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Unification of multiple models for complex system development

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Abstract: In the design of automotive product, the constant evolution of customer requirements and international regulations leads to new considerations of the system design process. The authors propose a modeling approach for complex system design based on the coupling of collaborative models and heterogeneous experts' (i.e. authoring) models used for product behavior assessment. The approach aims at modeling a system at different systemic and temporal levels in the design process and allows a flexible navigation with the possibility of changing or adding models in the design space. The purpose behind the use of this approach is to lead to an optimal design solution in the context of innovative design for complex system.

Keywords: Mechanical system design, Model Driven Architecture (MDA), design system process, data modelling

1 Introduction

Automotive industry market is witnessing a continuous expansion which is changing from a local to a global one. Nowadays, car manufacturers are finding themselves forced to assure the requirements of an international market that needs to be satisfied, taking into account new regulations in terms of cars' pollutant emissions. This expansion has led automotive designer to innovate and make an evolution in their designed products. Consequently, in order to realize that, they have to consider their product design process in another way in order to take into account these new design requirements and constraints.

Concepts of design process and complex system modeling are presented in the second section of the communication. A particular focus towards their applications in the automotive field is given in order to set forth the design methods applied and modeling tools used.

The third section, introduces the different models for system design found in the scientific literature. Our focus is done towards the interaction of all those models used in a design process and how they are linked together. The issue of design data transfer between one model to another according to the level of the granular decomposition of the system is discussed highlighting the interoperability between models in complex system modeling for design purpose.

Section fourth proposes the unification models approach based on a mediator structure. Such approach allows a dynamic navigation in the design environment between expert's (i.e. authoring) models at different granular levels of the system decomposition. Design constraints are taking into account from the beginning of the modeling and evolve simultaneously by the evolution of the model itself.

The proposed Information Technology (IT) system is also presented and discussed with respect to interoperable performances.

The fifth section, illustrates this proposal by presenting its application on a mechanical system. The aim is to evaluate the pertinence of the modeling approach proposed in order to optimize the design of complex system in a context of innovative design.

Conclusion and recommendations for further work are therefore presented.

2 Complex system design process and modeling

Automotive products are considered as complex systems, since their design requires an effort of understanding relationships among knowledge [1] of several scientific domains: mechanics, hydraulics, electronics and automatics, mathematics, Information Technologies, etc. The multi-physic aspect for such systems implies the involvement of multiple experts according to the knowledge required. Indeed, each experts has its own representation (i.e. model) of the system; each model being different than the others. Each model is therefore created for a specific use and product assessment (functional analysis, CAD, CAE, CAM, etc.).

As presented in [2], in a groovy design approach where system specifications are known through previous experimentations, design activities are considered as a simultaneous and/or sequential concatenation of expert knowledge to find "best" values of an already-defined-product breakdown and already identified product parameters. On the other hand, innovative design approach involves new knowledge considering the systemconfiguration since the design activity is to find new solutions (i.e. alternatives) in the design solution space. The innovative alternatives can be found either in the functional, conceptual, embodiment or detail design phases of the whole design process [3].

During the design process, the impact of each expert is therefore considered as a constant loop leading to the augmentation of the amount of product data dealt with (scientific knowledge, design constraints, system specifications, models data, physical principle, etc.) [4]. Such expert's specification depicts a function in the design process and is translated according to the concept of ***Knowledge-Intensive-Engineering*** [5] by technological attributes. In this amount of design alternatives, the final decision making is done according to performances assessments. Nevertheless, this assessment has to take into account both local and global system performances based on multiple-perspective criteria.

One of the greatest challenges in this context related to complex system design is therefore to get to a complete mastery of the evaluation and the control of the relationships existing between all of the defined product's models taking into account their various specifications.

3 Overview of the state of the arts with respect to Product Meta-Models used in innovative complex system design

3.1 Product Meta-models over the whole product life cycle

According to [6], building a model is an iterative procedure. It starts with the identification of essential features of inherent mechanisms of a dynamic system to be designed. In a step by step refinement of the understanding of a dynamic physical system, different forms of representation are used.
When processing a design problem, according to Pahl & Beitz's phases, four major aspects have to be taken into consideration for the system definition: The system functional description, the concepts selection, the embodiment of the system architecture (i.e. product breakdown) and the detailed parameters definition.

Functional description of a system can be done through models such as "Functional Block Diagram" [7] or "FAST Diagram" [8], etc. Those models are made in order to define the functional behavior of the system in terms of required performance. That enables the determination of first possible configurations for the technical solution that represent *the system concept selection*. These models are complementary to systems engineering activities and they represent the first level of system modeling leading to fix its operational concept [9].

In order to evaluate the *energetic aspect of a system*, representation models can also be used, and their exploration leads often to the establishment of the system control system strategy. Bond Graph models falls precisely within this context. This language of modeling consists in representing the energetic flows transfer between system components and sub components, bringing up the relations of cause and effect existing between each part of the system in order to systematically construct the mathematical models that will be used for system control.

Finally, current design practices use a lot of models in the detailed design phase to model *form features* (ex. CAD model) and assess the numerous multi-physics *product's behaviors* (ex. Finite Element Analysis models). A lot of authoring applications currently exist in commercial or academics solutions.

3.2 Meta-Models for collaborative relationships definition, information classification and retrieval

The previous section has presented meta-models related to specific design phase. Those meta-models are generally defined by specific individual designer.

Another level of meta-model is also used to define relationships among all those design phase (function, concepts, detailed design) and product assessment (manufacturing, structural analysis…) and to classify all the information (i.e. knowledge) in order to be retrieved (i.e. knowledge management) . The scientific literature gives plenty of Meta-Model proposals that all treat those two levels of concepts (knowledge modelling and knowledge relationships): Core Product Model [10] (CPM), FBS [11], MOKA model [12], PPO model [13], KC model [14].

3.3 Discussion on the state of the arts towards the scientific and IT proposal

Since many meta-models have been proposed in commercial or scientific solutions, it appears idealist for us to find only one (i.e. integrated model) that could be the "best" one and that could gather all the conceptual fundaments. Many standards have also been proposed for many years but none has been accepted as universal so far (cf. STEP, SYML, PLCS… [15]).

Therefore, authors argue that the current issue is then not to battle about which model fit the best anymore. It would be a wrong approach. As discussed in [16], authors argue that it is better to go toward a flexible approach that should be a hybrid one based on federative and unified approach (cf. figure 1): federative approach goals at linking straight one meta-model to another one (concepts of A are linked to concepts of B), unified approach goals at linking one meta-model to others via a mediator. A mediator can be one of the meta-model presented in 3.2. In a recursive mode, one mediator can be federated to another one. That approach goes toward a more adaptive way of modeling since concepts (seen as a meta-model) can be added or removed over the time and depending on the industrial design context. The "best model structure" is therefore the one set according to each design situation. This paper is focused on "unified meta-modeling". Federative approach can be found in [16].

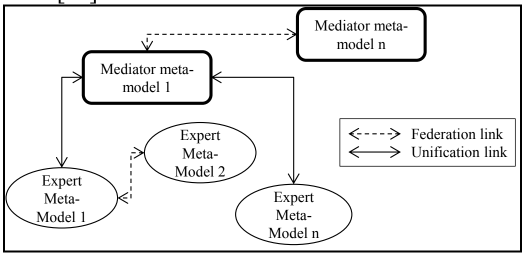

Fig. 1.Hybrid Federative and Unified approach

In the following section, authors propose a modeling approach based on the concept of Model Driven Engineering [17] which allows a flexible navigation with the possibility of changing or add models in the design space. This approach allows the coupling of unified collaborative meta-models and heterogeneous experts' (i.e. authoring) meta-models used for system behavior assessment.

4 Proposal: Model Driven Engineering approach for complex system modeling

As previously introduced, numerous models have to be set during the design phase. To treat the design of complex systems authors use a classification based on three main axes (cf. figure 2):

- Product life cycle mainly restricted of design phases as defined in [3]
- System granularity as mentioned in system engineering concepts
- Structure/Control chain axis of the dynamic system in order to link Multiple-perspective modeling in both structural and control domains.

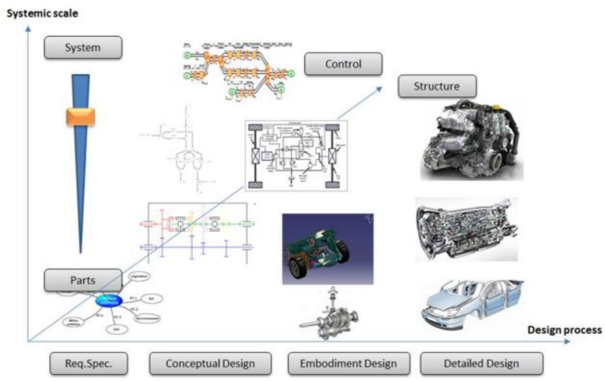

Fig. 2.Three axes for complex system modeling

4.1 Mediator meta-model for unification approach

While modeling a complex system, multiple views representing the evolution of the systemand its components during the design process can appear depending on the complexity of the system itself and the number of performance required. Those views go from a macroscopic representation of a general functional view of the system to a specific technological or geometrical view of a sub component of it. In order to represent that aspect while modeling a complex system, experts use multiple-view models to separate concerns during the design process and to control system evolution at different levels from functional aspects to deployment and verification. The concepts of this modeling are issued from works done by [13] in order to optimize the gathering of system information and formalization of the existing relations between it. These concepts have been updated and are given in figure 3:

- *Component* that represents the used objects to describe the system. This description can be done at different granular and multiple-views levels.
- *Interface* defines the part of one component allowing it to be in a relation with another one.
- *Relations* in order to formalize the existing relations between components through Interface.
- Each of the above concepts is inherited from the virtual classes *Modeled Entity* in order to construct the global mediator model. Each Modeled Entity is defined by *Attribute*.

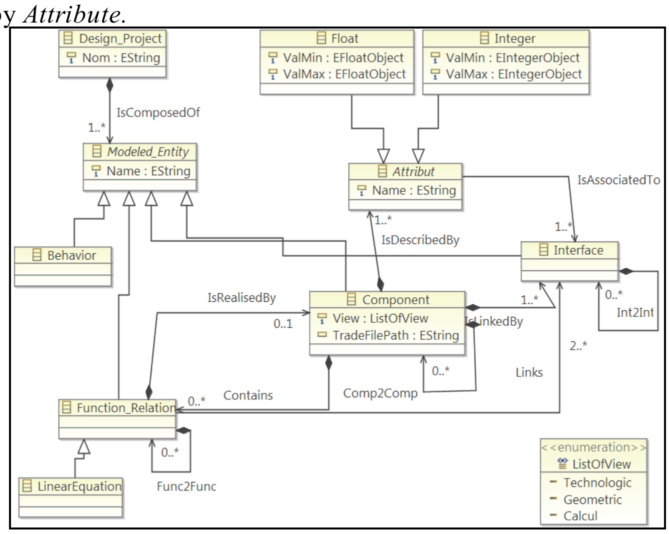

Fig. 3.Current mediator meta-model

In a context of innovative design, mastering the complete evolution of a complex systemas for its components and sub components, is a work that is build and done through the evolution of the design process itself. Experts' models are constructed

upon specific design constraints in order to validate a specific performance at each level of the system decomposition. And they evolve in a dynamic way during the design process. Thereby, experts can be brought to add and/or suppress some models or design constraints at some level during the design process.
The author proposes to work on a certain level of system modeling in order to create flexible and dynamic information exchange between design experts during a design process. This can be done through a representation of the existing mathematical and/or physical relations between the parameters of each expert's model at different systemic level of the system, insured through a constraint propagator.
The concept of multiple views that is used in this approach represents the different part of the product breakdown and the set of parameters that are shared among experts. That is the main role of a mediator model. (cf. figure 4).

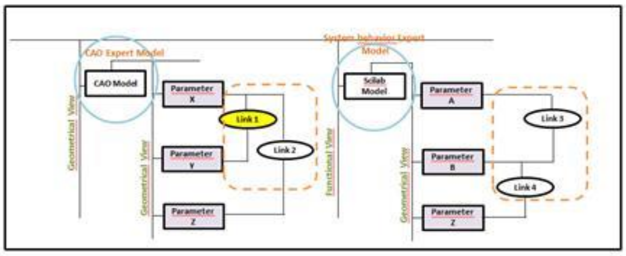

Fig. 4.Multi-views Decomposition of the system based on mediator model given on Figure 3

Expert models can be found at different levels in system decomposition. A part from views related to the global system; components, sub components and sub-sub components can have also views related to the expertise used for their design and their own performance to validate (manufacturing, multi-physics simulation, CAD…). And by that, expert models can be found at different systemic level and can have a local use (validate a component performance) and/or a global use (validate a component function and its interaction with other components) (cf. figure 4). Thus, authors show that it is possible to create a flexible navigation process between each model and another based on the modeling of the existing relations between the specific parameters of each models and by that the design constraints used to build each model and design the system. Relations manage both breakdown relationships (i.e. system engineering relations) and parameters relationships to be used in a local or global constraints solving problem to insure coherency among designers' knowledge. For instance, during the design of a mechanical system the CAD expert can decides to review a technical constraint that he has considered at the beginning of modeling and that is no more suitable at this stage of system design (cf. figure 4, Link1). This reconsideration automatically leads him to readjust the value that he has chosen before for the different parameters in order to integrate this constraint and also to make sure that the other constraints of his model are still respected. But by doing that, he is also changing the common parameter (parameter Z) that exists between his CAD model and the Scilab model of the system behavior expert. This parameter is going to influence the results given by the Scilab model through its relations with other parameters specific to Scilab model (parameter A, B), and of course the constraints considered by the system behavior expert while building hid functional model to validate his desired performance. This change is transferred to the system behavior expert by a notification alert appearing in the functional model. This transfer is ensured through the mediator meta-model that contains all the relations between the existing parameters that are common in both models.

4.2 Infrastructure of the information system

As far as Information technologies are concerned, and in coherency with modeling approaches presented in the previous section, authors argue that one unique integrated software solution is an idealist solution. Industrial and modeling context are indeed evolving very often over the time. IT system has therefore to be flexible (i.e. agile). The infrastructure that has been developed is therefore based on many layers (cf. figure 5) implemented into the Eclipse Modelling Framework (EMF):

- Authoring applications (i.e. expert model) used by design experts.
- Unification layer that manage the relationships. This layer allows the navigation among the entire three axes space of data (cf. figure 2).
- External CSP solution that keeps the coherency among relationships.

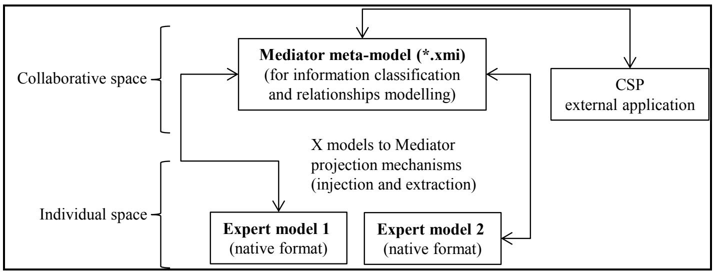

Fig. 5.Layers of the developed IT infrastructure implemented in EMF

As far as the design context is defined, adequate authoring application can be plugged or unplugged to the unification layer. This plug function is based on Meta-model projection [16] that allows easy way to use the "best" application for the current situation.

5 Illustration of the approach through the modeling of mechanical coupling system for hybrid transmission

In order to validate the modeling approach, a case study of hybrid transmission system is considered in the context of innovative powertrain project (cf. figure 6).

The geometrical view is done through CAD modeling tools and the functional view is achieved through Scilab tool. Each one of the models is built by an expert in order to select the “best” architecture for the system allowing validating the fixed performance that is CO2 emission for a driving cycle.

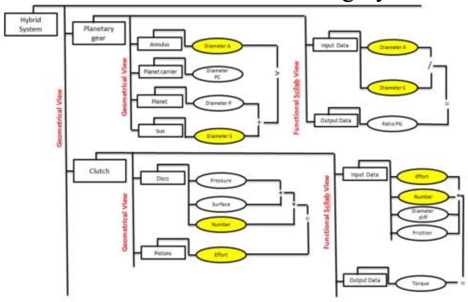

Fig. 6.Multi views modeling for hybrid system

The multi view model is constructed in parallel to the design of the system allowing mastering at different levels the relations between the different parameters. And from that base, the mediator model is constructed taking into account these relations and a navigation between one model to another and one view to another (i.e. navigation between geometrical view and functional scilab view). This model integrate the possible changes, adds and retrieves that can occur on the different parameter of each model and allow the propagation of its related information to other models.

6 Conclusion and recommendations for further work

In order to support the design of complex system in innovative design context, the authors propose to model and optimize the design process through a unification approach by allowing the navigation product models based on a three axes design framework. This navigation can be done through a model driven architecture concept based on a mediator meta-model that takes into account the existing relations between product breakdown and parameters of each model. This provides a new approach in order to support data exchange and to accelerate time consuming tasks. This approach is more flexible since it is based on one meta-models and agile IT solution that can be modified or changed according to the modifications occurring on experts’ models and design environment.
The illustration of this approach is done through a hybrid powertrain system for its prototype design. The implementation of this proposal in EMF (Eclipse Modelling Framework) is in progress. A possible further work will be to test the approach for the design of the series version of the hybrid powertrain system and to define performance indicators allowing optimizing the process design and the system architecture.

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