Virtual Reality as a Support Tool for Ergonomic - Style Convergence

Lionel Bennes, Florence Bazzaro, Jean-Claude Sagot

Virtual Reality as a Support Tool for Ergonomic – Style Convergence

Multidisciplinary Interaction Design Methodology and Case Study

Lionel Bennes, Florence Bazzaro, Jean-Claude Sagot
Institut de Recherche sur les Transports, l'Energie et la Société (IRTES)
Laboratoire Systèmes et Transports (EA n°3317)
90010 Belfort cedex - France
+33 3 84 58 39 62
Lionel.bennes@utbm.fr

ABSTRACT
The very competitive industrial context compels companies to fasten every new product design and underestimate the integration of the human factor. In order to keep designing user satisfactory products, a human centered, concurrent and collaborative product design methodology has been proposed. The setting up of this methodology is complicated by the difficulties of collaboration between professions. In order to overcome these difficulties, the use of virtual reality as an intermediate design representation is proposed through the implementation of immersive convergence support tools. In order to develop these specific applications, the ASAP methodology, aiming to assist immersive software designers, is proposed. This methodology is an on-going research work and this paper presents a case study: the design of a support tool for ergonomic-style convergence.

Categories and Subject Descriptors
D.2.2 [**Software Engineering**]: Design Tools and Techniques – *User Interface*; I.3.7 [**Computer Graphics**]: Three-Dimensional Graphics and Realism – *Virtual Reality*; H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Theory and Methods.*

General Terms
Design, Human Factors, Theory.

Keywords
Design Methodology; Support Tool; Product Design; Multidisciplinary Convergence; Immersive; Virtual Reality.

1. INTRODUCTION
Considering the very competitive industrial context with which the companies are currently confronted, every product development must be more rapid and technologically satisfactory while less expensive. As a result of these constraints, companies tend to underestimate aspects such as the integration of human factors, and many current products have not been designed to fulfill the end user expectations [17]. In order to help companies to consider the human factor in their product development cycle, while achieving competitiveness, a human centered, concurrent and collaborative product design methodology has been developed [15, 20]. The designed products can be manufactured products as well as workstations. This methodology is based on a cross-disciplinary synchronous approach [18], and is centered on three main players: industrial stylists, human factor experts and mechanical engineers. The collaboration of these three players allows the introduction of the human factor from the upstream phases of the product development cycle (Figure 1). But this collaboration between different professions can be quite difficult to fulfill. Indeed, each one of these areas of expertise employs its own methods, tools and a specific vocabulary [14]. In order to overcome these communication problems, intermediate design representations are usually employed to translate the information that needs to be shared and make it understandable by all involved players [3, 23]. These representations usually come as freehand drawings, digital mock-ups, physical prototypes, etc.

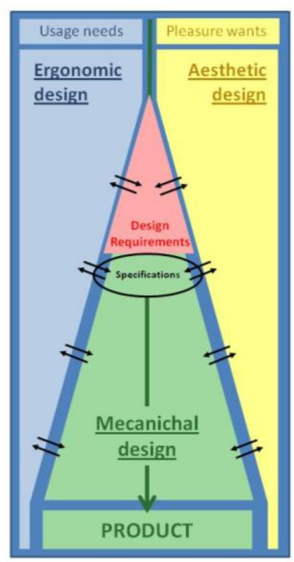

Figure 1. Human centered, concurrent and collaborative product design methodology from Guerlesquin et al. [12]

Virtual Reality (VR) can also be a relevant prop for these intermediate design representations [12]. Indeed, VR can create a reference link between the digital mock-up and the physical prototype by allowing designers to observe the future product at full size, to change its geometric configuration, to modify its colors and materials, etc. VR can also allow designers to put themselves in the place and point of view of future users of the product being designed.

Nowadays, in the industry, VR is mainly used as decision making tool and as design review [16]. For instance, VR can be used to decide which early design proposition to develop amongst all those suggested by the stylist. Virtual reality, used as a design review system, provides a non-codified illustration of the future product making all exchanged information understandable by all; as opposed to the regular tools used by mechanical engineers such as cross-section views or layout drawings for example.

Virtual reality also allows simulating the conventional use of the future product by inserting it into its operating environment. The immersive environment ease the work of human factor experts who can better evaluate their propositions by putting themselves in the place of the virtual dummies they commonly use [16].

In order to pursue the integration and acceptance of VR technologies within industrial product development cycles, several axes can be followed.

One of them is to position VR at the core of development cycles by providing a common tool to all the professions associated with new products design. Immersive modeling environments, such as the one developed by Fiorentino et al. [9], allow designers to create shapes directly within the 3D space. Another example is VR-CAD environments such as the VRAD demonstrator presented by Bourdot et al. [4] which provides an immersive and multimodal user interface allowing the creation of curves, surfaces and solids. But, current immersive modeling environments are lacking of advanced functionalities and accuracy, compared to standard CAD software commonly used in the industry. Additionally, the 2D interaction techniques already gained by CAD expert users are not directly transposable in an immersive environment. It is still a problem to let the user enter alphanumeric data, and the new interaction methods and technologies will need long acceptance phases. In order to overcome these difficulties, some works have tried to link immersive environments with classic CAD systems. This link allows designers to enjoy the immersive advantages of virtual reality while recognizing their usual workspace. In this case, design tasks are divided in two steps: modeling or editing the 3D model and immersive visualization. The works of Stark et al. [21] present a study on these integration possibilities. Despite its benefits, this approach is still slowed down by the technological barrier of data transfers between traditional CAD software and VR development environments. This transfer is currently carried out through a long conversion process during which the 3D model suffers accuracy and semantic content loss. Namely, it is also a loss of usefulness from a designer's point of view. Obviously, the same type of problems appears on the opposite direction when edited 3D models are transferred from the VR environments to the CAD software.

Another axis is to consider VR as an intermediate design representation. This point of view will be the one adopted for this study. These representations are used in multidisciplinary design process during convergence steps when various areas of expertise need to define a compromise, acceptable by all, regarding the evolution of the future product [22]. VR will then be considered as a "support tool for convergence". The purpose of this view is to graft VR on already existing product development process at specific steps where its contributions are the most relevant. This approach implies an accommodation of the interaction techniques to the specific framework of multidisciplinary interaction: fulfill the needs of each profession involved in the convergence step. In order to develop this type of tools, it seems necessary to go by a specific interaction technique design methodology [2]. In order to follow these specifications, methodology has been proposed: the ASAP methodology (As Soon As Possible). Its full definition is an on-going research work aiming to be refined through numerous application cases.

This study aims to put the ASAP methodology to the test within the framework of a multidisciplinary concurrent, and collaborative industrial product design project. In this paper, the current state of the ASAP methodology will be presented followed by an industrial use case, through the design of two ergonomic-style convergence immersive support tools. This use case allowed to validate two specific parts of the ASAP methodology: First, the setting up of the interaction module design phase within the punctual phase of the ASAP methodology. And secondly the validation of the interaction context set up within the continuous phase of the ASAP methodology.

2. ASAP METHODOLOGY

The ASAP methodology approach is aiming to define a set of specific steps and guidelines to assist virtual reality application developers. This methodology is meant to be used within an industrial environment, by a virtual reality department for example, with its specific constraints: time, cost and reactivity. This methodology is specifically dedicated to the setting up of design reviews using virtual reality as a support tool for multidisciplinary convergence. This methodology and its associated approach follow a top-down design strategy.

In order to precisely meet the needs of the industry, the ASAP methodology will be defined and refined through numerous industrial application cases following the Living Lab approach defined in [8]. The Living Lab concept originates from MIT through Prof. William Mitchell who argued that a Living Lab represents a user-centric research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts.

An overview of the general shape of the methodology has been defined following the study of multidisciplinary product design and the specifications proposed by reference VR approaches like the one proposed by Bowman et al. [5]. This general overview has already been refined through the implementation of immersive convergence support tools such as the one presented in [1].

2.1 ASAP Framework and Overview

In order to make VR an essential part of the product design process, it is essential to increase its acceptance by design teams. Indeed, immersive systems are still expensive and must often be shared in time and availability between all on-going design projects. In addition, VR input devices can sometimes be invasive or difficult to use. Because of this, VR is sometimes considered as a drawback by projects managers, despite its proven contribution [21]. In order to optimize the use of VR resources, we suggest creating light and highly specialized immersive applications matching exactly the requirements of each individual project.

The ASAP methodology is based on the 3I² methodology presented by Fuchs et al. [10] and on the design guidelines presented by Bowman et al. [5]. These two approaches can be considered as a reference framework for immersive VR applications design, but they are not fully fitted for the development of light and punctual VR applications. They are

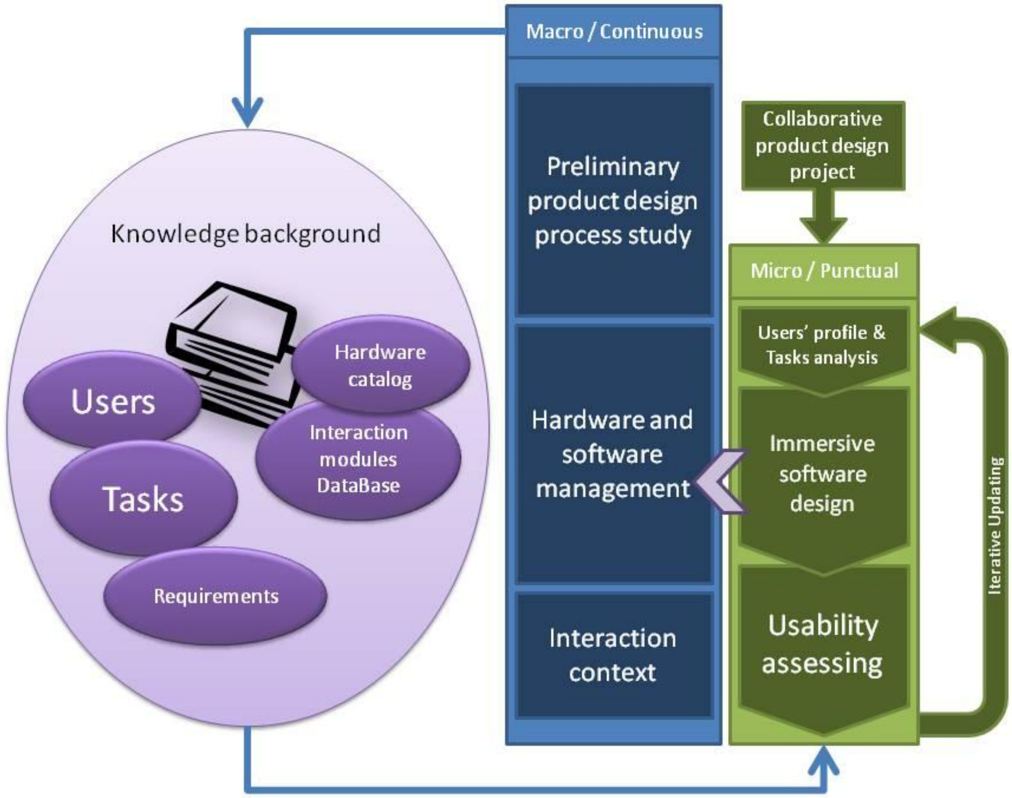

Figure 2. Overview of the ASAP methodology

more suitable for the design of complex or stand-alone immersive applications [2, 19].

As depicted in Figure 2, the ASAP methodology is divided into three main parts. The first one represents a set of data aggregating a wide range of information about the work environment in which the ASAP methodology will be implemented. This knowledge background will supply, and be supplemented by every new development. The second one is characterized in time as "continuous" and is meant to provide a macroscopic knowledge of the surrounding working environment, the product design methodologies in use and their associated professions. This macroscopic knowledge is meant to be reused for the second part of the methodology through the supply of the associated knowledge. The last part is, on the contrary, a punctual process to carry out alongside an individual product design process. It is meant to provide a microscopic view on specific convergence steps associated with the development of the new product. This microscopic project related knowledge used jointly with the knowledge background gathered upstream will allow supporting at best these convergences with an immersive tool.

2.2 Knowledge Background

The main purpose of the ASAP methodology is to provide a framework allowing the implementation of light and highly specialized immersive tools. In other words, this methodology will encourage the reuse of previously gathered information or previously implemented modules in order to fasten the programming of new, and suitable, immersive application programs.

Therefore, the knowledge background is at the core of the ASAP cycle. The macroscopic-continuous part supplies this database with general information whilst the microscopic-punctual part leans on it to produce a suitable immersive tool. It is also supplied with the information gathered through every new immersive tool development.

The knowledge background is divided into two main parts:

- Users' related information: this part gathers information about potential users of the immersive tools (i.e. mechanical engineers, industrial designers and human factor experts), their tasks and the associated requirements according to the product design processes in use within the surrounding working environment.
- Management of technical data: this part is composed by a hardware catalog classifying all the available interaction devices according to appropriate criteria, and by an interaction modules database allowing an efficient reuse of previously developed elements of interaction. This specific technical part will be detailed later in this paper.

2.3 Macroscopic – Continuous Part

Within an industrial environment, VR departments are usually confronted with only one type of product development cycle. Even if the individual projects are focused on very different parts of this product development cycle, a knowledge background based on the study of this cycle and its associated professions allows upstream identifying of which convergence steps to support and their implicit requirements. Implicit requirements correspond to non-formulated requirements, which will allow identifying the basic functionalities that the immersive tool has to provide. As detailed later in this paper, these early implicit requirements allow immersive software designers to propose an already efficient first version of the application.

2.3.1 Preliminary Process Study

This knowledge background can be gathered through observations of usual design reviews, focusing on convergence steps and the techniques, intermediate design representations, or collaborative tools in use (CAD software, stereoscopic screens ...) to share information between different professions. These observations can be completed by interviews of product design process actors. These interviews should be focused on the multidisciplinary product design process with an emphasis on personal experiences of the interviewees regarding multidisciplinary interactions and their associated difficulties. The analysis of the technical solutions used to solve multidisciplinary interaction problems can provide a set of implicit requirements.

2.3.2 Hardware and Software Management

2.3.2.1 Hardware Catalog

The reference approaches for immersive VR applications design [10] recommends purchasing or creating interaction devices according to the identified tasks and requirements. Within an industrial environment, and within the development context before-mentioned, it is inconceivable to renew the entire stock of interaction devices for each project. In order to develop as immersive interaction techniques as if the interaction device was chosen specifically for, a detailed hardware catalog should be defined. In this catalog, each interaction device has to be classified according to a set of criteria allowing the immersive software designer to efficiently choose the most suitable one for each interaction requirement (advantages, drawbacks, accuracy, weight, calibration ...).

2.3.2.2 Interaction Modules Database

In order to be able to develop immersive tools “on-the-go”, the backup and classification of previous developments is necessary.

In order to ease the work of immersive application developers, an approach based on visual programming is proposed through the use of interaction modules allowing designing visually the user’s interaction experience. An interaction module comes in the form of a black box encapsulating the handling of the user’s action according to the handled interaction devices. This independent interaction module can then be reused whenever the same type of user interaction is needed. The practical implementation of such modules will be detailed later in this paper.

In order to optimize their reuse, interaction modules should be classified within an interaction module database. The classification parameters of this database should be linked with the hardware catalog in order to associate each interaction device with every compatible interaction module. Other possible classification parameters could reference the interaction modules according to the user’s members involved in its use (one hand, both hands, etc.) or the type of interaction (travel, observation, object modification, etc.).

2.3.3 Interaction Context

Trying to replace every usual multidisciplinary interaction technique (such as pen and paper) by an immersive tool will often lead to the rejection of VR technology [21]. An immersive tool is not always the most efficient answer for a specific requirement. Therefore the interaction context surrounding the immersive system should be cleverly organized to support every usual multidisciplinary interaction technique that is not suitable for an immersive solution.

All these macroscopic elements should be kept updated in a continuous way in order to keep the knowledge background up to date with the design teams’ requirements.

2.4 Microscopic – Punctual Part

This second “punctual” part should be initiated simultaneously to each new collaborative product design. Indeed, even if the convergence steps to support are usually similar, every new project brings up specific requirements, and discards other ones. Depending on the type of product being developed and which profession is leader for this product development process (mechanics, style …).

2.4.1 Users’ Profile and Tasks Analysis

In order to develop an immersive support tool to ease a specific convergence, it is fundamental to determine correctly and precisely who are the future users and what functionalities they will need. Within the ASAP framework described earlier, the future users will mainly be designers: mechanical engineers, industrial designers and human factor experts.

These convergence support tools are meant to be developed alongside the progress of the design project. The users and tasks analyses must so be carried out during the very first convergence steps of the design process.

These analyses can be done, for example, through observations, guided by observation grids [7]. These grids enable the observer to focus on specific elements of the discussion without being distracted by the topic being discussed. The observed elements are determined after a first overview of the video footage. The observer has to analyze what is said, the gestures made or what medium is used (hand drawing, scheme highlight …) and extract the implicit and explicit requirements for the following convergence step.

2.4.2 Immersive Software Design

Using these project’s related requirements jointly with the users, tasks and requirements knowledge background, immersive software designers can identify a complete set of specifications.

Once all requirements have been identified, in order to maximize the acceptance of the immersive solution, it is necessary to identify which requirements should be fulfilled by an immersive solution. Indeed, there is no need to impose an immersive solution if the traditional one is much more efficient. Integrating VR to the product design process implies a modification of habits for designers. This can lead to a rejection of VR technologies if the immersive application brings more inconveniences than benefits. For all “non-immersive” requirements identified, a real life solution should be provided within the interaction context.

If the immersive system is a mono-user driven one, the “immersive” requirements can be divided in different categories in order to set up “profession-leading” modes for the future immersive application. For example in the case of a stylist to human factor expert support tool, three requirements categories can be defined:

- Stylist leading requirements
- Human factor expert leading requirements
- General collaborative functionalities continuously available.

These reorganized specifications will be used by the immersive software designers to develop a first valid version of the support tool.

For each immersive requirement identified, the immersive software designers have to try to identify the most intuitive interaction solution.

In order to find it, the 3I² methodology described by Fuchs et al. [10] can be used. Each tasks previously identified, within the tasks analysis phase, should be separated into elementary tasks; some of them can be sometimes merged.

For each remaining elementary tasks, a mental representation should be found to obtain a transparent interface. As defined in [10], a transparent interface is an intuitive interaction technique that ideally does not need any learning to be used efficiently by the user.

For each of these mental representations, immersive software designers have to find the most adapted input device within their hardware catalog, and correctly map the user's actions on this input device. An interactive behavioral assistance can also be set up in order to ease the user's interaction: magnetize the user's virtual hand to an interactive object for example.

In order to keep the efficiency of the development for this specific step, the immersive software designer can skim through the hardware catalog and the associated interaction modules database. In none of the already implemented module fit the needed interaction behavior, a new interaction module should be developed.

As detailed earlier, an interaction module comes in the form of a reusable black box acting as an interface between an interaction device (linked with the user) and the 3D scene (Figure 3).

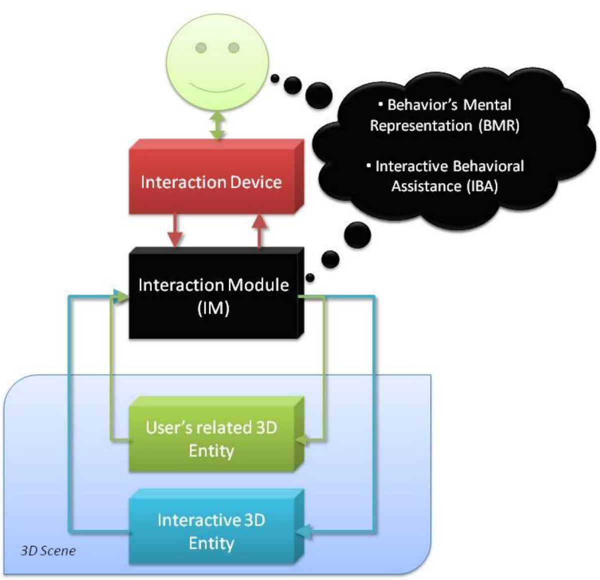

Figure 3. Integration of an interaction module within the framework of an immersive application

In order to design a new interaction module (IM), several essential elements has to be identified:

- Encapsulated IM elements: Each IM has to be associated with a Mental Representation of the Behavior (MRB) to simulate, and an optional Interactive Behavioral Assistance (IBA) in order to design a transparent interface. In order to be self-supported, each IM also has to provide the handling of every compatible interaction device (matching the defined MRB).
- External IM elements: In order to link the self-supported IM with the user's actions on the 3D scene, it has to be supplied with user's related variables (position and orientation of the user virtual hand for example) and involved interactive 3D entities variables.

2.4.3 Usability Assessing

Once the first version of the immersive support tool is functional, before its first utilization within a design review, two preliminary usability assessing phases has to be carried out.

The first one is based on basic and general usability guidelines, such as the ones described by Bowman et al. in [5], that immersive software designers can validate as a "check-list" to avoid common usability problems. These usability guidelines are classified into several categories that go from advices concerning the choice of input devices to generic system control advices.

In order to keep the efficiency of development, the second usability assessing of the immersive tools is based on the intervention of an expert user. He or she will need to identify the remaining and more specific usability problems before the first user test. This expert user evaluation can follow a cognitive walkthrough (stepping through common tasks that a user would perform [5]) or simply a "free-play" exploration of the user interfaces [13]. The assessment provided by the expert user is guided by his or her own knowledge of immersive interaction design and by a taxonomy of usability characteristics in virtual environments [11].

Once the immersive support tool validated, it can be used within the framework of the concurrent multidisciplinary product design project by designers in order to assist the following step towards convergence. This first use serves as a final usability validation step for the immersive tool, and so has to be observed by the immersive software designers in order to identify remaining usability problems (difficulty of use) and new requirements. The analysis of this fist session allows validating the identified immersive requirements and functionalities, and make corrections if needed through the iterative updating of the immersive tool. Furthermore, the new perspective provided by immersive reviews and the progress of the design process often leads to implicit or explicit new requirements. These requirements should be implemented (if technically feasible) for the next design review, through the iterative updating of the immersive tool.

3. CASE STUDY: DESIGN OF AN ELECTRONIC CARDS TEST BED

For this case study, we worked alongside an industrial project ordered by a company specialized in the design and manufacturing of tests and measures systems to assess the validity of electronic cards. The purpose of this specific project was to develop an ergonomic electronic cards test bed which would be visually associated with this company.

This study was carried out during the early steps of a human centered collaborative methodology [12]. It involved the concurring work of a stylist and a human factor expert (Figure 1).

In order to ease the collaboration of these two types of professions within this specific framework, we proposed to use virtual reality as an intermediate design representation in the form of an immersive support tool for ergonomic-style convergence.

In order to develop this immersive tool, we followed the early version of the ASAP methodology described earlier. As this methodology is currently in development, only some of the steps described before are applied in the following description.

This immersive tool has been developed for a CAVE type VR platform [6].

3.1 Early Ergonomic-Style Convergence Support Tool

The first version of this convergence support tool has been developed to assist an early convergence step at the very beginning of the product design process: after the selection of a limited number of early design propositions from the ones suggested by the industrial designer. This support tool has been developed following specifications based on the *knowledge background* gathered through the macroscopic and continuous phase of the ASAP methodology.

Preliminary product design process studies allowed determining that the objective of this convergence step is to choose which early design proposition to follow according to ergonomic criteria and the aesthetic rendering at full size.

Based on users, tasks and requirements *knowledge background* jointly with project related *user's profile and tasks analysis* through early design reviews observations, specifications for an immersive support tool for early ergonomic-style convergence has been determined:

- Human factor expert requirements:
  - Precise sensory feedback of heights and accessibilities.
  - Ability to try the real life sitting position in front of the virtual test bed.
- Industrial designer requirements:
  - Full size view of the design propositions.
  - Switch between design propositions.
  - Neutral rendering of the different design propositions, in order to limit the influence of colors and materials and increase the focus on the shapes and volumes.
  - Movable light to highlight specific shapes.
- General collaborative functionalities:
  - Non-distorted view of the immersed point of view for the participants outside the immersive environments.
  - Moving around the virtual model, see it from every angle.
  - Taking notes or freehand drawing design solutions.

Using these specifications, and following the ASAP *immersive software design* recommendations, an immersive tool has been developed offering solutions to the highlighted requirements (by order of citation):

- Virtual hands collocated with the users' hands using optical tracking. The collision of real hands with the virtual prototype is highlighted by a visual feedback.
- A real life chair disposed in the center of the CAVE.
- Full size view of the virtual prototype with verified "real life" dimensions.
- Switch between design propositions using a Wiimote™ button.
- Gray levels rendering of the virtual prototype with enhanced lights rendering (ambient occlusion).
- A graspable virtual light. The user can grab the virtual light using a Wiimote™.
- A deported view of the immersed point of view on a side screen.
- The user can rotate around the virtual model disposed inside a room-like virtual scene.
- A meeting table is positioned within the interaction context to support notes ad freehand drawings.

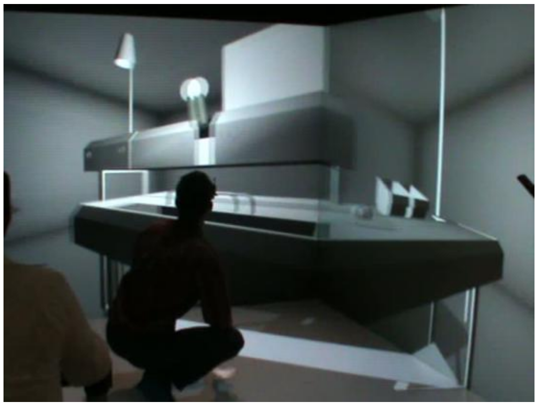

Figure 4. Early ergonomic-style convergence support tool

Usability assessing through the intervention of a VR expert user allowed correcting some minor usability problems such as the mapping of the users' actions on the buttons of the Wiimote™. The use of the graspable light has also been simplified with an automatic catching: the user no longer needs to pick the virtual lamp, it automatically teleports itself to the user's hand location.

In order to follow the progress of the design process, and adapt the immersive support tool through *iterative updating*, the first user test was recorded. New requirements have been identified by analyzing the resulting material with a lecture grid. The identified requirements mainly corresponded to the requirements needed for the next convergence step.

3.2 Advanced Ergonomic-Style Convergence Support Tool

The second version of the immersive tool matches with another convergence step. Within this step, a design proposition has been chosen and is being developed in details by the industrial designer (corrections of the general shape and details) and by the human factor expert (morphological adaptability of the workstation, adjustments and validation for ergonomic rules).

Using the result of the previous immersive design review and the knowledge background accumulated before, further requirements have been identified for the evolution of the immersive convergence support tool. Corresponding to the progress of the design process, these new requirements are mainly human factor expert's requirements:

- Assessing of virtual dimensions

- Collision feedback for occulting limbs (in order to be able to detect a collision between the workstation and the knees of the user for example)
- Virtual workstation adjustments, height of the working zone (according to the ones proposed by the human factor expert)

Following these new specifications, the immersive tool has been updated:

- A movable height gauge using the same Wiimote™ technique as before. In order to ease the use of the height gauge, it is linked with the ground, and so movable only alongside two dimensions.
- Adding of a tracking target on the right knee of the user paired with a visual and audio feedback in case of collision with the virtual model. A squared red shape is screened on the collision point and oriented according to the normal vector of the collision spot while a clicking sound is emitted to alert the user.
- The user can browse between the upper and lower heights of the workstation using the "+" and "-" buttons of the Wiimote™. An audio feedback occurs when the user reach the upper or lower configuration.
- A real life table is placed on the edge of the CAVE to allow immersed user to take notes while working with the immersive tool.

As for the previous version of the immersive support tool, the user interaction inputs and techniques were assessed and validated by the intervention of an expert user before the first user test.

Figure 5. Advanced ergonomic-style convergence support tool (accessibilities, graspable light, real life seat and knee collision)

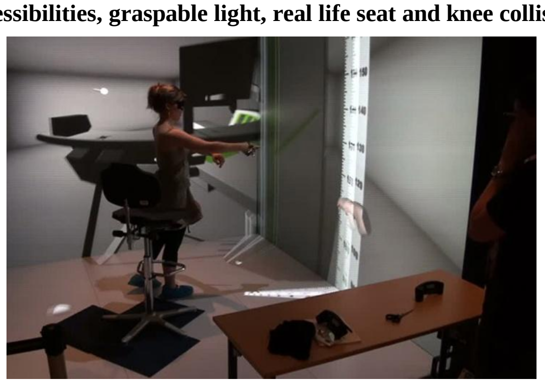

Figure 6. Advanced ergonomic-style convergence support tool (moving around the virtual model, graspable height gauge)

As before, the second immersive design review led to significant progress for the design process. Indeed, the support tool allowed designers to agree for good on specific design solutions after their confrontation with the immersive prototype.

Again we could identify some new requirements corresponding to the further steps of convergence. All the developments made within these two versions enriched the interaction module database and so can be re-used for similar purposes for further projects.

3.3 Interaction Modules

In order to better illustrate the concept of interaction modules (IM), some examples developed for this case study are detailed below. The following IM are depicted under a simplified shape: as defined in Figure 3, the encapsulated IM elements are detailed within the main IM shape while external IM elements a divided in two arrows. The upper one represents user's related 3D entities, and the lower one represents involved interactive 3D entities.

These three IM correspond to basic functionalities matching the identified immersive requirements for this convergence step. These three modules are mutually compatible.

3.3.1 Interactive Virtual Hands

This IM (Figure 7) aims to better immerse the user through a realistic behavior of his or her virtual hands. By pressing the lower trigger of a Wiimote™, the user see his or her hand "grasp" in the virtual environment.

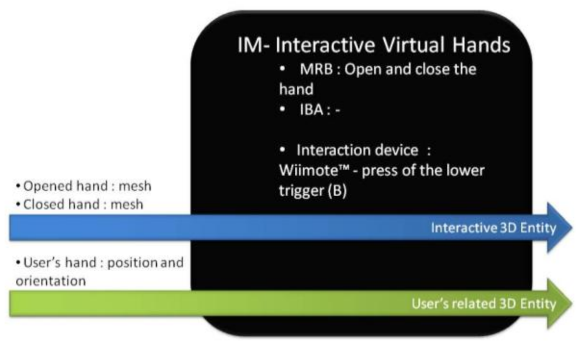

Figure 7. Interaction Module: Interactive Virtual Hands

3.3.2 Graspable Flashlight

This IM (Figure 8) allows the user to "call" and grasp a virtual flashlight in his or her hand by producing a grasping gesture on the Wiimote™.

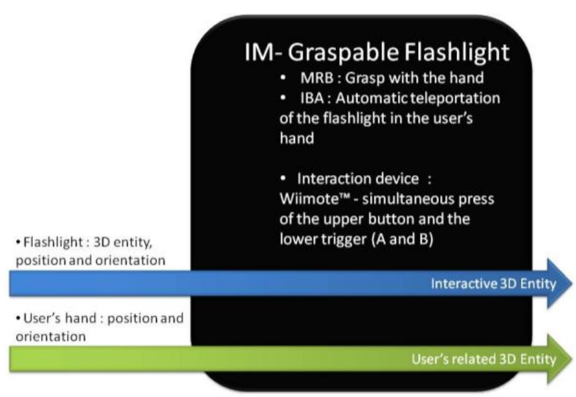

Figure 8. Interaction Module: Graspable Flashlight

3.3.3 *Movable Height Gauge*

This IM (Figure 9) allows the user to "call" and slide a virtual height gauge in his or her hand by producing a grasping gesture on the Wiimote™. In order to ease the measure of heights, the height gauge slides on the floor following the user's virtual hand.

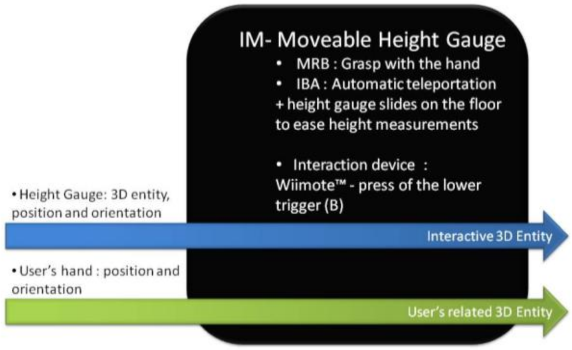

Figure 9. Interaction module: Movable Height Gauge

4. EXPERIMENTAL RESULTS

4.1 Ergonomic-Style Convergence Support Tool Qualitative Results

Following the two immersive design reviews, qualitative feedback had been gathered through semi-structured interviews of the involved designers. A semi-structured interview has a framework of predefined themes to be explored, and a set of standard questions but this method is flexible and allows new questions to be brought up during the interview according to the answers of the interviewee.

4.1.1 *Semi-Structured Interview*

The predefined framework of the semi-structured interview was composed by five general questions:

- What was the contribution of the immersive tool regarding the discussion with the others experts of different areas of expertise?
- Did the functionalities provided by the immersive tool allowed you to sustain your comments and express your ideas?
- Which functionality of the immersive tool did you find most relevant? Which functionalities were missing?
- Were the decisions taken during the immersive session definitive?
- Do you think that the immersive tool allowed a better and more efficient convergence towards the final product?

4.1.2 *Human factor expert feedback*

These two immersive sessions allowed the human factor expert to validate the design propositions. These propositions were made by the industrial designer according to the ergonomic norms provided upstream by the human factor expert.

The immersive tool provided a better feeling of the bulk and volumes of the workstation. It also allowed the human factor expert to formally validate the heights and accessibilities of the workstation using the virtual hands, the height gauge and the height adjustment of the worktop. By experiencing postures and gestures of the future manipulator, the human factor expert felt more confident regarding the validation of the workstation. The height gauge also helped her to have confidence in the validness of the perception provided by the immersive system.

Despite the knee collision feedback provided, the validation of the blacked-out parts of the work station required an extra validation test. Also, without force-feedback, the weight of hand held elements could not be validated.

The workstation elements validated during the immersive review sessions were preserved until the final product. Without the full scale perception the validation of the workstation would have need a set of full scale extra tests.

4.1.3 *Industrial designer feedback*

These two immersive sessions allowed the industrial designer to validate her product architecture choice, in terms of shapes and volumes; and to argue about the choices made with the human factor expert.

As for the human factor expert, the immersive tool provided a better perception of the bulk and general volume of the workstation to the industrial designer. Indeed, despite her habit to mentally project the conceptual workstation, this confrontation with a full scale view of the design proposition allowed her to identify a proportion error which could have led to major changes if detected later in the product design cycle.

The immersive tool helped the industrial designer to better argue and illustrate the choices made during her discussion with the human factor expert. This immersive tool also helped her to foresee and be prepared for the possible changes that may occur in the further phases of the product design cycle.

Without the immersive tool, a major design error could have led to significant changes in subsequent stages of the product design cycle. Also, the validation of the bulk and volumes of the future workstation would have required further full scale testing, using a cardboard mock-up for example.

4.2 Experimental Validation of the Interaction Context

Through the support of this ergonomic-style convergence and the observation of the last immersive design review, it was also possible to analyze the focus of attention. Through this study, the interaction context defined within the upstream phase of the ASAP methodology has been validated.

4.2.1 *Experimental Setup*

The immersive design review took place within the interaction context defined by the continuous part of the ASAP methodology. Upstream product design process observations allowed defining a multidisciplinary immersive interaction context according to the multidisciplinary requirements identified (Figure 10):

- A CAVE type immersive VR platform: PREVERCOS – active stereoscopic visualization system composed by two walls and a floor, an optical tracking system and a Wiimote™. This immersive platform allows only one immersed user. The 3D scene projection is computed to match the immersed user's point of view. The other users (designated as non-immersed users) will obtain a distorted view of the 3D scene when watching it from the outside of the immersive platform.

- A remote view monoscopic screen of the immersed user's point of view. This remote view allows non-immersed users to obtain a non-distorted view of the immersed user's point of view. And therefore, to clearly identify what is observed and discussed by the immersed user without the need of stereoscopic glasses.
- A meeting table allowing non-immersed users to discuss, freehand drawing and examine papers documents. This table is the center of the discussion and is ideally located in relation to the immersive platform and the remote view screen.

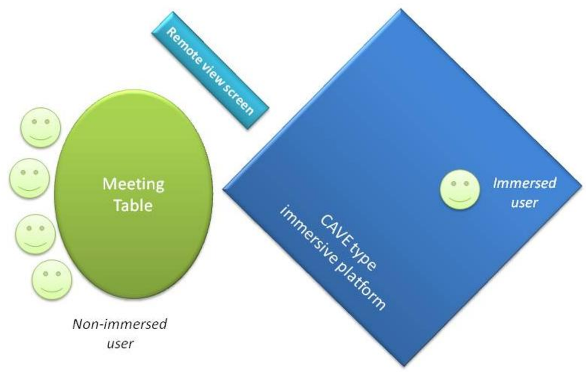

Figure 10. Immersive design review interaction context

This session lasted 60 minutes. It was filmed and analyzed using observation grids. The total length was divided into 1 minute time units. For each of these time units, the main behavior was recorded. These results are presented as percentages functions of the total session duration.

In order to characterize the focus of attention, 4 centers of attention have been defined:

- Waiting time: the focus of attention in undefined
- Immersive platform: the focus of attention is centered on the immersive platform. Non-immersed users are wearing stereoscopic glasses and are observing a distorted view of the 3D scene.
- Remote view: the focus of attention is centered on the remote view screen. Non-immersed users do not wear stereoscopic glasses.
- Table: the focus of attention is centered on the meeting table.

4.2.2 Results Analysis

Results of the observation presented in Figure 11 outline clearly that the main focus of attention is the remote view screen. Indeed, it represents 58.5% of the total length. The immersive platform is at the focus of attention during only 12.2% of the total length. A non-distorted view of the virtual prototype is essential to sustain a design review discussion. Additionally, the remote view allows the non-immersed users to observe the movement and gestures of the immersed user's virtual hands. The focus of attention is centered on the meeting table during 24.4% of the total length. This represents a non-negligible part of the design review, and justifies the presence of this table within the immersive design review interaction context. This table allows non-immersed users to sustain the discussion or to explore new technical solutions by producing freehand drawings.

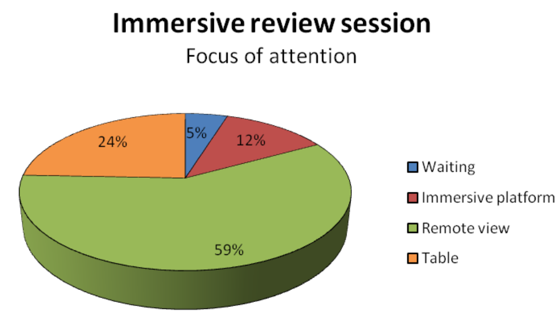

Figure 11. Focus of attention during the observed immersive design review

These results validate the effectiveness of the proposed interaction context when using VR as a support tool for multidisciplinary design convergence.

5. CONCLUSION AND FURTHER WORKS

The use of VR as a support tool to ease multidisciplinary product design process implies the implementation of light and highly specialized immersive tools to support multidisciplinary convergence. The constraints imposed by the industrial environment involve fastening and optimizing the development of immersive applications. In order to be able to produce numerous immersive convergence support tools, almost one or more specific tools for each new project, the use of a dedicated interation design methodology is necessary.

The works presented in [2] point out the fact that usual VR interaction design methodologies are not fully adapted to the development context detailes earlier.

The ASAP methodology is proposed to assit immersive VR applications designers for the implementation of such applications, while respecting the constraints imposed by the industrial environment. A first immersive support tool has been presented in [1]. Its beneficial effects on the design process have been qualitatively observed.

This case study presents the design and use of an immersive support tool for ergonomic-style convergence. This tool used within a validated interaction context led to a better understanding of the design proposition (bulk of the workstation, access to the supplying zones …) and helped the design team to converge more efficiently on this early design step. The qualitative feedbacks collected from the users were quite positive. The support tool allowed them to benefit from the advantages of the immersive simulation, and the use of the VR platform did not upset the rhythm and efficiency of their common design reviews.

Despite the validation of the interaction context, the results presented in this study are qualitative results. An on-going study will present quantitative results ensuing from a comparative experiment between a standard and an immersive design review.

The ASAP methodology is still an on-going research work. In order to define precisely each steps of this approach, numerous implementation cases are planned in a short future. Based on the multidisciplinary product design methodology presented by Mahdjoub et al. [15], various immersive support tools will be developed to assist the different types of multidisciplinary convergence steps from upstream to final design phases.

6. REFERENCES

[1] BENNES, L., BAZZARO, F., AND SAGOT, J.-C. Multifunctional virtual screen: a 3d user interface for stylist and mechanical engineer. In *Actes des cinquièmes journées de l'Association Française de Réalité Virtuelle* (2010).

[2] BENNES, L., BAZZARO, F., AND SAGOT, J.-C. Réflexions sur une méthodologie de conception de techniques d'interaction en réalité virtuelle dédiées à la collaboration inter-métier. In *Actes du 18ème Colloque des Sciences de la Conception et de l'Innovation, CONFERE 2011* (Juin 2011 2011), p. 10p.

[3] BOUJUT, J.-F., AND BLANCO, E. Intermediary objects as a means to foster co-operation in engineering design. *Computer Supported Cooperative Work (CSCW) 12* (2003), 205–219.

[4] BOURDOT, P., CONVARD, T., PICON, F., AMMI, M., TOURAINE, D., AND VÉZIEN, J.-M. Vr–cad integration: Multimodal immersive interaction and advanced haptic paradigms for implicit edition of cad models. *Computer-Aided Design 42*, 5 (2010), 445 – 461.

[5] BOWMAN, D. A., KRUIJFF, E., LAVIOLA, J. J., AND POUPYREV, I. *3D User Interfaces: Theory and Practice*. Addison Wesley Longman Publishing Co., Inc., Redwood City, CA, USA, 2004.

[6] CRUZ-NEIRA, C., SANDIN, D. J., AND DEFANTI, T. A. Surround-screen projection-based virtual reality: the design and implementation of the cave. In *Proceedings of the 20th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1993), SIGGRAPH '93, ACM, pp. 135–142.

[7] DE KETELE, J., AND ROEGIERS, X. *Méthodologie du recueil d'informations: fondements des méthodes d'observation, de questionnaires, d'interviews et d'étude de documents*. Pédagogies en développement: Méthodologie de la recherche. De Boeck Université, 1991.

[8] ERIKSSON, M., NIITAMO, V.-P., AND KULKKI, S. State-of-the-art in utilizing living labs approach to user- centric ict innovation - a european approach . *Technology 1*, 13 (2005), 1–13.

[9] FIORENTINO, M., DE AMICIS, R., MONNO, G., AND STORK, A. Spacedesign: a mixed reality workspace for aesthetic industrial design. In *Mixed and Augmented Reality, 2002. ISMAR 2002. Proceedings. International Symposium on* (2002), pp. 86 – 318.

[10] FUCHS, P., MOREAU, G., ARNALDI, B., BURKHARDT, J., CHAUFFAUT, A., COQUILLART, S., DONIKIAN, S., DUVAL, T., GROSJEAN, J., HARROUET, F., ET AL. *Le Traité de la Réalité Virtuelle*. Presses de l'Ecole des Mines, 2006.

[11] GABBARD, J. *A taxonomy of usability characteristics in virtual environments*. PhD thesis, Virginia Polytechnic Institute and State University, 1997.

[12] GUERLESQUIN, G., MAHDJOUB, M., AND SAGOT, J.-C. Multidisciplinary design methodology: an intermediate representation tool based on virtual reality. In *Proceedings of the 4th International Multi-Conference on Engineering and Technological Innovation* (Orlando, Florida, USA, 19-22 July 2011).

[13] HIX, D., SWAN, J.E., I., GABBARD, J., MCGEE, M., DURBIN, J., AND KING, T. User-centered design and evaluation of a real-time battlefield visualization virtual environment. In *Virtual Reality, 1999. Proceedings., IEEE* (mar 1999), pp. 96 –103.

[14] KVAN, T. Collaborative design: what is it? *Automation in construction 9*, 4 (2000), 409–415.

[15] MAHDJOUB, M., BAZZARO, F., WIND, L., AND SAGOT, J. A human centered collaborative design methodology. In *9th International Congress of Physiological Anthropology, ICPA* (Delft, Netherlands, 22-26 August 2008), p. 5p.

[16] MOREAU, G., FUCHS, P., AND STERGIOPOULOS, P. Applications of virtual reality in the manufacturing industry: from design review to ergonomic studies. *Mécanique & Industries 5*, 2 (2004), 171–179.

[17] NORMAN, D. *Emotional design: Why we love (or hate) everyday things*. Basic Books, 2004.

[18] PRASAD, B. *Concurrent Engineering Fundamentals*. Prentice Hall, 1996.

[19] RICHIR, S., AND FUCHS, P. La méthode i2i : "interaction et immersion pour l'innovation". *Techniques de l'ingénieur. Télécoms TEB3*, TE5910 (2006).

[20] SAGOT, J.-C., GOUIN, V., AND GOMES, S. Ergonomics in product design: safety factor. *Safety Science 41*, 2-3 (2003), 137 – 154.

[21] STARK, R., ISRAEL, J., AND WÖHLER, T. Towards hybrid modelling environments–merging desktop-cad and virtual reality-technologies. *CIRP Annals - Manufacturing Technology 59*, 1 (2010), 179 – 182.

[22] ULLMAN, D. *The Mechanical Design Process*, vol. 2. McGraw-Hill Higher Education, 2003.

[23] VINCK, D., AND JEANTET, A. Mediating and commissioning objects in the sociotechnical process of product design: a conceptual approach. In *Designs, Networks and Strategies*, V. D. MACLEAN (Donald), SAVIOTTI (Paolo), Ed., COST A3 Social Sciences, vol. 2, Bruxelles. Directorate General Science, R&D, 1995, pp. 111–129.