A Proposal for a Methodology of Technical Creativity Mixing TRIZ and Additive Manufacturing

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Abstract. The industry has quickly realized the importance of bringing creativity into product design. The industrial context requires robust and efficient methods and tools to access untapped sources of ideas.

Furthermore, Additive Manufacturing (AM) offers a large potential of creativity for product design. This potential is particularly significant at the level of Intermediate Objects. Previous works have demonstrated the interest of AM Intermediate Objects (Rias, 2017) in creativity phases. This new manufacturing process is revolutionizing the value chain associated with product design, from the ideation to the industrialization.

The purpose of this paper is to describe the bases for proposing a methodology of technical creativity based on TRIZ and Additive Manufacturing.

Keywords: TRIZ · Creativity · Design for Additive Manufacturing (DFAM) · Intermediate objects

1 Introduction

In recent years, Additive Manufacturing (AM) has become a major technology in modern manufacturing. It includes all manufacturing processes from an object designed in digital format (CAD) to a physical object; this manufacturing is done layer by layer by adding material. The gradual shift from prototyping to manufacturing of functional parts manufacturing is revolutionizing product design in all areas of industry, particularly in the automotive, aeronautics, aerospace and medical industries.

This technology is totally different from traditional manufacturing processes. Today, however, design teams rely on traditional processes to idealize, design and manufacture a product. A designer has cognitive barriers that will prevent him from innovating with AM processes. The challenge is therefore: how to structure a methodology that will make it possible to overcome these cognitive barriers? The issue is also: which design tools has to be integrated in the methodology?

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Thus, in this article, we will present the structure of a methodology of innovation and creativity by additive manufacturing, using the tool and the way of thinking of TRIZ.

The first part will focus on the literature on additive manufacturing, on Design for Additive Manufacturing (DfAM) and on TRIZ. In the second part, the methodological approach will be presented according to the findings of the work presented in the first part. Then in a last part, we will develop a tool based on the 40 principles of TRIZ and on the capabilities of additive manufacturing.

2 State of the Art

2.1 Design and Manufacturing

This part will help to define additive manufacturing and understand the difference and links between additive manufacturing and other manufacturing processes.

Design

Manufacturing is a technique of transforming or modifying raw materials or basic products into a finished product. This technique is therefore the tool that makes it possible to satisfy product design; that is, to complete and validate the design process. Indeed, design is the process from the identification of the problem to the manufacturing of the product, going through generation of concepts, analysis and evaluation (technical, economic, ergonomic, aesthetic, etc.) [1, 2].

In the literature, there are several design characterizations. Some studies distinguish four types of design from creative design to routine design, with innovative design and redesign in between [1, 3, 4]. The differentiation between creative and innovative design is characterized by the distinction between designs coming from innovative concepts and designs coming from concepts based on knowledge without existing conceptual development. Some authors group these two types into innovative design, but distinguish within this notion, breakthrough innovation and continuity innovation [5]. The definition of redesign is rather vague because it is only a question of making an improvement to the product; therefore, it is not possible to say with this definition if the improvement is an innovative function or not.

In our study, we will work with two types of designs and not with a scale of four designs. These two types of design are [6]:

- Innovative design. It is the set of designs that provides a solution to a problem that has never been solved. It can be a redesign with a new function, as well as a fundamentally new product.
- Routine design. It is the set of designs that is based on solutions already known. Often a routine design is an improvement in response to a competitor's innovative design.

This bipolar distinction will allow us not to differentiate between innovative design and creative design. We will talk about innovative design based on the result of the finished product, and we will talk about a creative approach for the process from problem to solution.

Manufacturing

In the context of a physical product design, manufacturing is a tool for developing the product. There are several types of manufacturing processes (Fig. 1).

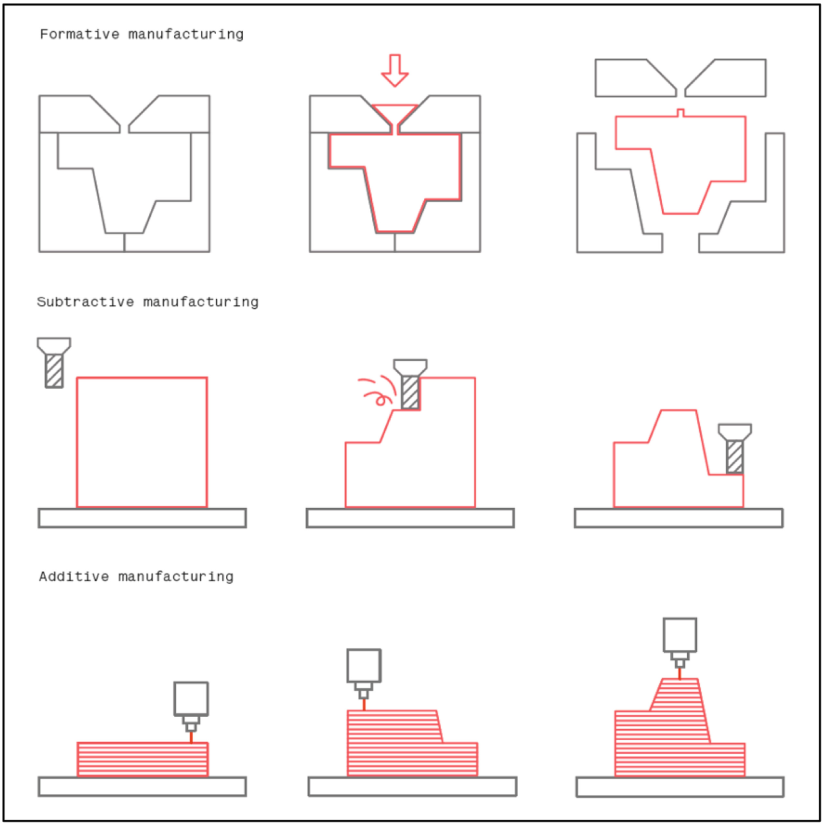

Fig. 1. The three types of manufacturing [6]

Additive manufacturing is a layer-by-layer manufacturing process by adding material; it is a generative manufacturing process. This technology is often referred to with other terms, considered reductive such as 3D printing or layered manufacturing.

Additive manufacturing disrupts traditional manufacturing techniques such as:

- Formative manufacturing: the material is brought into a liquid or viscous state, then the shaping is carried out by flowing this material into a mold (ex: foundry).
- Subtractive manufacturing: The product is made from a raw part on which the material will be removed in order to obtain the desired final shape(ex: machining).

2.2 Design for Additive Manufacturing (DfAM)

In order to operate and leverage additive manufacturing for product innovation, it has become imperative to structure and develop design tools and methods through additive manufacturing for design teams. In order to stimulate creativity through additive manufacturing, the designer needs a tool-based methodology to take into account the specificities of these new manufacturing processes in order to overcome the cognitive barriers printed in the customs and practices of design teams. To this end, several studies are focusing on Design for Additive Manufacturing so as to develop methodological supports that meet the needs of promoting the potential of additive manufacturing.

DfAM is “the set of methodology and tools that help the designer to take into account the specificities of additive manufacturing (technological, geometrical, pre/post processing …) during the design stage” [7]. Despite this definition, which highlights the design phases, many studies are working more particularly on product redesign, i.e. on designing with additive manufacturing an existing product usually build in traditional manufacturing.

Depending on the different approaches of Design for Additive Manufacturing, some authors will propose tools for analysing design problems, while others will rather propose tools for generating ideas.

Works on tools for analysing design problems are based on parametric optimization [8] or axiomatic design [9]. Studies oriented towards tools for generating ideas will instead use databases of additive manufacturing functionalities [10] or associations with intermediate objects during creativity sessions [11].

But current Design for Additive Manufacturing methods have certain limits because they do not take advantage of the potential of additive manufacturing, on creativity and innovation as early as possible in the design and innovation process of a product, at the ideation level. In order to really overcome cognitive barriers, the need to bring a methodology is found at the earliest stage in the design phase, during the phase of creativity and of intermediate object design [11].

2.3 Design with Additive Manufacturing (DWAM)

Laverne et al. propose a methodology adapted from Design with X (DWX): Design With Additive Manufacturing [12]. DWX objective is “to inspire designers and supports them in creating product because DWX focuses on innovations so the product design solutions have always an innovative character” [13]. The purpose of this methodology is therefore to provide designers with knowledge during the design phases and particularly in the upstream phases.

Unlike DfAM, which focuses on additive manufacturing technology, DWAM will expand the solution space by providing designers with new knowledge on additive manufacturing elements and characteristics. The DWAM allows the characteristics of intermediate representations to be linked with characteristics of products designed in additive manufacturing.

The advantage of DWAM is that it can be used in the upstream phases. However, this methodology is not intended to guide designers entirely towards one or more design solutions.

The approach of an innovative design consists in starting: from a problem, analysing this problem to arrive at solutions, then deepening the solutions to arrive at a feasible technical solution. To ensure that a methodology is in the early design phase, it is necessary to define how to introduce tools to benefit from the potential of additive manufacturing during the study of the problem, and not only during the study of the solution. This work on technical problems sends us to the theory of inventive problem solving (TRIZ).

2.4 Inter-methodological Gateway Between TRIZ and DfAM

The TRIZ invention approach consists in modelling the problem to achieve a solution through a solution model [14]. The tools used in TRIZ make it possible to go beyond cognitive limits by directing designers towards research areas to be developed. It is unlike other creative tools, which rather encourage them to deepen their own research areas. The 40 innovation principles guide designers towards innovation axes according to design problems.

Several studies have proposed inter-methodological bridges between TRIZ and other design methods. The work of Durand et al. presents several applications of methodologies that mix TRIZ with other design methods, such as Functional Analysis, FMECA or Quality Function Deployment [15].

In this perspective, it is interesting to look at the literature mixing TRIZ and DfAM. Gross et al. will propose a new TRIZ matrix, specific to additive manufacturing by defining the characteristics of additive manufacturing as the criteria for innovation [16]. This study uses the way of working defined by the TRIZ matrix but does not include any historical notion of the TRIZ theory.

Kretzschmar et al. sought an example for the 40 TRIZ principles in additive manufacturing, focusing both on the characteristics of a product made of additive manufacturing, and those of additive manufacturing processes (material extrusion, vat polymerization, powder bed fusion, material jetting, binder jetting) [17]. The articles from Kamps et al. focus on the intersection of TRIZ, biomimicry and DfAM. In these articles, the authors explain that the designers start with the function of the product and a product with a basic design, then the product is improved through a biomimicry database. The integration of a biomimetic design into the design is carried out through a TRIZ invention process [18].

The work mixing TRIZ and DfAM does not meet the need defined above: to have a methodology at the earliest in the design and innovation phase of a product, at the ideation level. This need will therefore be the challenge of our model.

3 Methodological Approach

3.1 Schematization

A TRIZ application associated with additive manufacturing capabilities can be used as a tool for generating ideas that can then generate innovative solutions to initial design problems. This methodology will force designers to expand their creativity with the technical potential of additive manufacturing. The purpose of using the TRIZ method is to expand this creative potential that designers can exploit.

Figure 2 below shows the schematization of our methodology. We can find all the elements presented in the above parts. The design includes all manufacturing processes, there is a distinction between traditional manufacturing (formative and subtractive) and additive manufacturing.

Within the "design" set, we observe a "creativity" set that corresponds to the innovative design, the rest being the routine design.

In the overall "creativity", one part represents the creative potential of traditional manufacturing and the other part represents the creative potential of additive manufacturing. Today, due to cognitive barriers, only a small part of this potential is exploited by designers. That is, a large part of it is not exploited.

The purpose of the TRIZ tool is therefore to guide designers towards solutions available in this untapped part.

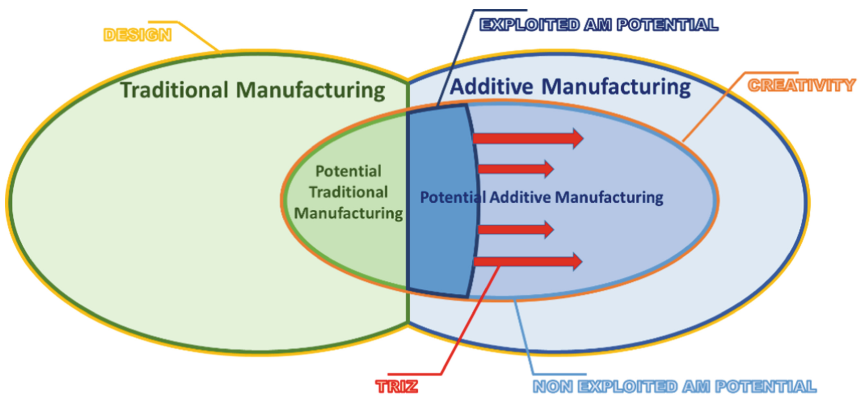

Fig. 2. Schematization of the methodology

3.2 Structuring the Link Between TRIZ and DfAM

In order to guide designers towards additive manufacturing, a link must be created between TRIZ and DfAM.

To create this link, we first focused on the capabilities of additive manufacturing. This technology has unique characteristics (inclusion, cavity, lattice structure…). In 2010, Gibson et al. presented these unique characteristics through four complexities [19]:

- Shape complexity: With additive manufacturing, it is possible to manufacture any shape within the constraints of the printing machine.
- Hierarchical complexity: Additive manufacturing makes it possible to design a product by varying the microscopic structure according to the technical needs of each part of the product.
- Functional complexity: It is possible to manufacture functional devices in a single construction, not just simple parts.
- Material complexity: Additive manufacturing makes it possible to build multi-material parts.

Gibson's four complexities are used as the basis for all DfAM approaches. We have therefore chosen to start from these complexities and compare them with one of TRIZ's tools, the 40 principles of innovation. For each of the principles, a team of eight people defined whether an additive manufacturing application did correspond. This team was composed of complementary profiles: a designer, two ergonomists and five engineers (a TRIZ specialist, two creativity specialists and two AM specialists). The result showed us that the complexity scale was too high to do this study. For functional complexity in particular, the latter includes several capabilities, which it would be more interesting to distinguish from each other.

To achieve a result, we looked at the capabilities of additive manufacturing; that is, the level below the level of complexity.

Based on the literature, we have defined 13 capabilities of additive manufacturing and classified them in relation to Gibson's complexities (see Table 1).

The work of comparing the TRIZ principles with the above capabilities provided more interesting results than with the complexities because the capabilities corresponded to fewer principles each. This work resulted in Table 2.

Two levels of links have been created, the "full" level (represented in red and with "X") and the "partial" level (represented in orange and with "x").

The "full" level was chosen when the capability fully corresponds to the TRIZ principle; i.e. all designs with this characteristic comply with the principle of innovation. When only a part of the designs with a given capability meets a principle, the level is defined as "partial". If no design with a given capabilities corresponds to the principle of innovation, then the box is not checked.

Finally, we note that 10 principles do not correspond to any of the capabilities. Conversely, some principles correspond to several capabilities. For example, the principle of local quality corresponds perfectly to 7 capabilities and partially 4 others.

Table 1. Complexity and capabilities of additive manufacturing

Additive manufacturing complexities	Additive manufacturing capabilities	Definitions
Shape complexity	Free form shapes	Possibility to build almost any shape
	Objects from 3D scans	Possibility to manufacture parts corresponding to scanned objects
Hierarchical complexity	Microstructure variation	The density of the parts can vary according to the porosity choices
	Texture	Possibility to create variant surfaces
Functional complexity	Monoblock	AM reduces the number of parts of a product
	Topology optimization	With finite element analysis, it is possible to integrate it into the AM
	Non-assembled mechanisms	Possibility of making kinematic joints
	Segmentation	Possibility to manufacture the parts separately to create a kit
	Embedded components	Possibility to trap an element in the part during manufacturing
	Internal channels	Possibility to design an internal network during manufacturing
	Infilling	The shapes of the inside of the structure can be adjusted according to the need
	Auxetics structure	Possibility to vary the Poison module of a room thanks to the structure
Material complexity	Material choices	Wide choice of AM materials
	Multi-materials	Possibility to design multi-material parts

3.3 Methodology Integration

We have seen the structure of the methodology through its schematization and the link between TRIZ and DfAM through the correspondence table between the 40 principles of innovation and the 13 capabilities of additive manufacturing.

The challenge now is to integrate this work into creative sessions to observe the results and see if designers will exploit the potential of additive manufacturing and if this method will overcome cognitive barriers.

The use of the TRIZ matrix, during modelling a problem, allows us to guide the designer towards one or more innovation principles. Once the principle(s) have been defined, the TRIZ/DfAM correspondence table will guide the designer towards characteristics specific to additive manufacturing.

Table 2. Table of correspondences between the 40 principles of TRIZ and the capabilities of additive manufacturing

	Shape Complexity		Hierarchical Complexity		Functional Complexity								Material Complexity	
The 40 TRIZ Principles	Freeform shapes	Objects from 3D scans	Microstructure variation	Texture	Monoblock	Topology optimization	Non-assembled mechanisms	Segmentation	Embedded components	Internal channels	Infilling	Auxetic structure	Material choices	Multi-materials
Segmentation			x	x			x	X	x			x		x
Extraction					x	x		x						
Local quality	x	x	X	X		x	X		X	x	X	X		X
Asymmetry	x	x				x					x			
Combination					X		x	x	x					x
Universality							X		x	X	x			x
Nesting			x						X	x				x
Counterweight			x							x	x			x
Prior counteraction														
Prior action		x					x	x	x					
Cushion in advance								x						
Equipotentiality														
Inversion							x							
Spheroidality	x					x					x			
Dynamicity							X		x			X		
Partial, overdone or excessive action				X							x		x	x
Moving to a new dimension	x													
Mechanical vibration														
Periodic action														
Continuity of useful action														
Rushing through														
Convert harm into benefit				x										
Feedback														
Mediator							x	x	x					x
Self-service									x					
Copying	X	X									x		x	
Inexpensive short life		x	x	x		x					x		X	
Replacement of a mechanical system														
Use pneumatic or hydraulic systems									x	x				
Flexible film or thin membranes	x					X		x			x	x		x
Use of porous materials			X						x					
Changing the colour			x										x	x
Homogeneity													x	x
Rejecting and regenerating parts			x	x				x			x			x
Transforming physical or chemical states			X	X					x		x			X
Phase transition													x	x
Thermal expansion									x				x	X
Use strong oxidisers														
Inert environment														
Composite materials									x		x			X

Keys:
- X — The AM capability fully corresponds to the TRIZ principle
- x — Only a part of the designs with a given AM capability meets a TRIZ principle

4 Future Work

The aim of this article was to propose a structure of creativity methodology combining TRIZ and additive manufacturing. Through the literature, we have observed that there is a real need for a methodology, and that it should stimulate the creativity of designers as early as possible in the design process. The use of a methodology at the beginning of the design process best allows designers to overcome cognitive barriers and thus allow them to innovate with the under-exploited additive manufacturing potential.

The creation of a correspondence between TRIZ's innovation principles and the capabilities of additive manufacturing makes it possible to guide the designer towards solution models specific to additive manufacturing.

To go even further upstream in the design process, it would be interesting to start from the notion of physical contradiction. The physical contradiction makes it possible to move more quickly from the problem to the principles of innovation and therefore to the additive manufacturing capabilities.

In addition, the use of terms for additive manufacturing capabilities may limit the creativity of designers. It would therefore be interesting to design intermediate objects beyond the terms that correspond to these capabilities [11]. This would increase the level of creativity.

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