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Knowledge synthesis by least commitment for product design

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ABSTRACT

Engineering design is a model-based activity which describes the product's multiple perspectives. With process model, we can also lead concurrent engineering activities. Both product and process models have been largely investigated. This paper aims at describing knowledge-based heterogeneous models chained to trace the design rationale that is the fundamental requirement to afford changes management. This knowledge chain supports the progressive by least commitment convergence of the space of design solutions. This rationale allows designers to go back and forth in the decision-making process. Moreover, the progressive convergence increases the possibilities for designers to integrate new knowledge towards innovation.

1. Introduction

The evolution of engineering design for almost 20 years reaches a situation where many persons work in a collaborative way using many software applications (CAX, PLM...) and taking into account the whole lifecycle of the product[1].

The paper first presents the main functions of an engineering design situation in order to introduce what we assume as an ideal way of designing a product. The state of the art is discussed in the second section to highlight the related work that provides adequate concepts to answer those functions. Section three details the proposal of an engineering design by least commitment based on knowledge synthesis and process modelling in order to trace design rationale and support agile design. Conclusions open the discussion towards lean design approaches and gives some recommendations for future work.

2. Evolution of engineering design, main functions and ideal motivations

Since the early 1990s, the product design has changed significantly due to changes in organizational practices (concurrent and integrated engineering [1]), due to the evolution of information technologies for engineering (PLM, ERP, CAX) and communication (CSCW), due to the evolution of the social and environmental context (ex: Corporate social responsibility, REACH regulation) and the evolution of manufacturing technologies (additive manufacturing is one of the latest examples).

Thereby, some main functions of an engineering design can be presented, as shown in Fig. 1, to depict what could be the ideal situation of lean design. With analogy to manufacturing domain, lean design aims at designing a product minimizing the non-added value tasks; in other words, minimizing the non-justified information that constrains the product definition. Authors talk about a "*by least commitments*" approach.

1. *Product modelling.* Since the design is a collaborative activity, several models[2] are used to represent the knowledge of the product on its global lifecycle (LC).
2. *Model integration.* Concepts from product modelling have to be linked (i.e. chain) in order to assure the semantic mapping to cover the different phases of the design [2]: requirements specification, conceptual design, embodiment design and detailed design.
3. *Data exchange.* Many IT applications are used in the design process. Therefore data extracted from modelling concepts have to be interpreted by several software applications. The syntax of the model has to be exchange among software applications.
4. *Alternatives management.* Since design projects provide several solutions and are lasting many months or years, product models are evolving. Alternatives and evolutions have then to be managed in order to trace this evolution over the time.
5. *Master design changes.* This last function is actually the final objective of what could be lean and agile design: revise the decision-making and the product solution as soon as the design context is changing: new industrial specifications, evolution of

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[1] In the paper, "product" is used to talk about the solution of the Product Development Process (PDP). This term can be largely understood as "system", "complex system" or multi-physical system.

[2] « model » has to be understood as a set of modelling concepts. We could have used meta-model as specified by the OMG but "model" simplifies the reading of the paper.

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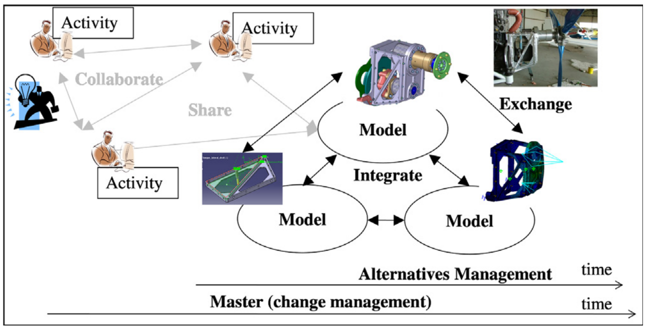

Fig. 1. Main functions of ideal collaborative PDP.

the industrial context and globalisation, evolution of users' requirements, evolution of technologies, etc.. . .

This last function is supported by the four first ones and is certainly the main objective in numerous industries that know what they do but do not master how and why they have reached such solution and then are not able to quickly answer the evolutions of the design context.

3. Discussions of the state of the art, main issues and objective of the proposal

3.1. Concepts for product modelling

On the one hand, modelling of manufactured products and parts, which were mainly physics has become highly (otherwise completely) digital. This development, initiated in the 1970s to facilitate the modification of manufacturing tools, coupled with the large increase in processing and digital storage capacity now allows modelling and simulating the entire product design, manufacturing processes, production and assembly lines. . ., to assess the product's complete product life cycle. We then speak of digital engineering, virtual prototyping, which is supported by a digital environment. Such environment can synthetically, consists of authoring applications supporting the functional analysis, structural analysis solvers, multi-physical assessments, manufacturing ranges (FAO tools), geometric modellers (i.e. CAD) to manage all the product features. The different product's and supply chain's configurations and evolutions are managed throughout respective software applications PLM and ERP.

On the other hand, design process and product modelling have also been largely studied by the scientific community [3,4] but it is also assume that those concepts are not sufficiently implemented in commercial software solutions and industrial minds [5].

3.2. Issue No. 1: lack of chaining of information towards design rationale from functions to end of life

With respect to function No. 1 and 2, despite the numerous product models, many conceptual semantic gaps are still remaining in order to justify the rational understanding of decision making from functions, conceptual design to detailed design. Those gaps do not allow going back and forth in the product modelling chain: why technologies answer functions? Which form features are involved to realize one function? Which form feature are really needed and constrained by functional characteristics.

In order to really master the design process (function No. 5), it is fundamental to formally trace the links among each product modelling concepts. That would give the possibility to understand the decision-making points and to manage every design alternatives with rationale.

3.3. Form featured centred design process: a reactive process

For almost 20 years, since the apparition of CAD software, many developments have been done to go from paper sketch to 3D digital model that provide nowadays very powerful algorithm to obtain the geometric model (i.e. Digital Mock-up) of a system and to apply analysis on it (CAM, FEA, optimization. . .). Unfortunately, the intellectual design activity has therefore been focused on that form features modelling and remains a reactive approach in which CAD modelling is the entry point for assessing the X-ability (ex: manufacturability) of one solution. In the same way the PLM software solutions have been largely improved but are still providing solutions based on file management.

3.4. Issue No. 2: lack of knowledge synthesis towards a "by least commitments" approach

As a first conclusion, those CAD and PLM software-centred solutions then provides very good support but have impoverished the intellectual design process which has to remain a collaborative decision making process to restrain the space of design solutions with respect to LC considerations [6]. In current approach, one person called "designer" creates the CAD model that make the design solutions spaces converged towards a single solution. Therefore, the other stakeholders can only react to this solution.

3.5. Objective of the proposal

The proposal presented in this paper is a synthesis of many results that have been investigated for many years by the authors and that are put together to provide a pedagogical point of view of the design method. This pedagogical point of view is for us very important to really go back to support a real knowledge-based synthesis design activity using benefits of concepts provided by the scientific community.

The intellectual design process has to follow a rationale concurrent process that aids designers to think function, think physical principles, think technology, think manufacturing, think . . . in order to collaboratively converge towards several alternatives of solutions and associated CAD models. Every stakeholder is then considered as a "designer" since he provides information to define the space of design solutions.

The CAD model has to be kept to collaboratively visualize the solution's form features but has to be the result of LC information synthesis. Those form feature are created "by least commitments" taking into account the minimal knowledge from every concepts of product model. As shown in Fig. 2 [7], as far as the constraints are

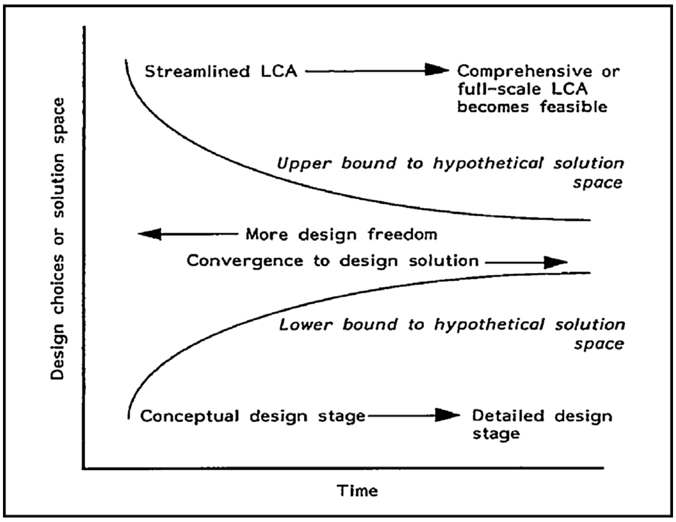

Fig. 2. Convergence speed of the space of design solutions with respect to least commitments LC integration (from [7]).