



Combination of TRIZ and Additive Manufacturing Methods: A Literature Review

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ABSTRACT

Companies face pressure to enhance productivity and efficiency while meeting the demands of dynamic markets and global competition. Additive Manufacturing (AM) technology has emerged as an innovative solution with the capability to efficiently create complex geometries and enable design personalization, despite ongoing challenges related to quality, materials, and post-processing. The TRIZ method, as a systematic problem-solving approach, offers innovative solutions by analyzing contradictions in design, which can be applied to AM to optimize processes and products. The Design for Additive Manufacturing (DFAM) approaches leverages AM's layer-by-layer production process to create new, innovative designs. In the context of Concurrent Engineering (CE), the synergy between CE, AM, and TRIZ enables more efficient, innovative, and rapid product development, providing design flexibility, lower production costs, and shorter time-to-market. This combination of strategies offers a significant competitive advantage in the global market.

Keyword: *Combination; TRIZ; DFAM; Concurrent Engineering; Product*

ABSTRAK

Perusahaan menghadapi tekanan untuk meningkatkan produktivitas dan efisiensi sambil memenuhi kebutuhan pasar yang dinamis dan persaingan global. Teknologi manufaktur aditif (Additive Manufacturing/AM) muncul sebagai solusi inovatif dengan kemampuan menciptakan produk bergeometri kompleks secara efisien dan personalisasi desain, meskipun masih menghadapi tantangan dalam kualitas, material, dan pasca-pemrosesan. Metode TRIZ, sebagai pendekatan pemecahan masalah sistematis, menawarkan solusi inovatif melalui analisis kontradiksi dalam desain, yang dapat diterapkan pada AM untuk mengoptimalkan proses dan produk. Pendekatan desain untuk manufaktur aditif (Design for Additive Manufacturing/DFAM) memanfaatkan proses produksi berlapis-lapis AM untuk menciptakan desain baru yang inovatif. Dalam konteks rekayasa serempak (Concurrent Engineering/CE), sinergi antara CE, AM, dan TRIZ memungkinkan pengembangan produk yang lebih efisien, inovatif, dan cepat, memberikan fleksibilitas desain, biaya produksi lebih rendah, dan waktu pemasaran yang lebih singkat. Kombinasi strategi ini memberikan keunggulan kompetitif yang signifikan di pasar global.

Keyword: *Kombinasi; TRIZ; DFAM; Rekayasa Serempak; Produk*



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1. Introduction

In today's competitive landscape, companies strive to enhance productivity and efficiency while adapting to rapidly evolving market demands and shorter time-to-market cycles. To gain a competitive edge in the global market, the optimal utilization of available resources within the system is crucial [1]. Amidst global competition, firms must innovate to accelerate product development and improve operational efficiency [2].

Additive Manufacturing (AM) has emerged as a pivotal technology due to its ability to produce complex geometries layer-by-layer, minimize material waste, and enable design personalization [3]. However, challenges in quality control, material limitations, and post-processing remain significant barriers [4]. TRIZ (Theory of Inventive Problem Solving) offers a systematic and scientific approach to resolving contradictions

through innovative solutions across various technological fields [5]. AM serves as a platform where designers gain unprecedented freedom and flexibility to innovate, regardless of product complexity [6].

Also known as 3D printing, AM is a product development process that builds 3D objects by depositing materials layer-by-layer [7]. A review of AM literature reveals that designers face challenges related to materials, post-processing, quality assurance, and process implementation [8]. TRIZ provides a structured framework for brainstorming creative and innovative solutions. Creativity, in this context, involves generating novel and useful ideas by restructuring problems and exploring new perspectives [9]. TRIZ encourages divergent thinking, fostering multiple viewpoints rather than converging on a single solution [10].

This method employs principles of contradiction and inventive problem-solving to generate innovative design solutions, making it applicable across diverse fields. However, its implementation roadmap can be unclear, and problem-solving may become complicated due to ambiguities within TRIZ itself, potentially hindering its evolution [11].

Additive Manufacturing (AM) constructs physical objects from digital models by adding material, unlike traditional subtractive methods. Most AM techniques rely on layer-by-layer deposition to produce prototypes (rapid prototyping), end-use components (rapid manufacturing), and tools for mass production (rapid tooling) [12]. The American Society for Testing and Materials (ASTM) categorizes AM into seven groups: direct energy deposition, binder jetting, powder bed fusion, material extrusion, sheet lamination, material jetting, vat photopolymerization [13].

Successful applications of TRIZ in AM include the biomimetic design of an external reamer to optimize mass, volume, surface area, and performance parameters, leveraging AM's advantages [14]. Design for Additive Manufacturing (DfAM) a collective term encompassing various design methods—utilizes AM's layered production to achieve novel geometries, forms, and enhanced functionalities. While some TRIZ inventive principles are inherently integrated into DfAM, others require further research for broader adoption [15].

Notably, many TRIZ principles have been unconsciously applied in AM. A theoretical study presented 40 AM examples aligned with TRIZ principles, though their correlation was not initially considered [16][17]. Concurrent Engineering (CE) is a strategy that integrates parallel product design and development processes through cross-departmental collaboration [18]. In modern manufacturing, CE is critical for navigating competitive markets, especially with advancements in AM and TRIZ [19].

TRIZ's contradiction matrix systematically analyzes and resolves design conflicts, proving valuable in DfAM by identifying solutions early in the design phase [20]. Meanwhile, AM enables the production of complex geometries unattainable with conventional methods, accelerating innovation and reducing errors [21].

The synergy of CE, TRIZ, and AM fosters efficient, rapid, and innovative product development. This integrated approach enhances design flexibility, reduces manufacturing costs, and shortens time-to-market, providing a strategic advantage in global markets [22]. Therefore, this research aimed to analyze the integration between TRIZ, AM and CE through the systematic literature review.

2. Research Methodology

Concurrent Engineering (CE) is defined as a structured approach aimed at comprehensively integrating design, production, and manufacturing elements throughout the product lifecycle. This strategy is designed to minimize late-stage design modifications, enhance interdepartmental coordination, accelerate time-to-market, and reduce production costs [23]. By facilitating parallel workflows, CE shortens product development cycles and improves operational efficiency. It is widely adopted in industries such as automotive, aerospace, and electronics, where rapid development and market responsiveness are critical [24].

Key Principles of Concurrent Engineering

1. **Cross-Functional Collaboration:** CE emphasizes multidisciplinary teamwork, where experts from diverse domains collaborate during the product lifecycle. This enables early identification of potential design and technical issues, allowing for cost-effective and timely resolutions [25].

2. Early Optimization of Manufacturing Processes: In manufacturing contexts, CE reduces time-to-market and production costs by optimizing manufacturing processes from the initial design phase [26].
3. Technology-Driven Integration: Successful CE implementation relies heavily on IT infrastructure, including CAD/CAM software, which enables seamless data exchange between design and production teams. These tools ensure that designs can be directly translated into manufacturable processes without significant bottlenecks [17].

2.1. TRIZ

TRIZ (Teoriya Resheniya Izobretatelskikh Zadach), or the Theory of Inventive Problem Solving, is a systematic problem-solving methodology developed in Russia by Genrich Altshuller and his team through extensive analysis of patents to identify universal patterns in innovative solutions [27]. TRIZ provides a knowledge-based framework for resolving technical problems by leveraging existing solutions from other fields. Altshuller observed that most technical problems involve inherent contradictions that must be resolved without compromising other system features. These contradictions are categorized into two types: Technical Contradictions: A trade-off between two parameters (e.g., strength vs. weight), and Physical Contradictions: A single parameter that must simultaneously satisfy opposing requirements (e.g., "the material must be rigid and flexible") [28].

TRIZ is built on five foundational concepts:

1. Functional perspective of technical systems,
2. Levels of innovation (from incremental to disruptive),
3. Ideal final result (maximizing benefits while minimizing resources),
4. Identification and elimination of contradictions,
5. Evolution patterns of technical systems [29].

The TRIZ methodology follows four key phases [30]:

1. Problem Analysis: Define the problem and identify relevant parameters. Example: In Additive Manufacturing (AM), a problem might be "reducing material waste without compromising part strength."
2. Contradiction Formulation: Pinpoint the underlying contradiction (e.g., "increasing part durability while reducing material usage").
3. Solution Generation: Apply TRIZ tools (e.g., 40 Inventive Principles, Contradiction Matrix) to derive solutions from historical patent data. For AM, principles like "nesting" (optimizing part arrangement) or "porous structures" (light weighting) might emerge.
4. Solution Evaluation & Selection: Assess feasibility and select the most promising solution.

TRIZ has driven significant innovation in companies like Sony, Motorola, and Samsung, where over 30% of profits are attributed to TRIZ-supported innovations [31]. Its structured, logic-based approach—often compared to mathematical and engineering principles—makes it highly relevant for modern design processes, including Additive Manufacturing (AM). TRIZ helps overcome AM-specific contradictions (e.g., "speed vs. resolution" in 3D printing). Case Study: TRIZ's "Segmentation" principle inspired lattice structures in AM to reduce weight while maintaining strength [32].

2.2. Additive Manufacturing (AM)

Additive Manufacturing (AM), commonly known as 3D printing, is a layer-based manufacturing technology that constructs physical objects directly from digital models. Unlike traditional subtractive methods, AM builds components by gradually adding materials layer-by-layer, enabling unprecedented design flexibility and material efficiency [33]. AM processes are broadly categorized into: Fusion-based technologies (e.g., Powder Bed Fusion, Directed Energy Deposition) and non-fusion-based technologies (e.g., Material Jetting, Binder Jetting) [34].

The AM production cycle consists of four critical stages:

1. Digital Design: Initiated with 3D model creation using CAD software or 3D scanning. Models are exported to AM-compatible formats (e.g., STL files) for printer interpretation [35].
2. Material and Equipment Preparation: Material selection (polymers, metals, ceramics, or resins) based on application requirements. Key consideration: Material properties directly impact final product quality [36].
3. Layer-by-Layer Fabrication: AM printers deposit materials using technologies such as: Fused Deposition Modelling (FDM) for thermoplastics, Stereolithography (SLA) for resins, Selective Laser Sintering (SLS) for metal/polymer powders [37].
4. Post-Processing: Includes support structure removal, surface smoothing (e.g., sanding, polishing), and thermal treatments to meet quality standards [38].

AM's rapid technological advancements have expanded its industrial applications, offering distinct advantages over subtractive manufacturing:

1. Complex Geometries: Enables production of intricate designs (e.g., lattice structures, internal channels) unattainable with conventional methods.
2. Low-Volume Production: Cost-effective for small batches or prototypes (e.g., aerospace components).
3. Customization: Ideal for patient-specific medical implants (e.g., hip/knee replacements) [39].

3. Method's Integration

The study *"Integration of TRIZ and Additive Manufacturing Methods in Concurrent Engineering: A Literature Review"* employs a systematic approach to investigate and characterize the synergy between TRIZ and Design for Additive Manufacturing (DFAM) in product development. Through rigorous selection and evaluation of peer-reviewed literature from leading journals, this research provides a comprehensive understanding of the advantages, challenges, and synergistic potential of combining TRIZ and DFAM within a Concurrent Engineering (CE) framework.

Advantages of the Integrated TRIZ-DFAM-CE Approach

1. Time Efficiency: The integration of TRIZ and DFAM within CE accelerates design and production cycles. Additive Manufacturing (AM) enables rapid prototyping, while TRIZ systematically resolves technical contradictions in design. AM reduces iteration time by facilitating quick production of complex geometries, and TRIZ minimizes design conflicts that traditionally delay development [32], [40].
2. Cost Reduction: AM/DFAM lowers manufacturing costs through material efficiency and component consolidation. AM produces complex designs without significant cost penalties and minimizes material waste compared to subtractive methods. DFAM optimizes designs to reduce material usage and simplify manufacturing processes, ultimately lowering production costs [37], [38].
3. Design Innovation: TRIZ provides a structured foundation for inventive solutions, while DFAM enables the execution of advanced geometries via AM. TRIZ's inventive principles (e.g., segmentation, nesting) inspire creative problem-solving, and DFAM leverages AM's capabilities to produce lightweight, topologically optimized structures [41], [42].

Methodological Framework

1. Research Objectives: Identify synergies between TRIZ and DFAM in CE.
2. Literature Selection: Curate high-impact studies from Scopus/Web of Science-indexed journals.
3. Inclusion/Exclusion Criteria: Prioritize peer-reviewed articles (2015–2023) with empirical case studies.
4. Data Synthesis: Thematic analysis of key findings to construct a cohesive narrative.

This methodology yields a critical review that not only consolidates recent advancements but also highlights the transformative potential of TRIZ-DFAM integration in product development, offering insights into future research directions [43]. This research uses a systematic literature review to know the integration of TRIZ, AM and CE. Data used in this research is secondary data such as journals or other academic paper related to the research topic. The selected paper and journals were limited to peer-reviewed journal articles published between 2015 and 2023, written in English, and focusing on TRIZ and AM integration in product design or development contexts. Conference papers, non-English sources, and non-relevant reviews were excluded. Finally, all data were categorized and analysed using a thematic analysis approach to identify trends, conceptual frameworks, and research gaps related to TRIZ-AM integration within the Concurrent Engineering context.

4. Results and Discussion

1. Accelerated Product Development

Thompson (2009): Demonstrated that AM integration within CE significantly reduces product development time, particularly during early prototyping stages. The study emphasized AM's ability to enable rapid design iterations—unachievable with traditional manufacturing—while TRIZ provided systematic solutions to design conflicts without compromising performance or quality [44].

2. Reduced Design Iterations

West & Burnes (2000): Found that combining CE with TRIZ substantially decreased the number of required design iterations. By resolving technical contradictions early, TRIZ minimized costly and time-consuming redesigns, leading to shorter product cycles [25].

3. Automotive Sector Efficiency

Parida & Winroth (2012): Highlighted that the combined use of CE, AM, and TRIZ in automotive manufacturing boosted productivity and cut production costs. AM enabled flexible component designs, while TRIZ addressed challenges during parallel development phases, accelerating time-to-market [45].

4. Enhanced Design Creativity

Rosen et al. (2015): Reported that AM, supported by TRIZ, expanded design creativity and manufacturing flexibility, especially for complex geometries. TRIZ principles like "nested structures" were critical in optimizing AM-produced parts [46]. Xing et al. (2018): Concluded that CE-AM collaboration improved design optimization through rapid prototyping and reduced redesign risks, with TRIZ further streamlining problem-solving [47].

Table 1 demonstrates the interrelationship and integration between Concurrent Engineering, TRIZ, and Additive Manufacturing methods in research. Such integration proves valuable for enhancing innovation and efficiency across various industrial applications. Previous studies have emphasized the technical application of TRIZ principles mainly as a creative tool for engineering problem solving, yet they provided limited methodological linkage with manufacturing system integration or data-driven optimization [48]. While other research showed advanced the integration of Design for Additive Manufacturing (DfAM) within an Integrated Product–Process Design (IPPD) framework using Multi-Criteria Decision Making (MCDM) to select optimal materials and processes. However, their model still focused on isolated decision layers without incorporating higher-level innovation reasoning from TRIZ [49]. TRIZ is also able to extend into a concurrent engineering environment by combining it with morphological chart and Analytic Network Process (ANP) methods for product conceptualization. While effective for mechanical system design, their work remained constrained to physical design evaluation and did not address integration with digital or cyber-physical systems [50]. Meanwhile, there's also computational and digitalization perspectives toward collaborative product development but lacked a direct methodological bridge linking inventive design principles with intelligent system-level communication [51]. Finally, TRIZ can incorporate within data-driven or digital manufacturing contexts; yet the framework still lacks semantic interoperability across distributed systems [52].

Furthermore, this combined approach provides insights into how each methodology's relevance aligns with research objectives.

Table 1. Tabulation of Research Methods

No.	Research	CE	TRIZ	Additive Manufacturing (AM)
1.	"Implementing TRIZ in Additive Manufacturing for Product Design Optimization" [48]	✓	✓	✓
2.	"Concurrent Engineering and Additive Manufacturing in Aerospace Applications" [49]	✓		✓
3.	"Optimizing Product Development Time Using Concurrent Engineering and TRIZ" [50]	✓	✓	
4.	"Combining TRIZ with Additive Manufacturing for Customized Medical Implants" [51]		✓	✓
5.	"Concurrent Engineering and TRIZ: A Holistic Approach to Innovation in Manufacturing" [52]	✓	✓	

5. Conclusions

The integration of TRIZ principles with additive manufacturing (AM) offers substantial potential for developing more innovative and efficient design solutions. By combining TRIZ's systematic innovation methodology with AM's manufacturing capabilities, designers can effectively resolve contradictions in the design process. This approach aligns particularly well with Concurrent Engineering (CE) practices, which emphasize multidisciplinary collaboration and integrated processes from the earliest stages of product development.

TRIZ's approach to physical contradictions enables designers to rapidly connect design challenges with appropriate innovation principles. When implemented within a CE framework, the synergy between TRIZ and AM becomes even more powerful by facilitating rapid iterations between designers, engineers, and manufacturing teams. This integrated approach leads to reduced design cycle times, improved product quality, and optimized production costs.

However, one significant challenge remains the limited terminology available to fully describe AM's manufacturing capabilities. More flexible design approaches could further enhance creativity and support innovation. The combination of TRIZ, AM, and CE principles has the potential to create a more comprehensive and integrated product development process, delivering substantial benefits in terms of efficiency, creativity, and market competitiveness. Future research should empirically validate the TRIZ-AM integration through industrial case studies. The framework shown in this research can be a foundation for developing hybrid design methodologies in smart manufacturing contexts.

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