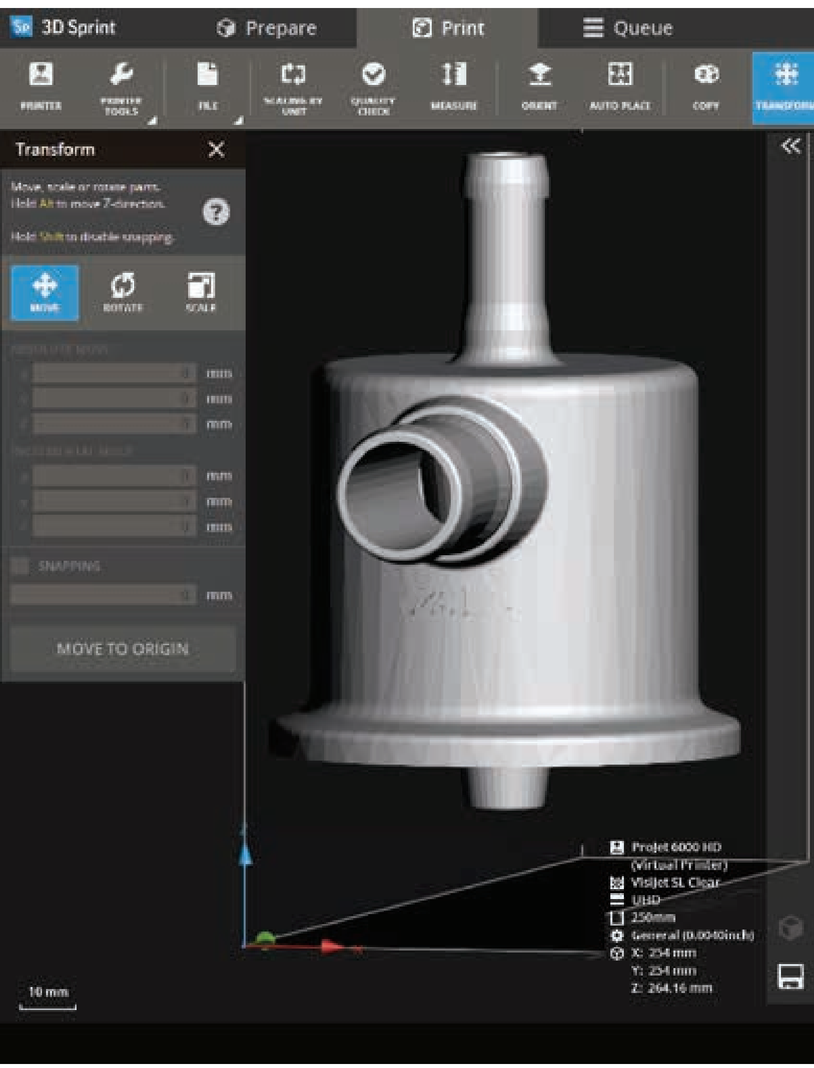
3D Printing
Application Guide



Key market segments' use of 3D Printing

Are you interested in exploring additive manufacturing – 3D printing – but don't know where to start?

That's why we created this 3D Printing Application Guide. It is designed to start with your needs in mind – what do you want to accomplish? What do you want to create? We then show you which additive manufacturing methods you should explore that can help you bring your big ideas to life. We also created this Application Guide to inspire you. The field of additive manufacturing is growing so fast, in so many fascinating directions, that it's hard to know what's possible. After all, that's what's really exciting about it – 3D printing enables you to make incremental improvements in the design and characteristics of your existing parts AND it enables you to envision new possibilities and designs that can't be produced any other way.

Best of all, we're presenting all of this important information in a quick-read format that's free of jargon and technical mumbo-jumbo. We hope you find this Application Guide to be an indispensable tool as you learn, explore and make decisions about the future of your products and manufacturing operations.

We're here to help. If you have questions about 3D printing, call us today. We'd love to learn more about your needs.

Helping to design your future,

Joe Jones, President
Big Systems LLC

The growth of 3D printing.

From its modest beginnings as a hobbyist's tool for making small objects on amateur desktop fabrication machines, 3D printing has matured into a technology that is disrupting many industries. Advances in printing technologies and materials now enable engineers and designers to create parts and assemblies with characteristics that weren't possible using subtractive production techniques such as milling and machining.

Just how fast is 3D printing growing?

These statistics shed some light on its trajectory:

- The worldwide market for additive manufacturing in 2017 is expected to be $ 8.8 billion and is forecast to grow to $26.4 billion by 2021 (Wohlers Report).
- 71% of manufacturers have adopted 3D printing and 52% expect 3D printing will be used for high-volume production in the next 3-5 years (PriceWaterhouseCoopers).
- GE estimates that by 2025 more than 20% of new products will involve 3D printing of some kind.
- The number of industrial printer units ($80,000 and above) in operation nearly doubled from 6500 units in 2010 to 12,500 units in 2015 (Wohlers Report)
- Additive manufacturing could reduce energy use by 50% and reduce material costs by up to 90% compared to traditional manufacturing (John Hornick: 3D Printing Will Rock The World)

Manufacturing

Injection Molding

In the world of injection molding, 3D printing makes possible the design of molds that use conformal cooling - designing cooling channels that naturally follow the contours of the part to be produced – to help keep an even temperature on the surface of the mold.

Investment Casting

Investment casting, also known as lost wax casting, requires lengthy lead times and often a lot of trial and error. Producing mold prototypes using FDM can be done much faster, enabling designers to identify and fix problems with the mold design equally quickly.

Custom Hydroforming

With 3D printing, there is no limit to the geometries that can be produced. The cost of die production and lead times can be slashed when compared to traditional hydroforming methods.

Jigs and Fixtures

Many manufacturing processes make extensive use of holding devices, guides and templates to precisely position parts for assembly. Work-holding devices, jigs and fixtures can be customized to each individual and task for better ergonomics.

Logistics

3D printed dunnage trays and kits can help you streamline the movement of parts within your facility or during shipment. You can customize them for optimum portability, and can easily revise your designs as parts or processes change.

Manufacturing Applications

Application	Part Characteristics	Material (s)	FFF/ CCF	MJP	CJP	SLA	SLS	ADAM	DMP
Jigs and fixtures	Precise positioning of item being fabricated	Composite plastic	●	●		●	●		
Dunnage trays, kits and boxes	Lightweight, customized sizes	Composite plastic	●	●		●	●		
Blow molding prototypes	Design mold and test pre-production prototypes quickly	Composite plastic	●	●		●	●		
Composite mold tooling	Withstand high temperatures and pressures during curing	Composite plastic	●				●		
Investment casting	Produce and iterate mold designs quickly	Composite plastic; wax	●	●		●	●		
Custom hydroforming	Use pressure to force sheet metal to take form of mold/die	Composite plastic	●						
Injection mold tooling	Withstand high heat and pressure, exact tolerances	Composite plastic	●	●		●	●		

Technology key: **FFF/CCF** Fused Filament Fabrication and Continuous Carbon Fiber (extruded plastic filament) **MJP** MultiJet Printing (photosensitive plastics or wax, cured by UV light source) **CJP** ColorJet Printing (full color models produced using a build powder and binder colorant) **SLA** Stereolithography (photosensitive polymers or composites, usually cured by a laser) **SLS** Selective Laser Sintering (plastics such as nylon, fused layer by layer using a laser) **ADAM** Atomic Diffusion Additive Manufacturing (metal powder encased in plastic binder that is washed out, leaving the remaining metal powder to be sintered in a furnace) **DMP** Direct Metal Printing (commonly known as DMLS: Direct Metal Laser Sintering) fine metal powders such as stainless steel, inconel, aluminum, cobalt-chromium, titanium and others, fused layer by layer using a laser

Automotive

In the automotive market, 3D printing is an invaluable tool for bringing designers' visions to life – to verify fit, finish and manufacturability. It has also been instrumental in helping designers to reduce the weight and increase the strength of tomorrow's vehicles.

Automotive Design

This is one of the most popular early uses of 3D printing in the automotive industry. The ability to design, print and test parts quickly makes it an ideal technology for designers to try out new design concepts and iterate them quickly.

Topographical Optimization

Optimizing the maximum strength with minimum weight and material is possible with a process called topographical optimization. The complex structures it creates are hard to manufacture in any other way than 3D printing.

Assembly Tools

Some 3D printed assembly tools are used to precisely attach certain components to cars during their production.

Just-in-Time Printing of Car Parts

This isn't quite a reality yet, but could be within a few years.

Automotive Applications

Application	Part Characteristics	Material (s)	FFF/ CCF	MJP	CJP	SLA	SLS	ADAM	DMP
Replacement parts	Durability	Composite plastic, nylon	●				●		
Pre-production assembly verification	Accuracy and precision of parts	Composite plastic		●		●	●		
Product development/ design	Accuracy and precision of parts	Reinforced plastic, composites	●			●	●		
High-performance turbocharger	Complex interior geometry, hard to cast, limited part run	Stainless steel, titanium							●
Manufacturing and assembly tools	Precise positioning and assembly of auto parts	Composite plastic	●	●		●	●		

Technology key: **FFF/CCF** Fused Filament Fabrication and Continuous Carbon Fiber (extruded plastic filament) **MJP** MultiJet Printing (photosensitive plastics or wax, cured by UV light source) **CJP** ColorJet Printing (full color models produced using a build powder and binder colorant) **SLA** Stereolithography (photosensitive polymers or composites, usually cured by a laser) **SLS** Selective Laser Sintering (plastics such as nylon, fused layer by layer using a laser) **ADAM** Atomic Diffusion Additive Manufacturing (metal powder encased in plastic binder that is washed out, leaving the remaining metal powder to be sintered in a furnace) **DMP** Direct Metal Printing (commonly known as DMLS: Direct Metal Laser Sintering) fine metal powders such as stainless steel, inconel, aluminum, cobalt-chromium, titanium and others, fused layer by layer using a laser

Aerospace and Defense

In the aerospace industry, reducing the weight of a satellite or spacecraft is critical. That's why 3D printing has made significant inroads into these high-tech, out-of-this-world applications.

Lost Wax Casting of Aircraft Parts

3D printing technologies now make it possible to design a master model with complex geometries or aerodynamic properties that were impossible to manufacture with traditional methods. In addition, they can be used to optimize the weight of each part.

Rocket Engine

The Rutherford engine, used in an experimental rocket developed by Rocket Labs, uses 3D printing for all of its primary components. As a result, the rocket is lighter in weight than conventional designs and has enabled its developer to reduce development costs and time.

Space Habitats

NASA is currently running a 3D Printed Habitat Challenge, part of NASA's Space Technology Mission Directorate to generate and develop ideas and practices for other-world exploration.

Hydraulic Valve Block for Aircraft

An experimental 3D printed valve block is used inside the actuator of an Airbus A380's spoiler, activated when landing the plane to reduce aerodynamic lift. The 3D print is made from titanium and is 35% lighter than the same part made through conventional milling. It is also composed of fewer parts, for a more compact and efficient design.

Military Micro-Drones

The US Department of Defense has created a swarm of 3D printed autonomous micro-drones that can fly together in formation. Perdix drones were originally designed by researchers at MIT and 3D printing was utilized to provide fast iteration of design and also reduce production costs.

Aerospace and Defense Applications

Application	Part Characteristics	Material (s)	FFF/ CCF	MJP	CJP	SLA	SLS	ADAM	DMP
Castings for parts/ assemblies for robotic space exploration	Lightweight, parts consolidation, precise size	Composite plastic, wax, metal	●	●		●	●	●	●
Satellite parts	Lightweight, precise size	Titanium							●
Lost wax casting of aircraft turbine blades	Complex geometry to improve aerodynamics, lightweight	Composite plastic, wax		●		●			
UAV cooling fan	Thermomechanical properties, lightweight	Composite plastic				●	●		
Prototypes for functional validation	Various	Composite plastic, wax, metal	●	●		●	●	●	●
Space habitats	Strength, lightweight	Composite plastic, wax, metal	●	●		●	●	●	●
Rocket engine	Heat-resistant, lightweight	Titanium							●
Hydraulic valve block for aircraft	Durability, lightweight	Titanium							●
Military micro-drones	Lightweight	Composite plastic	●	●		●	●		

Technology key: **FFF/CCF** Fused Filament Fabrication and Continuous Carbon Fiber (extruded plastic filament) **MJP** MultiJet Printing (photosensitive plastics or wax, cured by UV light source) **CJP** ColorJet Printing (full color models produced using a build powder and binder colorant) **SLA** Stereolithography (photosensitive polymers or composites, usually cured by a laser) **SLS** Selective Laser Sintering (plastics such as nylon, fused layer by layer using a laser) **ADAM** Atomic Diffusion Additive Manufacturing (metal powder encased in plastic binder that is washed out, leaving the remaining metal powder to be sintered in a furnace) **DMP** Direct Metal Printing (commonly known as DMLS: Direct Metal Laser Sintering) fine metal powders such as stainless steel, inconel, aluminum, cobalt-chromium, titanium and others, fused layer by layer using a laser

Medical and Health Care

3D printing has created a revolution in the fields of medicine and healthcare. From highly personalized 3D printed medical devices and implants to surgical simulation and planning, this technology is already changing lives today, and has much greater potential in the near future.

Surgical Planning and Simulation

Surgeons can plan medical procedures with precise 3D anatomical models created from CT scans. The variances and complexities of the human body make the use of 3D models ideal for surgical preparation; they can reduce operating time, lower risks from errors or complications, and produce better outcomes for patients. 3D-printed models have been used in numerous cases to gain insight into a specific patient's anatomy prior to a medical procedure.

Surgical Guides

Surgeons can create 3D guides for drilling and cutting with exceptional accuracy. For example, orthopaedic surgeons are using them to create patient-specific surgical guides for ulna and radius pediatric osteotomies. These precisely fabricated tools help them plan and execute complex cases for children as young as seven years old. When used together with 3D pre-operative planning, surgeons can be more confident in the outcome before and during these difficult surgeries.

Jigs and Fixtures

Doctors can now also use 3D printers to create temporary tools that are affixed to the skeletal structure of the patient to provide a precise "blueprint" for reshaping bone structure. Custom-printed drilling guides ensure that screws are placed precisely to ensure the best fit with a patient's body.

Prosthetics

Specialty medical-implant providers are using industrial printers to create custom implants for patients who would be otherwise have great difficulty finding a traditional implant solution. 3D printing can also provide faster delivery times than traditional methods of custom manufacturing prosthetics, which usually requires forging, milling and finishing of metal.

Fracture Braces

Soon, traditional, unwieldy fiberglass braces for bone fractures may be replaced by light-weight, precision-manufactured 3D-printable braces that can be snapped on and off in seconds, while allowing skin to breathe so it doesn't decompose.

Reconstructive Surgery

In some cases, patients who have had serious injuries to their face or cranium have had surgeons first model the damaged or missing bones, which were then 3D printed from titanium and implanted to help reconstruct their damaged features.

Hearing Aids

3D printing has transformed hearing aid manufacturing. Today, 99% of hearing aids that fit into the ear are made using 3D printing.

Sharing of 3D Models

The nature of 3D printing data files offers an unprecedented opportunity for sharing of models by researchers and doctors. Researchers can simply download an STL file and print out an exact replica of the medical model on their local 3D printer. Already, the National Institute of Health operates a 3D Print Exchange website for the sharing of medical and scientific 3D files and tutorials.

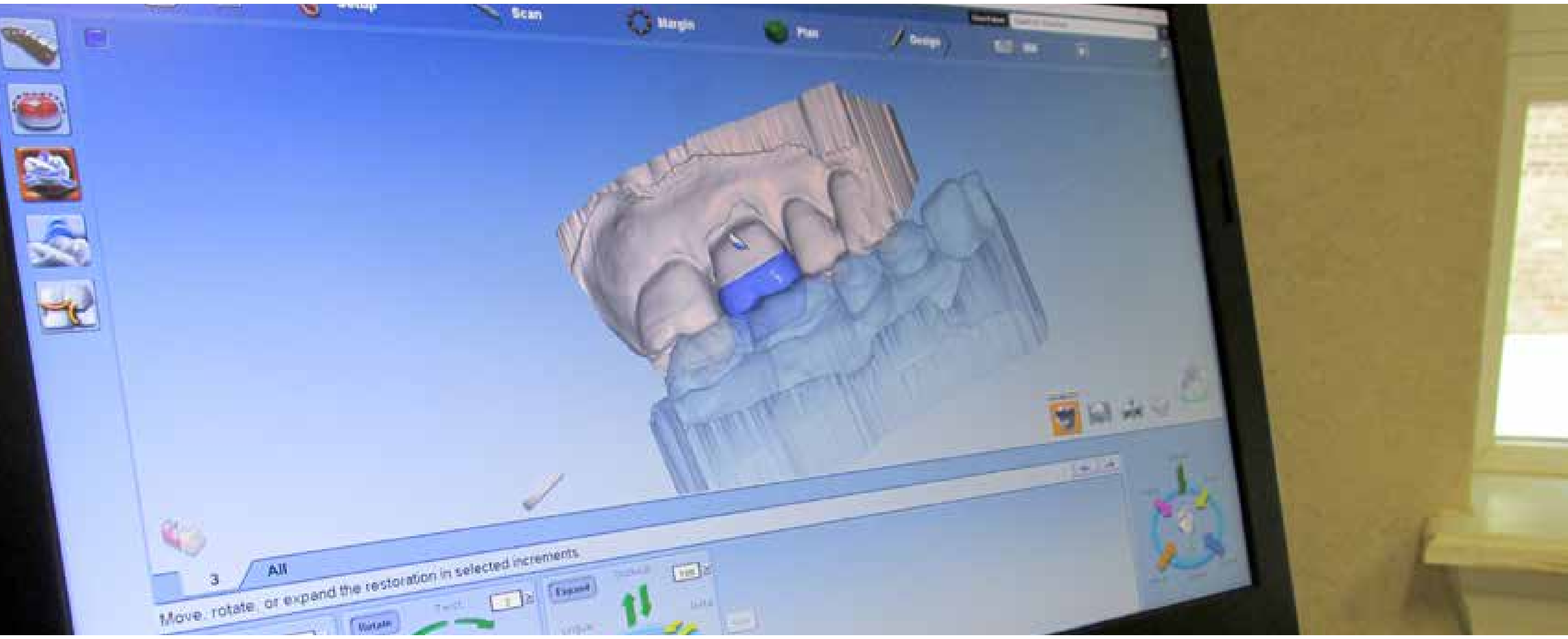
Bioprinting – The Next Frontier

Researchers are now developing the ability to 3D print living cells, layer by layer. This promises to open up new opportunity for 3D printed organs, skin replacement, precise medical dosing and much more.

Medical and Health Care Applications

Application	Part Characteristics	Material (s)	FFF/ CCF	MJP	CJP	SLA	SLS	ADAM	DMP
Implants (hip, knee, shoulder, jaw)	Lightweight, strength	Titanium (medical)						●	●
Middle ear prosthesies	Precise size	Composite plastic (medical)		●		●			
Cervical spine implant	Precise size, mesh to fuse with bones	Titanium (medical)							●
Surgical planning	Accurately model patient's body structure and organs	Composite plastic (medical		●		●			
Hearing aids	Precise, customized size	Composite plastic (medical)		●		●			
Prototyping medical instruments	Durability	Composite plastic, wax, metal (medical)	●	●		●	●	●	●
Prototyping an ambulatory cardiac monitoring device	Durability	Composite plastic (medical)	●	●		●	●		
Prosthetic arm	Durability, lightweight	Composite plastic (medical)	●	●		●	●		
Educational models, training	Full color, modular	Composite material			●				

Technology key: **FFF/CCF** Fused Filament Fabrication and Continuous Carbon Fiber (extruded plastic filament) **MJP** MultiJet Printing (photosensitive plastics or wax, cured by UV light source) **CJP** ColorJet Printing (full color models produced using a build powder and binder colorant) **SLA** Stereolithography (photosensitive polymers or composites, usually cured by a laser) **SLS** Selective Laser Sintering (plastics such as nylon, fused layer by layer using a laser) **ADAM** Atomic Diffusion Additive Manufacturing (metal powder encased in plastic binder that is washed out, leaving the remaining metal powder to be sintered in a furnace) **DMP** Direct Metal Printing (commonly known as DMLS: Direct Metal Laser Sintering) fine metal powders such as stainless steel, inconel, aluminum, cobalt-chromium, titanium and others, fused layer by layer using a laser



Dental

3D printing has created a quiet revolution in the dental profession, in much the same way as it has had a major impact in medical applications. It enables accurate one-time fabrication of complex structures in various materials that are ideal for dental applications.

Dentures

3D printing enables the creation of customized denture and orthodontic devices to help align teeth and brighten smiles.

Dental Surgical Guide

Cone-beam computed tomography (CBCT) makes it possible to create a detailed 3D replica of a patient's jaw, which allows clinicians and surgeons to carefully study its anatomy and plan or even practice a surgical approach before surgery is done.

Drilling and Cutting Guides

Until now, drilling and cutting have been approximate operations, highly dependent upon the observational and surgical skills of the dentist. 3D printing makes possible the fabrication of drilling and cutting guides that can lead to faster, less invasive and more predictable surgeries. This, in turn, can result in faster recovery times and fewer follow-up procedures.

Dental Implants

One of the biggest challenges with dental implants is pre-surgical determination of the optimum location, angulation and depth to place an implant. 3D printing enables dentists to create a detailed surgical guide for optimum positioning of each drill hole and implant placement.

Crowns and Bridges

3D scans are used to make a detailed "map" of the patient's jaws and teeth, which is printed in a resin. This, in turn, is used to make an investment casting, a negative mold of the mouth. The crown and bridge are then cast from a ceramic or metal alloy material.

Dental Applications

Application	Part Characteristics	Material (s)	FFF/ CCF	MJP	CJP	SLA	SLS	ADAM	DMP
Denture production	Precise size	Composite plastic, metal (dental)		●		●			●
Prosthodontics production	Precise size	Composite plastic (dental)		●		●			
Orthodontics (corrective alignment)	Precise size, customized sizing	Composite plastic (dental)				●			
Dental surgical guide	Precise size, custom fit to patient's mouth/jaw	Composite plastic (dental)		●		●			
Crowns and bridges	Precise, customized size	Composite plastic, metal (dental)		●		●			●
Mandibular reconstruction	Precise size, custom fit to patient's mouth/jaw	Composite plastic, metal (dental)		●		●			●
Drilling and cutting guides	Precise size, custom fit and positioning to patient	Composite plastic (dental)		●		●			
Dental implants	Precise size, custom fit to patient's mouth/jaw	Composite plastic, metal (dental)		●		●			●

Technology key: **FFF/CCF** Fused Filament Fabrication and Continuous Carbon Fiber (extruded plastic filament) **MJP** MultiJet Printing (photosensitive plastics or wax, cured by UV light source) **CJP** ColorJet Printing (full color models produced using a build powder and binder colorant) **SLA** Stereolithography (photosensitive polymers or composites, usually cured by a laser) **SLS** Selective Laser Sintering (plastics such as nylon, fused layer by layer using a laser) **ADAM** Atomic Diffusion Additive Manufacturing (metal powder encased in plastic binder that is washed out, leaving the remaining metal powder to be sintered in a furnace) **DMP** Direct Metal Printing (commonly known as DMLS: Direct Metal Laser Sintering) fine metal powders such as stainless steel, inconel, aluminum, cobalt-chromium, titanium and others, fused layer by layer using a laser

3D Printing Technology Types

FFF/CCF

Fused Filament Fabrication (FFF) is a 3D printing process that uses a continuous filament of a thermoplastic material. This is fed from a large coil through a moving, heated printer extruder head. Molten material is forced out of the print head's nozzle and is deposited on the growing workpiece. Continuous Carbon Fiber (CCF) combines carbon fiber strands with extruded plastic filament for a light, strong material. Carbon fiber reinforcement is perfect for applications requiring exceptional stiffness and strength but is still light a feather.

MJP

MultiJet Printing (MJP) is an inkjet printing process that uses piezo printhead technology to deposit either photocurable plastic resin or casting wax materials layer by layer. MJP is used to build parts, patterns and molds with fine feature detail to address a wide range of applications.

CJP

ColorJet Printing (CJP) involves two major components: core and binder. A core build powder material is spread in thin layers over the build platform with a roller. After each layer is spread, color binder is selectively jetted from inkjet print heads, which causes the core to solidify. The build platform lowers with every subsequent layer which is spread and printed, resulting in a full-color three-dimensional model.

SLA

Stereolithography (SLA) is a form of 3D printing technology used for creating models, prototypes, patterns and production parts in a layer-by-layer fashion using photopolymerization, a process by which light causes chains of molecules to link, forming polymers, which make up the body of a three-dimensional solid.

SLS

Selective Laser Sintering (SLS) uses a laser as the power source to sinter powdered material (typically nylon/polyamide), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure.

ADAM

Atomic Diffusion Additive Manufacturing (ADAM) creates a 3D part using a bound metal powder rod embedded inside a plastic filament. Heating the part allows the removal of the plastic and the sintering of the metal powder into a strong and dense part.

DMP

In Direct Metal Printing (commonly known as DMLS - Direct Metal Laser Sintering), fine metal powders such as stainless steel, Inconel (nickel-chromium-based superalloy), aluminum, cobalt-chromium, titanium and others, are fused layer-by-layer using a laser.

Big Systems LLC | W59 W14053 Bobolink Avenue | Menomonee Falls, WI 53051

888-244-4177 | bigsys.com