INTERNATIONAL CONFERENCE ON ENGINNERING DESING
ICED 05 MELBOURNE, AUGUST 15 – 18, 2005

SOFTWARE ARCHITECTURE FOR FLEXIBLE INTEGRATION OF SIMULATION IN THE PRODUCT DEVELOPMENT PROCESSES

Okba Hamri*,+, Jean-Claude Léon*, Franca Giannini+, Bianca Falcidieno+

Keywords: Simulation, digital mock-up, product development process, integration, product assessment

1. Introduction

The behavior simulation of structures is becoming widespread throughout design processes to assess some limits of a product. However, the diversity of configurations that can be currently handled by structural simulation software is still limited by the time and cost required to prepare the suited model for a given phase of the design evaluation process. Here, a software architecture is proposed that allows a wide range of models as input. The key process when setting up a simulation is the model preparation process where shape changes are performed. As a result, this aspect is particularly emphasized to characterize the user's knowledge fitting with this task. The description of the proposed software architecture demonstrates its flexibility with respect to the product development process and examples illustrate also some effective configurations that have been handled with the proposed approach. Therefore, the resulting flexibility and validity of the proposed software architecture are enforced.

The analysis of simulation engineers' knowledge shows how it helped specify the appropriate input parameters while being capable to adapt to a large range of simulation configurations within the product development process.

Then, it is also highlighted how the proposed approach can be extended over structural simulations to fit into other simulation applications like downstream design ones.

2. Current approaches to model preparation for simulations

The product development process incorporates several phases where the simulation of structural behavior of a product can take place. Most often, at the design level, the simulation process strongly relies on the connection with CAD software where the shapes of components and sub-systems are defined. Proportionally much more rarely, structural behavior may be also required during the life of a product to understand abnormal fractures or breakdowns … In this case, the input data may be obtained from CAD software only if the real product is still up to date, in terms of shape, with respect to the CAD model generated during the design process. Otherwise, reverse engineering of the component or of the sub-system of interest may be necessary. Here, structural behavior is restricted to simulations through Finite Element (FE) methods, which are now extensively used.

As a complement to the input sources, a simulation process incorporates also hypotheses formulated by simulation engineers to fit the objectives of the simulation process [1]. Often, the first result of these hypotheses is the shape adaptation of the input model to suit the corresponding requirements [2, 3, 4, 5, 6]. Such shape modifications are characteristic of the simulation preparation process and the changed shapes constitute part of the multi-representations and multi-views needed during product development process [7]. Such shape changes or remodeling phases are also part of the difficulties listed through the studies presented by Halpern [8] who pointed out that, between 1991 and 1996, advances in FE mesh generation, improvements in C.A.D-F.E.A. integration and the impact of adaptativity and error control have reduced the median time required by 27% to prepare models and by 48% to perform the full analysis. In addition, he asserts that the state-of-art has still not yet got to the point where it can satisfy the requirements of the early design practice. Also, the report by Stiteler highlights the cost of remodelling phases throughout the design process in area of aircraft industry [9]. Even though parametric modelling is one possible approach to perform shape changes, it is not sufficient to cope with the changes required for FE model preparation; thus it does not provide a possible efficient integration of the simulation process throughout the product development process.

Indeed, shape changes form a common process required to reuse models from one product view to another one. Such changes are also conducted using view or skill dependent data that prevent to be fully automatic. In the present case of model preparation for FE simulations, the mechanical hypotheses, the boundary conditions… are examples of such data and form expert knowledge that cannot be always generated automatically. However, the shape changes required depend also on the input model provided and on the data associated with it in accordance to the product development stages considered. Therefore, an effective and comprehensive approach should be scalable across the various stages of the product development process, i.e. compatible with all the models that could be encountered during this process, to ensure a flexible integration of FE simulation processes.

The current approaches concentrates on a specific input model, most often CAD models [2, 4, 6, 10, 13] and therefore are not really scalable through the product development process. When digitized models only are considered, they are also restricted to a subset of process development stages and not scalable either [11, 12]. To overcome such limitations, the proposed approach concentrates, on one side, on the shape transformations required independently of the input model and on the other side, on the maintenance and propagation of the data attached to this model (also called semantic annotations later in the text to express a wide range attributes) during the transformations [14].

The following points are addressed through the next sections. First of all, section 3 analyses the simulation process and the knowledge involved to perform a FE simulation and proposes an intermediate model to perform the required tasks. Then, section 4 describes the proposed software architecture to show how it can be scaled through various stages of the product development process and how it can cope with a wide range of input data to perform the required shape changes. Section 5 briefly outline how the proposed architecture can be also applied to a larger scope of simulations than only FE. Finally, section 6 illustrate various results obtained with the proposed architecture to demonstrate the flexibility and efficiency of this scheme.

3. Analysis of the simulation process and knowledge involved

Pre-existing works [1, 13, 15] have led to the structure of the analysis task in terms of concepts involved in this task to prepare the analysis data and to evaluate and draw the conclusions from the results obtained. However, these approaches have not been performed at a level enough detailed to produce specifications that can be generic for a significant range of components. The separation between engineering office and simulation department as well as the difference of software between CAD and FEA favor the difference of know-how or culture among the staff members of each activity, similarly to other activities involved in the design process [16].

Typically, this difference of know-how can be illustrated by the fact that members of the engineering office are not aware and don't understand the tasks performed by members of the simulation department and vice-versa. Indeed, staff members of the engineering office have been trained for technical design and have developed technical skills using a CAD software. Similarly, engineers at the simulation department act the same way for numerical methods, FE models, … Therefore, members of the engineering office can hardly understand the requirements of the simulation department concerning the structure and the organization of CAD models to help them prepare FE models. Similarly, members of the simulation department have no skills about the practice of the CAD software used at the engineering office and hence, they are not able to express clearly how a CAD model could be organized. As a result, CAD models are transferred without accurate monitoring to the simulation department.

Because CAD and FEA are different software environments, the current practice to transfer models is based on standardized neutral file formats such as IGES or STEP [17]. Even though protocols and methodologies have been set up to ease the management of the parameters of the file transfer interfaces, they are not still fully used, which results in a significant loss of data and semantic attached to the model during transfer. The above configurations can be assimilated to co-operation between designers [27] involving objects containing numerical representations like those exchanged through neutral file formats.

Therefore, due to the above described discrepancies both in the technology used and mainly in the experts' skills, the shape changes required for the FE model preparation phase can be very tedious, inefficient and can result in solutions where the shape for the FE model is generated from scratch rather than obtained from a transformation of the CAD model.

3.1 Characteristic knowledge attached to the FE simulation process

The previous section has reviewed the main aspects of the FE model preparation phase and addressed the corresponding difficulties. Prior, to the description of the proposed scheme for FE model preparation, it is also important to recall some of the main characteristics of FE models since they form the core knowledge of simulation engineers. First of all, a FE model is based on a discretized representation of the domain of study defined as a mesh. To achieve correct computations for FE simulations, the mesh must be *conform*. The conformity of a mesh over a domain Ω is characterized by [18]:

- The union of all the elements K of the mesh is equal to Ω,
- The interior of each element K of the mesh is not empty,
- The intersection of the interior of two distinct elements is empty,
- The intersection of two distinct elements is either empty or a vertex or an edge or a face (if the elements are volumes) common to the elements considered.

This conformity concept is critical for FE simulations since non-conform meshes are useless. Hence, simulation engineers are used to check models against non-conformities as long as they can access the corresponding functions to analyze and set the conformity of a model.

In addition, a simulation engineer is used to manipulate non-manifold models, i.e. models containing lines, surfaces, volumes linked together, since FE models are often non-manifold when block, shell, plate, beam elements are used into a FE model. Hence, from a geometric point of view, simulation engineers are used to generate consistent non-manifold models for their simulation purposes. Currently, such an activity is mainly performed through 'gluing' operations to fit together the various manifold components forming the overall non-manifold model. These operations can be performed either on the geometric model set to describe the domain of study, i.e. a B-Rep NURBS type model or CAD model, or on the FE mesh during the discretization process of the domain of study. When performed on a B-Rep NURBS type model, the task becomes long and tedious due to the structure of the model.

Among the data attached to a geometric model that can be used to monitor the FE model preparation process, the FE map of sizes defined by the user is one example of such data incorporated in the proposed approach. Figure 1a illustrates an example of a map of sizes defined as a discrete envelope (a set of spheres) spread over the surface of the component. Geometric entities contributing to the definition of Boundary Conditions are also part of the data currently handled during the preparation process (see Figure 1b).

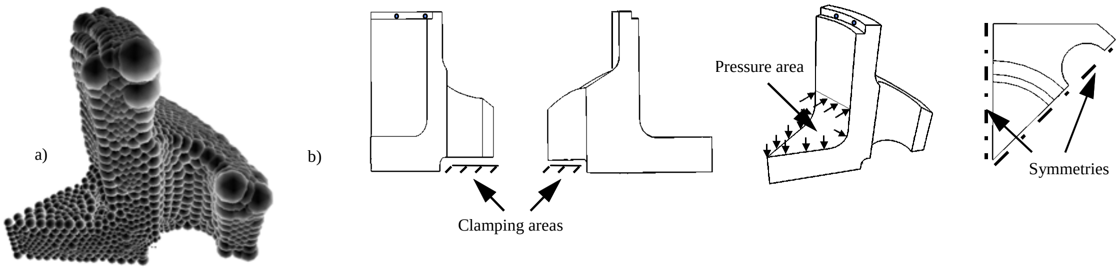


Figure 1: An example of discrete envelope (a) around a component to characterize details with respect to the target analysis (b).

As a result, areas of the geometric model that can be considered as details for a FE analysis can be automatically identified through the comparison between the discrete envelope and the dimensions of local geometric entities of the model. In order to detect easily the details, to take into account the knowledge of simulation engineers, to perform robust shape transformations, to achieve a flexible integration of the simulation task in the product development process, the geometric model used to describe a component is a polyhedron, i.e. a facetted representation of the B-Rep NURBS model. Such a model is similar to the previous definition of a mesh and therefore adequate with the knowledge of the simulation engineer acting as a user of this preparation process. The term polyhedron is used here to distinguish it from a FE mesh because it is dedicated to the preparation process and it may differ from the effective FE mesh used later on by the FE solver.

4. Software structure of the proposed approach

Figure 2 illustrates the structure of the proposed model preparation process, either starting from a CAD model (possibly feature-based) enriched with additional mechanical information (A1) or from digitized models (A2) or pre-existing FE meshes (A3) and finishing with standard FE mesh generators and solvers (C). This structure clearly shows that the preparation process can be inserted in any CAD-FEA software environment because it covers all the range of possible information sources, i.e. B-Rep models incorporating various levels of feature information as well as digitalised data or pre-existing FE meshes. Standard CAD modellers are distinguished from feature-based ones to clearly cover all the possible industrial configurations, i.e. CAD modellers that can use a variable range of form feature primitives. Here, we restricted ourselves to B-Rep models since they are always available through standard data exchange formats (e.g. IGES or STEP). The STEP standard is privileged among the others because it produces a more robust process since it enables to transfer more semantic about the model [17] than IGES (see section 4.4). The preparation process (B) is based on an intermediate polyhedral model to fit with the knowledge of the user and to ensure the scalability of the approach to deal with the various data types. Thus, the FE preparation and simulation processes can be integrated much more flexibly in the product development process. This capability is shown here to describe the overall model preparation scheme and to demonstrate how this scheme behaves depending on the amount of information existing in the input model. Further illustrations of examples based on digitized models or pre-existing FE meshes can be found in [11].

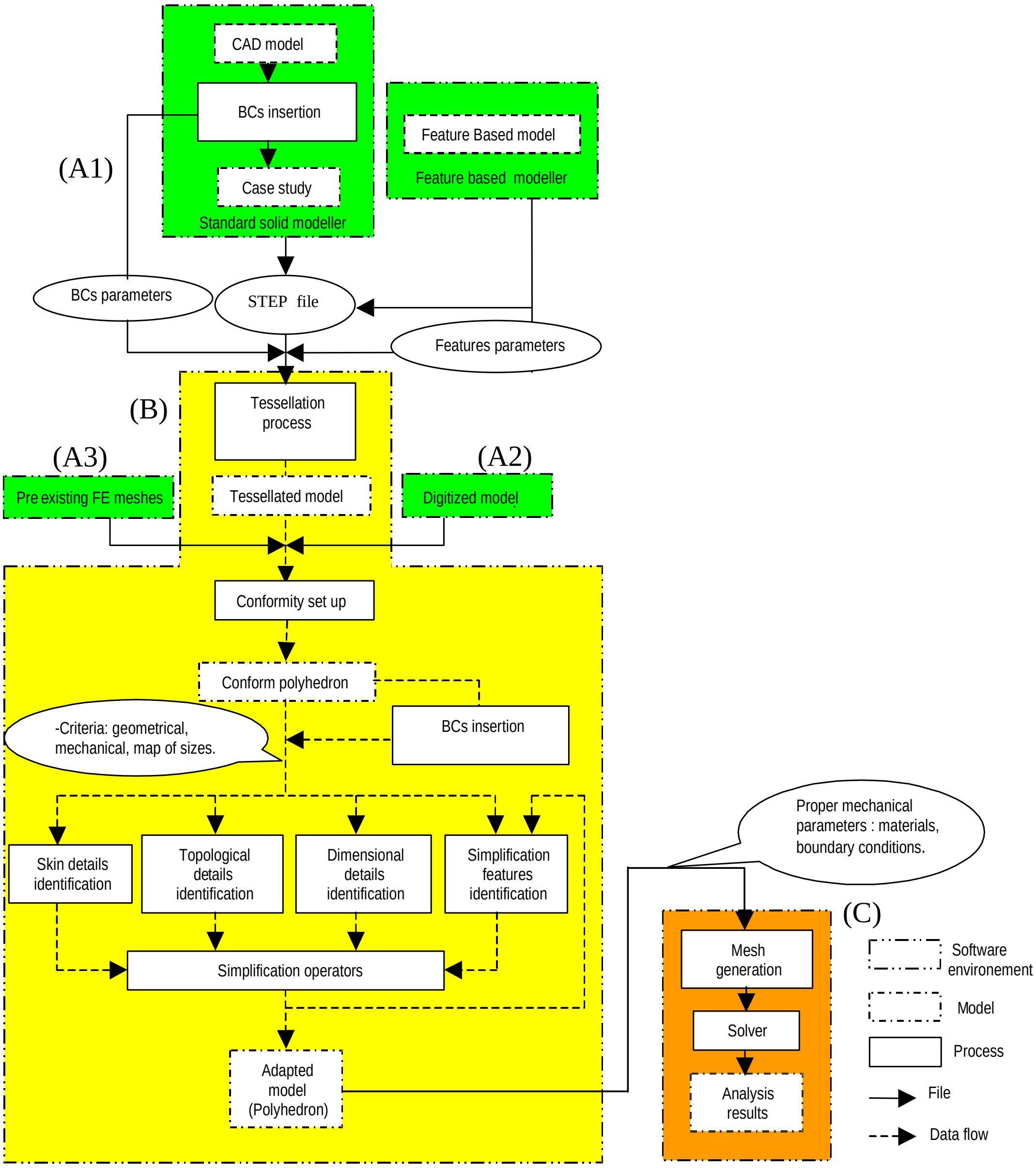


Figure 2: Data flow of the analysis model preparation process.

When models are originated from CAD modelers, at first a tessellation is performed on a face by face basis when considering B-Rep models. To improve the robustness of the process chain the tessellation process is monitored to avoid degenerated triangles that severely limit the behavior of following applied simplification operators due to numerical instabilities. Then, the conformity set up process takes place whatever the input source is, even though pre-existing FE meshes are conform because it is necessary to validate their status before starting the next treatments. As a result, this produces a generic process structure and the same set of conformity set up operators can be shared among the various sources of model input. When models are input though STEP standard the conformity set up can be automatically and robustly performed. The next step is the generation of the adapted model obtained through simplification processes according to the simulation objectives.

Once a conform polyhedron as been obtained, the detail removal operators can be applied. Depending on the type of modifications that must be carried out on the polyhedral model to remove details, four classes categorize the details and their associated operators as shown in Figure 3. Simplification features are not inserted in Figure 3 because they can combine several of the proposed categories and anyhow, they incorporate semantic information, which is another criterion that could be used to structure the simplification features. However, the progress about semantic classification fits into future work.

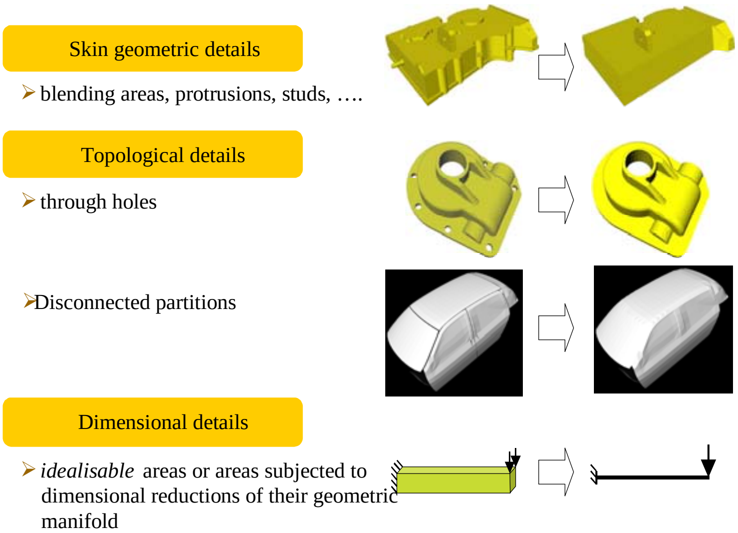


Figure 3: Examples of the four categories of details participating to the simplification process.

4.1 Skin details

Skin designates those details that can be removed by performing only continuous transformations like deforming a clay model (see Figure 3), and its associated removal operator is based on a decimation principle, i.e. an 'iterative vertex removal and local remeshing' [19, 20]. The identification criteria of this category of details, is based on the analysis of the influence of each vertex of the polyhedron on the geometric model of the object. The decimation operator is based on the FE map of sizes concept. A spherical zone is assigned to each vertex of the intermediate model. The radius of these spheres is defined through the user-specified FE map of sizes by mean of interpolation functions that smoothly assign radius values at each vertex using, as input, user-specified values at key points.
The set of spheres can be understood as a discrete envelope set up around the initial polyhedron where the decimated polyhedron must lie [11]. To this end, the vertex removal process is combined with an inheritance process such that spherical zones attached to the removed vertices are kept active entities of the discrete envelope during the decimation process. At each iteration, the inheritance mechanism is achieved with a redistribution process of the spheres over the faces resulting from the remeshing phase.
The combination of the vertex removal operator and the inheritance process helps formulate the shape restoration criterion to express that the decimated polyhedron stays always within the discrete envelope that expresses a subset of the simulation objectives.
The remeshing operator applied at each iteration creates a new geometry from the contour polygon of the candidate vertex. The shape restoration criterion is then applied to determine whether the vertex can be removed or not. If the geometry of the initial model is correctly restored, the current model is updated using the previously created mesh of this 3D contour polygon [21].

4.2 Topological details

Topological designates those details affecting the genus of the object, like through holes that cannot be removed by continuously deforming the object surface (see Figure 3). The goal of the hole removal operator is to locate and remove automatically through holes from the intermediate polyhedral model. These operators are taking benefit of the skin detail removal operator prior to use properties of fundamental group of curves and surfaces, and identify the set of faces forming the surface of the hole to remove [22].

This operator is applied to through holes inserted into closed two-manifold sub-domains of a polyhedron where each edge is exactly adjacent to two faces (Figure 4). It means that no topological criterion can be used to distinguish hole edges from others. Since geometric criteria are hardly robust and general to detect edges delimiting hole faces, the localisation phase cannot be performed on the input polyhedron. Indeed, this phase takes place during the decimation process where specific face-edge configurations are characterised from a topological point of view. Thus, the decimation process adds a dynamic insight, which can be exploited to robustly locate through holes in connection with the spheres specified through the FE map of sizes. For holes corresponding to details, the skin detail simplification process reduces a hole to its basic polyhedral shape, i.e. an open polyhedron with a triangular basis (see Figure 4b).

When each hole has been identified and characterised by a connected subset of faces, the topological operator removes all the nodes, edges, and faces defining this subset and generates two new faces based on each edge loop defining each hole boundary in order to close it. As stated, through holes are removed using a combination of topological properties, decimation process and a part of simulation objectives expressed through the FE map of sizes.

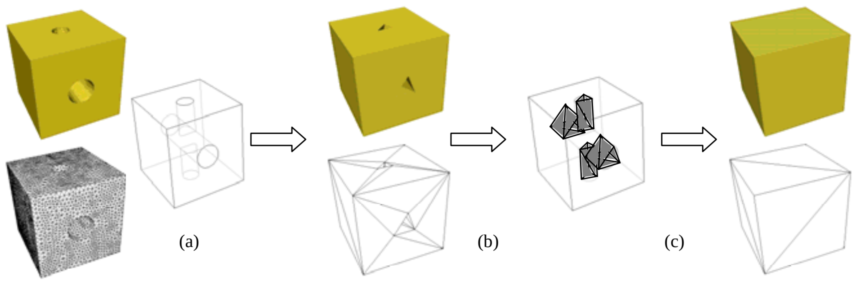


Figure 4: Successive stages of the hole removal process: (a) initial polyhedron, (b) decimation without topology changes, (c), holes removal and final decimation phase.

A second category of topological details exist to connect partitions of an object, i.e. when an object is made up from several disconnected pieces of polyhedrons. Such configurations often occur either when the input model is a sub-assembly or a B-Rep model tessellated face by face or a digitized model obtained through a set of independent scans. As stated, the range of configurations addressed by this category of details seems rather large. However, these configurations are somewhat similar to some conformity set up ones where closed contours need to be stitched to fill the corresponding area. As a result, these operators are based on the group of operators used to generate a conform polyhedron and hence can be regarded as a subset of these operators. However, this category is not yet fully defined because operators related to assemblies have not yet completely addressed [23].

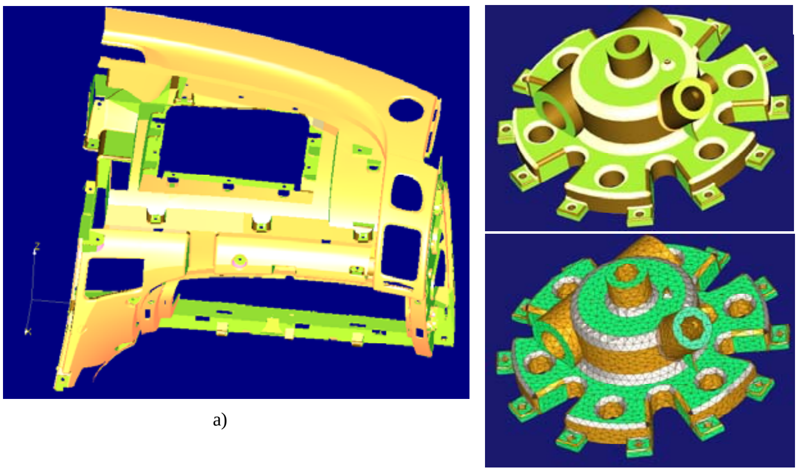
4.3 Abstraction details

Abstraction, i.e. dimensional details, refers to those areas of the object that can be idealized by using 2D or 1D geometry, e.g. lamina or polylines. Their associated removal operators

reduce locally the dimension of the geometric manifold of the component, using pairing operations between geometric entities of a given component (see Figure 3).
The idealization process operates in two stages and refers to the abstraction of sub-domains of the object. The first step may be called geometric idealization, since it uses geometric criteria as the only input to the process. It consists of a loop process ran all over the geometry. The process is as follows. Firstly, the geometry is analyzed to determine a starting point for idealization, depending on the specified geometric criteria: this is the localization process. It tells where idealizable areas are, using a concept of spheres that indicate whether some dimensions of FE elements highlight directions able to accept dimensional reduction. This is typically the case when a structure can be assigned a shell behaviour where the thickness direction can be removed to create an open surface. Secondly, the idealization algorithm itself is run over this area, creating a surface area and a locally non-manifold geometry. The automated process is reiterated over the complete geometry until it is unable to find any valid area to be idealized.
The second step requires mechanical data to modify the geometry and/or assigns mechanical data to areas of the idealized domain. This step is heavily application dependent and is still under development. During the first step, the constraint set on this algorithm is obviously that the process must respect the initial geometry, i.e. initial and idealized geometry must be consistent. Geometric criteria are used here to guarantee that the final state of the model will not be geometrically inconsistent with respect to the initial state. These criteria are based on the thickness, the curvature and the size of the idealized area.

4.4 Feature details

Feature details are starting to be inserted in the proposed approach [24]. They are currently based on the semantic that can be extracted from a B-Rep CAD model imported into the model preparation process through a STEP file [25]. As depicted on Figure 5, STEP files contain NURBS B-Rep faces as well as higher level semantic annotations. Greenish areas indicate faces that are considered planar, brownish areas indicate cylindrical faces. White faces on Figure 5b indicate toroidal faces and orange faces on Figure 5a are free-form NURBS surfaces.



a) b) c)

Figure 5: Examples of B-Rep models obtained through STEP files. a) Subset of a car dashboard (courtesy Renault), b, c) mechanical component (courtesy EADS CCR).

During the tessellation and the conformity set up processes, these semantic annotations stay attached to the intermediate polyhedral model generated. Such annotations form a source of information that can be exploited to detect drilling holes, for example, and perform the corresponding detail removal operation if it is compatible with the FE map of sizes. Using feature annotations is a way to open new possibilities of shape changes that can be better suited to specific simulation domains where the shape modifications cannot be obtained with the previous operators because of further geometric constraints.

5. Analysis of the proposed architecture and further extensions

As it will be demonstrated through the tests described in the next section, the proposed architecture is appropriate to the objectives described at the beginning of this paper, since it can ensure a flexible integration of simulation processes into the various product development phases through the variety of possible input models.

Since simulation results depends on the given Boundary Conditions (BCs), in our architecture their insertion and treatment within the overall preparation process is considered to guarantee the most effective FE mesh creation and simulation. Thus, we are currently investigating appropriate mechanisms for their usage and propagation along the preparation process. Here, the proposed scheme is essentially conceived for allowing a large possibilities of configurations. Similarly, the scheme is open to the adoption of further preparation criteria to help and monitor the creation of a simulation model. To this aim, additional criteria are currently under development and provide further objective evaluations of the shape simplifications' impacts [26].

Now, the proposed concepts can also be extended to other types of simulations, such as ergonomics or maintenance, during the product development process. In fact to produce data for simulation, two approaches can be taken. The first one create new geometrical and behavioural models from nothing, i.e. CAD models or scanned data. The second one is to reuse as much as possible existing data and to adapt them. Some works in the field of mechanical simulation show that the second one is the fastest as proposed here, provided the correct tools to transform geometry are available. Moreover, in an industrial context, the product can be extremely large and its definition is evolving constantly. Creating a new model for a given simulation with up-to-date data may not be feasible rapidly. Successfully integrating simulations into the product development process implies to be able to set up simulations and get results rapidly.

In the automotive and aeronautic industries, simulation relies more and more on the second solution. The geometrical data are extracted from the DMU (Digital Mock-Up), along with some information about the behavioural model which may also be present in the DMU. The full benefit of simulation can only be obtained through the implementation of automated seamless efficient data transfer processes linking the DMU to simulation processes. These processes, controlled by user-defined application–specific criteria, provide added value over traditional data conversions through the adaptation of shape data to application requirements and to the constraints of the preparation and utilization contexts (like hardware and software constraints).

The DMU is at the centre of many exchanges between the people involved in the product development process since it provides a more complete view of the product. The data attached to the DMU are mainly produced by the designers - namely the ones creating the digital representation of the product. They can be then considered the producers of the data.

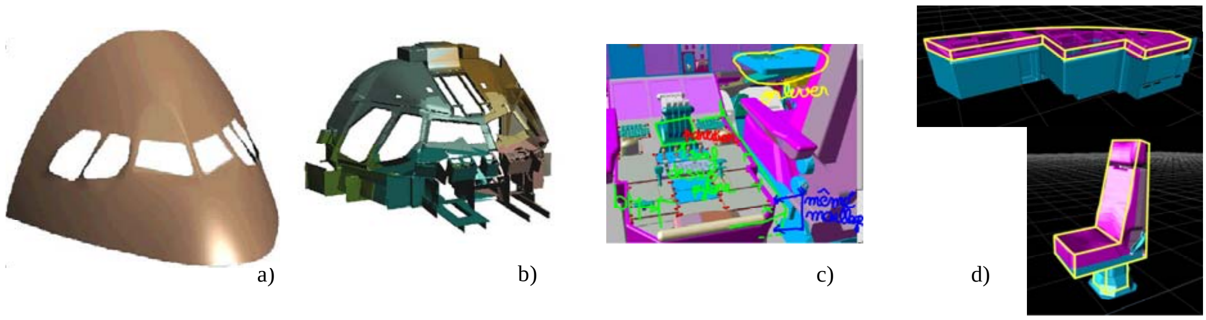
The other actors of the design process performing simulations need data from the DMU, and thus they can be considered as the consumers of these data. We call them the Downstream Users of the DMU. The data they use must to be adapted to include the necessary information and format suitable for their application, the Downstream Application. The results of this Adaptation (or Preparation) Process will be a different representation of the DMU with a

different shape, to be re-used for a given application and answering its needs. This representation is called the Downstream Digital Mock-Up (DDMU).
In some particular applications like visualization for marketing or pilot training, a DDMU can be taken as an input model, in order to create in fact another DDMU. This can be also the case for example when several models with a varying precision may serve for design reviews of different areas of a plane.
A DDMU can also serve as model for Virtual Reality applications, which are frequently used for particular types of simulations. Examples of simulations using Virtual Reality technologies in the aircraft industry cover ergonomics, simulation of maintenance operations … The proposed architecture, when incorporating ad hoc specific semantic annotations can therefore be extended to this range of applications. The shape preparation process, including the application dependent information, can be considered as a key process to spread simulation activities throughout the product development process, thus enforcing the flexible integration of the proposed approach in this process.

6. Results

This section provides a series of examples to illustrate the impact of the proposed approach on real industrial environment.

As a first example, the thermal model of an aircraft cockpit is considered. The objective here is to study the thermal behavior of the cockpit subjected to radiative, convective and conduction phenomena. Here, the input was a tessellated CAD model requiring a semi-automatic conformity set up process, which is tedious. Figure 6 illustrates the input model obtained from the engineering office, its complexity as well as its level of details, i.e. numerous geometric components are not necessary for the desired simulation and therefore needed an heavy shape simplification process (see Figure 6c and d). To give an idea, the model size is around 530Mb for the corresponding CAD file. This example shows that the proposed approach and the corresponding set of operators can efficiently handle complex configurations. It should be noticed that the present study is carried out early in the design process, i.e. the consistency of the digital mock-up didn't exist entirely because it contained components at various level of modifications. As an example, some windows of the external skin (Figure 6a) were not matching the corresponding ones of the internal skin (Figure 6b).



a) b) c) d)

Figure 6: Input model of an aircraft cockpit as available at a given stage of the design process (courtesy Airbus France EEI/EADS CCR). a) External skin of the cockpit, b) an example of internal structure of the cockpit, c) an example of level of details in the input model, d) examples of the detail removals desired for the target analysis (yellow lines indicate the desired geometry).

Figure 7 illustrates the adapted shape generated through the FE model preparation process described in the previous sections. Comparing Figures 6 and 7 clearly shows the shape changes performed to meet the objective of the thermal analysis. Figure 7 highlights how the FE model can be structured during the preparation phase to meet the FE model constraints in term of domain decomposition to express appropriate BCs. Here, this is highlighted through the colors used in Figure 7. Figure 7c shows also how the input polyhedral model can be enriched with new components since the pilot and co-pilot were not present in the input model but were required for the target analysis. These models where added during the FE preparation phase.

In order to evaluate the proposed approach with respect to the process currently adopted, a comparative study has been performed between this configuration and that of another cockpit. In this reference study, the relationship between the engineering office and the simulation department is classical, i.e. a CAD software is used at the engineering office and a different FE pre-processor software is used at the simulation department to generate the shape required for the FE analysis and the associated FE mesh. Data exchange is needed to transfer the partial digital mock-up among CAD and FE pre-processor software. As a result, many difficulties are raised to transfer and change the geometry of the model, as described at section 3. This configuration required a series of data exchange to solve the numerous problems faced when trying to generate the adapted shape for the FE analysis. These exchanges originated from the difficulty to properly monitor the parameters of the exchange and their impact on the geometry simplification phase. Once the adequate shape for the FE model is generated, new difficulties still exist to succeed at the FE mesh generation stage from the adapted model because some imported geometry still incorporated geometric tolerances of the initial CAD system that were not compatible with the mesh generation phase. More than four month time is required to perform such a task.

To apply the proposed approach, the original CAD model was reduced to a polyhedron model generated through a VRML type interface. In this case, it should be noticed that one single data transfer was performed, which already amounts to a significant time reduction. Then, on this model, the required shape changes for FE analysis requirements are achieved through the simplification shape processes described before. Afterwards, the obtained adapted polyhedron has been straightforwardly used for FE mesh in only one stage. As a result, the amount of time required to perform the task has been reduced to slightly less than one month compared to the above scheme, which demonstrates the efficiency of the overall approach proposed.

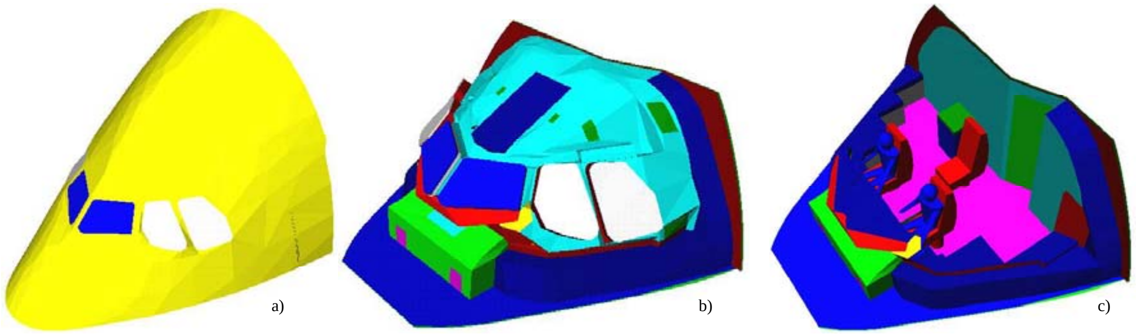


Figure 7: Polyhedral model obtained after the shape adaptation process performed on the intermediate model. (Courtesy Airbus France EEI/EADS CCR). a) External skin of the cockpit, b) an example of internal structure of the cockpit, c) inner part of the model.

As mentioned previously, the design model is not necessarily consistent during the early stages of the design process because multiple modifications can take place on different components, which result into an inconsistent model between the milestones of the design project. It is therefore even more difficult to base the model preparation process on the CAD data since these inconsistencies need to be identified and corrected during the FE model preparation phase. Such a configuration is more easily handled at the simulation department using the proposed approach where the proposed operators are better suited to the know-how of the simulation engineers.

Figure 8 illustrates another example of industry provided model handled through the proposed approach. In this case, the initial model has been obtained through a tomography scanning technique and exemplifies the configuration where a CAD model in not available to generate a FE mesh for the target analysis. In addition, this configuration combines the FE shape preparation phase and the FE generation phase into a single stage process, even though this capability of the operators has not been described for the sake of consistency. Figure 8a and b show the refinement level of the triangulation in the input model. Figure 8c, d and e show the quality of the FE mesh generated according to the user requirements in term of edge size of the finite elements. The quality of the FE mesh thus obtained has been evaluated with the standard parameters of FE software. No bad element was identified through this test. Incorporating the conformity process to check and correct the input model, the FE mesh generation constraints in terms of equilaterality, edge length, shape deviation leads to an overall process time of two hours. This process should be compared to the traditional approach in which the CAD model is prescriptive and considered as the necessary step prior to the FE model preparation, thus requiring the application of reverse engineering tools and methods. On such a model, the reverse engineering process to generate a CAD model from the tomography scan can be estimated to one week. In addition to this stage, the FE mesh generation phase should be added to obtain the desired result applicable to the FE simulation.

This example clearly shows how the prescriptive process based on a CAD model can be replaced by a much more adequate and efficient process based on the intermediate polyhedral model and the proposed set of operators.

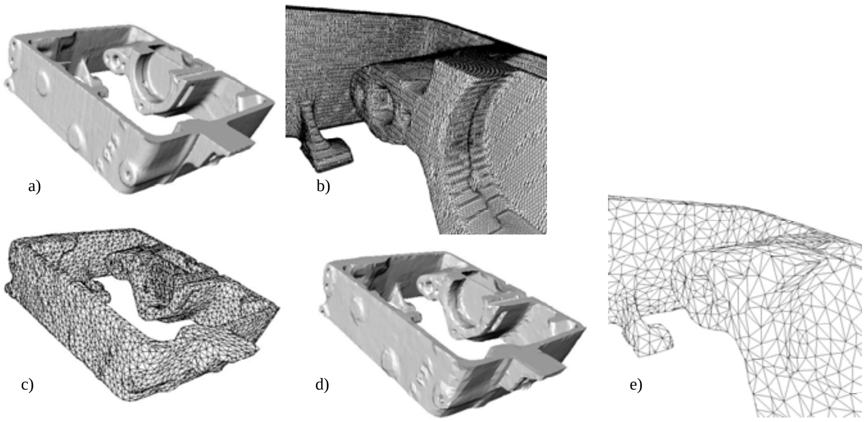
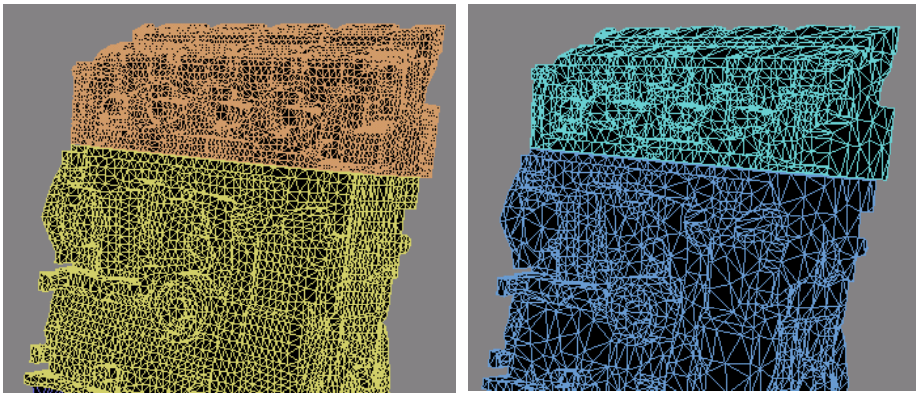


Figure 8: Example of combination of the shape adaptation process with the FE mesh generation process. (Courtesy Tomoadour). a) Polyhedral model obtained using a tomography scanning technique. This initial model has 427 132 faces, b) a detail of the input triangulation, c) FE mesh and adapted shape generated directly from a digitized model through a single treatment. The corresponding faces amounts to 11 924 faces, d) a shaded view of the FE mesh obtained, e) a detail of the FE mesh obtained.

The final example reported here is related to the reuse of pre-existing FE meshes (see Figure 9). This is the third category of input data accepted as input by our proposed FE model preparation process. Here, the objective is to use a FE mesh set up for thermal analysis (Figure 9a) for the generation of a coarser FE mesh for acoustics simulation (Figure 9b) while preserving the FE sizes in some user-prescribed areas. Indeed, the FE sizes are used to set constraint on edge lengths and the discrete envelope derived from these FE size is still active to monitor the shape deviation between the initial and final models. As a result, the new FE mesh is generated within a quarter of an hour from the initial one, whereas deriving the second mesh from the same CAD model used to generate the first mesh is more time consuming, especially if new shape modifications are required to suit the needs of the coarser mesh. In this case, hours or days is the time scale that can be required to obtain the target FE mesh.



a) b)

Figure 9: Example of reuse of FE meshes (Courtesy Metravib). a) FE mesh generated for a thermal analysis, b) FE mesh directly obtained through the model preparation phase for acoustics simulation.

Once again, this example shows how the integration of the simulation process becomes more flexible using the proposed architecture. It also demonstrates how the proposed architecture is scalable to address efficiently various stage of the product development process.

7. Conclusions

A software architecture has been proposed to perform a flexible integration of the simulation processes into the product development process. Based on three different categories of input models (B-Rep NURBS CAD, digitized models, FE meshes) it is possible to address a wide range of configurations where a simulation process can take place during the product development process. The concept of intermediate polyhedral model has been proved adequate because it is compatible with the various categories of input model and it also fits the simulation engineer knowledge compared to B-Rep NURBS models whose behavior is hard to monitor for simulation engineers. Rather than relying on prescriptive processes based on CAD models to generate the models suited for FE analyses, the proposed approach has demonstrated its efficiency in terms of time saved, which is critical to organize a product development process.

The set of proposed simplification operators has shown its ability to handle a variety of industrial model configurations. However, further progress can be made to extend the current set of operators to better fit the needs of the simulation engineers since the shape changes proposed are not covering all the user requirements like the shape changes desired for hexahedral meshes for example. This set of operators should also incorporate more adequacy to specific simulation models, i.e. thermal, crash …, which are formed by sub assemblies containing component interfaces that must be handled through specific operators.

The proposed approach has also demonstrated its ability to be generalized to a wider range of simulations like the ergonomics, maintainability … that are also required during downstream design processes. Such applications may also be related to VR simulation environments and raise new requirements for the proposed architecture because these simulations may need more than one model generated the preparation process. In addition, these models need to be consistent among themselves to achieve a correct simulation. Also, for fully exploit the approach potentialities in these downstream applications extra work is required to identify which semantic annotations are essential to prepare adequately the models for a given application. Though, this extension of the present work has already started, a significant amount of work still need to be performed to achieve new evolutions of the proposed architecture.

Acknowledgments

This work is currently carried out within the scope of AIM@SHAPE (Advanced and Innovative Models And Tools for the development of Semantic-based systems for Handling, Acquiring, and Processing knowledge Embedded in multidimensional digital objects) European network of excellence, EEC contract n°506766. The authors want to thank the mentioned companies for providing the test models: A particular thank goes to EADS Common Research Center for their support in developing the proposed approach and the corresponding software.

References

[1] N. Troussier, F. Pourroy, M. Tollenaere, B. Trebucq, “Information structuring for use and reuse of mechanical analysis models in engineering design”, J. of Intelligent Manufacturing, Vol. 10, n°1, 61-71, (1999).

[2] C.G. Armstrong, D.J. Monaghan, M.A. Price, H. Ou, J. Lamont, “Integrating CAE Concepts with CAD Geometry”, in Engineering Computational Technology edited by B. H. V. Topping and Z. Bittnar, Saxe-Coburg Publications, 75-104 (2002).

[3] V.Mobley, M. P.Carroll, S. A.Canann "An object oriented approach to geometry defeaturing for Finite Element Meshing", Proceeding of 7th International Meshing Roundtable, Sandia Nationnal Laboratories (1998).

[4] M. Rezayat, “Midsurface abstraction from 3D solid models: general theory and applications”, CAD, Vol. 28, 905-915, (1996).

[5] C.G. Armstrong, “Modeling requirements for finite-element analysis”, CAD, vol. 26, 573-578, (1994).

[6] M., Belaziz, A., Bouras, J.M., Brun, “Morphological analysis for product design”, CAD, Vol. 32, n°5-6, May, 377-388, (2000).

[7] MG-IT, “Multi-views and « multi-representations » design framework applied to a preliminary design phase”, P. Chedmail et al. editors, Integrated Design and Manufacturing in Mechanical Engineering, Kluwer, 553-560, (1999).

[8] M. Halpern, "Industrial requirements and practices in finite element meshing: a survey of trends", Proceeding of 6th International Meshing Roundtable, Sandia National Laboratories, 399-411 (1997).

[9] M., Stiteler, "CHAPS: Construction History and Parametrics: Improving affordability through intelligent CAD data exchange”, US Navy/ATI report, Jan. 2004.

[10] V. François, J-C. Cuillière, ‘3D automatic remeshing applied to model modification’, CAD, Vol. 32, 433-444, (2000).

[11] J-C. Léon, L. Fine, “A new approach to the Preparation of models for F.E. analyses”, Int. J. Comp. Appl., Vol. 23, n°2,3,4, 166-184, (2005).

[12] E. Béchet, J.C. Cuillière, F. Trochu, “Generation of a FEM Mesh from Stereolithography (STL) Files”, Proc. of the 7th Int. conf. on numerical grid generation in computational field simulations, Whistler, September 25-28, (2000).

[13] S. Arabshahi, D.C. Barton, N.K. Shaw, “Towards integrated design and analysis”, Int. J. of Finite Element in Analysis and Design, Vol. 9, 271-293, (1991).

[14] G. Foucault, P. Marin, J.C. Léon, “Mechanical criteria for the preparation of finite element models”, Int. Meshing Roundtable, Willamsburg (USA), 20-22 September, (2004).

[15] N. Troussier, “Contribution à l’intégration du calcul mécanique dans la conception de produits techniques: proposition méthodologique pour l’utilisation et la réutilisation”, PhD.Thesis Université Joseph Fourier, Grenoble, october 18th, (1999).

[16] S. Mer, “Les mondes et les outils de la conception. Pour une approche sociotechnique de la conception du produit”, PhD. Thesis, INPG, Grenoble, November 25th, (1998).

[17] STEP, “Standard for the Exchange of Product model data”, ISO 10303 standard, application protocols, Part 203, 214, integrated resources Part 41, (1995).

[18] P. J. Frey, P. L. George, Mesh generation: Application to finite elements, Hermes science, Oxford&Paris, (2000).

[19] L., Fine, “Processus et méthodes d’adaptation et d’idéalisation de modèles dédiés à l’analyse de structures mécaniques”, PhD. thesis, INPG, Grenoble, France, July 6th, (2001).

[20] L., Fine, L., Rémondini, J.-C., Léon, “Automated Generation of FEA models through idealization operators”, Int. J. For Num. Meth. In Eng., Vol 49, n°1-2, 83-108, (2000).

[21] P., Véron, J.-C., Léon, “Using polyhedral models to automatically sketch idealized geometry for structural analysis”, Engineering with computers, Vol 17, 373-385, (2001).

[22] L., Fine, L., Rémondini, J.-C., Léon, “Topological operators to improve F.E.A. geometry adaptation”, Fifth Int. Conf. on Comp. Structures Tech., Leuven, September 6-8th, (2000).

[23] P. Véron, S. Moisan, C. Mascle, “Identification and re-meshing of part interfaces in a polyhedral model of mechanical assembly”, 4th Int. Conf. on Integrated Design and Manufacturing in Mechanical Engineering, Clermont-Ferrand, France, may 14-16th, (2002).

[24] O., Hamri, J.-C., Léon, F., Giannini, B., Falcidieno, “From CAD models to F.E. simulations through a feature-based approach, Int. Conf. ASME DETC CIE, Salt Lake City, September 28th, (2004).

[25] M. J. Pratt, “Extension of ISO 10303, the STEP Standard, for the Exchange of Procedural Shape Models”, Int. Conf. On Shape Modeling and Applications, Genoa, Italy, 7-9 June, 317-326, (2004).

[26] G. Foucault, P. Marin, J.C. Léon, “Mechanical criteria for the preparation of finite element models”, Int. Meshing Roundtable, Williamsburg (USA), September 20-22th, (2004).

[27] C. Eckert, J-F. Boujut, “The Role of Objects in Design Co-Operation: Communication through Physical or Virtual Objects”, Computer Supported Cooperative Work, Vol. 12(2), 145-151, (2003).

Corresponding author : Pr. Jean-Claude Léon,
* Soils, Solids, Structures (3S) Laboratory, National Polytechnic Institute of Grenoble,
BP 53X, 38041 Grenoble France
Phone: (33) 4 76 82 51 27, Fax: (33) 4 76 82 70 43
E-mail : Jean-Claude.Leon@inpg.fr

+ Istituto per la Matematica Applicata e Tecnologie Informatiche - Department of Genova
Consiglio Nazionale delle Ricerche
via De Marini, 6 - 16149 Genova – Italy
Phone: (39) 010 64751, Fax: (39) 010 6475660
E-mail : {franca.giannini, bianca.falcidieno}@ge.imati.cnr.it