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# GENERATING ASSEMBLY MODELS FOR ADAPTIVE SIMULATIONS

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**Key words:** assembly, CAD models, idealization, mesh generation, functional information, a posteriori error estimator.

**Abstract.** Aircraft and automotive industries face increasing needs in generating large and complex simulation models, especially at the level of assemblies, sub-systems of complex products. Starting from the digital representation of sub-systems, i.e., digital mock-ups (DMU), as available from CAD software, the major steps of the simulation model generation are described. This incorporates the geometry analysis of the DMU to derive functional information. Subsequently, this information is used to perform model simplifications and domain decomposition consistently with the simulation objectives. Given the complexity of these models, the domain decomposition is a key issue to adaptive simulations to be coupled with COFAST software as well as error estimators using the LATIN method to avoid solving large systems and to take advantage of their decoupling capabilities. An assembly of bolted components illustrates the proposed approach.

## 1 INTRODUCTION

Companies, especially in the aircraft and automotive industries are increasingly interested in setting up numerical simulations throughout a product development process (PDP). Because of the inherent complexity of their products, simulations are not only targeting isolated components but there is now a strong interest at studying the behavior of one or more subsystems of these products [1, 2]. The corresponding requirement is the setting of rather complex FE models that cannot be currently handled within the time scale prescribed by an industrial product development project.

The purpose of the proposed contribution is to describe how FE simulation models can be derived from assembly CAD models and how adaptive simulations can take place with these large scale models. Consequently, the contribution focuses on the major steps of simulation model preparation and its interactions with an adaptive simulation process. The target addressed falls into the scope of the national research project, ROMMA [3], and, if all the connections between the steps are not completed yet, the paper will report the current progress in each of them.

On the one hand, domain decomposition approaches have been proposed but concentrate on the FE mesh generation process [9]. On the other hand, functional information attached to components is a current approach of design methodologies [10, 11, 12]. In this case, the top-down approach followed does not address the detailed connection with a 3D model [13]. This observation calls for new developments that address a detailed connection between 3D geometric entities and low level functions. To be able to process large assembly simulation models with an adaptive approach, the determination of components' interfaces is a key issue since it is a basic input of domain decomposition approaches. Interfaces are also part of the hypotheses of finite element analyses (FEA) to set contact with or without friction or even to merge domains representing components in accordance to simulation objectives. Assembly models as available either in or from CAD environments don't incorporate the description of interfaces between components. Contributions in this area have addressed B-Rep NURBS models as available in CAD software [2] or facetted representations [14]. However, in either configuration, the interfaces addressed reduce to contact areas, which is not the only configuration found in DMUs and no connection is initiated with basic functions of components, whereas this is a mandatory approach to produce a bottom-up approach connecting geometric information to component functions.

The paper structure is as follows. Section 2 describes how the automated enrichment of components with functional designations and interfaces can help producing simulation models with dimensional reduction of components. Section 3 briefly discusses some model requirements for adaptive simulations. Finally, section 4 describes the major steps of a domain decomposition approach taking advantage of a functionally enriched assembly model and shows how adaptive simulations can take advantage of this approach.

## 2 FROM CAD ASSEMBLIES TO SIMPLIFIED SIMULATION MODELS

### 2.1 Automated enrichment of CAD models with functional information

In a first place, studying the content and structure of an assembly model, as available in a Product Data Management System (PDMS), reveals that product assemblies or Digital Mock-Ups (DMUs) reduce to a set of components located in 3D space without geometric relationships between them. Complementarily, simulation models for assemblies strongly need geometric interfaces between components to be able to set up boundary conditions between them and/or meshing constraints, e.g. conformal mesh requirements.

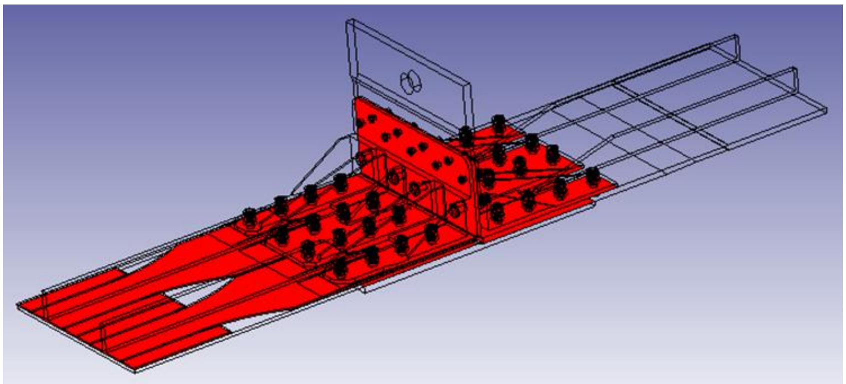


**Figure 1**: Interfaces extracted from a CAD assembly model. Components are represented with a wireframe setting whereas geometric interfaces are depicted in red.

Another observation derived from this analysis is the prominence of component functions as a means for specifying component simplifications/idealizations. This leads to a first step of the assembly processing scheme:

- Identification of geometric interfaces between components (see Figure 1). It has to be noticed the interfaces taking place between components in a DMU don't reduce to contacts and clearances. Indeed, components may interfere depending on their *conventional representation*. As an example, screws and nuts with threaded areas are often replaced by cylindrical ones. In this case, the screw has a cylinder diameter equal to the outer diameter of the thread. A similar setting applies to the nut. As a result, the interface between the screw and the nut becomes an interference. This observation must be taken into account when defining the shape transformation required when adapting the assembly model to simulation objectives [1];

- Assignment of functional designations to components. Currently, functional information is automatically added to some categories of components using a qualitative reasoning process. In the assembly of Figure 2, bolted junctions illustrate categories of components enriched with functional information, i.e. cap screws, nuts, locking nuts;

- As a result, components are structured geometrically, i.e. key geometric interfaces are located on the boundary of each component and in its neighborhood, as well as from a functional standpoint, i.e. functional designations of components fit into a taxonomy and set constraints over technological data describing the interfaces involved in their definitions [4]. Additionally, screws are associated to their load cycles, i.e. the set of components they tighten. This is obtained automatically from a qualitative reasoning process combining the 3D geometry of interfaces with reference states representing qualitative loading configurations.

All this information, derived qualitatively, contributes to the location of boundary condition areas in the assembly to set up FE models. It is also key information that can be used subsequently during adaptive FE analyses incorporating a posteriori error estimators.

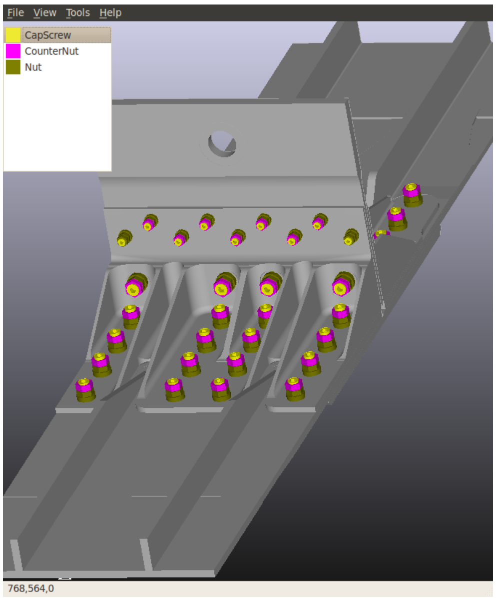



**Figure 2**: Assembly model with functionally enriched components, i.e. screws, nuts, counter nuts.

### 2.2 Simplifying assembly models using components' idealizations

Because assembly models can lead to highly complex simulation models when it focuses on car and/or aircraft models, idealizations of components are key issues of simulation model preparation since dimensional reductions is a means to generate efficient simulation models while keeping the number of Fes as low as possible. Idealization or dimensional reduction of components or sub domains is a common requirement to meet simulation objectives, especially when considering early design phases of complex structures.

To this end, component segmentation has been set up to analyze component morphology and decompose a component into sub-domains representing construction primitives. Indeed, a component is decomposed into a construction graph representing a set of non trivial construction trees. Depending on the primitive shapes, the dimensional reduction constraints help selecting the most suited tree that produce the idealized component (see Figure 3). This idealization algorithm is robust since the classical weakness of sub domain connection does not hold here. Indeed, the connections between sub domains is guided by the interactions between the primitives in the construction tree (see Figure 3d). These idealization algorithms take also into account meshing constraints, i.e. locations of stiffeners interact with the shape and size of FEs and choosing 'internal' or 'external' stiffener positions rather than mid-surface can improve the FE mesh quality.

Figure 4 illustrates the result obtained for the assembly depicted at Figures 1 and 2 after the idealization of the major components. In this model, bolts can be idealized as beams using the functional information derived in a first place.

This result is a first step to address large scale simulation models as needed for COFAST software [5] to meet simulation objectives at a rather global level.

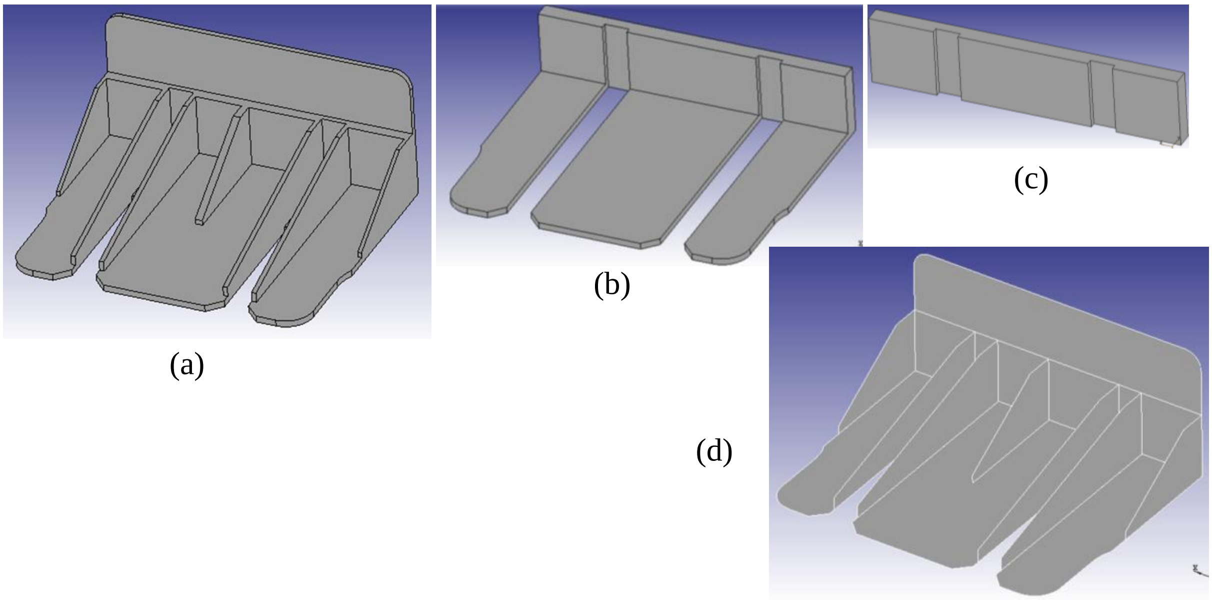
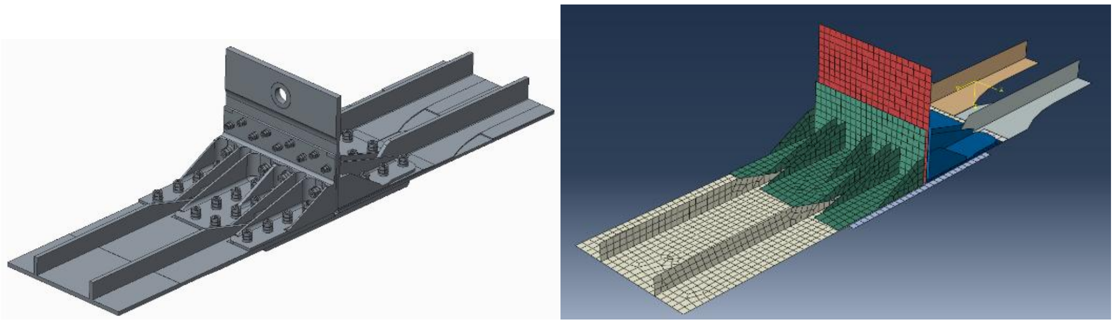



**Figure 3**: (a), (b), (c) construction tree derived from the construction graph as required for the dimensional reduction constraints. (d) idealized component derived from the construction tree.

## 3 ADAPTIVE FEA APPROACHES AND SIMULATION MODEL REQUIREMENTS

The iterative scheme that is used in COFAST, is derived from the LATIN method. The main principle is to separate the equations in order to avoid solving simultaneously a global and a nonlinear problem. The procedure searches for solutions that alternatively satisfy the global linear equations (kinematic admissibility and equilibrium on a substructure) and then, the local equations (interface equations). This leads to a decoupling of the problem. Because very few iterations of the LATIN method generate a solution over the whole time interval, the initialization overacts on the whole time interval. The solution obtained with this procedure ends up with a very low computation cost and can be parallelized to obtain a very good approximation of the solution.

Functional information becomes also important to set up simulation models dedicated to local analyses. Figure 5 illustrates how functional information can be used to simplify bolts and derive control areas around these bolts that are used to precisely meet simulation objectives. Here, the sub domains are used to model the friction phenomenon around each bolt as develops according to the Rotscher’s cone [8]. Additionally, these sub domains monitor the mesh generation process so that meshing strategies can be efficiently set up when processing complex bolted assemblies.



(a) (b)

**Figure 4**: (a) CAD model of an assembly, (b) model demonstrating the results obtained after component segmentations, an idealization process and a mesh generation. For illustration purposes some components have been idealized but not meshed, others have been idealized and meshed.

## 4 SIMULATION MODEL GENERATION BASED ON DOMAIN DECOMPOSITION

### 4.1 Setting up a domain decomposition for adaptive simulations

Functional information derived from the DMU is of qualitative type, e.g. cylindrical fittings are not quantified but classified as 'tight fit' or 'loose fit'. However, this information acts as a template that can be used when setting up the simulation parameters required at interfaces between components. Because components interfaces are clearly identified and can be categorized from a mechanical point of view, the simulation model preparation is strengthened: the number and type of parameters needed at various interfaces can be unambiguously identified, thus avoiding inconsistencies that could arise when setting up complex simulation models.

This concept of template can be extended to include shape transformations as needed to meet simulation objectives. Let us consider a configuration where the objective is to study the stress field around bolts and take into account the friction phenomenon around each bolt. Then, the template-based approach can incorporate all the shape transformations needed for this simulation objective (see Figure 5). The transformations can be listed as follows:

- Removal of the counter nut because the targeted stress field is in the tightened components rather than the screws,

- Merging screw and nut into a single sub-domain because their interface is not of interest with respect to the simulation objective,

- Transformation of the screw heads and nuts to simplify their shape as well as their FE mesh while preserving friction areas between the bolt and the tightened components,

- Generation of a sub-domain around the screw shaft to define the friction area of interest at the interface of each tightened component and to model more precisely the stress field around the screw shaft as required in the simulation objective.

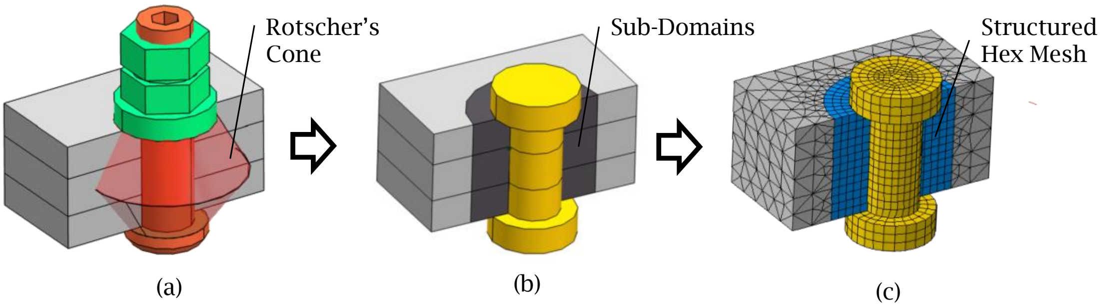



**Figure 5**: Template-based transformation of a bolted junction into simple mesh model with friction and contact areas definition around screw and nut.

The template-based transformation approach is parameterized with respect to the screw dimensions (diameter and length), the type of screw head (flat or hex type, …), the number of tightened components and the variants of the bolted connection (with or without locking nut, screw shaft with or without adjustement). This entirely parameterized template becomes very efficient to locate the various bolt configurations and set the appropriate interfaces with respect to the simulation objectives. Indeed, bolts can be identified from a user-specified function, e.g. bolted junction with locking function, which is a meaningful way for the user to process large assembly structures.

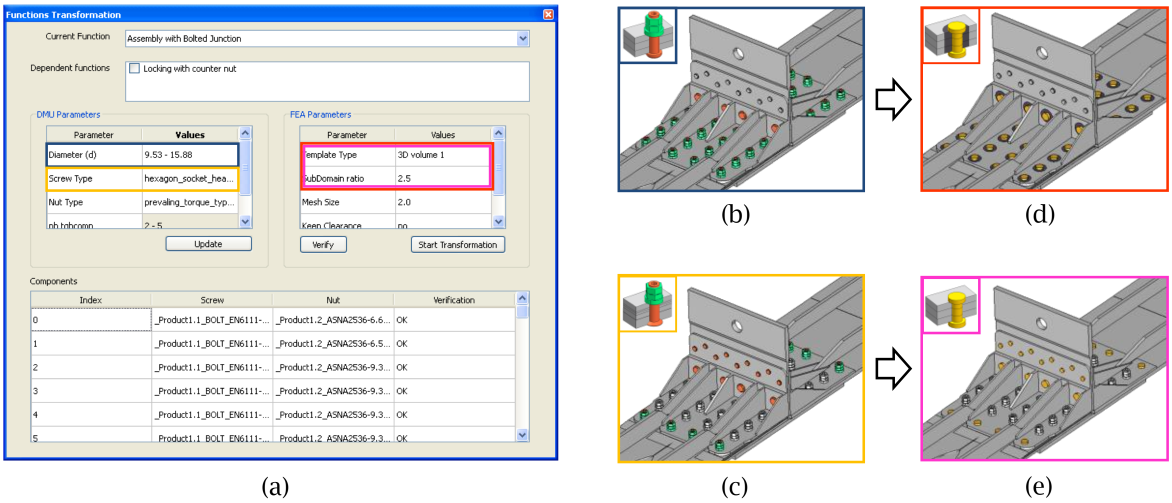



**Figure 6**: User interface for transformation of 'assembly Bolted Junctions' (a), filtering bolts based on diameters (b) or screw type (c), template-based transformations with (d) or without (e) sub domains.

Figure 6 illustrates the previous parameters as input parameters of the template, as seen by the user, to be able to target the proper category of bolts when generating his, resp. her, simulation model of interest. Once these transformations are performed, interface types and locations are entirely defined and can be structured to be transfered to a FE software to generate the FE mesh and set all the required boundary conditions deriving from the domain decomposition applied to the assembly model. Figure 7 shows the structure of the entities used to generate the FE mesh and the interfaces used to specify the boundary conditions of the FE model. Figure 8 illustrates this overall process on the assembly with bolted junctions of Figure 1. Because the components identified are related to a function, sub-domains and interfaces can be assigned all the parameters required for a FEA, which significantly improves the efficiency of FE model generation and their access to adaptive simulations.

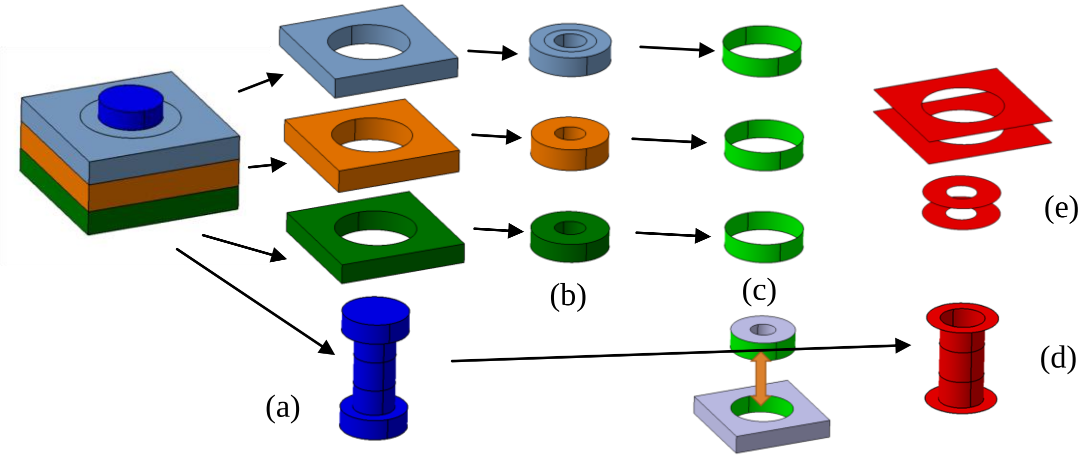



**Figure 7**: Domain decomposition obtained with the template-based transformation. (a) the simplified screw and nut, (b) inner domain of each tightened component containing the imprint of the screw head and nut as interfaces, (c) boundaries of inner domains, (d) interfaces around the screw and nut with an adjusted screw, (e) interfaces between tightened components.

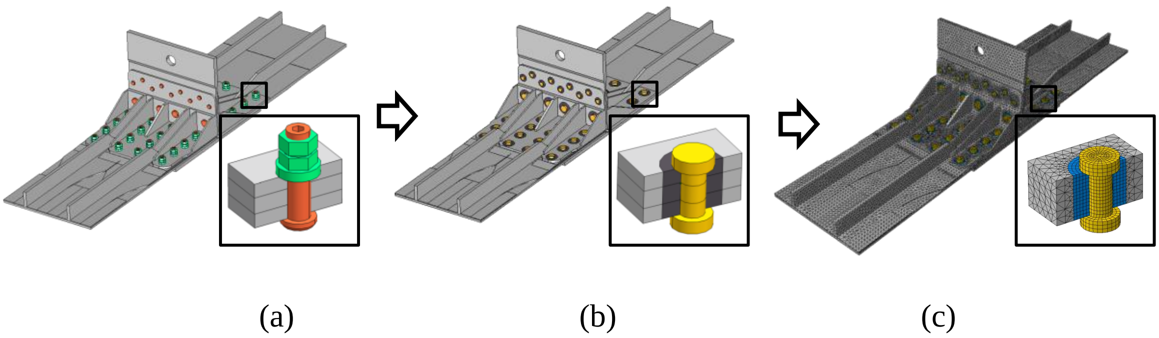



**Figure 8**: (a) CAD model of an assembly after the identification of functional designations of components (colors indicate the differences of functional designations), (b) model demonstrating the use of functional designations to simplify bolts and set up control volumes around them to adapt the model to the simulation objectives, (c) mesh model taking into account the interfaces obtained from the domain decomposition process.

## 4.2 Structuring an assembly model for adaptive simulations

Additionally, the precise location of interfaces becomes helpful for setting up input for a posteriori error estimators. Indeed, the estimator used here is based on the constitutive error relation concept. A pillar of the method is to construct admissible fields [7]. The knowledge of interfaces between substructures is then of primary importance. Nevertheless, in order to simplify the construction of admissible fields, a generic construction has been built when some data are missing [6]. When available, the precise location of the interfaces and more generally all the knowledge about the mechanical loading can be integrated in the generic method developed and improves the quality of the computed error estimation. The first results obtained in the framework of linear elasticity have to be extended to the framework of contact with and without friction. The final objective is to obtain a tool that enables the design of a robust simulation process of assemblies through an adaptive process.

The simulation model is based on a domain decomposition of the structure. Indeed, the structure is divided into interfaces and substructures (see Figure 9).

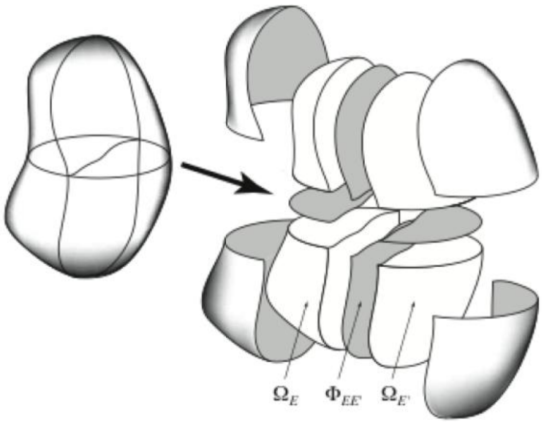



**Figure 9**: A structure split into sub-structures and interfaces.

Each sub-structure may correspond to a physical component. The interface may correspond to a contact with or without friction. One can also split a part into two sub-parts in order to decrease the computational cost. Another solution is to sort part by function, like for functional joints. High level mechanical contents can be inserted into some parts, e.g. non linear behavior for areas near the joint (Figure 8b).

With these partitions, the problem to solve has three sets of equations defined on the substructures and their interfaces:

- The kinematic constraints (Dirichlet's conditions and connection between interfaces and substructures);
- The equilibrium equations (Equilibrium, Neumann's condition and connection between interfaces and substructures );
- The constitutive relation equations (Classical constitutive equations and contact with friction on interfaces).

The constitutive error concept is a tool that measures the distance between the reference problem and its numerical simulation [7]. The computation of the measure in itself is easy to compute, the difficulty is to construct admissible fields. The construction of admissible fields, i.e. fields that check simultaneously kinematical constraints and equilibrium equations is a global problem. The construction of such admissible fields can lead to very high post simulations. Here, the method developed is to construct the admissible field on a sub-structure.

This local construction has a lower cost than the global method, but introduces an approximation. The first results show that for a reasonable number of substructures (up to 100), the results are very close to the one obtained by an optimization over the whole substructure (Figure 10).

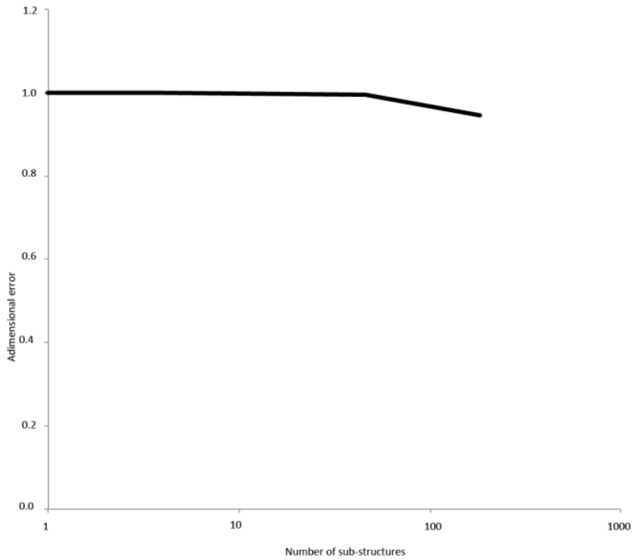



**Figure 10**: The quality of the estimated error vs number of substructures of interest.

Moreover, the method set up does not require a perfect description of the stress distribution and displacements at the interfaces of sub-parts to construct admissible fields. These quantities are only known in terms of generalized FE quantities. This approach introduces more flexibility and makes it possible to evaluate the error in a very simple and systematic manner on sub-parts, i.e. patches set around bolts in the example case of bolted assembly.

## 5 CONCLUSION

The generation of adaptive simulations for complex structures has been addressed for assembly models. Interfaces between components are a first key information that is extracted from the assembly model. From these interfaces, a qualitative reasoning process is able to derive the functional designation of some categories of components. These results have been illustrated with screws and nuts in assembly configurations. The functional designations incorporate also the location and type of interfaces between their components and their neighborhoods. This is another key information to set up adaptive analyses.

From the enriched assembly model with the functional designations of some components, it has been proposed to set up a template-based transformation that is able to produce a domain decomposition and interfaces as suited for adaptive simulations. The content of this template has been shown as fully parameterized to be able to address automatically a wide range of configurations and perform the corresponding domain decompositions.

Currently, the construction of admissible fields can be achieved efficiently with a decomposed when its interfaces are fully characterized. Current results lead to good quality simulations as shown with the estimated error obtained.

Further work will address the extension of the current numerical simulation scheme to be able to process interfaces with contact with and without friction. Also, complementary developments will address the enlargement of the categories of components that can be identified and structured with functional designations.

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