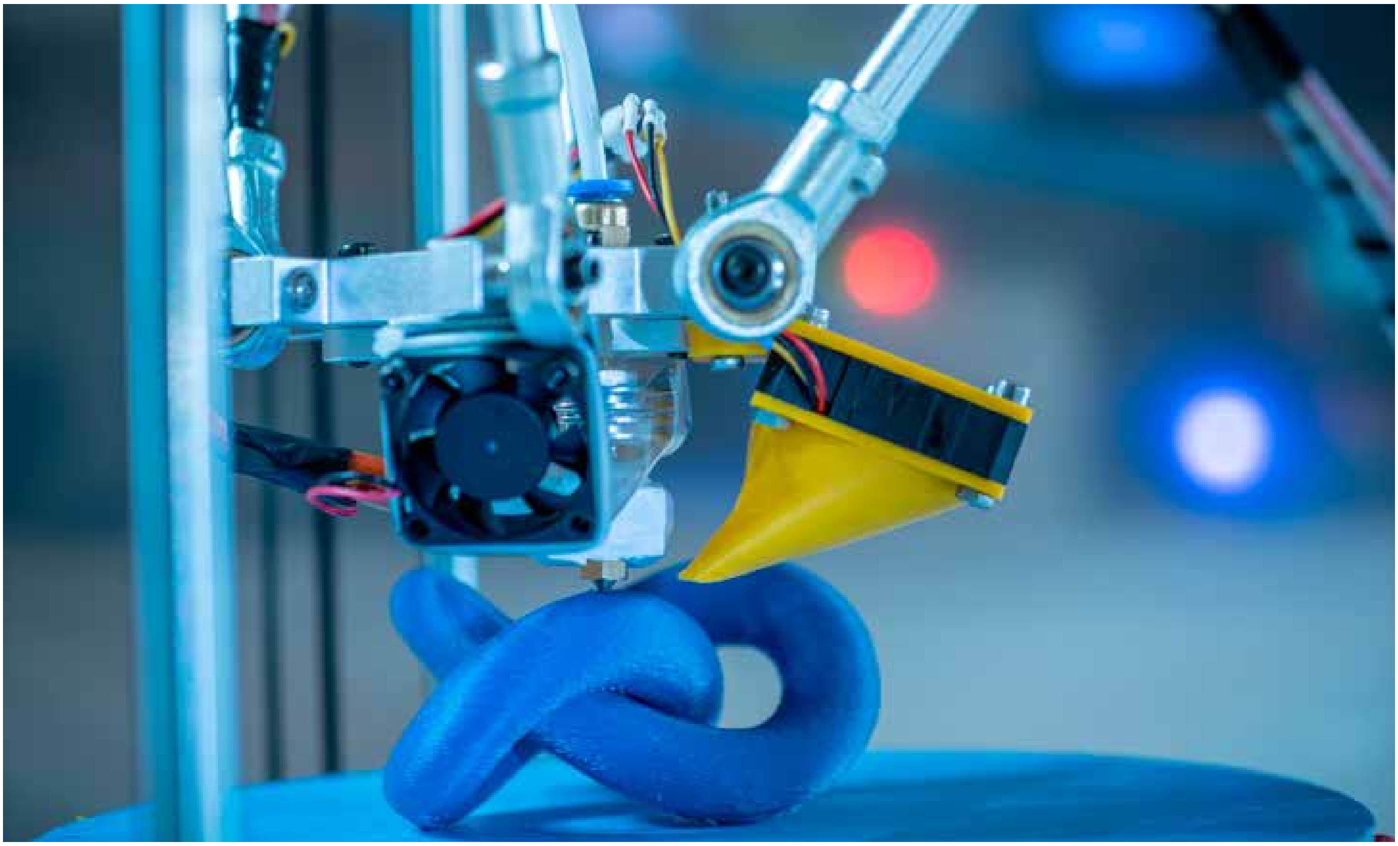
Additive manufacturing: Advances in 3D printing



TECH FRONTIERS

EEPC INDIA TECHNOLOGY CENTRE

The first article in a new series on innovative technologies. 3D printing technology is an additive manu-facturing process which is gradually replacing traditional manufacturing processes by subtractive method in a range of industries – from industrial design, architecture, engineering and construction, to automotive, aerospace, medical, education and consumer products industries

Traditional manufacturing methods involve a material being carved or shaped into the desired product by parts of it being removed in a variety of ways. Additive manufacturing is the polar opposite; structures are made by the addition of thousands of minuscule layers which combine to create the product. The process involves the use of a computer and special CAD software which can relay messages to the printer so it 'prints' in the desired shape. The idea of additive manufacturing describes a new way to produce objects by adding material, unlike traditional subtractive processes such as machining, drilling, or different cutting processes. These older, more conventional techniques entail re-

Figure1: Annual growth rings in trees show the amount of wood produced during one growing season

Figure2: Modern machine tools

moving material from an initial volume in order to obtain the desired shape.

Additive manufacturing processes eliminate much of the traditional manufacturing set-up requirements: they do not require any tooling design (mould or dies, plastic injection, or forging tools) or defining or organising different manufacturing steps (like machining or milling). They enable you to go almost instantly from the 3D design file to the physical object itself, which represents increased accessibility and significant time savings in the product development cycle.

Suitable for use with a range of different materials, the cartridge is loaded with the relevant substance and this is 'printed' into the shape, one wafer-thin layer at a time. These layers are repeatedly printed on top of each other, being fused together during the process until the shape is complete.

Additive manufacturing is currently a $2.2 billion industry worldwide and is expected to triple by 2018 to roughly $6 billion. For example, the injection moulding market is expected to be $252 billion in 2018.

Additive growth in nature

The concept of additive growth has, perhaps, been developed by observing natural growth. Each year, the tree forms new cells, arranged in concentric circles called annual rings or annual growth rings. These annual rings show the amount of wood produced during one growing season. The trunk of a tree is the end product of such additive growth each year.

Figure3: Carpentry uses many of the traditional processes of manufacturing

Traditional manufacturing processes

Whereby metal is bored, milled, cut, and subtracted in various other ways to obtain the desired product.

Carpentry by the traditional processes of manufacturing involves cutting, planing, drilling, surface treatment, and similar subtractive methods.

3D PRINTING

Additive manufacturing or 3D printing takes digital input in the form of a computer-aided design (CAD) model and creates solid, three-dimensional parts through an additive, layer-by-layer process. The first working 3D printer was created in 1984 by Charles Deckard Hull of 3D Systems Corp. He named the technique Stereolithography and obtained a patent for it in 1986. In the 1990s other companies developed 3D printers and, in 2005, Z Corp launched the first high-definition colour 3D printer. Also known as rapid prototyping, it is a mechanised method whereby 3D objects are quickly made on a reasonably sized machine connected to a computer containing blueprints for the object. This revolutionary method for creating 3D models with the use of inkjet technology saves time and cost by eliminating the need to design, print, and glue together separate model parts. The basic principles include materials cartridges, flexibility of output, and translation of code into a visible pattern.

Additive manufacturing represents a process of joining materials to make objects from 3D model data, usually layer upon layer. Multiple parts can be produced in one cycle and geometric complexity is not a limitation in 3D printing as shown in **Figure5**.

Objectives of 3D printing

- Providing industry expertise on machine and material selection
- Identifying novel applications and discovering ways to improve current product development practices
- Offering in-person support and instruction for engineers, technicians, and designers
- Testing/developing new materials
- Developing frameworks to maximise R&D efficiency and boost return on investment (ROI) for large-scale systems
- Metal 3D printing to manufacture made-to-order items that do not require product
- Speedy pattern making for casting industry and testing the same through simulation software.

General principles

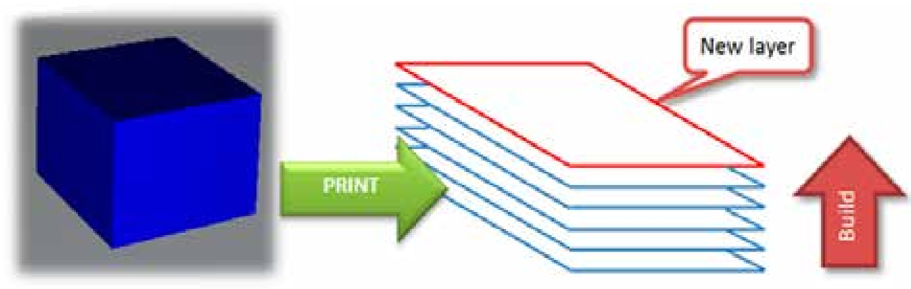


Figure4: Inkjet printing

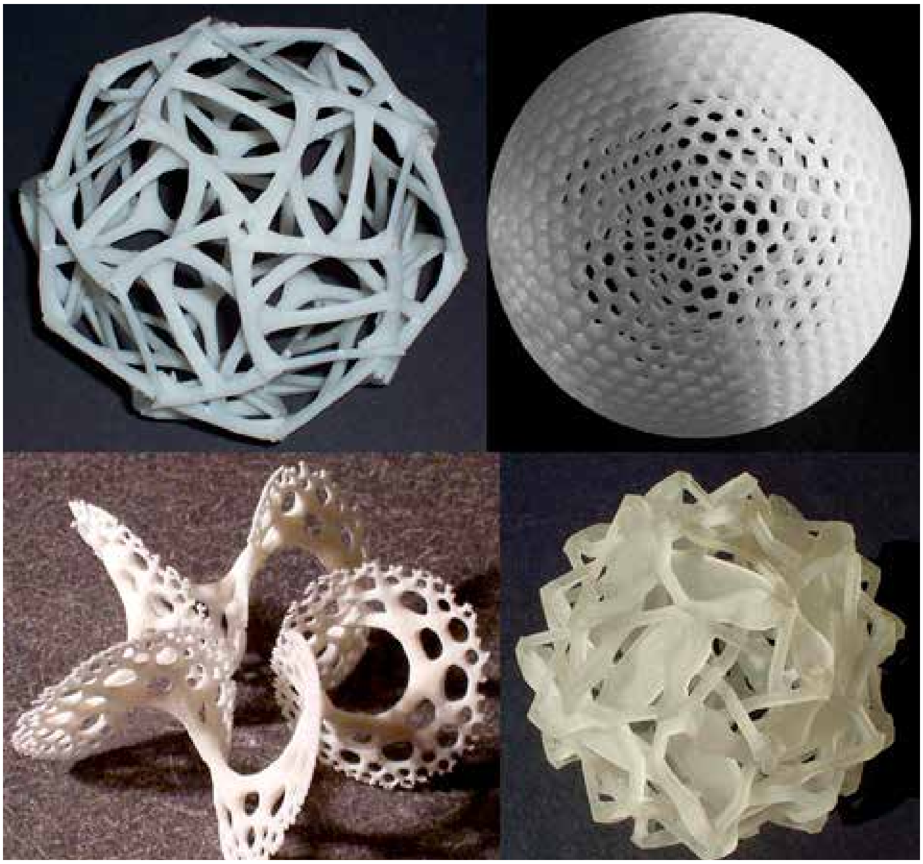


Figure5: 3D printing can create complex geometric figures

- *Modelling*: 3D printing takes virtual blueprints from modelling software and 'slices' them into digital cross-sections for the machine to successively use as a guideline for printing.
- *Printing*: To perform a print, the machine reads the design from an *.stl file and lays down successive layers of liquid, powder, paper, or sheet material to build the model from a series of cross-sections.
- *Finishing*: Different materials are used to construct parts; few of them are used with the main body to form different colours and texture, others are utilised to providing supports when building. Support materials can be removed or dissolved once the printing is completed.

Types of 3D printing

There are seven different types of 3D print-

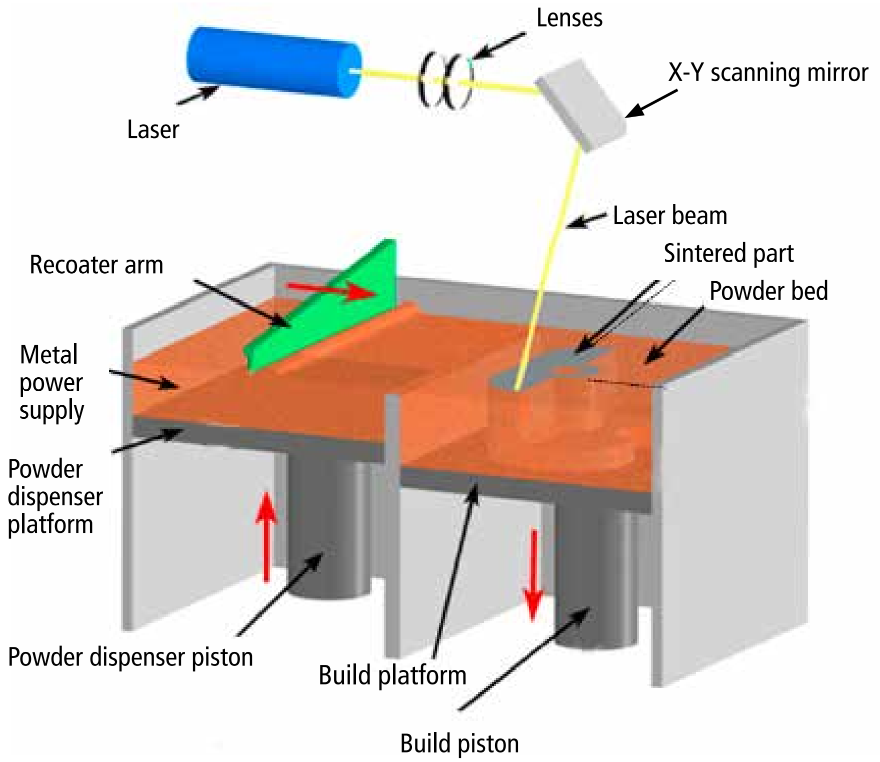


Figure6: Selective laser sintering

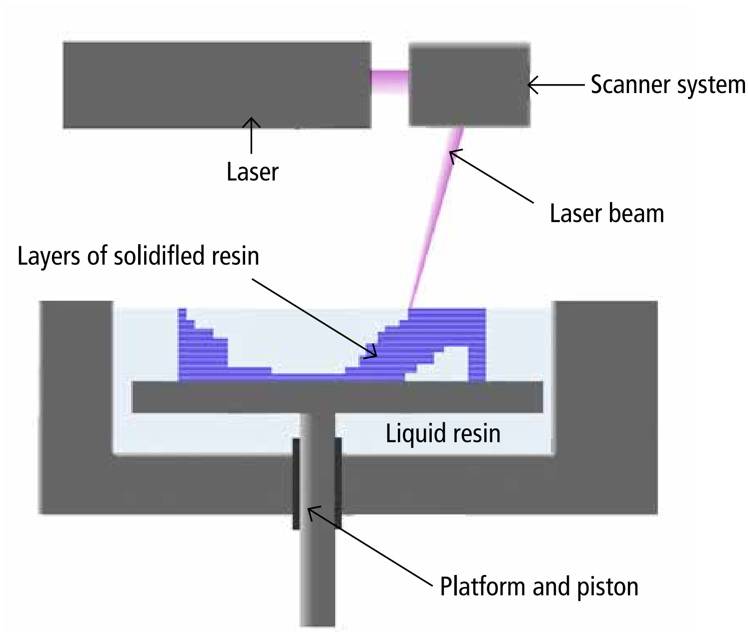


Figure7: Stereolithography

ing based on different building mechanisms, price points, materials, and uses. A few are described here.

Selective laser sintering

Selective laser sintering is an additive manufacturing technique that uses a high-power laser (e.g. CO2 laser) to fuse small particles of plastic, metal, ceramic, or glass powders into a mass that has a desired 3D shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3D digital description of the part (for example, from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed.

Stereolithography (SLA)

Stereolithography is an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer 'resin' and an ultraviolet laser to build parts' layers one at a time. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and solidifies the pattern traced on the resin and joins it to the layer below. After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer. Then, a resin filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer. A complete 3D part is formed by this process. After being built, parts are immersed in a chemical bath in order to be cleaned of excess resin and are subsequently cured in an ultraviolet oven.

Fused deposition modelling (FDM)

Fused deposition modelling builds parts layer-by-layer from the bottom up by heating and extruding thermoplastic filament.

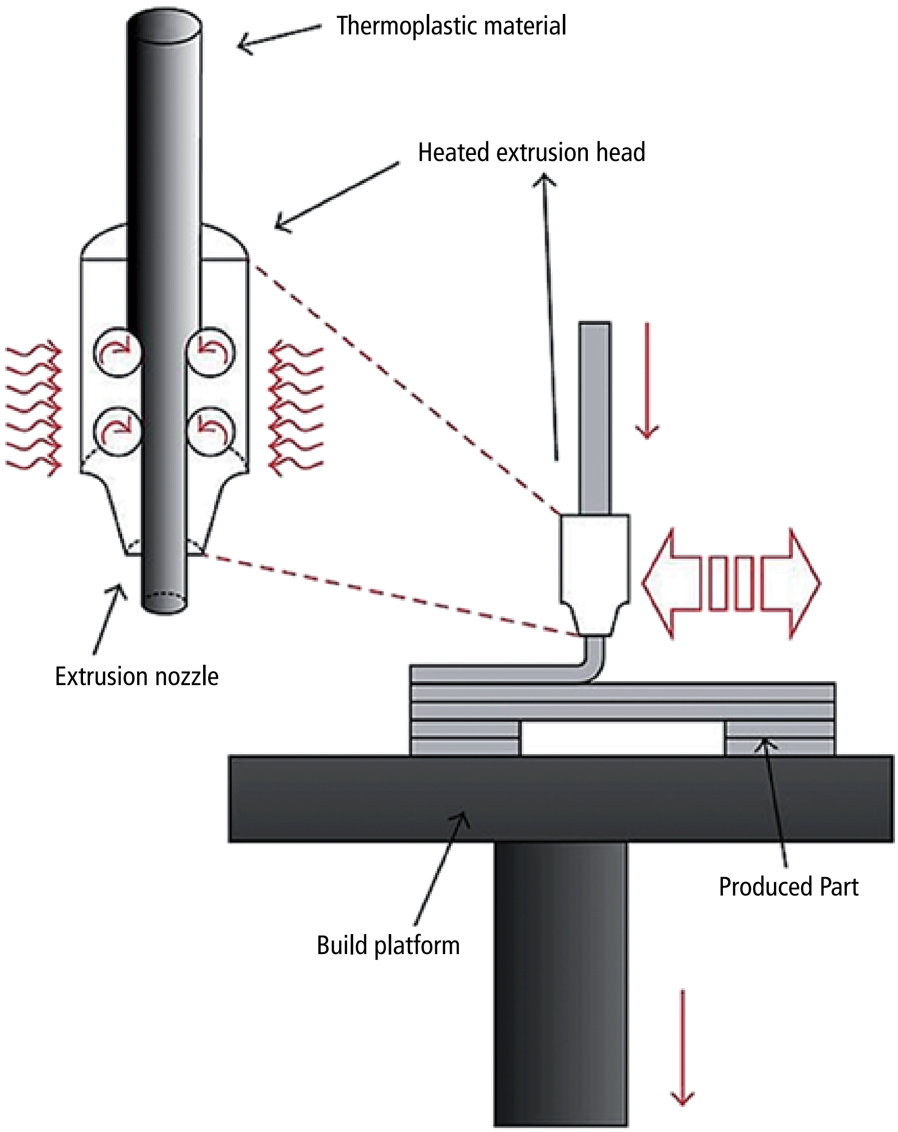


Figure8: Fused deposition modelling

Used for modelling, prototyping, and production applications, FDM works on an 'additive' principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle. Stepper motors or servo motors are typically employed to move the extrusion head. FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing. Rapid prototyping facilitates iterative testing, and for very short runs, rapid manufacturing can be a relatively inexpensive alternative.

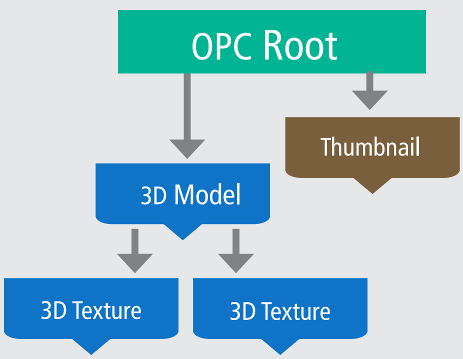
Rapid prototyping technologies

- 3D inkjet printing
- Laser engineered net shaping
- Selective laser melting
- Electron beam melting

Materials options for 3D printing

(i) Metallic materials – Plain Carbon Steel, Tool Steel, Stainless Steel, Aluminium, Copper, Titanium, Bronze, Nickel Alumides

3MF design considerations



Complete
- Open Pakaging Conventions (OPC)

Compact
- ZIP Package
- ferences avoid duplication

Human - readable
- XML
- Well-Known binary fomats (e.g. PNG, JPEG)

(ii) Polymers and polymeric composites – ABS, Nylon (Polyamide), Polycarbonate, PP, Epoxies, Glass-filled Polyamide, Windform, Polystyrene, Polyester, Polyphenylesulfone
(iii) Others – Sand, Ceramics, Elastomers, Tungsten, Wax, Starch, Plaster
(iv) Biocompatible materials – Polycaprolactone (PCL), Polypropylene-Tricalcium Phosphate, (PP-TCP), PCL-hydroxyapatite (HA), Polyetheretherketone-Hydroxyapatite, (PEEK-HA), Tetracalcium Phosphate (TTCP), Beta-Tricalcium Phosphate (TCP), Polymethyl Methacrylate (PMMA).

Focused area for 3D printing

3D printing is used in a variety of industries including jewellery, footwear, industrial design, architecture, engineering and construction, automotive, aerospace, dental and medical industries, education and consumer products.

- *Concept modelling*: This lets small design and engineering firms extend their reach by testing out more ideas.
- Pattern Making: Replaces traditional pattern making and delivers patters at a fraction of time.
- Low volume manufacturing: Traditional manufacturing process becomes too expensive if the quantity requirement is limited. In those cases the component can be directly 3D printed by using proper raw-material
- Manufacturing tools: Quick, low-volume tooling and custom fixtures give manufacturers the flexibility to embrace more opportunities.
- Customisation and personalisation: Customisation/personalisation needs, which usually entails smaller quantities, can be best addressed by 3D printing
- Art/design/fashion: Due to virtually unlimited possibilities, 3D technology is the best tool in the hand of an artist/designer
- Education: The world is three-dimensional but the traditional educational tools are mostly two-dimensional. Use of 3D tools would bring in paradigm shift in education
- Medical: Artificial arms for disabled, medical equipment, bio-printing tissues and organs – as each human being has different dimensions.

Advantages of 3D printing

- Rapid prototyping: 3D printing gives designers the ability to quickly turn concepts into 3D models or prototypes
- Clean process: Wastage of material is negligible
- Complex shape: Any shape can be produced
- Easy to use: No special skill is needed
- Reduced design complexity
- Cheap: Cheaper than any other process
- Accessibility: People in remote locations can fabricate objects that would otherwise be inaccessible to them.

Challenges with 3D printing

The major possible disadvantage of 3D printing is counterfeiting or production of 'fake' stuff, and the copyright infringement issues arising from this. This technology makes a manufacturer out of anyone who owns a 3D printer, and gets hold of the blueprint. Thus, it would be very difficult to trace the source of fake items, and copyright-holders would have a hard time protecting their rights.

Other challenges or disadvantages of 3D printing are:

- *Limited and high cost of materials*: Manufacturers would like reliable 3D printing systems that may provide the standards and promise they expect from their operations. But that quality and complexity comes at a price. Therefore, manufacturers have to carefully examine the value of system instrumentality and cost of materials that may become a barrier in 3D printing adoption.
- *Challenges scaling up technology*: Additive manufacturing is a new concept for industry that lacks efficient manpower to design, perform, and operate the machines.
- *Speed*: Additive producing additionally faces speed of production challenges, which limits mass-production potential.
- *IPR (intellectual property rights)*: 3D printing can be done anytime using design from anywhere without addressing IP concerns.
- *Environmental concerns*: Additive manufacturing uses high quality and relatively inexpensive plastic filament for prototyping and the leftover ends up in landfills. This practice contradicts the environmental movement to reduce reliance on plastic. Desktop 3D printers, which are widely accessible for rapid prototyping and small-scale manufacturing in home and office settings, release potentially harmful nano-sized particles in indoor air.
- *Surface finish and post-processing*: Additive producing additionally possesses challenges that may come with poor surface quality, physical properties, and use of specific supply material for part production. In order to improve the surface quality, several attempts have been made by controlling various process parameters of additive manufacturing.
- *Resolution and mechanical properties*: Build-up quality – integrity, strength, aesthetics, etc. – are the challenges that industry faces. While some sectors have done well and are reworking on their experiences, others have not moved to the far side of prototyping to production.

EEPC INDIA TECHNOLOGY CENTRE ON ADDITIVE MANUFACTURING

In the last six decades EEPC India had focused on promoting exports of engineering goods and services and has been successful in increasing engineering exports from $10 million in 1955-56 to $76.2 billion in 2017-18. However, it is a matter of great concern that more than 90 percent of the engineering goods exported involve low and medium technology. EEPC India appreciates the need for moving up the value chain for achieving substantial growth in exports in the future. With this objective, Technology Centres have been opened in Bangalore and Kolkata for the benefit of exporters and

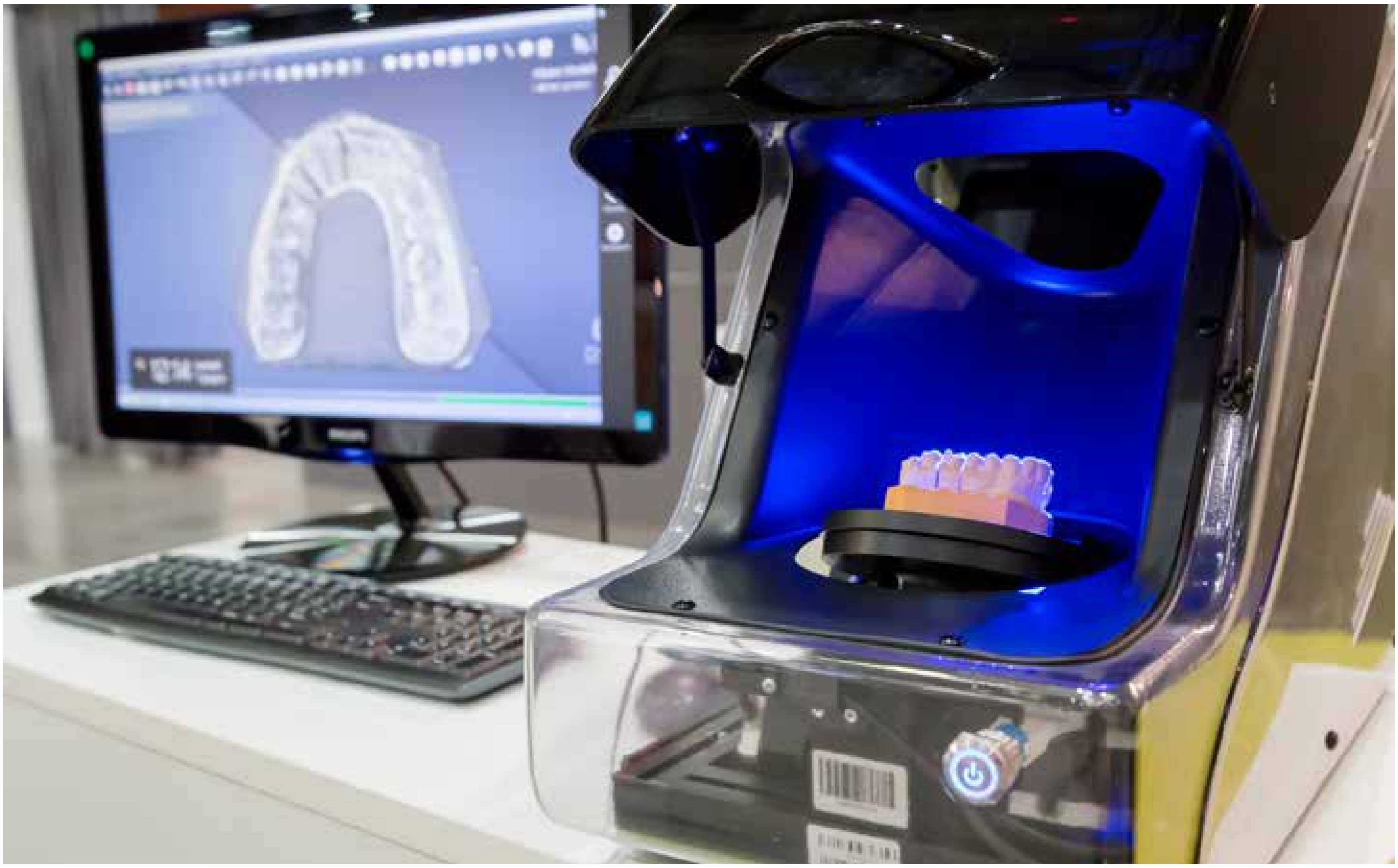


Figure10: 3D scanner

potential exporters, particularly from the MSME sector. The Technology Centre in Bangalore has been functional since June 2017, and the Centre in Kolkata will become operational very soon.

The Technology Centre in Kolkata would be equipped with 3D printer to aid EEPC India members and SME clusters in Concept modelling, Visual aids for tooling, Communication models, Visual aids for engineers, Marketing models, Sales models, Models for bidding, Product research, Form and fit models, Functional testing, Package design, Investment cast patterns, Production parts, Injection mould tooling, and Reverse engineering.

Additive manufacturing has been described as a technology that powers the next industrial revolution, thus transforming the way designers visualise concepts, companies do business, and manufacturers develop and create products. Advancement of 3D printing also includes the creation of design variations with endless possibilities, shortening of time-to-market to be a forerunner, validation and modification of designs in a more cost-effective way, and prevention of design leakage with in-house prototyping.

The Centre would also be equipped with 3D scanner, which is the ideal choice to receive a quick, textured and accurate three-dimensional scan. The scanner does not require markers or calibration. It captures objects quickly in high resolution and vibrant colours, which allows for almost unlimited application, an ideal tool for reverse engineering.

Future prospects

Research is currently going on to create 3D printers that could print out organs for people in need of a transplant. Within a decade, 3D printers will become commonplace in homes. The benefits of such technology are endless. 3D printers are extremely useful for creating prototypes, highly customised items, or small production runs.

- Airbus would like to make a 3D printer that is large enough to make planes from the ground up – a hangar-size printer as large as 80m x 80m.
- Made In Space Inc. is a US company experimenting with zero-gravity 3D printing. The process could potentially allow astronauts to print objects as required in space, saving valuable weight at launch.
- NASA has been looking at 3D printing for some time now, and considering the technology for long missions where astronauts could create their own equipment during the trip.