3 THE ROLE OF MIXED PROTOTYPING IN PRODUCT DESIGN ASSESSMENT

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The paper reasons about the use of Mixed Prototyping techniques for the assessment of the product design. Specifically, the paper addressed the assessment of products with aesthetic values and shows how new techniques and tools based on Mixed Prototyping contribute in reducing the product development time and related costs, in improving the quality of the designed products and eventually allows the involvement of product designers and stylists and of end users as well into the design loop.

Keywords: Mixed Prototyping, Haptics, Product Design, Conceptual Design.

1. INTRODUCTION

The typical design process of products includes several phases that start from market analysis and product conception and conclude with product distribution and maintenance. In this paper we concentrate on the analysis and reasoning about the design process of products with aesthetic value. The design process of aesthetic products includes a sequence of loops of activities. Each loop consists of a set of major activities that we have represented in Figure 1. The process starts from an initial idea or concept of the product and moves on with the representation of the idea through a modeling phase. Then, the evaluation phase of the generated shape starts. Product assessment methodologies are various and depend on the characteristics and functionalities of the product that we are interested to analyze. Design assessment practices typically address aesthetic properties of products, functional aspects, performances, ergonomics and usability issues, etc. Typically methodologies for product design assessment are based on the construction and evaluation of physical prototypes, on the use of realistic rendering of products, on their virtual representation providing morphological and aesthetic variants, on physics-based models allowing functional tests and analyses.

Considering aesthetic products, the evaluation of the quality of a shape is initially typically performed by means of pure visualization of the digital model, and then it is done on the physical prototype (PMU — Physical Mock-Up) of the digital model. In the case, as it often happens, that the shape is not fully satisfactory, some modifications are performed on the model — in its digital or physical form — and the process cycles several times on this loop (sequence of phases) until a fully satisfying result is achieved, or the time available has expired. The assessment of ergonomics aspects is instead performed almost exclusively by using physical prototypes.

The production of a physical prototype that is built from a digital one is not straightforward. In fact, it cannot be immediately derived from the digital model, but instead it requires a production phase that can be one of the following: it can be built manually, or through a technological process including CAM (Computer Aided Manufacturing), milling and finishing activities, or even through Rapid Prototyping, mainly applied to small objects.

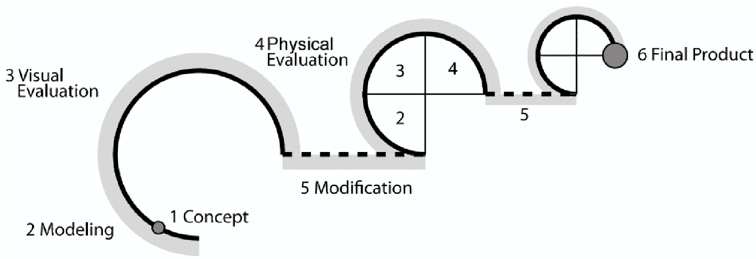

Figure 1. Main activities in a typical design process of aesthetic products.

Before reaching a final satisfactory design of the product the various activities are performed several times; this means that the several loops are carried out, and therefore several physical prototypes are built. This activity requires long execution time; in fact, the dedicated time is an order of magnitude higher than the time required by the other design phases. In addition, physical prototyping has several limitations. For example, the modifications performed on the physical prototype cannot be easily inserted into the original digital model. In addition, it often happens that in order to meet time constraints the number of built PMUs is cut down and fewer solutions can be evaluated to the disadvantage of products quality.

In order to effectively support the process of product assessment the research should focus on new tools that on one side allow a rapid and low cost assessment of products since the early stage of their design, and on the other side should support immediate and easy modification of the product design. The provision of methods and tools for rapid product assessment would allow users to perform several tests of various aspects of the product, would allow saving time and consequently reducing time to market of products, and would allow users to consider more products options in a given time. And finally, all this would possibly result in better quality of products.

Another aspect we would like to consider concerns the involvement of designers and end-users in the design process. Designers and stylists work traditionally on physical models of products and are therefore not directly part of the digital design process of products. This implies that they have to rely on other experts for those activities like design modification. End-users are called to assess the products when fully functioning physical prototypes are ready. Clearly, at this stage any request for design changes comes too late and often would be too expensive to consider. The overall design process would be improved by inserting both designers and end-users into the design loop so that they can be involved in the assessment and modification of new products early in the design process.

Virtual prototyping is a promising and effective methodology based on the virtualization of the product that allows designers and end-users to consider various alternatives at an early stage of the product design process.[1] The goal is to find problems-functional, ergonomics, and usability problems-early in the design of a new product so that improvements can be made as part of the iterative design process. Various tools based on Virtual Reality technologies have been developed with the aim of supporting product assessment and modification.[2] Most of them show some limitations that prevent their effective use: they are based on pure visualization, and the interaction supported has limited sensorial feedback.

Mixed Prototyping is a more flexible and powerful practice since it allows the interaction with both virtual and real prototype components, taking advantage of the possibility on one side of evaluating early in the design process components that do not exist already, and on the other side of better feeling the components through physical interaction. The practice can be effectively used for rapid design assessment of new products.

The paper reasons about the concept of Mixed Prototyping and provides some examples about various possibilities of using current and emerging technologies within the context of product design assessment.

2. MIXED PROTOTYPING

Mixed Prototyping is a method that has been proved to be efficient and effective in the development of interactive products.[3] Typically, the validation of these products, even when performed at the conceptual level, requires the involvement of real users that test and evaluate those aspects that cannot be evaluated and/or measured through the joint simulation of product and user, like it happens for the large majority of technical machines and systems where users are technical people acting by means of following predicted and predictable protocols and procedures.

The Mixed Prototype is an integrated and co-located mix of physical and virtual components usually seen by means of a see-through visualization system. In the context of product design, Mixed Prototyping offers to designers the possibility of optimizing product components, system set-ups and interaction strategies and modalities by means of a direct interaction with both virtual and physical components, real or simulated, of the product.

The following sections present some applications that we have developed and that are based on Mixed Prototyping for product design modification and for product design assessment. The reported examples show the benefits of using such techniques including the possibility of involving designers and end-users respectively into the design process.

3. MIXED PROTOTYPING FOR DESIGN MODIFICATION

In this section we consider the use of Mixed Prototyping techniques for the assessment and modification of the shapes of new products. Most of the time the designed products are represented by means of sophisticated and realistic visualization renderings, and the interaction with the model is based on its visual representation. We name this type of interaction indirect interaction with the prototype. The interaction is commonly based on vision, which is used for representing the current shape of the product and/or some related quantitative data, usually deriving from simulations (Figure 2). An example is provided by current CAD (Computer Aided Design) and FEA (Finite Element Analysis) tools. The realism experienced by the users can be very high only when the interaction is limited to vision and in some cases the user cannot visualize the whole prototype in real scale. The user can also modify the prototype by means of the program that has been used for creating the prototype (CAD tool, FEA tool, etc.), so via the mathematical and/or geometric drivers of shape. Since designers are not always able to use those design tools, they have to rely on CAD experts for performing any modifications on the model of the product.

A richer interaction is supported by direct interaction modalities. This kind of interaction has been recently provided by adding the possibility of touching the models of products through the use of haptic devices.[4,5] In fact the recent advent of haptic devices has offered the possibility of also using touch for

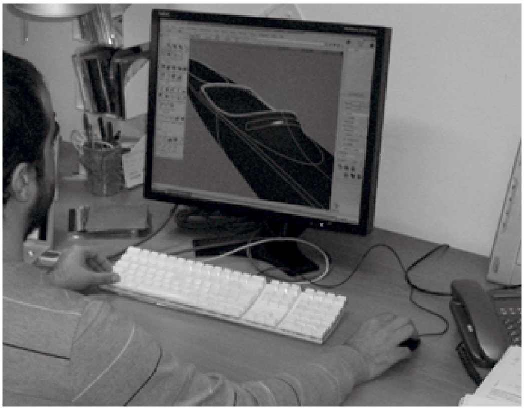

Figure 2. User assessing a product design through a Virtual Prototype.

interacting with virtual prototypes.[6,7] The user can feel, evaluate, and understand the prototype through touch; and he can also modify the prototype trough touch. The state of the art of haptic technology consists mainly of point-based devices, with a limited working space and force feedback. Haptic technologies can simulate the sense of touch with virtual object, but the realism of the interaction they offer mainly depends on the accuracy of the physics-based model used.[8] Examples of systems that allow the creation and modification of virtual shapes through haptic interaction that is not strictly point-based have been recently developed in the context of the two following research projects: T'nD[9] and SATIN.[10] Figure 3 shows the concept of the SATIN system that allows the exploration and modification of virtual shapes through the manipulation of a haptic strip. The physical strip takes the shape of the curvature of characteristic curves of an object shape; the users can see the whole virtual shape of an object and also see and touch its characteristic curves. The user can also deform the haptic strip for modifying the related curve, and consequently the object shape.

Another example consists of a system, named PUODARSI, which integrates an application for interactive fluid-dynamics simulation with an application for shape modification performed trough haptic interaction.[11] The system consists of a unique environment that can be used in a collaborative way by designers and engineers. The environment allows the designer to modify the object shape easily and intuitively, through the use of haptic devices, and the engineer to run in real-time fluid-dynamics simulation on the new shape (Figure 4). These activities are reiterated up to reaching a consensus about the aesthetic and technical aspects of the new product. Besides, the system supports the possibility to evaluate different solutions in a comparative way.

These applications demonstrate that early assessment of product designs performed in mixed environments is effective and that the inclusion of the possibility of interacting haptically with the product models allows designers, who are not skilled in these activities, to be part of the design process.

4. MIXED PROTOTYPING FOR DESIGN ASSESSMENT

The prototype that is used for product design assessment can be a mix of physical and virtual objects. In a space including user and prototype on the two axes, a Mixed Prototype consists of a varying

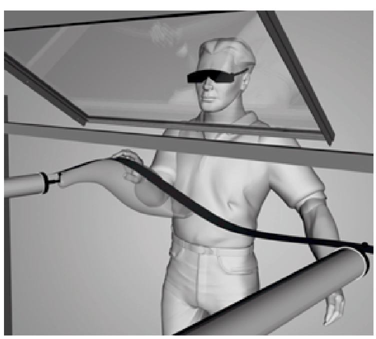

Figure 3. Conceptual image of the SATIN system for shape evaluation and modification based on the metaphor of the deformable strip.

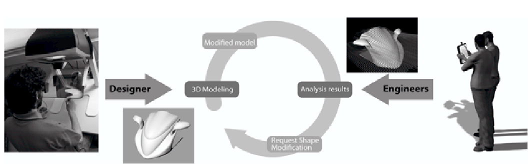

Figure 4. System integrating an application for shape modification based on haptic interaction with an application for fluid-dynamics simulation.

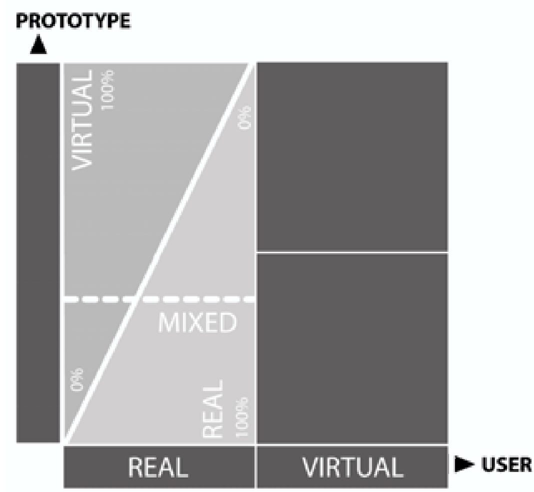

Figure 5. Mixed Prototyping consists of mixing real and virtual representations of a product.

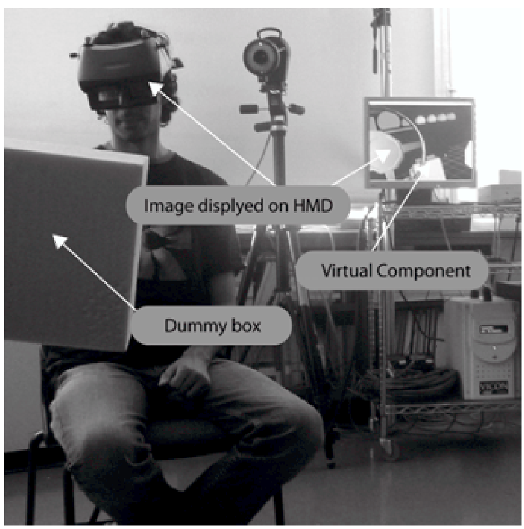

Figure 6. Mixed Prototyping application for directly repositioning components within the virtual space.

mix of real and virtual objects (Figure 5). Several applications implement a Mixed Prototype as a real environment augmented with the visualization of virtual objects. This technique has the goal of enhancing a person's perception of the surrounding system rather than replacing it, and has the big advantage of not requiring the modelling and simulation of the environment in which to locate the virtual objects. Other applications implement a more complex concept of Mixed Prototyping.

An example is an application we have developed that uses a dummy physical box for repositioning components within virtual system (Figure 6). The dummy box is associated with one component of the virtual system; the dummy box is tracked in space by means of an optical camera tracking system, so that its position and orientation in space can be detected and used for repositioning, in real time, the corresponding virtual component within the virtual system. During the design assessment session the user — by wearing a stereoscopic Head Mounted Display (HMD) — is able to find the right position of all the components and to define his/her own set-up.

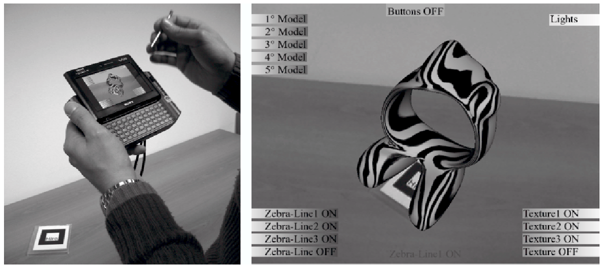

Figure 7. Mixed Prototyping application for early evaluating aesthetic properties of virtual objects within a real context.

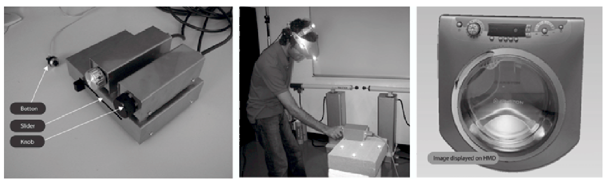

Figure 8. Mixed Prototyping application for the usability test of virtual washing machines by means of programmable interactive devices: knob, button, and slider.

Another example consists of the use of a tangible interface for displaying virtual objects within a real context. Figure 7 shows an example where a virtual product is displayed in a real environment.

The application allows the designers to load different digital models, change in real-time the texture mapped onto the virtual object and the light position; it is also possible to visualize the reflection lines in order to evaluate the quality of the virtual object surface.

In applications for the ergonomic assessment of the use of appliances, for the simulation of maintenance activities[12] users can interact with the virtual objects through the use of some interaction devices like gloves; these applications are effective if the kind of interaction is indirect, and therefore mainly visual. A more interesting and complete example of Mixed Prototype consists of a real environment that is integrated with virtual objects that the user can also touch. In this case, touch is added to applications that are based on the use of real object for what concerns the direct interaction, and on virtual object whose behavior may be changed. Examples are configurable interactive device mounted on board of systems such us car dashboard, airplane cockpit, washing machines, etc.[13,14] These devices are active device in the sense that they can in real-time change their feedback following the suggestions of the tester. In this way the test allows us not only to validate ergonomics and aesthetic aspects of the product before it is really built, but also its functionality, usability and physical response during its use.

We have implemented an environment where the user can see the 3D digital model of a washing machine by wearing a stereoscopic HMD (Figure 8); the user can also interact with the interface by means of a dynamic haptic device (knob). During the testing session, the user is asked to evaluate the washing machine interface performing some tasks; he can choose the knob behavior that he likes more among the proposed ones.

A second implementation of the application we have developed consists of programmable interactive devices that are mounted on a robotic arm (Figure 9). The application allows users to see simultaneously physical and virtual objects, to position objects within the scene, and to validate interaction devices that are simulated by means of programmable haptic devices. The behavior of the devices as well as their position can be changed simultaneously in the real and virtual environment. This application allows us to evaluate the devices visibility and accessibility, information availability, ease of use and sensorial feedback.

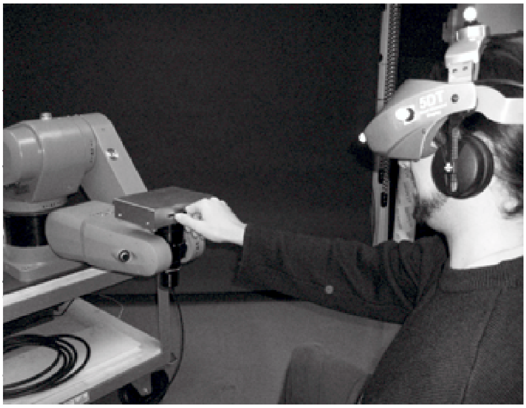

Figure 9. Robot positioning programmable interactive devices.

Also in this case, the applications that we have implemented demonstrate that early assessment of design performed in the mixed environment is effective and the possibility of involving the final users of the products early in the design process may be affective in order to design products that better satisfy end-users requirements and preferences.

5. DISCUSSION AND CONCLUSIONS

The paper has presented some examples of applications for product assessment based on Mixed Reality techniques and technologies. We have reported several examples where this practice has been effectively used for rapid design assessment of new products. In particular, the paper has addressed applications regarding the use of Mixed Prototyping practice for the modification of product shape where designers are directly involved in this activity performed using digital tools, and for design assessment of products where the end-users of products can be directly involved in testing and evaluation activities before the final product is really built. In fact, the process design cycle is more efficient and the number of PMUs is reduced, and this consequently reduces the lead-time for new products and their development costs.

We notice that the evolution of methodologies for product evaluation tends to go from physical prototypes toward virtual prototypes through intermediate mixed prototypes. In real situation, Mixed Prototype seems to be a good pragmatic and efficient solution providing flexibility and effectiveness. Mixed Prototyping supporting direct interaction includes various situations that are based on the use of interaction devices that allow users to interact with a mixture of virtual and real objects. This practice takes advantage from a combination of benefits of both virtual and physical prototyping. In fact, the interaction with real prototypes allows users to better feel and perceives the object, and the interaction with virtual prototypes allows an early evaluation based on digital models before the product is really built and available for testing. In addition, more simple evaluation environments allow the involvement of users like designers and end-users in the product design process since the early phases of conceptual design.

In summary, we have presented a reference framework where we have located user, prototype and interaction: we can map the applications we have described into this space (Figure 10). The user and the prototype can be real or virtual, and the type of interaction can be direct or indirect. In Mixed Reality applications a real user interacts with an application that is a mix of real and virtual objects where the interaction can be only visual or both visual and haptic. In fact, haptic interaction is becoming common in prototyping applications.

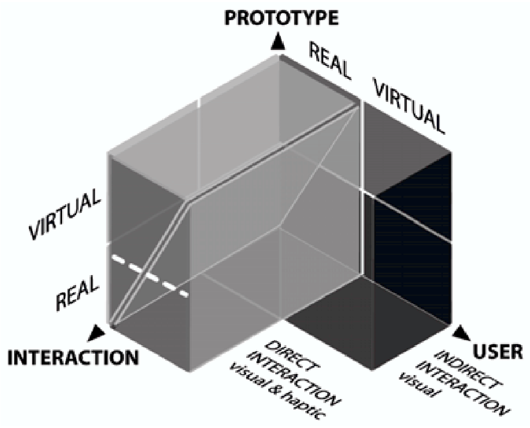

Figure 10. Reference Framework for Mixed Prototyping.

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