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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 amanufacturing residue. Improve the material volume and the global mass of the product is an essentialaim 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.
Keywords: Topological optimization, Additive manufacturing, Computer Aided Engineering (CAE) Computer Aided Design (CAD)

I. INTRODUCTION

In the last decade, the use of structural optimization has rapidlyincreased. The upstream phases of design process represent 5% ofthe involved time of a product development, but engage 75% ofthe global development costs [34]. The integration of optimizationin the early phases of a project is thus very important. The use of numerical simulation to optimize products has become essentialto test different forms, materials, but also to better understand theinvolved physical phenomena. The main difficulty of using compu-tational optimization is to manage the loops between CAD and CAE.Thus any change in geometry induced by the analysis can greatlyincrease the delay. Methods for shape optimization automate this chain and find an optimal solution with the inclusion of the spec-ifications. Besides the possibility to test original solutions, the useof 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 ofmechanical structures [1]:

"Parametric shape optimization: the shapes are parameterizedby a reduced number of variables (thickness, diameters, dimen-sions)." This class of optimization does not allow exploration ofother 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 bythe variation of the boundaries allows finding optimized contours structures without changing the initial topology ."Topological shape optimization: obtain, without any explicitor 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 explorenew concepts and solutions in areas of "no comfort" for engineers. (see basic example in Fig. 1)

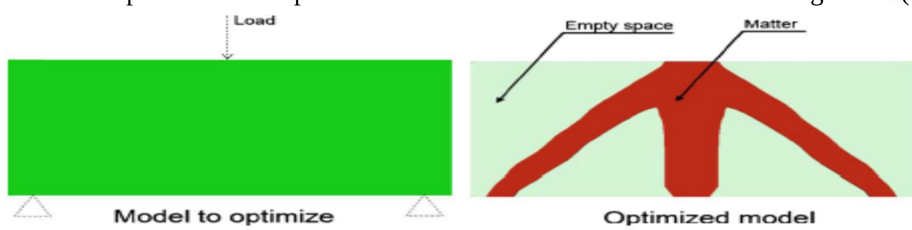

Fig. 1. Simple example of a topological optimization.

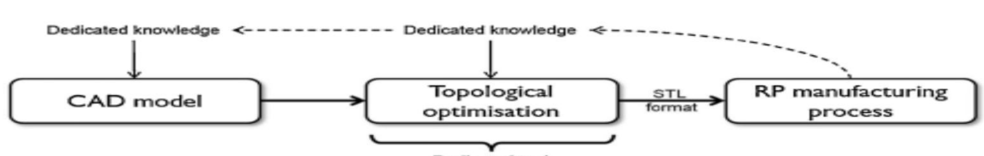

Fig. 2. Process of the project.

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The marriage between Additive Manufacturing (AM), which canbuild almost any shape, and topology optimization seems obvious.Indeed, the topology optimization will provide innovative formsbut requires adaptation process from traditional manufacturing(typically a "remodelling" is required). The objective of this paperis to present the development of a methodology that will serveas a basis to develop a product that will be positioned upstream of the rapid prototyping machine. This software and the associ-ated methodology are intended to be added on all types of AM machines. The material and mass saving obtained through the dig-ital optimization can apply for plastics, metals etc. However one of the major interests of optimization in general and more specifi-cally topological is to save mass on products. It is therefore naturalto mainly target AM of steel products. In the context of AM cen-tre NUM3D, we have access to a SLS machine type (Selective LaserSintering). But the approach can be applied to another AM steel pro-cess like EBM (Electron Beam Melting), DMLS (Direct Metal LaserSintering) 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.

II. 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.

A. Optimization In Additive Manufacturing

The use of optimization in AM [3] is generally done into thecontext of optimization of the build direction [4], parameter opti-mization trades, and optimization construction layers algorithmand so on. The optimization of the quantity of material used is an important goal. This optimization can match both the produc tmaterial 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.

B. Topological Problem Specification

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

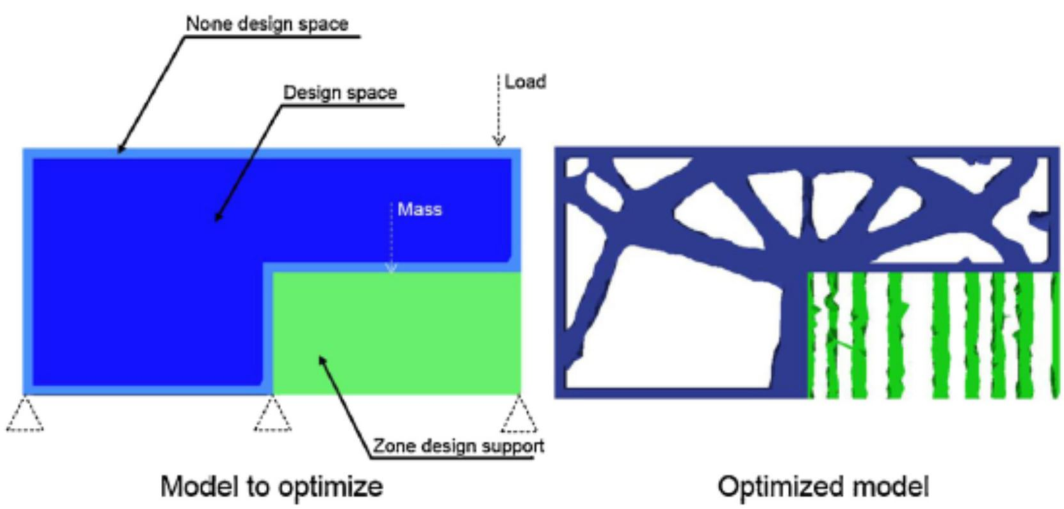

Fig. 3. Simple example of part and support optimization.

III. METHODOLOGY

A. Introduction

A major interest of AM is to build parts or areas of parts that arenot manufacturable by conventional methods (CN, plastic injectionand so on). In the context of this research the goal is to optimize the quantity of material used. Optimization can be used in two cases inPR:

1) all the part can be optimized (inner and outer – design and non-design space
2) the outer skin (or part of it) cannot be modified (due to func-tional/design specifications). In the first case, we use the AM to obtain innovative shape. Thisconcept is already well used in industry or research as well. As seenin the Fig. 5, topological

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optimization can be used for aeronauticpart with an ALM AM process. The optimized design weighed only326 g at the end, compared to 918 g in the original – a significant reduction of 64% [22].

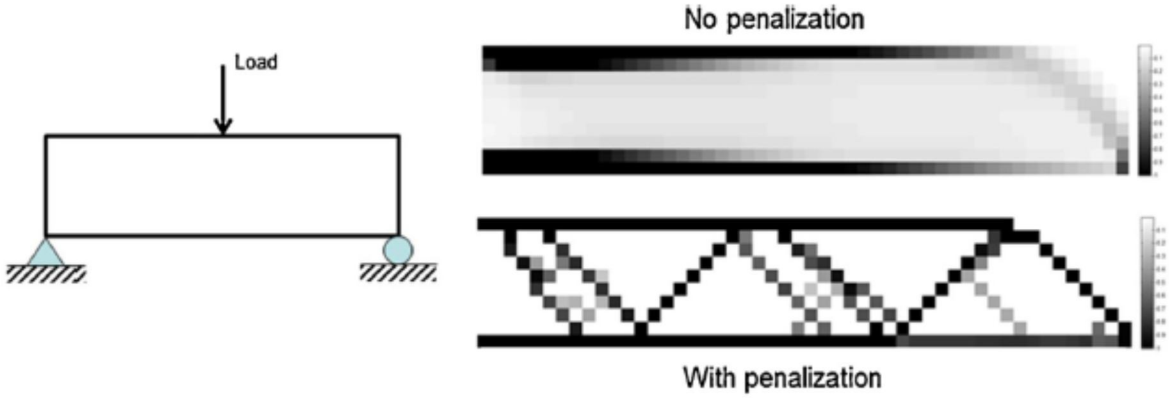

Fig. 4. Penalization comparison with SIMP model.

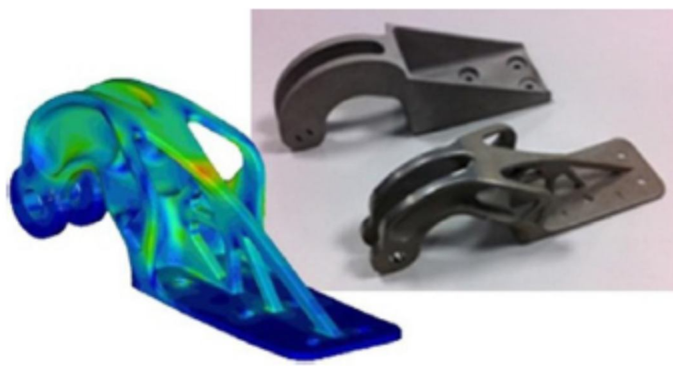

Fig. 5. Airbus A320 Nacelle Hinge Bracket (back) and the Optimized Design Produced by ALM (front) – Courtesy of EADS and ALTAIR.

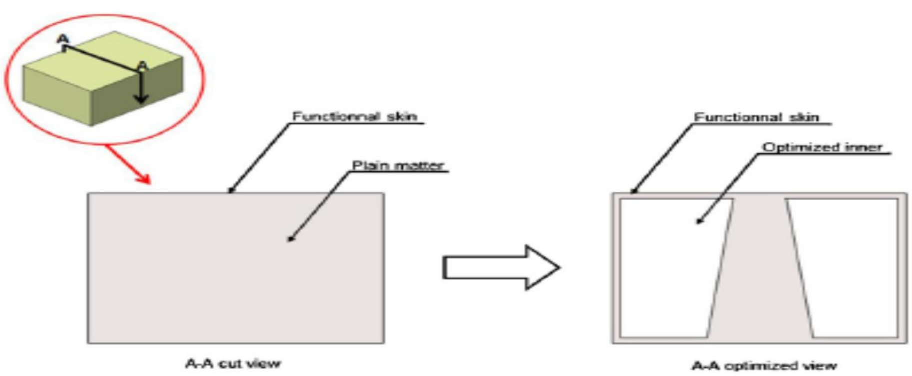

Fig. 6. Outline scoping illustration in a sample example.

It is important to note that many studies also use the power of optimization coupled with AM to work on completely and very innovative new form. In this way, Neri Oxman team [23] designs the engineering principles that will help to mature 3D printing into a technology able to produce complex structures inspired from nature. These biomimetic researches are also used in biomedical[24] to manufacture scaffolds for bone tissue. But as we saw on the state of the art section, the different works on the optimization of the inner are relative to find specific shape (like honeycomb). This paper deals mainly with second case namely works in the opti-

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mization of the inner part with a skin which cannot change (or few modifications like holes for the drainage system). As seen in Fig. 6,our aim is to optimize the quantity of material used in AM process.

B. Knowledge Management

The integration of knowledge in numerical simulation is directly linked to the AM process knowledge and the optimization method used in finite element solver. The knowledge capitalization and modelization is done with specific methods developed on previous works [25]. We explain in the two next sections how we manage knowledge for topological optimization and for process A Mmachining. A topology optimization problem relative to AM process can be defined by:- Design spaces: a design space corresponds to the interior of the objects and a non-design space corresponds to the skin of the object (or any other area that should not be modified such as theapertures for cleaning). These areas are identified in CAD model. Design variables: it is the set of parameters of the design spacerelated to the AM process to define the initialization problem of topological optimization. We find here the penalization factor,the pattern repetition and so on Responses: responses correspond to structural ones, calculated in a finite element analysis, or combinations of these responses to be used as objective and constraint functions in a structural optimization. Available responses could be for example static displacement, mass, volume, temperature, natural frequency, etc Constraints: Constraints are based on responses by marking them with specific values The objective function is, as we have seen before, the minimization (or the maximization) of the problem, here a spe-cific responses (for instance the aim is to manage one response by objective function).

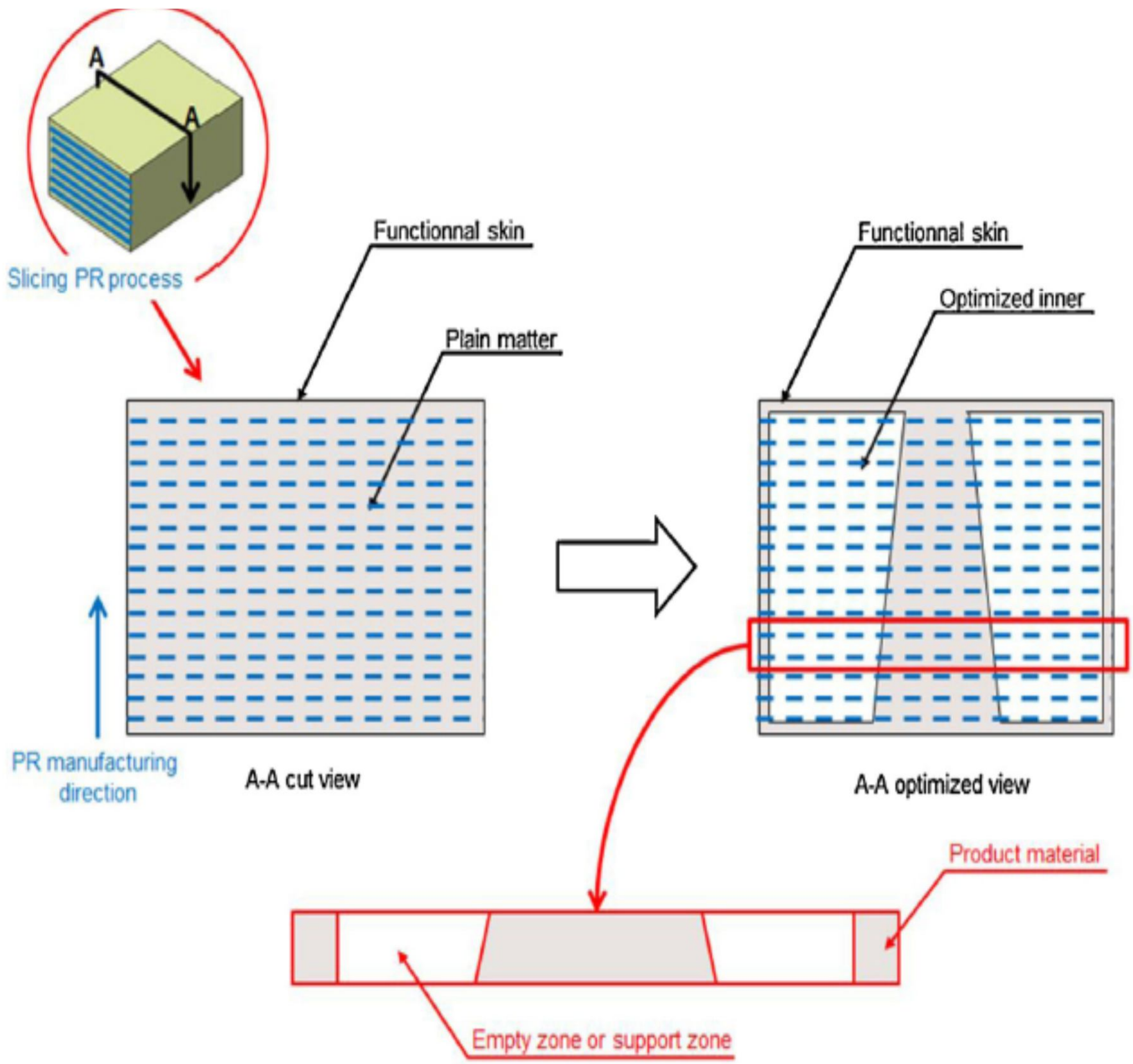

Fig. 7. View of the material benefit.

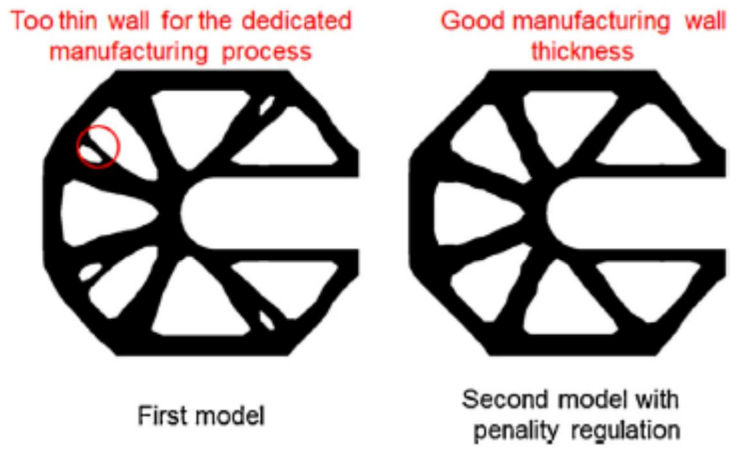

Fig. 8. Penalization factor management on a C-CLIP example.

1) *Knowledge Management In Am Process Machining:* Selective Laser Sintering (SLS) uses a moving laser beam to sinter powdered polymer and/or metal composite materials into successive cross-sections of a three-dimensional part. Additional powder is rolled onto a platform, which support the successive cross-sections, from a reserve before building the layer. The powder is maintained at an elevated temperature so that it fuses easily upon exposure to the laser. This work aims to quantify the inherent defects in each pro-cess by the parallel between possible measures in metrology and process-related settings. Our approach is different (and comple-mentary) since we determinate influential parameters and thereare critical values according to using context, based on [32]research. The experimental process to recover AM knowledge is based ontwo types of specimens-

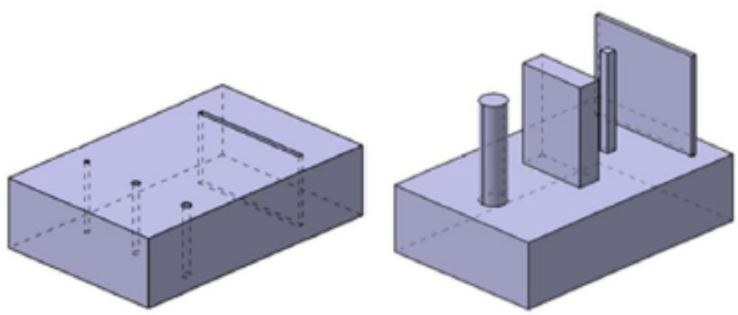

Fig. 9. View of the different method of manufacturing.

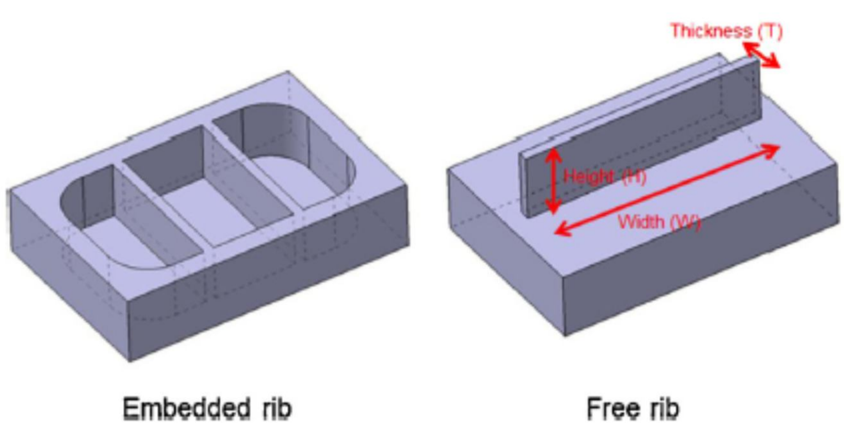

Fig. 10. Two kinds of tested rib features.

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We can see in Fig. 9 different manufacturing direction and shapeof the test parts.
Those configurations allow the determination of risk factors.Our approach involves the study of three very important factorsfor the topological optimization:
The minimum thickness printable and cleanable without part deterioration. We seek to maximize the minimum thickness of the wire cloth (final material) without loss of geometric and mor-phological qualities of the part.
The minimum diameter printable and cleanable without mechanical cleaning: the objective is to size the best channels dimensions for cleaning the internal structure of the piece (allow the powder evacuation)
The maximum height, in fact the ratio between the projected length and height of the part which may cause a falling down of the matter.
The first step of our methodology is to identify and define design spaces (see Fig. 11). A boolean opera-tion in CAD software is needed to delimit the different zone.
The optimized step is also defined as sub methodological process(see Fig. 12). The first step is to define design variables like the penalization factor as we explained before. This penalization factor is defined according to the minimal thickness obtain by test. We define then two specific responses: compliance response. The compliance is the strain energy of the structure and can be considered as a reciprocal measure for the stiffness of the structure. fraction of mass response. The fraction mass response is the mate-rial fraction of the designable material mass. It corresponds to aglobal response with values between 0 and 1. This allows the userto specify intuitive question like “I want to gain 30% of mass”,value transcribe as 0.3 in our programme.

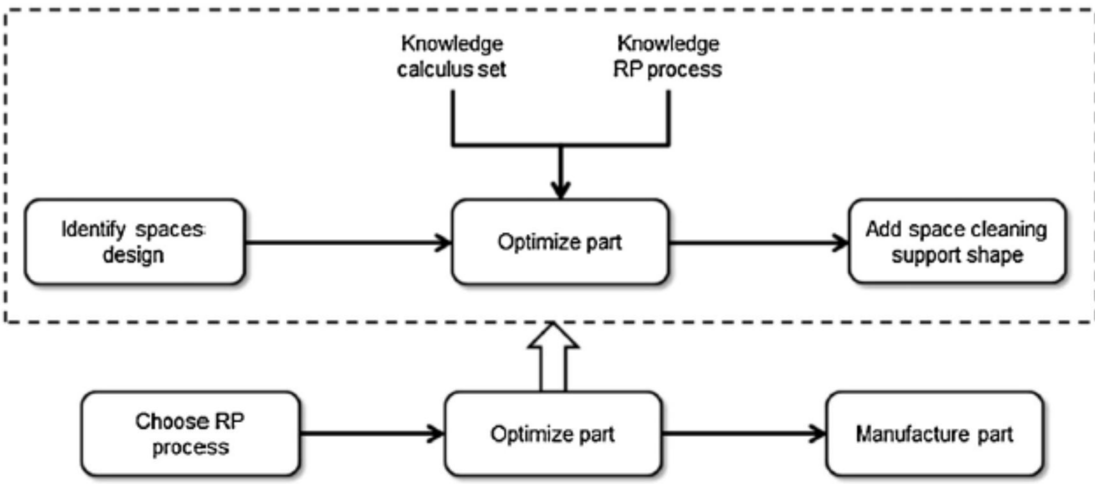

Fig. 11. View of global methodology.

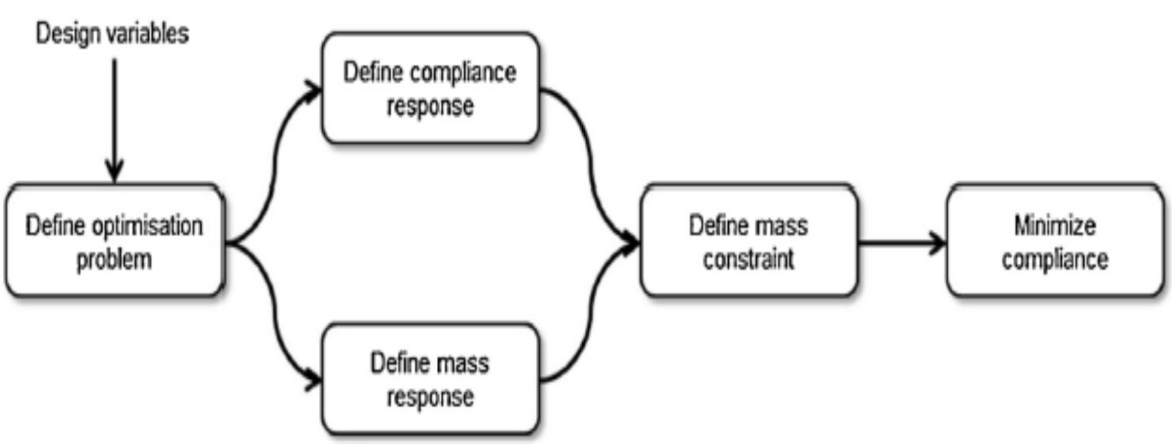

Fig. 12. View of optimization methodology.

IV. APPLICATION

To validate our methodology and prepare the software integration, we first verified our assertion with commercial software. We developed in Rhinoceros 3D an interface which helps the designer to prepare the CAD model and launch in background Optistruct(Altair) solver . The programme is developed in python.We study a prosthetic implant used in a hip replacement surgical procedure studied for one of our client (a simplify one with regardto the confidentiality). There are a large number of hip implantdevices on the market.

V. CONCLUSION AND FUTURE TRENDS

We explore the possibility of using topological optimization inRP and more generally in AM. We are particularly interested in theoptimization of the inner part. The aim is to optimize the volumeof material to be used and the global mass. The developed method-ology and the associate tool are presented in this paper with a steel part example. The weight gain is indeed more simple to explainbut the methodology was tested in more than ten parts with dif-ferent AM process.

VI. ACKNOWLEDGMENTS

This project is partly based on the platform NUM3D.

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