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IDEALIZATION OF CAD GEOMETRY USING DESIGN AND ANALYSIS INTEGRATION FEATURES MODELS

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ABSTRACT

The numerical simulation using Finite Element (FE) method is a main activity in the design – validation process of mechanical products. Using this method and CAD tools can give an efficient advantage in the CAD – Analysis loop. The geometric model (mesh) used in the FE method is mainly obtained from the CAD model (CSG, B-Rep). In order to reduce the analysis time without bringing precision on computation results, we propose to integrate a new link in the design and analysis interoperability process. This link is named Idealization or simplification of CAD model. So, the automation of the idealization task is important in the CAD-Analysis integration process.
In this paper, we propose an idealization approach which mainly depends on the geometry, the solicitations and the behavior of material. According to the analysis goal, the designer can have several alternatives of analysis models which depend on the level of eliminated details and the abstraction level (1D, 2D or 3D). The non manifold models should not be a barrier to the considered analysis model.
We start with a positioning of several geometry simplification methods for CAD models in order to generate analysis models adapted with the considered analysis point of view. Based on this state of the art, we present the idealization approach in an integrated design context. Then, we propose our general method of the CAD geometry idealization. This one is based on an original algorithm witch integrate tow alternatives approach (selective approach and automatic approach). In order to emphasize our contribution, we present some examples of idealized form features (parallelepiped, cylinder, and wedge) implemented with OpenCacade code. Finally, an example of mechanical part using implemented form features is developed. The output of the algorithm is some proposed analysis models based on the CAD model of the part.

Keywords: CAD geometry, Design process, Mechanical analysis process, Idealization, Features, dimension criteria,

1 INTRODUCTION

The product design is a dynamic activity which aims to meet specified needs using some technical constraints [1]. It is an activity with multiple objectives which are not only limited to the product definition but they also interfere with associated processes. Thus, the product definition requires the intervention of various trades (CAD geometry, analysis, manufacture...) in order to perform the total description of this one [2]. This description includes geometric and physical characteristics (mechanics, thermics...) and the product manufacturing process. This paper presents an original approach allowing the assistance of the designer at the transformation process from the CAD geometry to the mechanical analysis models. This transformation requires adapting or idealizing CAD models in geometrical models (figure 1) dedicated to the mechanical analysis (kinematic, static or dynamic analysis) [3]. The idealization step consists in adapting, according to rules, the CAD geometry to the analysis tools allowing the desired analysis [4]. In order to situate our approach, we have to begin with a state of the art. Then, an idealization algorithm will be presented. Finally, the approach will be illustrated with some examples developed using OpenCascade code, witch is in open source. These examples, allow the validation of the algorithm, prove the proposed approach and show the importance of the idealization task in the integrated design and analysis process.

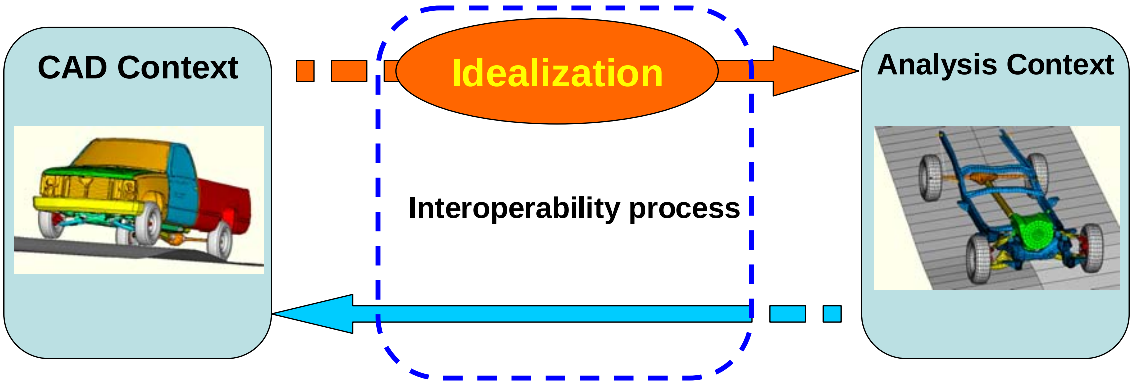

Figure 1. Integration of the idealization step in the CAD/Analysis process

2 STATE OF THE ART

Throughout the design process, CAD model is mainly used to define the geometry of a part or an assembly during its creation [5, 6]. Thus various CAD models are generated throughout this process. These representations can be very coarse for the first phases of the design process (use of elementary primitives such as cubes, cylinders..., which are associated to define for example an approximation of the part skin) or very detailed (use of B-Rep models for the definition of the set of the existing details on the geometry) for the final phases of the design process.

The analysis model is dedicated to the study of the physical phenomena (mechanical, thermal...) defining the behaviour of parts or assembly. The numerical resolution of these behaviour models depend on the precision and computation time. The objective is to be more adapted to the considered study and the analysis means used by the analyst.

The creation of an analysis model using CAD geometry is based on some analysis assumptions. These assumptions are related to the material behaviour, solicitations and the geometry definition of the part. In the bibliography, [2, 3, 7, 8, 9] several research tasks were interested to the CAD geometry adaptation problems to an analysis models dedicated to the mechanical analysis by finite element method.

- Dabke, in [10], uses an identification method of entities (features) to carry out the adaptation and the idealization of geometrical models by suppression, in CSG models. This technique is based on expert system implementing heuristic rules resulting from the analyst experience.
- Belaziz, in [11], proposes an adaptation method of geometry based on the features recognition approach. In this approach, the recognition is carried out by a morphological analysis of the CAD geometry, that's why this method is more flexible than the Dabke's method. The adapted and idealized geometry is generated by removal of some form features considered as non characteristics for the considered mechanical analysis.
- Sheffer, in [12], develops a suppression procedure of details and "cleaning" of CAD geometry using the principles of virtual topology. This topology is based on regrouping the faces constituting the B-Rep model in areas admitting the same characteristics of curve and dimension.
- Armstrong in [13] and Donaghy in [14] use Medial Axis Transform (MAT) to carry out the adaptation and the idealization of B-Rep geometry. The MAT method builds the skeleton of a geometrical representation in order to obtain the median axis. A circle with a variable diameter sweeps the interior of the structure remaining constantly in contact in at least 2 points with the structure. The skeleton is obtained by building the places of the center of the circle. For a 3D geometry the circle is replaced by a sphere and the places of its center represent a surface. This skeleton is then used to carry out an analysis of the geometry in order to characterize the set of details which composes the 3D geometry. Then, the geometrical representation is adapted or idealized by the means of the Euler operators. The implementation difficulty of this approach lies in the fact that the built skeleton does not perfectly represent the geometry because:

- Artificial ramifications are generated,
- In the case of a volume idealization, the method does not make it possible to identify the nature of the construction surfaces.

- Rezayat in [15] proposes an idealization technique based on the extraction of average surfaces starting from the B-Rep geometry. This approach is based on four stages:
  - Identification of surfaces of the part which can be associated with some geometrical criteria (distance, form...),
  - The creation of adjacency graphs based on the topology and the surfaces size,
  - The creation of average surfaces by Boolean operations and geometry interpolation,
  - The connection of average surfaces (between them or with the initial geometry) according to the relations of adjacency.

  Using this method, some problems inherent in the MAT method [13] (no creation of artificial ramifications, conservation of the part shape...) are resolved.
- Clémente in [16], proposes to carry out the CAD/Analysis link by using manual or semi-automatic operators of idealization who exploit the geometrical data of the CAD model. These operators implement a geometrical algorithm for obtaining average fibre of a machine element by approximation of the center of mass of each part section. From the whole of the center of mass, a new curve or a new approximated surface is built.
- Serré in [17] proposes a new technique, based on the generation of a metric tensor concept. The metric tensor is a mathematical model used to represent by a matrix some important informations related to the CAD geometry. Precisely, it is used to measure the distances and the angles of a given frame. Which represents the Brep model of a CAD geometry. In general, this technique is used in several applications like geometrical field [17] and tolerance [18, 19].

  Our objective aims at use the potential of the metric tensor in order to detect and eliminate geometrical details (holes, chamfers….), based on several criteria like volume of the detail, orientation of the detail etc. This aspect contributes in the idealization process of CAD geometry into analysis model.

The following table presents the principal idealization techniques CAD geometry. These techniques are classified according to their performances related to the removal details and reduction of dimensions. For example, the technique using the design by features and features recognition is mostly applied in the identification and the elimination of details. However, the technique using the metric tensor is recommended at the same time in elimination of details and reduction of dimension.

Table 1. Synthesis of idealization methods

Idealization techniques	**Removal details**		**Reduction of dimension**	
	Identification	**Elimination**	**Identification**	**Reduction**
Design by features and features recognition	X X X	X X X	X	X
Medial Axe Transform (MAT)	X		X	X
Boolean operator		X		
Virtual topology	X	X		
Metric tensor technique	X	X	X	X

3 OBJECTIVES

According to the bibliographical review, we note that it is necessary to perform simplifications on the CAD geometry for the generation of the analysis models [20], considering a CAD geometry can comprise forms which can present meshing problems [21], or also of the details whose presence can only increase the computing time without bringing precision on computation results [22].
In the following figure, we present an example of connecting rod, witch permit to present the difference between the mesh density of the connecting rod (a) with fillet forms and the same part (b) without fillet forms (idealised connecting rod).

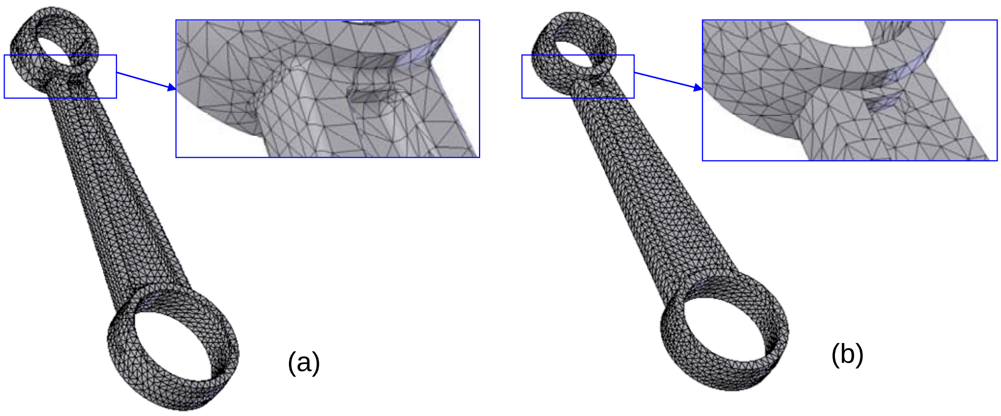

Figure 2. Effect of fillet in the mesh density (a) : mesh with fillet forms,(b) : mesh without fillet forms

So, our main problem consists on developing methods and models in order to automate, or at the very least to help the designer to create analysis models by simplification of CAD geometry. In the following sections, the approach suggested will be detailed. So, it is important to define the term: "simplification" of the geometry.

3.1 CAD geometry simplification

In order to build analysis models dedicated to the structural analysis by finite element method, the simplification of CAD geometry consists to remove details (holes, fillet, chamfer...) [23], considered as useless details and/or to reduce dimensions of the part.

3.1.1 Removal of details

It consists in removing or modifying details in order to simplify the simulation model (or analysis model) without affecting the results of the analysis. In the case of the structural analysis, the details to be eliminated are defined by entities of small size which are not carrying boundary conditions (solicitations), not subjected to stress concentrations and which do not influence the deformation and stress field in the remainder of the part.
In practice, the analyst will eliminate the details such as vacation, holes, embossings and chamfers. The following figure shows the difference between a detailed CAD model and a simplified model dedicated to the mechanical analysis.

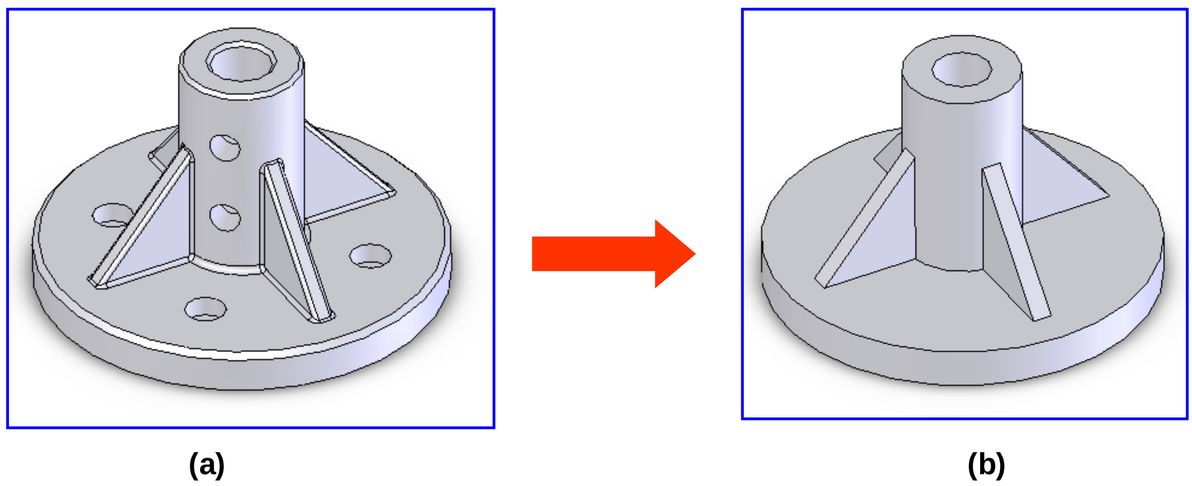

Figure 3. Principle of removal details; (a): a detailed design model, (b): an analysis model

3.1.2 Reduction of dimensions

It consists in defining the dimension of the analysis model according to the morphology and the boundary conditions (solicitation, displacement) of the part. The dimensional reduction consists in transforming a 3D model (volumic elements) into 2D model (plate, hull) or into 1D model (beam). In the following figure shows a 2D analysis model (plates) resulting from a 3D CAD model.

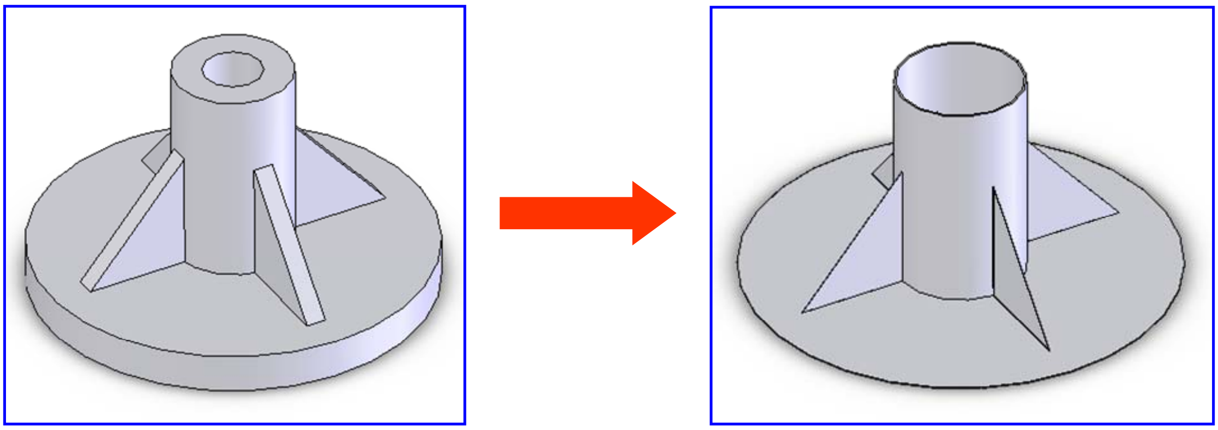

Figure 4. Principle of reduction of dimensions

The (Figure 5) shows that the use of the symmetry of the problem (geometry and boundary conditions) makes it possible to lead to a more simplified analysis model.

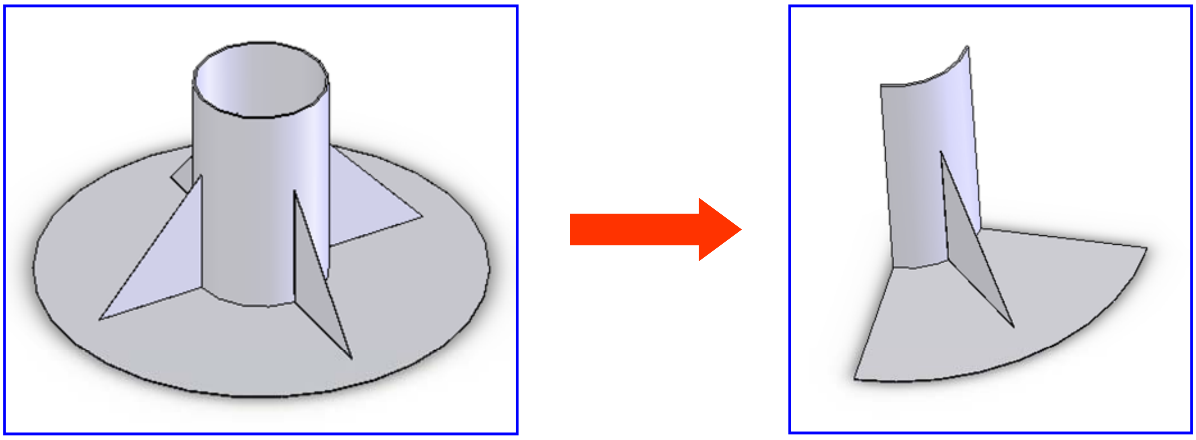

Figure 5. Use of the symmetry properties for the part simplification

4 IDEALIZATION ALGORITHM

According to the previous sections, the generation of the analysis models is based on two principal techniques, namely: the elimination of details and the reduction of dimensions. In (Figure 6) is presented an algorithm which organizes the principal steps of analysis models generation starting from a CAD model resulting from the design process.

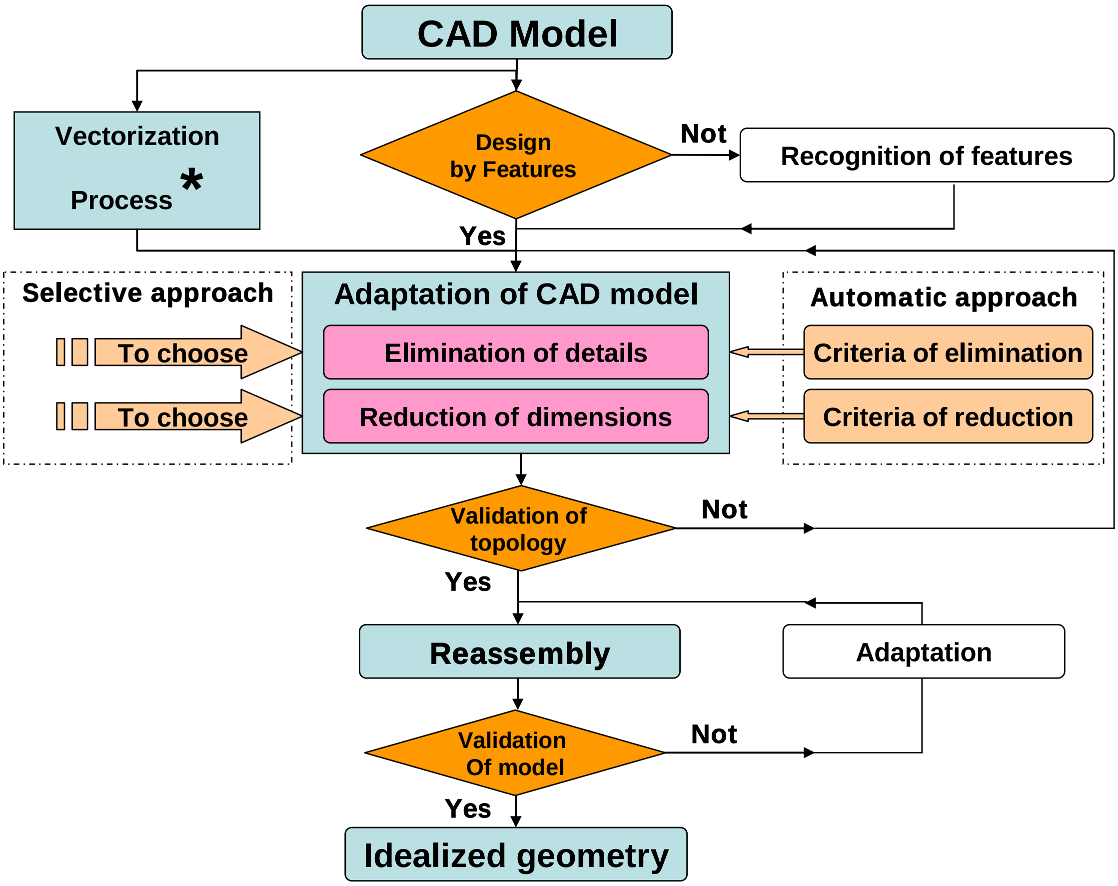

Figure 6. Generation algorithm of analysis models starting from CAD models

The vectorization process is developed in the following figure.

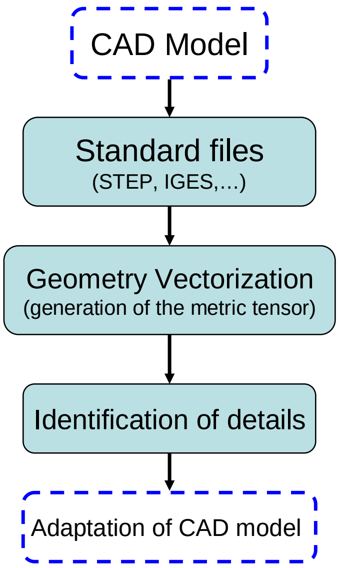

*Figure 7. Vectorization process **

In order to adapt CAD models to the mechanical analysis, two idealization approaches are possible (Figure 6). The first which is a selective approach, offers to the user a freedom of intervention on the elementary models to perform the operations of elimination or dimensions reduction. This approach is mainly based on the experiences of the designer. While the second approach which is considered as an automatic approach compared to the first one, aims at performing the idealization tasks according to a set of criteria of details elimination and dimensions reduction. These criteria are based on:

- Analysis type and desired precision;
- Volume and shape of the detail;
- Position and orientation of the detail in the structure;
- Functions of detail surfaces (boundary conditions...);
- Proportionality of dimensions according to the three directions;
- Type of material (physical properties and behavior).

These simplification operations of CAD geometry are carried out according to expert rules as: «if condition then action». Consequently a parameterized model (features of design) is judged suitable to ensure this multitude of representation models for analysis according to criteria which depend on the analysis objectives.

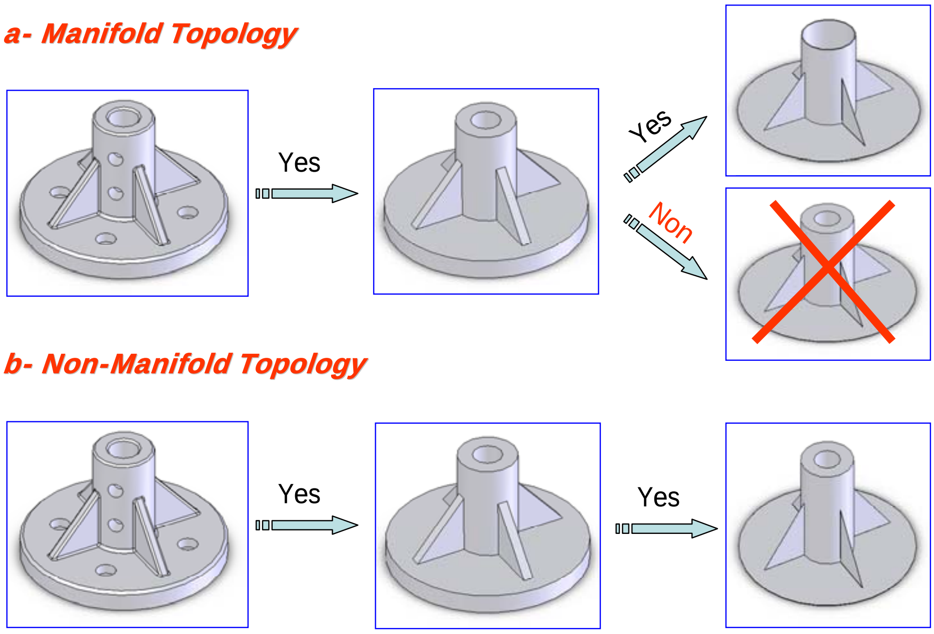

Figure 8. Analysis model Topology; (a): manifold topology, (b): non manifold topology

According to the analysis goal, the designer can have at disposal several analysis model alternatives depending on the level of details eliminated and the level of model abstraction (1D, 2D or 3D model). To perform an analysis model, the non-manifold topology should not be a barrier. In this case, a topology validation step is necessary because of the analysis tools can support this topology property (Figure 8). Finally, the elementary models must be assembled in order to validate the idealized geometry.

5 IMPLEMENTED EXAMPLES AND VALIDATION

At different steps of the design process, the designer must have various analysis models associated with the CAD model. The (Figure 9) present an interface of the idealization tool developed using "Open CASCADE", which is a software development platform freely available in open source. At this moment, only the skeleton of the tool is implemented. Using this tool, the designer can creates a sample CAD geometry based on elementary parameterized shapes. The parameters related to the idealization criteria are added directly on dialogue limp of shapes creation. According to some information (geometrical data and idealization criteria) specified by the designer, a code generate some suitable analysis models.

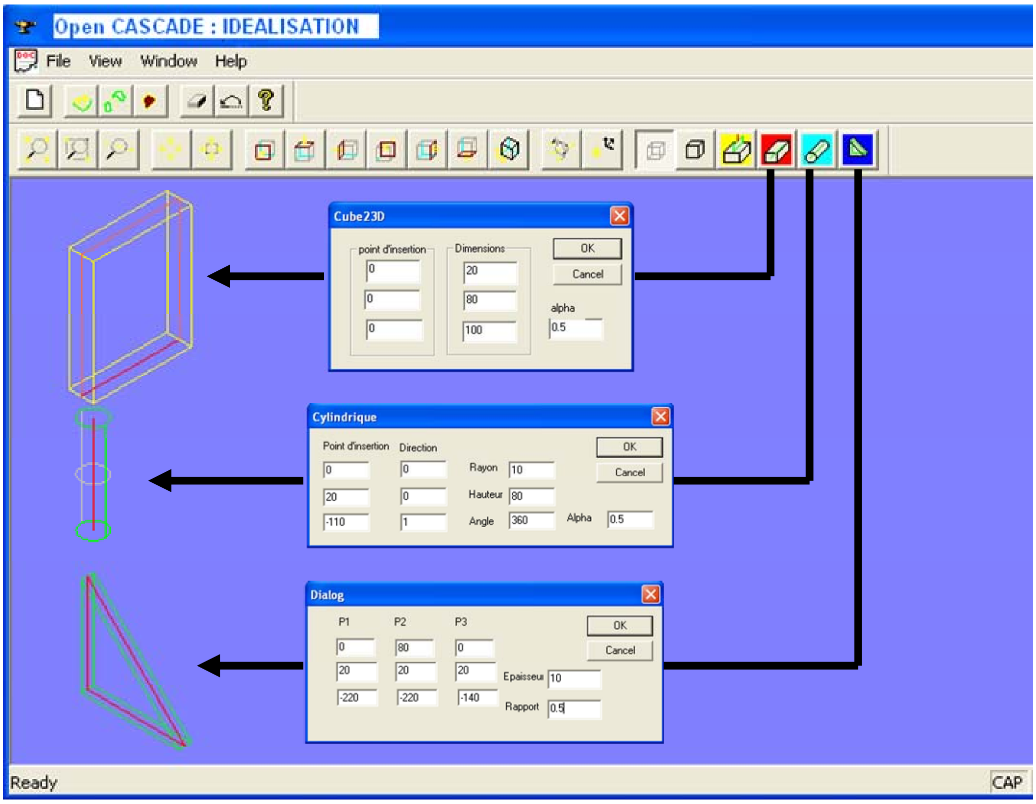

Figure 9. Idealization tool interface

Some algorithms are developed to implement the knowledge of the mechanical analyst in order to generate analysis models. The (Figure 10) introduces a dimension reduction algorithm of a parallelepiped shape and the various proposed analysis models according to proportionality criteria of dimensions in three directions.

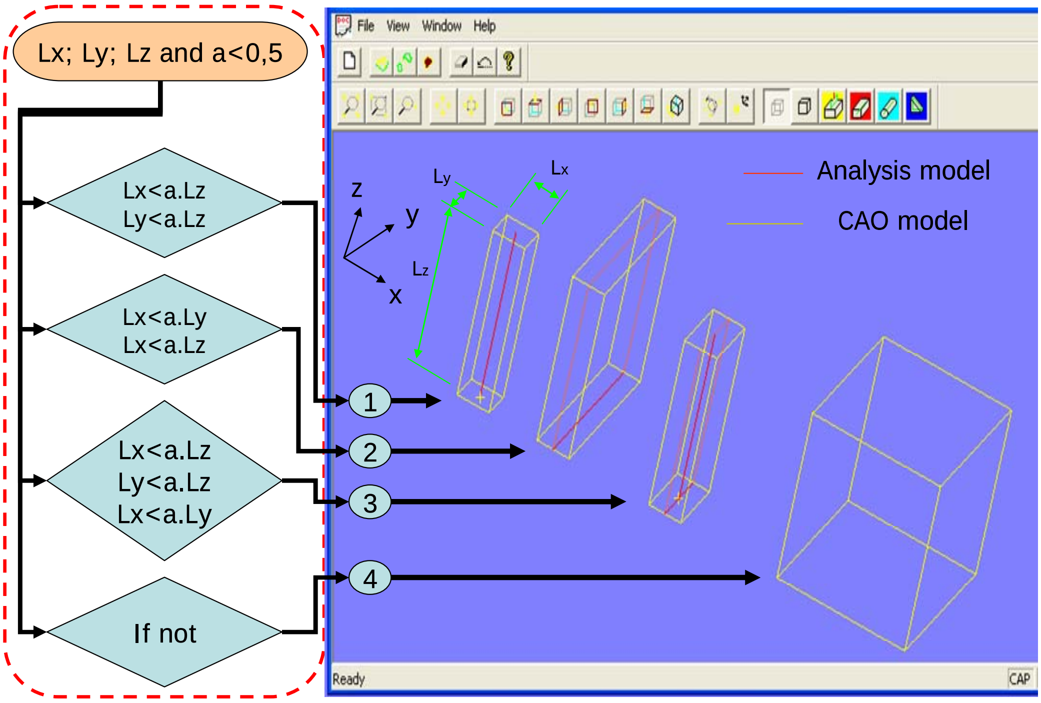

Figure 10. Idealization of a parallelepiped shape

Using the same principle, the idealization algorithms of a cylinder (Figure 11) and a wedge (Figure 12) are developed.

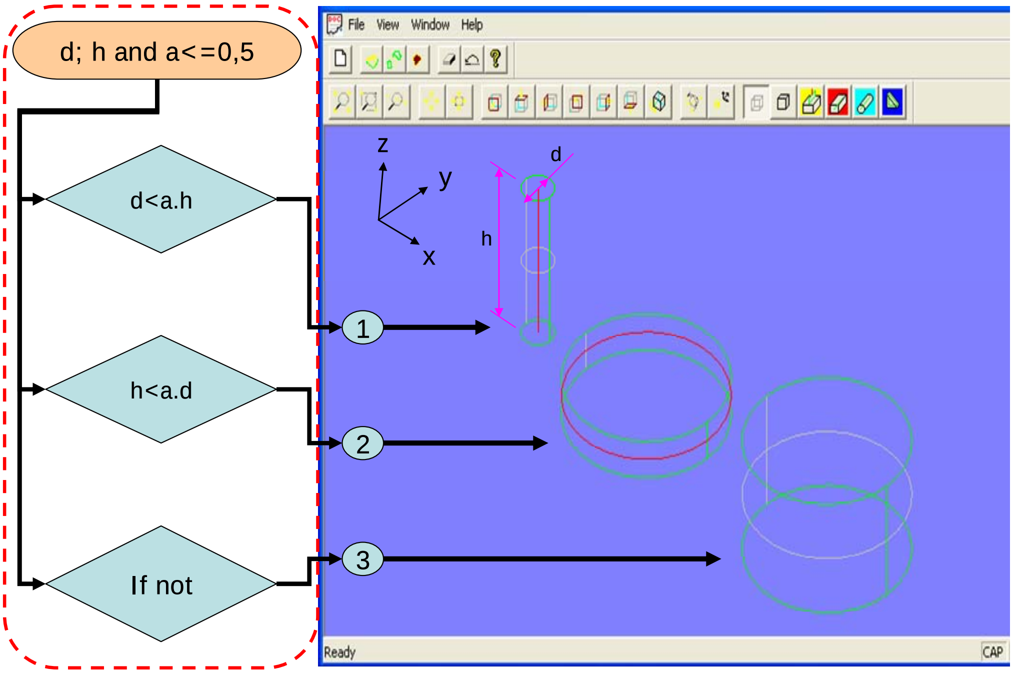

Figure 11. Idealization of a cylinder shape

As it is represented on the result of the implementation, a cylinder can be represented by:

- A beam if the height is very large compared to the diameter;
- A disc if the height is very low compared to the diameter;
- The CAD model if both dimensions are proportional.

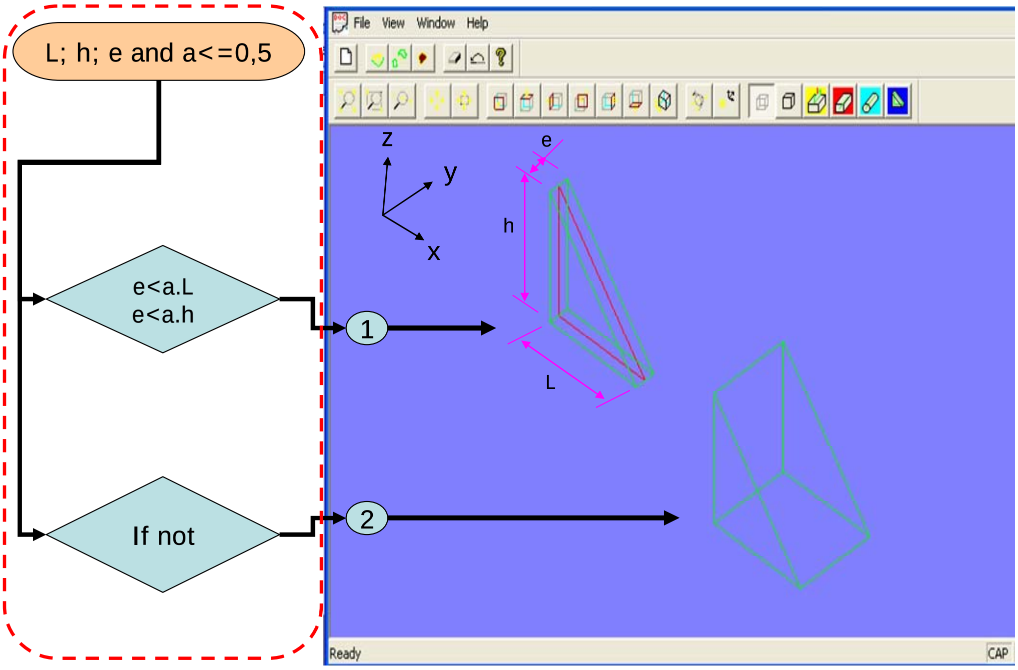

Figure 12. Idealization of a wedge shape

In order to validate our approach some examples are tested. The (Figure13) shows the generation process of various simplified analysis models, starting from CAD geometry. According to the eliminated details level and the reduction dimensions level, several analysis models are possible and the selection of any one is mainly related to the selection criteria presented in the previous section.

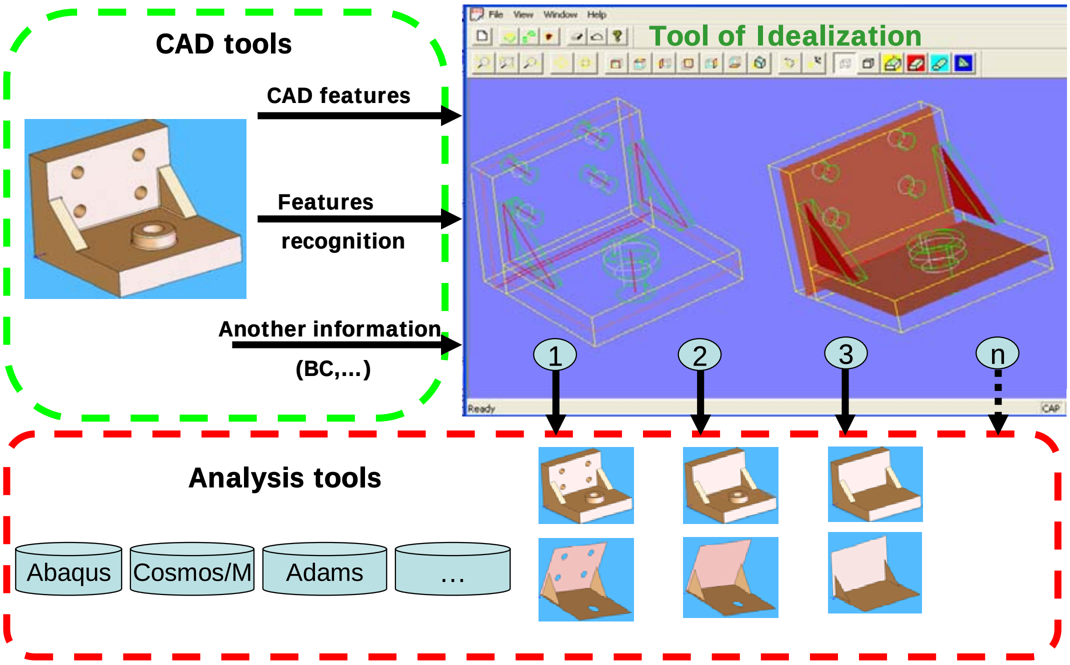

Figure 13. Example of idealization of a support and various possible models according to the criteria

6 CONCLUSION

In this paper an original integration approach between design and analysis processes is proposed. This approach is based on a state of the art related to several idealization methods. This one aims at assisting the designer in the idealization step which is a new link between design model (CAD model) and analysis model (beam model or mesh model for example) dedicated to mechanical analysis by the finite element method. According to the type and objectives of analysis, two steps are necessary to perform the idealization process. The details elimination step based on the designer experience (using a selective approach) or automatically by the system (using a set of rules). The second step consists in reducing dimensions of 3D CAD geometry in a reduced geometry (2D: plate or 1D: beam).

Then, an idealization algorithm was presented. This one aims to generate some alternatives analysis models (to perform mechanical analysis) based on the CAD geometry model. To perform this adaptation or idealization, some elimination and reduction rules are implemented. Actually, these rules are based on dimension criteria. Finally, some examples of idealization algorithms are developed. Actually, these algorithms can transform some form features like parallelepiped, cylinder and wedge in a reduced form features like beam, disc, etc. The link between the initial form and the idealized form is bilateral. An example of part (Figure 13) including three implemented from features (previously introduced) is developed and some alternatives analysis models are proposed based on the dimension criteria in the three directions. To perform analysis, the designer can select an analysis model from the proposed list.

In the future, the idealization algorithm presented in the (Figure 5) will be completely implemented using Open CASCADE platform. We propose to include other elimination rules based on boundary conditions, nature of material and the direction of the detail.

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