Title:

Development of a Decision Support Tool for Additive Manufacturing

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Introduction

In the NUM3D Platform, we search to integrate the knowledge about possibilities of additive manufacturing processes and characteristics of materials. The development of our various activities has highlighted a new Tetraptic CPMF (Control/Process/Material/Form).

We develop around this knowledge rules, a Decision Support Tool for Additive Manufacturing (DSTforAM) able to determine an optimal solution for the composition of the CPMF based on the predetermined constraint of the requirements specification.

State of art

Our problem is typically multi-criteria optimization; the solution we choose is the utilization of a genetic algorithm.

The concept of this type of algorithm is to make some randomized modifications on the constituent element in a realizable solution. After have making this evolution, we compare the evolved solution and the original solution with some optimization function.

If one or more evolved solutions give better result that the original one, they become the new population who have to evolve.

Otherwise, if none evolved solutions exceed the result of original, then we decide after some iteration that is because the original is already optimal.

The fast and efficient convergence of this type of stochastic algorithm have been study and demonstrate in several works in the 90's [1, 10, 13].

The existence of a multiplicity solution gives always the necessity to make a choice. This necessity bring the need of make a decision. On many problems, this decision is really no trivial and need an in-depth analysis of the situation before to determine the optimal solution.

The analysis of the choice and decision process that we use when we try to solve a problem, have be study in the 50's [7], and this allowed to bring, typically in informatics [11], the development of decision support tool. We identify typical three categories of difficulty for make a decision:

- The optimal result can be in the combinatorial explosion of possible results
- Multi-criteria optimization combine contradictory objective.
- Some criteria don't give recognizable direction for optimization

In our case, the two first difficulty are current and the third can't be ignored.

Problematic and knowledge management:

Our goal is to analyze a manufactured product split into four independent aspects. These aspects are:

- The shape of the object and all its geometric characteristics modeled in 3D = class "Form"
- The constituent materials with their mechanical characteristics = class "Materials"
- The manufacturing processes have achieved the part manufactured with all these specific = class "Processes"
- A method (or more) to enable monitor compliance of the finished product = class "Control"

In the CAD modeling framework (CATIA, SW, PTC ...), we can numerically represent a product based on its shape and constituent material. Therefore, we call “Numerical model” a class consist of two sub-class “Shapes” and “Materials” and which will represent the DFN product. It is not current to define 3D modeling taking into account the means of control or Manufacturing process. Although many studies demonstrate the importance of this integration (Concept DFM) [6], [12] and [9], therefore we associate with the class “Control” and “Processes” (see Fig. 1 Object arborescence in Unified Modelling Language).

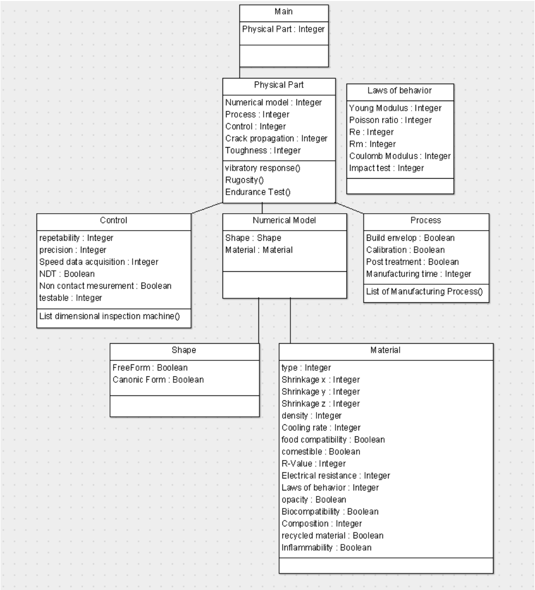

Fig. 1 : Object arborescence of CPMF.

The manufactured product will be virtually defining by the class physical part composed by classes “Processes” – “Control” – “Digital Model”. The “Digital model” based itself on classes “Shapes” and “Materials”; our physical part consists of classes that represented the 4 independent aspects of our structure.

The integration of our proposal at the heart of FEM software requires a lot of questioning of the laws of behaviors material comportment. For facilitate the exploitation by the algorithm, we have chosen to group this laws in a separate class who can easily be given as a parameter to specific programs.

In our case, we would realize a part manufactured. We dispose of some criteria, few of them can be:

- Minimal space
- Resistance to mechanical stress
- Budgetary and/or time of production constraint
- …

The objective is to determine the constitution of the "Tetraptic CPMF": What is the final form of the part? Which material will be use? What is the production process? And how will be metrological control to comply well the input criteria?

For a series of criteria completely define, it can be more than one acceptable combination of the CPMF. We are in the case of Multi-criteria optimization with multiple conflicting objectives. Therefore, it is necessary to determine a priority management for our criteria.

For validate our model, we acted on the capitalization of knowledge realized within Platform NUM3D of research laboratory CReSTIC (University of Reims, France). We have realize several experimentations for quantify the evolution of mechanicals characteristics in function of the different material, process or orientation on the work plate. And this for all the equipment we dispose. The implementation of Design of Experience (DOE) [8] gives critical values about the limitation of the equipment.

For example, we determine the minimal thickness printable or minimal diameter can be print and clean without deterioration of the part [4] [5] in fonction of the Tetraptic composition.

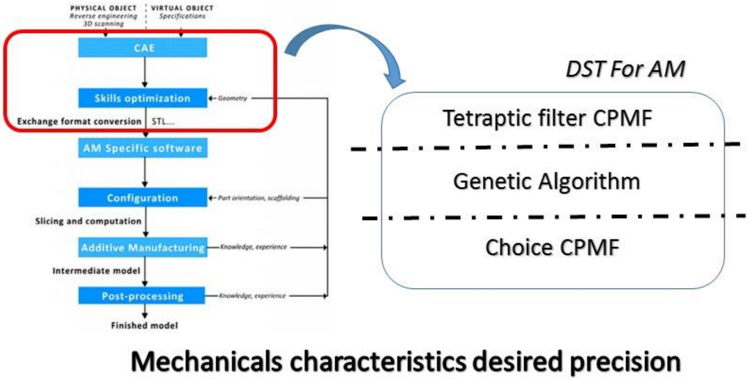

Fig. 2: AM engineering and manufacturing cycle with Decision Support Tool integration.

Lot of research have developed a representation of the AM manufacturing cycle [2] [14], we choose that of J. Gardan [3] who integrated the concept of Design For Manufacturing (Skills optimization) and of numerical simulation (CAE in the figure 2). It is at this level that our proposal can be integrated.

We integrate in our Decision Support Tool the geometry issues from design in CAD or reverse engineering by 3D scanning. The input (like geometry or mechanical constraint) are implemented in the DST for AM and pass by a Tetraptic CPMF Filter. A genetic algorithm proposes an optimal range of solutions (Pareto Front). Thus, the users can make the final judicious choice. Then, the AM engineering and manufacturing cycle can restart "normally".

Scenario:
Example of possible implementation: postoperative immobilization orthesis (wrist and thumb).
Following an operation leaving a scar or wound requiring regular care, it is not possible to use conventional immobilization techniques such as plaster. The need to conform the hand particular shape perfectly, leads us to consider 3D modeling of the member to protect and 3D-printing a specific orthesis.

This splint must respect several criteria: mechanical resistance, shapes of hand or minimal masses, etc. And without mention a production time as short as possible. The cost remains a non-priority criteria.
The acquisition of the shape of the hand is made by 3D scanning laser triangulation of the zone to be protected (see Fig 3).

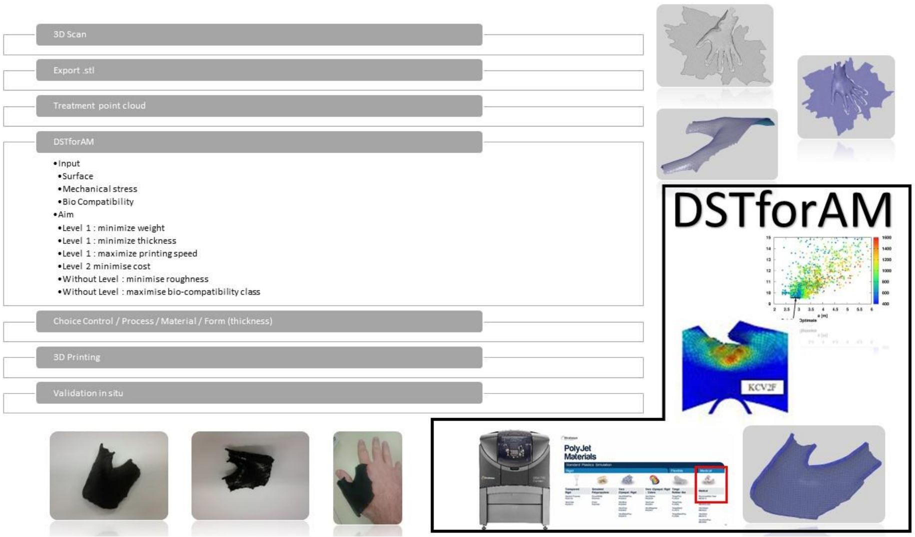

Fig. 3 : scenario implemented into DST for AM.

We integrate the input of our Decision Tool Support (Geometry from 3D scanning, Strain issue to the environment and the Bio-compatibility). We wish minimize the weight, the thickness, the cost and the roughness but too maximize speed production and the class of bio-compatibility of material. Our methodology gives this result (table 1) and propose the use of Eden260V© with MED610© material.

	Limits	*Results*
Level 1 : minimize weight	*0g→300g*	*127g*
Level 1 : minimize thickness	*0mm→5mm*	*2.8mm*
Level 1 : maximize printing speed	*0min→3600min*	*82min*
Level 2 minimize cost	*0€→1000€*	*49€*
Without Level : minimize roughness	*Ra6.4→Ra3.2*	*Ra6.4*
Without Level : maximize bio-compatibility class	*Class I → Class VI*	*Class VI*

Table 1 : Table of results from DSTforAM

Conclusion:

In this article, we use our knowledge inherent of manufacturing process specially in Additive Manufacturing domain, for develop a decision support tool targeted to determine the composition of our Tetraptic CPMF (Control/Process/Material/Form).

The feasible solution domain is define by requirement specification and we use some genetic algorithm for obtain a classification based on an optimality function.

Although oriented on Additive Manufacturing, our work can be extend of all types of manufacturing process, as well different material, forms or control.

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