International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review Additive Manufacturing: Bridging Design and Production Gap

[1]D. Sriveda Rama Ratnam

[1]Department of Mechanical Engg, GMR Institute of Technology, Rajam AP-532127
*Email Id: sriveda024@gmail.com

ABSTRACT:

This work innovatively proposes a method of Additive Manufacturing (AM), commonly known as 3D printing, has emerged as a disruptive technology that is transforming industries across the globe. This work delves into the diverse landscape of AM, exploring its principles, applications, and the pivotal role of materials in its evolution. Additive manufacturing processes take the information from a computer-aided design (CAD) file that is later converted to a stereo lithography (STL) file. In this process, the drawing made in the CAD software is approximated by triangles and sliced containing the information of each layer that is going to be printed. Stereo lithography (SLA) is a 3D printing method that uses UV light to solidify layers of liquid resin, building intricate objects layer by layer.

A central focus of this study is the crucial role of materials in AM. With a wide range of materials available, including polymers, metals, ceramics, and composites, AM has expanded its capabilities to suit diverse industries, from aerospace to healthcare. The paper discusses the impact of material properties on the final printed objects and how advancements in material science have driven the technology forward.

KEY WORDS: Additive Manufacturing (AM), technological revolution, subtractive manufacturing, precision geometries, waste reduction, energy consumption, time-to-market, customization, rapid prototyping, paradigm shift.

INTRODUCTION:

Additive Manufacturing (AM) stands as the vanguard of a technological revolution, revolutionizing our fundamental approach to production. Unlike subtractive manufacturing, where material is carved away from a solid block, AM is an additive process, meticulously constructing objects layer by layer under the guidance of digital designs and precision geometries. This paradigm shift not only broadens the horizons of what can be manufactured but also brings about significant reductions in waste, energy consumption, and time-to-market.

Furthermore, AM is intricately entwined with the principles of customization and rapid prototyping, heralding a new era of manufacturing possibilities. This technology empowers the creation of highly intricate and personalized objects with unmatched speed and precision. Whether it involves crafting medical implants tailored to individual patients or engineering

aerospace components fine-tuned for optimal performance, AM transcends the limitations of traditional manufacturing, offering engineers and designers an exceptionally versatile toolbox.

As we delve deeper into the realms of Additive Manufacturing, we will explore key methodologies such as Stereo Lithography (SLA), understand the pivotal role materials play in shaping AM outcomes, delve into its diverse applications across industries, and scrutinize real-world case studies that exemplify the transformative potential of this ground breaking technology. Join us on this journey through the layers of innovation that Additive Manufacturing unveils, reshaping the landscape of modern production.

EVOLUTION OF ADDITIVE MANUFACTURING:

1. *Prototyping Era (1980s-1990s):* The inception of Additive Manufacturing (AM) can be traced back to the 1980s when the technology primarily served rapid prototyping needs. Techniques like Stereo Lithography (SLA) and Selective Laser Sintering (SLS) allowed for the layer-by-layer construction of prototypes based on digital designs.

2. *Tooling and Direct Manufacturing (1990s-2000s):* As AM technologies advanced, the focus expanded beyond prototyping to include tooling and direct manufacturing applications. Industries began to explore using 3D printing for creating molds and tooling components, reducing lead times and costs.

3. Industrialization and Material Expansion (2000s-2010s): The 2000s witnessed a shift towards industrial applications of AM. The technology became integral to producing end-use parts in industries like aerospace and healthcare. Material options expanded beyond polymers to include metals, ceramics, and composites, broadening AM's capabilities.

4. Customization and Mass Production (2010s-Present): In recent years, AM has entered an era of customization and mass production. The ability to create highly intricate and personalized objects has been embraced across various sectors, from healthcare (custom implants) to aerospace (optimized components). Advancements in materials, processes, and post-processing techniques have contributed to AM's scalability.

5. Integration with Industry 4.0 and Smart Manufacturing: AM has become an integral part of Industry 4.0, aligning with the principles of smart manufacturing. The technology is seamlessly integrated into digital workflows, allowing for agile and efficient production processes. Machine learning and data analytics are employed to optimize AM processes further.

6. Sustainable Practices and Eco-Friendly Innovations: In response to environmental concerns, there is a growing emphasis on sustainable practices within AM. Innovations such as using eco-friendly materials, recycling, and reducing waste highlight the industry's commitment to environmental responsibility.

7. Ongoing Research and Future Prospects: Current research in AM is focused on addressing challenges such as post-processing requirements, material recycling, and standardization. There is a continual effort to enhance precision, scalability, and environmental sustainability. The future of AM holds promises of even greater efficiency, broader material possibilities, and novel applications across diverse industries.

PRINCIPLES OF ADDITIVE MANUFACTURING:

Digital Design:

- The process begins with a digital 3D model created using Computer-Aided Design (CAD) software. This digital design serves as the blueprint for the physical object.

Slicing the Model:

- The digital model is sliced into thin, horizontal layers. This step is crucial because it determines the resolution and intricacy of the final object. Each layer represents a cross-section of the 3D model.

Layer-by-Layer Construction:

- The sliced model is sent to the 3D printer, which interprets each layer and builds the object sequentially. Various additive manufacturing technologies use different methods for layer deposition, such as extrusion of molten material, curing of liquid resin using UV light, or sintering of powdered materials with lasers.

Material Deposition or Solidification:

- Depending on the specific AM technology, materials are deposited, solidified, or fused together layer by layer. This can involve adding liquid resin that solidifies, melting and fusing powdered materials, or extruding melted thermoplastics.

Support Structures (if needed):

- In certain cases, support structures may be added during the printing process to prevent overhangs or unsupported features from collapsing. These support structures are typically removed in post-processing.

Post-Processing:

- After the printing is complete, post-processing steps may be necessary. This can include removing support structures, surface finishing, heat treatment, or other treatments to achieve the desired properties and aesthetics.

Diverse Material Usage:

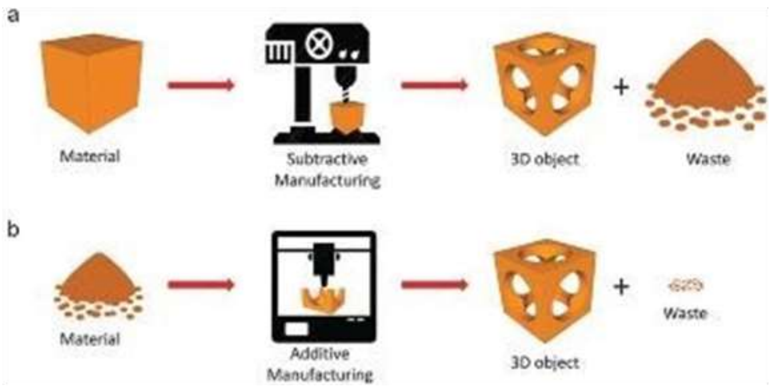
- AM allows for the use of various materials, including polymers, metals, ceramics, and composites. This versatility enables the production of a wide range of objects with different physical and mechanical properties.

Complex Geometries and Customization:

- One of the key advantages of AM is the ability to produce complex geometries that would be challenging or impossible with traditional manufacturing methods. Additionally, AM facilitates customization, allowing each part to be tailored to specific requirements.

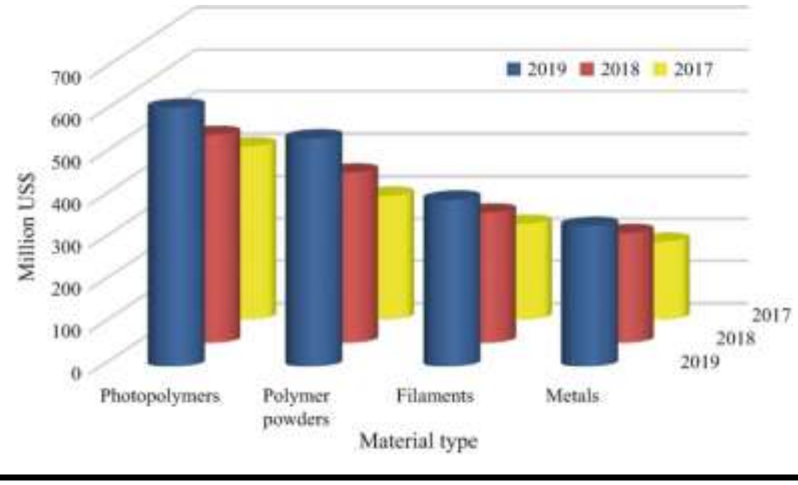
Reduction in Material Waste:

- Unlike subtractive manufacturing processes, where material is removed to create an object, AM builds objects layer by layer, minimizing material waste. This efficiency is particularly beneficial for sustainable and cost-effective manufacturing.



CHARACTERISTICS OF ADDITIVE MANUFACTURING:

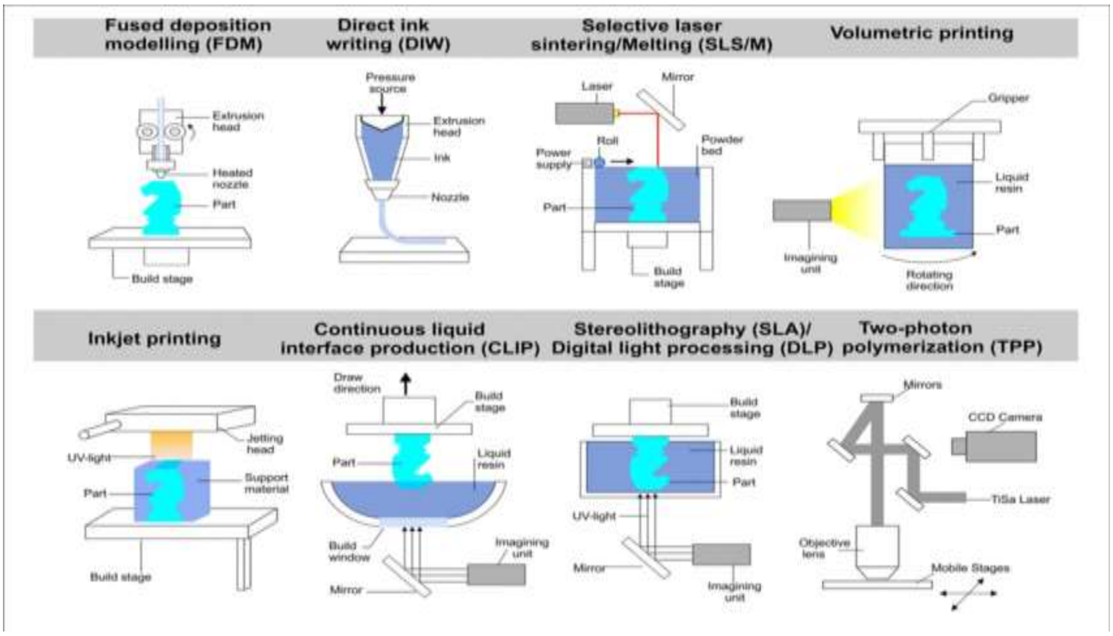
Additive Manufacturing (AM), commonly known as 3D printing, is characterized by distinctive features that set it apart from traditional manufacturing methods. At its core, AM involves the layer-by-layer construction of objects, a departure from subtractive methods that carve away material. The process relies on digital design and modeling, with Computer-Aided Design (CAD) files guiding the sequential addition of material. One of AM's strengths lies in its versatility of materials, accommodating polymers, metals, ceramics, composites, and biomaterials. This diversity enables the production of parts with varied properties to suit different applications. The customization potential of AM is noteworthy, allowing for the creation of bespoke products tailored to specific needs without the constraints of traditional tooling. Additionally, AM excels in crafting complex geometries and intricate internal structures, expanding its utility in industries like aerospace and healthcare. Notably, AM minimizes material waste by building objects layer by layer, contributing to sustainable manufacturing practices. Rapid prototyping is a key application, facilitating quick design iterations, while on-demand production reduces the need for large inventories. AM is a tool-free process, eliminating the requirement for molds or dies, and its design-driven approach allows for optimization based on functionality rather than manufacturing constraints. Integration with digital technologies, such as artificial intelligence, enhances efficiency, while post-processing steps may be needed for surface finish and part properties refinement. Overall, these characteristics position AM as a transformative and versatile manufacturing method with applications across diverse industries. The adaptability of AM to various production scales, from rapid prototyping to mass customization, further underscores its versatility. Overall, these characteristics position AM as a transformative and agile manufacturing method, heralding a new era in production and design.



TYPES OF ADDITIVE MANUFACTURING:

1. **Stereolithography (SLA):** SLA employs a vat of liquid photopolymer resin cured by ultraviolet (UV) light layer by layer. This method is known for its high precision and is commonly used in creating detailed prototypes and intricate parts.
2. **Fused Deposition Modeling (FDM):** FDM is one of the most widely used AM methods. It involves the extrusion of thermoplastic filaments through a heated nozzle, forming layers that solidify to create the final object. FDM is valued for its cost-effectiveness and versatility.
3. **Selective Laser Sintering (SLS):** SLS utilizes a laser to sinter powdered materials, such as polymers, metals, or ceramics, layer by layer. This technique is known for its ability to produce functional and durable parts with a wide range of materials.

4. **Direct Metal Laser Sintering (DMLS):** DMLS is a variation of SLS specifically designed for metal powders. It employs a high-powered laser to sinter and fuse metal powders together, producing strong and complex metal components used in aerospace and medical applications.
5. **Electron Beam Melting (EBM):** Similar to DMLS, EBM is used for metal powders but utilizes an electron beam to melt and fuse the material. EBM is known for its high-speed and is often employed in aerospace and orthopedic implant manufacturing.
6. **Binder Jetting:** This method involves selectively depositing a liquid binding agent onto a powder bed, layer by layer, to create the desired object. After printing, the green part is often sintered or infiltrated with a secondary material for strength.
7. **PolyJet Printing:** PolyJet technology operates by jetting layers of liquid photopolymer onto a build tray. Each layer is cured with UV light, and the process allows for the simultaneous use of multiple materials, enabling the creation of parts with varying properties.
8. **Digital Light Processing (DLP):** Similar to SLA, DLP uses a digital light projector to cure photopolymer resin layer by layer. DLP is known for its speed in comparison to traditional SLA.



APPLICATIONS OF ADDITIVE MANUFACTURING:

Additive manufacturing (AM) finds widespread use across various industries due to its versatility and ability to create complex structures. Some key applications of additive manufacturing include:

1. **Aerospace Industry:**
   - AM is extensively used in aerospace for manufacturing lightweight components, complex geometries, and parts with reduced material waste.
   - It enables the production of intricate engine components, lightweight aircraft interiors, and optimized designs for improved fuel efficiency.
2. **Medical and Healthcare:**
   - AM is employed in the production of patient-specific medical implants, such as custom-made orthopedic implants and dental structures.
   - Bioprinting, a specialized form of AM, is used to create tissues and organs for transplantation and pharmaceutical testing.
3. **Automotive Sector:**
   - The automotive industry benefits from AM for rapid prototyping, creating lightweight components, and manufacturing customized parts.
   - It allows for the production of complex, optimized structures that enhance vehicle performance and fuel efficiency.
4. **Architecture and Construction:**

- AM is increasingly used in construction for creating intricate architectural components and structures.
- It facilitates the construction of complex and unique designs while minimizing material waste.

5. **Consumer Goods:**
   - AM enables the production of customized consumer goods, from personalized accessories to household items.
   - It offers the flexibility to manufacture small batches of customized products economically.
6. **Tooling and Prototyping:**
   - AM is widely utilized in the rapid prototyping of product designs, reducing the time and cost involved in traditional prototyping methods.
   - Tooling and molds for traditional manufacturing processes can also be produced using AM.
7. **Military and Defense:**
   - AM is used to manufacture lightweight and high-strength components for military equipment and vehicles.
   - It allows for on-demand production of spare parts, reducing downtime and logistical challenges.
8. **Education and Research:**
   - AM is a valuable tool in educational settings for teaching design and engineering principles.
   - Researchers use AM to create prototypes and experimental setups for testing new concepts and materials.
9. **Electronics:**
   - AM is applied in the production of customized electronic components and housings.
   - It allows for the creation of complex, compact designs that may be challenging or impossible with traditional manufacturing methods.

RESEARCH METHODOLOGY:

The methodology employed in this research is anchored in an exhaustive literature review spanning diverse domains of additive manufacturing (AM). This comprehensive process involves the systematic analysis of research papers across varied applications such as aerospace, automotive, biomedical, Industry 4.0, construction, machine learning integration, eco-friendly practices, metallic part advancements, material categorization, and process optimization.

Through a meticulous comparative analysis, these research papers will be methodically categorized based on their primary focus, allowing for the creation of a structured framework. This categorization aims to streamline insights and findings, facilitating a cohesive understanding of the multifaceted aspects of AM. The synthesis of data from these diverse sources will contribute to identifying overarching themes, challenges, and opportunities within the expansive field of AM.

The subsequent phase involves a critical analysis of the collective information extracted from the literature review. This critical analysis is designed to distill key insights that will form the foundation for a proposed methodology framework. This framework will encompass crucial aspects such as material selection, process optimization, machine learning integration, and sustainability practices within the realm of AM.

The proposed methodology framework is envisaged to provide a holistic approach to navigating the complexities of AM research. It will culminate in offering recommendations for future research directions in AM, placing emphasis on potential areas for advancement and advocating for interdisciplinary collaboration. This comprehensive approach aims to contribute significantly to the evolving landscape of additive manufacturing and its applications across various domains.

CONCLUSION:

In summary, the research papers highlighted the diverse impact of 3D printing, or additive manufacturing (AM). They showcased how AM is transforming various industries and integrating advanced technologies like machine learning. The significance of materials in broadening AM applications, along with environmentally friendly practices and specific examples in satellite and construction, illustrates the wide-ranging potential of AM. The suggested future research methodology, covering material selection, process optimization, machine learning, and sustainability, offers a clear path for advancing AM technologies. Overall, the findings emphasize AM's crucial role in shaping the future of manufacturing and design.

Moreover, the papers demonstrated the close connection between AM and Industry 4.0, emphasizing the collaboration between material science advancements, process innovations, and design improvements. The focus on high-temperature engineering thermoplastic polymers for aerospace, automotive, and biomedical applications highlights how AM addresses industry-specific challenges. Exploring AM's role in crafting intricate architectural components and radio-frequency parts for satellites further confirms its versatility.

REFERENCES:

1. Vayre, B., Vignat, F., & Villeneuve, F. (2012). Designing for additive manufacturing. Procedia CIrP, 3, 632-637.
2. Bourell, D., Kruth, J. P., Leu, M., Levy, G., Rosen, D., Beese, A. M., & Clare, A. (2017). Materials for additive manufacturing. CIRP annals, 66(2), 659-681
3. Dilberoglu, U. M., Gharehpapagh, B., Yaman, U., & Dolen, M. (2017). The role of additive manufacturing in the era of industry 4.0. Procedia manufacturing, 11, 545554.
4. Lim, S., Buswell, R. A., Le, T. T., Austin, S. A., Gibb, A. G., & Thorpe, T. (2012). Developments in construction-scale additive manufacturing processes. Automation in construction, 21, 262-268
5. Calignano, F., Manfredi, D., Ambrosio, E. P., Biamino, S., Lombardi, M., Atzeni, E., ... & Fino, P. (2017). Overview on additive manufacturing technologies. Proceedings of the IEEE, 105(4), 593-612.
6. Wong, K. V., & Hernandez, A. (2012). A review of additive manufacturing.International scholarly research notices, 2012.
7. Qin, J., Hu, F., Liu, Y., Witherell, P., Wang, C. C., Rosen, D. W., ... & Tang, Q. (2022). Research and application of machine learning for additive manufacturing. *Additive Manufacturing*, *52*, 102691.
8. Alfattni, R. (2022). Comprehensive study on materials used in different types of additive manufacturing and their applications. *International Journal of Mathematical, Engineering and Management Sciences*, *7*(1), 92.
9. Adekanye, A., Mahamood, R. M., Akinlabi, E. T., & Owolabi, M. G. (2017). Additive manufacturing: the future of manufacturing.
10. Kumar, S. A., & Prasad, R. V. S. (2021). Basic principles of additive manufacturing: Different additive manufacturing technologies. In *Additive manufacturing* (pp. 17-35). Woodhead Publishing.
11. Singh, S., & Ramakrishna, S. (2017). Biomedical applications of additive manufacturing: present and future. *Current opinion in biomedical engineering*, *2*, 105-115.
12. Camacho, D. D., Clayton, P., O'Brien, W. J., Seepersad, C., Juenger, M., Ferron, R., & Salamone, S. (2018). Applications of additive manufacturing in the construction industry–A forward-looking review. *Automation in construction*, *89*, 110-119.