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FROM PIXELS TO PROTOTYPES: THE ENGINEER'S EXPLORATION OF ADDITIVE MANUFACTURING

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ABSTRACT
Additive Manufacturing (AM) is a revolutionary technique that offers design freedom and material variability, revolutionizing traditional manufacturing processes. It benefits industries like aerospace, automotive, medical, consumer products, and energy by reducing lead times, costs, and increasing sustainability. This paper explores AM's potential in engineering from an engineer's perspective, focusing on its diverse applications across sectors. AM's benefits include increased accuracy, improved durability, customization, cost savings, and faster production times. As AM evolves, engineers must harness its capabilities to drive innovation, sustainability, and efficiency.

KEYWORD
Additive Manufacturing (AM), Innovation, Product Development, Prototyping, Sustainability

INTRODUCTION
Additive Manufacturing (AM) is a revolutionary technique that uses 3D printing technology to create products or parts by layering material from a CAD file, as shown in Figure 1 (Wohlers et al., 2021; Wohlers Associates, 2020; Campbell et al., 2018). It is a significant advancement in product development and manufacturing, unlike traditional techniques like CNC machining, which eliminates material from a block (Prototype Projects, 2023; Timlin, 2021). 3D printing can be used for plastic, metal, or rubber pieces. Unlike traditional manufacturing processes, 3D printing does not require significant costs for complex geometries, making it suitable for complex and inventive items (National Security Technology Accelerator [NSTXL], 2024). Additionally, 3D printing is an additive process, reducing waste and contributing to more sustainable manufacturing processes. Traditional subtractive manufacturing processes can generate large amounts of material waste, making 3D printing an ideal choice for complex and inventive items (3D Solutions Provider, 2023).

Figure 1: Additive Manufacturing in Operation (NSTXL, 2024; 3D Solutions Provider, 2023)

Importance of Additive Manufacturing (AM) in Engineering
Additive Manufacturing has revolutionized the production of complex three-dimensional items, offering design flexibility and material variety. This technique uses thermoplastic filament, powdered materials, and lasers to create items layer by layer, offering new possibilities for various

sectors (Filament2Print, 2024; Engineering Product Design, 2024). It allows for rapid prototyping, reduced material waste, on-demand production, low-volume manufacturing, mass customization, design freedom, innovation, jig tooling, and customization with personalization. It also offers advantages such as rapid prototyping, complexity-free production, and mass customization (3D Solutions Provider, 2023; Loughborough University, 2023).

This paper explores additive manufacturing from an engineer's perspective, focusing on its potential in engineering and its impact on professionals, aiming to provide insights into its transformational potential.

Evolution of Additive Manufacturing (AM) Processes

The American Society for Testing and Materials (ASTM) has developed a set of standards, "ASTM F2792," to categorize additive manufacturing techniques into seven groups: VAT Photopolymerisation, Material Jetting, Binder Jetting, Material Extrusion, Powder Bed Fusion, Directed Energy Deposition, and Sheet Lamination. These processes vary based on the material and machine technology used, as illustrated in Figure 2.

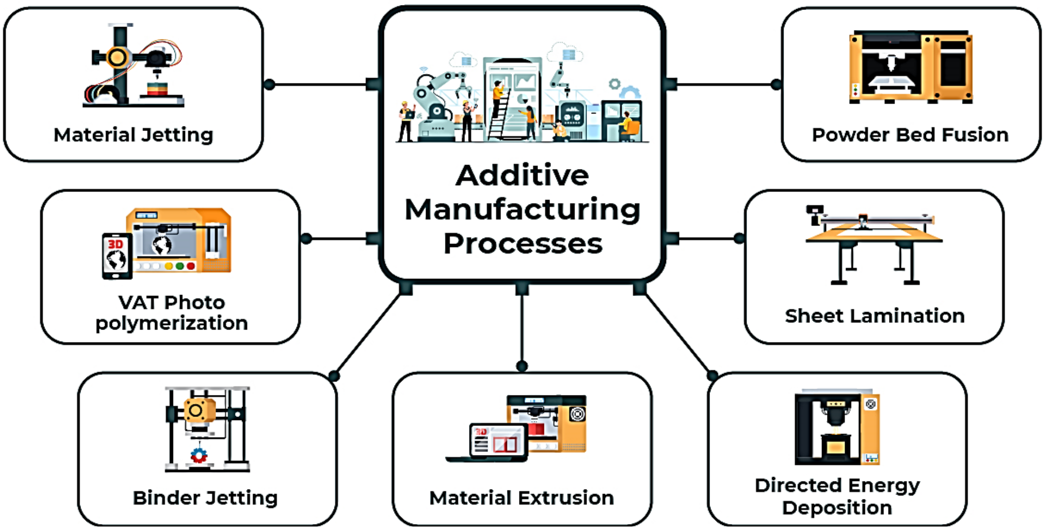

Figure 2: Additive Manufacturing Process (Kambale, 2021)

Operational and Procedural Steps of Additive Manufacturing (AM) Processes

The additive manufacturing process flow for seven different 3D object-building methods follows a basic sequence, as illustrated in Figure 3, despite variations in the process (Engineering Product Design, 2024).

MATERIAL AND METHODOLOGY

Materials Employed in Additive Manufacturing (AM) Processes

Additive Manufacturing uses polymers, ceramics, and metals in seven methods, with polymers being the most common as depicted in Table 1. Some techniques prefer specific materials over others. Materials are often generated in powder or wire feedstock. Layer-by-layer printing allows for material printing, but the final quality is influenced by the material. High temperatures and pressures can modify the microstructure of materials, making material qualities not always equivalent after fabrication compared to other manufacturing techniques (Loughborough University, 2023; Timlin, 2021).

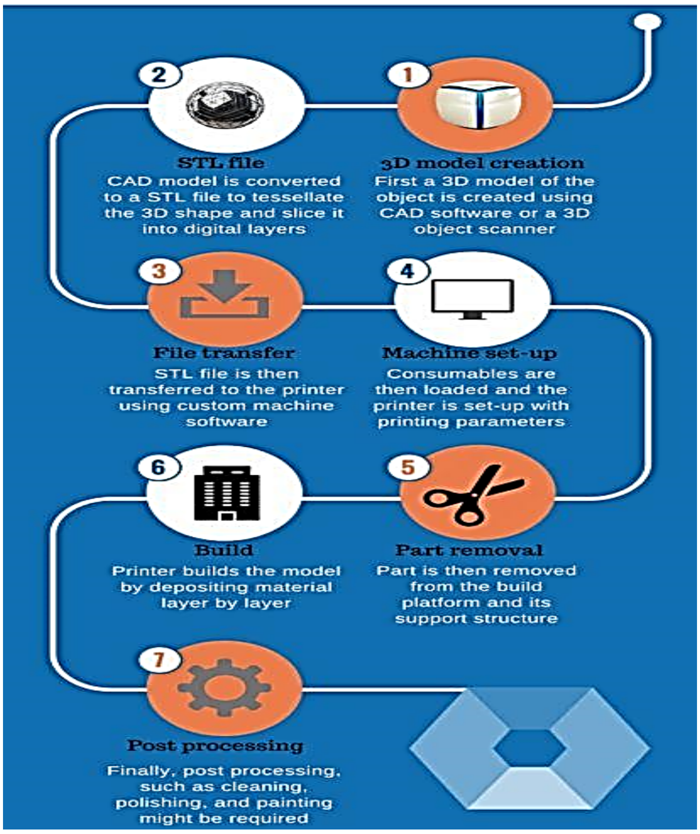

Figure 3: Additive Manufacturing-3D Printing Processes in Seven Steps (Engineering Product Design, 2024)

Table 1: Different Materials Used in Additive Manufacturing

Polymers	Metals	Ceramics
Acrylonitrile Butadiene Styrene (ABS)	Maraging Steel 1.2709 (Tensile Strength 1100 MPa)	Silica/Glass
Polylactide (PLA), including soft PLA	Titanium Alloy Ti6AI4V (Tensile Strength: 1150 MPa)	Porcelain
polycarbonate (PC)	15-5ph Stainless Steel (Tensile Strength: 1150 MPa)	Silicon-Carbide
Polyethylene Terephthalate Glycol (PETG)	Cobalt Chrome Alloy, Co28Cr6Mo (Tensile Strength 1300 MPa)	
Thermoplastic Polyurethane (TPU)	Aluminium AlSi10mg (Tensile Strength 445 MPa)	
Polyamide (Nylon)	Gold and Silver	
Nylon 12 (Tensile Strength 45 MPa)		
Glass-Filled Nylon (12.48 MPa)		
Epoxy Resin		
Wax		
Photopolymer Resins		

(Loughborough University, 2023; Juggerbot 3D, 2023)

Design Considerations for Additive Manufacturing

Engineering design principles for additive manufacturing optimize results by directing geometric considerations, material selection, building orientation, uniform wall thickness, eliminating unsupported overhangs, and optimizing specific printing processes (Sculpteo, 2024).

i. Design Freedom and Complexity: Additive manufacturing offers design flexibility and complexity through optimization approaches.
ii. Support Structures: It is crucial to consider support structures, as additive manufacturing cannot overcome gravity. Components with an undercut or outward sloping wall of 45 degrees or more must include supports in their design.
iii. Part Orientation and Build Orientation: Topology plays a significant role in additive manufacturing design, affecting part structure and build orientation as shown in Figure 4. Understanding topography minimizes manufacturing time and optimizes part strength.
iv. Surface Finish and Resolution: Surface finish and resolution are also important design elements for additive manufacturing. Different techniques offer unique finishing possibilities, while most materials can be sanded or post-processed with typical coatings or paints.

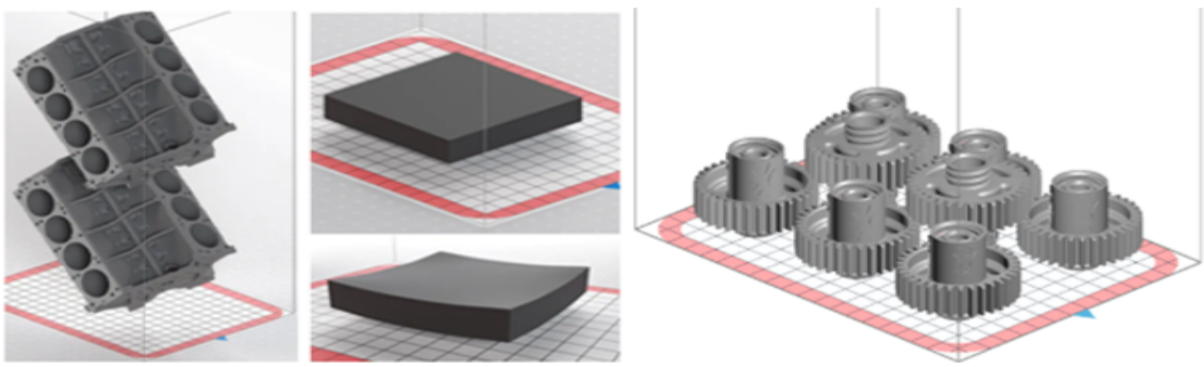

Figure 4: Build Orientation (Filament2Print, 2024)

RESULT AND DISCUSSION

Prototyping with Additive Manufacturing

Prototyping is a crucial step in the product life cycle, allowing engineers to refine and test designs iteratively. Originating from the first commercially accessible 3D printers, rapid prototyping is an essential part of product design and engineering(Prototype Projects, 2024; Priority Designs, 2021). Engineers create an early concept model of a part or product for testing, then create a preliminary prototype, undergo tests, and evaluate the design for improvements. This process is repeated to produce a final verified design that meets customer and engineering objectives (Brown, 2024; Ogle Models, 2024). Rapid prototyping uses digital technology to design and create prototypes quickly and easily, often using 3D printing technology to build prototypes quickly. This eliminates the need for tool or die sets and includes technical operations such as design, modification, and testing. Before commercial 3D printing, engineers relied on quick foam mockups and elaborate clay models, resulting in longer lead times and higher fabrication costs (Emifoniye, 2024; Ngoh, 2020). Figure 5 depicts proof of concept and prototype diagrammatic representation.

Significant Prototyping with Additive Manufacturing

Additive manufacturing allows companies to quickly build prototypes in-house, shortening lead times, facilitating faster iterations and product releases, and saving money by eliminating material waste and tooling requirements (Priority Designs, 2021; Ngoh, 2020).

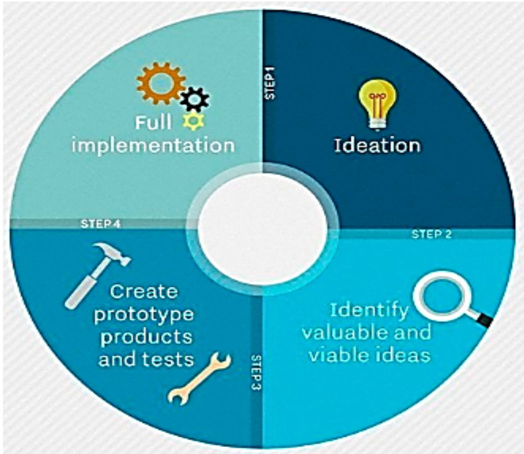

Figure 5: Proof of Concept and Prototype Diagrammatic Representation (Gillis and Pratt 2024; Lewis, 2024)

Applications of Additive Manufacturing in Engineering

Additive Manufacturing is used in various applications such as ECS ducting, customised aircraft interiors, rocket engine components, combustor liners, composite tooling, oil and fuel tanks, and UAV components, producing complex, strong pieces as shown in Figure 6 (Stratasys, 2018).

Figure 6: Additive Manufacturing in Industrial Applications (Xometry Europe, 2022)

CONCLUSION

In conclusion, Additive Manufacturing (AM) is a revolutionary engineering innovation that offers unprecedented possibilities for design, prototyping, and production. Its evolution through ASTM categorizations and material versatility has revolutionised traditional manufacturing approaches. Design considerations optimize AM's capabilities, allowing for complex geometries and efficient part orientations. Rapid prototyping accelerates product development cycles, enabling faster iterations and cost-effective design refinement. AM's applications span across industries like aerospace, automotive, healthcare, and consumer products, highlighting its transformative potential. As AM evolves, engineers must harness its capabilities to drive innovation, sustainability, and efficiency.

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