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Topological optimization of internal patterns and support in additive manufacturing

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ABSTRACT

Rapid prototyping (RP) and more generally Additive Manufacturing (AM) enable the manufacture of complex geometries, which are very difficult to build with classical production. There are numerous technologies that are using different kind of material. For each of these, there are at least two materials: the production material and the support one. Support material is, in most cases, cleaned and becomes a manufacturing residue. Improve the material volume and the global mass of the product is an essential aim surrounding the integration of simulation in additive manufacturing process. Moreover the layer-by-layer technology of additive manufacturing allows the design of innovative objects and the use of topological optimization in this context can create a very interesting combination. The purpose of our paper is to present a methodology and a tool, which allow the use of topological optimization for the preparation of model for RP and AM.

1. Introduction

In the last decade, the use of structural optimization has rapidly increased. The upstream phases of design process represent 5% of the involved time of a product development, but engage 75% of the global development costs [34]. The integration of optimization in the early phases of a project is thus very important. The use of numerical simulation to optimize products has become essential to test different forms, materials, but also to better understand the involved physical phenomena. The main difficulty of using computational optimization is to manage the loops between CAD and CAE. Thus any change in geometry induced by the analysis can greatly increase the delay. Methods for shape optimization automate this chain and find an optimal solution with the inclusion of the specifications. Besides the possibility to test original solutions, the use of numerical optimization can address the problem of computing integration in the early stages of the design process. It is then necessary to establish a methodology for capitalization and knowledge management.

There are three main categories of shape optimization of mechanical structures [1]:

"Parametric shape optimization: the shapes are parameterized by a reduced number of variables (thickness, diameters, dimensions)." This class of optimization does not allow exploration of other possible shapes, but it allows to find (calculate) the optimum dimensions of parametric forms (existing forms of the model).

"Optimization of geometric shapes which, from an initial shape, vary the position of the boundaries of form." This optimization by the variation of the boundaries allows finding optimized contours structures without changing the initial topology.

"Topological shape optimization: obtain, without any explicit or implicit restriction, the best shape possible even if topology changes." This third category of optimization is an appropriate method for the design phase of a new part, because it can explore new concepts and solutions in areas of "no comfort" for engineers (see a basic example in Fig. 1).

The marriage between Additive Manufacturing (AM), which can build almost any shape, and topology optimization seems obvious. Indeed, the topology optimization will provide innovative forms but requires adaptation process from traditional manufacturing (typically a "remodelling" is required). The objective of this paper is to present the development of a methodology that will serve as a basis to develop a product that will be positioned upstream of the rapid prototyping machine. This software and the associated methodology are intended to be added on all types of AM machines. The material and mass saving obtained through the digital optimization can apply for plastics, metals etc. However one

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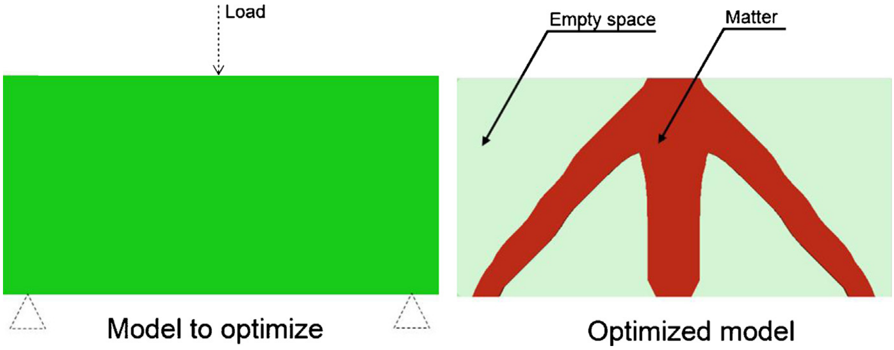

Fig. 1. Simple example of a topological optimization.

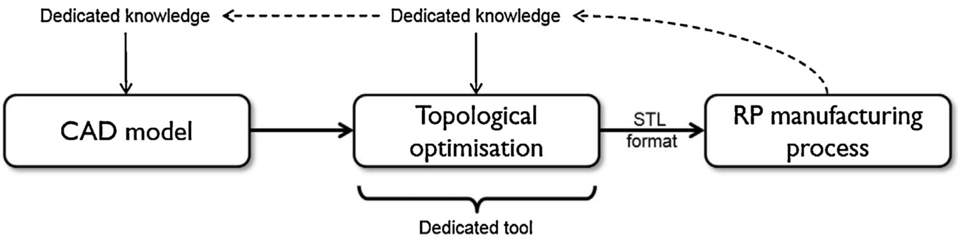

Fig. 2. Process of the project.

of the major interests of optimization in general and more specifically topological is to save mass on products. It is therefore natural to mainly target AM of steel products. In the context of AM centre NUM3D, we have access to a SLS machine type (Selective Laser Sintering). But the approach can be applied to another AM steel process like EBM (Electron Beam Melting), DMLS (Direct Metal Laser Sintering) etc. These different machining processes are brought together under the term ALM: Additive Layer manufacturing Metal application. Fig. 2 shows the positioning of the tool in AM process.

2. Related works

AM is nowadays widely used in industrial product development. The main advantage of the additive fabrication concept used in AM is the ability to create almost any possible shape. This capacity is governed by the built up layer-by-layer process. There are several available technologies based on this additive machining concept [2]: stereolithography, photo-masking, Selective Laser Sintering, Fused Deposition Modelling, 3D printing, etc. Researchers principally work on the influence of part orientation, slicing strategy, matching internal patterns to improve cost, product quality, built time, etc. Numerical topological optimization is a technical break that allows the modelling of really innovative shapes, based on trade knowledge. The next paragraph focuses on related works in the integration of optimization in AM. The second one, before a synthesis, presents topological optimization survey.

2.1. Optimization in additive manufacturing

The use of optimization in AM [3] is generally done into the context of optimization of the build direction [4], parameter optimization trades, and optimization construction layers algorithm and so on. The optimization of the quantity of material used is an important goal. This optimization can match both the product material and the support material. Fig. 3 shows the case of using a topology optimization on both the part and the support used (two optimizations are performed separately. Optimization in the "design" zone is the area that can be optimized, the "non-design" zone that cannot be changed).

AM machines generally offer the possibility of reducing the mass by using honeycomb shapes, lattices . . .. These algorithms model the simplified form without taking into account the specifications of mechanical strength. They are mostly applied for internal gain of matter. Actually, there are many researches on the influence of cellular structures. The influence of circular and rectangular shapes on the polyamide was studied through compression tests [5]. The study shows the influence of two types of geometric shape based on their use. The circular structure is able to absorb 43.5% more energy than a rectangular structure (very useful in high deformation rates for dynamic fast as crash, explosions etc.). Sugimura [6] investigated the use of lattice structures including rapid prototyping to lighten sandwich panels while maintaining their mechanical strength. The study enabled to determine the directions of the lattice anisotropy that influences the mechanical behaviour of the entire panel. The lattice modelling can be adjusted according to the specifications of mechanical strength. Other studies develop specific structures as curved [3], honeycomb [7], cell shape "tetrachirales" [8] or "hexachirales" [9]. However, these studies did not use the opportunity to integrate notion of mechanical strength. The topological optimization through numerical simulation can solve this problem. Ref. [10] shows the interest to integrate the topological optimization but also highlights some difficulties such as:

- The difficulty to manage the drainage system of the support part
- The size of the CAD file and the difficulty of implementation.

Recently [11] develops a methodology which allows the production of topological optimized part by a low cost FDM. This methodology uses the classic optimization process to optimize the mass of the part (included the skin of the part).

2.2. Topological problem specification

Topology optimization problem can be defined as the search for the best allocation or distribution of material in a given design