Interactive product design

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In book: Research in Interactive Design Vol. 3

Project: Research in Interactive Design

1. Introduction

The interactive product design is of major economic and strategic importance in the development of new and innovative industrial products and processes. Designers have to deal with new constraints coming from the increasing customer requirements, the new environmental constraints (fuel consumption, emission of dioxide of carbon…), the constant mutation of the product and the continuous needed of specialist employees to drive and realize such products and processes.
The research in interactive product design is related to a wide range of various thematic of research and engineering activities embracing high realistic multi-sensorial virtual prototyping. The main objectives are to facilitate, develop and support industrial innovations. The classical approaches supporting design and manufacture phases have to mute.
This mutation should enable industrials to develop new techniques to quickly emerge creative ideas, development of effective low cost solution and the creation of technical consensus to market, leading immediately benefits on the economic requirements. Virtuality should be used as early as possible all along the lifecycle of the development of product and associated processes. Since the tools related to the virtuality allow exploring rapidly solution spaces, to accurate study draft solutions into their future environment through a high realistic way and to assess the product efficiency with their future product end-users.
Interactive product design and manufacturing methods are implemented in various tools and processes responding to these expectations covering a wide spectrum of multidisciplinary research.

2. Interactive product design through the lifecycle

The early design phases, usually called preliminary design, starting from the research of feasible concepts to embodiment design, correspond to a series of crucial steps for the product. It is well known that at this earlier stage, every decision on the product engages the majority of the future costs of design, production, assembly, maintenance, disassembly… The challenge is to ensure that the design matches the best concepts and associated technical choices involved. The formalization of the behavior of the product through numerical or analytical models is a complex phase because, until this stage of design, the product is only partially defined (i.e. few elements of the system have been defined and some of data are imprecise). Thus, a possible way to face with these requirements is to use the interactive tools and methods. Since the recent research and technical improvements, interactive design and associated methodologies propose tools that can assist:

- Groups of specialists in their research of creative concept.
- Designers to develop products efficiently, quickly and accurately to ensure the required level of performance, by minimizing the associated risks during the situation

of using, to control possible failures, to warranty the reliability and the robustness, to valid the maintainability ...

During all these phases related to the genesis of the product, the tools of virtual reality provide solutions. Today, the exponential growth of simulation tools and the development of advanced calculations and simulations have greatly contributed to their popularization. These numerical tools are based on huge fields of knowledge, information and data which are modeled, developed and capitalized for assisting engineering activities and lead to innovative solutions.
During the phase of detailed design, the software supports are needed to improve the efficiency of the designer, to encourage the exchange between the different actors of the project. For that, an important among of knowledge, data base is available and has to be structured in the aims to facilitate their uses.

Once the product is fully designed, it is necessary to realize a transfer between the numerical models of the product, from cad system for instance, into the real product. Therefore, the choices of production machines, the organization of processes (…) are major factors that will achieve a good product quality that respects customer requirements assuring different technical aspects like the robustness, the reliability and the durability… For achieving these points, many technical data, business rules, technical skills based are all available resources that engineers have to exploit. The main difficulty is generally to formalize such knowledge information into mathematical or numerical tools which could be directly interpreted for example in the optimization phase of product or process.

In the framework of the manufacturing and product design, the most usual support is based on concept of product and process simulations. The challenging is to model all the different phases of the engineering activities into a virtual representation. This numerical artifact is useful to valid new innovative solutions and choices, to anticipate engineering defaults and allow the information supports between specialists, decision-makers and engineers in a particular context of extended enterprise.
Today, the exponential increase in performance computing machines, simulation tools and the development of advanced simulation techniques have greatly contributed to their popularization. These numerical tools are based on huge fields of knowledge, information and data which are modeled, developed and capitalized for assisting engineering activities and assuring to lead innovative solutions.
This conjunction makes the creation of virtual object possible by considering the virtual object behavior (in static or dynamic phase). The development of such tools has to be based first, on complex numerical behavioral model by considering multi-physical and multi-scale models, second, on structured model of engineering skills resulting from identified, extracted and capitalized knowledge, and finally, on innovative concept solutions that only can emerge from the creativity of the group of actors involved in project.

The uses of interactive tools are not restricted to the phase of design and phase of manufacture. Indeed, since the product is globally designed, developed and manufactured, virtual reality has useful support to guide and trains the users or future users. Among the first virtual reality, tools in this field of application include driving simulators object such as flight or boat simulators which consisted as primarily derive a particular behavior of the system based on actions performed by the user. The interaction between the user and the simulator were performed mainly through a screen and some actuators (i.e. buttons) on a dashboard. This initial version has been gradually expanded to reflect more complex behavior of the

controlled system. It has been observed the emergence of active controls to stimulate different senses of the user during simulation (noise, sounds, vibrations, accelerations ...). Now, these simulation tools are spreading in more general contexts such as the sequential simulation of the assembly phases of product, the training of medical personnel, for example, at the introduction of biomedical implants in the patient body. The virtual reality proposes more rich experiment with more realistic training for instance with total immersive experience by using haptic interface devices for feeling the motion, shape, resistance and surface texture of simulated objects.
Such numerical simulations can also improve the phase of maintainability of product by replacing the classical technical books which require specialists to analyze, understand and act on the defective product. For the disassembly phases of product, during the end of life of the product, same simulation can provide a well knowledge base to trace the material use, the disassembly procedure…

Finally, the virtual reality deals with very large topics which have started from the CAD/CAE software, the development of innovative techniques for the modeling of product and systems behavior. The generation of knowledge is a key factor of the virtual reality and it is necessary to integrate and centre the human into the general process of product and process development (i.e. research solutions and exploration of design space, interactive virtual representation…). Currently, one difficulty is that the initial product media is mainly based on tools for CAD / CAE and it is difficult to integrate, in a dynamic and real-time, for example, strains of adjacent parts of the product during the assembly phases or real interaction between user and numerical product.

3. Needed requirements for the interactive design

3.1. Evolutionary model of product

To be effective and relevant throughout the life cycle of the product, the product model must be scalable and adaptable. It must take into account different levels of knowledge:

- Understanding physical, economic, environmental;
- Business rules related to the formulation of manufacturing constraints, assembly, disassembly, recycling ... (DFX)
- Design heuristics
- Models to manage the interaction with humans (cognitive, sensorial interaction).

These different types of models use analytical techniques and formalization (fuzzy logic, rough sets, desirability functions...) to reflect uncertainties, requirements or rules.
These models reflect *a priori* the particular needs and requirements in terms of performance and robustness. The common resolution of physical models and empirical rules will converge through the numerical processing to the design problem of robust solutions both in terms of mechanical behavior and in terms of the robustness of decisions.
The challenge is to produce and use knowledge for a "new" product, free from any baseline. More the product is innovative, more the difficulties are amplified because they generate new situations for project managers, designers and potential users.
Thus, the tools of virtual reality and advanced computer simulations of behavior should be harnessed to fill up the lack of knowledge about this innovative product. The data can be used and may be derived from knowledge base of previous design solutions from existing and validated products. Different tools and methods can be used like data mining, pairwise comparison (...) to create or use data models of empirical rules.

3.2. Interactions of product with human and environment

The product is initially design for particular set of functions. During the situation of using, the product is in interaction with many different elements. First of all, the human is directly in interaction with the product. The main challenge concerning engineers is that they have to consider and mix both technical requirements and marketing sights. In this phase, the product and a human can exchange energy flows. These energy exchanges lead to generate sensations to the user or represents action of the user in the product.

To realize and channel this exchange, designers have to develop innovative system interfaces through different variety of medias. Designers have to be concentrated on the aspects of the interface that define and present its behavior over time, with a focus on developing the system to respond to the user's experience and not the other way around. The system interface can be realized thought artifacts (whether visual or other sensory) to lead designers and engineers to better understand the wishes of the end users of products and to develop more efficient tools and dashboards to interact with users.

The other type of interaction comes from the environment of the product and corresponds to pure physical interaction. The physical behavior of components is inevitably due to solicitations with other elements of its environment. The different energetic flows through the components constituting the system and finally can be exchanged with the environment. These energetic flows can be completely transmitted, operated or controlled by the component and exploit it for upholding its own behavior. This modification of behavior has consequence on the other one of the different components of the system.

These different coupling in the behavior of inner and outer component of system has to be modeled and simulated to improve the global efficiency of the product and limit the negative impact of the product on its environment.

3.3. Interactive simulation of product behavior

Traditionally, the simulation codes are used to model one or several physical phenomena. In general, these simulations are implemented and set up by experts. After calculation, the simulation produces results that are stored in files, then these results are analyzed using visualization tools (post-processing), providing maps of results fields or graphics. After analysis, the expert may choose to "re run" the simulation with new parameters and so on. This approach has the advantage of being simple to implement and enable easily archiving the results associated to each simulation. However, it requires a lot of manipulation and if the user wants to make, for example, sensitivity analysis of a large set of parameters, it could become very long and tedious analysis.

The interactive simulation is developed to improve this classical process of numerical simulation (modeling, computation, analysis). In this approach, the user is not waiting passively for the results of the simulation but can interact, in "real time" of the calculation, by modifying certain parameters of the model and more generally by controlling the calculation flows. This approach allows greater flexibility in the use of simulation tools. This alternative approach improves the productivity and the efficiency of analysis by significantly reducing the time between the changed parameters and the display of results. This approach can be very useful for rapid detection of errors, especially in the case of long simulations. Furthermore, by changing some parameters and visualizing the effects immediately on the model, the relationship between cause and effect becomes more obvious and the user can realize such approach as in experimental one. He can follow its own intuition, explore the model, develop and test hypotheses quickly. From a technical point of view, the development of such tools is a real challenge and must rely on multi-physics and multi-scale models.

During this exchange between the simulation tool and the user, it is necessary to develop tools for multi-sensorial virtual prototyping with high realistic behavior to propose a real interaction between the user and the simulated model. This immersion in virtual reality, should simplify the exchange product - human to make tangible the product before its real existence.

3.4. Decision support systems

Many applications of the engineering design are facing to the development of decision support systems. It is possible to cite some of the different heterogeneous fields concerned with the development of decision support systems like mechanical engineering, energy engineering, process engineering, material engineering, design for manufacturing and more generally design for X. The decision support systems have to manage the different models and results coming from analysis, physical modeling, simulation and knowledge base. It fulfills an important field in many industrial sectors dealing with decisional problems highly constrained by complex and coupled physical phenomena.

The challenge is to bring enough information to assist the decision process. Usually, the environment of the product or the process studied is often only partially defined and many elements of the problem are still established only vaguely. The problem is thus essentially posed in a very imprecise way while at the same time, coupled physical phenomena need to be studied and analyzed and their interaction is very much affected by this imprecision. It is essential to search for a compromise between the precision, exactness, complexity and extent of the area of application of all the knowledge brought into play in order to resolve a design problem.

The approach to develop here has to tackles this problem by focusing on the qualification and the adaptation of the model to provide decision support to assure a possible exploitation. These phases of qualification and adaptation have to lead to models which are sufficiently precise, exact and parsimonious with an area of application sufficiently large to be useful with decision support.

4. Feedback of the industrial engineering support systems and outlooks

The recent industrial experiences lead to conclude that ideal engineering support systems would be a tool able to:

- Reinforce the interrelation within engineers by improving the creative efficiency of the group. The creative activity and the research of innovative solutions always result from the association of technical knowledge, professional skills and for above all, from interactions between human.
- Provide and develop extended simulations where the studied virtual solution is really immersed in its future environment and being able of pure physical interactions with other elements. It is really common that the suitable solution appears because engineers have correctly anticipated the problem of possible noisly physical interactions with other components. This effect has to be reinforced with the all virtual where simulation of global environments may really highlight the problem of global organization that can not being visible on only isolated simulation of components.
- Allow a human to feel and to act on a virtual product as in the real life. It consists in guaranteeing the perceptual relations between a user and its future product through high realistic simulation.

Face to these challenges, commonly with industrial companies, the international scientific community develops and sets up models, methods and tools to better consider these three points. Most of them concern interactive simulations, the development of interfaces for virtual representation, the integration of human consideration into new systems and products. More particularly, tools and methods are devoted to the design phase such as interface for improving the design, the representation of design spaces for instance through architectural representation of feasible solutions.