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Mini Review



# Additive Manufacturing in Robotic Systems: Production Planning and Methodological Integration

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## Abstract

Additive manufacturing (AM) has become a key enabling technology in the development of modern mechatronic and robotic systems, supporting lightweight design, modularity, and rapid prototyping. However, its effective use requires systematic integration of production planning, optimization, and process-aware design methodologies. This mini review synthesizes selected research on production planning challenges in AM, including nesting, scheduling, and part-to-printer assignment, as well as design constraints relevant to robotic applications. Special attention is given to methodological integration of AM in specialized aerial and ground robotic platforms and modular educational robots. The review highlights the importance of holistic design and manufacturing approaches to fully exploit the advantages of AM, enabling flexible, scalable, and efficient robotic systems for autonomous and educational applications.

**Keywords:** Additive manufacturing, Robotic Systems, Production Planning.

## Introduction

Additive manufacturing (AM) has become an important enabling technology in the development of mechatronic and robotic systems due to its design flexibility, reduced lead times, and ability to fabricate complex geometries compared to conventional manufacturing methods [1]. The layer-by-layer nature of AM supports the production of lightweight and functionally integrated components, making it particularly suitable for robotic platforms with strict constraints on mass, modularity, and adaptability. When employed beyond rapid prototyping, AM introduces specific challenges related to production planning, part orientation, nesting within the build volume, scheduling across multiple machines, and selection of process parameters [2,3]. Inefficient planning can significantly increase production time and cost, limiting the applicability of AM in complex mechatronic systems. Consequently, recent research has emphasized methodological and optimization-based approaches that treat AM as an integrated manufacturing system rather than an isolated fabrication process.

At the same time, the design of modern robotic platforms, both ground-based and aerial-based, has evolved toward increased autonomy, modularity, and functional integration, placing additional demands on manufacturing methodologies. Similar requirements are present in educational robotics, where low-cost production, ease of assembly, and scalability are of particular importance. While AM is well suited to address these needs, its successful integration requires systematic design and production methodologies that account for process constraints and material behavior [4]. The aim of this mini review is to synthesize selected research on production planning, optimization, and methodological integration of AM in mechatronic and robotic platforms.

## Production Planning in Additive Manufacturing

The layer-by-layer fabrication principle of AM enables the simultaneous production of multiple parts within a single build volume. While this capability represents a major advantage over conventional manufacturing, it also introduces a set of complex production planning and optimization challenges. These challenges are commonly formulated as variants of nesting, packing, scheduling, and part-to-printer assignment problems, which are typically combinatorial and computationally demanding [2, 5-7]. Early studies addressed the problem of efficiently placing multiple parts within a build space in order to minimize build time and production cost. The nature of the nesting problem strongly depends on the applied AM technology. In material extrusion processes such as Fused Deposition Modeling (FDM), parts are typically manufactured on a build plate, which limits nesting primarily to two-dimensional placement and orientation problems.

In contrast, powder-based technologies such as Selective Laser Sintering (SLS) enable true three-dimensional nesting of multiple components within the build volume. Approaches focusing on two-dimensional and three-dimensional nesting have demonstrated that part orientation and geometric projection significantly influence build efficiency and part quality [5,7]. As the number of parts and geometric complexity increase, these problems motivate the development of heuristic and metaheuristic strategies tailored to AM constraints [2,6,8].

Beyond geometric placement, research has increasingly considered AM as a networked production environment involving multiple machines with heterogeneous capabilities. In such contexts, part-to-printer assignment and scheduling emerge as critical decision-making problems. Studies employing multi-objective optimization frameworks have shown that trade-offs between production cost, machine utilization, and delivery performance must be carefully managed, particularly in fused deposition modeling and powder bed fusion systems [6,9-11]. These works highlight that treating printers as interchangeable resources often leads to suboptimal outcomes, underscoring the need to account for machine-specific characteristics such as build volume, processing speed, and material compatibility [3,8].

More recent contributions have expanded the scope of production planning to distributed and network-based AM systems. In these scenarios, production resources are geographically dispersed and coordinated through digital platforms, enabling concepts such as social manufacturing and direct digital manufacturing [9,12]. Research in this area proposes integrated frameworks that combine part orientation, nesting, and scheduling decisions, often supported by decision-support systems and web-based tools. Such approaches aim to improve scalability and responsiveness while reducing overall production time and cost.

Several review and framework-oriented studies have attempted to systematize the diverse body of research on AM production planning. Taxonomies have been proposed to classify nesting and scheduling problems based on part characteristics, build configurations, and machine attributes [2,7]. These efforts reveal persistent gaps, including the lack of unified modeling frameworks and limited consideration of downstream design implications, while providing an essential methodological foundation for integrating AM into complex production workflows. Overall, the reviewed literature demonstrates that efficient use of AM in robotic system development requires a holistic production planning approach that integrates geometric, process, and system-level considerations. Such methodological integration is particularly relevant for robotic platforms characterized by modular architectures, low-volume production, and frequent design iterations, where AM can offer significant advantages if supported by appropriate planning and optimization strategies.

## Design Constraints and Methodological Integration of Additive Manufacturing in Robotic Systems

The effective integration of AM into robotic system development requires careful consideration of both process constraints and design requirements. FDM and other AM technologies impose limitations on mechanical properties, dimensional accuracy, and layer adhesion, which directly influence structural performance and functionality in mechatronic systems. Optimizing process parameters, such as layer thickness, infill pattern, and build orientation, is therefore essential to achieve components that meet functional and durability criteria while maintaining low mass and manufacturability.

In specialized aerial robotic platforms, such as multirotor unmanned aerial vehicles (UAVs), AM has been applied to produce lightweight structural components and functional assemblies with integrated carbon fiber segments [13,14]. Methodological approaches in this context emphasize a combination of mechanical testing, material selection, and design for additive manufacturing principles to ensure that 3D printed parts satisfy strength, stiffness, and weight requirements. Design frameworks typically involve iterative cycles of modeling, simulation, and prototyping, allowing the development of UAV components that are optimized for performance while leveraging the flexibility of AM.

Similarly, in the domain of educational robotics, modular platforms benefit from AM through rapid prototyping, low-cost production, and ease of assembly. Recent implementations demonstrate that 3D printed chassis and structural modules enable seamless integration of electronic and control subsystems, while supporting modular expansion and repairability [15,16]. The methodological integration of AM in educational robotics involves iterative design loops, where component geometry and assembly processes are continuously refined to balance structural integrity, manufacturability, and educational usability.

Across both specialized UAVs and educational robotic systems, common methodological considerations emerge. These include early-stage design optimization using digital models, evaluation of AM-specific material and process constraints, and systematic testing of functional prototypes. Integrating these considerations into the design workflow not only improves component performance but also accelerates development cycles, reduces production costs, and supports modular architectures suitable for autonomous or educational applications. Overall, the reviewed studies highlight that AM should be treated as an integral part of the robotic system design methodology. By combining process-aware design, iterative prototyping, and systematic testing, both high-performance UAV platforms and modular educational robots can be effectively realized, demonstrating the practical advantages of methodological integration of AM in robotics.

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## Conclusion

AM offers clear advantages for robotic system design, enabling lightweight, modular, and rapidly prototyped components. Efficient planning, optimization, and process-aware design are essential to fully exploit these benefits, whether in specialized UAV and UGV platforms or educational robots. Both application domains show that methodological integration of AM, combining iterative design, testing, and manufacturing considerations, improves component performance, accelerates development, and supports modular and scalable architectures. Challenges remain, particularly regarding material limitations, dimensional accuracy, and coordination in networked production environments. In conclusion, AM should be treated as a core part of the design and production workflow rather than as an isolated tool. When systematically integrated, it enables robotic platforms to achieve higher autonomy, flexibility, and functional efficiency, providing a solid methodological foundation for ongoing research in autonomous and educational robotics.

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## Conflict of interest

No conflict of interest.

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