A global approach of the Intermediary object: A case study in virtual environment

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Abstract

In collaborative design process, Intermediary objects (IOs) are used as external representations and mediators that facilitate the social interactions between heterogeneous social worlds. However, the IOs are loosely defined and loosely structured. They are always viewed as just the product models and confused with the technologies and the tools used to support them. Other aspects of the IOs like the product use and the interaction with the IO are neglected during their definition.

The aim of this paper is to introduce the concept and the roles of IOs and to propose a framework to define a structure for these objects. This framework could be used as a base for designing and choosing the IOs in the context of multidisciplinary convergence about "product-use" couple. We believe that IO is such a system that contains several interdependent models. To clarify this framework, we present a convergence step between 3 actors (ergonomist, mechanical designer and industrial designer) about a vehicle's cockpit design using a virtual reality (VR) platform. The case study shows an interactive process to modify the virtual mock-up of the vehicle based on snapshot tool on the VR platform, a sketching pen tablet and a CAD system.

1 Introduction

We currently witness a growing interest of industrial companies in product use to introduce innovative products and to take competitive advantage in the market. It has become indispensable, calling for User-Centered Design (UCD) and more recently User Experience Design (UXD) approaches throughout the product design process. Indeed, the design of the product and its use (which we call the design of "product-use" couple) required collaboration among different actors (stakeholders) drawing from different disciplines (like ergonomists, sociologists, marketing responsible, users, mechanical designers, industrial designer, etc.) during the design process [1].

Collaborative design process is well understood as a series of divergence-convergence phases [2]. Indeed, most collaboration happens in the convergent phases which are considered as phases of exchanges and argumentation between various actors to arrive at shared viewpoint and satisfying joint decision based on collective rationality. However, the involved actors in the convergent phases have different viewpoints shaped by their experiences, aims and backgrounds making it difficult to carry out the convergence between them. To support convergent phases, Intermediary Objects (IOs) are used as external representations and mediators that facilitate the social interaction between heterogeneous social worlds [3]. However, IOs are just viewed as the product model (product's representation). Other aspects of the IOs like the product use and the interaction with these objects are neglected during the definition or the design of IOs according to the actors' needs. We assume that a global approach to structure these IOs will help the actors to better understand these objects and consequentially to better choosing and designing them.

Thus, the aim of the present paper is to investigate a global approach of the IOs for the convergence about "product-use" couple and to apply it in real industrial case study. The first section presents a literature review about multidisciplinary convergence and the co-designing process of the "product-use" couple. Moreover, the concept and the roles of the IOs will be presented as the center of the social interaction in the convergent phases. The second section introduces a proposed framework to define a structure of the IOs. More precisely, we define four interdependent key models in the IO: (a) Product Model; (b) Product Use Model; (c) Interaction Model; (d) Support tools Model. More attention was paid on the Product Use Model to emphasis the use aspect of the IO. A case study from vehicle design project for postmen is presented to clarify the proposed framework. More precisely, we present a convergent phase between three actors (ergonomist, mechanical designer and industrial designer) based on an interactive process to modify the virtual mock-up of the vehicle using three tools: a snapshot tool on a Virtual Reality platform, a sketching pen tablet and a CAD system.

2 Background

2.1 Co-designing process of the "Product-Use" Couple

To clarify the co-designing process of "product-use" couple, it might be necessary to define the product use. Indeed, there is no common definition of the product use by researchers. However, we believe that the product use is the result of interaction between three elements: the user, the product and the context in which the user interacts with the product and with his environment (social environment, physical environment, etc.). Indeed, the studies of the product use are ranging from safety and health aspects, to traditional usability aspects, to affective and user experience aspects. Moreover, in accordance with Vallette et al. [1], we adopt a multidisciplinary approach to product use's definition. So, product use is a common topic among different actors like physical ergonomist, cognitive ergonomist, sociologist, marketing responsible, designer, etc. This list of actors could also include the users themselves as experts of their experiences [4].

Cleary, the product use is defined throughout the design process. For instance, the use actions or the physical activities of users are defined in the design process [5]. Forlizzi et al. [6] speak about designing the user experience and how interaction design and product design achieve specific user experience goals. Desmet et al. [7] found that it was possible to design interaction devices with different personalities. Indeed, we are no longer simply just designing products for users [4], we design for experiencing, for emotions, for interacting, for serving, for use, etc. In other words, we are moving from the design of product to designing for people's purposes [4].

Thus, we consider that design process is a co-designing process of the "product-use" couple in which the definition of the product and the definition of its use are depending on each other. As a result, different actors drawing from a range of disciplines have to collaborate together during the design process to define the "product-use" couple. Indeed, this collaboration is mainly achieved during successive iterative convergent phases of the design process. In the next part, we present this collaborative work in the convergent phases.

2.2 Multidisciplinary convergence

Most innovation happens at boundaries between disciplines or specializations [8]. So, Carlile [9] indicted that working across boundaries is a key ingredient of competitive advantage.

Convergent phases represent occasions for this working across boundaries. They are considered as phases of exchange and argumentation between different actors in order to reach a shared viewpoint or a satisfying joint decision based on collective rationality [10]. During these phases, the actors transmit, communicate, propose, criticize and share ideas like they are in a kind of debate. Each actor has his/her own viewpoint based on his/her constraints, objectives and experiences [11]. This viewpoint has a dynamic nature. It evolves during convergent phases through social interactions and communications between actors [11].

The purpose of the convergent phases is to reach a shared viewpoint which leads to joint decision between the actors. Détienne et al. [12] defined the shared viewpoint as the representation constructed through the argumentation process of the team and it is shared among the actors whatever their discipline.

Since the product design process is viewed as co-designing process of the "product-use" couple, convergent phases are needed to fill the gap between the product design and the use design through social interaction between the different actors. We can use the representation of Carlile [9] in the organization theory to represent the gap between the product design and the use design (Fig. 1). For instance, Hassenzahal [13] demonstrated a model of user experience from a designer perspective and a user perspective. The intended product character by the designer doesn't necessarily match the apparent product character of the user. The user perceives the product's features in different way. In other words, the user constructs a personal version of the product character which might be different from the designer's version.

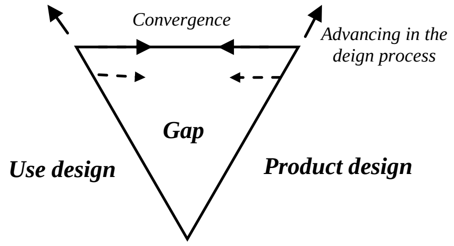

Fig. 1 Gap between product design and use design

To help the actors to fill this gap during the convergent phases, we believe that Intermediary Objects (IOs) are used as the center of the social interaction. They facilitate the externalization of the implicit individual viewpoints, argumentation and negotiation process between the involved actors. In the following section, the notion and the roles of the IOs are discussed in detail.

2.3 Intermediary Objects (IOs)

The concept of IO was first developed in sociology by Vinck et al. [14] during their works in actor-network theory. It appeared to refer to any object that circulates between members of a network. This concept was introduced later in the design studies like ethnography analysis of the design activities [15]. In this context, Boujut et al. [3] defined the IO as *"a general category embracing all types of artefacts, whether physical (plans, mock-ups, sketches, etc.) or virtual (CAD models, calculation results, etc.) produced by the participants during their work. In other words, it covers all kinds of externalisation".*

Three features of the IOs were defined, (a) mediation; (b) transformation or translation; (c) representation [16]. IOs transfer the intentions from one actor to another. Moreover, they support the social interactions and consequentially the construction of a compromise between the different actors. IOs are as indicators of transformation process of the product from one state to another state. They represent the whole or a part of the product identity. Furthermore, they represent the actors who created them by including their intentions, viewpoints, objectives and their ways of working or thinking [15]. Arias et al. [17] highlighted that external representations are especially important for collaborative design because they: (a) create a record of the mental efforts outside us rather than vaguely in memory; (b) represent artefacts that can talk back to us; (c) form the basis for critique and negotiation.

Boundary Object (BO) is another concept introduced by Star et al. [18] in sociology. These objects are located at the intersection between different heterogeneous social worlds and they maintain coherence across these worlds. Carlile [19] described the BOs as *"objects that are shared and sharable across different problem solving, contexts".* In accordance with Star et al. [18], he defined forth categories of the BO: (1) *repositories* (i.e., cost databases, CAD/CAM databases); (2) *standardized forms and methods* (i.e., standard for reporting findings); (3) *objects or models* (i.e., sketches, assembly drawings, mock-ups); (4) *maps of boundaries* (i.e., Gantt charts, process maps). In the context of participatory ergonomics, Broberg et al. [20] defined several characteristics of the BOs. For instance, they are objects-in-the making, built in affordance, flexible and malleable. Moreover, the context of using of these objects like the rules and instructions, the location and temporary learning space is highlighted.

However, the concept of IO is often confused with concept of the BO in the literatures. According to Boujut et al. [16], IOs act as BOs in the sense of Star et al. [18]. But IOs are also intermediate states of the product if we consider the objects as mediators translating and representing the future product. Vinck et al. [15] suggested that IOs could be BOs if they are equipped with a common structure between the actors. In this paper, we will adopt the concept of the IOs which constitute a large framework for analyzing the produced objects by the actors into product design process and used during the convergent phases.

2.4 Problematic and objectives

In the actual industrial context, dealing with and managing the IOs into product design process became a necessity for the industrial companies. This context which is characterized with unprecedented time pressure, highly competitive market and highly collaborative practices requires more interest to manage the IOs. Moreover, we witness increasing interest in co-design approaches making different stakeholders constructive participants into product design process, and no one is important than the others. Co-designing of the “product-use” couple is our domain of research, and the investigation of the IOs in this domain could be a way to innovate by the use value of the product.

The natures of the IOs are diverse. Consequently, the characteristics of and the needs for these objects are different. One IO could be good for one convergence situation, but bad for another convergence situation. For instance, a CAD drawing is good IO for the convergence between two mechanical designers, but it is useless for the convergence between a mechanical designer and an ergonomist. In other words, the choosing and the designing of the IOs are convergence situation depending. The problematic here is how we can choose and design the appropriate IOs for one convergence situation.

Hannah et al., [21] indicated the problem that designers need to understand the utility of different engineering representations. So, they investigated the difference between three types of engineering representations (sketches, CAD drawings and physical prototypes). Even though, the study was conducted on students from one discipline, it proved that the quality and the quantity of information about the product provided by the representations are different. Pei et al. [22] investigated shared representations among industrial designers and engineering designers into new product development process. To help the two disciplines to choose the appropriate shared representations, he developed a standardizing card system to provide information on the role and the significance of every design representation for both the industrial designers and the engineering designers throughout the product design process. This information was gathered through interviews with professional designers from both the two disciplines. However, the study of Pei et al. [22] was not based on a global approach of the IOs that includes the different aspects of these objects. Moreover, we cannot standardize all the IOs due to the multiple factors that affect their choosing like the product type, the participating actors (i.e., their experiences, preferences, familiarization with used technologies, etc.), the actors’ specific objectives in the convergence (i.e., evaluate some aspects of the product), cost, project context, etc. So, most of the time, we need to design the IOs depending on the convergence situation.

The IOs are often viewed as just external representations (i.e., product models) which represent the parts and the characteristics of the product. Other aspects of the IOs like the product’s use, the interaction with IOs are neglected during the designing and the choosing of these objects. Moreover, IOs are sometimes confused with technologies and the tools used to support them. For instance, a virtual mock-up is a representation of the product, while, the virtual reality is a technology to visualize and to interact with this representation of the product. Thus, to deal with this problem, we assume that a good choosing and designing of the IOs requires first a global approach to structure these objects. This approach should include all aspects of the IOs. Indeed, a lot of works have investigated the global roles and the global characteristics of the IOs into product design process. Moreover, the roles of specific IOs like sketches have been studied in detail. However, a few is known about the structure of IOs and managing these objects into product design process and especially in the convergent phases.

In the present paper, our objective is first to propose a global approach to structure the IOs in the context of multidisciplinary convergence about “product-use” couple and second to apply this approach in an industrial case study. This will be as a base for future work to manage the IOs and to better choosing and designing them. The next section develops the proposed approach.

3 A global approach of the Intermediary Objects (IOs)

Based on literature review and our practical experience from real design projects with industrial companies in our laboratory (SeT), we present in this section a global approach to structure the IOs for the convergence about “product-use” couple. Moreover, the proposed approach will be clarified by and applied in a real convergent phase in automotive design project.

In his paper to define the virtual prototype, Wang [23] indicated briefly that a complete virtual prototype should include three types of models: a 3D solid model, human-product interaction model and perspective test related model. However, we think it is necessary to propose a structure that could be applied for all the IOs and not just for the virtual prototype. The statement of Wang [23] could be a good starting point to develop and to detail our global approach to structure the IOs for the convergence about “product-use” couple.

We assume that an effective convergent phase should include a co-creation process of the IO. More precisely, we consider that IO is a common cadre of working for all the actors involved in the convergent phase. In accordance with Broberg [20], the IO is object in the making; it evolves during the convergent phases through the actions of the involved actors. So, it should involve elements of action and representations for all of actors. These appropriate elements of action and the representations will depend on the involved actors and their objectives in the convergent phases. In other words, it should be open objects for all the actors.

Based on the last discussion, we propose a structure of the IO for the convergence about the “product-use” couple that includes four interrelated models depending on each other (Fig.5):

3.1 Product Model

The product model consists of any representation of a part or the whole product's identity. The product's identity is defined by its parts, shape, interfaces, functions, mechanism, materials, characteristics, etc. The product's identity could be defined also as product's attributes or features referring to its important characteristics such as volume, mass, operating cost, etc.

Indeed, the natures of the Product Model are diverse (Physical, numerical, 2D, and 3D) (Fig.2). The Product Model could be represented simply by a text on paper (2D + physical) describing its different parts. It could be also represented by a sketch using a computer program (2D + numerical) or represented by numerical mock-up using CAD program (3D + numerical). Sometimes, the nature of the Product Model could be mixed like the mixed mock-up that contains physical and numerical elements at the same time.

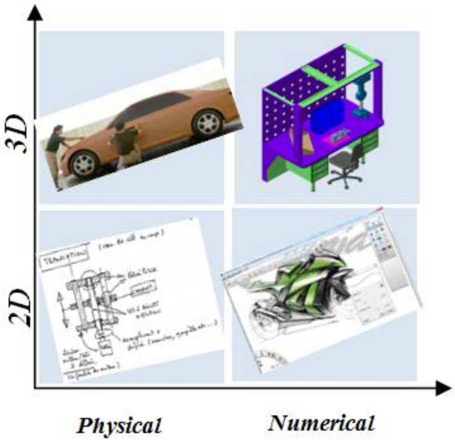

Fig.2 Cartography of the diverse natures of the Product Model with some examples

3.2 Product Use Model

For the convergence about the "product-use" couple, Product Model is not sufficient. Our hypothesis is that IO is a common cadre of working for all the actors involved in the convergent phases. So, IO has to represent also the product use during the convergent phases. For instance, CAD drawings represent just the product. The product use like user-product interaction is not represented.

More interestingly, Buchenau et al. [24] proposed the term *"Experience Prototype" "which means to emphasize the experiential aspect of whatever representations are needed to successfully (re)live or convey an experience with a product, space or system".* Moreover, to work effectively, it is necessary to construct a common viewpoint among the members of the design team about what they are trying to bring into being. The personal experiences of the designers and the users in using the product will give them more ability to understand the feelings and the problems of each other and of the other people who will be affected by their decisions. In accordance with Buchenau et al. [24], our objective is to emphasis the use aspect of the Product Model through the Product Use Model. Furthermore, this will help to arrive at a common viewpoint. We think it is necessary to detail the Product Use Model and its different components.

As we mentioned above, the product use is the result of interaction between three elements: the user, the product and the context in which the user interacts with the product and with his environment (social environment, physical environment, etc.). Thus, we defined three components for the Product Use Model which could be valid for customer products or industrial workstations:

- **Context of Use:** user-product interactions take place in a context of use, shaped by social, cultural and organizational behaviour patterns [6]. For example, cooking in a restaurant kitchen suggests different products, interactions than cooking in home kitchen. Krippendorf [25] suggested that "*Object is always seen in a context" and the meaning of an object is the sum of the total of its imaginable contexts.*
  From a marketing viewpoint, Green et al., [26] defined the context of use as all factors characterizing the application and environment in which a product is used and that may significantly impact costumer preferences for product attributes. They investigated the effects and the impact of the context of use upon customer's needs and product preferences. However, it might be necessary to investigate the effects and the impact of the context of use upon the product use; how it will affect the user-product interactions, the user experience with the product and the product's usability. The word context is most of the time related with the word environment. Context of use could include: physical environment (i.e., the natural features in the country, the buildings in the city, atmospheric or weather conditions, auditory environment, etc.), social environment or sociocultural environment (i.e., community of the users, habits, customs, etc.), organizational environment (i.e., regulation aspects, working in groups, management structure, etc.), etc. Sometimes, the problem is more complicated than understanding the actual context of use; it might be necessary to predict future context of use. Moreover, context of use evolves over the time, but some aspects change fast other change slow.
- **User:** The user is simply someone using the product. However, the looking at the user has been developed to a complex human being using the product in a special context. A representation of the user includes first his anthropometric characteristics, physical capacity and mental capacity. Moreover, it should represent, which it is the most difficult, the user's values, beliefs, personality, objectives, skills, needs, emotions, prior experiences. It should include how the user thinks, how he acts, and what he prefers, etc.
  What if we have a diverse audience of user? Cooper et al. [27] indicated that the best way to successfully accommodate a variety of users is to design for specific types of them with specific needs. Personas are as user models take the form of fictitious characters telling us how users behave, how they think, what they wish to accomplish, and why.
  A complete representation of user could be guaranteed by integrating the user himself into product design. However, other actors like ergonomists and psychologists may take the role of the user as representatives of his characteristics and needs.
- **User Activities:** Kanis [5] defined the user activities as sequences of: use action, perception, cognition, use action. Norman [28] proposed seven stages to interact with product (the world) (Fig.3). However, Norman indicated that this seven-stage process of action can be started at any point. For instance, you

may act to respond to the world without necessary constructing goals and intentions. Indeed, the elementary component of user activities is the actions which are the external, physical part of the user activities to activate the product functionalities [5]. For instance, actions could be touching, holding or moving a part of the product's interface. The user activities are described by tasks constructed of a goal and a prescribed sequence of actions. Different methods exist for modelling the task like Hierarchical Task Analysis (HTA) method [29], GOMS method [30].
The user activities do not just include the interactions between the user and the product, but they could include also the interaction between the user and his physical environment in the context of use.

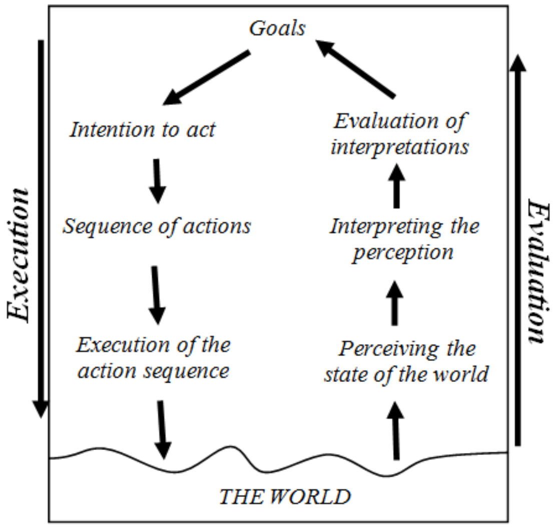

Fig. 3 the action cycle (Execution, Evaluation) [28]

When we study the Product Use Model, it is important to understand that: user-product interaction means that the product and the user will affect or act on each other. The user acts on the product by manipulating it or activating its functions using his physical forces. In other side, the product act on the user. The consequences on the user could be emotional consequences (e.g., pleasure, satisfaction, become upset, embracement, etc.), behavioral consequences (e.g., increased time spend with product, abandon the product, errors, etc.) and physical consequences (e.g. stress, fatigue, injuries, death, etc.).
As the Product Model, the Product Use Model with its different components could be represented in different natures (2D, 3D, physical, numerical) or (real, virtual) (Fig. 4). For instance, the Product Use Model could take the form of text describing its different components. It could take the form of a real simulation in the real world. Clearly, the nature of the Product Use Model might depend on the nature of the Product Model. If the Product Model is represented by 2D sketches, the context of use or the user activities could be represented also by 2D sketches. Moreover, depending on the convergent phases about "product-use" couple, the IO might be sometimes dominated by the Product Use Model or the Product Model. For instance, in the fuzzy front end of the design process where the product is not advanced in its definition, the Product Use Model will be dominant in the IO.

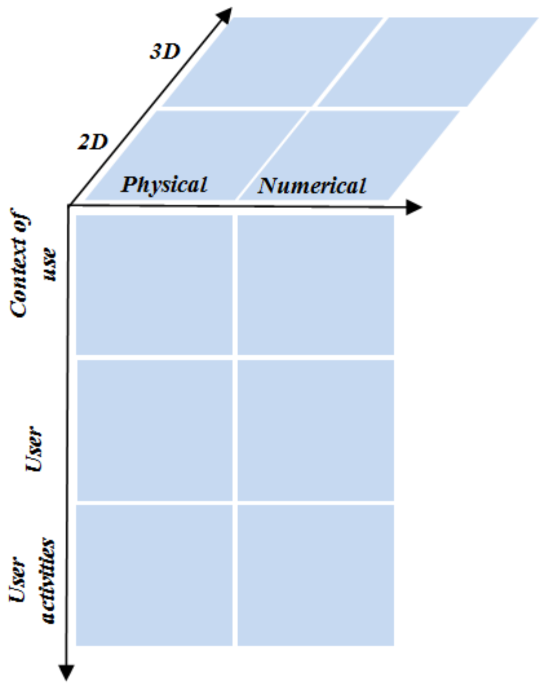

Fig.4 Cartography of the diverse natures of the Product Use Model

3.3 Interaction Model

The third model of the IO is the Interaction Model. We mean by the interaction here, the actors' interaction with the Product Model and the Product Use Model during the convergent phases. This interaction could be for several purposes:
Evaluation: the actors during the convergent phases need to evaluate the Product Model and the Product Use Model from their viewpoints and their objectives. This might require different evaluation interactions. For instance, to evaluate the Product Model, the designer may need to manipulate the Product Model, to rotate it, to visualize the interior mechanism, to measure some dimensions, to hide some parts, etc.
Modifying: as we mentioned above, the IO is object-in-making. It is not static. It is dynamic. It is changing with the actions of the actors during the convergent phases. Changing the IO is meaning here changing the Product Model or the Product Use Model. For instance, the actors may need changing some dimensions, changing the positions of some parts of the products, changing the sequences of the user's actions, etc.
Clearly, the Interaction Model depends on the nature of the Product Model and the Product Use Model. Moreover, it depends on the actors, their specific objectives. Sometimes, the interaction with IO needs some rules and instructions to guide the actors for good using of the IO.
The Interaction with IO could be done in 2D like sketching and annotating some drawings of the product, in 3D like manipulating a physical mock-up. Moreover, this interaction could be physical or numerical.

3.4 Support Tools Model

This model includes all the technologies and tools used to represent, visualize or interact with the IO. The examples are diverse here: virtual reality plateform, pen tablet, papers, computer, mouse, etc. They could also be programs like CAD programs, virtual reality simulation program, virtual human program, etc.

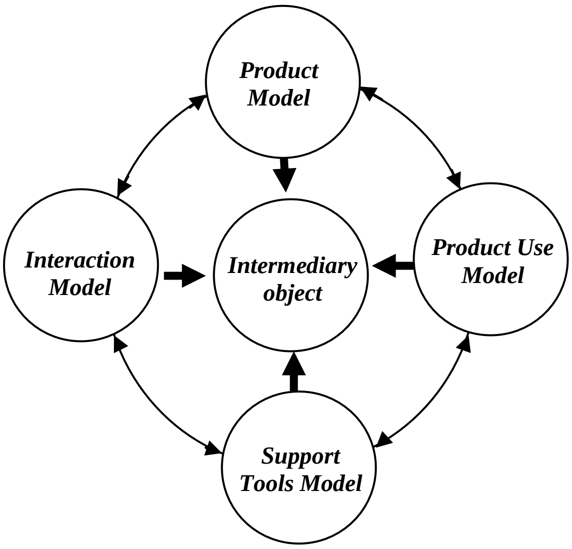

Fig.5 Approach global of the Intermediary Object

We defined four models of the IO for the convergence about "Product-Use" couple (Fig.5). Indeed, these models are interrelated and interdependent on each other. In other words, we consider the IO as a system of related models for a particular purpose which is helping the actors to collaborate together during convergent phases. Managing and designing the IO requires understanding the IO with all its aspects. Product Use Model was explained in detail in order to emphasis the use aspect of the Product Model.

In addition to the interdependence between the different models of the IO, they are also depending on several factors of the convergent phases. More precisely, they depend on: the involved actors in the convergent phases, the design process stages, the product type, the context of the project, the specific objectives of the actors, costs, etc.

The following section will present a case study to clarify and to apply our global approach of the IO. This case study represents convergent phase about "Product-Use" couple using the VR technology. It will also show us the importance of the IO during the convergent phases and its different roles.

4 Case study: Intermediary Object using Virtual Reality

4.1 Context of the Project

This case study represents a project review in an automotive design project (MobyPost). MobyPost is an ongoing project aims at developing a whole system combining a carbon neutral vehicle with a novel technology based on a solar hydrogen fuel cell system. It is conducted by nine partners; one of them is our laboratory (SeT). The objectives of our laboratory is to develop a vehicle for the post which has to be adapted to specific needs of the postmen (i.e. considering ergonomics and use aspects) with the respect to other aspect of the vehicle (i.e. considering mechanical and aesthetic aspects). Indeed, the use aspects play a critical role in the design of the current vehicle. For instance, one of the major constraints concerns the fact that postmen get in and get out of their vehicle about 350 times per day.

The project review presented in this paper is a synchronous (same time) and co-located (same location) convergent phase about "Product-Use" couple between three actors: mechanical designer, industrial designer and ergonomist. The objective was to arrive at a convergence between the involved actors about the vehicle's cockpit design and vehicle's front end design.

The project review was conducted using a Virtual Reality (VR) platform existing in our laboratory. In the next part, we present the different models of the IO used during the project to respond to the needs and the specific objectives of the different involved actors.

4.2 Procedure of the project review

We describe first the different models of the IO used during the project review. Indeed, the choice of these different models was depending principally on the involved actors' specific objectives.

The actors wanted a realistic representation of the vehicle's cockpit and the vehicle's front end in a real scale, permitting to them to arrive at a convergence. *The Product Model* was represented by the virtual mock-up of the vehicle which included the vehicle's cockpit and two versions of the vehicle's front end. Thanks to the VR technology and its stereoscopic vision, the actors could visualise the virtual mock-up in the real scale and in relief. Moreover, a physical seat was added as a part of *the Product Model* in the cockpit to enable the actors simulating *the Product Use Model.*

The Product Use Model was also represented in all its components in the virtual environment (VE). More precisely, it included the possibility to take the place of the postman on the physical seat, to simulate driving the vehicle, to simulate grasping the virtual envelope and putting it in the virtual mailboxes, to simulate getting out the vehicle. *The context of use* was represented in the VE by the two virtual mailboxes. One of the mailboxes (the right one) was chosen in the accessibility zone of the postman and the other (the left one) was chosen in the outside of the accessibility zone (Fig.7). The three actors, especially the ergonomist, could take the place of the user. When the actor touches the steering wheel and the mailboxes, his virtual hands change colours indicating that the actor is touching them. This is necessarily to give the actor a feedback due to the absence of the physical contact. Moreover, two virtual humans, one for the smallest woman and the other for the tallest man, could be located in the cockpit to represent anthropometric characteristics of the user. The real user was not integrated in this project review. However, the viewpoint of the user was represented by the ergonomist and the industrial designer. Indeed, the *Use Product Model* included also the user experience aspects like the personality of the vehicle (especially the vehicle's front end). In this case, the users are not just the postmen; they are also all the habitants in the city who will see the vehicle.

The Interaction Model consisted of the possibility to: 1) turn the VR mock-up and change its scale to check some details; 2) use a ray to indicate or to select some parts of the vehicle; 3) hide and display a virtual human in the vehicle, the reach zones and the vision zones; 4) change between the two versions of the vehicle's front end. Moreover, to act on and to modify *the Product Model* and the *Product Use Model*, the actors needed tools adapted to them. This could help the actors to better express their intentions and to explain their ideas and argumentations to other actors.

The fact of linking the VR technology with 2D sketching and annotating techniques could be a solution to act on *the Product Model* and *the Product Use Model*, and consequentially to improve the communication among the involved actors regardless their specialities. Indeed, sketching is viewed as an effective mean for the interpersonal communication [31]. Moreover, sketching is sometimes necessary for externalising the ambiguous mental images and the ideas of the actors. It also stimulates the actors' creativity and the ideas generation. Hisarciklilar et al. [32] indicated that annotations play an important synchronization role and participate in the design coordination and knowledge elicitation during synchronous phases. To link the VR technology with 2D sketching and annotating techniques, we developed in our laboratory a snapshot tool in the VE. This tool enables the actors to take snapshots of their viewpoints in the VE (Fig.8). A snapshot is 2D photo taken quickly in the VE. The taken snapshots are directly transferred on a sketching pen tablet. So, the actors could sketch on and annotate these snapshots to express their idea and intentions. Indeed, everybody can sketch and annotate, it is an intuitive way to express by all the actors (i.e., user, ergonomist, mechanical designer, industrial designer, etc). However, the quality of sketches achieved by some actors (i.e., industrial designer, mechanical designer) is better than other actors (i.e., user, ergonomist).

After communicating ideas and intentions by sketching on and annotating the taken snapshots, actors hope to see the proposed modifications and ideas on the virtual mock-up in the VE. To this end, we think that integrating a CAD system in this collaborative environment could be useful. Indeed, CAD system is a tool used only by the mechanical designer to create CAD models of the product. Integrating a CAD system in our collaborative environment can enable the mechanical designer to achieve quickly the light and small modifications and ideas of the actors during the project review. After that, the new CAD models of the product can be used directly to update virtual mock-up in the VE.

So, *the Interaction Model* included this interactive process to modify the virtual mock-up in the VE. This process is based on:

1) Linking the VR technology with 2D sketching and annotating techniques using snapshot tool on a VR platform and a sketching pen tablet which could be used by all the actors to improve their communication.

2) Modifications of CAD models of the product using a CAD system by the mechanical designer. Then, these new CAD models will be used directly to update the virtual mock-up in the VE.

Depending on the needs in *the Interaction Model*, the *Product Model* of the IO was changing its nature. First, *the Product Model* took the form of virtual mock-up. So, the actors could visualize and interact with it in VE. Second, the *Product Model* took the form of 2D snapshots on the sketching pen tablet. Thus, the actors could sketch on and annotate these snapshots. Third, *the Product Model* took the form of CAD models in the CAD system. So, the mechanical designer just could modify it.

The *Support tools Model* included all the tools and technologies to deal with *the Product Model, the Product Use Model and Interaction Model.* To this end, an Ethernet network was implemented between:

- A VR system which includes VR platform composed of 3 active stereoscopic screens (2.10m * 2.80m) (Fig.6-A). Images are displayed at 115 Hz with a 1400*1050 pixel resolution with Christie Mirage S+4K projectors (Fig.6-B). The stereoscopic images are generated by three graphic computers equipped with Nvidia Quadro FX 5600. The motion tracking is realized by an ART optical system which is composed of 6 cameras and numerous trackers for head, hands etc. To manipulate VR mock-up and to capture actor's viewpoint in VE as snapshots during project review, Wii (Nintendo®) Remote Controller is used. VR software (Virtools) is used to develop VR applications on the VR platform.
- A 2D sketching and annotating system which includes a sketching pen tablet (Fig.6-B). Autodesk SketchBook Designer software is used as user interface.
- A CAD system (Fig.6-C). More precisely, CATIA V5 software is used.

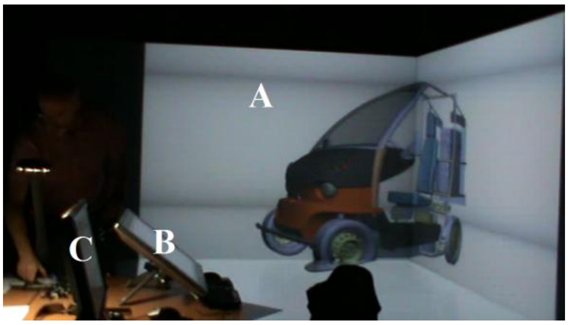

Fig. 6 Collaborative virtual environment: (A) VR platform (B) sketching pen tablet (C) CAD system.

The actors participating in the project review had some experience in working in the VE. However, a fast familiarization phase was conducted to explain to the actors the simulate Product Use Model, the different interactions in the Interaction Model and the modification process of the virtual mock-up. Moreover, a VR facilitator was in the disposal of the actors to help them when they had questions during the project review.

The project review was recorded by two video recorders; one was oriented towards the VR platform and the other was oriented towards the pen tablet and the CAD system. The participants in the study were then interviewed about the used IO after the project review.

4.3 Results

In this part, we present qualitative results based on the project review's observation and semi-structured interviews with the involved actors after the project review. During the project review, the different actors took the place of the postman. They simulated the delivering gests. The fig.7 shows that the ergonomist took the place of the postman in the vehicle and trying to touch the virtual mailbox.

The first impression of the actors about the simulation was very satisfying. The ergonomist said "Great!!! You are like in a real vehicle". The mechanical designer indicated that "When I see the VR mock-up on the platform, it gives me another vision of the vehicle than the CAD models". One interesting subject was the place and the visibility of the compartments of the mail in the dashboard. The ergonomist insisted on the fact that the postman should see the addressee on the mail when it is in the compartments. He suggested turning the compartments towards the user and getting down the vehicle's windshield which could change the design proposed by the industrial designer. However, the industrial designer commented that getting down the windshield is not problem for him. On the contrary, it could be a solution to the discontinuity between the vehicle's front end and the dashboard. Moreover, the industrial designer took snapshots for the vehicle fig.8. Then, he explained by sketching how he would change his design to adopt the viewpoint of the ergonomist.

Fig. 7 The ergonomist took the place of the postman on the VR platform. He was trying to touch the right mailbox. The virtual hand changed its colour when the actor touched the mailbox.

The actors tested also how it was easy to get in and get out the vehicle. This convinced them of the importance of the proposed solutions like putting the seat in the centre of the cockpit and reducing the width of the floor and the roof of the vehicle.

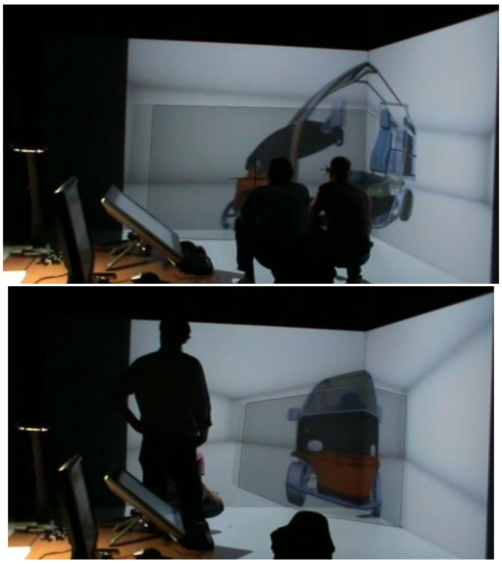

Fig. 8 The industrial designer took snapshots for the vehicle form different viewpoints using the Wii (Nintendo®) Remote

To choose between the two versions of the vehicle's front end, they could change between them on the VR platform. The industrial designer described this interaction "*It's awesome when I change between the two versions of the front end"*. The mechanical designer said "*Yes!! It's really amazing!!"*. The industrial designer was turning the vehicle and trying to evaluate the front end in the real scale. He used the ray of selection to indicate some parts to the other actors. He described what he was seeing in the second version of the vehicle's front end *"When I look at the vehicle from the lateral side, I see a crocodile eye. However, it gives you the impression that you see a witch from the front"*. He proposed some modifications in the form of the front end. Then, he took some snapshots and he started sketching to explain what he wants to modify fig.9. The mechanical designer started making the modifications required by the industrial designer on the CAD models of the vehicle front end. Discussions and exchanging between the actors took place during the modifications fig.9. After that, the modified CAD models were used to update the virtual mock-up in the VE to be evaluated.

The general feedback from the actors was very encouraging. Visualizing the virtual mock-up in the real scale permitted the actors the perception of the real dimensions and volumes of the vehicle. The ergonomist was satisfied with *the Product Use Model*. *The Product Use Model* created a common discussion and convergence among the actors by experiencing it. Moreover, all the actors were satisfied with *Interaction Model* like changing between the two versions of the vehicle's front end. The snapshot tool and the sketching techniques were very useful especially for the industrial designer. He asked to work using the VR platform, snapshot tool, and sketching tablet in the other days. Moreover, he appreciated the access to his traditional technique which is 2D sketching. The ergonomist participated in the sketching and annotating some of his ideas during his discussion with the industrial designer.

Fig. 9 The industrial designer was sketching the captured snapshots on the sketching pen tablet; near him the mechanical designer doing the modifications on the CAD models

The mechanical designer was satisfied with the access to CAD system which is his traditional tool of work. It permitted the mechanical designer to achieve the fast modifications in the CAD models. So, the actors could evaluate the update virtual mock-up on the virtual environment.

This case study showed us the IO with all its aspects. The IO is no longer viewed just as the *Product Model*. A successful defining of the IO has to take also in the consideration The *Product Use Model, Interaction Model* and *the Support tools Model.* The combination between the four models of the IO and different factors of the convergence situation generate a large variety of the IOs.

We found that the Virtual Reality (VR) is such an interesting technology thanks to its malleability to support a wide spectrum of the Product Model, Product Use

Model and Interaction Model according to the needs and the convergence situation.

5 Conclusion and future works

We are no longer just designing products for users. We are also designing product's use. So, we see the design process as a co-designing process of the product and its use together. To this end, collaboration between various actors is required into product design process, and more precisely in the convergent phases of this process. Intermediary Objects (IOs) are the center of the social interaction in the convergent phases. They help the actors working collaboratively across boundaries. Indeed, to manage the IOs for efficient convergent phases, it is necessarily to understand the IO in all its aspects.

The aim of this paper was: a) to present a global approach of the IOs for the convergent phases about "product-use" couple; b) to present a real industrial case study to apply and to clarify the proposed approach.

Based on the literature review and our experience form dealing with industrial projects, we proposed that the IO is the result of combination between four interdependent and interrelated models: 1) *Product Model* which represents the product; 2) *Product Use Model* which represents the different components of the product use; 3) *Interaction Model* that represents the interactions between the involved actors and the IO to evaluate and modify it; 4) *Tools support Model* that includes all the tools and technologies that used to support the IO. Moreover, three components of the *Product Use Model* were defined. They are *the context of use*, *the user* and *the user activities*.

The proposed approach was clarified and applied using industrial case study in an automotive design project. The case study represented a convergent project review between three actors: ergonomist, mechanical designer and industrial designer. The objective was to arrive at a convergence about the vehicle's cockpit and the vehicle's front end. *The Interaction Model* included an interactive process to modify virtual mock-up based on: snapshot tool in the virtual environment, sketching and annotation pen tablet and CAD system. The qualitative results from interviews with involved actors were very encouraging for continuing to develop our model of the IO. Moreover, we think that there is no an IO that could be used for all the convergence situations. IOs have to be selected or designed according to the convergence situation. Our future works will investigate the different factors of the convergence situation that could affect the choice of the different models of the IOs. Our understanding of the IOs has to lead us to a global approach to managing these objects throughout the product design process.

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