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OPTIMIZATION IN MECHANICAL PRODUCTS DESIGN : USE OF A COUPLING BETWEEN ALGORITHMS AND FINITE ELEMENT CALCULATIONS FOR THE DESIGN OF A VEHICULE FRAME.

Antoine Varret[1], Saïd Abboudi[1], Samuel Gomes[1] and Patrick Serrafero[2]
(1) Université de Technologie de Belfort Montbéliard, FR (2) Ecole Centrale de Lyon, FR

ABSTRACT
In traditional design, finding a solution is followed by a design and industrialization process. Finit element calculation solvers are mostly used as a means to validate the solution, and not as tools to facilitate the solution development. The resulting modifications lead to major costs because they occu late in the design process. This paper presents a coupling experiment between a finite element solver an a multi-criteria optimization algorithm to identify solutions when designing a racing vehicle chassis frame. Our proposed methodology is first tested on a simple example to bear out our theory and results.

Keywords: monocriteria optimization, multicriteria optimization, genetic algorithms, finite element calculations, mechanical products design.

1 INTRODUCTION

The design process can be defined as a development of technical solutions to meet customer needs through a functional specification [1]. It consists in solving incompletely-defined, open, collective c complex problems [2]. It is also connected with a process of constraint satisfaction, usually unconstraine at the beginning, and increasingly constrained later [3]. Multiple constraints - functional specification dimensional and production constraints- are taken into account gradually, resulting in a succession of elementary analysis - synthesis - assessment cycles [4]. These successive cycles may be due to creativ iterations, that is to say the integration of an unknown innovation when launching the project. Howeve these cycles are most often associated with dysfunction iterations such as the modification of the customer demand, difficulties in manufacturing, or maintenance [5]. While the need is to increase checkout loops to verify the customer demand compliance, the current general pattern remains that of a process under which considers constraints late and contains an insufficient number of checkout loops [6]

The rising product complexity responding to a customer request for more advanced functions, and the decrease of time-to-market tend to accentuate this phenomenon. Needs, constraints, and objectives ar multiplying. Meanwhile, companies have been focusing their activities on their expertise area for over 2 years, and outsourcing minor activities by generalizing the use of subcontractors. The traditional sequential design is less and less suited for this new context of time reduction and activity extended t outside companies. Collaborative engineering has been developed for several years [7], as well as the us of Product Lifecycle Management (PLM), Knowledge Based Engineering (KBE) [8] [9] and solution based on internet technologies [10] [11]. In an integrated design process, it is recognized that optimization should take place as soon as the design phase, by respecting functional specification constraints induced by different trades [12]. However, the solution identification meant to satisfy ever constraint is often the final stage of the project, while many parameters allow an unexplored variabilit and an untapped source of improvement [13]. Designing first, then calculating, and possibly optimizing remain widespread. Dimensioning is intuitive and performance evaluation is belated. Calculation widel remains a validation tool and not a tool for design help. It is used in a detailed design phase, when th CAD model is advanced. Every model modification following an assessment calculation is long and expensive to implement [14].

In terms of optimization, mathematical tools have also changed in recent years. The advent of genetic algorithms have lead to many fields of applications, allowed to manipulate discrete or mixed variables and non linear functions, which was not possible with older methods such as the gradient calculation. Th success of these methods, as well as their integration into more and more sophisticated software tools extend their application possibilities in the field of mechanical product design [15]. Coupling betwee optimization algorithms and finite elements (F.E.) calculations is not yet new. Many works have alread been realized, with statics, dynamics, fluid dynamics calculations, separately or combined, and it allowe structures topological optimization [16], [17], [18], [19], [20]. Optimization main difficulty in this are lies in the coupling between algorithm and F.E. calculation. Indeed, few F.E. solvers have such algorithms as integrated solutions. It is probably the reason why genetic algorithms are not widesprea although they are not new, and determinist algorithms are mostly used in these works. If there are sever objective functions, these will be balanced in a single global function, with associated difficult to hav non homogeneous magnitudes, and the need to restart optimization process if balance is modified. Finally, multicriteria optimization is not widespread in mechanical dimensioning.

This article aims at illustrating the contribution of some most common optimization algorithms, couple with F.E. calculations to help the mechanical product design. The aim is to explore the improvement scope of the identified solution, by using measurement results from F.E. calculations. Those are not only validation tool, but also a designing tool, taking part into the process of optimization. The latter tends t improve the originally developed solution. Indeed, time reducing and diversity of needs - economy, engineering and technology- make a complete optimization process difficult with a global optimum search. Our proposed approach will be first validated with an analytically verifiable simple case befo being applied to the design case of a racing vehicle chassis frame.

2 PLACE OF THE WORK IN A COLLABORATIVE DESIGN OF MECHANICAL SYSTEMS

Our collaborative design methodology of mechanical systems has been developed to cut down on time spent during routine design. This methodology is based on a direct approach of multiple objective optimization including functional requirements and knowledge-based engineering. It leads to a parametri CAD model of a product which is optimized according the functional requirements and design rules. Its structure uses the Internet technology and a collaborative PLM environment [21] [22].

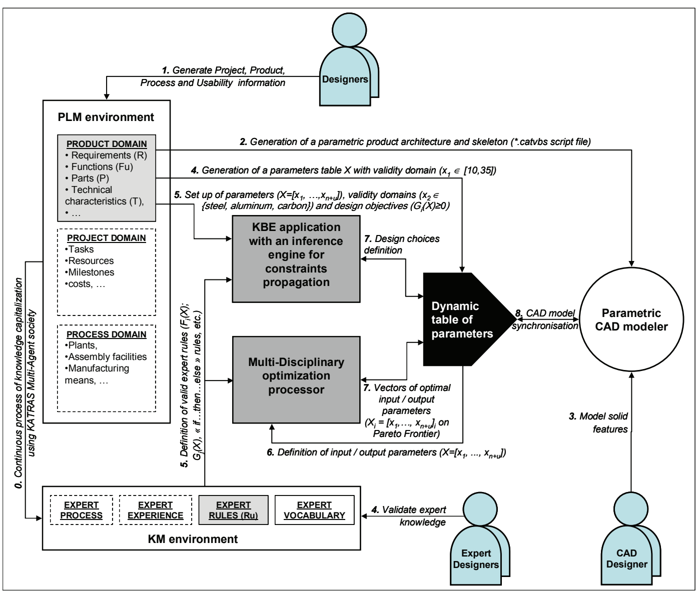


Figure 1 Proposed collaborative design methodology

Abbreviation	meaning	Abbreviation	meaning
KBE	Knowledge Based Engineering	**PLM**	Product Lifecycle Management
KM	Knowledge Management	**SMA**	Multi Agent Society

Table 2 Used abbreviations

As shown in Figure 1, the methodology involves several steps :

- First stage: from functional requirements recorded in the PLM environment, automatic generatio of CAD parameterized architecture.
- Second stage: designers build their model by respecting the generated parameterized architecture
- Third stage: Use of an inference engine with constraint propagation to interconnect the variou design parameters, objective functions and constraints.
- Fourth stage: optimization of the product according to the objective functions, functional parameters and expert rules. This step is based on a multicriteria optimization process to suppo decision and help the selection of optimal values for the product director settings [24]. Since objective functions are not analytical in any case, this step uses meta-heuristics optimization methods.
- Fifth stage: visualization of the final product by upgrading the parametric CAD model with th final values of optimized parameters.

The work presented in this article only relates to the fourth stage of the process. It focuses on the integration of the optimization step in the design process, by using measures from a F.E. solver for th objective functions. This step will be as easy to implement as the mechanical design could be formulate in an optimization problem :

- Definition of the input problem variables: they are unfixed quantities of the initial solution.
- Identification of validity areas for these variables: lists of eligible materials, minimum dimensio and maximum size...
- Objective formulations : weight decrease, rigidity increase, material costs and manufacturing tim reductions...
  These objective functions can come from a mathematical formulation, -calculation model linkin constraints and objective functions to the input variables- or from numerical simulation result such as F.E. calculations for example, made from a CAD model. In this case, the CAD mod must be parameterized according to the input variables.
- Formulation of constraints to respect (constraints of equality or inequality)

The introduction of an optimization loop in a design process is done according to the following steps:

- Identification of a solution satisfying all the specifications of the functional requirements
- Use of an optimization algorithm to explore areas of validity in the respective input variables
- Solution selection located in the Pareto front, which emphasizes the objective function considere as a priority, or the solution with a good compromise between several objectives while respectin all the constraints.

3 APPLICATIONS

3.1 Software tools used

The implementation of this approach was based on the use of the following tools:

- CAD parametric modeler : use of CATIA V5.
- F.E. solver : use of ANSYS software. The input variables have been declared as ANSYS mod parameters.
- Optimization algorithm and loops : use of MODEFRONTIER software allowing the coupling of large number of algorithms with ANSYS for driving direct numerical simulations.

3.2 Validation of the approach

The result validity obtained with this software series was first checked out with an example of finite element calculations which were simple enough to be analytically verifiable. This example has demonstrated the following points:

- Validity of strain values obtained from F.E. solver for the analysis of the structure behavior subjected to a static loading.
- Validity of the deformation values resulting from the optimization algorithm coupled with th finite element solver.

This example also allowed to assess the performance of different optimization algorithms in terms of convergence speed and coherence with the obtained optimal solutions.

3.2.1 Simple case presentation

The studied structure is a plane triangular structure made of three beams of identical length, L = 100 mm subject to a constant load, figure 3. Beams have a square tubular section (width *a* and thickness *e* The choice of such a structure is related to the design of the chassis frame as shown below, consisting i various tubular section tubes (round, square, or various sizes) assembled by welding, and a composite floor. The triangular structure incorporates the design principles and finite element calculation principle applied to the chassis frame : digital wire structure covered with 1-dimension mesh, allocation to thi mesh of material and section characteristics (steel used type S235). Only the case with square sections presented, although the case with round sections has also been considered.

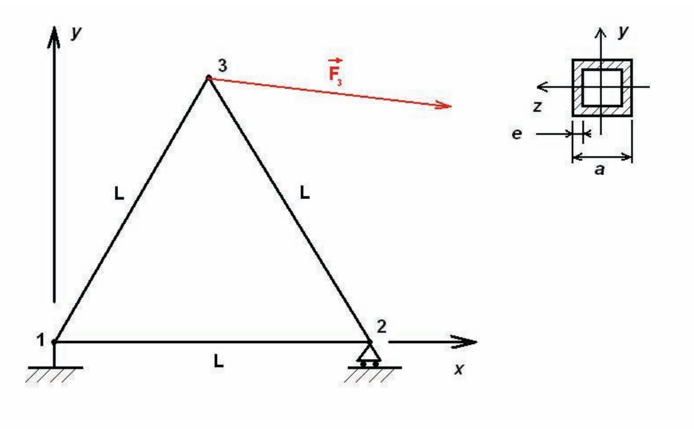


Figure 3 Triangular structure used for the analytical calculation

The physical and geometrical properties of the structure are defined in Table 4 below. Among these dat we have kept only two variables: the width and thickness of the beams.

Constants of the problem				
Material	Standard steel (S235)		Static load	
Elasticity modulus	E=210 000 MPa		peak 1	Knuckle link
Density	ρ = 7850 kg/m3		Peak 2	Linear annular link of Ox axis
Beam lenght	L=1000 mm		Peak 3	Constant load (F_{3X}=10kN ; F_{3Y}=-1kN)
Variables of the problem				
Beams	Constant section		Normal section area	$S = a^2-(a-2e)^2$
Section type	Square, hollow, tubular			
Section width	$10 \leq a \leq 100$ mm		Moment of inertia	$I = [a^4-(a-2e)^4]/12$
Section thickness	$0{,}5 \leq e \leq 5$ mm		Mass of the structure	$m = 4\,\rho\,S\,L$

Table 4 Problem data

The analysis goal is to identify the structure displacements u_i, v_i and rotations θ_i at nodes (1, 2, 3 $(X_i; Y_i; M_i)$ are the coordinates of loads transmitted at nodes (1, 2, 3). The global expression of the stiffness matrix leads to the following system: :

$$F = K.U \qquad (1$$

With : F : matrix of loads applied to the structure
U : matrix of displacements
K : stiffness matrix (symmetric)

$$K = \frac{E}{4L}\begin{bmatrix} 5S+3A & \sqrt{3}.(S-A) & 0 & -2B\sqrt{3} & -4S & 0 & 3A-S & \sqrt{3}.(A-S) & -2B\sqrt{3} \\ & 3S+5A & -4A & 6B & 0 & 4B & \sqrt{3}.(A-S) & -(3S+A) & 2B \\ & & 3S+5A & -4B & \sqrt{3}.(A-S) & -6B & \sqrt{3}.(S-A) & -(3S+A) & -2B \\ & & & 32.I & 0 & 8.I & 2B\sqrt{3} & -2B & 8.I \\ & & & & 5S+3A & -2B\sqrt{3} & -(S+3A) & \sqrt{3}.(S-A) & -2B\sqrt{3} \\ & & & & & 32.I & 2B\sqrt{3} & 2B & 8.I \\ & & & & & & 2(S+3A) & 0 & 4B\sqrt{3} \\ & & & & & & & 6S+4A & 0 \\ & & & & & & & & 32.I \end{bmatrix} \quad F = \begin{bmatrix} X_1 \\ Y_1 \\ Y_2 \\ M_1 = 0 \\ X_2 = 0 \\ M_2 = 0 \\ X_3 = 10000 \\ Y_3 = -1000 \\ M_3 = 0 \end{bmatrix} \quad U = \begin{bmatrix} u_1 = 0 \\ v_1 = 0 \\ v_2 = 0 \\ \theta_1 \\ u_2 \\ \theta_2 \\ u_3 \\ v_3 \\ \theta_3 \end{bmatrix}$$

With : $A = {}^{12\,I}/_{L^2}$ $\qquad B = {}^{6\,I}/_{L}$

The Cholesky method is used to solve the linear system (1). Displacement at node 3 is determined by th following relation : $\Delta l = \sqrt{u_3^2 + v_3^2}$ (2

3.2.2Formulation of the optimization problem

The study objective is to minimize the structure mass while retaining displacements within acceptabl limits. The problem can occur in two different ways:

- Mass minimization with a maximal displacement constraint at node 3: This is a mono-objectiv optimization problem with inequalities constraints.
- Identification of a compromise between two objectives to minimize : mass and displacement a node 3. This is a multi-objective optimization problem.

3.2.3Mono objective optimization problem

The problem is formulated as follows :

Find	$f(x^*) = \min_{x\in S}[f(x)]$
Under constraint	$C(x) \leq 0$
With :	$x = (a; e) \in \mathbb{R}^2$
	$0{,}5 \leq e \leq 5$ mm
	$10 \leq a \leq 100$ mm
	$f(x) \in \mathbb{R}$
	f(x) = 3 ρ S L with S = a2-(a-2e)2
	$C(x) \in \mathbb{R}$
	$C(x) = \Delta l - 1 = \sqrt{u_3^2 + v_3^2} - 1$

The "objective" function f (x) denotes the structure mass. This function depends on two variables: width and thickness *e* of the beams. The constraint function C (x) reflects the displacement of node 3 limited t 1 mm in this study.

From a software point of view, the coupling (noted FEM-OPT) between F.E. solver and optimizatio software allows the automatic F.E. calculations on the basis of input variables values defined by the optimization software. Results from the solver (objective functions values) are uploaded in the optimization software that will determine new values of input variables for the next iteration. Th coupling allows to launch series of F.E. calculations for different configurations automatically. Howeve the main limitation is the duration of an iteration: a few minutes for a basic calculation as in the studie type. The outlined process contains several hundreds of iterations, and requires dozens of hours for calculation.

Among the mostly used determinist algorithms, we can cite gradient method which search the higher slope direction of the objective function and BFGS algorithm (Broyden-Fletcher-Goldfarb-Shanno), use to approximate the hessian matrix of the objective function, and known to be more stable and converg faster than others algorithms in general. This one uses the following equation :

$$B_{k+1} = B_k - \frac{1}{s_k^T B_k s_k} B_k s_k s_k^T B_k + \frac{1}{y_k^T s_k} y_k y_k^T \quad (3)$$

With B_k : Hessian matrix of the objective function (B_0 : identity matrix)
s_k : change in x during the k-th iteration : $s_k = x_{k+1}-x_k$
x_k : design vector
y_k : change in gradient

The results show that progress is mainly done by following the thickness, except when the minimum thickness is reached. 3 series of iterations have been done from different initial solutions. Series converg to different solutions depending on initial start point, but with identical characteristics for the mass an the displacement at node 3. The results show that there are many solutions to this mono objective optimization problem. It is justified by the objective function shape, as an inclinated shape following th thickness (this function has none optimum values following the thickness). The solutions identified hav different thickness and width values but all reach the same minimal value for the mass (2,55 kg) and th same acceptable maximal displacement at node 3 (1 mm).

Variables values for different initial solutions				
Initial solution	**Thickness [mm]**	**Width [mm]**	**Mass [kg]**	**Displacement / node 3 [mm]**
n°1	2.75	55	13.54	0.19
n°2	0.75	20	1.36	1.88
n°3	4.75	20	**6.82**	**0.37**

Results						
Initial solution used	**Values obtained for the final solution**				**Gain [%] / initial solution n°3**	**Number of iterations**
	Thickness [mm]	**Width [mm]**	**Mass [kg]**	**Displacement / node 3 [mm]**		
n°1	0.5	54.51	2.54	1.00	63	80
n°2	2.44	13.55	2.55	1.00	63	155
n°3	1.55	19.04	2.55	1.00	63	160

Figure 5 Results obtained for the mono objective optimization problem

3.2.4 Multi-objective optimization problem

The multi-objective optimization problem is formulated as follows :

Find $F(x^*) = \min_{x \in D} \{f_1(x); f_2(x)\}$

With : $x = (a; e) \in \mathbb{R}^2$

$0,5 \leq e \leq 5$ mm

$10 \leq a \leq 100$ mm

$f_1(x) \in \mathbb{R}$ $\quad f_2(x) \in \mathbb{R}$

$f_1(x) = 3\rho SL$ with S = a2-(a-2e)2

$f_2(x) = \Delta l = \sqrt{u_3^2 + v_3^2}$

The difference between this problem and the previous one is that the displacement at node 3 has been considered as the second objective function to minimize, instead of the constraint function (1 mm acceptable maximal displacement).

The problem is solved by constructing the Pareto front which includes al thel "not superior" solutions. can be defined as the set $\hat{\mathbf{X}}$ of solutions $\hat{x} \in \mathbb{R}^2$ respecting the following condition : , $f_1(x)$ can't b improved without deterioration of $f_2(x)$ and reciprocally. Building the Pareto front allows to make choice between the best possible compromises.

The problem was sorted out by using standard genetic algorithms (MOGA-II) as defined in [26]. These methods implement iterative mechanisms of stochastic type. The idea is to generate a population of individuals at random (the search points), and to make this population evolve by following 3 basic operators:

- Selection: choice of two individuals
- Crossing: building of two new individuals
- Mutation: random disturbance of the individual characteristics (amendment of its "genetic code"

The results show that all the solutions are localised into the Pareto front. The reason could be that the tw objective functions are probably linked by the following kind of function (not demonstrated) :

$$\text{Displacement} = \text{constant} / \text{mass}^{n}$$

It means that it is not possible to reduce mass and displacement at node 3 simultaneously. One should then select solutions that tend to favor the mass, or the displacement, which depends on the favored objective.

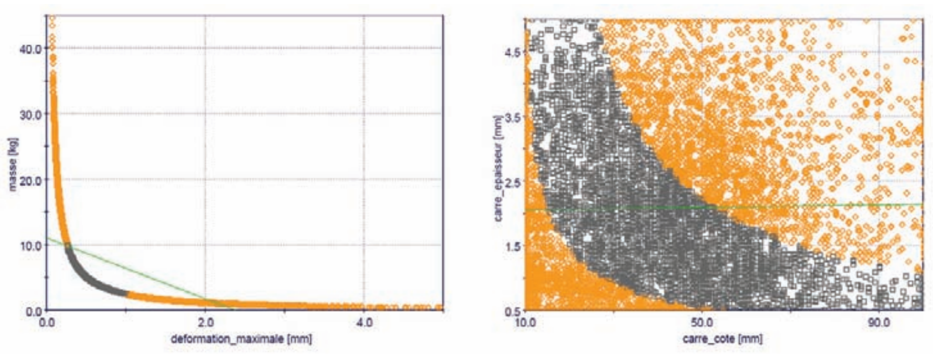


Figure 6 Results obtained with genetic algorithms for the multi-objective optimization problem Orange color is used for solutions with excessive mass value (over than 10 kg) or excessive displacemen value (over than 1 mm).

The FEM-OPT calculation approach (coupling between finite elements solver and optimization softwar is the same as described previously.

3.2.5Results validation

On Table 8, the results of the analytical solution and of the FEM-OPT coupling are presented. We no that the differences between the two methods are sufficiently low (0% for the mass, 0.16% for displacement at node 3).

solution	e [mm]	a [mm]	Mass [kg]			Displacement at node 3 [mm]		
			Software result	Analytical result	**difference [%]**	Software result	Analytical result	**Difference [%]**
Initial n°1	2.75	55	13.535	13.535	0	0.1877	0.1880	0.16

Table 7 Comparison between analytical and FEM-OPT calculations

3.3 Approach extended to a specific application case

3.3.1 Project context

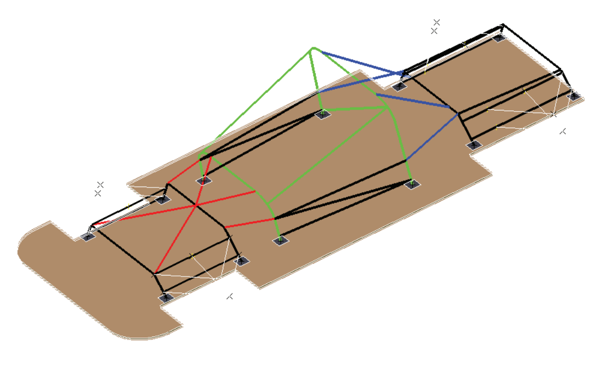
Once our methodology is validated, it will be carried out on on a real case design, that is a racing vehicl chassis frame. This vehicle is designed and produced entirely by students taking part in the SIA challenge, a French road racing organized by the SIA – "Societé des Ingénieurs de l'Automobile".

It is a contest opened to student teams whose goal is to go as far and as fast as possible, but polluting a less as can be, with 10 liters of gasoline only, and with a vehicle complying to regulation. The latte includes design requirements and safety rules to be observed in different parts of the car : chassis fram ground links, motorization, cockpit, and bodywork.

Our university has been taking up this challenge for several years, with the ambitious goal of redesignin and implementing a new vehicle every year, so as to achieve a 30 percent superior performance, compared with the vehicle designed the year before with an equal budget. Our objective is all the more ambitious that the team is completely renewed from year to year, owing to student graduations at the en of the year (only graduating students are involved). In this context, any contribution to improve the performance and design of this vehicle is fully justified.

3.3.2 Design characteristics

The vehicle chassis frame is made of a set of welded tubes and a composite floor. All mechanical organ of the vehicle are supported by the chassis frame, while the composite floor is only used to rigidify th structure. The tubular part is made of 4 different groups of tubes, three groups with a round section wit various dimensions, and one group with a square section. All the tubes are made of standard steel (S23 type). The floor is composed of a 28-millimeter-thick sandwich structure coated on both sides with fiberglass impregnated with resin (1 mm thickness). Figure 9 shows the position of the different groups c tubes. To facilitate the distribution of efforts generated by the road on the chassis frame, ground links ar modeled in a simplified form but with the actual position of their different attachment points.



Colors meaning

Black : Square tubes

Green : Round tubes, size 1 (big size)

Blue : Round tubes, size 2 (middle size)

Red : Round tubes, size 3 (small size)

White : Ground links

Mushroom : Composite floor

Figure 8 chassis frame design characteristics

The chassis frame CAD design uses digital wire elements (the tubular structure) and surface elemen (central alveolar structure, upper and lower skins of the floor). The section characteristics for the digit wire element and the surface elements have been implemented into the F.E. solver.

3.3.3 Finite elements analysis of the chassis frame

The analysis carried out with the F.E. solver is a static analysis of the chassis frame, subject to the loa defined in compliance with the Regulation:

- Cockpit back roll bar subject to a vertical force with an intensity equal to 7.5 times the vehicl weight
- clamping links with the ground in the front wheels

- Contact link with the ground for the rear wheels.

Figure 10 shows the analysis results of the initial chassis frame calculations, before the optimizatio stage. Dimensions of the different profiles have been intuitively determined, regarding to the suppose areas of maximum constraint, and in compliance with the Regulation. Characteristics of this initial solution is a 37 kg mass and 61 mm maximal displacement, which is located at the vertical force application point.

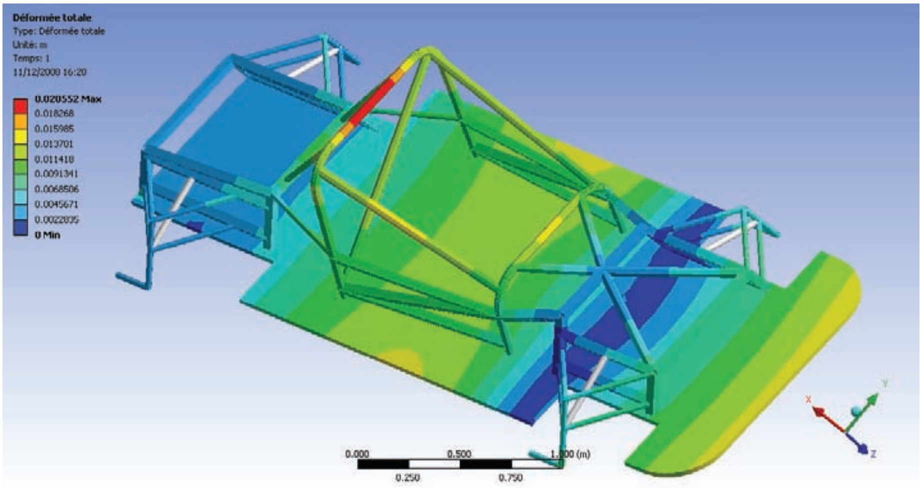


Figure 9 : F.E. calculation on the initial chassis frame

3.3.4Formulation of the multi-objective optimization problem

This problem is similar to the multi-objective optimization problem regarding the triangular structure The input variables are more numerous, and correspond to the different groups of tubes used in Figure 9 Table 11 details the various data of this problem

Input variables		
Square section tube	20 ≤ carre_cote ≤ 50 mm	0,5 ≤ carre_ep ≤ 4 mm
Round section tube, size 1	45 ≤ rond1_diam ≤ 60 mm	0,5 ≤ rond1_ep ≤ 5 mm
Round section tube, size 2	20 ≤ rond2_diam ≤ 40 mm	0,5 ≤ rond2_ep ≤ 3 mm
Round section tube, size 3	15 ≤ rond3_diam ≤ 30 mm	0,5 ≤ rond3_ep ≤ 3 mm
Objective functions		
Mass of the chassis frame	Measured value from the finite elements solver	
Maximum displacement	Measured value from the finite elements solver	

Table 10 multi-objective optimization problem data for the chassis frame

3.3.5Results obtained

Figure 12 and table 13 show the results obtained after the optimization phase. The mass and maximu displacement values of the initial chassis frame (37 kg – 61 mm) are the upper limits of the optimizatio process. For the resolution, genetic algorithms were used in the same manner as in the triangular structure. The successive simulations carried out by the F.E. solver were launched automatically from th software optimization. On the hardware aspect, calculations have been done on a late model of an offic automation computer (2 GHz, 3072 Mo). Two calculation series have been done. A 300 iterations fir serie took a calculation time of 19 hours. For this serie (left image), around 90% of the solutions ar outside of the limits (orange points). The resolution allowed to build the Pareto front, containing the no superior solutions. We know that a modification of an input variable for a solution taken on the Paret front will deteriorate one or both objective functions. This first optimization phase showed that the thickness values where globally excessive and width values where insufficient. Normally, rigidity can b increased without modify the mass by increasing width and decreasing thickness. Referring to these observations, a 20 iterations second calculation phase have been done with new values domains for th input variables, allowing to obtain about ten supplementary points on the Pareto front. This second optimization phase give more possibilities to the designer to choose an alternative solution (a lighte chassis but more flexible, or more rigid but heavier) between the two extreme cases obtained at the fir: phase :

- Item 65 : similar mass with initial solution, 48 mm maximum displacement, corresponding t a 21% decrease.
- Item 154 : similar maximum displacement with initial solution, 30,8 kg mass correspondin to a 20% decrease.

We can see that solutions identified at the second optimization phase have decreased values of maximur displacement, the best solution regarding this objective allows a 33% decrease (item 3).

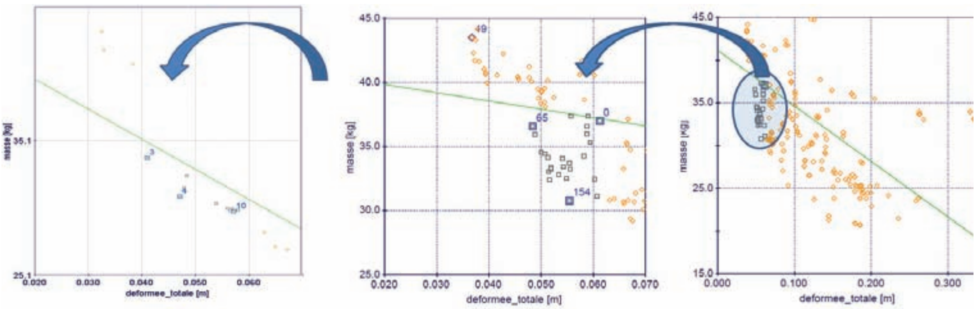


Figure 11 Results from the coupling FEM-OPT allowing to test different parameter sets.

First optimization phase										
Id	square widht [mm]	square thick [mm]	round1 diam [mm]	round1 thick [mm]	round2 diam [mm]	round2 thick [mm]	round3 diam [mm]	round3 thick [mm]	Max Disp. [m]	ma: [k
0	30	2	48	3,2	48	3,2	30	2	0,061	37,05
49	40	2	56	4,1	40	2,5	15	1,1	0,037	43,55
65	40	1,7	55	2,6	36	2,8	15	1,7	0,048	36,61
154	45	1,3	60	1,6	50	0,8	20	0,9	0,055	30,83

Second optimization phase												
<ID>	square width [mm]	square thick [mm]	round1 diam [mm]	round1 thick [mm]	round2 diam [mm]	round2 thick [mm]	round3 diam [mm]	round3 thick [mm]	Max Disp. [m]	Max disp. Decrease	mass [kg]	Mas decr
3	55,0	1,2	70,0	1,5	40,0	1,8	12,5	2,0	0,041	33%	33,8	9%
4	55,0	1,0	70,0	1,5	40,0	1,0	12,5	2,0	0,047	23%	30,9	16%
10	47,5	1,0	65,0	1,8	30,0	1,2	12,5	2,0	0,057	7%	29,8	19%

Table 13 : characteristics of the optimized solutions

About the planning, this optimization process have been done after the race, and results could not be use for the vehicle realized. However, it allows to identify possible progress margins and process to follo for the next challenge.

4 CONCLUSION AND PERSPECTIVES

Our approach has helped to illustrate the benefits of using optimization algorithms coupled with F.E. calculations in a process of product design. The F.E. solver has been used to get the solution, not only as traditional validation tool. The method gave results with no need to have a mathematical expression of objective functions. However, some remarks are to be made:

Our analysis was exclusively based on a model made of digital wire and surface elements. The advantag of this model is time saving for finite elements computations. In this context, the convergence speed c the algorithm was not an essential factor. The deployment of the approach on other projects with moı complex models, would require longer computing time. It would then be necessary to develop and asses methodologies allowing to minimize the number of simulations, and thus the computing time.

This study made with a static load is partially representative of the chassis frame life situations. A dynamic study would therefore bring a significant contribution to the design. This study will be the further work.

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