DESIGN FOR USABILITY IN VIRTUAL ENVIRONMENT

F. Bruno, R.M. Mattanò, M. Muzzupappa, M. Pina

Department of Mechanical Engineering – Università della Calabria

ABSTRACT

Design for Usability (DFU) is a well known concept in computer science, since it refers to an important topic for the Human-Computer-Interaction research community. In the industrial design field this term is not so widely employed although the product usability is considered one of the most important factors for a product to be successful on the market. The importance of usability addresses the relationship between the interface of a product and its users. The success of several products on the market depends on complex interfaces, which require the user's intense interaction. Often such devices, which the designer sees as being extremely efficient, are too complex and incomprehensible to the user. Usability should be one of the peculiar aims of the design, and thus assessed throughout the design itself. It should work on the assumption that final users should be involved during all the phases of the development of a product.

The present study proposes a methodology of participatory design based on the user-product interaction in a virtual environment, and developed by involving users in the definition of the interface of an interactive product for household use.

Keywords: Participatory design, virtual reality, usability

1   INTRODUCTION

The failure of a large number of products on the market points out the limits of traditional design, which solely focuses on designers and on company needs. Innovative products, on the other hand, are quality products, which ensure a success on the market. It is thus necessary to define a new design philosophy, which involves methodologies able to take into consideration and elaborate all material and immaterial features of the product.

All objects are thought up and produced for man whom, being the consumer of the product, interacts with it thanks to physical-relational skills. The quality of such interaction sanctions the outcome of the design process. Whilst defining a new product, it is thus extremely important to consider users the core of design processes and to aim to users' satisfactory fruition of the product.

Within such design philosophy, it is possible to delineate a methodology, which allows the product to fully satisfy man's needs thanks to the direct intervention of final users throughout the design process. The traditional design approach deals with limited disciplinary sectors, whereas a methodological approach focusing on users' contributions and knowledge cannot solely deal with technical-manufacturing sectors, but should take into consideration psychological, social, cognitive and organisational aspects of human behaviour. A human centred design approach cannot prescind from the knowledge of the context in which the user/product interaction takes place, as well as the knowledge of the subjects of the interaction itself. According to such methodology the subjectivity of man and behavioural diversities in different contexts and activities cannot be reduced to technical knowledge. Such knowledge is undoubtedly necessary to define a problem and to find a solution, but the final parameters of assessment of any design proposal are users and their different ways of facing the chosen solution.

In fact, the user has an important role throughout the lifecycle of a product, from its conception to its disposal. The acknowledgement of the centrality of man will lead the design team to a deeper study of human behaviour and of human cognitive processes related to all types of user-product interactions:

deciding to buy the product, the choice of the product itself, the ways of using it, the user's behaviour at the end of the product's lifecycle, and emotional bonds [1].

The usability of an industrial product is the quality, which better than others helps the designer to define the compatibility between design and user [2]. But the notion of usability may not be separated from the notion of assessment of the usability itself. That is why it is important to have interactive prototypes to carry out the assessments. Therefore, it is necessary to make design and assessment activities more "participatory". The various phases of the design process can no longer involve simply designers, but they must involve experts in other disciplines and, most of all, the final users of the product. In order to realize such a project, it is necessary to have several tools, not only *CAx* systems at present used only by experts.

We consider virtual reality systems the tools that, more than others, have the right requirements for a participatory design approach, since they allow a more natural interaction with the virtual prototype and an immersive visualisation which facilitates the work carried out during collaborative design sessions.

In the past few years, the authors have been carrying out a study aiming to the definition of new design methodologies, which use virtual reality as a tool for involving final users in the product development process.

It is our belief that as long as the designer and his competence remain the core of the product development process, RV will carry on being the only prerogative of big enterprises or research centres. On the other hand, involving final users as from the initial phases of the design process would lead also small and medium enterprises to the use of RV techniques.

The present study proposes a methodology for participatory design, based on RV, which aims to support the design of interactive products (provided or supplied with electronic interfaces) mainly assessing aspects connected to usability. A previous series of tests, whose results are shown in [3-4], aimed to determine the influence of the virtual interface on the assessment of the usability of an industrial product. In order to be able to validate the methodology, the present study has analysed two case studies (a microwave oven and a washing machine), considering, like evaluation metrics, the improvement of the usability of interfaces, which were redesigned using the proposed methodology, rather than other commercial interfaces (currently on the market).

2   STATE OF ART ON PARTICIPATORY DESIGN

Participatory design is a particular design approach [5-8] characterized by a strict collaboration between designer and user in order to realize a man-sized product. The designer/user collaboration may be reached in several ways: depending on the product typology, the user's opinion may be expressed thanks to interviews (face to face, by phone, on-line), focus groups or thanks to the user's direct interaction with a physical prototype. In [9] you may find an exhaustive list of the techniques used to involve users throughout the design process is presented.

Participatory Design (PD) origins in the Scandinavian countries and focuses on the improvement of working class and clerks' working places [10]. The approach is based on the concept that users will offer the greatest contribution for the improvement of their own working place and that their perceptions and requirements are as important as technical requirements. Participatory Design is a highly interactive process within which objectives and strategies are constantly reviewed: "*PD looks to compromise rather than consensus as an end goal*" [11].

In [11], the authors illustrate two approaches for the application of the principles of PD. According to the first approach, ''*mutual reciprocal learning*'', users and designers are called to learn from one another, through combined experiences; this way designers may find out about working experiences or the uses of an artefact, whilst users become more aware of technical abilities. The second approach, ''*design by doing*'', is a creative approach which directly involves the users who are asked to make comments and speak about new ideas to designers; generally in this case, interactive experiments on prototypes or low technology instruments are used, such as tests or drawings on blackboards, post-its or forms (files/cards). In [12] the authors point out that: ''*Through this approach, 'users move out of roles such as observer, approver 'knowledge repository' . . . and into roles such as peer co-designer, design owner, expertise contributor, and self-advocate*''.

An extensive bibliography on participatory design already exists, which mainly regards the development of software or architectural design (especially concerning the development of working

places) [13-15]. On the other hand, there are few references concerning the design of interfaces of consumer goods and the use of virtual reality techniques.

In [16], the authors describe a software (*Envisionment*) which, through virtual reality, is able to support and facilitate participatory design in working places. Thanks to this software, users may plan a working place that reflects their needs. After that, they may also assess the results of their choices by analysing the virtual prototype from several points of view, by surfing within the virtual working place, choosing between several settings (lights, textures).

The approach proposed in [17] uses the Web to assess the usability of an industrial product through virtual prototypes. The research is founded on the idea that it is not possible to relegate the relationship between man and artefact to a psycho-individual frame. To be able to fully exploit systems and interfaces, the knowledge of social and contextual aspects is also necessary. The internationalisation of markets underlines the need to assess and examine products during the design phase, with users from different cultures, and in worldwide environments. The software developed by the authors has been designed to carry out usability tests at a distance.

3   THE PROPOSED METHODOLOGY

Despite the user being the starting and finishing point of the process of product development, in traditional design methodology (figure 1), the user's collaboration is usually reduced to the definition of customer requirements and, seldom, to the interaction with the physical prototype (ergonomic tests, aesthetics assessments, etc) for testing purpose.
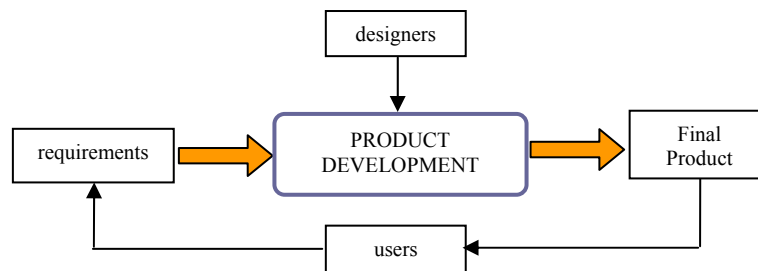

Figure 1. Traditional approach

As we have mentioned, in the previous paragraph, participatory approach, on the other hand, requires the user/designer collaboration during the design phase; information and hints provided by final users will, thus, effectively affect design choices (figure 2). The present limit of such approach is the lack of adequate tools able to favour the collaboration between the user, who is lacking experience and design culture, and the designer. Therefore, the only possible tools remain the low technology ones (described in paragraph 2) or physical prototypes.
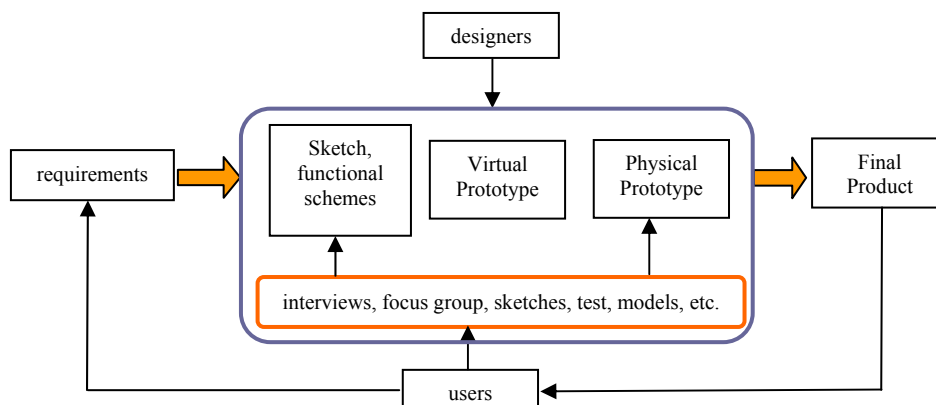

Figure 2. Participatory approach

The methodology we propose aims to favour the user/designer collaboration, through the direct interaction with the (3D and interactive) model of the product; thus overcoming the existing limits of participatory approaches which use drawings, notes or interviews. Our objective is to gather more information regarding the user's expectancies as concerns the product that is being designed (figure 3).
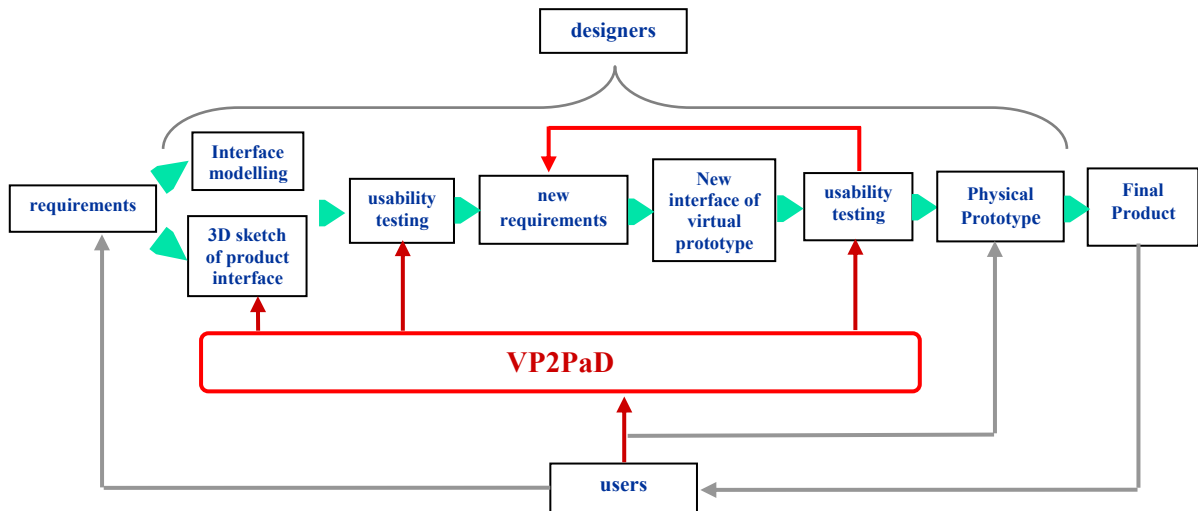
Figure 3. Participatory approach based on the proposed methodology

Such methodology is based on a software tool, called **VP2PaD** (*Virtual Prototyping oriented to Participatory Design*), designed to facilitate the involvement of final users in the initial design phases, and, in particular, during the product conceptualisation phase. VP2PaD has been developed for design of industrial products characterised by interactive electronic interfaces (figure 4) and it is a tool which requires a specific implementation in relation to the product that has to be analysed. During this initial phase of our research, we implemented two particular product interfaces to test the methodology, that is a washing machine and a microwave oven. The particular hardware set-up is described in [5, 18].

Figure 4. Type of devises considered

VP2PaD contributes to the development of new concepts (before the building of physical prototypes) through two particular functionalities:
- the sketch of the product interface;
- the interaction with the interface itself.

In both cases, VP2PaD may be used as follows: the user may interact with the product through the mediation of an operator or by himself. The first procedure fastens the definition and the use of the product interface if the user is not familiar with hardware and/or software; whereas the second procedure, more frequently carried out when users have good computer skills, allows a more direct involvement of the user despite the increasing cognitive load (due to the use of virtual devices) which is necessary to reach the final objective.

3.1 The sketch of the product interface

VP2PaD is structured through a series of menus, which allow one to select all possible typologies of functional elements (HIEs, *Human Interface Elements* [19]), such as buttons, handles, switches, etc.) that are necessary to define the interface of a specific interactive product. When the VP2Pad starts, it shows the control panel of the object, with no functional elements, and the menu (figure 5a). Through the menu it is possible to visualize the relative series of functional elements by selecting the various functions (figure 5b).
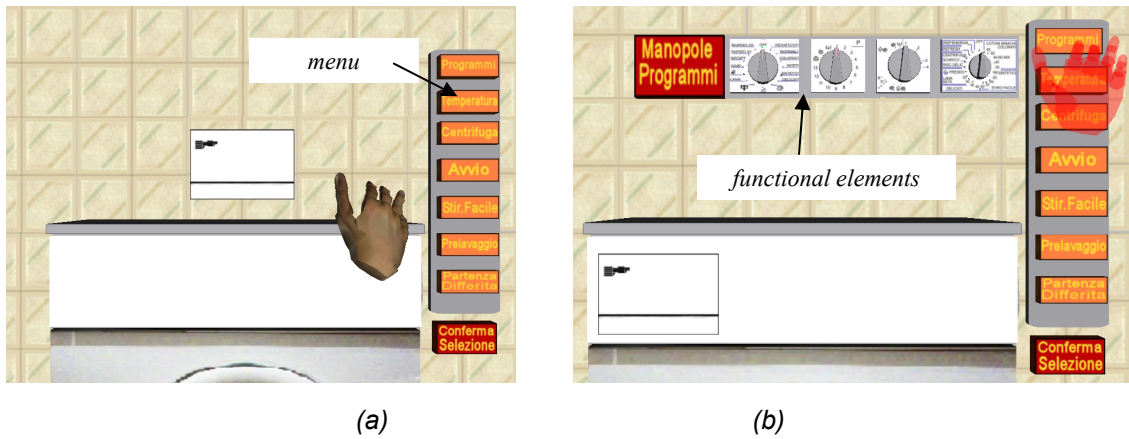
menu

functional elements

(a)   (b)

Figure 5. The interface of VP2PaD: (a) main menu; (b) sub-menu with of functional elements

In keeping with his/her aesthetic and functional assessments, the user may choose and select the type of functional element he/she prefers (figure 6a) and he/she may freely pull it and place it onto the interface of the product (figure 6b).
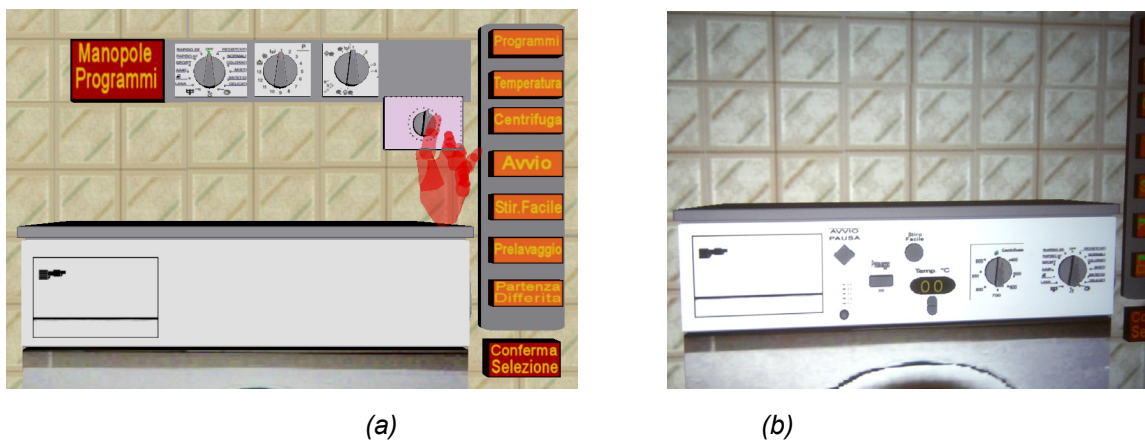

(a)   (b)

Figure 6. VP2PaD interface: (a) selection of an element; (b) modeling the interface

As we have already mentioned, it is possible to sketch the interface in two different ways: the user may interact with the product thanks to the mediation of an operator or interact with it in first person. The tests that have been carried out have pointed out the efficiency of both methods (figure 7).

(a)   (b)

Figure 7. Different ways of carrying out sketch session: (a) with operator; (b) without operator

3.2 Usability tests

The main objective of usability tests is to assess all features of cognitive ergonomics, that is to say the cognitive load that is necessary to understand the functioning of the interface of a product: the bigger is the cognitive distance between perception and action, the least usable is the object [20].

To be able to carry out usability tests in a virtual environment the interface of the virtual prototype must be fully operational. This functionality has been implemented defining all possible configurations and changes caused by the user's actions; it is thus necessary to define the various ways the user may give input to the system and foresee the corresponding answers. For each typology of functional elements (*HIES*) its effect on the product behaviour has been defined: for example a knob may lead to a change of information on the display or a button may cause the opening of the door, etc.. VP2PaD is able to reproduce (in the virtual environment) the behaviour of the product interface so that it may adequately react to inputs coming from users.

The usability test of a product was carried out asking a user, facing the virtual prototype, to carry out a series of realistic tasks. The ways of carrying out the tasks were chosen step by step, in keeping with the designer's needs, the typologies of users and the kind of interface to be designed (figure 8).

Figure 8. Usability test with the virtual prototype of two industrial products

While the test is being carried out, it is important to monitor it attentively, taking notes of performance time and all other elements useful to assess usability (mistakes and comments made, facial expressions, asking for help, etc.); the use of a video-camera allows a more accurate post-analysis of the test [21].

If the user is not able to use RV devices, it is, however, possible to use the virtual prototype, by forming a focus group. A focus group is a sort of qualitative research in which a group of people is asked about its attitude towards a certain product; the questions are asked to an interactive group, which may also communicate. Generally, those who take part to a focus group are already able to use certain products; whereas, through VP2PaD it is possible to have a focus group that uses a virtual product that is not necessarily on the market, thus allowing one to gather information that one may usually obtain only after the product launch. VP2PaD allows one to realize this sort of collaboration without having to ask the user to employ any devices. In this case the group may openly talk about the product whilst an experienced operator illustrates the functioning of the virtual interface (figure 9).

Figure 9. Focus group with the virtual prototype

4   CONDUCTION OF A DESIGN SESSION

The methodology, schematised in figure 3, is structured into five phases:

1.   The first phase includes two approaches, which may be carried out alternatively or in sequence.

    a.   Sketching of a certain number of product interfaces carried out by users, through the choice of knobs-buttons-switches, suitably chosen by designers. The result of this first phase is the creation of a series of interfaces that reflect the aesthetic and functional opinion of users (figure 14). After having listened to and observed users and analysed the results, the designer may gather new specifications, find out what the user wants, the functions he/she prefers, gather information on the typology and disposition of buttons/knobs. Since the obtained interfaces are in working order, they may be used to assess usability.

    b.   Definition – in a virtual environment – of a fully operational model of the interface of one of the competitor's products on the market, or of an old model which must be re-designed.

2.   Usability tests of the interfaces realized by users and definition of assessment criteria. The results of the tests above are usually summarised in charts (figures 11-12), thanks to which it is possible to make comparisons between the interfaces or to compare all the interfaces to one in particular. The measures obtained through usability tests are the ones suggested by norms (ISO 9241): time needed to carry out a task, number or mistakes, degree of satisfaction, etc. [3, 4].

3.   Re-definition of the interface requirements. Thanks to the results of phases 1 and 2, the designer has much new information which allows a clear understanding of the problem and, if necessary, the redefinition of any further requirements.

4.   Design the interface. The designer may redesign the interface taking into account all technical aspects as well as the suggestions of users and experts.

5.   Usability test. The designed interface may be compared to reference interfaces (competition or old models). Also in this case the results are summarized in graphs and allow, thanks to a series of comparative assessments, to confirm or further refine the model [4, 18].

The fourth and fifth phase may, obviously, be repeated until one achieves the desired results.

5   RESULTS OF THE EXPERIMENTS WITH VP2PAD

To assess the excellence of the proposed methodology we have examined two different case studies (a microwave oven and a washing machine), considering, like evaluation metrics, the improvement of the usability of redesigned interfaces (achieved thanks to the use of the proposed approach) compared to the commercial interfaces used as references.

The first case studio considered the alternative to the methodology described in section 4, point 1b. In particular, a series of usability tests were carried out in a virtual environment, as from the modelling of the interface of a microwave oven currently on the market (figure 10a).

The test was carried out according to the methods described in section 3.2: usability tests carried out directly with users or through a focus group.

In order to carry out the test (which took place in the Department of Mechanical Engineering, University of Calabria) we chose 2 samples of mechanical engineering students aged 23-26. Both samples (*A1, A2, ... A10*) e (*B1, B2, ... B10*), presented homogeneous features especially as concerns the knowledge of the product we were testing. The sample users (*A1, ..., A10*) was asked to carry out the usability test with the commercial interface. The indications obtained through usability tests allowed us to redesign the interface of the microwave oven (figure 10b). The second sample of users (*B1, ... B10*) was asked to assess the usability of the redesigned product.

Figures 11 and 12 show some of the most significant data for the assessment of the effectiveness of the two interfaces: the graph in figure 11 allows one to compare the total number of mistakes (grouped according to typology) made by the two samples of users while carrying out the test; the second graph (figure 12a) allows an assessment concerning the number of users who have completed the assigned task; figure 12b reports the number of mistakes for each task. From the graphs above one can infer that the redesigned interface has a better degree of usability than the commercial interface.
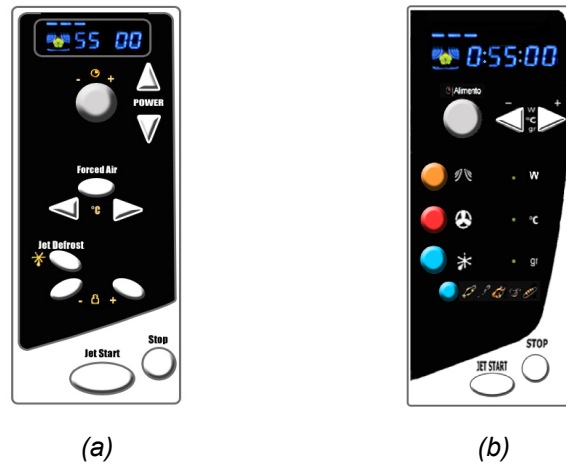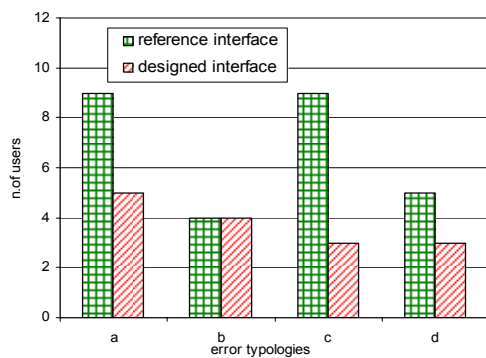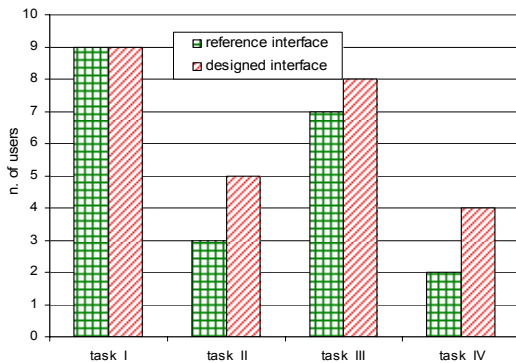
(a)   *(b)*

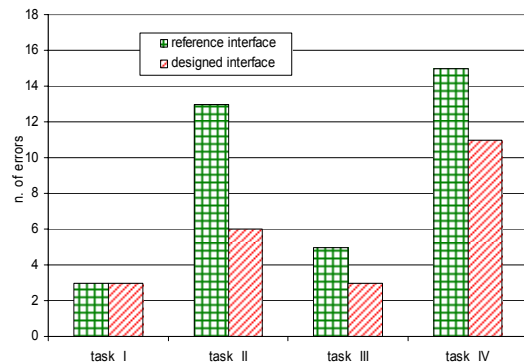*Figure 10. (a) Commercial (reference) interface; (b) redesigned interface.*

Type of mistakes detected

a) user does not activate the requested function
b) user does not understand the requested operation
c) user repeatedly selects the same function
d) user activates a non requested operation.

Figure 11. Main kinds of mistakes and frequency during test

(a)   *(b)*

Figure 12. (a) Tasks which were successfully carried out in two minutes; (b) total number of mistakes for each test

In [4], the authors have described an experimental approach based on the comparison between user-real product iteration (traditional approach) and user-virtual product iteration, in order to determine the influence of the virtual interface on the usability evaluation. The data obtained show that:
1. the virtual interface does not lead to an increase in the number of mistakes committed by users while carrying out the tasks (fig.13a);

2. users, which carried out the test with the virtual object, registered longer execution times than the average times registered by the users which carried out the test with the real object (fig.13.b).
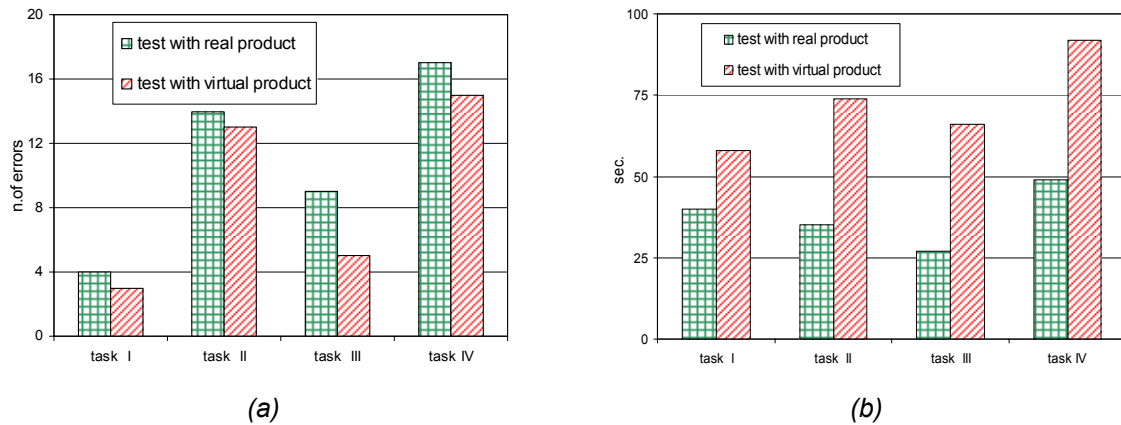

(a) (b)

Figure 13. (a) Total number of mistakes committed while carrying out the four tasks; (b) average time required to carry out the four tasks successfully.

A focus group was conducted with a sample of 15 people aged between 30 and 60 (with a good knowledge of electrical appliances), using the two interfaces shown in figure 10. Thanks to this procedure, an experienced operator showed the users how to operate the two interfaces, thus avoiding a direct interaction between users and virtual devices. The test, for both interfaces, was carried out in three phases:

- The operator carries out three tasks to prove that the interface works,
- The users repeat the tasks by using a drawing of the interface,
- The users fill in a questionnaire on the interface (efficiency perceived, comprehensibility, facility of use, satisfaction, etc.).

These three phases were followed by a free discussion (which was also recorded) on the functioning of the two interfaces. Also in this case the results proved that the designed interface has a better degree of usability than the interface currently on the market. Significant results are shown in figure 14.
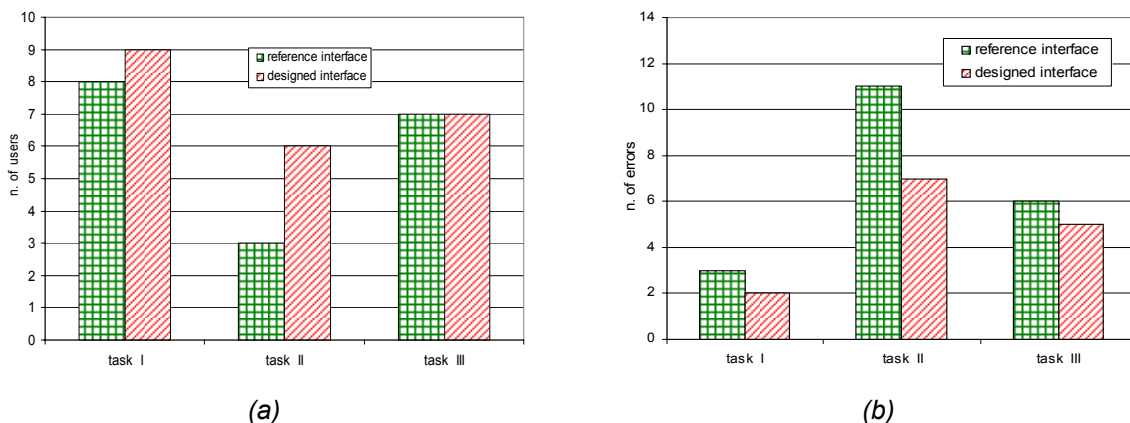

(a) (b)

Figure 14. (a) Users that carried out the assigned task successfully; (b) number of mistakes

The second experimental campaign, on the other hand, was based on the approach described in section 4, point 1a. The methodology was tested on two samples of users: 5 inexperienced users with little knowledge of washing machines and 10 more experienced users with a good knowledge of the electrical appliance. The sample of inexperienced users, formed by young graduates aged 25-30 with good computer skills, used the system in first person, and the interaction with the virtual prototype took place after having shortly practiced using RV devices. The second sample of users, formed by

women aged between 30 and 50, used the system with the technical support of an experienced operator who carried out the functions that were verbally given to him/her by the user (figure 7).

The user was asked to define the interface of the washing machine and, after that, to carry out a simple usability test by carrying out some tasks. The confrontation with the user ended with a short discussion on the designed interface, and, finally, the user was given the possibility to modify the proposed methodology.

In order to gather as much information as possible, notes were taken on all comments made, the whole activity was recorded and a file containing all significant passages of the definition of the interface was memorized. At the end of the test, 15 different interfaces were modelled (figure 15).
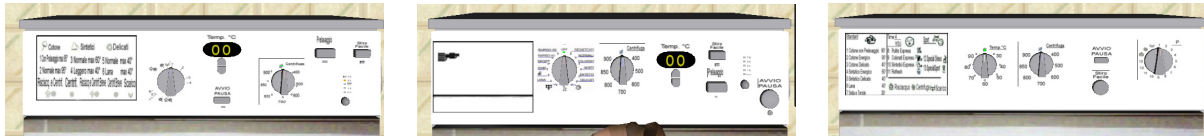

Figure 15. Some of the interfaces designed by the users

All data collected was used to design a new command panel for a washing machine (figure 16b). The new panel was compared to the interface of a washing machine currently on the market, through a usability test (figure 16a).
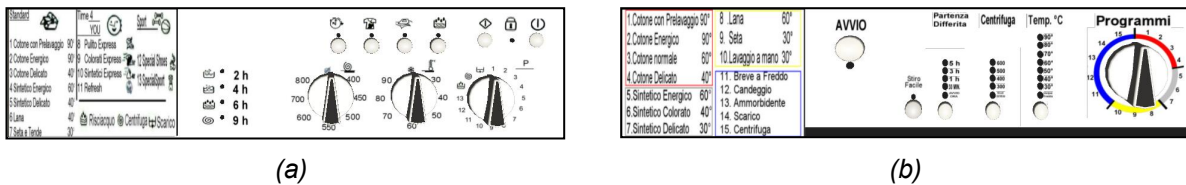

(a)   *(b)*

Figure 16. Commercial (reference) interface and designed interface

Once again the usability test, carried out on two samples of people (aged between 23 and 29 with experience in using a washing machine) in keeping with the procedures used for the first test case, showed a definite improvement in terms of usability of the designed interface (figures 17 and 18).
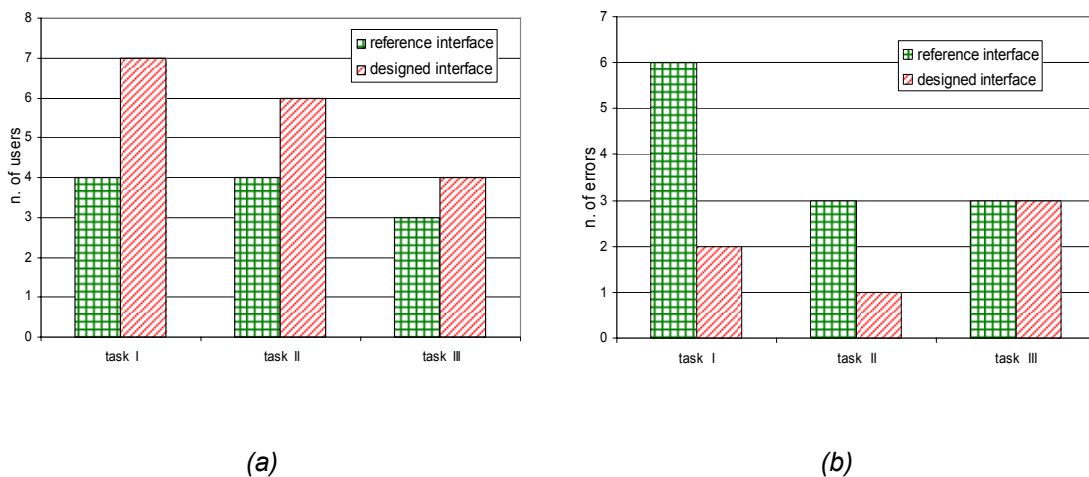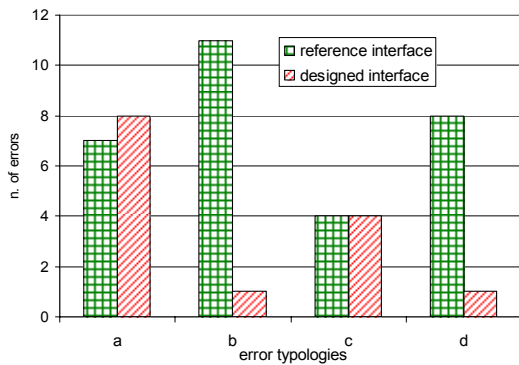

(a)   *(b)*

Figure 17. (a) Users who carried out the assigned task correctly; (b) number of mistakes

Types of mistakes detected.
a) user does not activate the requested function
b) user does not understand the requested operation
c) user repeatedly selects the same function
d) user activates a non requested operation.

Figure 18. Main typologies of mistakes and frequency during the test

6   CONCLUSIONS

The present study has presented a methodology for participatory design based on Virtual Reality techniques. We believe virtual reality to be the best tool for satisfying the needs of a participatory design approach. The results obtained thanks to numerous tests carried out by using such methodology have pointed out that the virtual interface is not an obstacle to the comprehension of the functionality of a product, and that, by interacting with the virtual prototype, the user may supply interesting design suggestions concerning the usability of the product one wants to realize.

Briefly, the proposed methodology allows one to:

- involve final users during the first design phases,
- define new product requirements (improve clearness and define problems),
- easily individuate weaknesses and strengths of the products compared,
- verify several design alternatives,
- cut down the costs for the realization of physical prototypes.

The methodology is based on a hardware/software environment, called VP2PaD, which presents the following peculiarities:

- it has a low cost (it is affordable by PMI),
- it is directed towards design electronic interfaces,
- it allows an assessment of aspects of cognitive ergonomics, in particular emotional aspects of the project.

REFERENCES
[1]   Norman D. A.. *The emotional design*, 2004. (New York: Basic Books).
[2]   Nielsen J.. *Usability Engineering*, 1996. (AP Professional, New York).
[3]   Bruno F., Mattanò R. M., Muzzupappa M., Pina M.. Participatory Design in Virtual Environment. In *Proc. of XVII International Conference XVII Ingegraf - XV ADM*, Sevilla, June, 2005.
[4]   Bruno F., Mattanò R. M., Muzzupappa M., Pina M.. A new approach to participatory design: usability tests in virtual environment. In *Proc. of Virtual Concept 2005*, Biarritz France, 2005.
[5]   Greenbaum, J.. PD: A personal statement. In *Communications of the ACM*,1993, 36(4), p.47-51.
[6]   Muller, M., et al. Participatory design. In *Communications of the ACM*, 1993, 36(6), pp.24-28.
[7]   Sanoff, H.. *Participatory Design: Theory and Techniques*, 1990. (Bookmasters, Raleigh, NC).
[8]   Ehn, P., et al. The Envisionment Workgroup – from vision to practice. In *Proceedings of the Participatory design Conference*, Boston: MIT, 1996, pp.141-152.
[9]   http://www.usabilitynet.org/trump/methods/methodslist.htm
[10]   Jensen, P.L.. The Scandinavian Approach in Participatory Ergonomics. In *Proceedings of the13th Triennial Congress of the International Ergonomics Association, vol. 1*, Tampere, Finland, 1997, pp. 13–15.
[11]   Carmel, E., et al. PD and Joint application design: A transatlantic comparison. In

Communications of the ACM, 1993, 36(4), pp. 40–48.

[12] Bilal, D.. Children design their interfaces for Web search engines: A participatory approach. In *Proceedings of the 30th Annual Conference of the Canadian Association for Information Science*, Toronto, Canada, 2002, pp. 204–214..

[13] Demirkan, H.. Adaptable house design. In *Proceedings of XXIVth IAHS World Housing Congress,* Ankara, Turkey, 1996, pp.19–29.

[14] Eriksson, J., et al. Adaptation of Workplaces and Homes for Disabled People Using Computer Aided Design. In *International Journal of Industrial Ergonomics*, 1996, vol. 17, no. 2, pp.153–162.

[15] Oya, D., et al. Universal product design involving elderly users: a participatory design model. In *Applied Ergonomics*, 2004, 35, pp. 361-370.

[16] Davis, R.. Adapting Virtual Reality for the Participatory Design of work Environments. In *Computer Supported Cooperative Work*, 2004, 13, pp. 1-33.

[17] Kari, K., et al. Virtual prototypes in usability testing. In *Proceedings of the 34th Hawaii International Conference on System Sciences*, 2001.

[18] Bruno F., Mattanò R. M., Muzzupappa M., Pina M., An interactive product design approach based on participatory design in virtual environment. In *Proc. of XVIII International Conference Ingegraf*, Barcellona, June 2006.

[19] Han S.H., et al. A Methodology for Evaluating the Usability of Audiovisual Consumer Electronic Products. In *Applied Ergonomics*, 2002, 33, pp. 419-431.

[20] Normann D.A.. *The Psychology of Everyday Things*, 1988. (Basic Books).

[21] Rubin J., *Handbook of usability testing: how to plan, design and conduct effective test*, 1994. (John Wiley&Sons, NY).

Contact: M. Muzzupappa
Università della Calabria
Department of Mechanical Engineering
Via P. Bucci, 44/C
87036 Rende (CS)
ITALY
phone: +390984494604
fax: +390984494673
e-mail: muzzupappa@unical.it