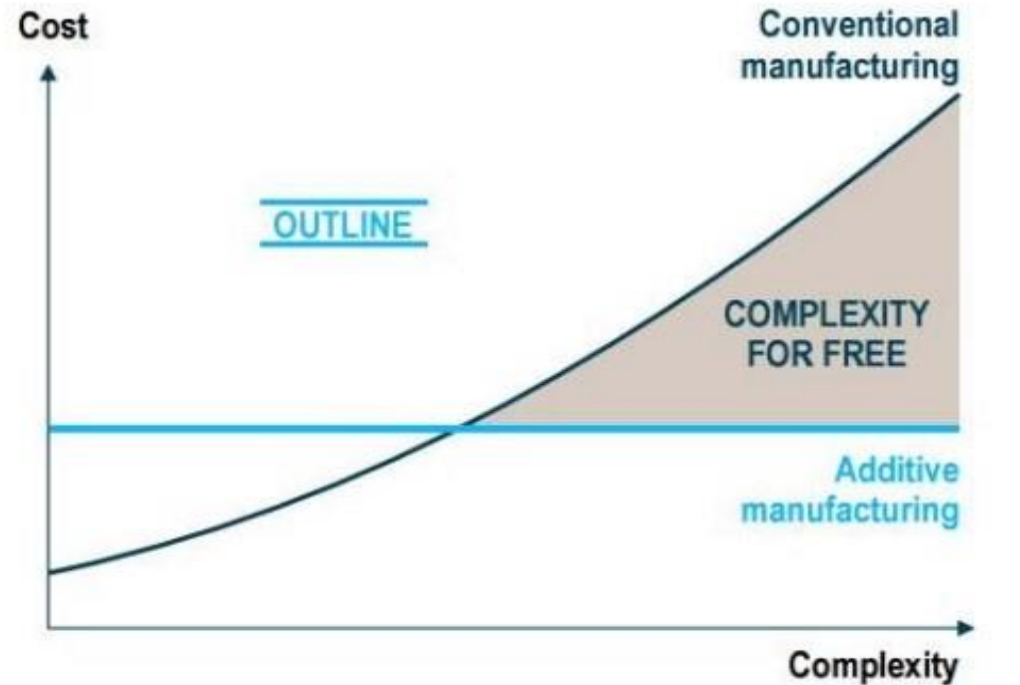
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Benefits

AM benefits: Complexity for free

AM ENABLES NEW GEOMETRIC SHAPES ...

Source: PEP

> AM enables the manufacturing of new geometric shapes that are not possible with conventional methods

> Example: AM makes it possible to design advanced cooling channels that cool tools/components better and therefore reduce cycle time

Cost

OUTLINE

Conventional manufacturing

COMPLEXITY FOR FREE

Additive manufacturing

Complexity

... AT NO ADDITIONAL COST

Source: Roland Berger

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Benefits

AM for customized medical products

DENTAL CROWNS/BRIDGES
Source: EOS

> **AM holds a large share of the dental crowns and bridges market** – Geometry is scanned and processed via CAD/CAM. More than 30 million crowns, copings and bridges have already been made on AM machines over the last 6 years

> **Increasing market share** – Experts estimate that more than 10,000 copings are produced every day using AM

> **Faster production** – One AM machine produces up to 450 crowns per day, while a dental technician can make around 40

IMPLANTS
Source: EOS

> **AM offers advantages with regard to manufacturing time, geometric fit and materials** – Example of a skull implant with modified surface structure

> **Improved fit via AM** – Based on 3D scans of the skull, the resulting implant fits perfectly into the skull cap, leads to faster recovery and reduces operation time

Additive manufacturing will replace conventional manufacturing methods for customized products

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Source: Roland Berger

Future: Home Manufacturing

Old toothbrush

Customization:
- Bristle hardness
- Colour
- Handle Style and shape
- Etc.

New toothbrush

Laser scanner to input
personalized data

Home 3D Printer

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Basic steps of AM

- AM involves a number of steps that move from the virtual CAD description to the physical resultant part.

- Steps involved in AM

    1. CAD model design

    2 .STL convert

    3 File transfer to machine

    4 Machine setup

    5 Build

    6 Remove

    7 Post-process

    8 Application

1 CAD
2 STL convert
3 File transfer to machine
4 Machine setup
5 Build
6 Remove
7 Post-process
8 Application
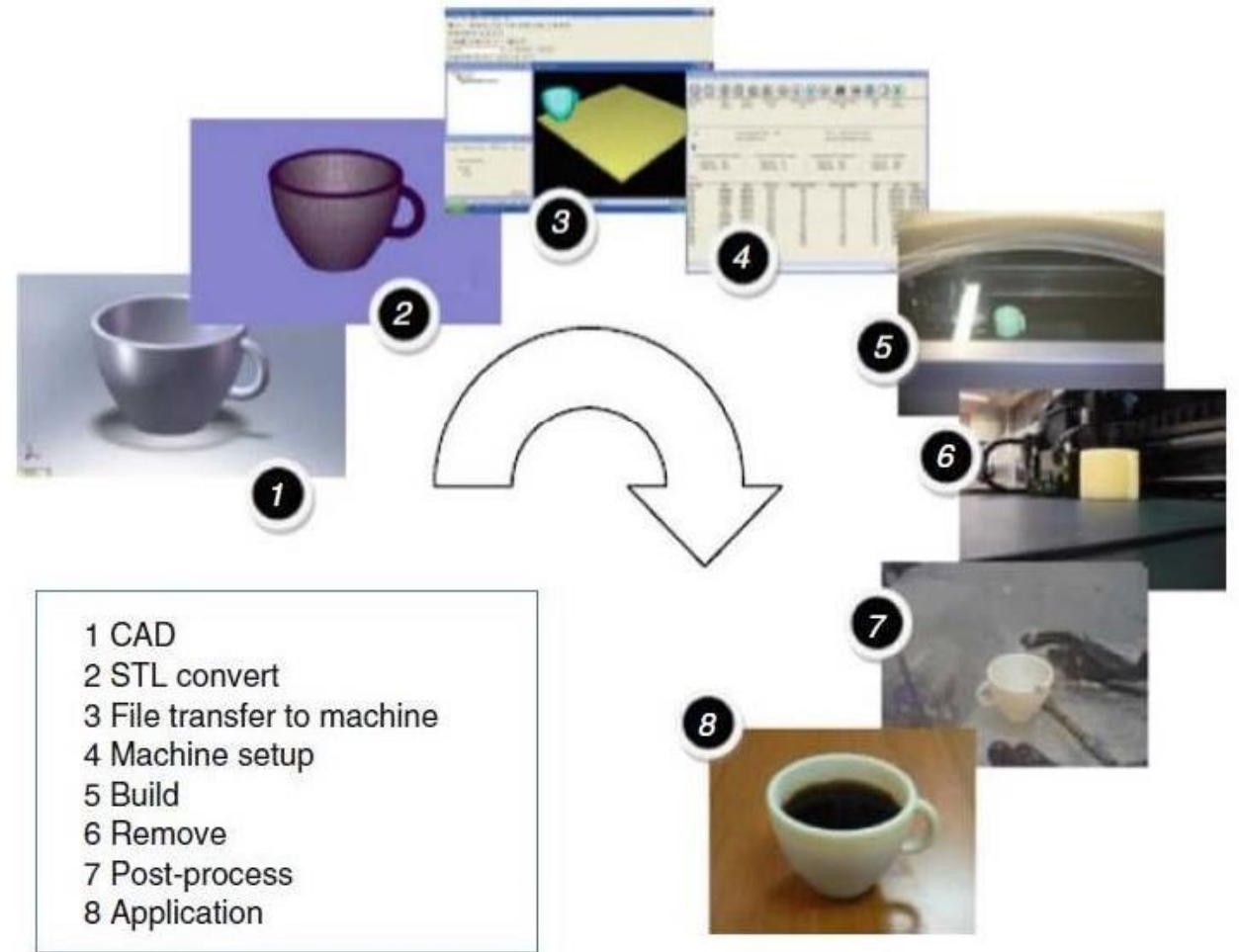
Source: Gibson, Additive Manufacturing

1. CAD model design : All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software (like Auto CAD 3. D/Solidwork/Inventor Autodesk

2. Conversion to .STL and Slicing the model: Nearly every AM machine accepts the STL file format and nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices the CAD model.

3. File transfer to machine and STL File Manipulation : The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

4. Machine setup: The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, Nozzle speed, nozzle Temperature etc.

5. Build : Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

6. Remove: Once the AM machine has completed the build (Physical model), the parts must be removed.

7. Post-process: Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use.

8. Application: Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish.

3D Printing Machine (FDM type)

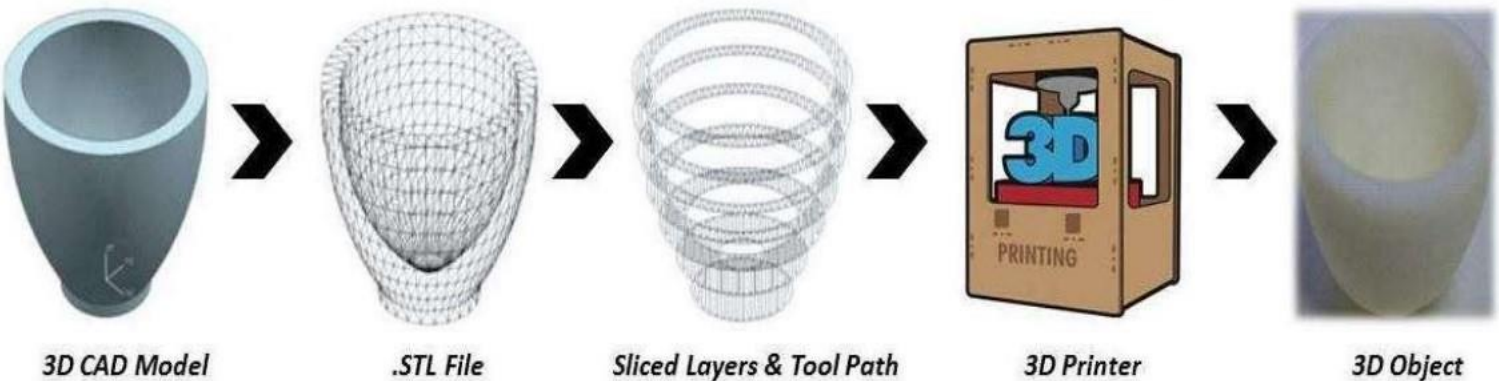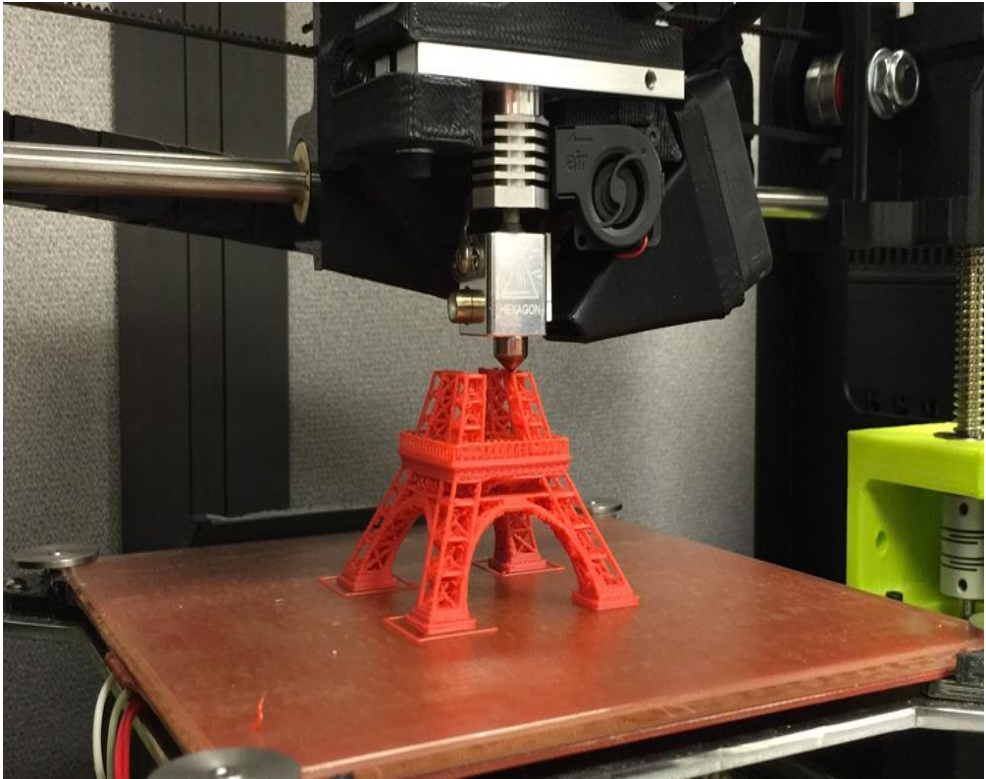3D CAD Model → .STL File → Sliced Layers & Tool Path → 3D Printer → 3D Object
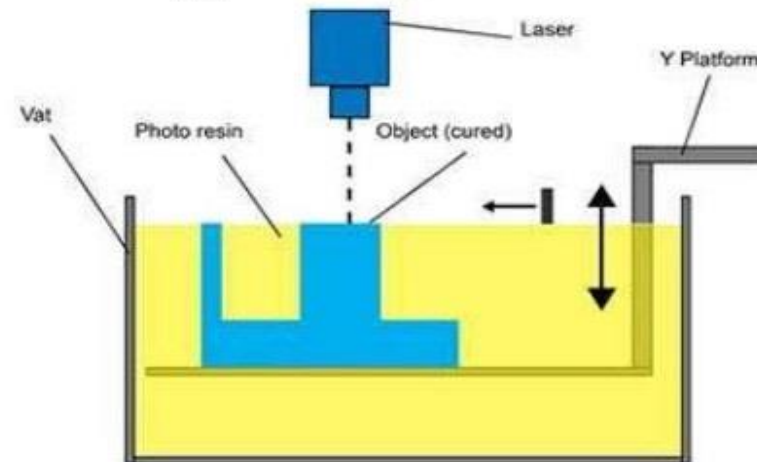
Fig: Google Image

Type of AM Process

AM processes are classified into seven categories

1) Vat Photopolymerisation/Steriolithography
2) Material Jetting
3) Binder jetting
4) Material extrusion Or Fused Deposition Modeling (FDM)
5) Powder bed fusion
6) Sheet lamination
7) Directed energy deposition

Vat photopolymerization/Steriolithography

- Laser beam traces a cross-section of the part pattern on the surface of the liquid resin
- SLA's elevator platform descends
- A resin-filled blade sweeps across the cross section of the part, re-coating it with fresh material
- Immersed in a chemical bath

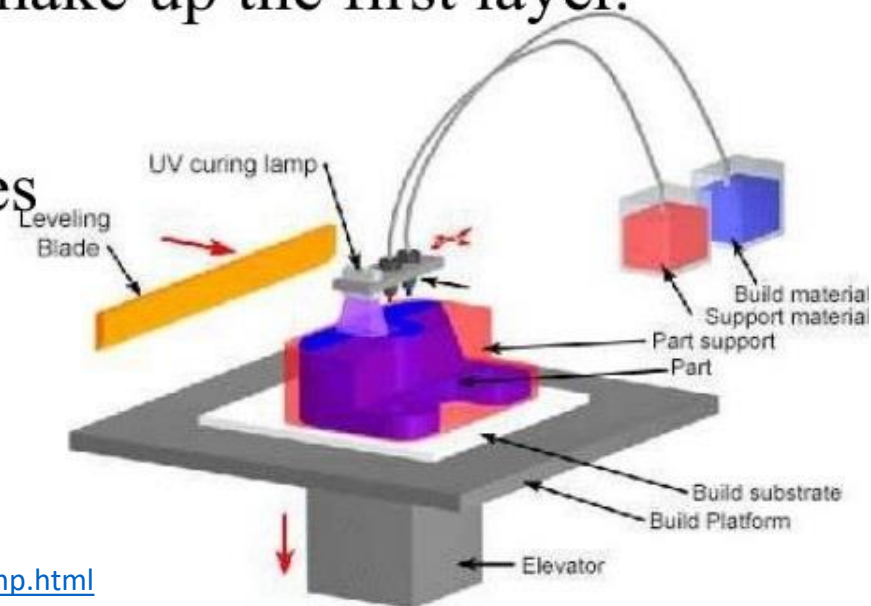Stereolithography requires the use of supporting structures

By: M. K. PODDAR, Asst. Professor, S.I.T Sitamarhi
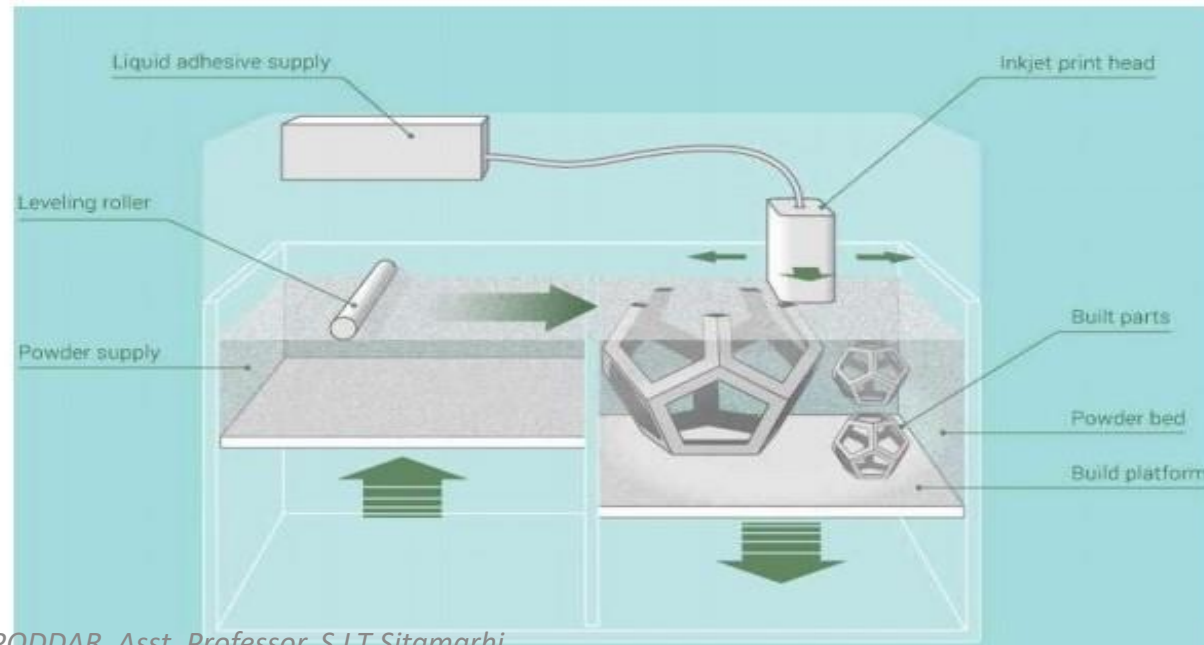Personal web link: https://ajourneywithtime.weebly.com/wmp.html

Material Jetting

- Drop on demand method
- The print head is positioned above build platform
- Material is deposited from a nozzle which moves horizontally across the build platform
- Material layers are then cured or hardened using ultraviolet (UV) light
- Droplets of material solidify and make up the first layer.
- Platform descends
- Good accuracy and surface finishes

UV curing lamp

Leveling Blade

Build material
Support material
Part support
Part

Build substrate
Build Platform

Elevator

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Binder Jetting

- A glue or binder is jetted from an inkjet style print head
- Roller spreads a new layer of powder on top of the previous layer
- The subsequent layer is then printed and is stitched to the previous layer by the jetted binder
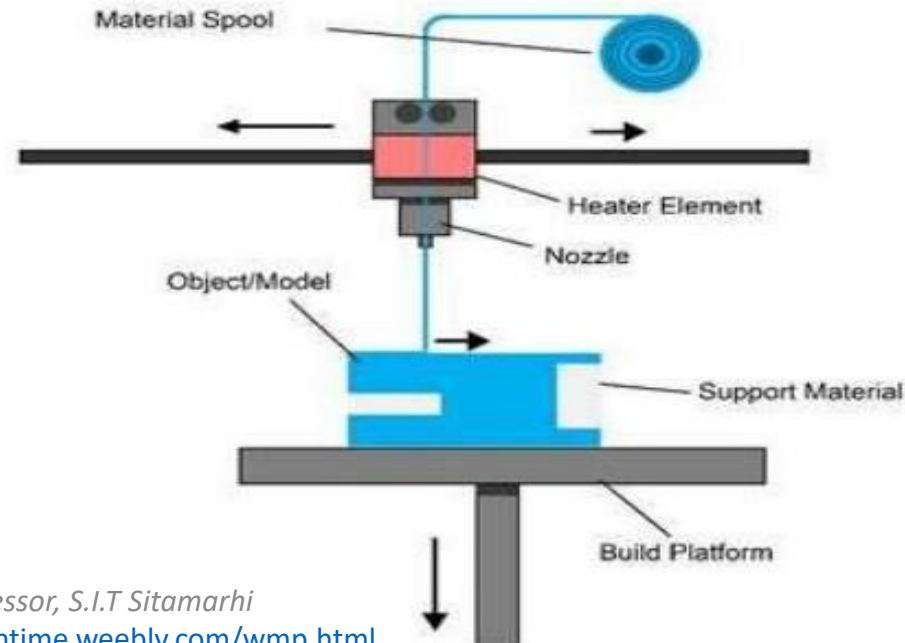- The remaining loose powder in the bed supports overhanging structures

Liquid adhesive supply

Inkjet print head

Leveling roller

Built parts

Powder supply

Powder bed

Build platform

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Material Extrusion/FDM

- Fuse deposition modelling (FDM)
- Material is drawn through a nozzle, where it is heated and is then deposited layer by layer
- First layer is built as nozzle deposits material where required onto the cross sectional area.
- The following layers are added on top of previous layers.
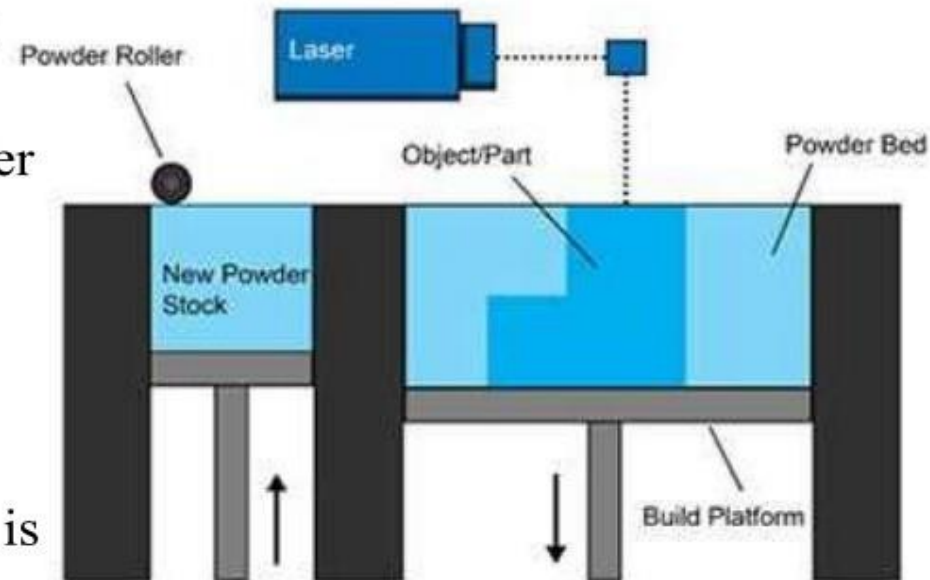- Layers are fused together upon deposition as the material is in a melted state.

Material Spool

Heater Element

Nozzle

Object/Model

Support Material

Build Platform

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Powder Bed Fusion

- Selective laser sintering (SLS)
- Selective laser melting (SLM)
- Electron beam melting (EBM)

No support structures required

PROCESS

- A layer, typically 0.1mm thick of material is spread over the build platform.
- The SLS machine preheats the bulk powder material in the powder bed
- A laser fuses the first layer
- A new layer of powder is spread.
- Further layers or cross sections are fused and added.
- The process repeats until the entire model is created.

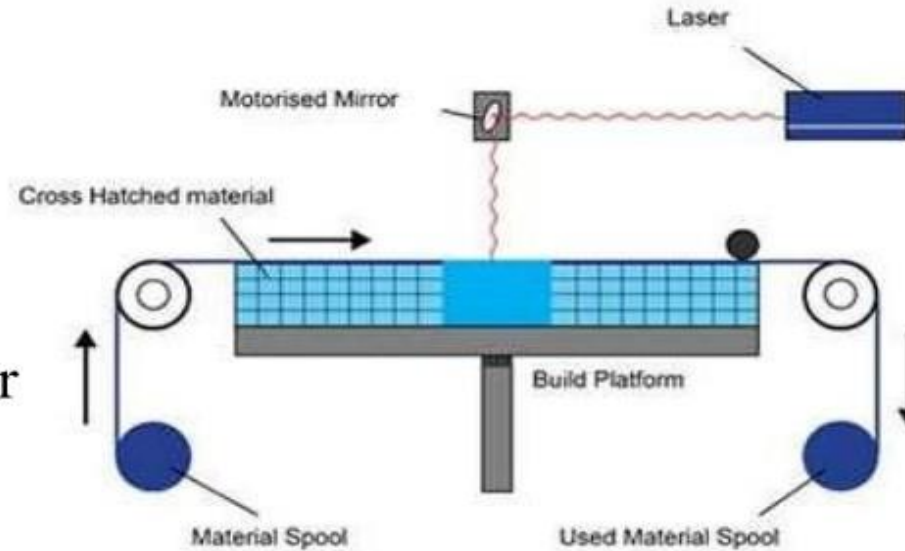*By: M. K. PODDAR, Asst. Professor, S.I.T Sitamarhi*
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Sheet Lamination

- Metal sheets are used
- Laser beam cuts the contour of each layer
- Glue activated by hot rollers

PROCESS

1. The material is positioned in place on the cutting bed.
2. The material is bonded in place, over the previous layer, using the adhesive.
3. The required shape is then cut from the layer, by laser or knife.
4. The next layer is added.

Laser

Motorised Mirror

Cross Hatched material

Build Platform

Material Spool

Used Material Spool

Directed Energy Deposition

- Consists of a nozzle mounted on a multi axis arm
- Nozzle can move in multiple directions
- Material is melted upon deposition with a laser or electron beam

PROCESS

1. A4 or 5 axis arm with nozzle moves around a fixed object.
2. Material is deposited from the nozzle onto existing surfaces of the object.
3. Material is either provided in wire or powder form.
4. Material is melted using a laser, electron beam or plasma arc upon deposition.
5. Further material is added layer by layer and solidifies, creating or repairing new material features on the existing object.

Electron Beam

Material (metal) wire supply

Obeject

Metal wire

Build Platform
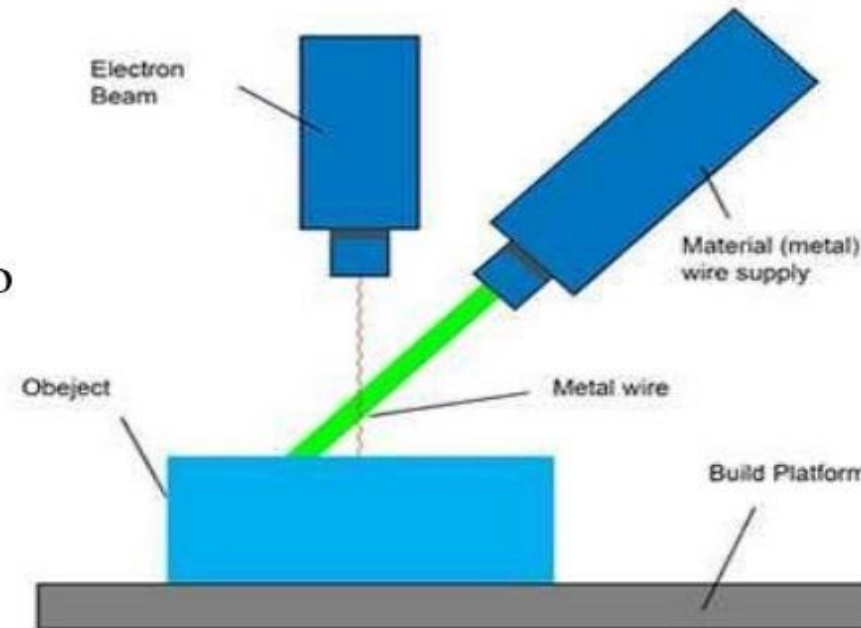
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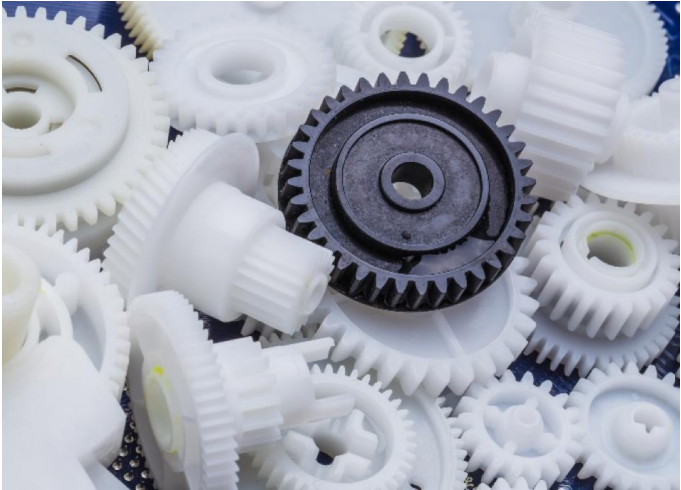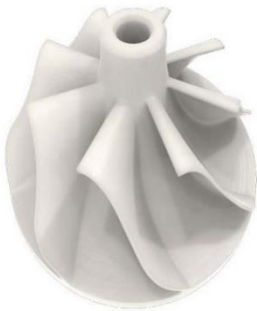
Some parts manufactured by AM

Fig: Google Images

Case Studies

CASE STUDY

ROLLS-ROYCE

Rolls-Royce is considering embarking on the additive manufacture of entire components because of the benefits of faster production and reduced costs that it offers. Says Rolls-Royce's Neil Mantle: "At the launch of an engine programme we start to consider forgings, and AM gives us a great opportunity here because conventional methods of manufacture can take 40, 50 or even 60 weeks, while a component using AM will take one month." Likewise, he praised the improved buy-to-fly ratio on materials: "Sometimes we machine away 90% of the materials to create the final component, but with AM that figure is much reduced." Neil Mantle added that while AM offers distinct advantages, investing in AM machines will require Rolls-Royce to feel confident of their economic viability and that the processes will be as robust and reliable as traditional methods.

CASE STUDY

VIRGIN UPPER CLASS MONITOR ARM

In a Technology Strategy Board (TSB) funded project for Virgin Atlantic, the arm holding the TV monitor in the airline's Upper Class seats was redesigned for AM. Latticing reduced the arm's weight by 50%, saving 0.5 kilograms for every unit, in turn saving $45,000 worth of fuel across the 30-year lifetime of the aircraft. "You can make an economic case for AM on that one component," said Dr Chris Tuck, Associate Professor of Additive Manufacturing and 3D Printing Research Group at the University of Nottingham.

Source: Royal Academy of Engineering

References:

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- Additive Manufacturing (iitk.ac.in), NPTEL http://home.iitk.ac.in/~jrkumar/download/Lecture-5.pdf

- Book on 'Additive Manufacturing Technologies and Applications' by Salvatore Brischetto, Paolo Maggiore and Carlo Giovanni Ferro, ISBN 978-3-03842-549-6 (PDF), First Edition 2017, MDPI AG

- https://www.slideshare.net/StephinAbrahamSabu/additive-manufacturing-ppt

- https://www.google.com/search?q=images+of+3D+printing+object&hl=en&tbm=isch&sxsrf=ALeKk00I1-0o9p5PjL6SJ51VtN1YZQBWCw%3A1627154653497&source=hp&biw=1280&bih=562&ei=3Wj8YIf6Gr KwmAWE7r34Cg&oq=images+of+3D+printing+object&gs_lcp=CgNpbWcQAzoHCCMQ6gIQJzoECCM QJzoFCAAQsQM6AggAOggIABCxAxCDDAToECAAQAzoGCAAQCBAeOgQIABAYOgQIABAeUMug AVjA1AJgp9kCaAFwAHgAgAG3AYgB5yWSAQQwLjI4mAEAoAEBqgELZ3dzLXdpcGei1pbWewAQo&sc lient=img&ved=0ahUKEwjH3PO4t_zxAhUyGKYKHQR3D68Q4dUDCAc&uact=5