

Introduction to Additive Manufacturing (AM)

Evolution of AM and 3D Printing

Additive Manufacturing (AM), commonly known as 3D printing, originated in the early 1980s. Dr. Hideo Kodama and subsequent inventors pioneered the concept of building objects layer by layer. In 1984, Charles Hull developed Stereolithography (SLA), which led to the first commercial 3D printers in 1987. Through the 1990s and 2000s, technologies like Selective Laser Sintering (SLS) and Fused Deposition Modeling (FDM) were introduced, vastly expanding application possibilities. Initially used for prototyping, AM is now integral in end-use parts for industries such as aerospace, automotive, healthcare, and consumer products. As the technology matured, newer processes like Direct Metal Laser Sintering (DMLS) and multi-material printing emerged, shifting AM from a niche tool to a key part of modern manufacturing ^{[1] [2] [3]}.

Comparison with Subtractive and Forming Processes

Aspect	Additive Manufacturing	Subtractive Manufacturing	Forming Processes
Principle	Adds material layer by layer	Removes material from solid block	Shapes by deformation
Design Complexity	High – intricate, internal features	Limited by tool geometry	Depends on mold/tool setup
Material Utilization	Highly efficient, minimal waste	Significant material waste	Moderate (scrap, flash)
Surface Finish	May require post-processing	High (after finishing)	Varies, often good
Setup and Tooling Cost	Low for custom/short runs	High for complex/multiple parts	High initial, low per part
Suited For	Prototyping, complex, custom parts	High-precision, mass production	Bulk/simple shapes
Flexibility	High – fast changeovers	Medium (retooling needed)	Low (new tools needed)
Example Processes	SLA, FDM, SLS, SLM, binder jetting	CNC machining, milling, turning	Casting, forging, stamping

AM excels in material efficiency, design freedom, and rapid, on-demand production, whereas subtractive and forming processes are better suited for high-throughput, precision, or large-scale manufacturing ^{[4] [5] [6] [7]}.

Advantages of Additive Manufacturing

- **Rapid Prototyping:** Fast turnaround from design to part, supporting multiple design iterations^{[8] [9] [10]}.
- **Complex & Custom Geometry:** Enables production of intricate or internal features impossible by other means^{[9] [10]}.
- **Material Efficiency:** Minimal waste since only required material is used^{[8] [10]}.
- **Cost and Lead-Time Reduction:** Ideal for low-volume, custom, or on-demand parts; reduces upfront tooling investments^{[9] [8]}.
- **Design Flexibility:** Easy to modify and optimize designs without changing hardware^{[8] [9]}.
- **Supply Chain Agility:** On-site, distributed, and digital-to-physical workflows improve response to demand changes^{[9] [10]}.
- **Environmentally Friendly:** Lower material and energy usage compared to conventional processes^{[9] [10]}.
- **Streamlined Assembly:** Allows part consolidation, reducing the need for multiple fasteners and assemblies^{[9] [10]}.

Classification of AM Processes

According to international and industry standards (such as ASTM), AM is broadly classified into seven main categories:

Category	Principle & Example Methods
Vat Photopolymerization	Curing liquid resin with light (SLA, DLP, LCD)
Material Jetting	Droplets selectively deposited and cured (PolyJet, MultiJet)
Binder Jetting	Binder selectively joins powder material (sand, metal, ceramics)
Material Extrusion	Thermoplastic filament extruded layer by layer (FDM, FFF)
Powder Bed Fusion	Laser or electron beam fuses powder in a bed (SLS for polymers, SLM/EBM for metals)
Sheet Lamination	Stacking and binding sheets (laminated object manufacturing, paper/metal)
Directed Energy Deposition	Focused energy melts material as it's deposited (DED, laser/arc/wire deposition)

Each process category offers unique benefits and is suited to specific materials, accuracy, and application requirements^{[11] [12] [5]}.

Key Steps in Additive Manufacturing

1. **Design & Modeling:** Create a 3D digital model (usually using CAD software)^{[13] [14] [15]}.
2. **File Conversion & Slicing:** Convert design to machine-readable format (e.g., .STL, .AMF), and slice model into thin layers^{[13] [15]}.

3. **Material Selection:** Choose suitable material (metal, polymer, composite, ceramic) based on end-use and AM technology^{[14] [13]}.
4. **Machine Setup:** Prepare printer and load material; validate machine parameters (temperature, speed, etc.)^[14].
5. **Printing/Building:** AM system fabricates the part layer by layer as per the sliced file^{[13] [14]}.
6. **Part Removal:** Separate the printed part from the build platform upon completion^[14].
7. **Post-Processing:** Remove supports, clean, surface finish, anneal, or otherwise refine part for its final use^{[13] [14]}.
8. **Quality Control & Testing:** Inspect dimensions, properties, and performance to ensure compliance with requirements^{[13] [14]}.

Note: Process steps and requirements may vary depending on material, process type, and application^{[13] [14] [15]}.

Additive Manufacturing represents a transformative shift in how products are developed, enabling innovation, customization, and sustainability across industries^{[9] [8] [10]}.



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