ProtoCAM
Excellence in Additive Manufacturing

GUIDE TO ADDITIVE MANUFACTURING

Outline

01 Introduction

What is Additive Manufacturing?

Additive manufacturing (AM) is the process of building objects by creating successive layers of a material. It includes the processes of 3D printing, rapid prototyping, freeform fabrication, and more.

Additive manufacturing creates objects by adding material layer-by-layer until completion. Think of how a house of bricks is built—additive manufacturing builds objects in a similar way, starting with very small pieces of material and combining them, layer-by-layer, to form a larger finished product.

Additive Manufacturing has even recently been used to “build” an entire house

Why Use Additive Manufacturing?

Additive manufacturing is an ideal approach for making items out of plastic, metal, ceramic, and other materials. AM specializes in creating objects with complicated geometries or manufacturing complexities that traditional manufacturing methods can’t produce. It allows for the rapid production of parts, both finished products and prototypes. It reduces the cost of low-volume production runs. It also creates parts with complex shapes that can’t be made by traditional “subtractive” processes such as machining, which carves objects out of solid blocks.

Additive manufacturing can also be used as a complement to traditional manufacturing processes. When used in conjunction with injection molding, tool and die machining, and other processes, it improves product quality and expands the range of what you can make.

Example: The Benefits of Additive Manufacturing

Recently, a rocket with 3D printed parts was successfully sent into space. By reworking the ducting system using AM parts, United Launch Alliance was able to reduce the assembly from 140 parts to only 16, which delivered a cost savings of 57%.

Industries Currently Using AM

Additive manufacturing is common in many industries, with new applications being developed every month. There's no limit to how AM can be applied.

Here are some of the most common industries served:

Transportation: Parts for automobiles, aircraft, and railcars. Parts include titanium car exhausts, lightweight aviation plastics, and more.

Medical: Additive manufacturing excels at creating the design elements used in medical devices, such as curves, internal chambers, and channels. It is an ideal way to make everything from prototypes to finished products.

Consumer Goods: Highly stylized jewelry, home décor, personal hygiene items, and more.

Manufacturing: Replacement parts for industrial equipment to extend the life of machines and to reduce the downtime and costs associated with unplanned maintenance.

Electronics: Ultra-precise plastic and metal components for computing, communications, and more.

The Additive Manufacturing Process: From Idea to Product

The process of making an object involves three main steps: modeling, printing, and finishing.

1. Modeling creates a computerized 3D design of an object with a computer-aided design (CAD) program. Then, depending on the process chosen, this design may be converted to an **STL file**. The digital model is finalized, and the design file is loaded into a 3D printing machine where it guides the printing process.

2. In **Printing**, machines use additive processes to create a three-dimensional object. There are many printing processes, each with its own strengths. The common printing processes are described in the next section.

3. During **Finishing**, printed objects are prepared for use. This may involve rinsing, polishing, painting, smoothing or other tasks. One of the main considerations when selecting an additive manufacturing service bureau is the **quality and level of finish** they can provide.

02 Additive Manufacturing Printing Processes

Depending on the specific industry and application, a variety of [AM printing processes] can be utilized. The choice of process depends on the material used and complexity of the end product.

Here are the most common AM printing processes:

Stereolithography
An UV laser traces a pattern on the surface of liquid photopolymer resin, solidifying the resin into a pre-programmed shape. Then the hardened layer of resin is withdrawn into the liquid, and the process is repeated to add another layer to the part. The process is repeated until the part is complete.

Selective Laser Sintering (SLS)
A laser traces a pattern on powdered material (usually nylon) to fuse the material into a solid structure. New powder is applied atop the hardened material, and the process is repeated to add layers to the part until completion.

PolyJet
Think of an inkjet printer for polymers: The printer shoots droplets of photopolymer onto a build tray and each droplet is instantly hardened with ultraviolet light. Droplet by droplet, the printer "builds up" a part.

Fused Filament Fabrication (FFF)
Think of a hot glue gun: A long thread of plastic is fed into the heated nozzle of the printing machine. The nozzle melts the material and deposits it on a build tray, layer by layer, to "build up" a part. *FFF is also known as FDM, or Fused Deposition Modeling™, a trademark of Stratasys Inc.*

Urethane Castings
Additive manufacturing is the preferred way to create master patterns for urethane casting. Using the techniques above, a master pattern can be created faster and less expensively than with Computer Numeric Control (CNC) machining. Additive manufacturing also allows for more complex master patterns—shapes, holes, and grooves that are beyond the capabilities of CNC.

Metal Prototyping

Additive manufacturing enables a variety of metal prototype techniques such as metal casting and direct metal laser sintering (DMLS). The best technique depends on the project's manufacturing priorities:

Metal casting
Ideal for rapidly creating short-run metal parts with high accuracy, durability, and quality.

DMLS
Ideal for rapidly creating highly complex, intricate 3D parts that would be difficult or impossible to produce with traditional subtractive methods.

03 Additive Manufacturing Materials

A tremendous variety of materials can be used in additive manufacturing. This variety offers countless applications for AM across all industries, and creates many advantages for companies that use and produce AM parts.

The list below introduces the common classes of materials used in additive manufacturing. Within each class, there are many variations of materials available, including branded products.

Stereolithography
- Clear UV resin
- Off-white UV resin

Selective Laser Sintering
- Powdered nylon
- Powdered nylon with glass fill

PolyJet
- Rigid plastics, choice of color
- Flexible plastics, choice of color
- Custom plastics, tailored to the production spec

Urethane Castings
- Plastics to replicate the production materials.
- Many colors and durometers (hardness) are available.

Metal (for casting)
- Aluminum
- Stainless steel

FFF (FDM®)
- Extruded ABS plastics
- Polycarbonate
- ULTEM

04 Ideal Uses of Each Additive Manufacturing Technology

Each additive manufacturing technology has an ideal application. To select the best technology for your project, consider the part's intended use.

Intended use is made of a combination of elements: dimensional precision, surface finish, durability, flexibility, opacity, and color. Production speed and cost are also important variables that can influence not only which method is best, but which method is possible.

While each project and part must be evaluated on its own, here are some tips on what each technique is best for:

Stereolithography

When aesthetics, details and dimensional tolerance are critical.
Stereolithography offers the tightest dimensional tolerances of any additive manufacturing technology. Published tolerances for stereolithography (SLA) are +/- 0.005" (0.127mm) for the first inch, and an additional 0.002" for each additional inch. Part geometry and build orientation can also have an effect on tolerances. If dimensional tolerance is a critical factor, SLA is typically the best choice.

Laser sintering

When mechanical strength is more important than aesthetics.
Laser sintering provides good dimensional tolerances as well. The typical published tolerances for a non-metallic laser sintered part are +/- 0.007" (0.1778mm) for the initial inch, and 0.003" (0.0762mm) for each additional inch.

Industrial 3D printing with PolyJet

When details, mechanical strength, and aesthetics are essential.
Surface and dimensional quality is nearly as good and occasionally better than SLA. In some PolyJet materials strength rivals, and in some geometries exceeds, that of SLS.

	Stereolithography	Laser Sintering	PolyJet 3D Printing
Brief Description	Laser cured resin	Laser cured powder	Sprayed material
Accuracy	Great	Fair	Good
Color	Clear or white, can be dyed or painted	White, can be dyed or painted	46 colors
Clarity	Opaque to nearly glass-clear	Opaque	Opaque to translucent
Surface Finish	Smooth, can be sanded	Somewhat coarse	Smooth to rubber-like
Durability	Fair, a bit brittle	Good	Good
Water Resistance	Good to excellent	Poor, absorbent	Good
USP	Available	No	No

Prototype copying with RTV Molding and Urethane Casting

Urethane casting from RTV molds is an additional technique to create near-perfect copies of an original prototype.

First, a stereolithography prototype is created. Next, an RTV (room temperature vulcanization) mold is made from that prototype. Third, urethane casting material is injected into the mold to create the copy of the prototype.

The use cases for copying prototypes include:

- Small-batch manufacturing
- Pre-production parts
- Engineering design verification
- Functional prototypes
- Alpha and beta builds

Choose this technique for short-run production when the final part will be injection-molded plastic.

We'll help you choose the right technique

ProtoCAM's engineers have decades of experience and up-to-date knowledge of recent innovations. We leverage this expertise to help you evaluate, define, and complete your project in the best possible way. We also help you reduce costs by choosing a process that will deliver the best performance, as efficiently as possible, at a competitive price.

05 Best Practices for Setting Up Your 3D Model

Additive manufacturing machines build parts by following the instructions of 3D models. A 3D model is simply a computerized, three-dimensional design of an object.

The 3D model is created with a CAD software program, and often converted to an STL (stereolithography) file. The STL file is loaded into a 3D printing machine where it guides the printing process.

We accept files from any CAD package, provided the geometry is exported into an **STL file format**, the standard for the rapid prototyping industry.

STL is an ideal file type because it approximates the surface of a parametric solid model with a mesh of triangles. In addition to STL files, we also accept these file formats:

- Pro/ENGINEER (*.PRT.*)
- SolidWorks (*.SLDPRT)
- STEP (*.STEP/*.STP)
- Binary Parasolid (*.X_B)
- Parasolid (*.X_T)
- Neutral (*.NEU)
- Rhino 3D (*.3DM)
- IGES (*.IGES/*.IGS)

Here is a detailed guide to preparing CAD files for rapid prototyping.

3D Model Design Considerations

It is important to consider every detail of your 3D model. The checklist below will help you make sure you've given thought to every angle.

- Do any surfaces require special tolerances?
- Are there any holes that have to be reamed to a specific size?
- Do any holes need inserts?
- Have secondary use cases been considered?
- Will this be a printed part or a casting?

Specialty Considerations

Height

Height is the biggest contributor to the cost of making a part. Most parts are built using a .004" layer thickness, or a .002" layer thickness for a high-resolution build. The 3D file is "sliced" into layers, traced, and solidified layer by layer on the SLA machine. Height adds layers, and each layer adds production time. For example, a 12" part (3,000 layers) takes longer to build than a 6" part (1,500 layers) and costs more.

Design Tip: In your 3D model, orient the part to have the smallest possible z-height, or consider the cost/benefits of allowing ProtoCAM to produce the prototype in two pieces which will be glued together.

Volume

Volume of material is the second largest contributor to the cost of a part. Generally, the larger the part, the greater the volume of material needed and the greater the expense.

Design Tip: To reduce material volume and lower a part's cost, prototypes can be created hollow rather than solid. You can also reduce the thickness of your part's walls.

Complexity

Complex parts require detailed finishing work, which can add production time and expense. When a part comes off an SLA machine, excess resin and support material must be removed. The prototype is then post-cured in a UV oven and generally bead-blasted to provide a consistent finish.

Depending on the complexity of the part shape, such as small details and number of supports, it can take anywhere from several hours to several days to sand the piece to presentation level.

We'll help you perfect your design

Our engineers always orient parts to give you the best quality production in the shortest amount of time. No matter what your scheduling or budget constraints, contact ProtoCAM and we'll see what we can do for you.

06 Additive Manufacturing Products

Thousands of products are made by additive manufacturing, and more are created every day. Consumer products include toys, jewelry, art, and even shoes. Industrial products are wide-ranging: jet engine fuel nozzles, carbon fiber fan blades, heat exchangers, and more.

It seems like new materials for additive manufacturing are available every week. The field is growing fast with specialty plastics, metal composites, glass, and ceramics. Even asteroid matter has been used for 3D printing.

Custom Medical Devices

Examples of specialty medical devices include Invisalign® braces, hearing aids, and custom dental crowns. Additive manufacturing also excels at creating components to work within larger medical devices, as seen in this case study of our work with Coapt, LLC, on the COMPLETE CONTROL™ for upper-extremity prostheses.

A new technique to print complex metallic architectures in "midair," without using support structures, was recently demonstrated by Harvard's Wyss Institute for Biologically Inspired Engineering and the John A. Paulson School of Engineering and Applied Sciences (SEAS). This technique promises to expand the range of medical devices made with additive manufacturing.

Motorcycles

The world's first 3D-printed motorcycle was recently created using an aluminum-magnesium-scandium alloy.

Sporting Equipment

Additive manufacturing is especially well-suited for creating new, innovative sporting goods. We are proud to have helped build the Ball Cannon, the first robotic football launcher for backyard use.

ProtoCAM also helped create golf accessories for UpGrade Golf Systems, including the UpGrade Ball Tray and the Range Divider.

Toys

There's no limit to the galaxy of toys that additive manufacturing can produce. ProtoCAM has created hundreds of toy prototypes for clients including Transformers, K'NEX, and Hasbro. Other notable ProtoCAM projects include action figures, puzzles, vehicles, construction toys, Pez dispensers, and Star Wars-branded items.

Consumer Goods

ProtoCAM has worked with many inventors, engineers, and designers to bring new consumer goods to market. Many inventors bring only a sketch, and partner with us from design through production.

Most products are created as prototypes, and later mass produced by injection molding, plastic thermoforming, or other processes. However, many consumer products can be produced by AM and marketed directly.

There's no limit to what additive manufacturing can do

All of these examples show that additive manufacturing is an essential part of any designer's tool kit. If you have an idea, contact us to bring it to life.

07 Additive Manufacturing Post-Processing

Post-processing is the last step in the process of additive manufacturing. In this step, parts receive finishing touches such as smoothing and painting. Post-processing is also known as finishing.

Why is post-processing important?

Post-processing improves the quality of parts and ensures that they meet their design specifications. The finishing process can enhance a part's surface characteristics, geometric accuracy, aesthetics, mechanical properties, and more. For samples and prototypes, this can mean the difference between a sale or a loss. For production parts, finishing creates a part that is ready to use.

Pro Tip: Consider post-processing capacity

When placing your order, it's important to consider an additive manufacturer's finishing capacity. Some companies dedicate only a small area of their facility to finishing. This can lead to expensive post-processing, outsourcing, or bottlenecks at the finishing stage of production. It can also be an incentive to rush through finishing.

At ProtoCAM, 80% of our facility is dedicated to post-processing. We offer all types of finishing processes, and make sure every finishing job is done right. Our large finishing capacity ensures that your parts are made quickly and with attention to detail.

Common Finishing Processes

Many different post-processing techniques exist. Additive manufacturing companies often specialize in certain types of finishing, and may even have their own proprietary finishing processes. Proper finishing leads to prototypes that create new orders, and dependable performance parts that create repeat customers.

Common finishing techniques are presented below, as well as proprietary techniques found only at ProtoCAM. These techniques may be slightly modified for specialty materials.

Natural

The natural finish is the most basic finish. It cleans and sands the places where support structures held the part in the AM machine. This finish does not affect the part's geometry, and is ideal for parts with small features.

- **Results:** Sharp details.
- **Available for:** SLA, SLS, PolyJet 3D printing, FDM
- **Best used for:** Parts with small features and precise geometries.

Standard

This is the most common finish. It begins with the natural finish, described above. Next, the part is bead-blasted to create a uniform matte surface.

- **Results:** Uniform smoothness for good aesthetics. A professional look and feel.
- **Available for:** SLA
- **Best used for:** Uniform matte prototypes. Production parts with average aesthetic requirements.

Standard + External

This finish begins with the bead-blasted standard finish, described above. Next, the part's exterior surface is sanded to remove build lines or stair stepping, creating an extremely smooth, low-friction surface. This finish is ideal for parts that slide against another surface. It is also recommended for high-quality prototypes.

- **Results:** Extremely smooth outer surface and superior aesthetics.
- **Available for:** SLA, PolyJet
- **Best used for:** Production parts needing a low-friction surface. High-quality prototypes.

Standard + All

This finish begins with the bead-blasted standard finish, and adds sanding over both the interior and exterior of the part. It is ideal for making master patterns for casting or other types of foundry molds. The completely smooth surface makes it easy to remove a master pattern from the mold without the pattern catching on build lines or stair stepping.

- **Results:** Completely smooth surface, inside and out.
- **Available for:** SLA, PolyJet
- **Best used for:** Foundry patterns.

Primed

For this finish, a part is coated with primer after the Standard + External finishing process. Two coats are applied, with a round of light sanding in between, if necessary. Primed parts are smooth and fully prepped for your in-house paint department, saving hours of labor.

- **Results:** Exceptional smoothness, paint-ready parts.
- **Available for:** SLA, SLS, PolyJet
- **Best used for:** Paint-ready pieces for your in-house paint department or specialty painting contractor.

Presentation

This finish delivers a completed, ready-to-show part. It can be brought to a trade show, presented to a client, or used right away in photos and video. Here at ProtoCAM, we paint the part for a final production look. We mix automotive-grade paints to create finely tuned colors for an exact match.

- **Results:** A fully-painted, ready-to-show display part with the highest aesthetics.
- **Available for:** SLA, SLS, PolyJet
- **Best used for:** Painted, show-ready pieces.

Clear

For clear SLA parts, the part is sanded where supports were used during production. A coat of clear urethane is applied to the sanded areas to restore a finished shine. The clarity of the part may vary in sections, and build lines and some stair stepping may remain.

- **Results:** A clear part with a basic look-through finish and some opacity.
- **Available for:** SLA
- **Best used for:** Clear proof-of-concept prototypes or functional finished parts.

Improved Clear

For improved clarity, build lines and stair stepping are removed from the part's surface. Then the entire part is sanded and a clear coat is applied.

- **Results:** A clear part with a high level of surface consistency and clarity.
- **Available for:** SLA
- **Best used for:** Clear, show-ready pieces.

Clear Bottle: A Proprietary ProtoCAM Finishing Process

Bottles and similar parts with small entries traditionally present a finishing challenge: their large internal surfaces usually remain matte and cloudy. But now with ProtoCAM's proprietary Clear Bottle finish, customers can achieve exceptional clarity on even the most complex pieces.

The Clear Bottle finish almost perfectly replicates the look of a mass production plastic bottle. It has a truly clear, see-through surface on both the interior and the exterior.

- **Results:** Exceptional transparency for complex parts, bottles, and other items with small entries and large internal surfaces.
- **Available for:** SLA
- **Best used for:** Crystal-clear prototypes and samples. Ideal for bottles, containers, complex clear tubes, and vessels.

USP Class VI

This finish ensures that medical-grade parts and prototypes conform to USP Class VI certification. These parts are safe for in vivo use.

- **Results:** A USP Class VI-certified part that is safe for in vivo use.
- **Available for:** SLA
- **Best used for:** Medical-device prototypes and production parts.

08 Create Your Next Project with ProtoCAM

Trust ProtoCAM for Your Next Project.

We'll guide you through the manufacturing process, from design to printing to finishing. If you are uncertain about the best way to build your project, we'll help you make the right choices and avoid costly mistakes. Every day we talk to people who are new to additive manufacturing, and we help them turn their ideas into 3D printed parts.

Experts Welcome

If you have finished design files and only need printing, we're here for you too. We work with many expert designers to provide top-notch production and finishing services. In this case, we'll simply take your instructions, load your design files, and start building.

Get the Highest Quality Parts from ProtoCAM

If you wish, our engineers will help you adjust your product's design to make it easier and less expensive to mass produce. Often, a few adjustments to the design will increase your profits while maintaining or even enhancing the product's functionality.

Request a quote here to get started—because the quality of your parts depends on the quality of your partner.