Virtual reality as a multidisciplinary convergence tool in the product design process

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ABSTRACT

Nowadays firms have to use concurrent design to meet customers' expectations. A plural approach to the design process is essential. Unfortunately, the design activity involves experts specialized in various aspects of the product such as aesthetics, ergonomics and mechanics. Thus the collaboration between these experts is particularly difficult in the convergence steps and often results in complex adjustments.
This paper details a proposition of design methodology based on a multidisciplinary approach, using virtual reality tools. Our goal is to facilitate the integration of ergonomics and aesthetics in a mechanical design process. In this context, we consider virtual reality as an intermediary design tool useful for collaborative decision support during convergence phases. We present our methodology and associated tools tested during an industrial project, by focusing on an aesthetics-mechanics convergence step.
Keywords: Design methodology, virtual reality simulation, user integration, mechanical design.

1. INTRODUCTION

In recent years, manufacturing companies have been innovating in order to improve competitiveness and business performance. They must introduce innovative products into the market more efficiently and faster to maximize customer interest and sales. Moreover, engineers cannot always treat qualitative data they have at their disposal such as ergonomic and aesthetic characteristics. Thus, it is often through common sense rules that designers integrate these characteristics coming from different needs. As a consequence, many products surrounding us have not been designed to respond to end-user needs [1]. Many needs exist, affecting future product functionalities (ergonomic, quality, aesthetic, commercial, etc.). Each one is studied by specialists. In our study, we focus on ergonomic and aesthetic needs. Ergonomic needs correspond to the expression of the user's demand, they match the product's usefulness and they are related to all usage notions, according to the physiological and psychological characteristics of the user [2]. The aesthetic needs are linked to the user's expectations. They are often considered secondary needs because they are not essential to the product usability or performance. Nevertheless, they allow the product to be better adapted to the customer and therefore sell better [3]. Jordan calls them the "emotional benefits" [4].
Ergonomics and aesthetics require a specific integration in design process because of large culture differences between specialties. Thus, the product technical designers require the help of specialists to treat aesthetic and ergonomic needs. Unfortunately, there are few methodologies allowing them to work together and it is very difficult for designers to combine ergonomic and aesthetic features.
This paper depicts the first results of a research work on the articulation of design disciplines, and in particular ergonomic design and aesthetic design. We therefore present, in a first part, a new design methodology. This methodology is based on a proposal for a global approach to the design process, including the three actors we consider: the ergonomic designer, in charge of the ergonomic needs and the user characteristics, the aesthetic designer, in charge of the aesthetic needs, and the

mechanical designer, responsible for the technical aspects of the product and leading the multidisciplinary convergences. In a second part, we will present a case study emphasizing the virtual reality technology benefits in this methodology and more particularly in the convergence phases. In this first experiment, we use a new design tool based on virtual reality technologies to support our methodology. Preliminary results show that this new approach paves the way for a new type of collaborative design.

2. TOWARDS A MULTIDISCIPLINARY DESIGN METHODOLOGY

Aesthetics and ergonomics integration in design process

For many years, design methodology was oriented towards the technical aspects of products. The aim was to increase profits by optimizing the process in accordance with the quality-cost-delay triad which left out the final-user needs and wants [2]. Today, mechanical designers, specialists of these technical aspects, need to be helped by specialists of ergonomic design and aesthetic design, considered as co-designers [5]. Each of them has their own specific tools and methods used at different steps of the design process [6] [7] [8]. Unfortunately, the collaboration is complex and the tools are generally not compatible with one another because of the culture and vocabulary differences [9]. Moreover, designers do not rely on the same data type: ergonomic designers use some numbered prescriptive criteria necessary to mechanical designers, whereas aesthetic designers apply subjective ratio and equilibrium. However, a collaborative work is essential to design a product that satisfies all specifications (mechanical, ergonomic and aesthetic) [10]. Thus, it is necessary for designer teams to set a methodology based on the differences between various approaches and tools. In order to develop products in accordance with the various approaches mentioned, we base our work on DFX methods. DFX (Design For X) is a succession of product development techniques which can be applied effectively to the design process. It allows not only the rationalization of the products, but also of the associated processes and systems [11]. In this work, we will focus more particularly on Design For Usability (DFU) [12] or Design For Ergonomics (DFE) [13], and Design For Pleasure (DFP) [4] or Design For Aesthetics (DFA).

Multidisciplinary design methodology

In order to allow a better cooperation of experts during the design process, we propose a multidisciplinary global design methodology (Fig.1). This methodology has already been implemented in seven urban equipment designing projects to be tested [14]. Our objective is to integrate ergonomics and aesthetics, which are essential in a human-centred design process. Thus, the ergonomic approach based on ergonomic needs, and the aesthetic approach based on aesthetic needs, are organized around a central support, the mechanical design. The design methodology proposed includes the multidisciplinary interactions with the aim to anticipate and develop a set of specific tools for each step of the design process. These interactions are the subject of reasoned discussions and compromises often difficult to assess. They occur generally in convergence steps, signalled by double arrows in fig.1 [8].

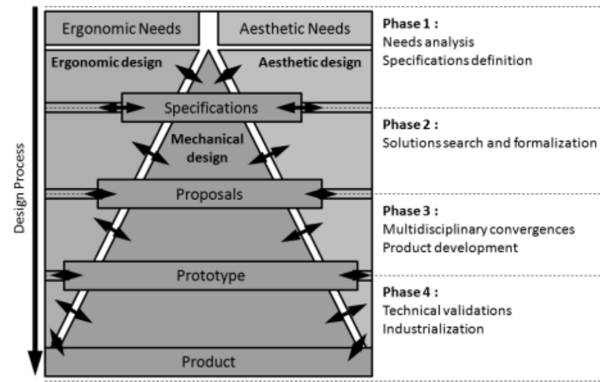

Figure 1: Multidisciplinary global design methodology [14]

Several experiments have shown that our methodology required convergence tools for designers to improve the collaborative aspect. In this manner, it is important to develop new collaborative tools in order to allow a better multidisciplinary convergence, accommodating the importance of expertise. The intermediate representations appear to meet this requirement [15].

Virtual reality as intermediary tool for help multidisciplinary convergence

The concept of intermediary representation exists in numerous design models and allows the transition between the design process steps as well as communication between experts [15]. According to Pascal [16] the intermediary representations fulfil three functions: i) the object representation within its environment and its background as well as its end use, ii) the translation giving a universal or multidisciplinary understanding, iii) the mediation because these objects are necessary to take a decision. Thus, drawing, cardboard mock-up, prototype, listing and screen copy are considered as intermediate representations useful in the design process. Each expert has their own intermediate representations enhancing various aspects of the product.

In order to represent and test the product, we operate in the virtual prototyping area [17]. The numerical aspect is a guarantee of reactivity and simplifies the object evolution through the various steps of the design process. However, the tools for conventional virtual representation such as 3D-CAD or 2D-realistic are not elaborated for a collaborative use. They do not allow optimal communication between experts. In this context, a universal numerical representation or a more flexible representation would provide each partner with an adequate tool for collaborative design.

In our work, in accordance with numerous authors [18] [19], we propose to use virtual reality tools in the design process and more particularly in the convergence phases. We assume that the collaborative aspect of immersive virtual reality facilitates the mediation and the translation, and allows all experts to simultaneously interact on a same model. Indeed, Virtual Reality adds to CAD-model properties, some VR specificities, such as immersion and interaction in real-time. Some authors have proposed virtual reality tools to try to address the convergence problem [20], but without any real multidisciplinary design methodology. For example, Krause proposes a system for creating and modifying the virtual prototype in real-time [21]. These applications are generally developed with the aim of helping aesthetic designers to formalize proposals. Unfortunately, it remains difficult for mechanical designers to integrate these proposals in their own work.

3. CASE OF STUDY: AESTHETICS-MECHANICS CONVERGENCE WITH VIRTUAL REALITY TOOLS

Context of study

In order to test our methodology and VR associated tools, we applied it to a multidisciplinary project involving the design of a new product: the F-city vehicle. F-city is a small urban car constructed by FAM, a French company specialized in automotive subcontracting. It is equipped with two seats and an electric motor. The design of this new concept car required a multidisciplinary approach and we therefore deployed our methodology. The design team was composed of five mechanical designers, two ergonomic designers and three aesthetic designers.

The case study presented deals with an aesthetics-mechanics convergence: validating materials configuration, according to colour and texture propositions. This convergence arose during the product development phase (Fig. 1). Study partners were one aesthetic designer and one mechanical designer. The elements involved were the vehicle body and interior equipment: dashboard, seats, inner liners, etc. Virtual Reality was used as a collaborative intermediary representation tool and an interactive and reactive design system. In the related convergence phase, we focused on materials validation.

Procedure

First, the aesthetic designer analyzes aesthetic needs and makes suggestions (Fig2.A). To facilitate the information transmission to the mechanical designer, the aesthetic designer has a VR application for texture and colour configuration. The application allows configuring vehicle elements while enjoying the VR benefits in terms of scale and a real-time simulation. Once suggestions are formalized, colour data are extracted in TXT format (CMYB). Textures, predefined in a specific library, are also listed.

The extracted data are integrated directly into the CAD modeller and the mechanical designer can infer acceptable materials. For every possible material, the mechanical designer tests the technical behaviours to validate the best choice (Fig2.B). When materials are defined, the mechanical designer dumps his CAD data (CATIA Model) to VR software (VIRTOOLS). Corresponding colours and textures are exported toward the application. The received file can be imported into the application, putting preconfigured colours and textures on the selected vehicle part.

From then on the technical proposals are submitted, a multidisciplinary convergence phase is carried out in virtual reality (Fig2.C). Once more, the application for texture and colour configuration is used. An additional mode dedicated to materials allows the mechanical designer to simulate real-time display of the various technical proposals. The tool is used as a communication tool, allowing, in our opinion, the aesthetic designer and the mechanical designer to reach together the best solution integrating the aesthetic and technical characteristics.

When a satisfying proposal has been reached, texture/colour/material characteristics are exported toward a technical specification board.

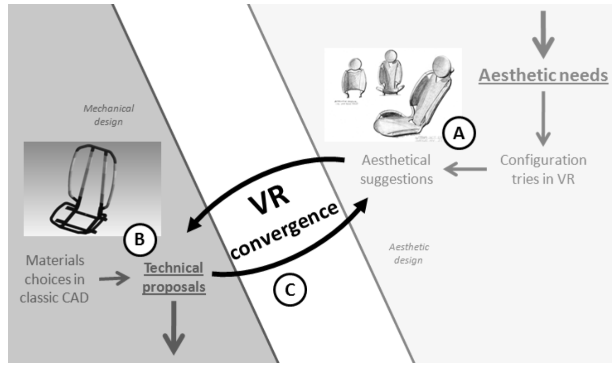

Figure 2: Virtual Reality Aided Multidisciplinary Convergence method

Equipment used

As shown in fig.3, during our experiment, we use a virtual reality platform composed of 3 active stereoscopic screens (2.10m * 2.80m). Images are displayed at 115 Hz with a 1400 x 1050 pixel resolution with Christie Mirage S + 4K projectors. The stereoscopic images are generated by 3 graphic computers equipped with Nvidia Quadro FX 5600. The motion tracking is realized by an ART optical system which is composed of 6 cameras and numerous trackers for user body. The hand gesture is recorded / tracked thanks to 5DT data gloves and for more precise gestures we can use ART Finger tracker.

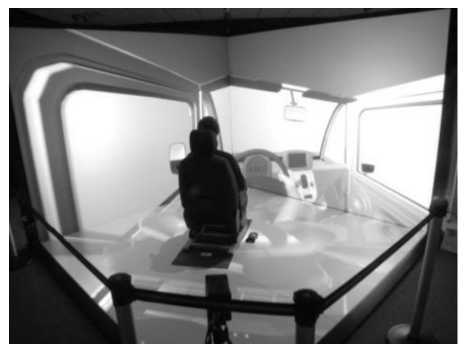

Figure 3: Virtual reality platform used in our approach

A tactile tablet of PC type was also used to support the colour-texture-material application.

Developed application

The used application was implemented following an interface design methodology [22]. The principle was to provide two interfaces on the same 3D model, one for the aesthetic designer, and the other for the mechanical designer. The application allows the aesthetic designer to control the texture and colour of the vehicle body, dashboard, seats, opening, with the interface shown in fig.4. The designer interacts with the virtual model using an interface integrated in the tactile tablet PC.

Thus, thanks to the application, the aesthetic designer can move himself or the 3D model in several virtual environments (Fig 4A). He can modulate the colours from Cyan, Magenta, Yellow and Black (CMYB), and see the results in real time, with the exterior (Fig 4E) independent from the interior (4F). Moreover, the application allows obtaining a simulation of the lights and the opening movements (Fig 4B). Finally, it is possible to export the chosen configurations using a global backup (Fig 4C).

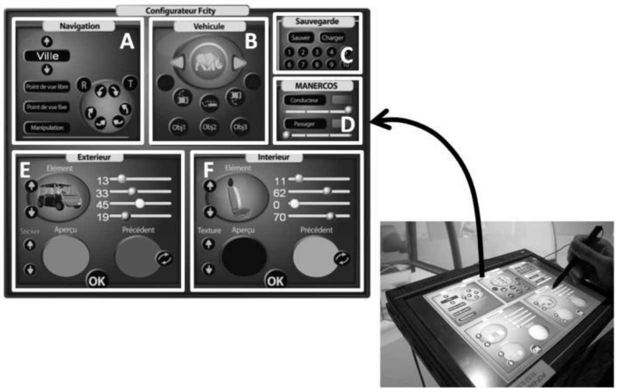

Figure 4: Configuration colour-texture interface

The mechanical designer has a specific mode at his disposal, allowing the display of technical proposals. The selection of one technical proposal sets the terms of colour characteristics.

Experiment results

In agreement with the instructions for the marketing positioning required by the company, the aesthetic designer first worked on the product trend and on the product environment to understand the aesthetic needs of the customers. This work led him to propose various graphic universes, represented by trend boards and product boards.

In the first step of the experiment, the aesthetic designer made configuration choices on the virtual reality platform, according to the trend proposals. He had his trend boards and the tactile tablet to help him to make proposals (Fig.5).

To illustrate this paper, following are three examples: body sides, seats and window posts. In every case, the aesthetic designer tested different colour and texture configurations and saved them when they were satisfactory. The CMYB manipulation was a request from the aesthetic designer.


Figure 5: Texture-colour configuration in Virtual Reality

After a creativity phase, the aesthetic designer defined colours and textures characteristics for each considered part. Those characteristics are shown on the Table 1.

Vehicle part	Colour	C	M	Y	B	Texture
Body sides	Cream	0	0	10	5	Matt and smooth
Seats	Brown	20	35	50	0	Large stitch
Window posts	Grey	8	6	6	0	Shiny and smooth

Table 1: Colours and textures selected by the aesthetic designer

The second step of the experiment was the data transmission toward the mechanical designer. He based the materials choice on the aesthetic designer suggestions, according to the technical requirements. He has selected painted steel for body sides to respect the cream colour requested. The seat has been equipped by a brown fabric, to respect the aesthetic designer wants. As regards window posts, they are structural parts requiring high resiliency. Thus, the mechanical designer gave priority to the material yield, selecting 22MnB5 Steel, darker than the requested colour. Selected materials and associated colours are showed on the Table 2.

Vehicle part	Material	Surface finishing	C	M	Y	B
Body sides	Steel	Painted : White 9010	0	0	10,2	5,1
Seats	Fabric	Sattler 804 K73	18,8	36,9	56,2	0
Window posts	Steel 22MnB5		58,1	43,5	41,9	7,1

Table 2: Material and surface finishing suggested by the mechanical designer

Once the mechanical designer had defined the materials based on the aesthetic designer's suggestions, a convergence/validation phase was required (Fig. 2C). The two designers used a VR platform to compare their proposals and assess the gaps to reach a solution. The interface was handled by them both and offered proposals which allowed for further changes. Furthermore, the aesthetic designer used his trend boards, while the mechanical designer used a selected reference materials book, and colour variants for each one.

Initially, the evaluation began with a quick assessment by the aesthetic designer. He appropriated the mechanical designer's proposals, by manipulating the object and moving some parts of the model.

In the next phase, the aesthetic designer compared the materials set proposals with a trend board, and then examined the aesthetic proposals, to assess differences. Some comparison between proposals was made possible thanks to VR (Fig.6).

Figure 6: Seat colour comparison

Finally, the differences observed were discussed. As regards body sides, the colour suggested by the aesthetic designer could be adopted thanks to a large measure of freedom existing in the paint ranges. Unfortunately, the matt texture could not be accepted because it was incompatible with the smooth appearance requested by the aesthetic designer. However, during the discussion, the mechanical designer pointed out that this choice was arbitrary, and could be changed. Thus, following the mechanical designer's recommendations, the aesthetic designer chose an epoxy-polyester powder coating which allowed obtaining a sanded matt texture.

As regards window posts, there was a convergence problem because the aesthetic designer's desired colour could not be adopted. The technical choice being unsatisfactory, it became subject to a reasoned discussion. The objective of the aesthetic designer was to find another material that offered similar yield. Unfortunately, the mechanical designer had already studied various materials and concluded that no flexibility was possible on the window post, the driver's safety being a priority. For this reason, the aesthetic designer allowed his suggestion to be rejected and the mechanical designer's proposal was chosen.

Once a satisfactory configuration was reached, the two designers recorded the proposal. The exported data were the characteristic CMYB numbers of each component and some views of the different states. A report on the selected materials was also produced. Fig.7 shows the final CAD model of the chosen seat. This study has been extended to every part of the car. Fig.8 shows one of the final configurations, which has been manufactured.

Figure 7: Final CAD model of the chosen seat

Figure 8: Final selected configuration for F-City manufacturing

Discussions

The textures and colours configuration is a representative step of aesthetics-mechanics convergences because it involves accommodations with the materials and surface treatments. The application developed has allowed us to highlight the interest of equipping designers with convergence tools based on virtual reality. Convergence phases are always difficult because of the confrontation of proposals coming from various experts. Our new application allows designers to reach compromises to satisfy aesthetic needs, according to technical requirements. The virtual reality platform permits each partner having a product representation according to his usual design methods. It also allows everyone to test the product according to his own criteria for technical solutions and to evaluate and validate the final product.

The basic model (Fig.1) depicts the articulation of the design disciplines involved. It brings out multidisciplinary informal interactions and this without specific tools. Thanks to this first experiment, we can introduce a new tool based on virtual reality. It allows formalizing exchanges between the different designers. Thus, new interactions appear which result in a new way for the mechanical designer to integrate the expertise of the aesthetic designer in the design process.

4. CONCLUSION AND PERSPECTIVES

The F-City project was a first test for our global design methodology, positioning Virtual Reality as a collaborative intermediary representation. Our first results demonstrate that the virtual reality platform can offer a narrow collaboration between the designers, providing a fast and pertinent convergence for design. In this approach an important point is that the aesthetic designer uses his expertise in an immersive virtual reality environment. Scale 1 had a strong effect on the perception of the proposed concepts and their evaluation.

The originality of our study is the importance of virtual reality in aesthetics-mechanics convergence. Our approach is thus a new way to combine a global design methodology and a new collaborative tool for intermediary representation. Another aspect which we consider to be important is the advantage of being able to extract the qualitative data coming from the aesthetic designer, in the convergence step. In addition to the integration of each expertise, this approach allows the mechanical designer to better interpret and appropriate the qualitative data coming from aesthetics analysis.

Nevertheless we have been able to target several improvements to be brought to the proposed application. Those improvements concern in particular the integration of functionalities dedicated to mechanical designers. The configuration tool could allow the integration of company manufacturing capacities. Thus, we propose to predefine characteristics of standard materials and available surface treatments, and to associate automatically textures and colours. Finally, we propose some measure of freedom indication for the material choice when colour and texture are chosen.

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