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Mechanical Embodiment Design with Digital Desktops

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RÉSUMÉ

Cette contribution décrit l'aide potentielle que le concept de table interactive apporte à certaines tâches du concepteur en mécanique. Le travail de recherche présenté n'en est qu'à sa genèse. La problématique est la suivante : une fois la faisabilité d'une idée de produit (le *concept*) est prouvée, le concepteur développe l'architecture et les composants du produit (*embodiment design*). À ce niveau, l'esquisse joue un rôle prépondérant tant au niveau créatif qu'au niveau de l'analyse (calculs). D'autre part le concepteur doit communiquer très souvent avec les ingénieurs de production. Les outils actuels de conception assistée par ordinateur (CAO) ne donnent pas la même liberté, la même sensibilité, ni la même possibilité de communication et de compréhension que l'esquisse. La table interactive dans ce domaine-là se présente comme une solution technique qui prend en compte la majorité des besoins du concepteur.

MOTS CLÉS : conception mécanique, esquisse, table interactive, collaboration colocalisée et à distance, expérimentations, usage, besoin.

ABSTRACT

This paper describes the potential help that the interactive desktop concept can bring to the execution of embodiment design tasks. The presented project is still in its infancy. The research framework is the following: once a product concept has been approved, the mechanical design engineer develops the product architecture and product part (also called *embodiment design*). Sketches at that level are essential both for synthesis and analysis purposes. Moreover, the designer has often to collaborate with the production department. The current CAD tools do not allow the same freedom, sensitivity nor the same possibility of communication and understanding the sketch. The interactive desktop is a technical mean that would allow taking into account the majority of the mechanical design engineer needs during embodiment design.

KEYWORDS: mechanical engineering design, sketch, interactive desktop, co-located and remote collaboration, experiments, use, needs, mechanical analysis.

CATEGORIES AND SUBJECT DESCRIPTORS: H.5.2 [Information Interfaces and Presentation]: User Interfaces; H.1.2 [Models and Principles]: User/Machine Systems.

GENERAL TERMS: Human Factors, Design

INTRODUCTION

There are many moments during the mechanical engineering design activity that still rely on plain pen and paper – it is still the quickest and least intrusive way to develop one's design. In this contribution, we describe these moments for the embodiment design phase of the mechanical engineering design process, and the service interactive desktops can bring to facilitate the design engineer's work.

In the first section, the embodiment design phase is presented. Then the ways interactive desktops could help the design engineer by fulfilling his/her needs and overcome certain related issues are presented, ways that remain to be implemented.

EMBODIMENT DESIGN

The mechanical engineering design process is usually presented as a three-phased process: conceptual design, embodiment design, and detail design [1]. During the conceptual design phase, the mechanical design engineer develops new ideas, new principles of solution based on physical principles and evaluate their feasibility. Once an idea (a *concept*) has been chosen, the product architecture and product part development starts. This phase is the embodiment design phase, illustrated by an example Figure 1. Finally, during the detail design phase, the product is carefully analyzed by means of analysis tools (Finite Element-based tools mainly) and simulation systems, is adapted to production requirements and documentation is compiled.

Of these three phases, embodiment design is treated like a poor relation in the engineering design community. Lots of efforts a put towards conceptual design, because the problems at this level are ill defined, thus complex, and because the actions and decisions impact the whole remaining of the product development process.

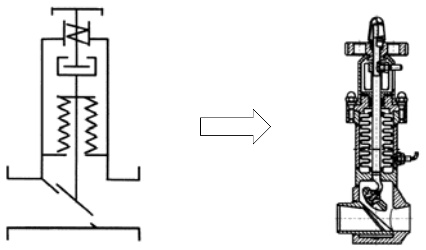

Figure 1: during the embodiment design phase, the concept is transformed into the embodiment (from [2]).

During the detail design phases the problems are well defined, thus multitudes of tools and techniques exist to support the different engineering design activities. Embodiment design is in-between, demanding both support for creativity and analysis, but mixed with routine design activities. The ways interactive desktops could help the design engineer by fulfilling his/her needs and overcome certain related issues are presented next, preceded by a short description on how those were defined.

DETERMINING THE ISSUES: OBSERVING THE DESIGNERS

In order to determine the difficulties the design engineers encountered during the embodiment design process, the practitioners have been observed in a quasi-experimental set-up. 3 novices and 3 experts have participated. Each design engineer was given an embodiment task to fulfill — a support for a piston (Figure 2) and the session was videotaped. The design engineers were asked to think aloud and their utterances were transcribed. Then a verbal protocol analysis (VPA) was performed, following the method of [3]: a set of categories representing design characteristics was determined; the transcript was then analyzed by assigning a category to each semantic episode; an overview of the design process could then be extracted. The complete results can be found in [4].

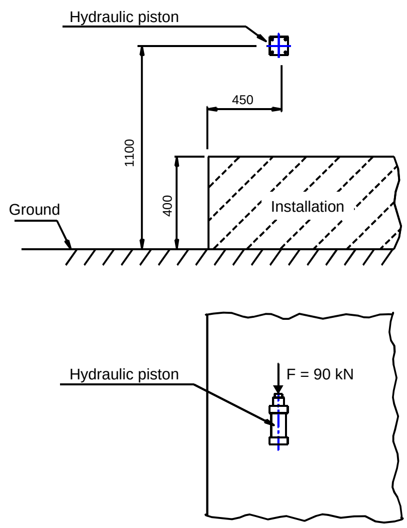

Figure 2: *Sketch of the problem in the assignment [5].*

From the preceding study, a series of necessary improvements is currently being defined. Those that can be achieved with the help of the interactive desktop are presented below. The main way designers express themselves during embodiment design is through sketches. If these sketches can be captured and interpreted, they can be processed to help the design engineer in different ways.

THE INTERACTIVE DESKTOP AT THE SERVICE OF EMBODIMENT DESIGN TASKS

Sketches as dimensioning support objects

The sketches of the design engineers are often inaccurate. Imprecision and incompleteness seems to lead to more creativity because the ambiguity in the sketch leads to the considerations of several variants at a time (see [6]). However it leads also to uncertainties and even errors during the analysis activities. Figure 3 is an example of an imprecise design that led to form giving difficulties. In figure 3, the left-hand sketch (beams of the support represented by simple lines) hinders him to see that he/she will have difficulties interfacing the support with the piston (right-hand sketch). The novice will eventually totally re-design the piston support [7] also found that the presence of dimensioned sketches early in the design led to better design outcomes. The application behind the capture of the sketches could warn the design engineer in case of missing measurements and incompleteness, before any analyses are made. The way this help should be provided is still under discussion and requires testing:

- Free sketch: the application analyses the sketch but does not interfere nor complete it.
- Sketch with morphing: unlike other design domains, the shapes are relatively simple (squares, ellipses and circles mainly), thus it should be easy to change in real-time the design to make it more accurate. Some examples of implementations are [8-9].
- Sketch with help of predefined features, like the current CAD systems libraries or Finite Element (FE) object libraries [10].
- Direct 3D sketches, like GiDES++ [11].

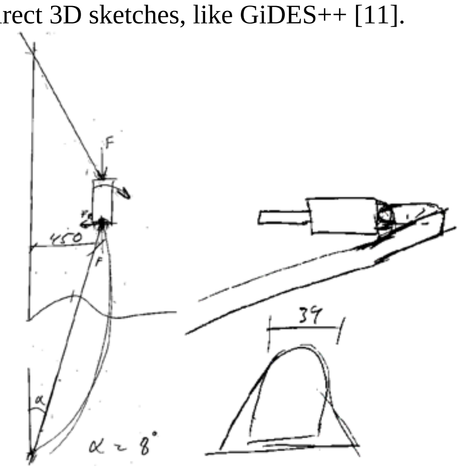

Figure 3: *design sketches of a novice.*

Sketches as support of reflection

The sketches are made mainly in 2D, probably because the design engineers are educated to sketch using the standards of technical drawings. However they use 3D sketches in order to get an overview of the design problem or for explanation purpose. 3D sketch could be extracted from the 2D sketches as the application EsQUIsE [12] does for architectural sketches.

Reuse of existing elements

During embodiment design, some parts of the sketches are existing components or previously design product parts. These could be retrieved by the application, either by classic text-based database query or by sketch-based database query [13]. If the elements come from CAD systems or FE-libraries, they have to be transformed to be compatible to the sketch application (like implemented in EsQUIsE).

Exploitation of the sketches for synthesis

There exists a large set of basic rules, guidelines, and principles at the service of the design engineer during the embodiment design activity. A whole body of such knowledge can be found in [1]. These help the designer during the creative part of embodiment design (or synthesis) and their implementation would assist the him/her to design right from the start. However these basic rules, guidelines, and principles would be very difficult to implement because most of them are qualitative in nature. The most quantitative of them are already implemented in diverse expert systems, like the Molding Advisor [14]

Exploitation of the sketches for analysis

The usual procedure employed by the design engineer is to re-draw the sketched design into an analysis tool such as ANSYS or SIMULIA. This implies a huge loss of time and flexibility: 1) the original sketch already exists; 2) it takes more time to draw in those systems; the results can lead to dramatic changes that lead to new pen-and-paper designs not initially present in the sketch. With an electronic sketch, most of these activities could be semi- or totally automated. This has been tested successfully with the sketch-recognition module of the software EsQUIsE from Lucid Group [12] and ANSYS. Figure 4 shows a shear stress analysis of a handmade beam. Figure 5 displays the potential modification to the beam after a topology optimization. The blue areas are those that are possible to cut away from the beam in order to reduce the weight. This gives the designer indications of potential areas of material reduction under the given loading situation.

The main areas of analysis would be structure analysis, thermal analysis and some specific parameter studies and optimizations. These analyses concern of course relatively simple designs in a routine design process and are not intended, in the current state, to replace dedicated systems. [15] describes how analysis could be carried at the embodiment design phase. The results could be either applied directly to the sketch or presented to the design engineer as decision support.

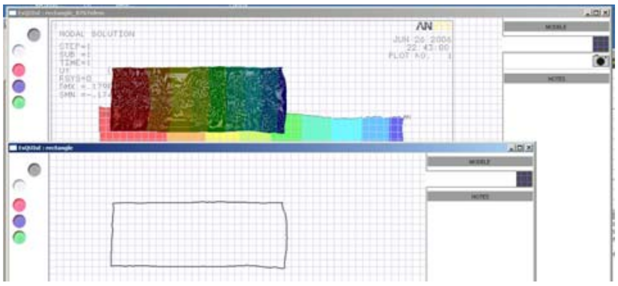

Figure 4: *Original sketch (beam below) and result of the structural analysis in ANSYS (above) imported into EsQUIsE*

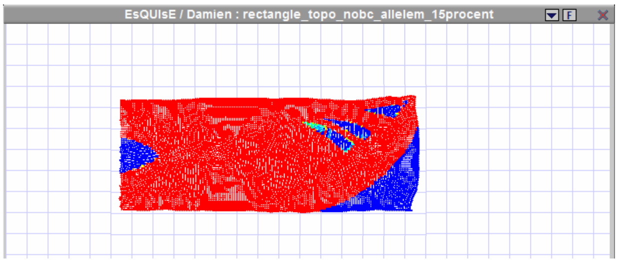

Figure 5: *Potential modification of the original sketch based on result from analysis in ANSYS and imported into EsQUIsE*

Collaboration and multimodality

Even if the design engineer works mostly alone during the embodiment design phase, his sketches and calculations are presented to other design engineers working on other parts of the same product, to production engineers and even sometimes to marketers. Nowadays, the teams are scattered around the world and interactive desktops are one of the interfaces that will allow real-time discussions and modifications. No investigations on that area related to embodiment design have been found in the literature though. Multimodality has not been studied for embodiment design so far, but even if the design engineer works alone, gestures probably would help the application "guessing" what the design engineer's intentions are. Such a study can be found at [16].

IMPLEMENTATION

The division of Machine Design at Lund University is a part of the International Virtual Design Network presided by Lucid Group at Liège University (http://www.arch.ulg.ac.be/Lucid/Ressources_Virtual_desktops.php). The interactive desktops used are the Interactive Whiteboard of the Prometheus Company together with two projectors so as to have a resolution sufficient enough to give the sketches the same appearance as pen-and-paper ones (Figure 6). A Wacom Cintiq tablet, a tablet PC and electronic paper are also available at the division for testing their adequacy as sketch and design support tools in comparison with the interactive desktop.

Figure 6: *The interactive desktop system at Lund University*

As the last section showed, the application needed for design engineers would not require many novel concepts for the use of the interactive desktops (The sketch recognition and interpretation of a 3D object with an incomplete sketch would be an AI challenge though.) It is rather a gathering of already implemented solutions, but the range of problems is of great importance for the industry. The architecture of an application that would correspond to the description of the last section would be similar to the generic architecture of EsQUIsE [12] concept developed by Lucid Group and should be developed in co-operation with this laboratory. It would consist of a stroke recognition module, a multi-agent-based interpretation module, and from there other different modules would be coupled (error-controlling module, links to simulations systems, etc.).

CONCLUSION

This contribution presented some of the current issues faced by the design engineer during the embodiment design phase and the service that an interactive desktop could bring: 1) an interface that is non-intrusive, without any interferences (i.e. respecting the cognitive limitations of the designers and the constraints of his/her working environment), yet facilitating his/her daily activity; 2) a guiding and decision support thanks to the links between the sketching tool and mechanical analysis and synthesis support systems.

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