

# **Additive Manufacturing Technologies for Advanced Engineering Production**

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## **Abstract**

Additive manufacturing (AM) has emerged as an important advanced production technology capable of transforming conventional engineering manufacturing through layer-by-layer material deposition and digitally controlled fabrication. Unlike traditional subtractive manufacturing processes, additive approaches can produce complex geometries, customized components, lightweight structures, and integrated functional features while potentially reducing material waste. This paper examines additive manufacturing technologies for advanced engineering production, with emphasis on process principles, material systems, digital design, production optimization, quality control, and industrial applications. The study develops a conceptual analytical framework for evaluating major additive manufacturing processes according to geometric capability, production flexibility, material utilization, dimensional accuracy, productivity, and sustainability. Technologies including powder bed fusion, directed energy deposition, material extrusion, vat photopolymerization, material jetting, and binder jetting are considered from an engineering-production perspective. The analysis demonstrates that additive manufacturing can support rapid prototyping, customized production, lightweight engineering, complex component fabrication, and distributed manufacturing.

Digital workflows connecting computer-aided design, simulation, process planning, manufacturing, inspection, and data analytics further enhance production flexibility. However, widespread industrial adoption remains constrained by production speed, equipment costs, material limitations, surface quality, residual stresses, dimensional accuracy, process variability, and limited standardization. Advanced process monitoring and artificial intelligence provide opportunities for improving defect detection and manufacturing consistency through real-time analysis of thermal, optical, acoustic, and geometric information. Future development should emphasize hybrid manufacturing, intelligent process control, sustainable feedstocks, multi-material fabrication, digital twins, automated quality assurance, and lifecycle-oriented production strategies. Additive manufacturing can therefore serve as a significant foundation for advanced engineering production when technological capabilities are integrated with robust process control, engineering validation, material science, and industrial quality-management practices.

**Keywords:** Additive Manufacturing, Advanced Manufacturing, 3D Printing, Engineering Production, Powder Bed Fusion, Digital Manufacturing, Process Optimization, Smart Manufacturing

## **1. Introduction**

Advanced engineering production increasingly requires manufacturing systems that can accommodate complex geometries, customized components, shorter product-development cycles, and rapidly changing

market requirements. Conventional manufacturing technologies remain highly effective for many applications, but processes based on machining, casting, forging, and molding can involve significant tooling requirements, material waste, and geometric limitations. Additive manufacturing provides an alternative production paradigm in which components are constructed progressively from digital models, allowing material to be deposited or consolidated only where required.

The development of additive manufacturing has expanded significantly beyond its early role in rapid prototyping. Modern AM technologies can process polymers, metals, ceramics, composites, and specialized functional materials. Industrial applications now include aerospace components, automotive parts, medical devices, tooling, energy-system components, and customized engineering products. The ability to fabricate complex internal channels, lattice structures, topology-optimized geometries, and integrated assemblies provides opportunities that can be difficult to achieve using conventional production processes.

A major advantage of additive manufacturing is its connection with digital engineering workflows. A three-dimensional computer-aided design model can be transformed into a manufacturing strategy through slicing, tool-path generation, process simulation, and machine control. This digital continuity can reduce the need for physical tooling and support rapid design iteration. Engineering optimization techniques can also be integrated into the design process to minimize mass while maintaining required mechanical performance.

Material efficiency represents another important characteristic of additive production. Conventional subtractive manufacturing may remove considerable quantities of material to obtain a desired geometry, whereas additive manufacturing can theoretically deposit material according to the required structure. However, the actual material and energy efficiency of AM depends on the manufacturing technology, support structures, powder utilization, post-processing, machine energy demand, and material recovery. Sustainable production therefore requires lifecycle evaluation rather than assuming that additive processes are automatically environmentally superior.

Quality assurance remains one of the most important requirements for industrial AM. Process conditions such as temperature, energy input, deposition rate, powder characteristics, layer thickness, and environmental conditions can influence the final properties of manufactured components. Defects such as porosity, lack of fusion, warping, delamination, residual stress, and dimensional inaccuracies can compromise component performance. Consequently, real-time monitoring, process modeling, nondestructive inspection, and data-driven quality control have become increasingly important.

Additive manufacturing is also becoming closely connected with Industry 4.0 and smart manufacturing. Sensors, industrial networks, cloud platforms, digital twins, artificial intelligence, and machine learning can be integrated with AM equipment to create intelligent production systems. These technologies can monitor manufacturing processes, detect deviations, predict defects, and optimize production parameters. Such integration provides a pathway from digitally controlled fabrication toward adaptive and data-driven engineering production.

This paper examines additive manufacturing technologies from an advanced engineering production perspective. It reviews major AM processes, materials, digital workflows, quality-control strategies, and industrial applications. The study also analyzes the potential contributions of additive manufacturing to production flexibility, material efficiency, customization, and engineering innovation while identifying major technical and operational challenges. Future research directions are proposed to support intelligent, sustainable, reliable, and scalable additive manufacturing systems.

## 2. Objectives

### 2.1 Evaluation of Additive Manufacturing Technologies

The first objective is to examine major additive manufacturing technologies used in advanced engineering production. The study considers powder bed fusion, directed energy deposition, material extrusion, vat photopolymerization, material jetting, and binder jetting according to their process characteristics, material compatibility, geometric capabilities, production requirements, and industrial applications.

### 2.2 Assessment of Advanced Production Contributions

The second objective is to assess how additive manufacturing can improve production flexibility, customization, material efficiency, product development, lightweight design, and manufacturing innovation. The study also evaluates major implementation challenges related to quality, cost, productivity, materials, process consistency, post-processing, and industrial standardization.

## 3. Review of Literature

### 3.1 Fundamentals of Additive Manufacturing

Additive manufacturing is based on the controlled creation of three-dimensional objects through successive material layers. International standards classify AM technologies into major process categories according to how material is deposited, cured, bound, or selectively consolidated. The layer-wise principle provides substantial geometric flexibility because the manufacturing process does not necessarily require conventional cutting tools or molds.

Early AM technologies primarily supported prototyping and design verification. Continued developments in material science, machine control, laser systems, electron-beam technologies, and computational modeling have expanded AM toward functional component production. Industrial AM now provides opportunities for manufacturing geometrically complex components that may be difficult or uneconomical to produce through conventional techniques.

### 3.2 Metal Additive Manufacturing

Metal AM represents one of the most important areas of advanced engineering production. Powder bed fusion processes use concentrated energy sources to selectively consolidate metal powders, while directed energy deposition introduces material into an energy field during deposition. These technologies can manufacture aerospace, automotive, medical, and energy components from materials such as titanium alloys, aluminum alloys, stainless steels, and nickel-based superalloys.

Metal AM can provide significant design freedom, but component quality depends strongly on process parameters. Laser or electron-beam power, scan speed, layer thickness, powder characteristics, thermal conditions, and scanning strategies influence microstructure and defect formation. Residual stress and thermal distortion can also require specialized support structures, heat treatment, machining, or other post-processing procedures.

### 3.3 Polymer, Ceramic, and Composite Additive Manufacturing

Polymer-based AM includes material extrusion, vat photopolymerization, and material jetting technologies. These processes support rapid prototyping, customized components, tooling, and selected

end-use products. Their relatively accessible equipment requirements have also contributed to widespread adoption in research, education, and small-scale manufacturing.

Ceramic and composite additive manufacturing provides opportunities for applications requiring high-temperature stability, wear resistance, stiffness, or specialized functional properties. However, ceramic processing may involve complex debinding and sintering stages, while composite AM requires careful control of reinforcement orientation and matrix compatibility. Continued development of multifunctional feedstocks and improved process control can increase their engineering applications.

### 3.4 Digital and Intelligent Manufacturing

Additive manufacturing is inherently connected with digital production because component fabrication begins with a digital geometry and relies on computational process planning. Advanced workflows can integrate computer-aided engineering, topology optimization, finite element analysis, process simulation, machine monitoring, and automated inspection.

Industry 4.0 technologies can further transform additive manufacturing into intelligent production systems. Sensors can collect real-time information about melt pools, temperature, vibration, geometry, and machine conditions. Artificial intelligence can analyze these measurements to detect process deviations and support predictive quality control. Digital twins can provide virtual representations of manufacturing systems, enabling process optimization and simulation before or during production.

## 4. Methodology

### 4.1 Research Design

This study adopts a conceptual and analytical research design to evaluate additive manufacturing as an advanced engineering production technology. The methodology synthesizes established research on AM processes, engineering materials, digital manufacturing, process monitoring, quality control, and industrial applications. The analysis focuses on the relationship between manufacturing technology characteristics and production outcomes such as geometric flexibility, material utilization, productivity, customization, and component quality.

The research treats additive manufacturing as an integrated production system rather than an isolated printing operation. The framework includes digital design, material preparation, process planning, layer fabrication, monitoring, post-processing, inspection, and final application. This systems perspective allows technical benefits to be considered alongside manufacturing constraints and quality requirements. It also provides a basis for examining how intelligent manufacturing technologies can improve the reliability and scalability of AM production.

### 4.2 Technology and Production Framework

The proposed framework organizes additive production into interconnected stages beginning with digital component design and ending with quality verification. Design optimization can be used to exploit AM's geometric flexibility, followed by material and process selection. Manufacturing parameters are then established according to material characteristics and machine capabilities.

**The principal production stages include:**

- **Digital design:** Development of three-dimensional component geometry.
- **Design optimization:** Application of topology optimization and engineering simulation.

- **Material selection:** Selection of polymers, metals, ceramics, or composites.
- **Process selection:** Matching manufacturing technology with component requirements.
- **Process planning:** Generation of layer structures, supports, and machine parameters.
- **Layer fabrication:** Controlled material deposition, curing, binding, or consolidation.
- **Process monitoring:** Continuous observation of thermal, optical, acoustic, and geometric conditions.
- **Post-processing:** Heat treatment, surface finishing, machining, cleaning, or sintering.
- **Quality inspection:** Dimensional, mechanical, microstructural, and nondestructive evaluation.

## 4.3 Analytical Evaluation

The analytical evaluation compares additive manufacturing technologies according to production flexibility, geometric complexity, material compatibility, productivity, quality requirements, and sustainability potential. The analysis recognizes that no individual AM technology is optimal for all engineering applications. Process selection depends on component geometry, production volume, material properties, dimensional requirements, surface characteristics, and economic constraints.

Production performance is therefore evaluated through a multidimensional engineering perspective. Manufacturing speed, material efficiency, process reliability, design freedom, post-processing requirements, and quality assurance are considered together. The methodology also recognizes the importance of digital integration, because advanced AM production increasingly depends on software-controlled design, process planning, monitoring, and inspection.

## 5. Analysis

### 5.1 Major Additive Manufacturing Technologies

Additive manufacturing technologies differ considerably in how materials are introduced and consolidated. Powder bed fusion provides high geometric freedom and is widely used for advanced metal and polymer applications. Directed energy deposition is particularly useful for larger components, repairs, and material additions. Material extrusion provides accessible polymer fabrication, whereas vat photopolymerization offers high-resolution production for suitable resin systems.

**Table 1: Major Additive Manufacturing Technologies for Engineering Production**

| AM Technology              | Typical Materials    | Major Capability                    | Engineering Application  |
|----------------------------|----------------------|-------------------------------------|--------------------------|
| Powder Bed Fusion          | Metals, polymers     | Complex high-performance components | Aerospace and automotive |
| Directed Energy Deposition | Metals               | Large components and repair         | Heavy engineering        |
| Material Extrusion         | Polymers, composites | Flexible and accessible production  | Prototyping and tooling  |
| Vat                        | Photopolymers        | High-resolution                     | Medical and precision    |

| AM Technology       | Typical Materials               | Major Capability                        | Engineering Application         |
|---------------------|---------------------------------|-----------------------------------------|---------------------------------|
| Photopolymerization |                                 | fabrication                             | components                      |
| Material Jetting    | Polymers, specialized materials | Multi-material and detailed fabrication | Functional prototypes           |
| Binder Jetting      | Metals, ceramics, sand          | High-volume potential                   | Industrial components and molds |
| Sheet Lamination    | Metals, polymers, composites    | Layered sheet fabrication               | Specialized manufacturing       |

**Interpretation:** The table shows that AM technologies provide different combinations of material compatibility, geometric freedom, production scale, and component quality. Powder bed fusion is particularly appropriate for complex high-performance components, while directed energy deposition provides advantages for larger components and repair applications.

Material extrusion remains valuable for accessible production and prototyping. Therefore, technology selection should be based on component requirements rather than treating additive manufacturing as a single uniform production process.

## 5.2 Production Performance and Engineering Benefits

Additive manufacturing can improve production flexibility by eliminating or reducing tooling requirements and enabling direct fabrication from digital models. This capability is especially valuable for customized components, low-volume production, spare parts, rapid prototyping, and geometrically complex structures. Design optimization can further reduce mass while preserving required structural performance.

**Table 2: Engineering Contributions of Additive Manufacturing**

| Production Dimension | Additive Manufacturing Contribution | Potential Benefit          | Main Consideration         |
|----------------------|-------------------------------------|----------------------------|----------------------------|
| Design Flexibility   | Complex geometry fabrication        | Greater design freedom     | Process limitations        |
| Customization        | Digital component modification      | Personalized products      | Production economics       |
| Material Efficiency  | Layer-wise fabrication              | Reduced material waste     | Supports and unused powder |
| Product Development  | Rapid prototyping                   | Shorter development cycles | Post-processing            |

| Production Dimension | Additive Manufacturing Contribution | Potential Benefit              | Main Consideration     |
|----------------------|-------------------------------------|--------------------------------|------------------------|
| Lightweight Design   | Lattice and optimized structures    | Lower component mass           | Structural validation  |
| Supply Chain         | Distributed digital production      | Reduced inventory requirements | Equipment availability |
| Repair               | Local material deposition           | Extended component life        | Process compatibility  |
| Quality Control      | In-process monitoring               | Earlier defect identification  | Sensor integration     |

**Interpretation:** The table indicates that additive manufacturing can influence multiple dimensions of advanced production. Its strongest contribution is the combination of digital flexibility and geometric freedom, which enables customized and lightweight component designs.

Material efficiency can also improve in appropriate applications, although support structures, powder losses, and post-processing must be considered. The integration of process monitoring provides additional opportunities to improve manufacturing reliability and reduce the probability of undetected defects.

## 6. Discussion

### 6.1 Design Flexibility and Customized Production

Additive manufacturing significantly expands the design space available to engineering producers. Components can incorporate internal channels, lattice structures, topology-optimized regions, and integrated functional features that may be difficult to manufacture using conventional methods. This capability enables designers to focus more strongly on functional performance rather than restricting geometry to shapes dictated by traditional tooling and machining processes.

Customization is another major advantage. Digital manufacturing allows component geometry to be modified without necessarily requiring new molds or dedicated tooling. This characteristic is valuable for medical devices, aerospace components, specialized industrial parts, and low-volume production. However, customization becomes economically beneficial only when digital preparation, production time, material costs, and post-processing are appropriately managed.

### 6.2 Material Efficiency and Sustainable Production

Additive manufacturing can reduce material waste because material is deposited or consolidated selectively according to digital geometry. This can provide significant advantages for expensive engineering materials, particularly in aerospace and high-value industrial applications. Lightweight structures can further reduce material consumption while maintaining required functional performance.

Nevertheless, sustainability depends on the complete production lifecycle. Energy consumption during printing, powder production, support structures, failed builds, heat treatment, surface finishing, and transportation can influence the environmental footprint. Therefore, additive manufacturing should

be compared with conventional alternatives using lifecycle-based metrics rather than assuming that reduced machining waste automatically results in lower environmental impact.

### 6.3 Intelligent Process Control and Quality Assurance

Quality assurance is essential for industrial additive manufacturing because small variations in processing conditions can influence the final component. Real-time monitoring technologies can observe melt-pool behavior, thermal characteristics, layer geometry, acoustic emissions, and machine conditions. These measurements can be analyzed to identify abnormalities during fabrication rather than discovering defects only after production.

Artificial intelligence can enhance this process by learning relationships between process parameters, sensor signals, and component quality. Predictive models can potentially identify defect-prone conditions and support adaptive parameter adjustment. Digital twins and process simulation can further assist in understanding thermal behavior and predicting distortion. However, intelligent quality systems require reliable datasets, validated models, sensor calibration, and engineering acceptance criteria.

## 7. Challenges

A major challenge in additive manufacturing is production productivity. Many AM processes remain slower than established mass-production techniques, particularly when large components or high production volumes are required. Layer-by-layer fabrication can result in substantial build times, while post-processing may add additional production stages. Consequently, AM is currently most competitive in applications where design complexity, customization, material value, or tooling reduction offsets slower production rates.

Material limitations also restrict broader adoption. Not every engineering material can be processed reliably through every AM technology. Material feedstock quality, particle-size distribution, thermal characteristics, viscosity, curing behavior, and chemical compatibility can influence process stability. Metal AM may experience powder oxidation, porosity, residual stress, and thermal distortion, while polymer and composite processes can face issues related to interlayer bonding and anisotropy.

Quality consistency and standardization represent additional challenges. AM components can exhibit directional properties because of layer-wise fabrication. Surface roughness, dimensional variation, internal defects, and residual stresses may require additional processing or inspection. Different machines and process conditions can also produce different component characteristics from nominally identical digital designs. Standardized qualification procedures and robust process-control frameworks are therefore essential for safety-critical industrial applications.

## 8. Future Research

### 8.1 Hybrid and Multi-Material Manufacturing

Future research should investigate hybrid production systems that combine additive and subtractive manufacturing within integrated platforms. Additive processes can create complex geometries, while machining can provide high-precision surfaces and dimensional finishing. Multi-material AM is another promising direction because components could potentially combine structural, thermal, electrical, and functional materials within a single manufacturing process.

## 8.2 AI-Enabled Process Optimization

Artificial intelligence is expected to play an increasingly important role in AM process optimization. Future research should develop models capable of linking process parameters, sensor measurements, microstructure, and final component properties. Closed-loop control systems could use real-time information to modify energy input, deposition rate, scanning strategy, or other parameters during production.

Research should also emphasize explainable and physics-informed AI. Combining physical process models with data-driven learning could improve prediction reliability and reduce dependence on extremely large experimental datasets. Such systems may enable more reliable defect prevention and automated process qualification.

## 8.3 Sustainable and Circular Additive Manufacturing

Future research should focus on improving the environmental performance of additive manufacturing throughout the product lifecycle. This includes energy-efficient machines, recyclable feedstocks, optimized support structures, powder recovery, renewable material sources, and improved component repair strategies. Lifecycle assessment should be incorporated into technology selection and product design.

Circular additive manufacturing could also enable digital inventories in which components are manufactured on demand rather than stored physically for long periods. Distributed production could reduce certain transportation and inventory requirements, although these potential benefits must be balanced against machine energy consumption and material logistics.

## 9. Limitations

This study is conceptual and analytical and does not present original experimental results from a specific additive manufacturing machine or material system. Consequently, the performance characteristics discussed in the analysis represent generalized engineering considerations rather than experimentally validated outcomes for a particular production environment. Actual manufacturing results depend on machine configuration, process parameters, material quality, component geometry, and post-processing conditions.

Another limitation is the rapid development of additive manufacturing technologies. New machines, materials, software platforms, and process-monitoring methods continue to emerge, making long-term comparisons difficult. In addition, different industrial sectors have different quality standards and production requirements. Therefore, the conclusions should be interpreted as a general engineering framework, while application-specific experimental validation remains necessary before industrial qualification.

## 10. Conclusion

Additive manufacturing technologies have become an important component of advanced engineering production because they enable direct fabrication of complex geometries from digital designs. Powder bed fusion, directed energy deposition, material extrusion, vat photopolymerization, material jetting, and binder jetting provide different combinations of material compatibility, geometric flexibility, production speed, and component quality. These technologies support applications ranging from rapid prototyping to high-value functional components and specialized industrial production.

The analysis demonstrates that the principal engineering value of additive manufacturing lies in its ability to combine digital design freedom with flexible production. Topology optimization, lattice structures, customized geometries, and integrated functional features can improve component design and potentially reduce material requirements. Additive manufacturing can also support repair, distributed production, and shorter development cycles. However, productivity limitations, material constraints, residual stresses, surface quality, dimensional accuracy, post-processing requirements, and process variability continue to influence industrial adoption.

Future development should focus on intelligent, integrated, and sustainable additive manufacturing systems. Hybrid manufacturing, multi-material fabrication, AI-enabled process control, digital twins, automated inspection, and circular material strategies can address several current limitations. Greater standardization and engineering validation will also be necessary for safety-critical applications. When additive manufacturing is combined with advanced digital engineering, robust quality control, and lifecycle-oriented production planning, it can provide a powerful foundation for flexible, efficient, customized, and technologically advanced engineering production.

## References

1. Soori, M., Karimi Ghaleh Jough, F., Dastres, R., & Arezoo, B. (2025). Additive manufacturing modification by artificial intelligence, machine learning, and deep learning: A review. *Additive Manufacturing Frontiers*, 4, 200198. <https://doi.org/10.1016/j.amf.2025.200198>
2. Yeshiwas, T. A., Tiruneh, A. B., & Sisay, M. A. (2025). A review article on the assessment of additive manufacturing. *Journal of Materials Science: Materials in Engineering*, 20, Article 85. <https://doi.org/10.1186/s40712-025-00306-8>
3. Yu, K., Dunn, M. L., Qi, H. J., & Maute, K. (2025). Recent advances in design optimization and additive manufacturing of composites: From enhanced mechanical properties to innovative functionalities. *npj Advanced Manufacturing*, 2, Article 26. <https://doi.org/10.1038/s44334-025-00040-1>
4. Shen, C., Guo, Y., Shen, Z., Yan, F., & Zhong, N. (2025). Additive manufacturing of aerospace composites: A critical review of the material–process–design interplay and prospects for application. *Materials*, 18(18), 4280. <https://doi.org/10.3390/ma18184280>
5. Gupta, V., Bankapalli, N. K., Saxena, P., Bajpai, A., & Ruan, D. (2025). Additive manufacturing of fiber-reinforced polymer matrix composites through material extrusion: A comprehensive review on filament fabrication, printing, testing methods, applications, and challenges. *Advanced Engineering Materials*. Advance online publication. <https://doi.org/10.1002/adem.202500676>
6. Faegh, M., Ghungrad, S., Oliveira, J. P., Rao, P., & Haghighi, A. (2025). A review on physics-informed machine learning for process-structure-property modeling in additive manufacturing. *Journal of Manufacturing Processes*, 133, 524–555. <https://doi.org/10.1016/j.jmapro.2024.11.066>
7. Jin, L., Zhai, X., Wang, K., Zhang, K., Wu, D., Nazir, A., Jiang, J., & Liao, W.-H. (2024). Big data, machine learning, and digital twin assisted additive manufacturing: A review. *Materials & Design*, 244, 113086. <https://doi.org/10.1016/j.matdes.2024.113086>
8. Shen, T., & Li, B. (2024). Digital twins in additive manufacturing: A state-of-the-art review. *The International Journal of Advanced Manufacturing Technology*, 131, 63–92. <https://doi.org/10.1007/s00170-024-13092-y>

9. Das, A., Ghosh, D., Lau, S.-F., Srivastava, P., Ghosh, A., & Ding, C.-F. (2024). A critical review of process monitoring for laser-based additive manufacturing. *Advanced Engineering Informatics*, 62, 102932. <https://doi.org/10.1016/j.aei.2024.102932>
10. Soleimani, M., Nankali, M., Duley, W. W., Zhou, Y. N., & Peng, P. (2024). Additive manufacturing processing with ultra-short-pulse lasers. *Journal of Manufacturing Processes*, 131, 2133–2163. <https://doi.org/10.1016/j.jmapro.2024.10.006>
11. Patel, S., Liu, Y., Siddique, Z., & Ghamarian, I. (2024). Metal additive manufacturing: Principles and applications. *Journal of Manufacturing Processes*, 131, 1179–1201. <https://doi.org/10.1016/j.jmapro.2024.09.101>
12. Li, H., Shi, X., Wu, B., Raimondi Corradi, D., Pan, Z., & Li, H. (2024). Wire arc additive manufacturing: A review on digital twinning and visualization process. *Journal of Manufacturing Processes*, 116, 293–305. <https://doi.org/10.1016/j.jmapro.2024.03.001>
13. Capasso, I., Andreacola, F. R., & Brando, G. (2024). Additive manufacturing of metal materials for construction engineering: An overview on technologies and applications. *Metals*, 14(9), 1033. <https://doi.org/10.3390/met14091033>
14. Maware, C., Muvunzi, R., Machingura, T., & Daniyan, I. (2024). Examining the progress in additive manufacturing in supporting lean, green and sustainable manufacturing: A systematic review. *Applied Sciences*, 14(14), 6041. <https://doi.org/10.3390/app14146041>
15. Su, J., Ng, W. L., An, J., Yeong, W. Y., Chua, C. K., & Sing, S. L. (2024). Achieving sustainability by additive manufacturing: A state-of-the-art review and perspectives. *Virtual and Physical Prototyping*, 19(1), e2438899. <https://doi.org/10.1080/17452759.2024.2438899>
16. Singh, G., Mehta, A., & Vasudev, H. (2024). Sustainability of additive manufacturing: A comprehensive review. *Progress in Additive Manufacturing*, 9, 2249–2272. <https://doi.org/10.1007/s40964-024-00579-z>
17. Zhao, J., Yang, Y., Kobir, M. H., Faludi, J., & Zhao, F. (2024). Driving additive manufacturing towards circular economy: State-of-the-art and future research directions. *Journal of Manufacturing Processes*, 124, 621–637. <https://doi.org/10.1016/j.jmapro.2024.06.018>
18. Kanishka, K., & Acherjee, B. (2023). Revolutionizing manufacturing: A comprehensive overview of additive manufacturing processes, materials, developments, and challenges. *Journal of Manufacturing Processes*, 107, 574–619. <https://doi.org/10.1016/j.jmapro.2023.10.024>
19. Taherkhani, K., Ero, O., Liravi, F., Toorandaz, S., & Toyserkani, E. (2023). On the application of in-situ monitoring systems and machine learning algorithms for developing quality assurance platforms in laser powder bed fusion: A review. *Journal of Manufacturing Processes*, 99, 848–897. <https://doi.org/10.1016/j.jmapro.2023.05.048>
20. Qin, J., Hu, F., Liu, Y., Witherell, P., Wang, C. C. L., Rosen, D. W., Simpson, T. W., Lu, Y., & Tang, Q. (2022). Research and application of machine learning for additive manufacturing. *Additive Manufacturing*, 52, 102691. <https://doi.org/10.1016/j.addma.2022.102691>