Tool for generation of analysis models by simplification of CAD model

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Abstract :

The activity of design and mechanical analyses are in close connection. The increasing tendency to integrate these two activities, while guaranteeing the reduction of the simulation time, obliges us to carry out the analyses stage on adapted models to the objective of analyses. The latter are the results of the simplifications operations carried out on the original model. In this paper, we propose a tool for simplification of B-rep model mark, which makes it possible to generate the two models of predetermination and checking, while being based on a whole of identifying information of details that can be idealized. The developed tool is based on a hybrid method which uses two techniques: Removal of details and fusion of faces. In order to validate our tool, we have studied a set of mechanical parts, which shows the significant profit in computing times, all of them respect the precision wished for the results of simulation.

Mots clefs : **CAD geometry, Integration, Simplification, Simulation, Hybrid method**

1　Introduction

For a long time, design and mechanical analysis were considered as two independent activities [1]. Our research tasks aim at the improvement of CAD models preparation's phase even before starting the mesh stage [2]. The preparation of a CAD model consists in idealizing or cleaning the geometry by eliminating details (holes, chamfer, fillet, etc), considered superfluous for simulation [3]. Then, these details are 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 [4].

The objective of this paper is to propose an original method which can guide the designer in the phase of the CAD model's preparation for a simulation by the Finite Elements Method (FEM). According to the suggested approach, 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 or for fusion if they are positioned in the stress concentration zone. The first part of the article presents a state-of-the-art on the principal techniques used to eliminate details from the CAD geometry. The second part introduces the proposed method of idealization. A data-processing implementation, using "Open CASCADE", of the proposed algorithm allows showing on some examples of mechanical parts, the time savings as well as the percentage of computation results error before and after the CAD geometry's idealization. That contributes enormously to the reduction of the design time and the cost of the product.

2　State-of-the-art

The generation of an analysis model using the CAD geometry is based on some analysis assumptions. These assumptions are related to the material behavior, solicitations and the geometry definition of the part. In the bibliography, [5, 6, 7, 8 and 9] several research tasks were interested in the CAD geometry adaptation problems to an analysis models dedicated to the mechanical analysis by the finite elements method.

- Fine and al in [5], introduce idealization operators for the Finite Element Analysis. The operators are based on the vertex removal and spherical error zone concept. Mobley reported an object oriented approach to develop surface-based defeaturing operators to suppress small features for the FEA model preparation.

- Lee and al in [8], present a method to generate progressive solid models (PSM) from feature based models using a cellular topology-based approach. Here, cellular topology is used to generate the PSM, and then surface entity based operators are developed to simplify the model. The main concept in this paper is to start with a feature based model as input and generate a sequence of solid models representing the underlying object with various levels of details. The intended purpose of the PSM is to stream models over a network efficiently.

- Thakur and al. [10]. In his works they study the existing model simplification techniques that are useful for physics based on simulation and classified them broadly into four main categories based upon the type of simplification operators used in the respective techniques, i.e. surface entity, volumetric entity, explicit feature and dimensional reduction.

- Dabke and al, in [11], 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 and al, in [12], 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 the removal of some forms of features considered as non-characteristic for the considered mechanical analysis.

- Sheffer and al, in [13], develops a suppression procedure of details and "cleaning" of the 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 and al, in [14] and Donaghy in [15], use the 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.

- Clémente and al, in [16], proposes to carry out the CAD/Analysis link by using manual or semi-automatic operators of idealization which exploit the geometrical data of the CAD model. These operators implement a geometrical algorithm to obtain the average fiber 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.

- Date and al in [17], report vertex and edge collapse-based technique for the mesh model simplification and refinement. They define three metrics based on the overall geometry error, face size and face shape. The metrics are evaluated for edges to determine their priority index for simplification.

3   Discussion

Based on the bibliography presented in section 2, our contribution is positioned in the: "model simplification technique for surface entity-based operators" (10). Our method is distinguished by:

- In our idealization process, the input and output files are in a STEP format, which is a neutral format (used by the totality of CAD and Analysis tools and systems).

- Our idealization process is based on a hybrid method, to ensure the quality of simulation result.

- Our idealization process is interactive. After treatment, the CAD part is presented by an iso-zone model, so the designer can intervene in the choice of details to be deleted using some criteria.

- Our idealization process is based on a CAD model, the reconstruction process is performed without approximation.

- A hierarchic link is saved between the initial model and the adapted model, to allow a perfect CAD/Analysis integration.

4   Algorithm of idealization with hybrid method

The proposed algorithm composed of three principal interdependent phases is represented in figure 1. Each phase implies overlapping stages.

In order to be independent of the CAD/CAM systems, the proposed algorithm relies on a neutral file (Standard for Exchange of Product: STEP) to import 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 (STEP).
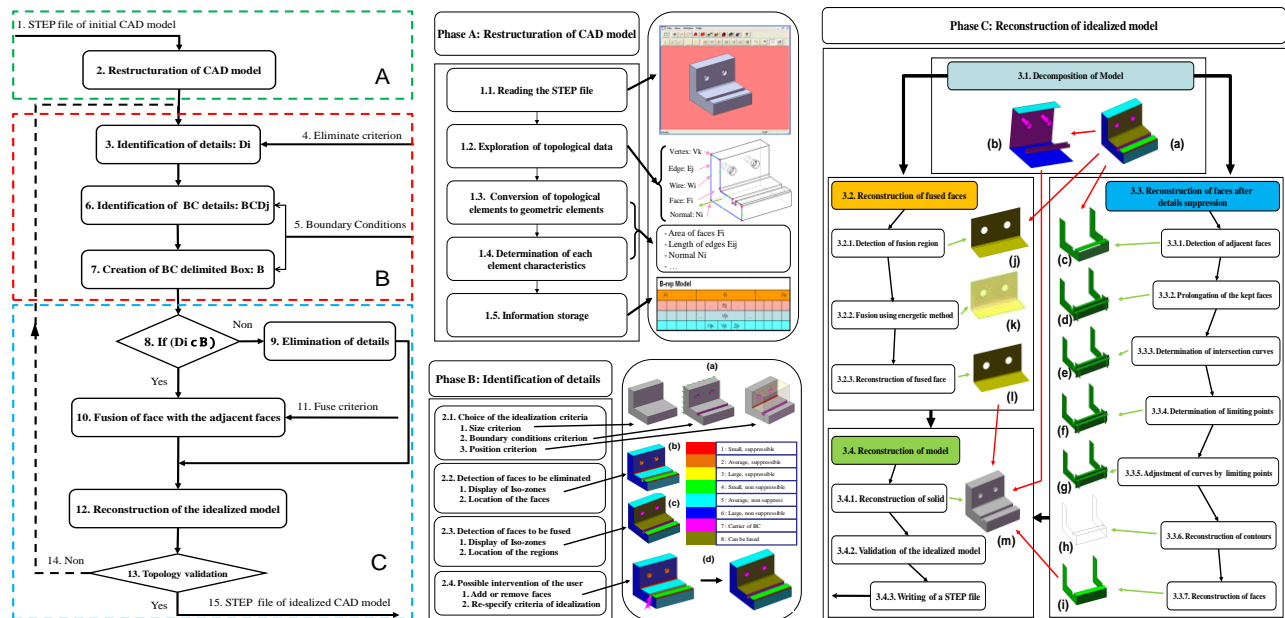

FIG. 1 – Algorithm of idealization with a hybrid method

The phase (A) of the algorithm consists in a step of pre-treatment of CAD model. It allows restructuring the Boundary Representation (B-rep) model of the part to a database. The structured information in this database related to the faces, the normal's of faces, the wires, the edges and the vertex which includes the geometry model of the part.

The phase (B) consists in identifying the details candidates for idealization. That implies the implementation of algorithms of identification based on criteria (forms, sizes, function, position…). The result of this phase is a representation of Iso-zones targets for simplification. These Iso-zones are entities (edges, faces) colored according to the specificity of each face. This original vision enables the 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 a high order of criticality, or to apply the automatic algorithms of simplification. The stage (7) consists in the creation of Boundary Conditions (BC) delimited box.

And the phase (C) allows the reconstruction of the simplified model. Stage (9) consists in removing the identified details, if they are outside the BC delimited box, then in rebuilding the geometric model after suppression. Stage (10) consists in the fusion of the identified details with the adjacent faces if they are inside the Box (the details represent the concentrators stress). The result of stage (12) is an idealized CAD model whose elementary topology is validated in stage (13). At the exit of the algorithm, the designer has at his disposal an idealized model saved in the STEP format for a simulation by finite elements.

5   Data-processing implementation and validation on example

5.1   Data-processing implementation

The data-processing implementation of the idealization algorithm was carried out on development's platform, 'Open Cascade'. Open Cascade 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.

The user interface of our tool for simplifying CAD models based on the hybrid method are shown in the following figure.

The processing steps of the CAD model simplification are illustrated in figure 2:
a: reading of initial model
b: displays initial CAD model
c: choice of size criterion and display colorful model
d: result of simplification based on the size criterion
e: choice of two criteria size and CL, and colorful display of model
f: result of simplification based on the size criterion and the CL criterion
g: choice of three criteria of size, location and CL and colorful display of model
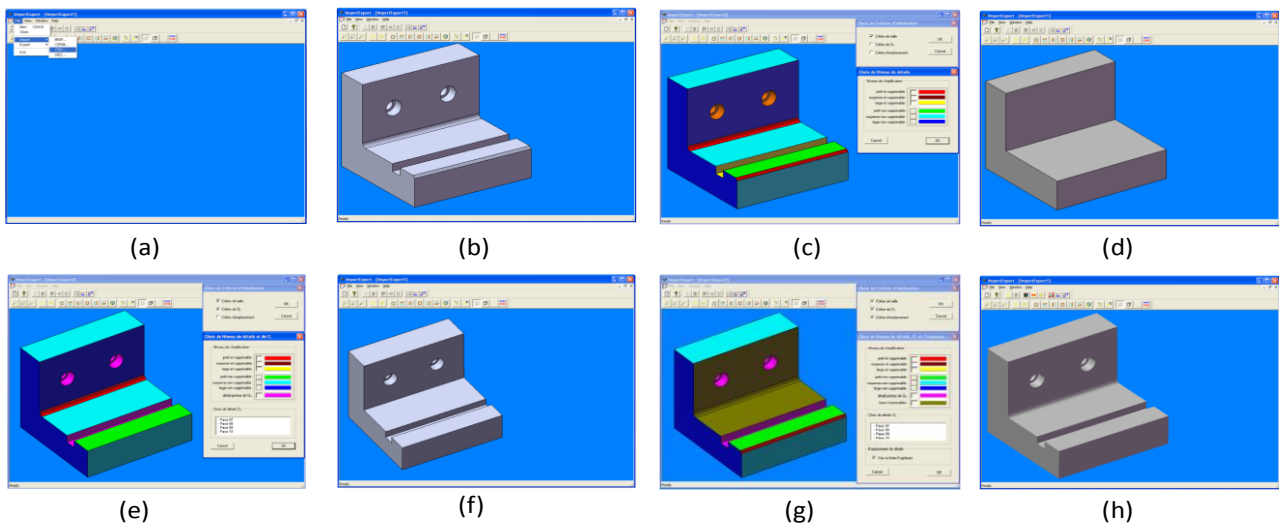h: results of simplification based on the size criterion, the CL criterion and the location criterion

(a)	(b)	(c)	(d)
(e)	(f)	(g)	(h)

FIG. 2 – The user interface of tools

5.2 Example of validation

In this section, one example of validation will allow validating the principal functionalities of the idealization algorithm. The part "casing" was 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. Figure 3 presents the used material and loading conditions.
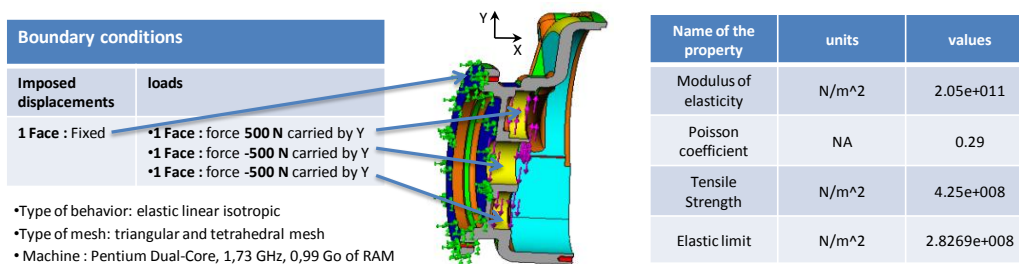

Boundary conditions				Name of the property	units	values
Imposed displacements	**loads**			Modulus of elasticity	N/m^2	2.05e+011
1 Face : Fixed	•**1 Face : force 500 N** carried by Y			Poisson coefficient	NA	0.29
	•**1 Face : force -500 N** carried by Y			Tensile Strength	N/m^2	4.25e+008
	•**1 Face : force -500 N** carried by Y			Elastic limit	N/m^2	2.8269e+008
•Type of behavior: elastic linear isotropic						
•Type of mesh: triangular and tetrahedral mesh						
• Machine : Pentium Dual-Core, 1,73 GHz, 0,99 Go of RAM						

FIG. 3 – The used material and loading conditions

Figure 4 presents the illustration of the principal stages to pass from a CAD model of the "casing" (figure 4-a), to a model of analysis whose geometry is idealized (figure 4-k). A very important stage (figure 4-c) represents the casing by Iso-zones. These iso-zones give to the designer a very clear idea of the details candidates to elimination by sharp colors, according to the level of criticality, details function and details position (figure 4-d), the boundary conditions are defined (loading and fixing) (figure 4-e), this information allows to identify the BC faces (figure 4-f) and to create the BC box (figure 4-g), the (figure 4-h) present the region of faces that can be fused, in the (figure 4-I) it is presented the model after the stage of details

elimination, the (figure 4-j) present the simplified model using all the criterions (hybrid method), and simplified model is saved at a neutral file (figure 4-k).

Figures 5 represents the computation results by finite elements of the initial model, the model 2 after simplification using only size criterion (the most used criterion in the state-of-the-art) and the model 3 after idealization using hybrid method. Figures (5-a-1) and (5-a-2) represent respectively the states of stress and the displacements of the part before the application of the idealization algorithm. The figures (5-b-1) and (5-b-2) respectively show the states of parts stress and displacements after idealization using only a size criterion. And the figures (5-c-1) and (5-c-2) represent respectively the states of stress and the displacements of a simplified model after idealization using the hybrid method. For the model 2, we notice that the saving time of computation is 51.25%. The error relating to the values of displacements is 1.16%, while that of the equivalent stress is 4.65%. And for the model 3, it is noted that the saving of time of computation is 43.75% and the error relating to the values of displacements is only 0. 03%, while that of the equivalent stress is only 1.11%.
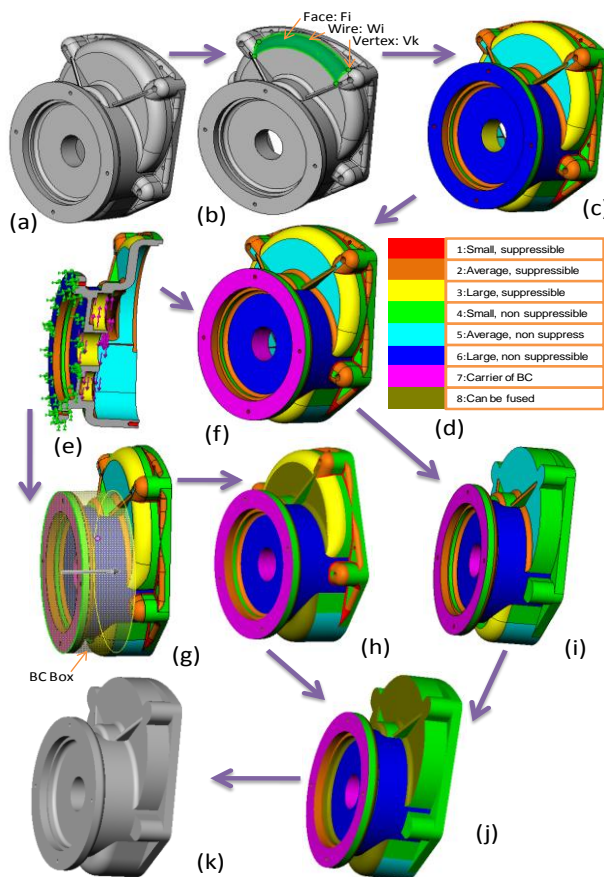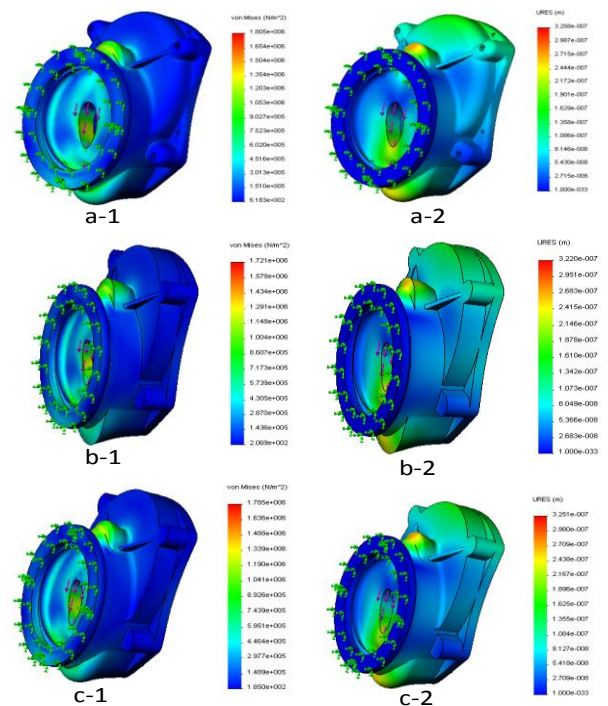

FIG. 4 – Stages of CAD Model simplification using a hybrid method

FIG. 5 – Computation results

	t (s)	S (Mpa)	d (μm)	% t $=\frac{(t_i - t_1)}{t_1} \bullet 100$	% S $=\frac{(s_i - s_1)}{s_1} \bullet 100$	% d $=\frac{(d_i - d_1)}{d_1} \bullet 100$
Model 1	80	1.805	0.3258			
Model 2	39	1.721	0.3220	51.25	4.65	1.16
Model 3	45	1.785	0.3257	43.75	1.11	O.O3

Model 1: Initial model　　　　　　　　　t: simulation time　　% t: time percentage
Model 2: Simplified model (Criterion 1)　S: stress Max　　　% s: stress percentage
Model 3: Simplified model (Criterion 2)　d: displacement Max　% d: displacement percentage

For a preliminary dimensioning analysis, the error of the first method 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 using the hybrid method. This won't allow removing the forms which are concentrators 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.

6　Conclusion

This paper presents an idealization tool of CAD models for a simulation by the finite element method. The tool 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 and to fuse the details localized in the concentrator stress zone. 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 results of the simulations carried out on the three models, before idealization, with the application of the size criteria and the consideration of site criterion, show well the major advantage of the hybrid method compared to the method based only on the size criterion because it gives a model better adapted to the need for analysis. Although the method based on the size criteria remains acceptable for preliminary dimensioning analysis and the hybrid method is used much better for a checking analysis, because it gives a good quality of results with a computing time weaker than the same analysis carried out on initial CAD model.

To improve even more our idealization method, we can also take into account the orientation of the details compared to the loadings, this criterion will be subject of future work.

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