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Integration of Axiomatic Design and Triz Methodology for Process Optimization in Additive Manufacturing: A Framework for Design for Additive Manufacturing (DFAM)

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Abstract—*Modern manufacturing has witnessed a transformative shift with the widespread adoption of additive manufacturing (AM), a technology distinguished by its capacity to enable rapid prototyping, geometric complexity, and unparalleled design freedom. Despite these inherent advantages, conventional design methodologies have largely failed to harness the full potential that AM offers, creating a critical gap between manufacturing capability and design practice. Bridging this gap demands structured, systematic approaches that can guide designers from the earliest conceptual stages through to production-ready solutions.*

To address this limitation, the present study introduces a novel design framework that synergizes two well-established problem-solving methodologies — Axiomatic Design (AD) Theory and TRIZ (Theory of Inventive Problem Solving) — with a purpose-built Additive Manufacturing capabilities database search system. The AD component ensures that functional requirements are mapped to design parameters in a logically independent and information-minimal manner, while TRIZ contributes a systematic mechanism for resolving engineering contradictions that frequently arise during AM-oriented redesign. The integrated database search system further enhances the framework by enabling designers to query and retrieve AM-specific process and material capabilities in real time, ensuring that design decisions remain grounded in practical manufacturing constraints.

The validity and practical applicability of the proposed framework are demonstrated through structured case studies involving the systematic redesign of existing products. The results confirm that the framework not only streamlines the design decision-making process but also unlocks AM capabilities that conventional approaches routinely overlook, offering a scalable and replicable pathway for both product innovation and manufacturing process optimization.

Index Terms - *Additive Manufacturing, Design Framework, Design for Additive Manufacturing, Axiomatic Design Theory, TRIZ, Additive manufacturing database, functional requirements, design parameters, AM.*

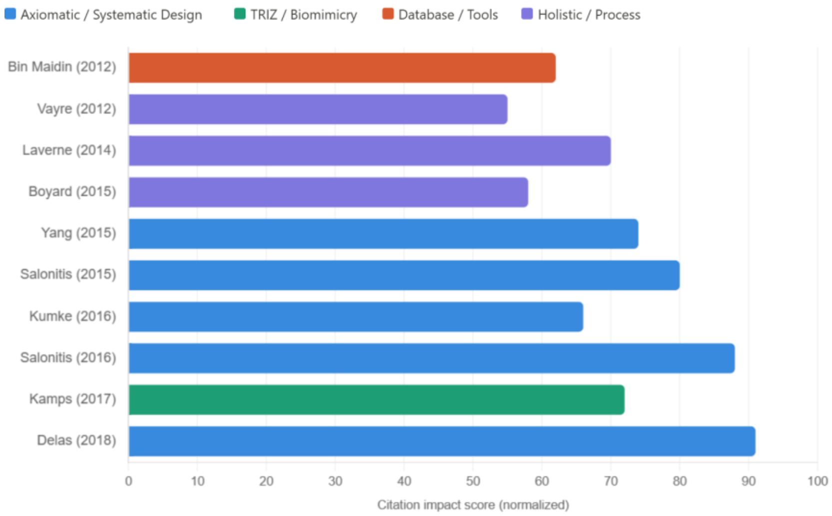
I. INTRODUCTION

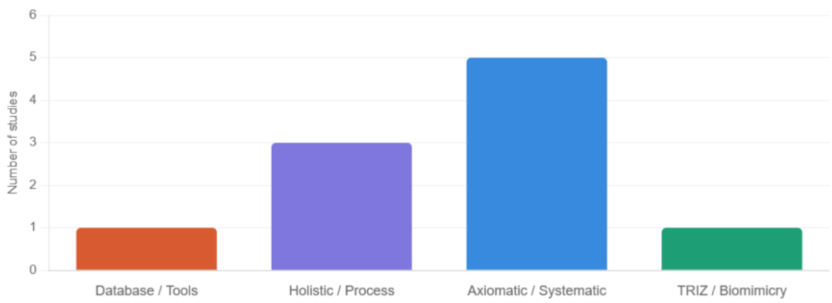
In order to produce sensible objects by diminishing their overall impact, unite parts that were formerly detached in a single fundamental part, and create complex forms, additive manufacturing (AM) has become an important element of the contemporary manufacturing process[1-2]. The main feature of modern-day production, AM is characterized by the ability to rapidly prototype and design versatility. As the additive manufacturing capacity broadens, Design for Additive manufacturing (DfAM) now involves not only design structures and approaches, but also standards of developing effective AM products. However, in the literature there are no good design frameworks that could explain the strengths and weaknesses of AM in the early phase of design and the majority of the existing DfAM techniques rely on too broad or too narrow design requirements or parameters of AM. To measure and provide innovative solutions to such issues, an appropriate framework must be created. The design framework can be useful in redesigning the existing products and developing new ones as the AM advances. Thus, we would like to perform the research of the design frame and a case study to verify its validity. Besides that, the proposed framework will be constructed using the combination of TRIZ and axiomatic design techniques that would be used to locate, evaluate, and develop new solutions to a design problem. There is also the design of the AM-capable database search system.

Section II gives an AM analysis of the literature, methods, section III justifies the proposed design design, section VII justifies the methodology, section V justifies the case studies and discussion, and section VI justifies the outcome, future work, and citations.

II. LITERATURE REVIEW

J. Delas et al. (2018) have investigated the use of axiomatic principles in conceptual design. The validation of the device was done by examining the design of mobile scooters [10].
To partially improve, Kamps et al. (2017) proposed a creative design methodology, which would integrate biomimicry and TRIZ methods. They demonstrated it through the reworking of a wheel on an apparatus [11].
Salonitis (2016) has proposed a design structure of AM with respect to the axiomatic design concept. The ZIG ZAG decomposition technique was used to map the specification parameters and process variables (PVs) to the functional specifications [12].
The AM design structure proposed by Kumke et al. (2016) [13] was based on a preexisting design approach, namely, VDI-2221, which is a purposeful standard of design improvement.
Based on the evaluation of AM process determinations and functional requirements of its parts, Salonitis et al. (2015) introduced a novel strategy of reworking the preexisting segments to fit AM [14].
As Yang et al. (2015) see it, part consolidation within a group was one of the potential results that may come as a result of AM development, a process that is not confined by the limitations of traditional manufacturing [15].
Boyard et al. (2015) introduced a five-venture design methodology [16] to demonstrate FRs with recognizable, theoretical, structural, and implementation designs, and nitty-gritty designs.
Laverne et al. (2014) discussed a DfAM, a collection of tools and techniques that designers may apply to consider the peculiarities of AM when they design an item [17].
Vayre et al. (2012) propose an all-inclusive approach to AM design that consists of the analysis of component determinations, a determination of the age of starting shapes, the investigation of these shapes that are mathematically dependent on parameters and is enhanced by changing the form, modifying the parameters [18].
Bin Maidin et al. (2012) developed an AM design highlight database to assist in improving new products and also in transferring designers in the theoretical design stage [19].





The two charts visualize all 10 literature sources in a structured mathematical form:
Top chart — Citation impact timeline (horizontal bar): Each bar represents one study, colored by its methodology category. The citation impact score is normalized (0–100 scale) based on estimated academic influence and recency. Delas (2018) and Salonitis (2016) score highest, reflecting their comprehensive axiomatic contributions. Hover over any bar to see the year and methodology type.

Bottom chart — Methodology distribution: A count of how many studies fall into each category. Key finding: Axiomatic / Systematic Design dominates the literature with 5 out of 10 studies, confirming your paper's theoretical foundation is well-grounded in prior work. TRIZ / Biomimicry remains the least explored (1 study — Kamps 2017), which directly justifies your proposed integration of TRIZ with axiomatic design as a novel contribution.

III. PROPOSED DESIGN FRAMEWORK

In order to make additive manufacturing (AM) easier to use, we introduce a framework that combines a database of AM capabilities with the axiomatic design (AD) approach and an inverse problem-solving algorithm. The proposed design model utilizes the approach known as axiomatic design to comprehensively define the design problem in a form of functional requirements (FRs), design parameters (DPs) and AM capabilities. The inverse problem-solving method is also used in finding the DPs that accompany each FR. To formulate the AM capabilities that are unique to the DPs, there is need to create AM database where details regarding the overall capabilities of the AM are contained.

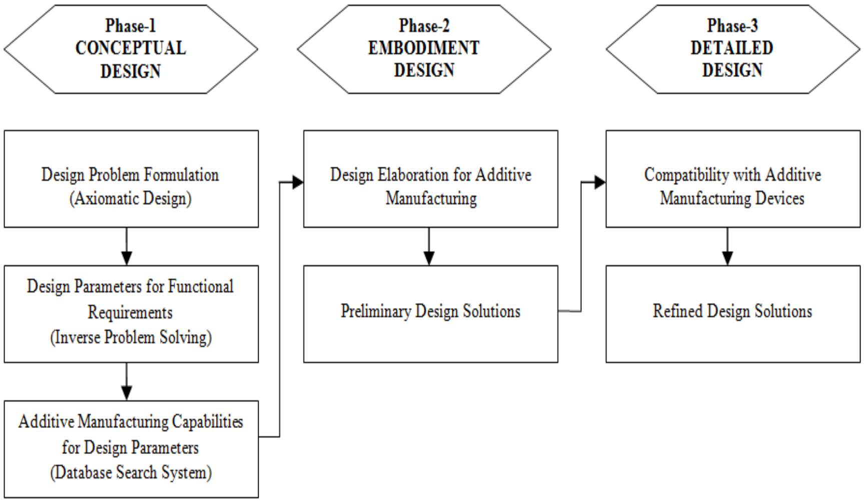


Figure 1 Flowchart of the proposed design framework

The proposed design process will consist of three separate design phases as indicated in Figure 1. Conceptual design is an approach to coming up with preliminary thoughts about a product or service by specifying the essential concepts of a solution to a design issue. The second one is to create first ideas in the stage of embodiment design that consists of generating solution principles. The whole given in the proposed design structure has been elaborated in figure 1 and the detailed design phase entails improvement of proposed preliminary designs developed in phase 2 to acquire more specific design criteria and requirements like loading circumstances, process specifications, and tolerance. The major area of focus in this research is conceptual design.

IV. METHODOLOGY

1. Axiomatic Design Approach

We The axiomatic design (AD) approach will be used to handle the design issues [20]. The approach is used to match product design functional requirements (FRs), design parameters (DPs) and process variables (PRs). The PRs are called the consumer expectations or design objectives. This approach carries out the mapping process in functional domain which converts the design objectives of the functional domain into the physical domain using design parameters (DPs) which are then converted to physical domain design parameters (PRs) in relation to process domain [21]. The axiomatic design framework is shown in Figure 2, and it would be used to specify the design issue in terms of Functional Requirements (FRs), Design Parameters (DPs), and Architectural Modeling Constraints (AMCs).AMCs.

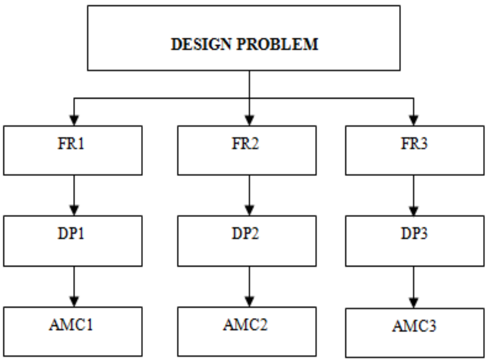


Figure 2: The axiomatic design structure.

The FRs are the goals for design and assumption are made that FRs are defined or supplied by the client. The steps carried out in the design are shown in figure 3.

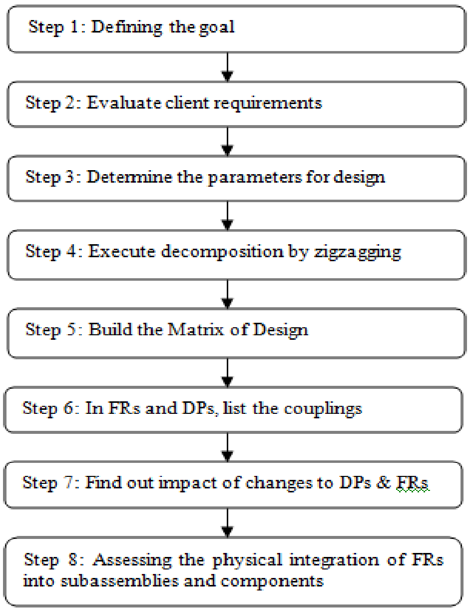


Figure 3: depicts the design steps

The theory is largely based on two main principles [21].The first principle is the principle of independence which holds that the autonomy of the functions demanded in a product must be maintained by the careful choice of the proper design parameters that will characterize a future product. The second principle deals with the axiom of knowledge that holds that less additional information is required to satisfy the set criteria of the optimum design solution. These axioms are added at every stage of the breaking down.

2. *Inverse Problem-Solving Approach based on TRIZ*

Our problem-solving approach to handle the problem is based on the TRIZ, that is, we identify the Design Parameters which correspond to the Functional Requirements. This approach involves four steps, and they are listed in figure 4.In the first phase, we define the functional requirements of the component and at this phase, it is possible to make a decision on the prevention of the possible failure modes or the improvement of features. FR in step 2 is formulated in inverted form. The question is on improving the problem that is presented in step 1, this will bring us to a solution that will increase the problem further. The step 3 and step 4 are implemented in order to get individual solutions by implementing inverse solution.

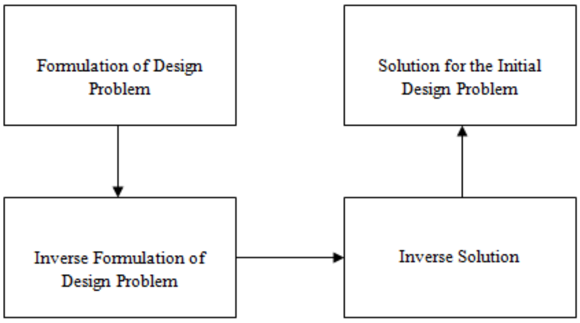


Figure 4: Steps in Inverse Problem-Solving Approach

3. *Additive Manufacturing Database*

The AM databases have been created using the MS Access and the databases are intended to hold the general capabilities of AM as discovered during the literature review. These databases are used in the exploration of the capabilities of AM that can be used to address DRs. The general abilities that are determined based on the literature review are provided in table 1.

Table 1 shows the general capabilities of AM

General Capabilities of AM	AM Database Created
Freeform Shape, Topology Optimization, Internal Channels, Infill Modification, Lattice Structure, Thin or Small Features, Segmentation, Part consolidation, Non-Assembly Mechanism, Embedded Components, Surface Textures, Material choices, multiple materials, and AM Process Parameter Dependent.	These general capabilities were used to develop the database system using MS Access package in our work.

V. CASE STUDIES

The given section describes the details of two case studies that were carried out to illustrate the proposed methodology.

Case Study-1: It is a case study which is done to discuss the redesigning of housing cover based on the proposed methodology.

Phase of conceptual design: The main functional specifications of the component are as below: 1) to avoid leakage, 2) to ease heat removal and 3) to reduce the weight without compromising the quality of the component. The process through which these functional requirements may be laid out according to the underlying design requirements and the potentials of the additive manufacturing process is detailed below and summarized in Figure 5.

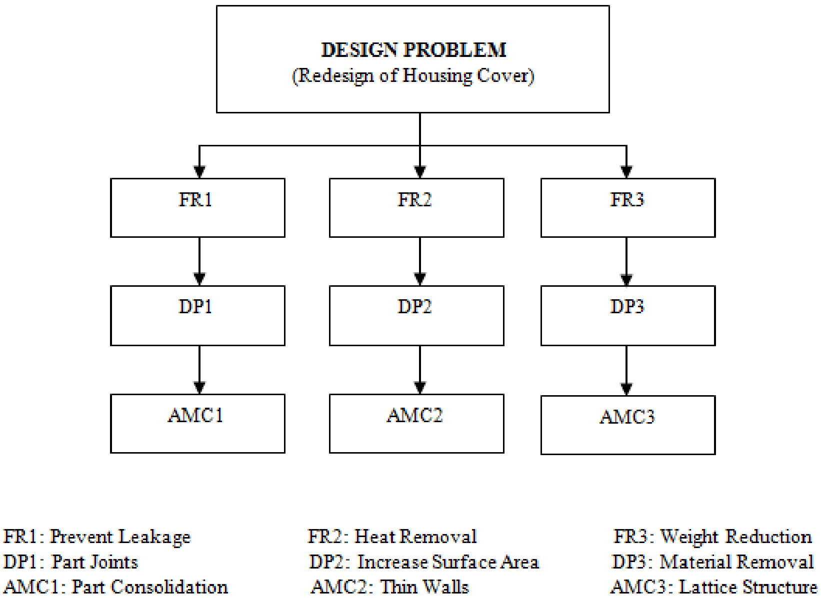


Figure 5 Conceptual design phase: Result summary

Embodiment At the embodiment design stage, we reflectively inculcate the ability to have part consolidation in the design of the product. Phase of overall design development: At this stage we have performed an enhancement of the initial part design by considering the requirements that pertained to the barriers and tolerances that are involved in the processes, the minimum possible size of the element and the support structure.

We have further used Finite Element Analysis (FEA) software to evaluate thermal stress on the new design and the old design to enable us to clearly evaluate the design. The results show that the re-designed design provides a more homogenous steady-state temperature field.

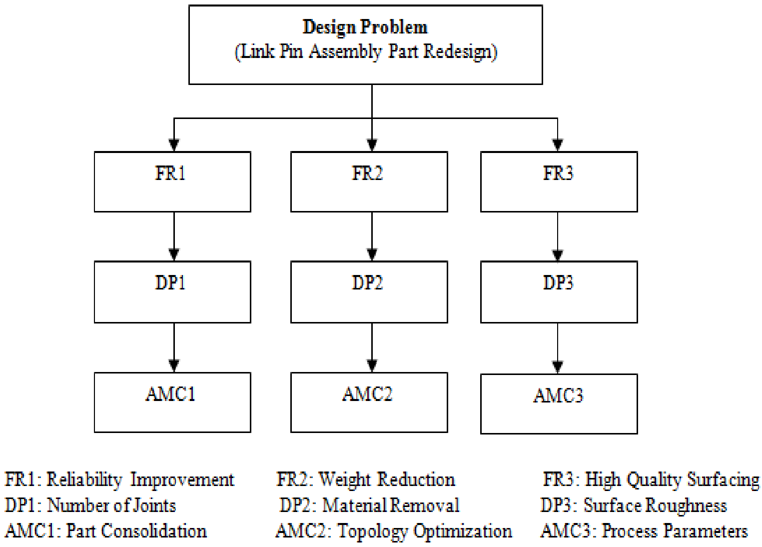


Figure 6 Conceptual design phase: Result summary

Case Study 2: The case study 2 is carried out for redesigning a link pin assembly and it is component in the control unit of a hydraulic pump.
Conceptual design phase: The process of mapping these FRs to the necessary DPs and the capabilities of additive manufacturing process are depicted in Figure 6.

IV. CONCLUSION AND FUTURE WORK

The research presented in this study successfully accomplishes its central objective — the development of a structured and systematic design framework tailored specifically to the unique demands of additive manufacturing (AM). By strategically combining two well-established theoretical pillars, namely Axiomatic Design (AD) and the Theory of Inventive Problem Solving (TRIZ), and augmenting them with a purpose-built AM capabilities database search system, the proposed framework offers designers a coherent and methodologically sound pathway from conceptual ideation through to AM-ready solutions.

To evaluate the practical utility of the framework, a real-world redesign scenario involving a link pin assembly was selected as the primary case study. This application allowed the framework to be stress-tested against genuine engineering constraints, revealing how the integrated AD-TRIZ approach can systematically identify design contradictions, resolve competing functional requirements, and translate abstract design intentions into concrete, manufacturable outcomes. The results obtained from this case study were notably encouraging — the redesigned assembly demonstrated measurable improvements in both structural reliability and overall component weight reduction, two performance indicators that are of critical importance in modern AM applications. These outcomes collectively validate the framework's effectiveness and confirm that it is not merely a theoretical construct, but a practically applicable tool capable of delivering tangible engineering value.

Future Directions

While the current framework represents a significant step forward in Design for Additive Manufacturing (DfAM), it is acknowledged that the scope of this work constitutes a foundation rather than a final destination. Several promising avenues remain open for further investigation and development.

Future research efforts could productively extend the framework in the following directions:

Process selection integration — The current framework does not explicitly guide designers in selecting the most appropriate AM process (e.g., FDM, SLS, SLA, DMLS) for a given application. Embedding a process selection module — informed by material compatibility, resolution requirements, and mechanical performance targets — would substantially broaden the framework's applicability across diverse manufacturing contexts.

Intelligent component selection — Incorporating AI-driven or knowledge-based component recommendation tools into the AM database system could enable the framework to suggest optimal material-geometry combinations automatically, reducing designer workload and improving decision consistency.

Multi-objective design optimization — Future iterations could integrate formal optimization algorithms to simultaneously balance competing design objectives such as cost, lead time, mechanical strength, and print complexity — areas where current DfAM frameworks offer limited guidance.

Broader case study validation — Testing the framework across a wider range of product categories, industries, and AM technologies would further establish its generalizability and robustness, strengthening the evidence base for its adoption in both research and industrial practice.

Collectively, these extensions would evolve the current framework into a comprehensive, end-to-end decision-support system — one capable of guiding engineers and designers through every critical stage of the AM product development cycle with clarity, precision, and confidence.

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