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Virtual Reality as a Support Tool for Ergonomic-Style Convergence

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Abstract

The competitive industrial context compels companies to speed-up every new product design. In order to keep designing products that meet the needs of the end user, a human centered concurrent product design methodology has been proposed. Its setting up is complicated by the difficulties of collaboration between experts involved in the design process. In order to ease this collaboration, we propose the use of virtual reality as an intermediate design representation in the form of light and specialized immersive convergence support applications. In this paper, we present the As Soon As Possible (ASAP) methodology making possible the development of these tools while ensuring their usefulness and usability. The relevance of this approach is validated by an industrial use case through the design of an ergonomic-style convergence support tool.

Keywords: Design Engineering; Product Design; Multidisciplinary Convergence; Virtual Reality

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1 Introduction

Companies are currently confronted with a very competitive industrial context. In order to cope with this situation, every product development must be at the same time more rapid, technologically satisfactory and less expensive. As a result of these constraints, companies tend to underestimate aspects such as human factors' integration, and many current products have not been designed to fulfill the end user expectations [Nor04].

In order to help companies to consider human factors in their product development cycle, while achieving competitiveness, a human centered, collaborative and concurrent product design methodology has been developed by Mahdjoub et al. [MBWJC08]. The designed products can be manufactured products as well as workstations. This methodology is based on a cross-disciplinary synchronous approach [Pra96], and is centered on the collaboration and concurrent work of three main players: industrial stylists, human factor experts and mechanical engineers. Their collaboration allows the introduction of the human factor from the upstream phases of the product development cycle (see Figure 1).

This collaboration between different experts can be quite difficult. Indeed, each one of them employs its own methods, tools, and a specific vocabulary [Kva00]. In order to overcome these communication problems, Intermediate Design Representations (IDR) are usually used to translate information that needs to be shared and understood by all involved players [BB03, VJ95]. These representations usually come as drafts, digital mock-ups, physical prototypes, etc.

They are used during convergence phases when designers need to define a compromise, acceptable by all, regarding the evolution of the future product [Ull03].

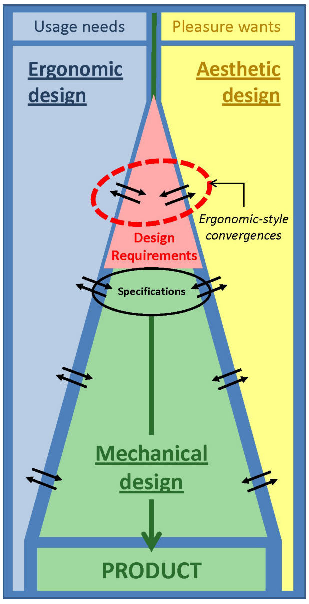

Figure 1: Human centered, concurrent and collaborative product design methodology from Guerlesquin et al. [GMBS12]

Virtual Reality (VR) can be a relevant prop to handle IDR [GMBS12]. Indeed, immersive technologies allow the immersed user to ”be here” and thus interact with the virtual prototype in an intuitive manner, independently from his or her domain of expertise. During regular design reviews, mechanical engineers traditionally use representations such as cross-section view or layout drawings. These representations provide a codified view of the virtual prototype that cannot be fully understood by other ares of expertise such as industrial designers or human factor experts. VR provides a non-codified illustration of the future product, making all exchanged information understandable by all.

Nowadays, in the industry, VR is mainly used as a decision making tool and as design review support [MFS04]. For instance, VR can be used to decide which early design proposition to develop among all those suggested by the industrial designer. 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 [MFS04].

Despite its proven contribution regarding costs and delays in the product design process [SIW10], VR is still not fully accepted by designers. We conducted a survey within the VR departments of ten major French manufacturing companies in order to identify brakes on VR acceptance. The results show that the most important brakes are the low availability of immersive systems, the bulkiness of interaction devices, and long development delays of an immersive application. Moreover, in most cases, a few broad immersive applications are applied to a wide variety of product design projects: design reviews are forced to adapt to these applications, and not vice-versa as it should ideally be. Therefore, the more diverse designed products are, the less immersive applications are suitable. We tried to address those brakes through the implementation of quickly developed and easy-to-use project-specific tools. In order to pursue the integration and acceptance of VR technologies within industrial product development cycles, several axes can be followed.

The first axis is to position VR at the center of product design process by providing a common tool to all involved professions such as immersive modeling environments. The one presented by Fiorentino et al. in [FdAMS02], allow designers to create shapes directly within the 3D space. Another example is VR-CAD environments such as the Virtual Reality Aided Design (VRAD) demonstrator presented by Bourdot et al. [BCP$^+$10] which provides an immersive and multimodal user interface allowing the creation of curves, surfaces and solids. But, existing immersive modeling environments are still lacking of advanced functionalities and accuracy compared to standard Computer Aided Design (CAD) software, which are now commonly used in the industry. Another technical solution is to link existing CAD environments to immersive platforms [SIW10]. However, there is still a technical gap limiting the integration of VR environments in the Product Lifecycle Management (PLM) : data processing. Indeed, due to the constraints of real-time rendering, CAD data must be converted and optimized to be suitable for use in VR. During this process, CAD files must often be degraded and data is lost, which prevent the reintegration of modified VR files into the PLM workflow. As stated by Kim and Weissmann [KW06], the data exchange between CAD and VR systems is recognized as a fundamental element for the full integration of immersive modelling environments, and VR, in the PLM. Some solutions have been introduced

[SKW$^+$06, MPF09, CM13], but are not yet industrialized.

The second axis is to consider VR as an IDR. This approach will be the one adopted in the present study. VR is here considered as a support tool for multidisciplinary convergence. The purpose of this approach is to graft VR on already existing product design processes. The integration of VR will occur 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. Furthermore, in order to enhance the acceptability of VR, this approach aims to address each acceptance brakes identified above. It implies the development of single-use and specialized immersive applications that will adapt to the type of product being designed, while evolving jointly with the status of the design project. In order to comply with these constraints, we propose the ASAP methodology (As Soon As Possible) enabling the development of such immersive applications . In this methodology, despite the induced sustained development pace, a particular attention will be paid to the usability of these immersive applications through the use of Imported Behavioral Schema (see Section 2.3.3).

In this paper, we will present the ASAP methodology and its contributions to the integration of VR technologies within industrial product design processes. We will then demonstrate the feasibility of this concept through an industrial use case: the ASAP methodology applied to a multidisciplinary concurrent and collaborative industrial product design project : the design of an ergonomic electronic cards test bed.

2 The ASAP Methodology

The ASAP methodology is an attempt 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. It aims to adapt the use of VR resources to the needs of multidisciplinary, collaborative and concurrent product design projects.

Existing techniques for VR application design, such as the one presented by Kim [Kim05], follow a techno-centered approach focused on the optimization of software performances. They usually only define a set of standard interaction techniques [BKLP04] but do not provide guidelines to define new ones. A human-centric VR application design approach has been proposed by Fuchs et al. [FMG11]. This approach is focused on the usability and naturalness of the interaction through the use of mental models, but the guidelines provided have been defined in order to design complex or stand alone immersive applications.

The ASAP methodology address the limits of these approaches by combining a human-centric approach with a development workflow specifically dedicated to the implementation of light and specialized immersive applications exactly matching the user's requirements of each product design project. The constraint induced by this context of application implies a sustained application development pace. Thus, in order to make this development process feasible, a combination of existing software, HCI and VR design techniques [BKLP04, FMG11, Tid10] has been defined in order to optimize development delays while ensuring usefulness and usability of immersive applications.

This methodology and its associated framework follow a top-down design strategy. In order to precisely meet the needs of an industrial use, we first defined an overview of the general shape of the ASAP methodology. We then refined this general overview through the implementation of various immersive convergence support tools such as the one presented in [BBS10].

In the following paragraphs, we will first present an overview of the ASAP methodology and its associated framework. Then, we will present in further details the two main phases of the methodology, and each of their components.

2.1 ASAP Framework and Overview

The ASAP methodology is divided into two distinct phases: a continuous phase and a punctual phase.

The continuous phase (see Figure 2), on one hand, is composed of three processes collecting macroscopic knowledge (i.e. non-specific to a design project) in a continuous way. This knowledge is then organized in a knowledge background database, aggregating a wide range of data about the work environment in which the ASAP methodology is implemented.

The punctual phase (see Figure 3), on the other hand, is only triggered when a new collaborative and concurrent product design project is started. This

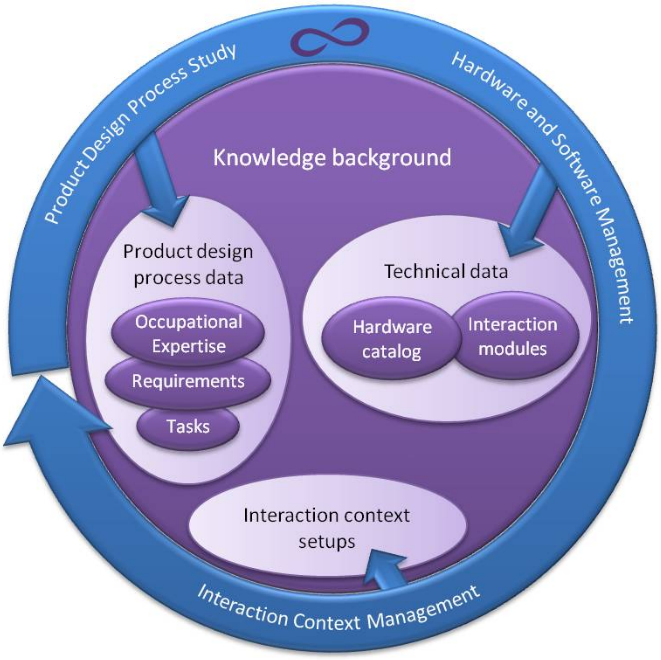

Figure 2: ASAP continuous & macroscopic phase

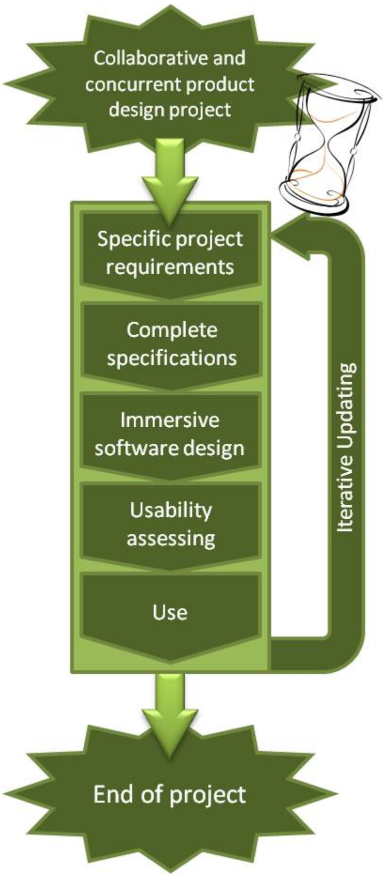

Figure 3: ASAP punctual & microscopic phase

phase is meant to be iteratively carried out with the progress of this product design project. It collects microscopic-scoped knowledge on specific convergence phases of a specific product design project. This microscopic knowledge used jointly with the knowledge background will allow providing a specialized and project-specific immersive convergence support tool.

Both ASAP phases are linked to each other and exchange information: for example, tools developed within the punctual phase strongly rely on knowledge compiled within the continuous phase. Conversely, these same tools will be processed *a posteriori* within the continuous phase in order to capitalize the new developments.

2.2 Macroscopic & Continuous Part

This phase is activated in a continuous way, as a background set of tasks to carry out during the spare time between projects. This phase will be predominant at the beginning of the setting up of the ASAP methodology, but will quickly become a simple information management process with the multiplication of supported product design projects.

As depicted in Figure 2, the central knowledge background is filled by three continuous peripheral processes that we will detail in the next sections: hardware & software management, interaction context management and product design process study.

2.2.1 Hardware and Software Management

The hardware and software management process classify hardware resources into a hardware catalog and capitalize reusable previous developments into an Interaction Modules library.

Regarding hardware resources, the human-centric VR application design approach presented by Fuchs et al. in [FMG11] recommends acquiring interaction devices according to the interaction metaphor. In an industrial environment this recommendation is not suitable in terms of costs and delays. We recommend choosing the interaction devices that match the best with the main interaction metaphors among the available interaction devices. To ease this choice, each available interaction device is classified into a hardware catalog according to a set of criteria defined by the VR development team:

- Type : sensorial (input), motor (output) or sensori-motor (input/output) interfaces as defined by Fuchs et al. in [FMG11]
- Sensors : number, type, degrees of freedom, accuracy, etc.
- Body parts : one hand, both hands, full body, etc.
- etc.

Each of these interaction devices can be linked with one or more Interaction Modules. These modules should allow an efficient reuse of previous developments in the form of autonomous elements that can be linked with any interactive scene, in any immersive convergence support tool. The concept of Interaction Modules, inspired from Object Oriented Programming, will be detailed later in this paper (see Section 2.3.3).

Therefore, when an immersive convergence support tool required the development of a new type of interaction, this development is processed afterwards (i.e. during inter-project time) in this software management process. The new behavioral interaction is untied from the previous immersive application and encapsulated into a new Interaction Module, ready to be deployed into any new immersive application.

2.2.2 Interaction Context Management

The interaction context management organizes the interaction context surrounding the immersive platform in order to sustain the effectiveness of the discussion [Ste72].

Indeed, an immersive tool is not always the most efficient answer to a specific requirement [SIW10]. In this case a real life prop is provided (such as a drawing board for quick drafts). Furthermore, most of the immersive platforms only bear one immersed user. In order to sustain the group dynamic, this immersed user must be able to exchange with the other (non-immersed) participants of the design review.

Therefore, the interaction context should be cleverly organized according to the number of participants involved in the design review and the status of the product design process.

2.2.3 Product Design Process Study

The product design process study aggregates knowledge related to experts' working habits likely to use VR technologies within the product design process.

This knowledge is related to experts' occupational expertise, their usual requirements and the tasks carried out for a specific step in the product design process. It is gathered using traditional HCI techniques [Tid10] such as observations of traditional design reviews during convergence phases and experts' interviews in order to pre-identify implicit requirements (i.e. basic or non-verbalized requirements). Observations are focused on the techniques, intermediate design representations, or collaborative tools in use to share information between different area of expertise (CAD software, stereoscopic screens, etc.). Interviews are focused on personal experiences of the interviewees regarding multidisciplinary interactions and their associated difficulties. The analysis of traditional solutions used by designers to solve multidisciplinary interaction problems can provide a set of implicit requirements.

The gathered knowledge plays a part in the optimization of development delays. Indeed, in major manufacturing companies, even if individuals product design projects can be focused on a large variety of products' types (mass market product, workstations, etc.), the product design process followed by product design teams is usually the same. A knowledge background based on the study of this cycle allows pre-identifying product designers' basic requirements functions of their domain of expertise and the product design process' status. These basic macroscopic-scoped requirements allow immersive software designers to optimize the time needed to obtain the complete specification of an immersive convergence support tool (see Section 2.3.3).

Product design process study also helps enhancing the acceptance of immersive tools. Indeed, it allows immersive software developers to identify implicit requirements, and so ensure the usefulness of the proposed tools for each area of expertise involved in the convergence phase.

2.2.4 Knowledge Background

As depicted in Figure 2, the three continuous processes presented above fill a central knowledge background database. This database is divided into three main components: product design process data, technical data and interaction context setups.

This knowledge background database will optimize development delays and maximize the usefulness of immersive support tools to be developed by:

- Pre-identifying basic requirements for the development of new immersive applications;
- Keeping up to date the previously developed Interaction Modules library, and the related interaction devices catalog;
- Encouraging the cohesion between the immersed user and the other participants of the design review.

The efficiency of the ASAP methodology is based on the synergy of the continuous phase, aggregating macroscopic knowledge in a knowledge background, with a punctual phase, triggered with every product design project, allowing to produce a project-specific immersive tool. The design and development process of such a tool will be detailed in the following paragraphs.

2.3 Microscopic & Punctual Part

In opposition to the continuous phase, the punctual phase is triggered by the beginning of a new product design project. Indeed, even if the convergence phases associated with the product design process are usually similar, every new project brings up specific requirements, and discards other ones. This phase provides a more microscopic point of view on the product design project, complementing the macroscopic view given by the continuous phase.

This phase combines the traditional waterfall model of software development [Roy87] with Object Oriented Programming applied to the management of previous developments [Lar04] in terms of interaction. The punctual phase is iteratively executed alongside the progress of the product design process. Thus, immersive convergence support tools can be updated to evolve simultaneously with product designers' expectations.

In the following paragraph, we will detail the five steps of the ASAP punctual phase leading to the development and implementation of an immersive convergence support tool:

- Identification of project-specific requirements;
- Drawing up of the complete specification;
- Design and development of the immersive software;

- Usability assessment;
- Use and iterative update.

2.3.1 Project-Specific Requirements

Immersive systems are in majority deployed within major industrial groups that can produce a variety of very different products: from workstations to everyday objects. Therefore, specific project requirements must be determined in order to ensure the usefulness of immersive convergence support tools.

For the first iteration, the main issues of the starting project must be determined by immersive application developers through semi-directed experts' interviews conducted during the initial design reviews [Tid10].

For all the following iterations, the evolution of projects-specific requirements will be determined by immersive application developers through observations conducted during the use of the immersive tool's previous iteration (See Section 2.3.5).

2.3.2 Complete Specification

In order to maximize the acceptance of immersive support tools by designers, once the specific projects requirements are identified, they can be enriched by basic and implicit requirements, resulting from the macroscopic knowledge background. This set of requirements constitutes the complete specification of the immersive convergence support tool.

Afterwards, the requirements for which an immersive solution would be too complex to implement within the time span or not suitable in terms of accuracy are withdrawn from the software development process. A real life solution is then implemented within the interaction context to satisfy the withdrawn requirements. For example, if an additional result from a computational fluid dynamics software is needed, this software can be set up on a traditional computer near the immersive platform.

Then, in order to better prepare the immersive software design phase, the main requirements (i.e. those which will be most frequently used) should be identified.

2.3.3 Immersive Software Design

The main requirements identified in the previous step are the requirements for which natural interaction is required. Therefore, in order to transform them into usable immersive functionalities, the $3I^2$ behavioral interfacing, presented by Fuchs et al. in [FMG11], is used.

It aims at maximizing the user's immersion by providing a natural behavioral interfacing. Briefly, each task is associated with an interaction metaphor called an Imported Behavioral Schema (IBS). IBS are behavioral schemas adapted from user's habits into the virtual world: for the opening of a door, for example, the most natural IBS it to grab the door's handle. The next step is to associate each of these IBS with the most appropriate input device among the ones classified in the hardware catalog. Finally, the user's actions must be correctly mapped on this input device to accurately reflect the chosen IBS. An IBS can be completed by one or more Behavioral Software Aid (BSA). These BSA will help the user to effectively use the devices to achieve the IBS interaction.

The ASAP methodology implies the development of a new application for each convergence phase, for each product design project. Thus, it induces a sustained development pace. In order to be technically feasible, the ASAP methodology relies of the re-use of previous developments. The encapsulation and re-use of previous developments is a common practice in Object Oriented Programming with the use of generic model classes [Lar04]. Interaction Modules (IM) encapsulate an element of behavioral interfacing. As presented above, this type of interfacing calls upon interaction metaphors or IBS to provide natural interaction for a specific functionality. An interaction metaphor is not only linked with a mental representation, but also with an user's action and a system's response. Thus, an IM encapsulate the complete modeling of an interaction metaphor:

- User's action : management of various input devices, and the associated coding of the gesture, or sequence of gestures, to be detected (the detection of a specific hand pose thanks to a data glove for example);
- System's response: management of various output devices and the coding of the system's response through several types of feedbacks (auditory, visual, haptic, etc.);
- Embedded entities, to represent the interaction metaphor (ray, 3D widget, etc.);
- Optional Behavioral Software Aid(s) (BSA) in order to ease the user's task.

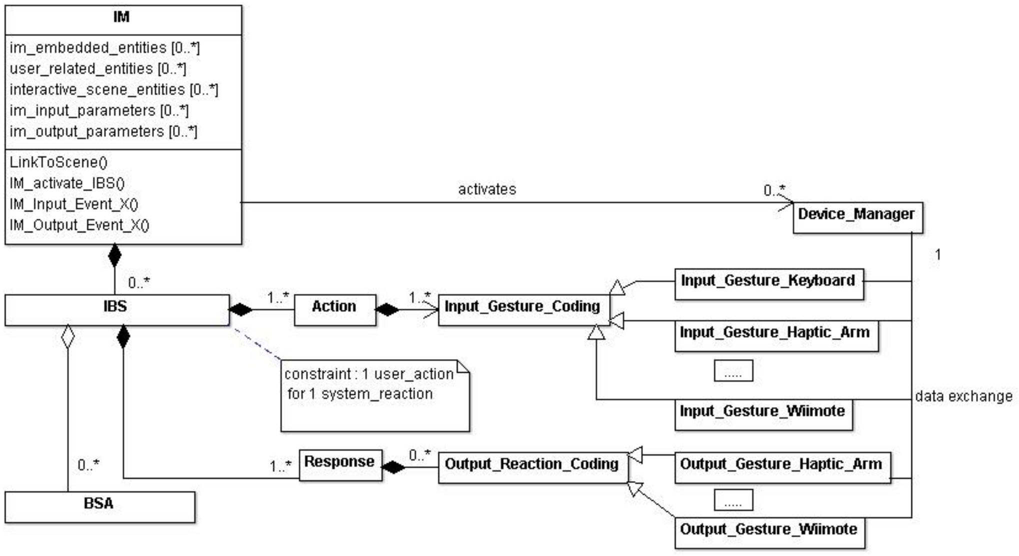

Figure 4: UML class diagram for the internal structure of Interaction Modules

The corresponding IM's internal structure is described in Figure 4 under the formalism of a United Modeling Language [Obj14] class diagram.

When needed to integrate an IM into a new scene, immersive software developers must link it with the new scene so that it can have an effect on the entities of the interactive scene (See Figure 5). Every IM comes with a complete documentation which allows the software developer to know which entities should be linked with the module, such as interactive entities from the scene or user related entities (avatar, or entities that represent the user). It also let the developer defines which interaction device(s) will be used.

Once linked with an interactive scene, an IM will let the immersed user perform his or her task by interacting naturally with the immersive scene. The IM will handle the detection of the user's action. This action can be a signal from the interaction device, or an action of the user on the interactive entities of the scene. For every action the IM returns a response. This response can affect the interactive objects of the scene, or the interaction device. If a BSA is defined, it can affect the interactive scene or the management of data from the interaction device.

In order to optimize the development cycle, before starting to implement a new functionality, developers have to check, in the library of Interaction Modules (previous developments), if what they need has not yet been developed.

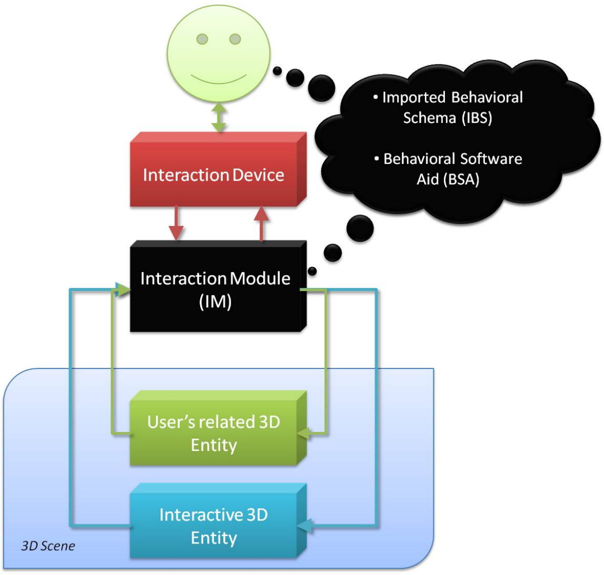

Figure 5: Integration of an Interaction Module to an immersive application

In the case of a suitable IM which is not yet compatible with the chosen interaction device, a new mapping of the encapsulated IBS can be added by immersive application developers in consultation with the usability expert.

Once behavioral interfacing is set up for the main requirements, immersive application developers can map the remaining requirements (i.e. those which will be less frequently used) on the available buttons, commands or gestures of already used interaction devices. We made this choice in order to limit the number of interaction devices, and so maximize the acceptance of the immersive convergence support tool [SMK98]. Moreover, less interaction devices should reduce the loss of time induced by the time needed to equip the immersed user. Therefore, the participants of the design review will be prone to frequently change of immersed user. This mapping will then be validated in the usability assessing step.

2.3.4 Usability Assessment

When the immersive convergence support tool is functional, two usability assessment steps must be carried out before the first use.

The first one is based on a large set of usability guidelines [BKLP04, Kau98, SMK98, BS03], each one being classified by a theme and a scope in order to provide a usability check-list to the immersive application designers :

- Theme:
    - User's task;
    - Learning phase;
    - Environment;
    - Interaction context;
    - etc.
- Scope:
    - Interactive objects;
    - Autonomous elements;
    - Navigation;
    - Selection;
    - etc.
- Example :
    - Guideline - User's Task / Navigation : In order to reduce cybersickness, it is necessary to adapt the navigation metaphor to the user's task, from [SH98].
    - Example of application : if the user's task is to observe a virtual prototype, immersive application developers will replace the initial gaze directed navigation metaphor by a navigation metaphor centered on the virtual prototype in order to ease this observation task. This usability issue has thus been corrected at the development stage.

Following an approach similar to the MAUVE tool presented by Stanney et al. in [SMR00], we plan to extend the classification of usability guidelines in order to provide immersive application developers with the most adapted usability check-list functions of the type of immersive tool being developed. The dynamic creation of this usability check-list will be provided by a simple tool based on a usability guidelines database.

The second usability assessment is based on the intervention of a virtual environment usability expert. He or she has to identify more specific usability problems before the first real life use. This intervention is based on his or her expertise and on taxonomy of usability characteristics for virtual environments [Gab97]. If usability issues are identified, developers should correct them before the first use.

Thanks to this double usability assessment, and because new IMs are extracted from immersive tools that were validated as regards to usability, the re-use of extracted IMs optimize future developments by reducing the amount of usability issues to correct.

2.3.5 Use and Iterative Updating

Once the immersive convergence support tool has been validated, it can be used within the next convergence phase. The new perspective provided by immersive design reviews often leads to a progress of the product design process resulting in the evolution of user's requirements. These changes should be iteratively implemented for the next immersive convergence phase. This iterative process is carried out all along the product design process progress, until its last phases when a final physical prototype is usually needed to comfort the final decisions.

In order to demonstrate the feasibility of the ASAP methodology, and in order to identify the contribution of light and specialized immersive convergence support tools, we applied it to industrial product design project. This case study and its analysis is detailed in the following paragraphs.

3 Case Study: Design of an Electronic Cards Test Bed

The case study presented in this paper is an application of the ASAP methodology to an industrial product design project: the design of an ergonomic electronic cards test bed for a company specialized in the design and manufacturing of tests and measures systems to assess the validity of electronic cards. The specificity of this project was to point up the visual identity of workstation so that it could be visually associated with this company. This study was carried out during the early steps of a human centered collaborative methodology [GMBS12]. It involved the concurring work of an industrial stylist and a human factor expert. The position of the studied convergence phases regarding to the concurrent and collaborative product design process is materialized in Figure 1.

In order to ease the collaboration of these two areas of expertise we provided two immersive convergence support tools following the ASAP methodology. The second tool being the iterative evolution of the first one.

In the following paragraphs we will present how the ASAP methodology was applied. The first iteration involved the two ASAP phases (continuous and punctual), while the second iteration only involved the punctual phase of the ASAP methodology.

3.1 Early Ergonomic-Style Convergence Support Tool

The first convergence support tool has been developed to assist an early convergence step at the very beginning of the product design process. The aim of the studied convergence phase was to choose a pre-concept proposition among the ones proposed by the industrial designer according to ergonomic criteria and the aesthetic rendering at full size.

In order to describe the implementation of this early ergonomic-style convergence support tool, we will detail the application of the two ASAP methodology phases below.

3.1.1 ASAP Continuous Phase: Hardware & Software Management

The hardware set up associated with immersive design review is composed of:

- A visualization system in the form of a CAVE^{TM}type immersive VR platform [CNSD93] PREVERCOS (Figure 6) equipped with an active stereoscopic visualization system (two walls and a floor). 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 stereo audio system;
- A set of interaction devices: An optical tracking system (two hands and the user's head) and a Wiimote^{TM}.

Figure 6: The PREVERCOS platform

3.1.2 ASAP Continuous Phase: Interaction Context

Our interaction context for immersive design review is composed of:

- 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.

3.1.3 ASAP Continuous Phase: Product Design Process Study

Knowing the characteristics of the present convergence phase, we identified some implicit user's requirements using product design process data gathered in our knowledge background database during previous product design projects:

- **Precise sensory feedback of heights and accessibilities**: The human factor expert needs to be able to create a spatial framework between the position of his or her real hands and the virtual scene in order to be able to assess the heights and accessibilities of the virtual prototype;
- **Full size view of the design propositions**: the industrial designer needs to be able to obtain an accurate feedback of the bulk and volumes of the virtual prototype;
- **Non-distorted view of the immersed user's point of view** : Non-immersed participants obtain a distorted view of the virtual prototype from outside the CAVE^{TM}. In order to reinforce their interaction with the immersed user, a remote view of the immersed user's point of view should thus be provided
- **Move around the virtual prototype**: The navigation of the immersed user is center on the virtual prototype in order to maximize his or her immersion by giving him or her the impression to face a physical prototype;
- **Taking notes or freehand drawing of design solutions**.

3.1.4 ASAP Punctual Phase: Project-Specific Requirements

We also identified specific requirements thanks to early stage interviews with designers involved in the project:

- **Ability to mimic the operator gestures**: The human factor expert needs to be able to put himself or herself in the place of the future operator of the workstation. the real life sitting position in front of the virtual test bed;
- **Switch between design propositions**: Three pre-concepts have to be compared through a global switch function;
- **Neutral rendering of the different design propositions**: The industrial designer needs to obtain a neutral rendering of the pre-concepts in order to limit the influence of colors and materials and increase the focus on the shapes and volumes;
- **User controlled light to highlight specific shapes**: the industrial designer needs to be able to point up specific shapes and volumes in order to support his or her arguments.

3.1.5 ASAP Punctual Phase: Complete Specification

The merging of the macroscopic and project-specific requirements allowed defining the complete specification for the immersive convergence support tool:

- Move around the virtual prototype;
- Accurate feedback of the user's hands position;
- Switch between design propositions;
- Controllable virtual light.

The other requirements were intrinsically fulfilled by the immersive platform (full size view), or implemented as real life solutions in the interaction context:

- 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;
- A real seat collocated with the virtual seat on the immersive platform in order to provide and accurate simulation of the operator body posture;
- A meeting table allowing non-immersed users to discuss, freehand drawing and examine papers documents.

3.1.6 ASAP Punctual Phase: Immersive Software Design

In order to limit the time needed to equip the immersed user, we chose to use a Wiimote^{TM}as the main interaction device in addition to the optical tracking of the user. For each main requirement, we defined an interaction metaphor (or IBS). Following the ASAP methodology, we then identified previously implemented IM that could satisfy the specification requirements:

- Move Around IM : Table 1;
- Virtual Hands IM : Table 2;

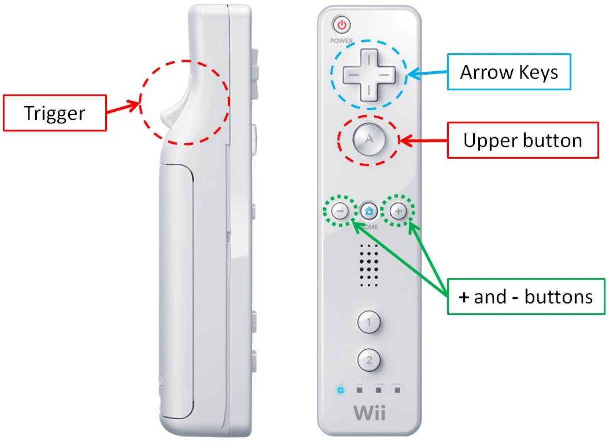

Figure 7: Wiimote$^{\text{TM}}$buttons designation

For the remaining main requirements: the switch and the neutral rendering, in the absence of suitable previously developments, specific interaction techniques were developed. These techniques were structured following the concept of Interaction Modules (Section 2.3.3 - Figure 4) in order to ease their extraction and re-use in future developments:

- Graspable Flashlight IM: see Table 3 and Figure 8;
- Model Switch IM: see Table 4.

3.1.7 ASAP Punctual Phase: Usability Assessment

During the first usability assessment step, an immersive application developer identified an usability issue corresponding to the following guideline: *the spatial organization of the virtual environment must appear natural to the user*. Indeed, the virtual prototype was displayed in a uniform virtual world with no boundaries. The natural environment for design review involving physical prototypes is a neutral showroom with controlled lighting. Thus, a virtual showroom was added to the virtual environment, providing a spacial framework, and boundaries.

Figure 8: Graspable flashlight Interaction Module

During the second usability assessment step, the virtual environment usability expert asked to add one more Behavioral Software Aid to the Graspable Flashligh IM (see Table 3) in the form of an automatic catching: the user no longer needs to pick the virtual lamp, this one automatically teleports itself into the user's hand.

3.1.8 ASAP Punctual Phase: Use and Iterative Updating

Once validated, the immersive convergence support tool was proposed during the industrial design review (see Figure 9). In order to adapt the immersive support tool to the progress of the product design process, and the evolution of user's requirements, the first user test was analyzed in order to identify new requirements for the next convergence phases.

3.2 Advanced Ergonomic-Style Convergence Support Tool

As detailed in section 3.1, the first version of the ergonomic-style convergence support tool allowed designers to choose a pre-concept that defined the direction of evolution for the following product design phases. The second version of the immersive tool was set up for the support of another convergence phase. Between the two convergence phases, the chosen pre-concept evolved in terms of aesthetics and ergonomics. The aim of this convergence phase was to discuss and validate the choices made by the

Move Around IM	
IBS	**Move around the prototype as if it was a physical prototype**. The user's movements will be centered on the virtual prototype
BSA	Reset command : resets the point of view in its original configuration (provides a reference point to the immersed user)

Table 1:

Virtual Hands IM	
IBS	**Touch or point out an element of the prototype**. Provides an accurate feedback of the user's hands position using virtual hands collocated with user's real hands.
BSA	Virtual hand's highlight: enhances the user's feedback by highlighting user's virtual hands when close to a predefined point of interest. Also, by pressing the trigger of the Wiimote$^{\text{TM}}$(see Figure 7), the user see his or her hand making the gesture of catching something in the virtual environment.

Table 2:

Graspable Flashlight IM	
IBS	**Grasp a flashlight and light something**. The immersed user catch the virtual flashlight and while the user's hand remains closed, the virtual flashlight follows its position. The grasp gesture is materialized by the use of the Wiimote$^{\text{TM}}$trigger to activate the function (see Figure 7).
BSA	The enlightened objects are rendered in gray levels in order to limit the influence of colors and materials while increasing the focus on the shapes and volumes. The visual aspect of shapes and volumes being enhanced with ambient occlusion.

Table 3:

Model Switch IM	
IBS	**Choose a proposition on a rotating display case**. The immersed user rotates the display case to alternatively display each pre-concept proposition. The rotation of the display case is activated using the '+' or '-' Wiimote$^{\text{TM}}$button (see Figure 7).
BSA	In order to reinforce the interaction metaphors, the pre-concepts appear and disappear as if they were disposed on a rotating display case.

Table 4:

Figure 9: Early ergonomic-style convergence support tool

industrial designer (corrections of the general shape and details) and by the human factor expert (morphological adaptability of the workstation, adjustments and validation with regards to ergonomic standards).

This second tool being the iterative evolution of the first one, its design only involved the punctual phase of the ASAP Methodology. This iterative evolution process is detailed hereafter.

3.2.1 ASAP Punctual Phase: Project-Specific Requirements

For the advanced ergonomic-style convergence support tool, we identified new project-specific requirements using the results of the early convergence support tool's study, and additional interviews with designers:

- **Assessing virtual dimensions**: Assessment of the heights influencing the accessibility for the operator;
- **Collision feedback for occulting limbs**: Detection of collisions between the workstation and the knees of the user. Indeed, for the immersed user, the occulting limb is always superimposed with the virtual environment. This fact making it impossible for the immersed user to obtain an accurate feedback of the position of the occulting in relation to the virtual prototype ;
- **Assessment of virtual workstation predefined settings**: Assessment of the predefined height settings proposed by the human factor expert for the height of the working zone.

However, some functionalities implemented in the previous interaction of the convergence support tool were no longer useful regarding the aims of the supported convergence phase. The neutral rendering, and the switch between design propositions were discarded.

3.2.2 ASAP Punctual Phase: Immersive Software Design

The development of this advanced ergonomic-style convergence support tool induced the development of new Interaction Modules (as no suitable previous development could be identified):

- Movable Height Gauge IM: See Table 5 and Figure 10;
- Occulting Limb Collision IM: See Table 6.

The switch between the predefined height settings proposed by the human factor expert for the height of the working zone was simply mapped onto the Wiimote$^{\text{TM}}$'+' and '-' buttons.

3.2.3 ASAP Punctual Phase: Usability Assessment

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. In the present case, the immersive support tool did not present major usability issue.

3.2.4 ASAP Punctual Phase: Use and Iterative Updating

The use of the advanced ergonomic-style convergence support tool (see Figure 11) by designers to a significant progress of the product design process' status. Indeed, the support tool allowed designers to make final decisions regarding 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:

- Graspable Flashlight IM;
- Model Switch IM;
- Movable Height Gauge IM;
- Occulting Limb Collision IM.

In order to identify the benefits brought by the use of these two immersive tools to the progress of the product design process, we conducted interviews with the involved designers a short time after the last immersive review session. The procedure followed to carry out these interviews, as well as the qualitative results obtained are detailed in the next section.

Figure 11: Advanced ergonomic-style convergence support tool

3.3 Ergonomic-Style Convergence Support Tools Qualitative Results

Shortly after the two immersive design reviews, qualitative feedback was gathered through semi-structured interviews of the involved designers. A semi-structured interview sets up a general structure: the interviewer decides in advance the ground to be covered and the main questions to be asked. The detailed structure is left to be worked out during the interview. Thus, the interviewee has a fair degree of freedom in what to talk about, how much to say, and how to express it [Dre95].

3.3.1 Semi-Structured Interview

The predefined framework of the semi-structured interview was composed of 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

Movable Height Gauge IM	
IBS	**Catch a height gauge and measure**. The catching gesture is implemented using the Wiimote^{TM}trigger, as before, but it is specialized by the upper button (see Figure 7).
BSA	In order to ease the use of the height gauge, it is linked with the ground, and so movable only alongside two dimensions. As for the usability updated version of the graspable flashlight, the height gauge teleports itself in the user's hand.

Table 5:

Occulting Limb Collision IM	
IBS	**Natural interaction between occulting limbs and occulted 3D objects**. The detection of a collision between an occulting limb (like the user's knee for example) is detected using an optical tracking target place on the user's knee. Sensorial feedback is provided in the form of an auditory feedback (clicking sound) when a collision is detected
BSA	In order to help the user know the origin of the collision a squared red shape is screened on the collision point and oriented according to the normal vector of the collision spot.

Table 6:

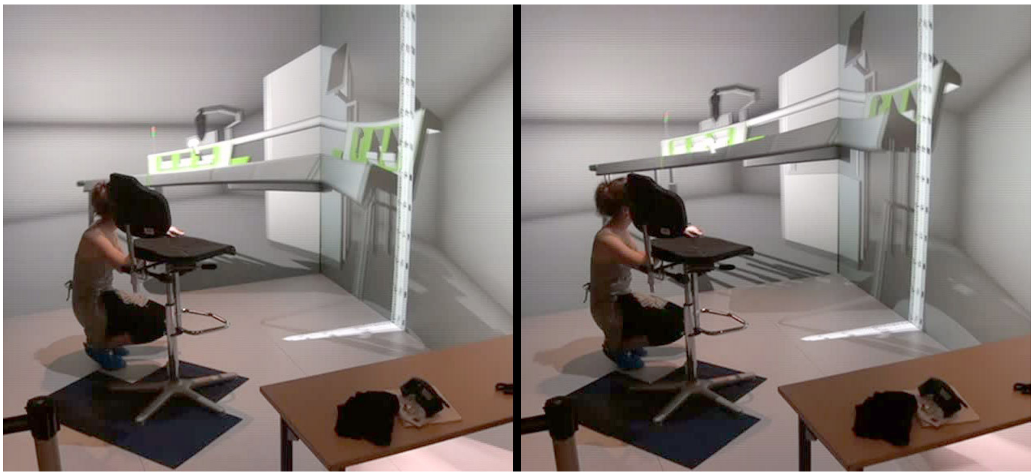

Figure 10: Height gauge Interaction Module

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?

3.3.2 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.

3.3.3 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.

To sum up, the integration of two immersive convergence support tool designed following the ASAP methodology allowed:

- Saving the expensive and time consuming realization of full-scale mock-ups;

- Avoiding a major design error that could have led to a major extension of project' costs and delays;

- Making final decisions regarding the evolution of the future product. The important fact being that these decisions were valid until the realization of the first physical prototype.

Finally, the use of VR technologies did not affected the pace of the project, and designers have shown a positive feedback regarding this experiment. From a qualitative point of view, it seems that the ASAP methodology enabled to maximize the acceptance of VR through the development of light and specialized immersive convergence support tools, while ensuring their usefulness and usability.

4 Conclusion and Further Works

The use of VR as a support tool for multidisciplinary product design convergence phases implies the implementation of numerous light and specialized immersive tools to support multidisciplinary convergence. The key point of this approach is to maximize the acceptance of VR technologies by product designers. This is done by providing useful and usable immersive convergence support tools, as soon as possible.

To sum-up, the As Soon As Possible (ASAP) methodology presented in the present paper enables the rapid development of useful and usable immersive convergence support tools thanks to a combination of existing software, HCI and VR design techniques [BKLP04, FMG11, Tid10]. The efficiency of the ASAP methodology is based on the synergy of a continuous phase, aggregating macroscopic knowledge (reusable in all projects) with a punctual phase, triggered with every product design project, producing a project specific immersive tool.

Moreover, the ASAP methodology ensures the usefulness of the developed tools through the completion of general requirements by project specific requirements so that they induce a better contribution to the progress of the product design process. An iterative updating of the convergence support tool allows ensuring its usefulness all along the product design process. In the same way, the usability of the developed tools is ensured by a double usability. Furthermore, the reuse of previous developments that were validated as regards to usability, in the form of Interaction Modules enables providing a natural interaction [FMG11] while optimizing the development process.

The case study presented in this paper has allowed us to demonstrate the relevance of the use of VR as an Intermediate Design Representation. Indeed, the developed tools 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 during early design phases. 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.

The results presented in this study are qualitative results. Our future work will thus focus on the quantification of our IM based approach (in terms of costs and benefits). Towards this end, we intend to compare the ASAP development process with traditional immersive software development process for the support of a set of very different product design processes. We also plan to identify some classification criteria in order to ease the selection of available IM among the IM database.

Finally, in order to strengthen the links between the ASAP methodology and the industrial constraints, it should be deployed for the support of numerous industrial product design processes so that we can precisely define all the necessary tools associated with each phase and step of the ASAP methodology. Finally, we will test the robustness of the ASAP methodology by developing numerous immersive convergence support tools in a short period of time.

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