Journal of International English Research Studies (JIERS), ISSN: 3048-5231
Volume 3, Issue 2, April-June, 2025
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# A Design Frame Work for Additive Manufacturing Based on Axiomatic Design and Inverse Problem Solving Approach

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Article history: Received: 26 March 2025, Accepted: 16 April 2025, Published online: 20 April 2025

**ABSTRACT**

**Additive manufacturing (AM) has emerged as an important part of modern manufacturing due to its unique rapid prototyping and design flexibility abilities. These benefits have not utilized by existing design methods and to utilize the full advantage of additive manufacturing several design methods have been investigated. This paper presents the design framework that combines the axiomatic Design and TRIZ with an AM capabilities data base search system. In this paper we present case studies for redesigning of existing product that has been carried out to validate framework.**

**Index Terms - Additive Manufacturing, Design Framework, Design For Additive Manufacturing, Axiomatic Design Theory, TRIZ , Additive Manufacturing Data Base, Functional Requirements ,Design Parameters, AM.**

## INTRODUCTION

Additive manufacturing (AM) has ascended as a key bit of present day manufacturing considering its capacity to fabricate complex shapes to join disengaged parts into one fundamental part, and to make sensible things by diminishing their common effect[1-2]. Because of its unique rapid prototyping and design versatility a capability, AM has emerged as an important part of modern manufacturing. In order to take full advantage of additive technology, Design for Additive Manufacturing (DfAM) has grown to include design frameworks, methodologies and a set of criteria for effective product designs in AM. However, the existing DfAM methods have limitations in that most techniques rely on either too general or too specific design requirements or parameters of AM; there are no suitable design frameworks in literature that can take into account the capabilities and limitations of AM at an early design level. To address these issues a appropriate framework must be designed to evaluate and provide innovative solutions. Also, the design framework can be useful to redesign the existing products and to design new products using advances in AM. Hence, we propose to investigate the design framework and a case study will be carried out to validate the proposed design frame work. Also,the proposed frame work will be designed by combining axiomatic design and TRIZ techniques to identify, evaluate and construct innovative solutions to a design problem. Also, a database search system with AM capabilities will be design.

## LITERATURE REVIEW

J. Delas et al (2018) has been investigated the application of axiomatic design concepts in conceptual design. The validation was carried out through an analysis of design of mobile scooters [10].

Kamps et al. (2017) suggested a technique of inventive design that incorporates biomimicry and TRIZ for partial improvement. They demonstrated via the redesign of an apparatus wheel [11].

Salonitis (2016) has been a design structure for AM using concept of axiomatic design. The mapping of specification parameters and Process variables(PVs) to functional specifications were carried out using ZIG ZAG decomposition method [12].

Kumke et al. (2016) has proposed design structure for AM based on a existing design approach i.e VDI-2221, a deliberate standard for design improvement [13].

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Salonitis et al (2015), proposed a novel technique for redesigning existing segments for AM, by evaluations of determinations of AM process and and its part's functional prerequisites [14].

Yang et al. (2015) discussed the possibilities for part consolidation in a get together, due to the progress of AM, a method that is not constrained by the constraints of customary manufacturing [15].

Boyard et al. (2015) proposed a five-venture design approach and this approach contains proof of FRs with recognizable, theory, structural and implementation design, and nitty-gitty design[16].

A DfAM has been studied by Laverne et al (2014) as a range of techniques and instruments that enable designers to take into account the particularity of AM during an item design phase [17].

Vayre et al. (2012) have suggested an overall design methodology for AM, including analysis of component determinations, age of starting shapes, mathematical parameter dependent investigation of these shapes, and advancement of the form by parameter adjustment [18].

**PROPOSED DESIGN FRAME WORK**

We propose a design of framework on the basis of synergetic utilization of the axiomatic design (AD) approach and inverse problem solving method with additive manufacturing (AM) capabilities database for AM application. Under the proposed design framework the design issue is systematically described in terms of functional requirements (FRs), design parameters (DPs) and capabilities of AM with the use of approach known as axiomatic design. Also, the inverse problem solving approach is used for identifying the DPs that are corresponds to each FRs. The AM database will be created and it provides information on general AM capabilities and it is used to define the AM capabilities corresponding to the DPs.

**Figure**

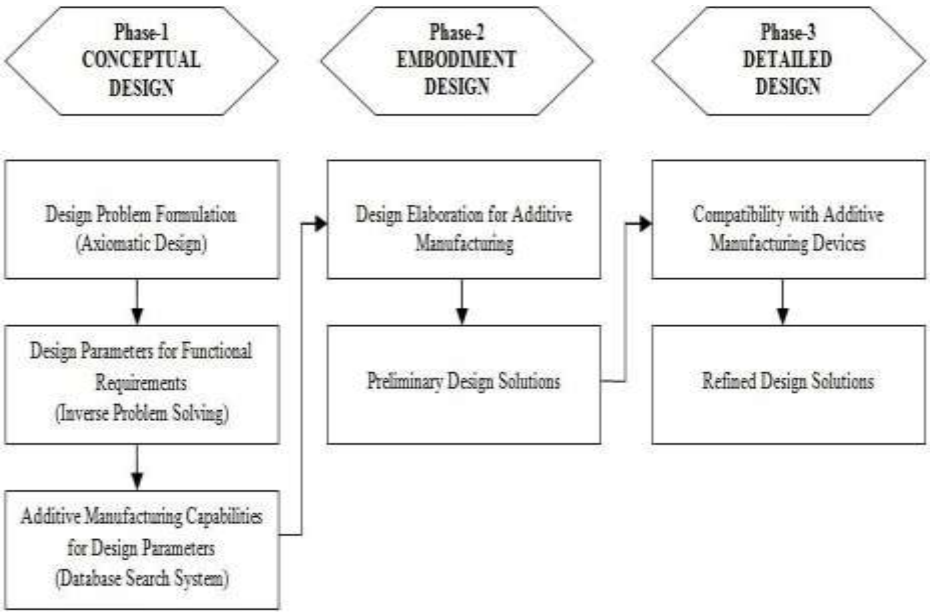


**Figure 1 Flowchart of the Proposed Design Framework**

The design process proposed consists of three design phases as seen in figure 1. In the process of conceptual design the principles of fundamental solution for design problem are described to extract initial design concepts. Then, in embodiment design phase with the elaboration of solution principles preliminary designs are created.

In the detailed design phase the preliminary designs created in phase-2 are refined to obtain more precise design criteria and requirements (such as tolerance, loading conditions, and process specifications), and a detailed description of the proposed design structure is given in figure1. The key focus of this work is on the conceptual process of design.

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## METHODOLOGY

### Axiomatic Design Approach

We will use the principle of axiomatic design (AD) approach for solving the design problems [20]. This methodology is used to interrelate FRs for product design, DPs and process variables (PRs). The PRs are known as consumer expectations or design goals. This approach performs the mapping process in functional domain and it carry out mapping process of design objectives of functional domain in terms of DPs into the physical domain.and then further the mapping of physical domain in terms of PRs into the process domain is carried out [21]. Figure 2 shows the structure of axiomatic design and which is used to describe the design problem in terms of FRs, DPs and AMCs.

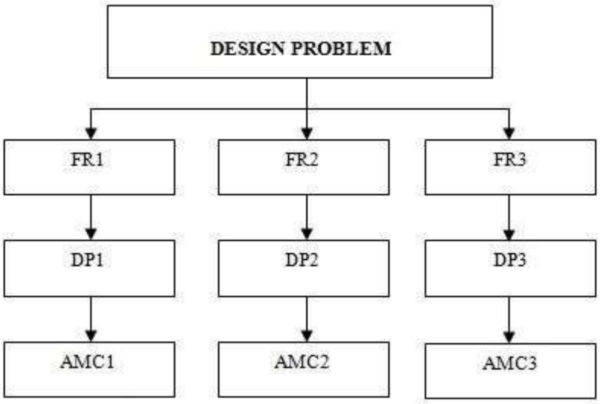


**Figure 2:The axiomatic design structure**

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.

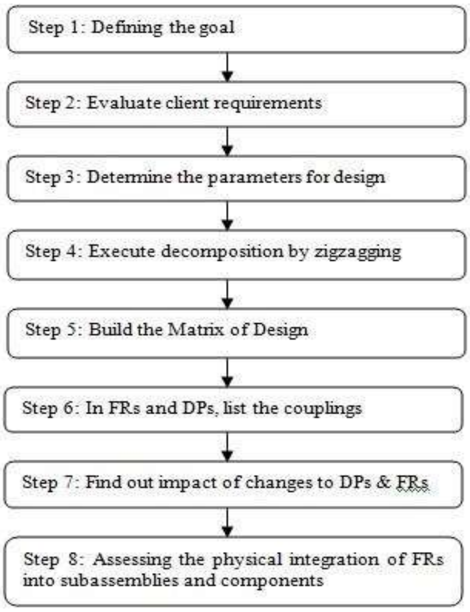


**Figure 3: Depicts The Design Steps**

The theory is based primarily on two axioms [21].The first one is the independence axiom and it states that the independence of the functional specifications requested for a product must be maintained by selecting appropriate DPs which define a later product.

The second one is the axiom of knowledge and it states that less additional information is required to satisfy the specified requirements for the best design solution. At every decomposition point, these axioms are added

### Inverse Problem-Solving Approach based on TRIZ

We use a problem solving approach on the basis of TRIZ to identify the DPs that fit the FRs. This approach ishaving four steps and these are depicted in figure 4.In the first step we formulate FRs of part and the FR s in this step the decision can be made as avoiding of failure mode or improvement in feature. In step 2 the FR is inversely formulated the question is how to amplify the problem in step1 and we obtain its solution that amplifies the initial problem. The step 3 and step 4 are carried out to obtain unique solutions with the use of inverse solution

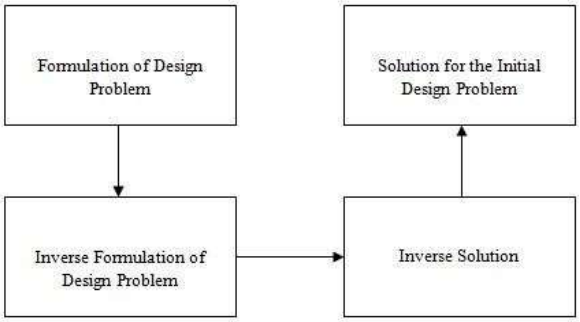


**Figure 4: Steps in Inverse Problem-Solving Approach 3.Additive Manufacturing Database**

The databases for AM were built using MS Access and the databases created are used to store general capabilities of AM identified form the literature review. We use these databases for searching the capabilities of AM that can fulfill DRs. The general capabilities that are identified from literature review are shown in table 1.

### Case Studies

In this section, we present the details of two case studies that are carried out to illustrate the proposed methodology.

**Case Study-1:** The case study 1 is carried out to housing cover redesign with the use of proposed methodology.

Conceptual design phase**:** The main functional requirements (FRs) of the part are**:** 1) to prevent the leakage, 2) to enable heat removal, and 3) to reduce the weight without giving up the quality of the part. The technique these FRs can be mapped to the fundamental DRs and to the capabilities of the additive manufacturing process is appeared underneath and summed up in Figure 5.

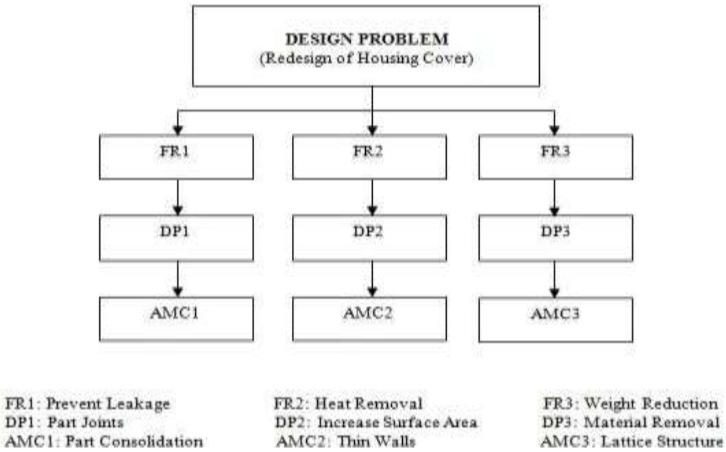


**Figure 5 Conceptual Design Phase: Result Summary**

Embodiment design phase: In this phase, we integrate the "part consolidation" capability into the design of the product.
Detailed design phase: In this phase we have carried out the refinement of preliminary part design by considering the criteria for process constraints and tolerance, the minimum feasible size of the element and the support structure. Further, we have used the Finite Element Analysis (FEA) software to compare thermal loads on new and old designs,

the design is evaluated. The study shows that in the new design, the steady-state temperature distribution is more uniform.

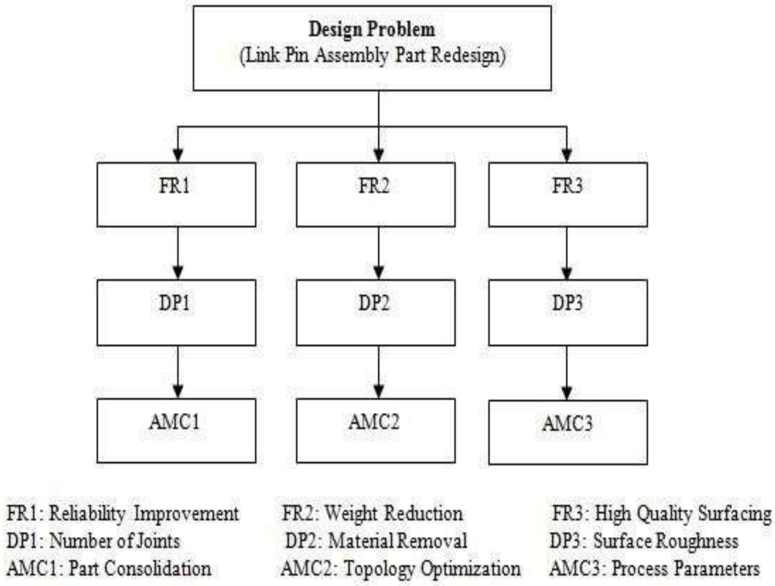


**Figure 6 Conceptual Design Phase: Result Summary**

**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.

## CONCLUSION AND FUTURE WORK

We have successfully carried out the investigation of framework design for additive manufacturing. The framework was design with the use of AD and TRIZ with an additive manufacturing database search system. The methodology was demonstrated with the case study of redesign of link pin assembly. From the results we see that the reliability of part and also weight of the part are improved and design framework is effectively used for AM.

This work can be expanded by considering additive manufacturing conditions such as process selection, component selection, and optimum design selection.

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