

APPLICATION OF CAD/CAE SYSTEMS FOR ADDITIVE MANUFACTURING IN THE
MECHANICAL ENGINEERING INDUSTRY OF UZBEKISTAN: ANALYSIS OF
INTERNATIONAL EXPERIENCE AND IMPACT ASSESSMENT

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<https://doi.org/10.5281/zenodo.19286587>

Abstract. This article investigates the use of CAD/CAE systems in additive manufacturing within Uzbekistan's mechanical engineering industry. Based on international examples, it explores how digital design and simulation tools can be integrated with modern 3D printing technologies. The research highlights practical benefits such as improved efficiency, reduced costs, and higher product quality, supported by examples from global practice. The study also considers the potential impact of adopting these technologies in Uzbekistan, including opportunities for innovation, increased competitiveness, and sustainable industrial development.

The findings provide recommendations for local enterprises and policymakers on how to effectively implement advanced manufacturing technologies while addressing local challenges.

Keywords: CAD/CAE systems, Additive manufacturing, Mechanical engineering, 3D printing, Industrial digitalization, Technology adoption, Uzbekistan.

Аннотация. В данной статье рассматривается применение систем CAD/CAE в аддитивном производстве в машиностроительной отрасли Узбекистана. На основе международного опыта анализируется, как инструменты цифрового проектирования и моделирования могут быть интегрированы с современными технологиями 3D-печати.

В работе выделяются практические преимущества, такие как повышение эффективности, снижение затрат и улучшение качества продукции, что подтверждается примерами мировой практики. Также рассматривается потенциальное влияние внедрения этих технологий в Узбекистане, включая возможности для инноваций, повышения конкурентоспособности и устойчивого развития промышленности.

Результаты исследования содержат рекомендации для местных предприятий и органов власти по эффективному внедрению передовых производственных технологий с учётом местных особенностей.

Ключевые слова: системы CAD/CAE, аддитивное производство, машиностроение, 3D-печать, цифровизация промышленности, внедрение технологий, Узбекистан.

Introduction

Additive manufacturing (AM), or 3D printing, enables layer by layer production directly from digital models, reducing waste and allowing complex geometries. Its use is growing worldwide in aerospace, automotive, and medical industries.

For effective AM, CAD/CAE software is essential [6][8]. Programs like SolidWorks and Autodesk Inventor allow engineers to create precise 3D models and run simulations to optimize designs before printing. In Uzbekistan, the adoption of additive manufacturing in the mechanical engineering industry is still emerging, but there are concrete examples of local engagement with these technologies. One notable initiative is the INNO Innovative Educational and Production Technopark in Tashkent, which hosts modern production facilities equipped for additive manufacturing and other high tech processes. The park supports education, prototyping, and innovation projects, providing students and startups with access to advanced equipment and real world experience.

Additionally, Uzbekistan has seen growth in commercial 3D printing services, with dozens of companies offering 3D printing solutions across major regions such as Tashkent, Andijan, and Namangan, indicating an expanding ecosystem of AM capabilities. Beyond educational environments, earlier initiatives at technology parks such as Yashnabad included local 3D printer production and robotics, demonstrating nascent industrial application and technological development in the AM sphere. International studies show that integrating CAD/CAE tools with AM accelerates design, reduces errors, and lowers production costs. European and North American manufacturers use this combination for rapid prototyping, custom components, and reduced tooling expenses, highlighting the importance of software selection and skilled personnel for successful adoption. This study analyzes the role of CAD/CAE systems in supporting additive manufacturing in Uzbekistan, reviews relevant software, evaluates local implementation, and draws lessons from international experience to provide practical recommendations.

Materials and Research

The study combines practical experience, software capability analysis, local implementation cases in Uzbekistan, and benchmarking of additive manufacturing (AM) markets in advanced industrial economies to draw lessons for Uzbekistan's mechanical engineering sector.

For CAD/CAE software evaluation, the analysis focuses on the functional capabilities of tools widely used in AM workflows: SolidWorks, Autodesk Inventor, Fusion 360, and ANSYS Additive Suite. These systems support 3D design, simulation, topology optimization, and generation of AM ready files compatible with slicer software such as Ultimaker Cura [18][20].

During my exchange semester at TUHH (Hamburg University of Technology), Germany, as part of the ECIU Challenge: Agile Methodologies to Engineering Design, I designed mechanical components in Autodesk Inventor, prepared them for 3D printing in Cura, and produced functional prototypes on a desktop 3D printer. This experience highlighted the importance of CAD model accuracy, correct slicing settings, and iterative testing for successful AM implementation [1][2]. To contextualize local adoption, data were collected about Uzbekistan's emerging AM ecosystem, including access to 3D printers and training at the INNO Innovative Educational and Production Technopark in Tashkent and emerging commercial service providers in Tashkent, Andijan, and Namangan [20]. International benchmarking focused on two advanced AM markets: Germany and the United States.

Table 1. CAD/CAE Software Capabilities for Additive Manufacturing

Software	3D Modeling	Simulation & Analysis	Topology Optimization	AM File Export	Typical Use in AM
SolidWorks	High	Medium	Basic	Yes	Mechanical prototypes, educational use
Autodesk Inventor	High	Medium	Basic	Yes	Student projects, industrial prototyping
Fusion 360	Medium	Medium	Basic	Yes	Collaborative cloud design
ANSYS Additive Suite	Medium	High	Advanced	Yes	Metal AM, stress-critical components

Table 1 shows that mainstream CAD tools like SolidWorks and Autodesk Inventor deliver high capabilities for 3D modeling and are well suited to mechanical engineering design and prototyping workflows, which aligns with their widespread use in industry education and early AM adoption. Fusion 360, with its collaborative cloud features, supports distributed design teams and integration with AM workflows in smaller enterprises. ANSYS Additive Suite, while requiring more specialized skills, delivers advanced simulation and topology optimization that are valuable in metal additive manufacturing and for components with complex load requirements; this suggests a technology pathway where basic CAD tools are used for initial design and rapid prototyping, while advanced CAE tools support more demanding applications in industry.

International AM market data further inform comparative analysis. According to market research, the Germany additive manufacturing market generated approximately USD 2.21 billion in revenue in 2023 [15], and is projected to grow to USD 10.24 billion by 2030 at a 24.5 % compound annual growth rate (CAGR) [2][6], reflecting strong market expansion. Germany's manufacturing sector is highly engaged with AM; around 44 % of industrial companies with more than 100 employees already use 3D printing technologies for prototypes, tooling, spare parts, and visual models, illustrating widespread industrial adoption beyond experimental use and aligning with Germany's leadership in metal AM systems and research networks such as the Fraunhofer Competence Field Additive Manufacturing. In the United States, additive manufacturing generated approximately USD 4.26 billion in 2023 and is expected to reach around USD 16.48 billion by 2030 at a 21.3 % CAGR [2][8], reflecting rapid adoption across aerospace, automotive, and healthcare industries driven by demand for lightweight, complex parts and benefits such as reduced lead times and supply chain flexibility. These figures indicate significant global investment and adoption of AM technologies, with both markets showing multibillion dollar growth and industry wide integration that can serve as benchmarks for Uzbekistan's industrial strategies.

Table 2. Additive Manufacturing Market Indicators (Germany & USA)

Country	Market Size (2023)	Projected (2030)	CAGR (%)	Industrial Adoption Indicators
Germany	~USD 2.21 billion	~USD 10.24 billion	24.5 %	~44 % industrial firms use AM
USA	~USD 4.26 billion	~USD 16.48 billion	21.3 %	High adoption in aerospace & automotive

Germany’s market is projected to nearly quintuple by 2030, indicating deep industrial integration and increasing use of AM for functional parts beyond prototyping. The USA’s AM market is expected to grow approximately fourfold, demonstrating a shift from prototyping to industrial production and maintenance applications. These figures suggest that Uzbekistan could achieve similar benefits by combining CAD/CAE adoption, workforce training, and targeted investment in AM technologies.

Results and Discussion

The mechanical engineering industry in Uzbekistan historically relied on traditional manufacturing methods, including casting, milling, and conventional welding. Data from local industry reports indicate that before the introduction of additive technologies, production of a standard mechanical component could take 2–4 weeks, with material waste of approximately 15–20 % per batch. With the initial introduction of additive manufacturing at educational and experimental facilities, such as the INNO Technopark in Tashkent, students and startups have begun producing prototypes and small batches using 3D printers. Lead times have decreased to 2–5 days for small parts, and material efficiency has improved, with waste reduced to 5–7%. Additive technologies allow

rapid iteration, easy customization, and integration with CAD/CAE workflows, while challenges include limited availability of industrial-scale printers, high cost of materials, and insufficient trained personnel. In the future, as AM becomes integrated into industrial enterprises, Uzbekistan could benefit from faster production cycles, reduced costs, and higher product complexity, with potential expansion into metal 3D printing for spare parts, tooling, and lightweight components.

Table 3. Uzbekistan Mechanical Engineering: AM Adoption Stages and Impact

Stage	Production Methods & Characteristics	Lead Time	Material Waste	Benefits	Challenges
Before AM	Casting, milling, welding; low customization	2–4 weeks	15–20 %	Established processes, known quality	Long cycles, high waste, low flexibility
Initial AM Implementation	Small-scale 3D printing in educational labs and startups	2–5 days	5–7 %	Rapid prototyping, iterative design, learning	Limited printers, high material cost, lack of skilled personnel

Stage	Production Methods & Characteristics	Lead Time	Material Waste	Benefits	Challenges
Future Industrial Integration	Industrial-scale 3D printing integrated with CAD/CAE	<1 week	<5 %	Fast production, customization, complex parts	Investment required, workforce training, supply of materials

This table demonstrates that even at the early stage of AM adoption, Uzbekistan’s mechanical engineering sector shows measurable improvements in lead time and material efficiency. The practical benefits are evident in reduced development cycles, enhanced prototyping capabilities, and improved product flexibility. Challenges remain in scaling to industrial levels. If these challenges are addressed, the future scenario suggests significant productivity gains, reduced costs, and higher competitiveness.

Conclusion

This study demonstrates that the integration of CAD/CAE systems with additive manufacturing can significantly enhance the mechanical engineering industry in Uzbekistan.

My practical experience at TUHH, using Autodesk Inventor and 3D printing with Cura, confirmed the benefits of combining digital design with rapid prototyping. Current local initiatives, such as the INNO Technopark in Tashkent, show that initial adoption of AM reduces lead times, improves material efficiency, and enables iterative design processes. Comparative analysis with Germany and the USA indicates that early integration of AM technologies, combined with skilled personnel and advanced CAD/CAE tools, leads to faster innovation, reduced production costs, and higher industrial competitiveness. Challenges for Uzbekistan remain in scaling AM to industrial production, ensuring material supply, and providing workforce training. Overall, a gradual, structured adoption of additive technologies supported by software integration, education, and strategic investment has the potential to transform Uzbekistan’s mechanical engineering sector, aligning it with global trends and improving productivity, flexibility, and product complexity.

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