Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 65 (2017) 259 – 266
www.elsevier.com/locate/procedia
3rd CIRP Conference on BioManufacturing

Systematic Biomimetic Part Design for Additive Manufacturing

Tobias Kamps*[a], Melanie Gralow[a], Georg Schlick[a], Gunther Reinhart[a, b]

[a]Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV, Augsburg, Germany
[b] Institute for Machine Tools and Industrial Management (iwb), Technical University of Munich, Garching, Germany

* Corresponding author. Tel.: +49 821 90678 166; fax: +49 821 90678 150 E-mail address: tobias.kamps@igcv.fraunhofer.de

Additive Manufacturing (AM) provides an industrially relevant technology for serial production of complex parts. A layer-wise buildup permits an innovative product design, for instance via functional integration, lightweight design following biomimetic principles. This results in a vast design solution space for product optimization. Exhausting the potential of AM relies on a systematic and economic design phase. The wide range of the design solution space prevents an economic exploitation of design freedom and results in an incomplete part optimization. This leads to an unsystematic design, a cost-intensive and long term trial-and-error part design optimization. This paper presents a systematic design approach. A situative application- and target-oriented TRIZ-based methodology is introduced that incorporates database-enhanced biomimetic part design specifically for AM. Inspired by nature those examples provide a vast design solution space due to an extensive evolutionary development of various optimized systems. The work is concluded with a validation through a case study of a design optimization problem.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on BioManufacturing 2017

Keywords: additive manufacturing; TRIZ; biomimetic design; systematic part design; technical biology

1. Introduction

Designing for Additive Manufacturing (AM) is a challenge, especially for designers that are used to develop parts for conventional manufacturing technologies like casting or machining [1]. Due to a layer-wise buildup of the part instead of a subtractive production process, AM challenges existing design experience and methodologies. By offering a large design freedom, it creates a vast solution space for technical design problems. Thus, to avoid a trial-and-error approach designers rely on tools like design methodologies or software-based approaches in order to create a part [2].

Additively manufactured parts draw their overall economic potential from their superior part performance closely linked to an intelligent part design as well as an economic production of the often times complex part [3]. In order to compete with a conventional design and manufacture, both the part performance as well as the part costs have to be superior in order to provide a worthwhile alternative.

In summary, this makes design for additive manufacturing a high-complexity optimization problem. For a thorough industrial application of AM, a systematic anchoring in design thinking has to take place [4]. This work presents an approach for an integrated part design methodology by employing a TRIZ-based framework (TRIZ: Russian acronym for “the theory of inventive problem solving”), providing a systematic biomimetic part design in order to leverage part performance fully exploiting the design freedom of AM. The approach aims at guiding the user to improve the design thinking away from the existing part to a functional consideration of the problem. This way, innovative designs closely linked to biomimicry are nurtured to evolve. Nature offers excellent conditions for an adaption in TRIZ, since biological systems mostly demand an implementation of contradictory requirements [5] like a light and at the same time high strength structure for plants.

Fig.1 displays a classification of concepts for redesigning a part for AM with different extents of exploitation of the design freedom of AM, leveraging its potential, and the creativity connected.

Peer-review under responsibility of the scientific committee of the 3rd CIRP Conference on BioManufacturing 2017
doi:10.1016/j.procir.2017.04.054

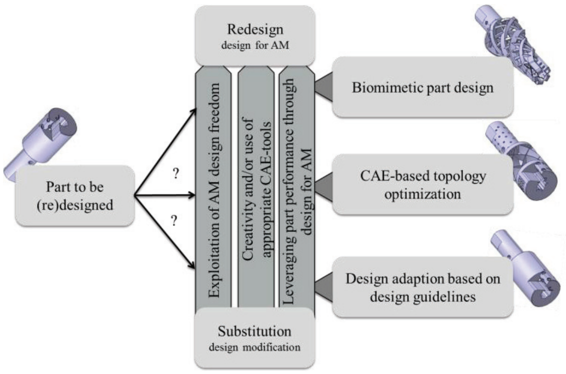

Fig. 1: Approaches for part (re)design depending on the goal of the design optimization using the example of an external reamer, based on [6, 7]

2. State of the art

The focus of this paper is to introduce an application-oriented methodology that systematically uses TRIZ (Russian acronym for "Theory of Inventive Problem Solving") [8] as a methodological framework. Based on the TRIZ-framework, links to biomimicry and design for AM are drawn in order to create a holistic design methodology. Despite a lot of intersecting sets of the three considered disciplines Design for AM, biomimicry, and TRIZ, the exact reasonable intersections have to be identified (shown in Fig. 2). Hence, the disciplines are introduced subsequently.

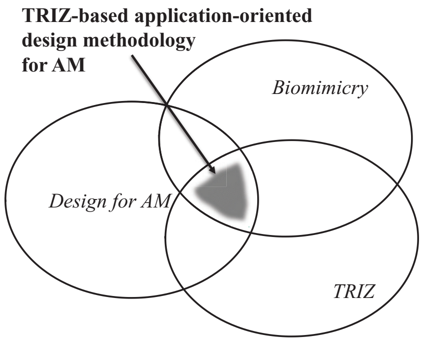

Fig. 2: Display of the scientific disciplines considered, intersecting sets, and the approach presented

2.1. TRIZ

TRIZ was developed to support engineers and natural scientists solving inventive problems by using the knowledge of former inventors [8]. For this purpose, TRIZ offers a comprehensive set of methods to analyze and solve problems by considering different perspectives. Basic approach and central demand of TRIZ is solving inventive problems by its abstraction instead of approaching a direct problem solving [9]. The abstracted problem is solved on an abstract level, which offers possible concrete solutions for the specific problem [10]. The abstract solutions are finally converted into a concrete solution.

In order to overcome technical problems and contradictions, G.S. Altschuller extracted 39 technical parameters and 40 innovative principles from hundreds of thousands of patents [11]. The parameters and principles are comprised in a technical contradiction matrix that serves as an elementary method in TRIZ for systematic problem thinking. TRIZ as a general logic for application of interconnected methods also can be augmented with new methods [9].

Linking it to biomimicry, a project-group at the University of Bath, GB [12, 13] for instance added a methodology to integrate functions and effects of biological systems. 500 biological phenomena were analyzed, which were described by the use of the innovative principles of TRIZ. The results showed a great discrepancy between technical innovative principles provided by TRIZ-standard and nature's innovative principles. Thus, a new contradiction matrix resulting from the innovative principles was formulated. The newly introduced matrix makes working with biological and evolutionary innovative principles for technical problems possible, which is why it is entitled "Bio-TRIZ" [14].

2.2. Biomimicry

Biomimicry aims at using biological analogies in technical systems as a stimulus of innovation [15]. Thus, biomimicry introduces an interface between the disciplines technology and biology, hence, relying on harmonization on both sides. Ideally, biology provides principles and structures that can be employed in technical applications through biomimicry.

Following ISO 18458 [16], AM offers a good opportunity for integration of biomimetic structures because of its advantage "complexity for free", which in general makes a rethinking of the part design process opportune. Transferring the observed biological principle into a technical application by means of abstraction is crucial for the exploitation of the biomimicry potential [17].

So far, only few companies employ the innovative principles of biomimicry due to a shortage of resources. Especially in small and medium size companies, a profound use of biomimicry is not economically possible [18] due to a lack of application-oriented methodological approaches [12, 19]. A systematic integration into an industrial innovation process lacks a substantiated knowledge base.

According to [20], natural design principles can be summarized as direct introduction and compensation of force, maximum moment of inertia and resistance, reinforcement of structures in main direction of load using the support effect of curvature, integral structural design employing fine textures and structural voids, and absolute exploitation of a specific design.

In summary, biomimicry offers a large design space for technical problems and part optimization. However, nature's