4 PLM — DIGITAL ENGINEERING AND NUMERICAL SIMULATION FOR COLLABORATIVE PRODUCT DEVELOPMENT

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Product Lifecycle Management (PLM) is a strategic business approach supporting the collaborative management of product and process definition information from concept to end of life. This information management is carried out across the extended enterprise and by a set of IT solutions integrating digital engineering and numerical simulation systems. Those systems are used to define, assess and validate the physical behavior of products or complex systems. Digital engineering and numerical simulation systems thus enable to minimize the use of physical prototypes for design decision making. Regarding the reduction of product development costs and times, the integration of digital engineering and numerical simulation systems in PLM is not completely achieved. Indeed, the heterogeneity of digital engineering and numerical simulation systems and models does not facilitate the link with others systems of the PLM environment. The aim of this paper is to present literature survey on digital engineering and numerical simulation systems integration in PLM environment enabling an effective collaborative product development.

Keywords: PLM, SLM, CAD, CAE, CAM.

1. INTRODUCTION

The present paper deals with problems of numerical simulation tools in PLM environment. PLM is "a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life".[1] According to Ref. 2 PLM is historically born from engineering database management for static elements such as databases of materials.[3] In the early 1990s, these databases has evolved and became PDM systems that have the objective to support information management for design process, mainly CAD models. Later, the scope of PDM systems has changed to information management of product during the entire lifecycle. This evolution has led, step by step, to the emergence of PLM systems.[4,5]

PLM systems are heterogeneous and made of a wide set of computer tools constituting a single digital chain for product development,[6] such as CAx, PDM, Manufacturing Process Management (MPM), Enterprise Resources Planning (ERP), etc. To achieve their mission that consists in supporting the product development process, PLM systems have to ensure a full integration of all computer tools. This paper deals with the integration of the numerical simulation tools in a PLM environment. In the following section, the interest to integrate numerical simulation tools with other computer tools is shown. Then, a survey of technologies enabling integration of numerical simulation tools in PLM environment is detailed. Finally, a new approach for the integration of numerical simulation tools in PLM environment is presented.

2. NEED FOR INTEGRATION OF NUMERICAL SIMULATION TOOLS

Last decades, engineering processes were subjected to many changes. They evolved from a sequential to a concurrent approach. Concurrent Engineering (CE) approach is based on team and expertise integration concepts, proposing methodology and technology for information exchange and resource sharing between the various collaborators of a company.[7] CE consists in taking into account, at the same time, the needs of the various times of the product lifecycle. It addresses, above all, the expertise integration. The expertise integration within engineering processes is enabled by the specification of methodologies and rules.[8] Digital engineering tools, including those dedicated to numerical simulation, aim at supporting this integration.

Numerical simulation aims at effectively analyzing and validating the physical behavior of products or systems. The objective is to check early the fulfilment of the functional and technical specifications. It allows a huge time reduction. From this viewpoint, numerical simulation has became a major activity in the product development process. Its main advantage is to allow the validation of design choices almost without, or with less, no prototypes. For the development of an aircraft engine which involves hundreds of design choices, the accomplished savings of time and cost are interesting. Numerical simulation is also used to optimizing and understanding the product behavior, and to support the innovation by assessing new concepts.

Although numerical simulation brings many advantages, it has not reached its full potential regarding to the product development process. It is due to its non effective integration with others digital engineering tools: platforms for data and processes management (PDM) and specific applications (Computer-Aided X).

To integrate two computer tools means to take into account, in each application, the constraints of the other one. These constraints are mainly related to the technology used to develop these tools. The integration of numerical simulation tools and CAx involves at least three problems. Numerical simulation tools are mainly integrated to CAD systems. This is due to the first and main objective of numerical simulation that is to validate the design choices. CAD models being the most used and shared models during the design stage, numerical simulation have to be, first of all, integrated with CAD systems. Today, gaps still remain between numerical simulation tools and CAD systems. Models provided by CAD systems are often very detailed and geometry-oriented, while numerical simulation tools require abstract, or idealized, model.[9] These details produce inconsistencies in meshes which slow down solver and produce poor and inappropriate simulation results.[10] Definition and optimization of design concept from CAE product model is another gap in the integration of numerical simulation tools with CAD systems. For this numerical simulation oriented approach, automated and semi-automated procedures are required.[9] One of the stake is then the improvement of optimization process using the integration of numerical simulation in the early stage of the design process. The evolution of IT has led to a spread use of numerical simulation to all product lifecycle stages, such as manufacturing or recycling. In manufacturing stage, numerical simulation aims at evaluating the physical behaviors of products to manufacture and of tools during machining operations. Except thermic and surface treatments, manufacturing processes mainly aim at obtaining the final form of the product by modifying a raw form.[11] This could be done by conserving (milling, drilling, etc.) or not (foundry, forge, etc.) the mass, or also by using an assembly (wilding, etc.). To simulate these processes, models corresponding to raw and final products are required. CAD systems provide the model corresponding to the perfect final product. CAM systems transform this model to obtain a raw form used in machining processes, and these new models, provided by CAM systems, are data inputs for the numerical simulation tools. As for CAD models, CAM models are often very detailed and an idealization process for numerical simulation is required.

The wide use of numerical simulation during engineering and development processes has led to the growth of generated data. The efficient management of the simulation data is thus required to ensure the information sharing between the actors of the design process and the reliability of the decision making.[12] PDM systems were developed to solve some problems of data management for product development process. They ensure an efficient data and process management, concerning with data storage, information exchange and workflow management.[13,14] Therefore, PDM systems enable the integration in PLM environment of all computer tools related to product development process. However, PDM systems, which were developed for CAD applications used by designers, are not adapted enough to numerical simulation activities and tools. The development of new functionalities in PDM systems, or the development of new data management systems dedicated to numerical simulation activities is thus required.

3. ENABLING THE INTEGRATION OF NUMERICAL SIMULATION TOOLS IN PLM ENVIRONMENT

Several works in literature have studied the integration of numerical simulation tools in PLM environment. The first approach is to develop methods and tools to facilitate the exchanges between numerical simulation tools and the other specific applications (CAx). The second approach is to integrate numerical simulation tools to existing PDM systems or to develop an IT environment dedicated to numerical simulation.

3.1. Numerical Simulation Tools and CAx

The integration of numerical simulation tools with other CAx gathers two problems. The first is related to the construction or the conversion of models. It is about the construction of numerical simulation model from other CAx models and vice versa. The second is related to the reliability of the simulations.

The numerical simulation tools use several types of methods, such as Discrete Element Method (DEM), Lattice Geometrical Model (LGM), Finite Element Method (FEM), Smoothed Particle Hydrodynamics (SPH), etc.[15] However, Numerical simulation tools, in Mechanical Engineering, often use Finite Element Method. Consequently, research works on the construction of the models for the numerical simulation tools have focused on FEM. These works have started in 1980s with the evolution of artificial intelligence, and aims at automating or simplifying the construction of simulation models by using the geometric models provided by CAD system and by taking into account the needs of simulation.[9–10,16–18]

Although several CAD/CAE systems, such as CADfix, integrate methods for automatic construction of Finite Element Analysis (FEA) model from CAD model, there still are some improvements to be made. For example, the lack of semantic relation between FE mesh and CAD model doesn't allow the propagation of information attached to CAD model such as boundary conditions. Foucault *et al.* in Ref. 10 propose an approach which consists in adapting CAD model topology for finite element analysis. They propose a "Mesh Constraint Topology" (MCT) model with automatic adaptation operators. These operators aim at transforming CAD model boundary into a FE model, featuring only mesh-relevant faces, edges and vertices. The objective is to avoid inconsistencies in meshes which slow down the solver and produce poor or inappropriate simulation results. However, in addition with the fact that there is a lack of synchronization, this approach is unidirectional in terms of communication between tools.

Lee in Ref. 9 tends to solve this problem of communication between tools. Indeed, his approach lies on a common modeling environment for a bi-directional CAD-CAE integration. This environment allows CAD systems to automatically generate analysis models, and allows the CAE system to automatically change geometric models and to run new analyses. This approach uses feature-based multi-resolution and multi-abstraction modelling techniques, especially non-manifold topological (NMT) modelling. It is very interesting because it is not only adapted to engineering analysis but also to other applications such as virtual prototyping and manufacturing (Figure 1). Nevertheless, this approach has some limits, especially the lack of robust semantic relations between CAD and CAE models.

The second kind of research works about the integration of numerical simulation tools and CAx integration focuses on the reliability of simulation.[19–21] Indeed, the numerical methods solve exactly the mathematical problems only on the "limit" and in the frame of the mathematical models which are some approximations of physical reality.[19] The work of Shephard *et al.,* on this topic, is very

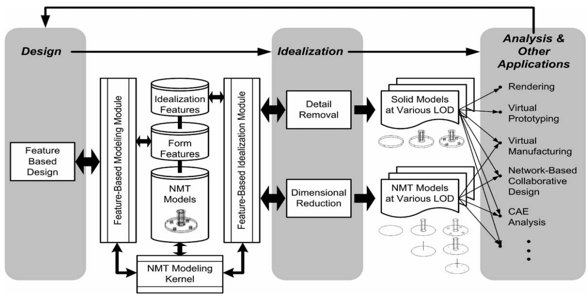

Figure 1. Design process in the CAD/CAE-integrated approach.[9]

interesting.[19] They have developed adaptive control tools available for geometric models for both begin and end of design, taking into account the fact that geometric models are often incomplete early in the design and with many useless details for simulation later in the design process. These tools must determine the appropriate mathematical models, select discretization technologies, evaluate the accuracy of the predictions obtained and determine the improvement of the models and discretizations needed to obtain the desired accuracy.

Several studies have been made on simulation model construction and simulation reliability. The result is that the technology in this field is very advanced, although it remains some gaps to fill to reach a complete and robust automatic construction of CAD models from CAE models and vice versa. On the other hand, the evolution of numerical simulation have highlighted some problems of data management in simulation, that should be explored more in details.

3.2. Numerical Simulation Tools and PDM Systems

This last few years, several works have been done on the integration of the numerical simulation tools in PDM systems.[12,22–27] However, a distinction should be made between the adaptation of PDM systems to numerical simulation and the development of environment dedicated to the numerical simulation.

3.2.1. Adaptation of existing PDMs to numerical simulation tools

Eben-Chaime *et al.,*[22] have adopted the first approach and have proposed an integrated architecture for simulation, based on three components: input/output (I/O) handling, autonomous operation, and control. I/O handling component is responsible for collecting, storing and retrieving input and output simulation data. This component manages information exchanges with PDM systems. This architecture enables also the automation of actions with Autonomous operation component. It is, for example, possible to execute a number of runs (batch) in the background while automatically recording results upon completion of each run. The autonomous operations are managed by a control component of the architecture. The control component allows for example the PDM system to activate simulation and specify which runs to be executed.

Always in the same approach, the proposition of Shephard *et al.,* in Ref. 24 consists in developing the missing components to support simulation-based design, using a concept referring to simulation of the entire lifecycle of the product.[28] They have developed an environment, the Simulation Environment for Engineering Design (SEED), based on four components which aim at linking the PDM on one hand and the Computer-Aided Design and Engineering on the other hand. Figure 2 shows the interactions between components when an engineering simulation is executed:

— The Simulation Model Manager that is responsible for controlling the overall simulation process and providing to the other components the information they need about the base simulation model definition.
— The Simulation Data Manager that is responsible for housing the simulation result information as needed during the simulation process.

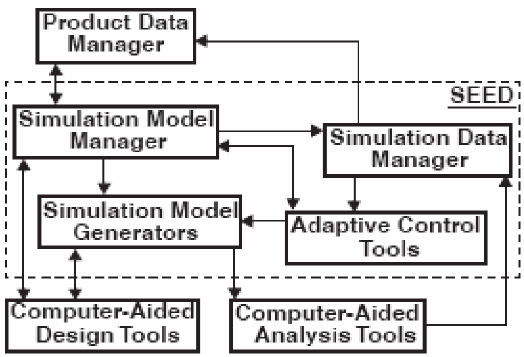

Figure 2. Simulation Environment of Engineering Design.[24]

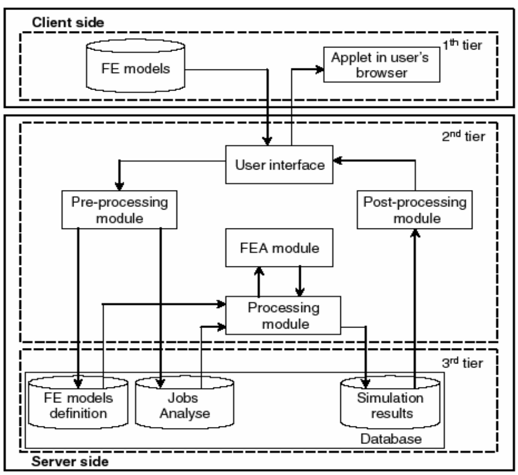

Figure 3. An architecture specification for FEA and viewer modules.[25]

— The Adaptive Control Tools that are responsible for selecting and controlling the simulation models so that the estimates of the performance parameters are to the level of accuracy requested.
— The Simulation Model Generators that are responsible for constructing the models used by the CAE tools accounting for the current design information and adaptively defined analysis model construction information.

The different research works, presented above, focus on managing simulation processes. On the contrary, Eynard *et al.,* in Ref. 25 focus on the simulation information exchange in extended enterprise context. A Web-based collaborative engineering, support system for mechanical engineering and Structural analysis, has been developed. The system, Teamproject, aims at ensuring the sharing and the viewing of 3D data (CAD and FEA models). This study has led to the specification of an architecture for FEA and 3D data viewing. Figure 3 presents this architecture, based on Java3D, and its main components which are: the user interface, the FEA module, the processing module, the pre and post-processing modules, and the database.

Nguyen has treated the same issues.[26] He has contributed in specifying a collaborative environment and a data model based on STEP in order to support information exchanges (including simulation data) between an aerospace engine manufacturer and its partners and subcontractors. The integration of numerical simulation tools, in this environment, is ensured by a simulation data manager.[12] This environment has been implemented[29] with the applications CATIA, Enovia VPM and SimManager.

3.2.2. Data manager systems of simulation

Data manager systems of simulation are gathered by the acronym SDM: Simulation Data Management. The SDM systems are environments developed to manage simulation data and processes by applying PDM functionalities which are essentially technical data organization and capitalization, data classification, data evolution management, data secure, process control, project team management, data sharing and viewing.[1]

The interest of SDM systems is to be dedicated to simulations with all PDM advantages, in opposition to the others concepts which try to fill up PDM gaps for the integration of numerical simulation tools. This approach places numerical simulation tools at the same level than design or manufacturing tools.

Among the number of research works on SDM concepts,[12,30–32] the contribution of Charles is very interesting.[12] Indeed, he proposes an environment of simulation data management based on a new data standard model. This environment was developed to fill gaps of SDM systems in term of functionalities and interoperability. About functionalities, the system brings solutions to the problems of simulation data structuring and simulation loop organization. In addition, this system integrates in details the concepts of alternatives management, project lifecycle management and workflows. However, the most interesting in this approach is the data model proposed to solve the problems of interoperability: the SDM schema. This model is based on features of STEP AP209, PDM schema, and new elements developed related to simulation such as loops and alternatives management. The concept has proved its effectiveness within the framework of an aircraft gear box development in the LASMIS laboratory project of Université de Technologie de Troyes.

In an industrial context, SDM systems are used by people having different experiences in numerical simulation domain. That involves the integration of knowledge management within the concept of SDM. Two approaches exist to address these problems: the Composable Simulation[33] and the Multi-representation Architecture (MRA).[34] The interest of Ref. 35 is to combine these two approaches to create a knowledge repository for behavioral models to support simulation in engineering design. These behavioral models integrate both meta-information (i.e. versioning and tracking) and meta-knowledge useful for models reuse.

4. DEVELOPMENT OF SDM SYSTEM FOR AN AEROSPACE ENGINE MANUFACTURER

During engineering processes, the numerical simulation is used to evaluate the physical behavior of products. The objective is to check, as soon as possible, if the product respects the functional requirements. It seems thus indispensable to make a robust link between product requirements and numerical simulations performed during engineering processes. However, this relation doesn't exist or is not developed enough in actual approaches.

Within the framework of a SDM development for aeronautic company, we have adopted an approach that consists in linking simulations to functional requirements. The aim is to build a master model including functional requirements and models used in design, simulation and manufacturing processes. This relation between functional requirements and models for simulation will allow a better management of simulations performed when there are not yet descriptive models. Indeed some simulations, such as bearings calculation, are performed without geometrical models. They are thus mainly linked to functional requirements which concern them. As soon as the geometrical model is created, the simulation is linked to both functional requirements and geometrical model of the product.

The development of this master model, based on results of VIVACE project,[29] is in progress. Because of the heterogeneity of simulation models used in the company, the model will first integrate constraints related to simulation. In order to solve interoperability issues, the model is specified in STEP.

5. CONCLUSION

In this paper, we have introduced our research project concerning with the development of a simulation data management system. The objective is to have an integrated management of requirements, design, analysis and manufacturing processes. This work will lead to the definition of a new data model and new collaboration method adapted to the constraints of the aeronautic industry. Currently, the analysis of engineering processes of the company is in progress. This analysis will enable to the identification of the best practices and the gaps collaboration methods and data management. The result will be used for the specification of the new data model introduced above in this paper.

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