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Design Automation of Electric Vehicle's Aerodynamic Parts

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Abstract. The design process of electric vehicle aerodynamic parts is a specific challenge for engineers, especially in automation of such design tasks case. Classical techniques of the design process automation such as simple model parametrization become not sufficient for the surface modelling techniques. Furthermore, validation of every implemented changes into the model forces the need for special CFD (Computational Fluid Dynamics) software application. Such approach requires data transfer between usually two or more different kinds of methods supported by different advanced software. Any model changes are based on subjective CFD analysis results interpretation. In this paper, authors show a novel approach to design of electric vehicle aerodynamic parts using specially developed distributed system that combines CAD, CFD and additional optimization control software. The main task of the proposed system is automatic generation of elements optimal from the aerodynamics point of view. The main issue in such case is proper distribution of different design tasks between different kinds of software performing their tasks on the basis of advanced methods. Proper data transfer and complex mathematical description of parametrised surfaces is necessary to control such process of optimization in proper way. Mathematical approach allows for parametrization and optimization of generated surfaces. All of those problems with proposition of the distributed optimisation system are indicated and described in the paper.

Keywords. Electric vehicle, Generative Model, Computational Fluid Dynamic, Aerodynamic, Optimisation, Surface Modelling

Introduction

The need of development of the complex methodology of model's generation directly results from the characteristic of objects, that are in the field of authors interest. The design of the vehicle body, especially designed to participate in the race, requires an interdisciplinary approach. This difficulty with the issue concerning the complex shape and surface structure causes many problems on the ideation and design stage of the project. The standard procedure used during design is an iteration process based on

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knowledge and experience of designers and features of version under modification. This approach gives good results, but it is very laborious and time-consuming. The additional problem is in many cases data flow between different environments (CAD and calculation software) used during the design process. The important issue is also the necessity to participate in this process specialists/experts of many domains, who perform each stage from the beginning to the end. Not always the modifications lead to the project, that is acceptable in the context of the next stage or its condition is better in context of the other aspects or criteria (e.g. modification concerning the aerodynamic aspects can result in complications in mechanical solutions, strength or technological aspects). Therefore, in order to improve the efficiency of the design and construction process, it becomes necessary to have a system that integrates the various stages and coordinates the direction and method of design modification due to all aspects affecting it.

The object that requires the most effort while designing the vehicle is the body. This is due to several factors. The main ones are the necessity to solve problems in many areas at the same time and to create a model that will allow for easy changes at the modification stage. Therefore, an attempt was made to conceptual work on the development of a system allowing for an automated process of creating and optimizing the race vehicle trim. The assumption of the system is the autogeneration of the body structure based on a predefined mathematical model controlled by initial assumptions, limitations and feedback data from analyzes being part of the system. The proposition of the authors is the fusion of three different environments that ensure the complexity of the system:

- CAD environment that allows to implement predefined patterns and integrate results and visualization
- The environment of FEM calculations that allows conducting strength and CFD analyzes
- The computational environment that enables advanced process of optimization and interpretation of results

The process sequence is to generate a point cloud based on predefined models, initial assumptions and constraints. The point cloud will be transformed into a surface that will be a version of the body. Then the model will be sent to strength calculations and CFD. The results of these calculations will be the input data for the optimization process. The results of the optimization process will be control data during the modification phase of the surface model, the next version of which will be subjected to the presented procedure. The number of iterations will depend on the adopted limit value of certain parameters, e.g. the value of the air resistance coefficient. This procedure is described in detail in the following parts of the article.

1. Surface modelling techniques

The Surface modelling technique is one of the most advanced techniques of CAD design. The main difficulty is related to the complex mathematical description of a modelling object. The need of knowing the curves and surfaces theory forces a special approach to the design proces [1]. On Figure 1 is presented an example object designed by surface modelling techniques.

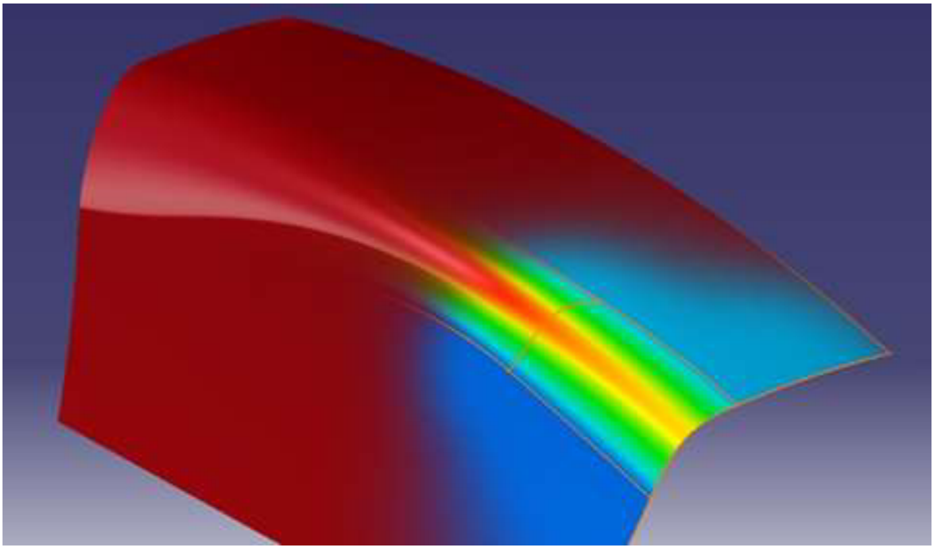

Figure 1. Examples of an object designed by surface modelling techniques.

One of two main approaches can be used for a surface model elaboration. The first one is the Freestyle Surface Design (FSD) technique, the main concept behind the FSD is to generate a simple shape and then shaping it by manipulation of control points[1][2][3]. Using this technique is possible to develop very complex shapes in a fast and easy way, but one of major disadvantage of such type elaborated models is that they are unique. By unique should be understood that the way how the model was shaped is almost impossible to reconstruct a very difficult to redesign. Usually, the FSD is used in cases that are especially focused on the product design, in engineering usage is not so popular [1] On Figure 2 is shown a design process of an example surface by using the FSD technique.

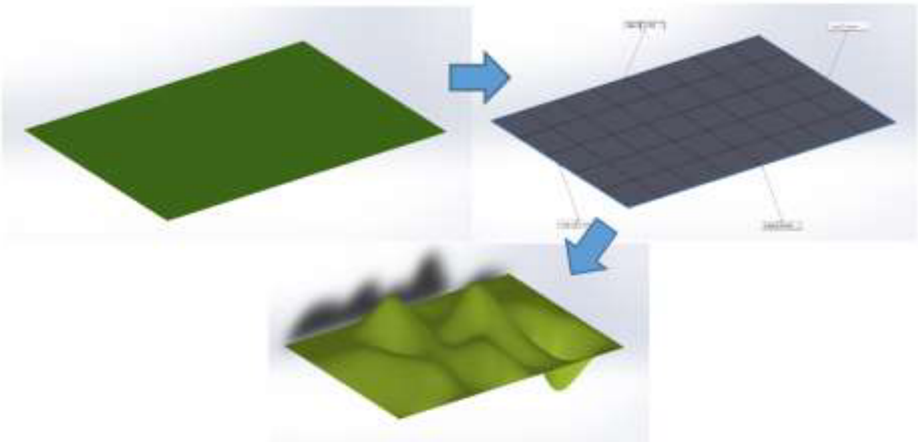

Figure 2. An example of the FSD techniques usage.

The second approach to the surface modelling is modelling by using parametric curves and surfaces. In this approach, the model is elaborated by previously defined profiles [1] [2] [3]. As profile, any curve that does not feature closed loops can be used. Using operations such as extracting or swiping change profiles into surfaces [2] [3]. The approach based on parametric surfaces is widely used in engineering design tasks because it gives an engineer more control on the final shape of the model and can be easily reconstructed or redesign [1]. On Figure 3 is presented an example process of a surface developing by using parametric curves.

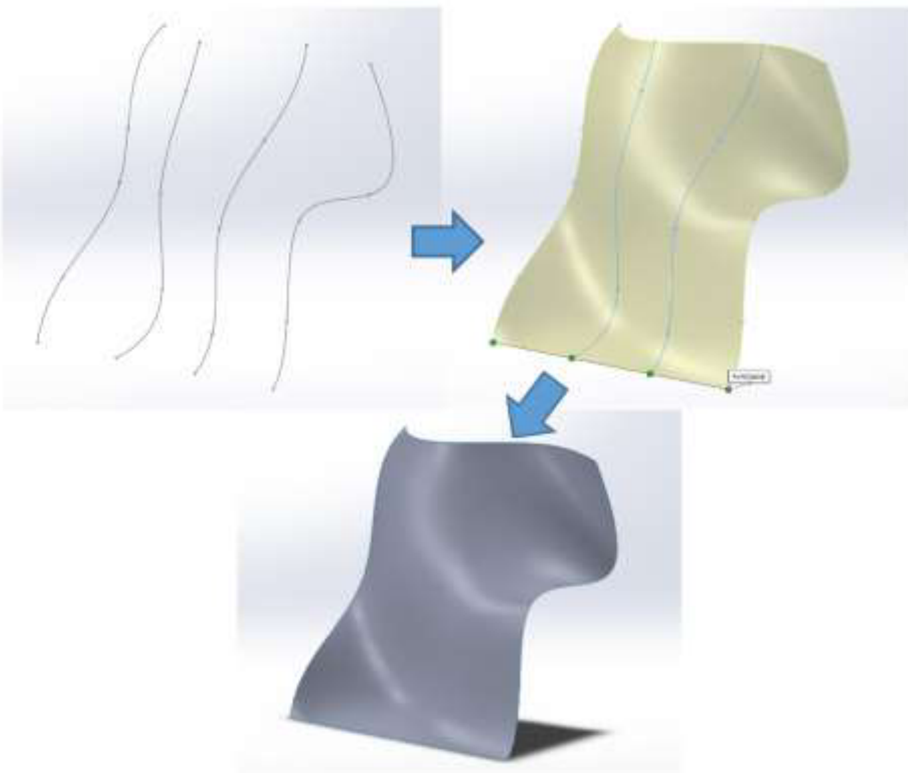

Figure 3. The process of developing a surface by using parametric curves.

2. Automation of the surface modelling process

Considering all advantage and disadvantage of both approaches, the FSD and the parametric, the authors decided to find a way to combine them and create an easy to automate system for surface models developing. The mentioned system will be a core element of a distributed system for aerodynamic parts design.

The main authors' idea is to generate a parametric surface by using control points and mathematical description such as Bezier equation for surfaces (1) [4] [5] [7]. On Figure 4 is shown the concept of the Bezier surface.

$$p(u,v) = \sum_{i=0}^{n} \sum_{j=i}^{m} B_i^n(u) B_j^m(v) k_{ij} \tag{1}$$

$$B_i^n(u) = \binom{n}{i} u^i (1-u)^{n-i} \tag{2}$$

$$\binom{n}{i} = \frac{n!}{i!\,(n-i)!} \tag{3}$$

Where: $u, v -$ the parametric surface's coordinates in u and v direction,
$n, m -$ the surface's degree, $i, j -$ number of the control point in i and j direction,
$k -$ the control point's coordinates.

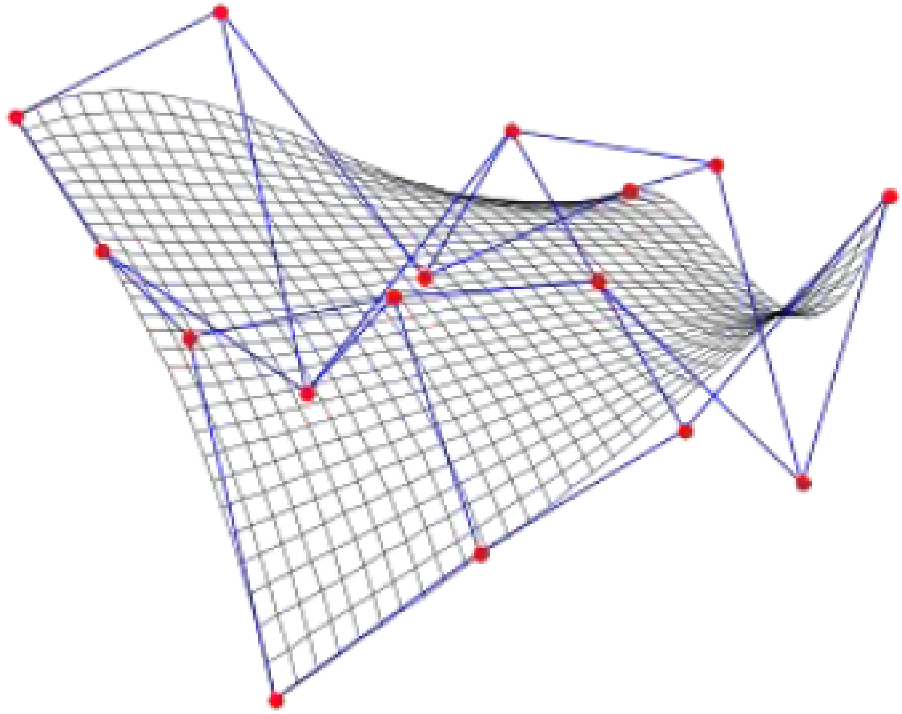

Figure 4. Graphical interpretation of the Bezier surface. Red – control points, blue – a control grid, black – a resultant surface.

The presented way allows design complex surfaces using parametric curves but not defined directly, but defined by few number of control points [4] [5]. By reducing the number of variables, a process of surface models automatization become much easier. In the presented approach, the atomization system is used in a Generative Model form to control coordinates of a relatively small number of control points where the position of points can be controlled by for example a CFD analysis results [4] [5] [7].

3. Numerical computational aerodynamic studies

Numerical computational aerodynamic studies represent a significant part in the design and optimization of car bodies. In comparison with tunnel based research, carrying out research using numerical methods [7,8] is relatively faster and less expensive. Based on numerical methods of calculation it is possible to simulate any ambient conditions, referred to as boundary conditions and visualize the distribution of parameter values as desired, for example the pressure distribution on the surface of the vehicle or the air speed distribution in the plane coinciding with the plane of symmetry of the car. Depending on the developed model, numerical methods [7,8] could provide high accuracy data. Their results can be compared with ongoing tunnel research on the physical model. This type of research—using virtual models created in a CAD environment eliminates necessity to manufacture physical model of the object of every developed version of optimized object, which significantly increases the costs of development process. Such approach makes it possible to determine the right direction of its development and to optimize its shape for the lowest aerodynamic drag in the early stages of the car body surface design process. Optimisation of vehicle aerodynamics considering its influence on total vehicles movement resistance is extremely important. It allows a significant reduction in the size of the required power units, which is associated with reduction of vehicle total weight and the energy absorbed by the power unit. Due to the continually rising fuel prices as well as environmental considerations in the current trend of the development of the automotive industry, vehicle weight reduction and energy consumption are very important issues.

In fluid mechanics, there are different flow distributions due to different criteria. From the aerodynamics point of view, the division of flow due to the motion of fluid particles is important [9,10]. Consistent with this criterion the flow may be laminar or turbulent. Laminar flow [8] is a stratified flow, where the fluid flow creates a parallel, smooth layer. Depending on the shape of the walls of the object on which the fluid passes, the flow lines are straight or gently curved. The flow of this type is for small and medium speed for contractual Reynolds numbers less than 2300. Turbulent flow [8] is characterized by the presence of time-varying flow disturbances, so-called turbulences, manifesting with blenders fluid particles. The characteristics of the flow are variable in time and space. Turbulent flow occurs at high flow velocities Reynolds numbers above 2300.

Aerodynamic forces acting on the car in motion in air [11,12] have several components. The components of the aerodynamic force relevant to the issues to be analysed are components acting along the longitudinal axis of the vehicle (so-called drag force) Px (4) and the lift Pz (5).

$$F_x = \frac{1}{2} * \rho * S * v^2 * c_x \tag{4}$$

$$F_z = \frac{1}{2} * \rho * S * v^2 * c_z \tag{5}$$

where:

ρ is the air density, S the surface area of the object, v the speed, c_x is the longitudinal drag force coefficient and c_z is the lift drag force coefficient.

Other forces and moments acting on the car in motion are the lateral force FPy, the pitching moment My, heeling moment Mx, deflection moment Mz.

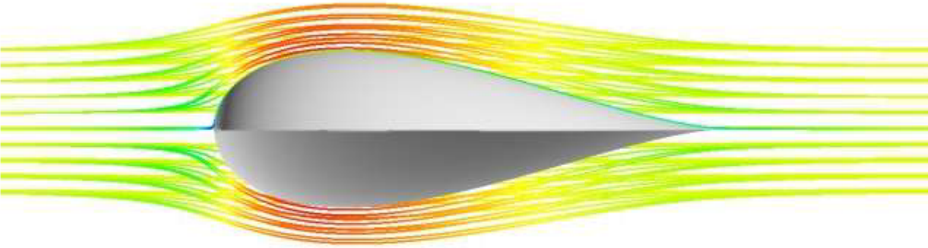

Figure 5. Flow directions in CFD aerodynamics.

Aerodynamic resistance [11÷14] is a movement counter force. Natural coordinate system of the tested issue is the coordinate system of a vehicle. However, it is preferable to adopt analysis system associated with the axes of the vehicle, since the vehicle is stationary and air is moving. A very important factor for consideration for car aerodynamic drag is a dimensionless drag coefficient c_x [11÷14]. It is associated with the shape of the body. The greater the drag coefficient, the greater the aerodynamic drag of the vehicle. Coefficient c_x is determined by measuring analytically drag forces. Boundary layer [11÷14] is a layer of medium flowing in a short distance from the surface of the test object. In the boundary layer, there are significant changes in speed. On the surface of the object the speed of medium flowing over the test object is equal to zero and increases to the set speed with the distance from the surface. The phenomenon of the boundary layer is related to the fluid viscosity. It is very difficult to determine unambiguously the thickness of the boundary layer. It is assumed that the value of the boundary is the place where the speed is 1% in comparison with the set speed.

4. Optimization in the aerodynamic case

Optimization process [15÷18] consists of a couple of sub processes (Figure 6). Based on the simplified CAD model, the vehicle is aerodynamically analysed according to the methodology described among others in [19].

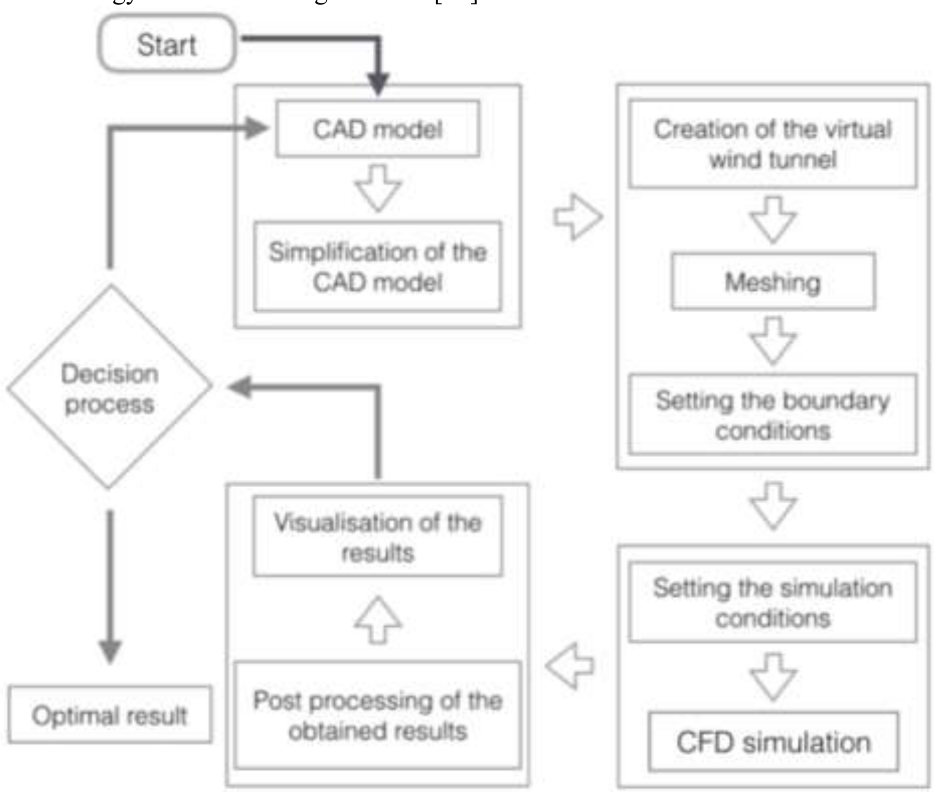

Figure 6. Optimization methodology diagram [20,21].

The optimization is carried out iteratively. After each iteration the set of obtained results was analysed — the drag coefficient, the drag force of the whole vehicle and the flow streamline distribution. Then it is decided if the solution can be considered as an optimal one and the optimization can be stopped, or should be changed and the optimization should be continued.

The geometry is parametrized. In optimization process the set of the geometric parameters is changing selectively. Parametrization includes the design variables relation and assumption that the cross sections of optimized parts (inlet channels) are constant to avoid air flow turbulences. In the optimization process possible wide parameter area is searched. The design parameter sets are different for each optimized part. For instance for the inlet channels parametrization the authors decided to follow such design parameters as size and shape of the channels inlet cross section. In another example - the front bumper parametrization the authors decided to follow design the following parameters: radii of curvatures of the bumpers cross section in two perpendicular surfaces with assumption of constant width of the bumper. For the wheel arch deflector parametrization the authors followed such design parameters as width, height, length of the deflector and the curvature radius of the deflector face.

5. Changes to the surface geometric model

Making iterative changes to the CAD geometric model enables the appropriate parametric preparation of the model. Such easy introduction of changes is a prerequisite for the automation of the optimization process because the introduction of changes itself is related to the next iterative calculation of the next version of design. The optimization process controls the very process of changing subsequent optimization versions. The basic problem is to build a parametric geometric model that allows such changes and the complexity of this model. In the case of very complex surfaces such as the elements of the car outside surfaces, the degree of surface complexity is so great that it usually prevents any serial change of parameters causing errors in the generated surface elements. Another problem is the large number of variables that control the generation of the surface, complicating and extending the calculation process, and in some cases preventing the achievement of the result at real time resources of hardware and time. On the basis of experience with building surface generative models a modified aerodynamic design method is proposed, using intensive use of surface generative models (Figure 7).

In the case of the design of aerodynamic objects in automotive technology, the very automation of the construction of a geometric model is of key importance for the efficiency of the entire design process.

6. Conclusions

Design oriented towards the optimization of structural and aerodynamic features is gaining importance especially in the application to modern electric cars due to the need to minimize energy consumption. The problem of optimization in this case is associated with the automation of changes of complex surface geometric models, which with typical design can not be sufficiently flexibly changed. The Generative Model-based Design/Optimization methodology including the application of a suitable combination of geometric modeling and generative modeling methods together with CFD methods and numerical optimization methods proposed by the authors is developed for the design of energy-efficient electric vehicles and mobile robots. The key issue of developing a surface generative model of elements of designed objects is to be solved using the method of building a simplified self-generating surface model built on the basis of points or contour curves. Such a simplified model has a much greater ability of associativity and enables cooperation with an optimization algorithm as well as CFD systems and methods.

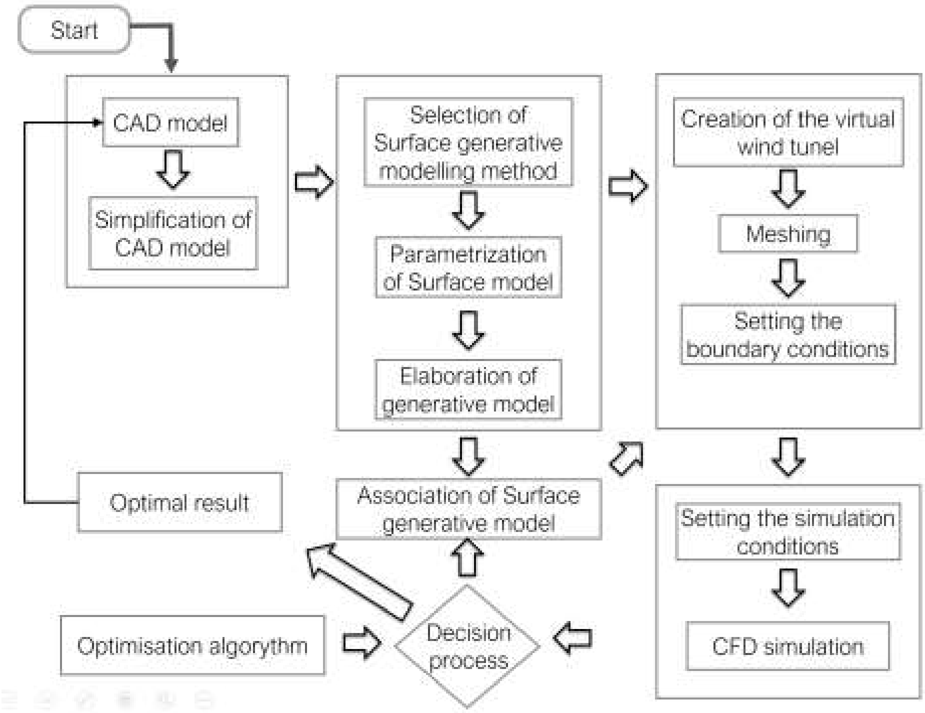

Figure 7. Modified Generative Model-based Optimization methodology diagram.

In the case of structural fragments such as bumpers, intake channels, this method passes the exam. The overall optimization of external aerodynamic surfaces, however, is a complex issue. In subsequent studies, the authors will strive to improve the methodology, thus enabling the optimization of such complex global objects.

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