Idealization of CAD model for a simulation by a finite element method

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ABSTRACT. *At present, the simulation is at the heart of the product development cycle. To accelerate the design and simulation cycle, it is necessary to prepare the Computer Aided Design (CAD) model before the simulation process. This pre-processing task consists in cleaning the CAD geometry, performing a mesh, specifying conditions boundary and loads, etc. This paper presents a method based on an original algorithm in order to prepare the design geometric model to a simulation by the finite element method. It consists in the idealization of the CAD geometry by eliminating details (holes, chamfers, etc.). These details increase the computing time due to a refined mesh in these details, which are considered as constraints hubs, without providing more precision in the simulation. An implementation of the proposed algorithm on the Open Cascade platform is also presented. The last part of this paper presents two examples of mechanical parts, which are simulated before and after idealization. The simulation's results show the major contribution of the proposed method in terms of gain in computing time without loss of accuracy on the simulation's results.*

KEYWORDS: *CAD geometry, Integration, Idealization, Simulation, Optimization, Finite Element Method.*

1. Introduction

Design and mechanical analysis were considered, for a long time, as two independent activities. The designer and the analyst work, each one in his domain, on distinct models. Designers propose the product starting from delivery requirements and basing themselves on specific designer tools. While the analysts, evaluate the proposals of designers basing themselves on analyses tools. The use of distinct data-processing tools obliges the analyst to systematically do again the geometry scheduled from the CAD's environment in order to be able to evaluate their performances. Any modification made by the designer to CAD model leads the analyst to resume, from the beginning, the whole tedious work of geometry's preparation for simulation. There is no way to update the model being used for the analysis starting from CAD model provided by designers. The analysis' time becomes excessively long. The consequences of a modification, in an advanced stage of the design, become disastrous for the analysis. The multiple backward and forward between design and analysis do nothing but increase the time of marketing of the product and thus its cost price. This logic of cohabitation between the two activities, design and analysis (simulation), was quickly suspected. Nowadays, methodology of work and software are in continuous development, that's why simulation is considered to be the cycle core of the mechanical product's elaboration. It is on the basis of simulation's results that the decisions of validation, re-examination or improvement (optimization) of the design proposals will be considered. The phase of the mechanical simulation requires a stage of the design model's preparation called a phase of pre-processing, and requires also a stage of simulation results' exploitation (tables of values, histograms, Iso-values of constraints or deformations, etc), which is called a phase of post-processing. The pre-processing phase is considered as the most important one. Its objective consists in redoing the geometrical model, resulting from the design, by cleaning, gathering subsets, creating a grid, specifying boundary conditions, adding a loading, etc. This phase, according to Lockheed Martin Corporation which is specialist in structural analysis, can consume up to 95% of the total time of the mechanical analysis [1]. Thus it is clear that economies of time and possible costs by the improvement of the pre-processing phase are really gigantic. The analysts will again be able to fully concentrate on their genuine work namely, their contribution to the improvement of the design [2].

Our research tasks are perfectly conformed to the objectives of improvement of CAD models preparation's phase even before starting the stage of mesh [3]. The preparation of a CAD model consists of idealizing or cleaning the geometry by eliminating details (holes, chamfer, fillet, etc) considered to be superfluous for simulation [4]. These details are then zones where the mesh will be automatically refined which will generate a very important computing time without bringing more precision on the results of simulation [5]. The temporary elimination, since the design phase, of these details, in preparation for the simulation, allows to an important time savings without damaging the results of simulation.

The objective of this paper is to propose an original step which can guide the designer in the phase of the CAD model's preparation for a simulation by the finite element method. According to the approach suggested, the elimination of the details is based on a representation by Iso-zones enabling the designer to visualize the details which are candidates for elimination which depend on the degree of criticality of the detail to eliminate. The process of elimination of the details can be automatic or interactive with the designer. The first part of the article presents a state of the research on the principal techniques used to eliminate details from CAD geometry. The second part introduces the model of idealization proposed. A data-processing implementation, using "Open CASCADE", of the algorithm proposed allows showing, on some examples of mechanical parts, the time savings as well as the percentage of computation results error before and after CAD geometry's idealization. That contributes enormously to the reduction of design time and the cost price of the product.

2. State of the research

The process of a CAD model's preparation passes by a phase of idealization or of cleaning of the geometry. That consists in elimination of details whose role, towards simulation, does only increase the time of simulation without any improvements to the quality of simulation results [5].

The review of the literature in the field of the idealization of the geometry allows enumerating several techniques of idealization of the geometry. The following paragraphs detail some principal techniques.

2.1. Using of forms features

In this framework, the features are functions of geometrical model's creation. They aim to couple, to only one entity, geometrical and semantic information (hole, groove, fillet, etc). These entities, which have strong geometrical components, support suitable significances for a trade or a specific application (design, manufacture, analysis, etc). The use of features is in two manners: modelling by features and the extraction of features. For example, the entity hole can be interpreted within the meaning of analysis like carrier of boundary conditions or concentrator of constrain, etc. The suppression of a geometrical form consists simply in eliminating it from the shaft generates of the part [6, 7]. Each actor intervening in the product's life cycle has so his own language of description and interpretation based on forms features. The extraction of features of forms in a process of simplification of the geometry passes by two aspects. At first, it consists in identifying the associated characteristic and topological parameters (faces, edges and vertexes). In the second time, it is a question of reconstituting the geometrical model without the removed forms (figure 1) [8, 9].
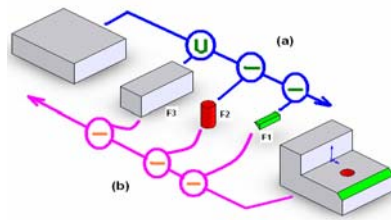
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Figure 1. *(a) Addition of forms features (b) Extraction of forms features*

2.2. Extraction and suppression of the fillets

Venkataraman [10] proposes powerful algorithms to extract the fillets. In its work, the algorithm of suppression predicts final topology by using the structure of the fillets chains, and then finds a geometrical solution based on the intersection of support faces of the fillet. Final topology is deduced by contraction of edges E1 and E2 in vertex (figure 2-a), then by the fusion of the two edges of the face in only one edge and removal of the face of connection (figure 2-b). Work of Zhu [11] and Venkataraman [12] are in the same category.
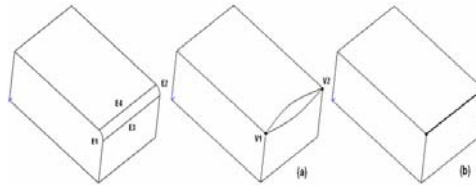

Figure 2. *Deduction of final topology by use of Euler operators*

2.3. Median surfaces transformation

For a 3D geometry, a sphere with a variable diameter sweeps the interior of volume. The place of the center of this sphere represents a surface (figure 3). This skeleton is then used to carry out an analysis of the geometry in order to characterize the whole of details which make it up [13], [14] and [15].
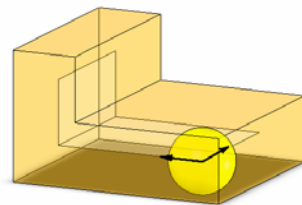

Figure 3. *Median Surface*

2.4. Boolean operators of simplification

The operators of merging and collapse allowing to remove details of 3D geometries are: merge faces, merge edges, kill void, kill holes, collapse face to edge, collapse face to vertex (figure 4).

The operators of Euler proposed by Armstrong [13] are used to remove the shift between two faces and to produce a convex face. That's why two vertexes are created on the edge in order to create a face and to start up an operation of contraction of this face towards the edge.
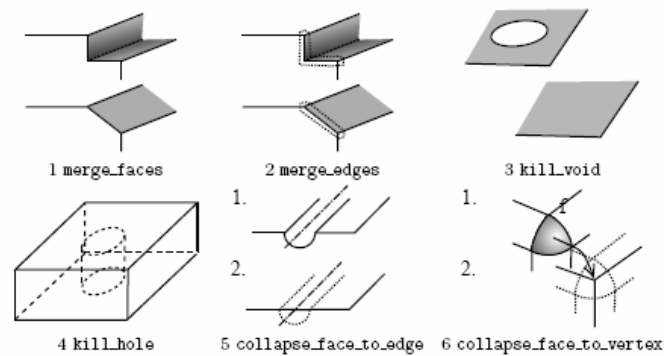

Figure 4. *Euler Operators for details suppression [13]*

2.5. Virtual topology and regrouping of faces

Virtual topology consists in regrouping faces in regions (figure 5). That allows, for example, making mesh "multi-faces" [16], provided that the faces define an enough plane surface. The criteria of regrouping of faces in region are thus mainly the flatness of the region. So this method allows removing the low-size faces by merging them with their adjacent faces or by contracting them in edges. It cannot be considered as a simplification technique of the geometry but rather as a particular method of mesh.
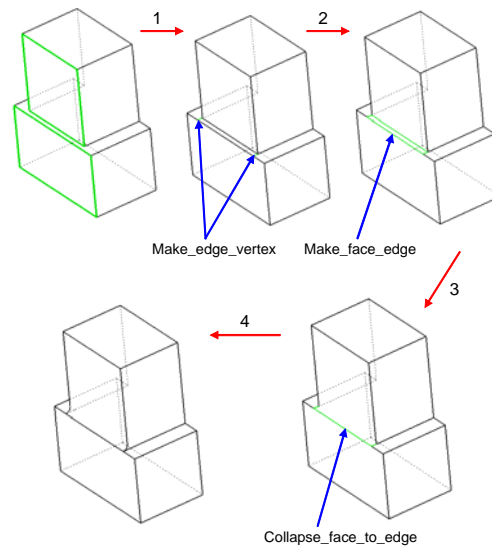
Figure 5. *Different suppression stages of faces shift*

3. Algorithm of idealization

The proposed algorithm composed of three principal interdependent stages represented in figure 6. Each stage implies overlapping algorithms.
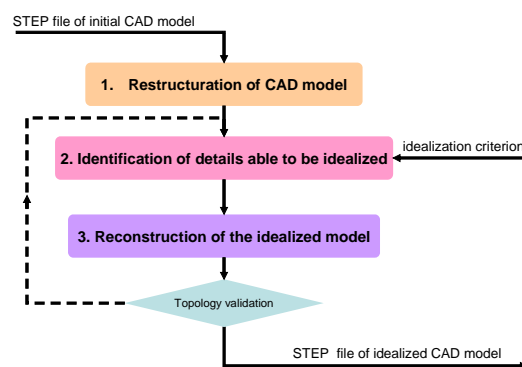

Figure 6. *General algorithm of idealization*

3.1. Principle

In order to be independent of the Computer Aided Design and Manufacturing CAD/CAM systems, the proposed algorithm relies on a neutral file (STEP) to recuperate the data of the part to be idealized. To use various tools of simulation, the idealized CAD geometry will be also stored under the same neutral format (Standard for Exchange of Product (STEP) model). The stage (1) of the algorithm consists of a phase of pretreatment of CAD model. It allows restructuring the Boundary Representation (B-rep) model of the part to a data base. The structured information in this data base relates to the faces, the wires, the edges and the vertex which includes the geometry model of the part. The stage (2) consists in identifying the details candidates for elimination. That implies the implementation of algorithms of identification based on criteria (forms, sizes…). The result of this phase is a representation of Iso-zones (comparable with the representation of the Iso-values of constraints, deformations in the computational tools by Finite Element Method (FEM)…) targets for elimination. These Iso-zones are entities (edges, faces) colored according to a gradient of criticality. This original vision enables designer to visualize the least influential zones (high order of criticality) on the computation results, giving him the possibility either to inter-actively eliminate the entities which have high order of criticality, or to apply the automatic algorithms of elimination. The stage (3) consists in removing the identified details, then in rebuilding the geometrical model after suppression. The result of this phase is an idealized CAD model whose elementary topology is valid. At the exit of the algorithm, the designer has at his disposal an idealized model recorded in format STEP for a simulation by finite elements. The algorithms associated at the above mentioned stages are developed in the following sections.

3.2. Stage 1: Restructuration of CAD model

The reconstruction of the CAD model aims to explore and make easy to handle the topological and geometrical data associated with piece. Figure 7 presents the algorithm associated with this stage.
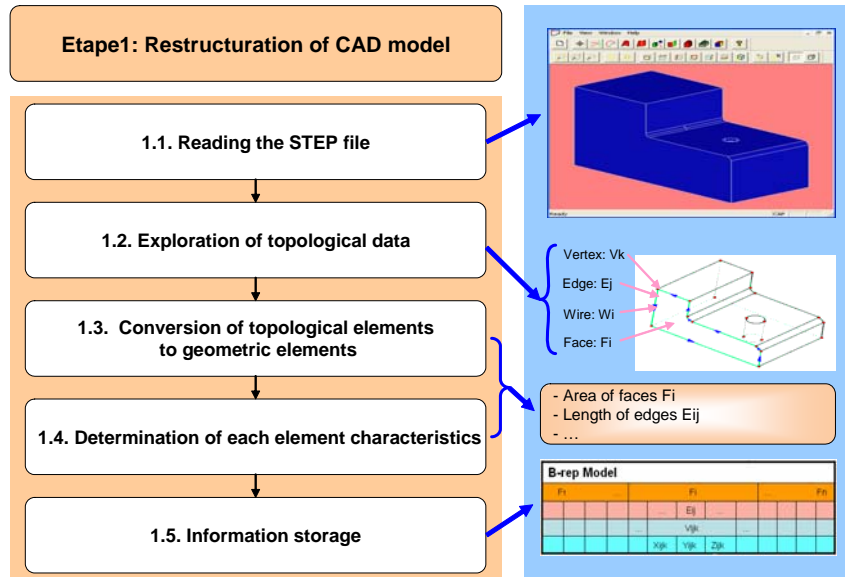
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Figure 7. *Algorithm of restructuration of CAD model*

Reading the file STEP led to determine the characteristics of each element of B-rep model, namely

- vertex: (cordinates),

- Edge: (associated vertex, length),

- wire: (associated edges, orientation, length),

- Face: (associated wire, normal, area).

This information will be stored in a data base allotted to the part. Any geometrical handling on the part implies the processing of information indexed in the data base. For a given face, it is evident to know the associated wire, the participating edges also the list of vertex appearing in the face. Geometrical information such as perimeter and surface of the face are directly deduced.

3.3. Stage 2: Identification of details

On the basis of the collected information in the preceding stage, the designer has to specify an idealization criterion (figure 8-a). Three criteria are already identified. The criterion of size relates to the lengths of the edges and the areas of the faces. An increasing or a decreasing sort, on the faces and the edges, is quickly carried out

starting from the data base of part. The procedure of sort consists in studying the ratio of edges's lengths to the longest edge and the ratio of faces' surfaces to the largest face. The Boundary Conditions (BC) criterion does not allow removing the details which have BC. Currently, details that have BC are specified by the designer. These details will be automatically eliminated from the list of the details candidates to elimination. The criterion of the detail's position compared with the loading allows keeping details, if they are regarded as concentrators of constraints because of their orientations compared with the loading, even if they are eligible from point of view size. This criterion is not taken into account to date.
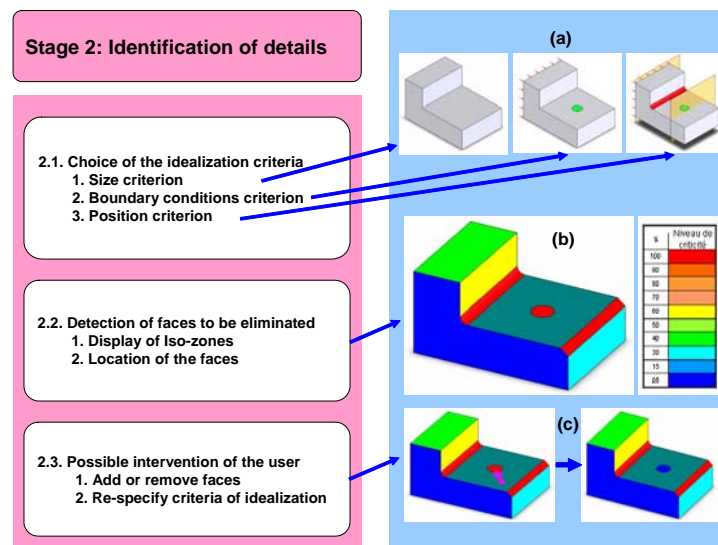

Figure 8. *Algorithm of details identification*

Once criteria are specified, the result of the detection of the details to eliminate is represented by Iso-zones (figure 8-b). Faces and Edges represented by sharp colors are target to elimination (high level of criticality). The designer has finally the interactive choice to eliminate or keep the details. He can also add other faces (or edges) to the list of the entities to eliminate (figure 8-c). This stage is easy because, the designer has access to the B-rep model of the part.

3.4. Stage 3: Suppression of details and rebuilding of idealized CAD model

The objective of this stage is to remove the details identified in the preceding section then to rebuild the idealized part (figure 9). The procedure of CAD model's rebuilding, after elimination of faces and edges, consists, firstly, in detecting the

adjacent faces to the removed entities. The detection of adjacent faces is based on the part database processed in the first stage (figure 9-b). Secondly, it consists in prolonging these faces in all directions (figure 9-c). That will lead to detect intersections curves due to the prolongation of faces (figure 9-d) Vertex limit will be determined from curves(figure 9th), then the edges will be delimited by vertex (figure 9-f). CAD model is regenerated by rebuilding faces associated to new wires (figures 9-g and 9-h). A new database of the idealized part is thus completed. The designer has the B-rep model of the part before and after idealization. A file 'STEP' is finally generated in order to use the idealized CAD model by an analysis tool.
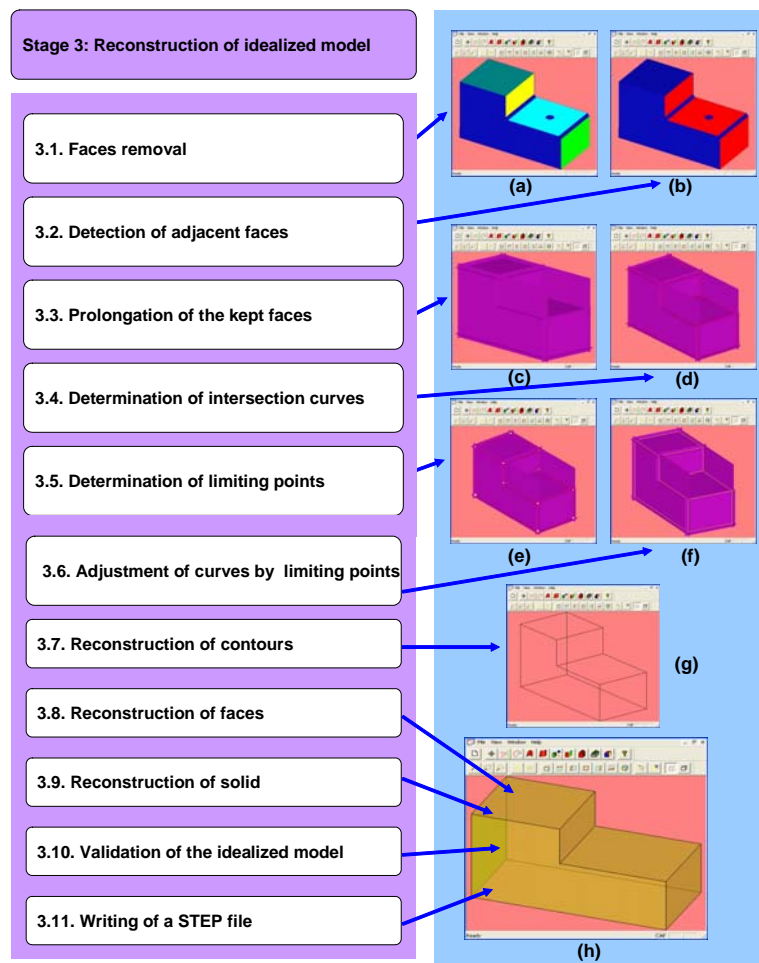

Figure 9. *Algorithm of details suppression & rebuilding of idealized CAD model*

The proposed algorithm of idealization is adjudicated universal because it is based only on the B-rep model of the CAD geometry. This algorithm is completely independent of the tree of CAD geometry creation, because of the non-uniqueness of this tree. In addition, CAD model, once exported, loses any information on its manner of creation. Attempts at re-creation of Constructive Solid Geometry (CSG) model exist, in fact the module FeatureWorks of SolidWorks, but the results obtained are not very conclusive.

4. Data-processing implementation and validation on examples

4.1. Data-processing implementation

The data-processing implementation of the idealization algorithm was carried out on development's platform, 'OpenCascade'. OpenCascade is an environment dedicated to the development of 3D applications of CAD-CAM multi-platforms. This platform is available and free on Internet. It is based on a bookstore of C++ classes and tools developed and available in open source.

4.2. Examples of validation

In this section, two examples of validation will allow validating the principal functionalities of the idealization algorithm. Figure 10 presents two supports. These parts were selected because they have a broad variety of mechanical parts in terms of its forms, the boundary conditions, and also the details which they contain.
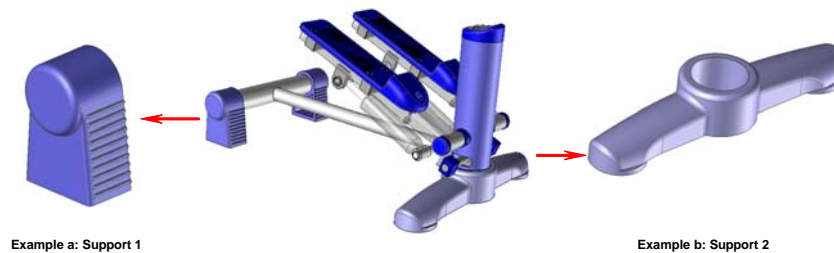
Example a: Support 1   **Example b: Support 2**

Figure 10. *Examples of validation*

Figure 11 presents the illustration of the principal stages to pass from a CAD model of the support 1 (figure 11-a), where boundary conditions are defined (loading and fixing), to a model of analysis whose geometry is idealized (figure 11th). A very important stage (figure 11-c) represents the support 1 by Iso-zones.

These izo-zones give to the designer a very clear idea of the details candidates to elimination by sharp colors, according to the level of criticality (going from 0% to 100%).
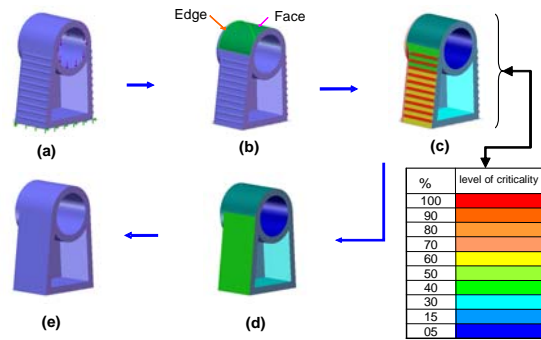

Figure 11. *Representation by Iso-zones of the support 1*

Figure 12 also represents the support 2 by Iso-zones. It shows also the principal step leading to the idealized model of the support.
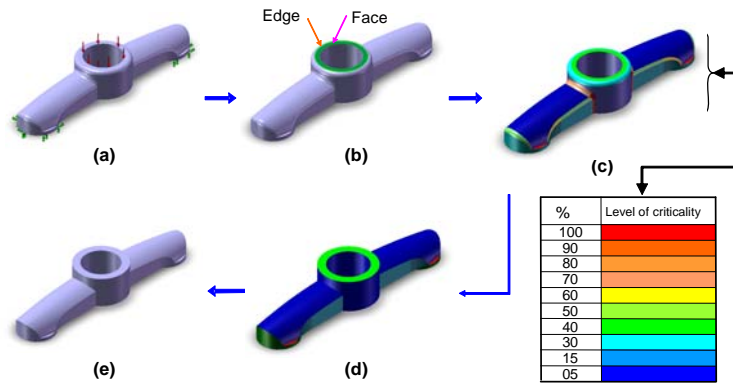

Figure 12. *Representation by Iso-zones of the support 2*

Figure 13 represents two OpenCascade windows in which, are represented, the idealized CAD models of the support 1 as well as the support 2. These models will be saved in 'STEP' format to be simulated by the finite element method.
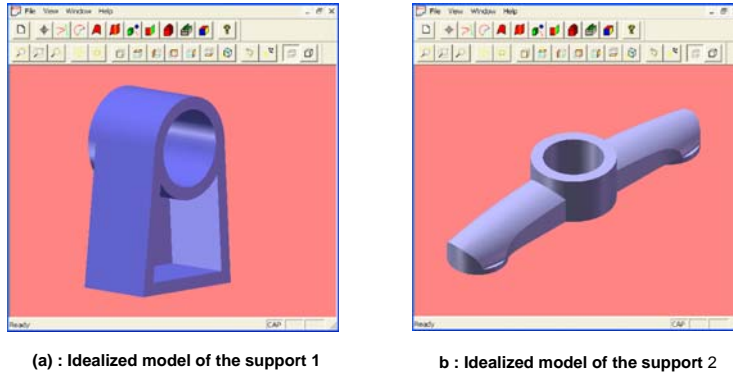
(a) : Idealized model of the support 1   b : Idealized model of the support 2

Figure 13. *Results of the idealization algorithm implemented by OpenCascade*

Table 1 represents the number of the entities B-rep of the support 1 and the support 2, before and after idealization. It's shown that the number of entities after idealization is lower than that before idealization. That generates a saving of very important time during the mesh and computation of the idealized model.

	Number of Faces		Number of Wires		Number of Edges		Number of Vertexes	
	Initial Model	Idealized Model	Initial Model	Idealized Model	Initial Model	Idealized Model	Initial Model	Idealized Model
Support 1	77	14	81	18	194	27	120	16
Support 2	207	142	222	156	572	399	368	260

Table 1. *The B-rep entities before and after idealization*

Figures 14 and 15 represent the computation results by finite elements of the support 1 and the support 2 before and after elimination of details. Figures (14-a) and (14-b) represent respectively the states of constraints and the displacements of the support 1 before the application of the idealization algorithm. The figures (14-c) and (14-d) respectively shows the states of parts constraints and displacements after idealization. We notice that the saving time of computation is 68%. The error relating to the values of displacements is 0.9%, while that of the equivalent constraint is 7.5%. For the support 2, we represent respectively on figures (15-a) and (15-b) the states of constraints and displacements before the application of the idealization algorithm, whereas they are represented respectively on figures (15-c) and (15-d) but this time after idealization of parts. It is noted that the saving of time of computation is 62.5% and the error relating to the values of displacements is 2. 13%, while that of the equivalent constraint is 1.36%. For a preliminary

dimensioning analysis, this error is considered to be acceptable. If the designer aims to have a much more precise analysis in order to check the chosen dimensions, he can apply more strict criteria of idealization to dimensions of the details to be removed or to the site of the details compared to the loading. This won't allow removing the forms which are concentrator of constraint. In all cases, the taking into account of the idealization link in "design-analysis" chain brings an important saving of computing time without any significant loss on the quality of the results. We must notice that this procedure of idealization requires a negligible execution time compared to the total simulation time.

(a)   (b)

	Initial Model	Model idealized	percentage
Contraint Max (MPa)	5.886	5.444	7,5%
Displacement Max (mm)	$1.441 \ 10^{-1}$	$1.455 \ 10^{-1}$	0,9%
Simulation Time	28	9	68%

(c)   (d)
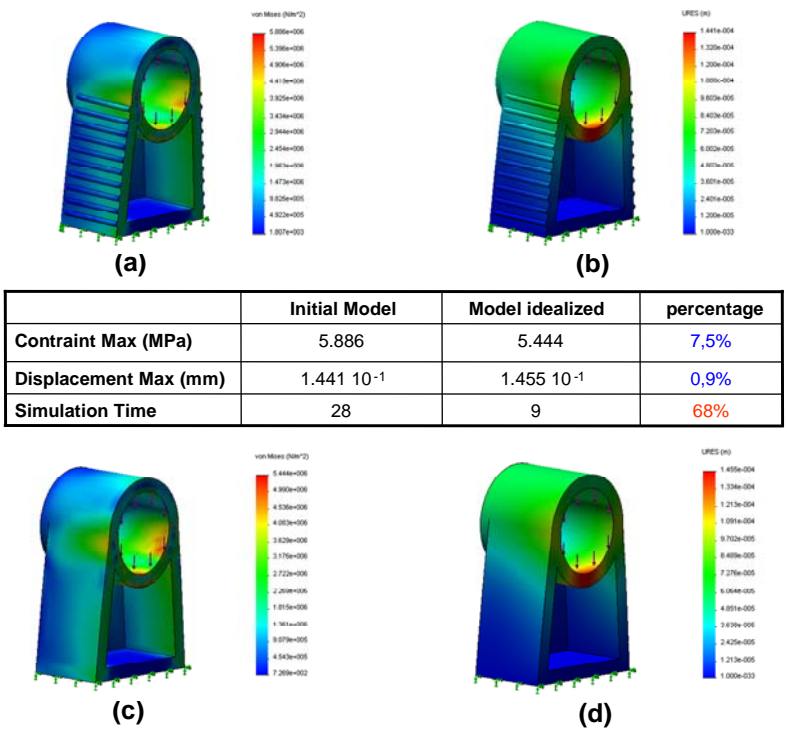
Figure 14. *Computation results of the support 1*

(a)   (b)

	Initial Model	Model idealized	percentage
Contraint Max (MPa)	5.438	5.364	1,36%
Displacement Max (mm)	1.469 10^{-1}	1.501 10^{-1}	2,13%
Simulation Time	32	12	62,5%

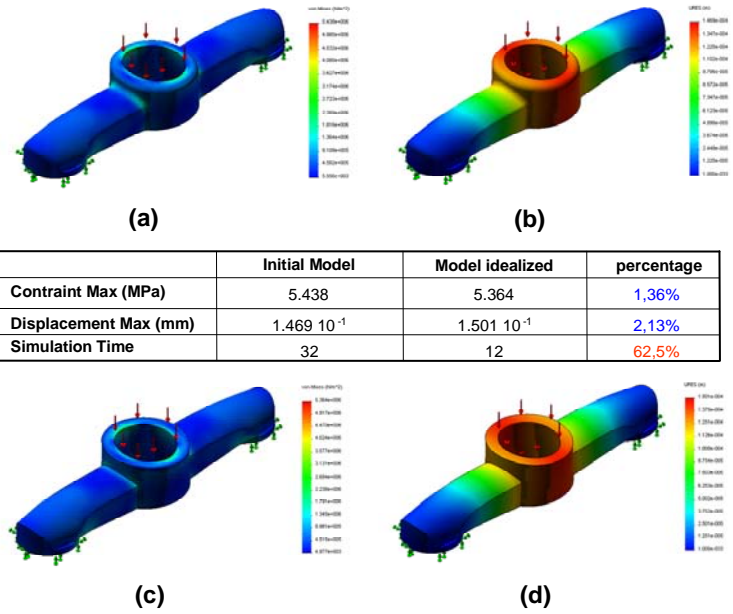(c)   (d)

Figure 15. *Computation results of the support 2*

5. Conclusion

This paper presents an idealization algorithm of CAD models for a simulation by the finite element method. The algorithm proposed consists in reading the B-rep model of the CAD geometry in order to identify, then to remove the details considered to be superfluous for mechanical analysis. In this work, the tree of creation of CAD model (CSG) is not taken into account because of the non-uniqueness of this tree and because it is easily lost by a simple export of the CAD model from a working tool to another.

The examples of validation showed that a suitable elimination of the details in a CAD model allows saving a very important time (up to 70%) in the procedure of simulation while keeping a high quality of the computation results (an error which do not exceed 2%).These observations were found by doing simulations by finite elements before and after idealization. This work obeys perfectly with the current tendencies of the industrialists who are interested more and more to the need for preparing CAD models during the pre-processing phase.

At short notice, it is important to consider other criteria of idealization such as the position of the detail compared to BC. Now, designer is the one who has to check the list of the details to be removed in order to keep those which are carrying BC, also those which are placed in the direction of the loading. Information on BC, are now, specified since design phase. However, they do not yet appear in the file of export 'STEP'.

At long terms, a user interface must be developed in order to provide the use of the idealization tool more ergonomic.

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