# Design optimisation for additive manufacturing: reduce cost using lattice structures

H. Sapardanis[1], D. Pullini[2], F. Gili[2], J. Bajolet[3], N. Maillol[3]

1: Altair Engineering France, 5/10, rue de la Renaissance 92184 ANTONY Cedex, France
2: CRF, Corso Settembrini 40, porta 8, corpo 1 ingr. 109a 10135 TORINO, Italia
3: CT-IPC, 2 rue Pierre & Marie Curie – 01 100 BELLIGNAT, France

**Abstract**: Metallic additive manufacturing process faces many costs factors that can be reduced in the very first step: design process. Topology optimisation is a very strong numerical tool to deal with time to design reduction. In this paper, an innovative approach combining process hybridisation (DMLS and Cobapress), topology optimisation and lattice structure is developed. The method is applied to an automotive suspension knuckle to reduce mass and costs factors during the manufacturing while maintaining the mechanical performances. The design is dedicated to additive manufacturing process. The paper details each step of the design process and the first results obtained using this approach.

**Keywords**: Additive manufacturing, Topology optimisation, lattice structures, Lightweight, cost

## 1. Introduction

The additive manufacturing technology for metallic components enables to produce small series with high degree of customisation in various industries such as automotive, heath care and aeronautics [1]. To become more mature and tackle the mass market, this technology is now facing new challenges to enhance productivity and costs [2].
Cost factors are significant in every step of the additive manufacturing process, from design to post-process, as illustrated on Figure **1**. The origin of costs is multiple: design, labour, built time, material, finishing, etc [3]. The work presented in this article focuses on the design step.

Designing a component for additive manufacturing consists in creating the best geometry following the mechanical, thermal, … specifications on one hand and, on the other hand, anticipating all stages of the manufacturing workflow. Thus, this step is a key element to reduce costs, for example by using topology optimisation.
Topology optimisation is a strong numerical design assistant tool which has emerged in the late 80's with the work of Bendsøe and Kikuchi [4]. This tool enables to achieve an optimal shape of a component from a design space fixed by the user. Through the years, topology optimisation has been constantly upgraded including manufacturing constraints like in Altair OptiStruct [5] giving the opportunity to deal with a wide range of design issues [6, 7]. This tool is now widely used by designers and engineers. Additive manufacturing allows the creation of highly complex shapes that cannot be manufactured by traditional processes. Generally, these parts require supports to be printable, supports which are removed after manufacturing generating extra costs (powder, machine time, labour, etc).

The challenge here is to provide an optimal design of an automotive suspension knuckle, key element of the full suspension system, Figure 2. This performance aluminium component currently is manufactured by Cobapress$^{TM}$, a hybrid process developed by Saint Jean Industries [8] consisting in

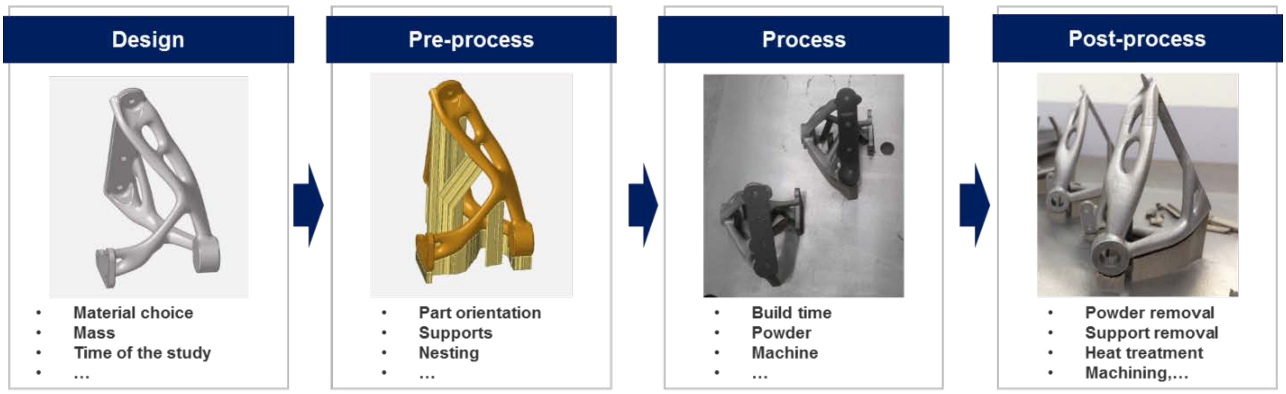


Figure 1: Cost factors in metallic additive manufacturing workflow, a non-exhaustive list

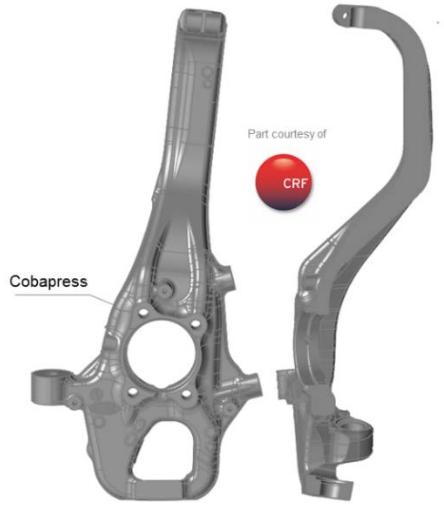


Figure 2: Automotive suspension knuckle, baseline design

casting a preform and pressing it one time with a forging press.
The objective of the new optimized design is to have a component 30% lighter preserving its mechanical properties in fatigue. This new design is dedicated to Direct Metal Laser Sintering process (DMLS), a powder bed-based technology. In this process, a thin layer of powder is applied by a re-coater which is then melted by a laser beam whose trajectory is defined by the computer-generated part design.

In this work, three approaches are combined to reduce cost and design a new part lighter, with better mechanical performances and minimum amount of manufacturing supports: manufacturing process hybridisation, topology optimisation and lattice structures application. Hybridisation, intended as a combination of several processes to manufacture one component, provides a high degree of customisation and limit cost of standard parts. The hybrid knuckle will be manufactured by Cobapress$^{TM}$ and DMLS.
Lattice structure is a type of architectured material combining massive material and space areas [9]. Lattice structure is employed in various field as light-weight structure, energy absorber or heat extractor [10]. In the present study, lattice structure will be integrated in the design as manufacturing supports and also structural supports. Topology optimisation and lattice structures will be combined to minimise the mass of the component and reduce the time to generate the geometry, the amount of material and time in process and post-process stages.

This work is led in context of H2020 MAESTRO project [11]. This European project aims to improve productivity by 30%, to reduce cost by 30% and to increase speed to bring this technology to a larger scale, towards mass market applications.

## 2. Topology optimization

The overall methodology is presented in Figure 3. The first step is the topology optimisation performed with Altair OptiStruct implicit solver. Two analyses were carried out. The first one aims at identifying which part of the knuckle will be manufactured by Cobapress and by DMLS. Then, the DMLS part of the hybrid processed knuckle is optimised. The results of the topology optimisation are a support for the designer to re-design the component, taking into account the main load paths going through it. These results are finally interpreted using NURBS surface creation tool to provide the new geometry.

### 2.1 Definition of the hybrid component

The design space considered for this section is presented in grey in Figure 4. It was taken as large as possible in order to make the best use of topology optimisation. Several formulations of optimisation were investigated, the objective was always to minimise mass keeping the stiffness performances for each loading case same as the baseline design. Four distinct loadings cases were considered. All results showed a hollow upper part and a massive lower part whose shape is very similar to the lower part of the baseline design, Figure 4. The mass saving reached

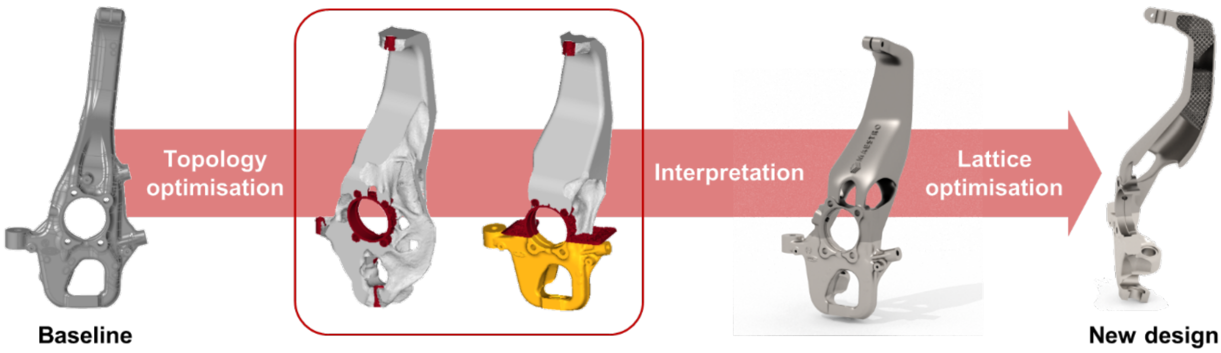


Figure 3: Re-design process for the hybrid suspension knuckle Cobapress/DMLS

for these raw results is 15%. The lower part is the most solicited, so a limited mass saving is obtained in comparison with the upper part. Thus, to reach the target weight reduction of the hybrid component, the upper part must be optimised. Consequently, the lower part of the knuckle will be manufactured in Cobapress and then the upper part will be directly built on the Cobapress preform using DMLS process.

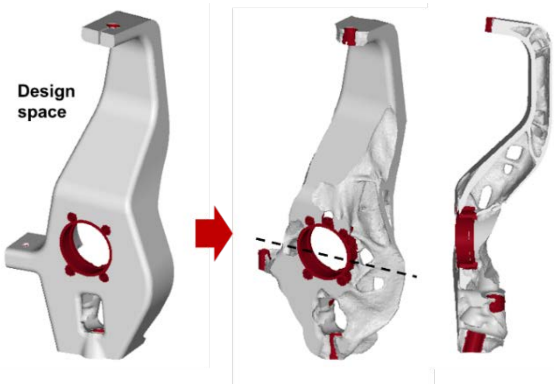


Figure 4: Design space and topology optimisation results on the full knuckle

2.2 Re-design of the hybrid knuckle

The second part of the work aims at optimising the upper part in DMLS of the knuckle. The design space is illustrated in the Figure 5. The investigated formulations of optimisation are the same as the full optimisation ones. The results are very close to the optimisation of the full component, the DMLS part is a skin with two series of stiffeners located in the middle of the component and on top of it. The mass saving reached for these raw results is 17%, below target.

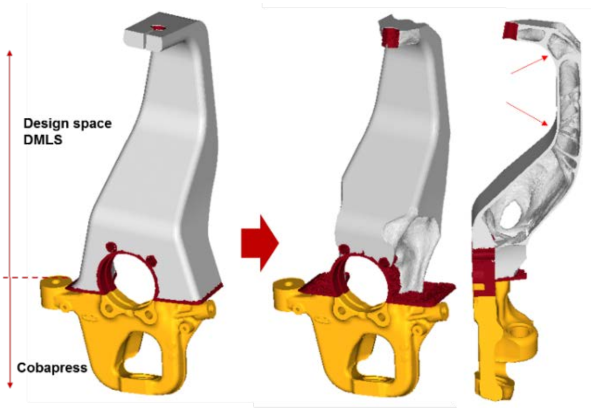


Figure 5: Design space and topology optimisation results on the DMLS part of the knuckle

For DMLS process, when the overhang angle is larger than 45°, manufacturing supports are required. In our case, the upper part of the knuckle will be print vertically directly on the flat surface of the Cobapress. This means that the top of the skin and stiffeners will require supports during printing which must be removed during the post-process stage, Figure 6. This operation is almost impossible as the stiffeners are located below the skin.

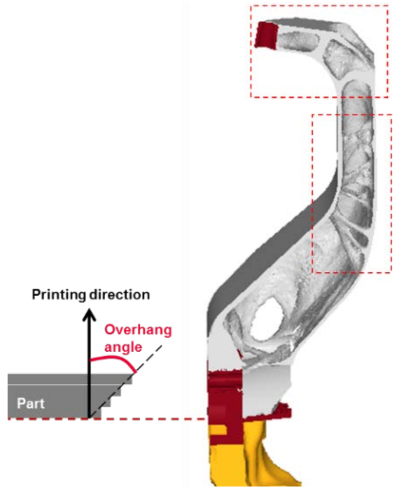


Figure 6: Cross section of the topology optimisation results indiquating supports location

To tackle this issue, lattice structures have been employed to replace the stiffeners but also to generate a self-supported geometry during manufacturing of the top of the skin. The lattice structure will be fully integrated in the design and will also enable to increase the mechanical performances of the knuckle.

Consequently, the stiffener have not been included in the interpreted geometry. In this interpretation, the skin respects the overhang angle, Figure 7. Only one area will require manufacturing supports because of the shape of the design space, these supports will be easy-to-remove after process.


Figure 7: Interpreted hybrid design without stiffeners

### 3. Lattice structure optimization

3.1 Preliminary printing tests

Dodecahedron pattern has been selected to fill the hollow part of the knuckle. Before any re-design process, a series of  specimens have been printed to determine the best dimensions of the lattice structures, pattern size 9mm and maximum and minimum beam diameter respectively 1 and 2mm, Figure 8. These dimensions were then used to build the model for lattice optimisation.

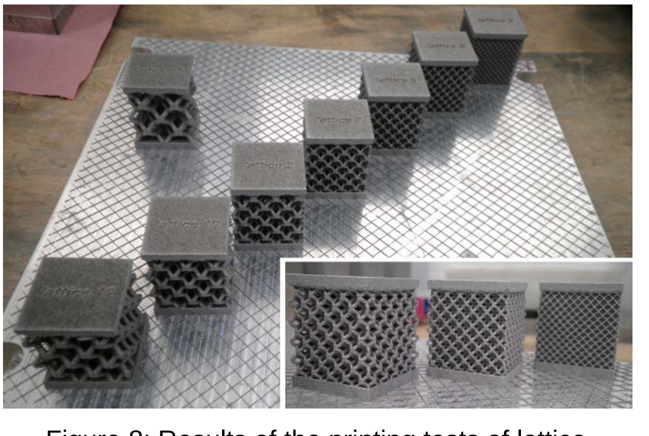

Figure 8: Results of the printing tests of lattice structures

3.2 Lattice Optimization

Like topology optimisation, lattice optimisation is implemented in OptiStruct. It enables to optimise the diameter of each beam section regarding bound fixed by the user. These beams form the lattice structure of the component.

In case of the knuckle, two separate volumes are filled with lattices as illustrated in Figure 9. The dimension of the pattern is fixed during the optimisation, only the beam diameters can differ. The load cases applied are the same as in the previous topology optimization.

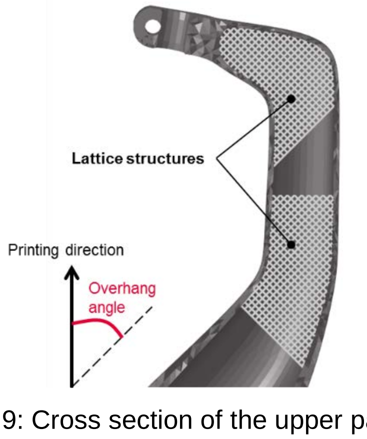


Figure 9: Cross section of the upper part of the knuckle filled with lattice structure

After optimisation, the distribution of diameters of the beams vary with the location of these beams in the lattice structure, illustrated in Figure 10. The larger beams are located along the load paths identified in the first topology optimisation. For this new design, a mass saving of 3% was found.

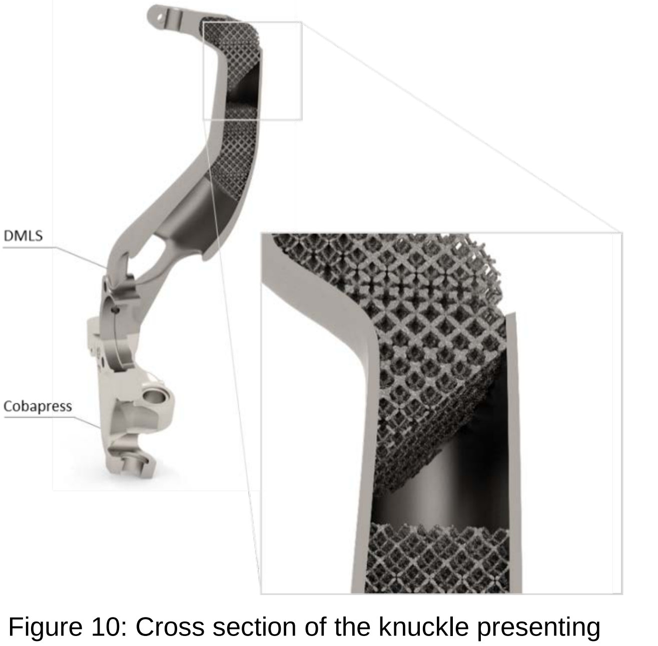


Figure 10: Cross section of the knuckle presenting the lattice optimisation results

### 4. Performances comparison

A structural elastic analysis has been performed on the baseline design and the new one to compare their performances. The lattice structure was represented by the beams of previous optimisation. The values of compliance, displacements and stresses are compared.

The compliance of a component under a particular loading is the internal strain energy of the loaded part. These values decreases by an average of 27% with the new design consequently, the new design has better stiffness performances than the baseline. These results are correlated with the mapping of the maximum Von Mises stresses and maximum displacement magnitude for the four loadings, Figure 11. The maximum displacement and the Von mises stresses respectively decrease by 49% and 10% with the new design. The mass saving achieved, 3%, is lower than the expected target, 30%.

These first results are promising and reveal that the optimisation process leads to a new design lighter with better mechanical performances than the baseline.

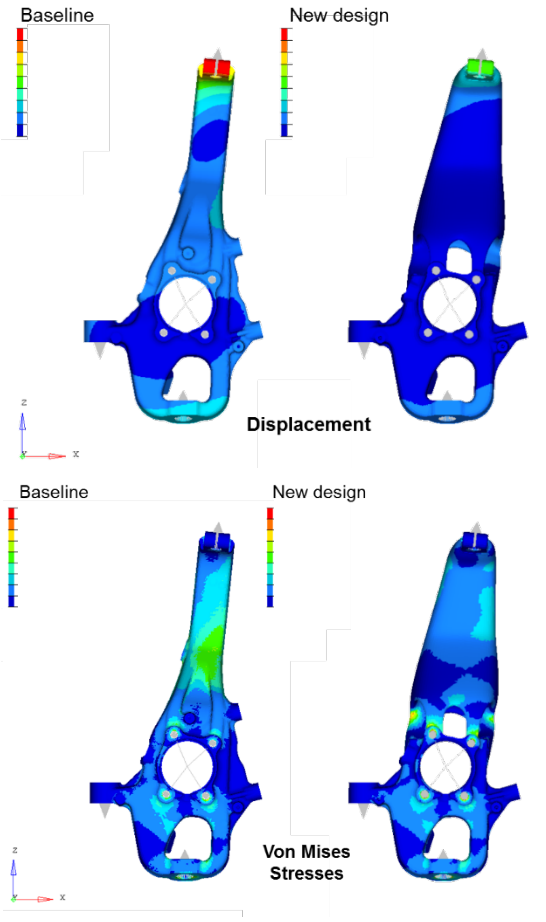


Figure 11: Maximum displacement and maximum Von Mises stresses for the baseline and the new design

The study is still on going. In order to come closer to the mass target, several improvements are currently investigated: design space to maximise mass saving in topology optimisation raw results, interpretation of the raw results to better fit results and minimise the mass gap between raw results and new geometry and the refining of lattice structure.

## 5. Conclusions

In this paper, an alternative approach of design has been investigated combining hybridisation of processes (DMLS and Cobapress), topology optimisation and lattice structure to reduce mass of an automotive suspensions knuckle and cost factors of its manufacturing. The approach provides a lighter design with better machinal performances than the baseline design. The first printing tests demontrate the printability of the chosen lattice structure.

The mass saving remains under the mass target so to better fit the target, several improvements will be studied. Then, the whole cost analysis will be carried out. As the new design is manufactured in the frame of MAESTRO project, materials and process related to the component are currently under qualification and an experimental testing campaign is foreseen to assess the numerical analyses results comparing the mechanical and fatigue performances.

## 6. References


[1] *Identifying current and future application areas, existing industrial value chains and missing competences in the EU, in the area of additive manufacturing (3D-printing),* EC/EASME, July 2016.

[2] *Final FoFAM implementation roadmap*, Deliverable number: D4.3, Grant Agreement No 636882, December 2017.

[3] D.S. THOMAS, S.W. GILBERT: *Costs and cost effectiveness of additive manufacturing*. NIST Special Publication, vol. 1176, p. 12, 2014.

[4] M. Bendsøe, N. Kikuchi: *Generating optimal topologies in optimal design using a homogenization method*, Comput Meth Appl Mech Eng 71:197–224, 1988.

[5] Altair HyperWorks, *Altair HyperWorks 2018.0: OptiStruct Reference Guide*, 2018

[6] A.T. Gaynor, J.K. Guest: *Topology optimization considering overhang constraints: Eliminating sacrificial support material in additive manufacturing through design*, Structural and Multidisciplinary Optimization, vol. 54, no. 5, p. 1157-1172, 2016.

[7] M. Zhou and R. Fleury: *Fail-safe topology optimization. Structural and Multidisciplinary Optimization*, 54(5), 1225-1243, 2016.

[8] http://www.st-ji.com/

[9] M. Ashby, *Designing architectured materials*, Scripta Materialia, 68(1):4-7, 2013.

[10] https://altairenlighten.com/opinion/lightweight-lattices-liberate-new-product-performance/

[11] https://www.maestro-project.eu/


## 8. Glossary

*COBAPRESS:* COuler BAsculer PRESSer, process that combines forging and casting.

*HT:* Heat treatment

*MAESTRO*: **M**odular l**A**s**E**r-ba**S**ed addi**T**ive manufactu**R**ing platf**O**rm for large scale industry

*DMLS*: Direct Metal Laser Sintering

*NURBS*: Non-Uniform Rational Basis Splines