STRUCTURAL OPTIMIZATION OF AUTOMOTIVE CHASSIS: THEORY, SET UP, DESIGN

Marco Cavazzuti and Luca Splendi

(joint with Luca D'Agostino, Enrico Torricelli, Dario Costi and Andrea Baldini)

MilleChili Lab, Dipartimento di Ingegneria Meccanica e Civile, Modena, Italy
Università degli Studi di Modena e Reggio Emilia
`millechililab@unimore.it`

ABSTRACT

Improvements in structural components design are often achieved on a trial-and-error basis guided by the designer know-how. Despite the designer experience must remain a fundamental aspect in design, such an approach is likely to allow only marginal product enhancements. A different turn of mind that could boost structural design is needed and could be given by structural optimization methods linked with finite elements analyses. These methods are here briefly introduced, and some applications are presented and discussed with the aim of showing their potential. A particular focus is given to weight reduction in automotive chassis design applications following the experience matured at MilleChili Lab.

1. INTRODUCTION

Optimization techniques are very promising means for systematic design improvement in mechanics, yet they are not always well known and applied in industry. Despite this, the literature over the topic is quite rich and is addressing both theory and applications. To cite a few applications in the automotive field the works of Chiandussi *et al.* [1], Pedersen [2], and Duddeck [3] are of interest. They address the optimization of automotive suspensions, crushed structres, and car bodies respectively.

Structural optimization methods are rather peculiar ways of applying more traditional optimization algorithms to structural problems solved by means of finite elements analyses. These techniques are an effective approach through which large structural optimization problems can be solved rather easily.

In particular, with the term structural optimization methods we refer to: (i) topology optimization, (ii) topometry optimization, (iii) topography optimization, (iv) size optimization, (v) shape optimization. In the following some of these techniques will be introduced and their application to chosen automotive structural design problems discussed.

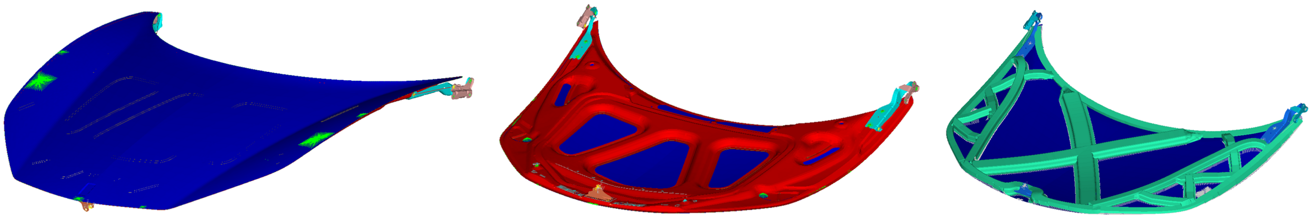
2. STRUCTURAL OPTIMIZATION

In the definition of any optimization problem a few elements are necessary, these are: (i) design space or space of the possible solutions (*e.g.* in structural optimization this is often given by the mesh) (ii) variables, (iii) objective(s) (*e.g.* mass minimization), (iv) optimization constraints (*e.g.* stiffness and/or displacements targets), (v) the mean through which, for a given set of variables, targets and objectives are evaluated (*e.g.*, in our case, finite elements analyses), (vi) the optimization algorithm (*e.g.* in structural optimization this is commonly a gradient-based algorithm, such as MMA).

Trying to simplify in a few words a rather complex and large topic, it could be said that the various structural optimization methods essentially differ from each other in the choice of the variables of the optimization problem as follows.

2.1. Topology Optimization

In topology optimization it is supposed that the elements density can vary between 0 (void) and 1 (presence of the material). The variables are then given by the element-wise densities. Topology optimization was firstly introduced by Bendsøe and Sigmund and is extensively treated in [4]; it has developed in several directions giving birth to rather different approaches, the most simple and known of which is the SIMP (Single Isotropic Material with Penalization).



(a) reference model, top view (b) reference model, bottom view (c) optimum layout

Figure 1: Ferrari F458 Italia front hood: reference model and new layout from the optimization results. The optimization was performed in three stages: topology, topometry, and size.

2.2. Topometry Optimization

The idea behind topometry optimization is very similar to that of topology optimization, the variables being the element-wise thicknesses. Of course, this method does not apply to 3D elements where the concept of thickness could not be defined.

2.3. Topography Optimization

Again topography optimization can be applied only to 2D or shell elements and aims at finding the optimum beads pattern in a component. The concept is yet similar to the previous cases and, simply speaking, the variables are given by the set of the elements offsets from the component mid-plane.

2.4. Size Optimization

Size optimization is the same as topometry optimization, but in this case the number of variables is greatly reduced in that the shell thicknesses of components are considered in place of the single elements of the domain.

3. APPLICATION EXAMPLES

3.1. Automotive Hood

The internal frame of the Ferrari F458 front hood has been studied aiming at reducing the weight while keeping the same performance target and manufacturability of the reference model. The targets relate to bending and torsion static load cases, compliance when closing the hood, deformations under aerodynamic loads.

A suitable preliminary architecture has been defined by means of topology optimization. The results have been re-interpreted into more performing thin-walled cross-sections. A serie of topometry optimizations followed to find the optimal thickness distribution and identify the most critical areas. The solution was refined through size optimization. In the end, the weight was reduced by 12 %, yet in the respect of all the performance requirements (Fig. 1).

3.2. Rear Bench

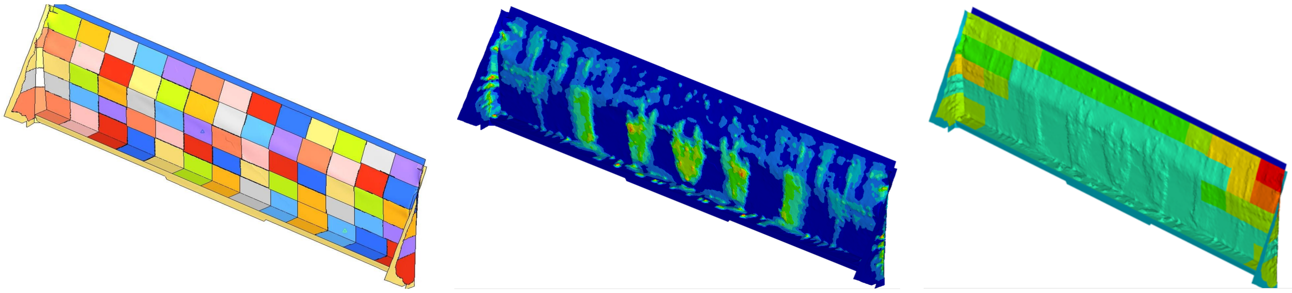
The rear bench of a car is fundamental to isolate acoustically the passengers compartment from the engine. The bench of Ferrari F430 has been analyzed with the objective of reducing the weight while maintaining the same vibrational performance of the reference panel.

Generally, the damping material distribution is not known during the numerical verification stage, but is decided later during the experimental analysis, where the material is added iteratively to counteract the first normal modes.

In this study vibration-damping material distribution and panel design, in terms of beads and thickness, have been optimized through size and topography optimizations at the same time. Size optimization is applied to control the thickness of the aluminum plate and of the vibrational-damping material. The presence of damping material should be limited to essential parts due to its relatively high weight. Thus, just one thickness variable was created for the aluminum layer because its value should be uniform along the plate, whereas several thickness variables were created locally for the damping layer. Topography optimization was used to improve the beads disposition in the panel. The objective of the optimizations was mass minimization, while the first normal mode frequency was constrained to be outside the range of interest (Fig. 2).

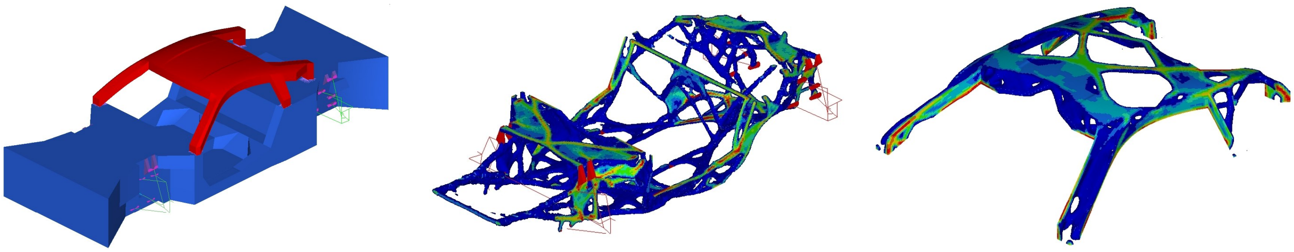
3.3. Automotive Chassis

Topology optimization has been applied to the design of an automotive chassis. The objective of the optimization is still the weight reduction while the performance requirements regard handling and safety standards, in detail: (i) global bending and torsional stiffnesses, (ii) crashworthiness in the case of front crash,



(a) Size optimization variables subdivision (b) Optimum configuration deformed shape (c) Damping material optimum thickness distribution

Figure 2: Rear bench coupled optimization. In the results, blue stands for low deformation/thickness, red for high.



(a) domain, or design space (b) optimum chassis configuration (c) optimum roof configuration

Figure 3: Automotive chassis topology optimization. In the results, the density range from 0.1 (blue) to 1.0 (red).

(iii) modal analysis, (iv) local stiffness of the suspension, engine, and gearbox joints. The initial design space is given by the provisional vehicle overall dimensions of Ferrari F430 including the roof (Fig. 3(a)). The results for the chassis and the roof are shown in Figs. 3(b) and 3(c). A more detailed discussion on a combined methodology for chassis design including topology, topography and size optimizations was presented in [5] by the authors.

4. CONCLUSIONS

A quick overview on structural optimization methods has been given including various application examples. Their potential has been shown to be large and it is believed that their spreading in mechanical design could boost innovation in industry considerably. Examples in the automotive field have been provided.

To be noted that the different methods have different characteristics and in a design process it is recommended to rely on more than just one technique. For instance, topology and topometry optimizations are more suitable for an early development stage, whose outcome could be further refined through size and shape optimizations. On a general basis these techniques do not deliver the shape of the final product, but they give useful hints to the designer in view of the product development and engineering.

5. REFERENCES

[1] G. Chiandussi, I. Gaviglio, and A. Ibba, *Topology optimisation of an automotive component without final volume constraint specification*, Advances in Engineering Software, 35:609-617, 2004.

[2] C. B. W. Pedersen, *Crashworthiness design of transient frame structures using topology optimization*, Computer Methods in Applied Mechanics and Engineering, 193:653-678.

[3] F. Duddeck, *Multidisciplinary optimization of car bodies*, Structural and Multidisciplinary Optimization, 35:375-389, 2008.

[4] M. P. Bendsøe and O. Sigmund, *Topology optimization: theory, methods and applications*, Springer, 2004.

[5] M. Cavazzuti, A. Baldini, E. Bertocchi, D. Costi, E. Torricelli, and P. Moruzzi, *High performance automotive chassis design: a topology optimization based approach*, Structural and Multidisciplinary Optimization, 44:45-56, 2011.