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HUMAN-CENTRED EARLY PROTOTYPES OF CONSUMER PRODUCTS: INSIGHTS FROM HCI

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1. Introduction

In recent years the notion of Product Experience [Schifferstein and Hekkert 2011] has gained a lot of attention for many categories of products, including domestic appliances, mobile phones, cloths, perfumes, coffee, cars, and many others. It is demonstrated that taking into account the experience evoked by a product into the potential customer, during its design, increases the possibility to sell the product [Jordan 2003], [Schifferstein and Hekkert 2011]. Consequently, companies are investing a lot of effort trying to design not only the product but rather its experience.
Product Experience is something complex to define. Somehow, it can be defined as something related to user interaction with products, in a specific context of use at a certain moment. These products can be of diverse typologies and not necessarily computer-based. This clarification is important, because for years the problem of designing the experience has been mainly related to computer-based products since those are, by definition, used by humans.
Considering all the factors involved in the human-product interaction is usually addressed as User Experience [DIS 2010]. This is a topic extensively studied by the Human Computer Interaction (HCI) community. The problem of the usability of interfaces has brought HCI scientists to consider human factors earlier than other academic and industrial communities. Over the years the problem of User Experience in HCI has evolved from addressing usability issues to a more complex concept of Product Experience and in a more general sense [Hassenzahl 2010]. Consequently, human factors have assumed a broader meaning. They are no more only limited to be requirements for measuring the correctness of a user's task, but are also used for validating the product elements/features that are expected to elicit a positive experience in the users [Hassenzahl and Tractinsky 2010].
One of the ideas behind this change is that in order to design User Experience or Product Experience, i.e. something related to user-product interaction, it is important to have working prototypes as soon as possible. This is what Buchenau and Suri call Experience Prototyping [Buchenau and Suri 2000]. Prototypes -low or high-fidelity- for such an objective have to be built and then used in a way that allows users to really interact with them, and to express their preferences about the experience elicited. In our research work we aim to use a similar approach, but applied in the engineering design domain, also considering non computer-based products, which are anyhow used by humans.
Hence, by initially underlining the reasons why prototypes first and Experience Prototypes [Buchenau and Suri 2000] later, have acquired a great interest within the HCI community (leading to significant and inspiring scientific contributions that will be mentioned along the discussion in the text), this paper attempts to transfer and integrate this point of view within the engineering design domain. The meaningfulness of this attempt is supported by the fact that nowadays the distinction between computer-based products and industrial/engineering ones is becoming more and more subtle,

especially within the consumer good market: today a product like a washing machine can be seen as a smart device able to communicate its "state of being".
More specifically, the discussion is focused on early prototypes, since they are considered having a key role in guiding the path of the design process [Reilly et al. 2005], [Hartmann et al. 2006], [Coughlan et al. 2007], and on the possible prototyping strategies and techniques that can help in taking into account not only technical issues but also the *human variable*, in terms of the experience the prototype is able to elicit on humans [Buchenau and Suri 2000]. This is due to the fact that, as underlined in [Berglund and Leifer 2013], deciding what to prototype, which prototyping technique is better to use, and how to make the prototype able to stimulate an interested audience (e.g. marketing experts, R&D managers, users) who can express feedbacks, are key aspects at the basis of engineers' and designers' activity.
Even if choosing the right prototype to build, as well as properly communicating its qualities to the audience is still considered a sort of "art" [Houde and Hill 1997], however, this paper aims to underline the necessity of investing effort on these issues. Particularly important is building prototypes able to stimulate and capture the audience's feedback, so that the design teams can redirect and adjust the design on the basis of those [Hartmann 2009]. Reaching this target would represent an important step towards the improvement of the communication between the designers and the other stakeholders of the design process.
From all these considerations a research question follows: what are the tools/techniques that can support engineers/designers in building early prototypes able to correctly represent not only the new features/attributes of the product as they have been intended, but also the effects these ones elicit onto humans?
Specifically, one open issue concerns how to make the early prototypes more credible. An improper representation of an idea, especially if clearly in progress, may increase the risk of: failure in "selling" the idea to the interested audience; improper evaluation of some "qualities", especially the ones related to human aspects; advancing something that is not technically/industrially feasible. Another open issue concerns the confusion and uncertainty about the level of details to be achieved for the representation [Hess and Summers 2013], and how the "rough edges" of these prototypes [Reilly et al. 2005] should be shaped.
In conclusion, the aim of this paper is to address these issues presenting a reasoned collection of the insights we have elaborated acting both as external observers of the HCI community and as internal "practitioners" of the topics related to virtual prototyping in the engineering field, at the research and educational level. The intent of our research is to contribute in transforming the "prototyping art" [Houde and Hill 1997] for product experience into something more systematic.

2. The starting point: (Early) prototypes as filters of the design problem

The Section starts by mentioning the following principle, which underlines two important insights: "*Prototyping is an activity with the purpose of creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole*" [Lim et al. 2008]. The first insight is that prototyping is a task that designers perform in order to make an instantiation of selected (i.e. filtered) qualities of the new product. Hence the way this manifestation is built should be decided according to the qualities that the designer wants to represent, as well as the modalities for their evaluation. The second insight is that when dealing with the design of complex products, this instantiation should be congruent and coherent with the overall system the prototype is part of, and also with what, in [Gero 1990], is defined as the *specific design situation*: the boundary conditions and the knowledge at the basis of this manifestation should be identified well in advance before building the prototype. This is recommended because without a proper up-front activity towards this aim there is a high and real risk of wasteful re-design loops [Berglund and Leifer 2013].
Moreover, in [Lim et al. 2008] the authors give an interesting classification of what are the "filtering dimensions" referred to a prototype. These are: its *appearance* (i.e. the physical dimension of the prototype that takes into account not only the visual stimulus but for example also the haptic and the auditory ones); *data* (i.e. the amount and the kind of data the prototype shows, such as the one

available on a screen display); *functionality* (i.e. the function(s) designed for the prototype); *interactivity* (i.e. the physical interface of the prototype enabling the interaction with people); its *spatial structure* (i.e. how each component of the prototype is arranged in order to behave as a part of a whole).

Despite this classification has a strong basis in the HCI field (e.g. the *data* dimension is strongly related to the design of Graphical User Interfaces - GUIs), it highlights what are the main aspects that a prototype should be able to represent. It also underlines that in selecting the filtering dimension(s) to represent, the designer/engineer applies a sort of prioritization [Hartmann 2009] of the kind of aspects he/she is interested to explore. This classification can be seen as an evolution of the funding principle of prototyping defined in [Gero 1990], where the design of early stage prototypes is first focused on the function it provides and on how it behaves in order to accomplish that function. Hence, the classification of [Lim et al. 2008] introduces what in [Forlizzi and Battarbee 2004] is seen as the purpose of learning about the social interactions and co-experience that take place when humans interact with a prototype. The concept of filtering is even more important in case of early prototypes, where in order to have a quick and credible evaluation of an idea it is not feasible to represent the entire product but instead it is more effective to concentrate the effort on those aspects seen as priorities (i.e. the filtered dimension(s)).

In order to clarify the issues discussed above it is worth considering two simple examples using the classification provided in [Lim et al. 2008]. They are graphically represented in Figure 1, and refer to the redesign activity of a dishwasher. The illustration on the left represents an example of technology push innovation, where the request is to redesign a new water recirculating system with the aim of improving the cleaning efficiency of the machine (e.g. the amount of water to be used for a standard washing cycle). In this case the designer gives priority to the understanding of the functional improvement that the new technology (e.g. the new pumping system) will provide, and also which will be the domino effects on the current architecture of the product. Most of the innovations in dishwashers can be classified as technology push [Rosa et al. 2012]. Consequently the early prototype, as is typical in the industry, will consist of an experimental set-up, i.e. a proof of concept, which is aimed to explore the new technology potentials and performance. The outcomes coming out from this preliminary exploration activity determine if it is worth investing effort in further and more detailed technical evaluations.

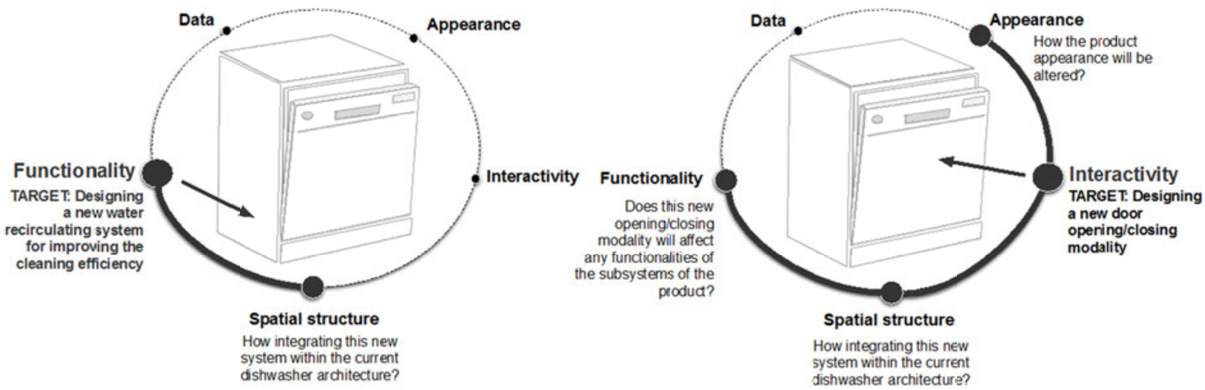

Figure 1. The filtering dimensions defined in [Lim et al. 2008] used to represent two examples related to the redesign of a dishwasher

The illustration on the right side of Figure 1 represents an example of market-pull innovation: the marketing department has requested a new opening/closing system for the dishwasher door (e.g. one easy to open and comfortable). In this case the main and primary aspect to evaluate is the one related to the interactivity. Hence, the question here is how to design an opening/closing modality able to elicit a positive experience (e.g. easiness and comfort) on users. First, it is necessary to understand how to reproduce the desired opening/closing modality, and second to investigate how practically recreating the desired behaviour of the door. Also in this case there can be domino effects -either positive or negative- on the dishwasher components and characteristics. The new door design may alter the product spatial structure, its functionality (e.g. the desired soft closing behaviour does not guarantee a proper locking of the door during the washing cycle), and its appearance (e.g. the handle position has to be redesigned). In this case the early prototype should be an Experience Prototype [Buchenau and Suri 2000], which is a prototype of the door offering the possibility to render different behaviours. However, it is not feasible building several physical variants of the door, where each one is equipped with a specific hinge mechanism enabling a set of behaviours to test. Therefore, in industry, for this kind of evaluation, it is typical using as early prototypes commercial products that are taken as market references. Indeed it is the job of marketing people organizing sessions where users are asked to interact with these products. Here the most desired behaviour of the door is identified among those already existing and proposed to the test participants. This approach, even if amply applied in industry, is well away from being efficient and bringing innovative products, since the new behaviour (of the door in the example) is actually an adapted replica of something already existing on the market.

In the HCI field the possibility of having different variants of the prototype of an interface, and also of the software controlling this one, is less wasteful in terms of costs and time with respect to the engineering design field, due to the "digital" material these prototypes are made of [Lim et al. 2008]. This is an additional reason why the interactive aspects have been well addressed in the HCI field.

This second example, as also discussed in [Buchenau and Suri 2000], underlines the fact that when dealing with the need of recreating an integrated experience, it is required a hybrid and overlapping skill-sets, including the collaboration of engineers and marketing experts, and also the involvement of additional specialized expertise such as the one of psychologists. This multidisciplinary aspect of prototyping starts to be well-known in the HCI field, and conversely it is still less in the engineering design field, which is, by tradition and background, more used to deal with problems similar to the one reported on the left side of Figure 1. This fact is even truer in industry.

To conclude this Section, it is worth recalling the considerations made in [Houde and Hill 1997]: the approach to prototyping should be selected according to the design problem (or filtering dimension(s)) to address. Hence, making explicit since the beginning what is the target aspect to investigate is fundamental in order to make the right choice concerning prototyping. But before selecting the prototyping strategy, the designer has to make a further consideration about who will be the target audience interested in experiencing the prototype. The following Section addresses this point.

3. The next point: Prototyping for an interested audience

It is clearly reported in literature that the kind of prototype to create and use is also influenced by the prototyping culture (or tradition) of an organization [Houde and Hill 1997], and thus by the kind of product manufactured. For example, in the home appliances market the interactivity and the appearance dimensions (as discussed in Section 2) are now starting to play a leading role that is dominated by the marketing department. Therefore, practitioners know very well how fundamental are the level of resolution and fidelity of the prototype. Once more this fact underlines how much the characteristics of the prototype to build are strongly influenced by the nature of the audience, which determines the kind of expectations to satisfy [Houde and Hill 1997], [Buchenau and Suri 2000], [Hartmann 2009]. This is especially the case of early prototypes, since improperly "selling" an idea, i.e. not meeting the expectations of the audience since the beginning, may increase the risk of failure of the product. Besides, it is understandable that the "hidden" desire of the target audience is to see and experience a solution that is very close to the final one. In a sense, obviously exaggerating, the audience does not like so much testing intermediate solutions.

Concerning the influence of the target audience in selecting the prototyping strategy, as also discussed in [Buchenau and Suri 2000], there is a further aspect to consider: the kind of presentation of the proposed solution has to be shaped according to the kind of audience, so as to make it more convincing.

Recalling the example of the dishwasher on the right side of Figure 1, in Figure 2 an example of its target audience is provided. Considering the interactive aspect as a priority, the engineer will have to deal with the marketing expert. To perform the necessary evaluations, these ones would need more than one high-fi prototype, in order to test different kinds of behaviour of the door, as mentioned in

Section 2. So the tests are necessarily carried out using commercial products. The same high level of fidelity is also required later on in the design process for evaluating any issue concerning the product appearance (i.e. surface finishing and colour, dimensions and position of the handle of the door) made by the product marketing expert, the product designer and the marketing brand expert (i.e. the person who is in charge of controlling the coherence existing between the product and the company brand used to market the new product).
As previously said, new proposed solutions may cause domino effects in the current product architecture and functionalities, which must be verified. To investigate these aspects, the engineer will have to interact with other experts, as other design teams or production engineers. Therefore, the kind of audience becomes wider. Obviously, when dealing with these technical issues we are no more in the early phases of the design activity but later in the product development process.
Just to give a more comprehensive overview of the members of a potential audience, even if not directly related to the reference example, in Figure 2 are included also the interface designer and the hardware-software engineer. They are the ones responsible for defining the data and the information flow within the product trough the design of its main board and user interface.

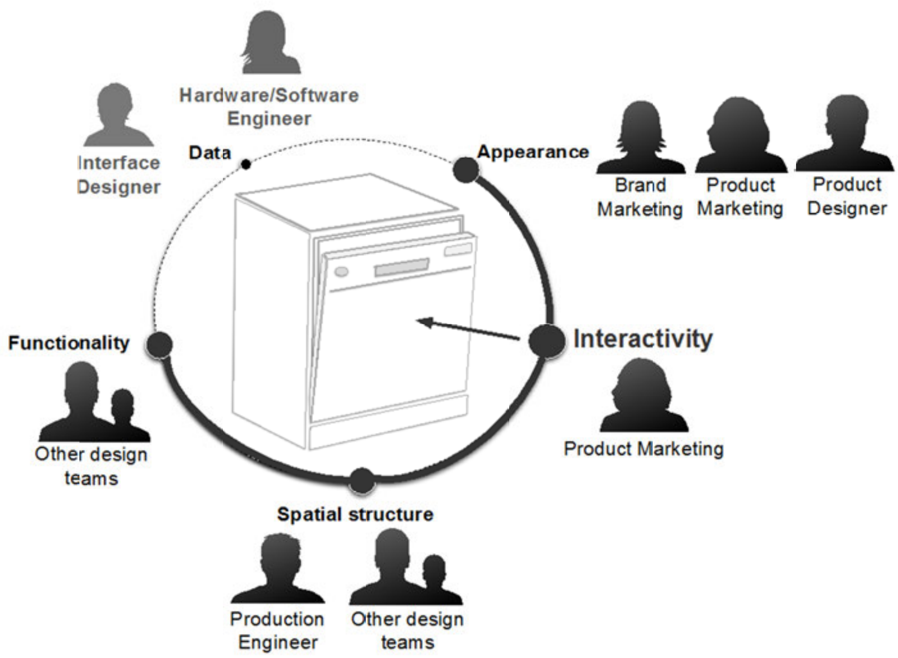

Figure 2. The target audience overview

This overview is proposed on the basis of the authors' experience in the domestic appliance field, having collaborated with various manufacturers. It is evident that according to the kind of product and also to the kind of organization, the members of the "interested audience" could change, but the considerations at the basis of the authors' reasoning will be the same. Actually this example aims to underline not only how significantly wide the target audience a designer has to deal with may be, but also that for this reason different kinds of prototypes have to be built to address the different issues of the design problem [Houde and Hill 1997]. Hence, once having clearly identified the filtering design dimension to be solved and the audience to satisfy, it is now time to select the prototyping strategy to apply. This issue is discussed in the following Section.

4. A further point: Current prototyping strategies

It is important to underline how much prototyping represents a key activity for designers/engineers since, as also discussed in [Hartmann et al. 2006], it enables to better learn about the issues still undiscovered related to the design problems. This is the reason why companies like IDEO (www.ideo.com) put a great effort in creating prototypes since the beginning of the design process [Coughlan et al. 2007]. It is clear that, dealing with early prototypes, which are developed almost at the beginning of the product design process, it is permissible to sacrifice the realism, or even to allow some bias [Reilly et al. 2005], but it would be recommended to avoid any oversimplification. In fact, proposing an idea to an audience by oversimplifying the problem may lead to discover further issues to be solved only once the idea has been already approved, i.e. when a step backward is no more possible since the marketing expert has already "fallen in love" with the idea. This risk is even higher especially for aesthetic issues. Building the shape of the new product with a material that is not the same of the final one (plastic instead of steel) would enable technically and economically feasible solutions that on the contrary would not (for example some folding operations may not be allowed). This would demand to the engineer, and in this case also to the product designer, a careful analysis of the design problem in terms of the technical/embodiment and economical requirements they have to satisfy. Oversimplifying means also not taking into account the working conditions (e.g. in terms of space needed, sensitivity to any external conditions) that the new technology implemented into the products will demand for or will undergo. Again this fact demands for a strong ability to anticipate all these side effects or requirements: even if not implemented in the prototype since the design process is still at its initial phases they should be at least pointed out to the audience as warning messages.

The strategy of creating a high number of low-fidelity prototypes built using cardboard or foam is still amply used in the HCI field, and it is recognized to be of great help. Considering the necessity of designing interactive systems, narrative and scenario-based prototyping techniques such as storyboards and videos are used within the context of scenario-based design. However, also in this case there are concerns about the need of further research effort to understand how much the "media" effect, i.e. the kind of prototype used that is far from the real situation, affects the results of the tests [Sellen et al. 2009]. This is the main reason why a sort of dissatisfaction is growing with respect to this kind of low-fidelity techniques since they are not always reliable in properly conveying the intended experience, as it is in the mind of the designer [Hartmann et al. 2006]. Hence the risk of transforming this intended experience into an artifice [Reilly et al. 2005] has not to be underestimated.

However, as correctly discussed in [Blomkvist and Holmlid 2011] it is clear that, especially for the early phases of the design activity it should be avoided the use of expensive materials or of techniques that slow down the design process. This is because such kind of prototypes should be more explorative than evaluative, and for this reason the use for example of rapid prototyping techniques (i.e. additive printing) is seen as a good compromise not only in the engineering design field but also in the industrial design one. Obviously, the realization of such kind of rapid prototyping based objects comes after the realization of sketches, CAD models and virtual simulations, which at least address the main issues of the design problems. This is also the reason why this kind of prototypes does not come very early in the design process.

Still continuing with the example of the dishwasher, we can now add another element to further detail it, which concerns the kind of prototyping media used to support the specific filtered dimension(s) to evaluate. As anticipated in Section 3, interactivity aspects are evaluated by means of real products that act as the prototypes of different variants (i.e. of opening/closing modalities of the door). Users are asked to select among these variants the preferred ones. This is the only way used in industry to perform such kind of early testing. Then, the designer can use the results obtained from these tests and start modifying the design (i.e. the 3D model) of a product already existing, in order to figure out the mechanisms necessary to implement the desired behaviour.

But this is not an easy task for the engineer. In fact, marketing people mainly give qualitative indications, and the maximum they can get from this test is an experimental characterization of the existing product classified as the best in the market in relation to its opening/closing system. Then, the changes that will be applied to the 3D model of the existing product to be redesigned will have to be shared internally in order to discuss the previously mentioned domino effects on the current product architecture. To test the functionality issues, a proof-of-concept is required. This is typically done by using both rapid prototyping techniques and real mechanical components. Finally, high fidelity renderings are sufficient for marketing experts for early evaluating and validating aesthetic changes.

From this overview it is evident that the traditional engineering design approach for prototyping is not efficient when the focus is on the design of interactive systems. This remark is also valid in the HCI field where the need of having an appropriate prototyping environment through which it is possible to easily create and test different variants of the system to be designed in real-time is already a research topic under investigation [Hartmann 2009]. Hence there is a growing need in the HCI field to experiment the use of new materials as well as new design tools to satisfy this need [Buchenau and Suri 2000]. As already discussed in literature [Berglund and Leifer 2013] high-resolution virtual prototypes may represent a valid supporting media toward this aim, by enabling the possibility to evaluate also interaction-based aspects and not only the ones limited to the appearance of the product. The following Section addresses this final point of the discussion.

5. The final point: The digital (virtual) artefact

Before going into more detail on the analysis of virtual prototypes, we would like to better clarify some few aspects. The first is that prototyping for Product Experience design means reproducing a product, or at least how users, in a specific context of use, interact with and perceive it. Second, this experience is multisensory: it involves all the human sensory modalities, even those that users are not necessarily aware of. This is a well-known problem in companies: they are conscious that the sound or the smell emitted by a product can influence how humans perceive this one. It means that in this simulation all the senses should be theoretically involved and also properly reproduced.

Virtual Reality (VR) technologies are by definition high-end interfaces that are used to reproduce human multisensory interaction with a virtual world [Burdea and Coiffet 2003]. Virtual Prototyping is based on VR technologies and can be used for designing Product Experience. Actually, before affirming that virtual prototypes are the best candidates to support companies to design product experience we will analyse them critically. Based on the experience of several years of research on virtual prototypes we have identified four important issues that need further investigation. These are the following:

1. How to reproduce the multisensory product perception;
2. How to reproduce the sensory cues faithfully;
3. How to reproduce the context of use;
4. How to correlate the virtual prototype with the real product.

The first issue is about reproducing the multisensory experience of a product. Despite VR technologies have been developed in years addressing at least four of the five senses, i.e. vision, hearing, touch and smell, the main problem of creating a multisensory experience is integrating the simulation of senses correctly. Technologies may be cumbersome, as for example those for vision (let us think for example to Head Mounted Displays) and for force-feedback haptics that in order to return forces to the user must be grounded. Integrating multiple technologies together might bring to the situation where the user does not feel to be immersed into a virtual world. This is a well-known problem of presence [Witmer and Singer 1998]. From the software perspective, despite the effort of the VR community toward the development of high-end tools for the creation of multisensory environments, there is not yet a software library able to manage four senses altogether.

The second issue regards the reproduction of sensory cues faithfully. In years technologies for the various senses have evolved differently. Technologies for vision and hearing are more advanced compared for example to those for the sense of touch and smell. It comes out that one of the main problems of virtual prototyping for product experience is still the necessity to develop specific devices able to reproduce faithfully information through a sensory modality. Examples in the field of haptics are reported in [Strolz et al. 2011], [Shin et al. 2012], where authors created a specific haptic device to reproduce a 1DOF rotational element such as a door, or in [Millet et al. 2009] where a high fidelity transparent 1DOF haptic device is described. Olfactory displays [Nakamoto 2013] are still at the prototyping stage to be considered usable for such a purpose.

The third issue is about reproducing the context of use. The problems of creating that context are similar to those of reproducing the prototype: they are mainly affected by technological limits. A possible solution to the above listed three issues comes from what is called Mixed Reality [Milgram and Kishino 1994], which applied to prototyping is referred to Mixed Prototyping. By simplifying, it means that prototypes do not have to be necessarily virtualized in their totality. Virtual information can be added into a real context of use (this would solve the problem of reproducing the context of use) or can be added to an existing real product. This would solve the problem of the faithful representation of cues for the single modality, or mixing different modalities where not all the technologies are sufficiently advanced. For example to interact with a virtual prototype a haptic device is necessary. The issue here is that the end-effector of the device does not represent the same tactile feedback, as the product will perform, since it has a different shape and is made of a different material. For this reason to render the proper interaction with, for example, the door of a dishwasher it is suggested to substitute the end effector of the device with the real interface of the product used as reference in the design activity (Figure 3).

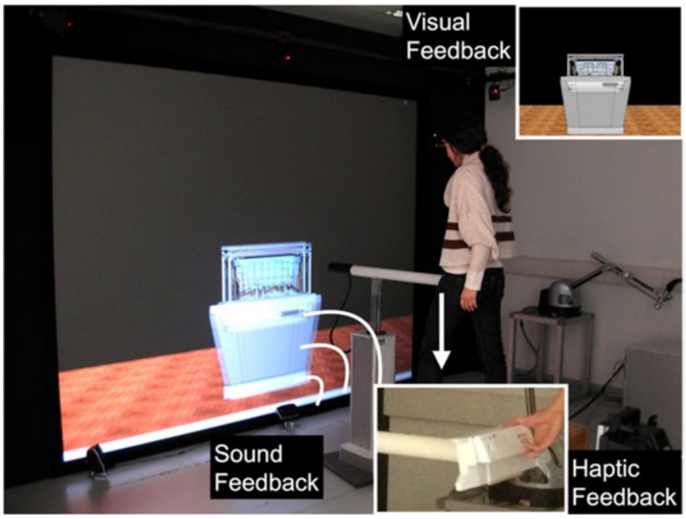

Figure 3. An example of a multisensory experience virtual prototype of a dishwasher door

The fourth issue concerns how to go back from the simulation to a real product. This issue can be addressed as performing the reverse engineering of the multisensory simulation. In fact in virtual worlds we can create simulations that do not necessarily correspond to, or can be created into, the real world. Therefore, it is possible to create experiences that solely exist in the virtual world, and have no correspondence with an experience with a real existing object. The authors have spent a considerable effort in trying to overcome this issue for the sense of touch, with interesting and promising results [Bordegoni and Ferrise 2013], [Ferrise et al. 2013], [Graziosi et al. 2013], [Graziosi et al. 2014] while, for vision and hearing [Van der Auweraer et al. 1997], some examples are available in literature. Recalling the example of the dishwasher opening/closing system, in Figure 3 is represented the multisensory and parametric virtual experience prototype we have created to redesign this system involving marketing experts and engineers. It is evident that the analysis provided in this Section does not pretend to be exhaustive. Only the discussion of the limitations existing for each sensory stimulus would demand for more critical and deeper considerations. This Section has been conceived to sensitize the engineering design community towards the possibilities offered by the virtual artefacts as flexible and rapid prototyping approaches for enabling a high-fidelity representation of the design problem, especially of those filtering dimensions of the problem where the human point of view could be no more taken into account as it has been done up to now. Obviously, before reaching this target, the issues previously mentioned have to be technically overcome, or new alternative paths identified.

6. Conclusion

The paper attempts to demonstrate how carefully in a design process, the prototyping activity should be performed since a number of aspects have to be taken into account at the same time. They are: the specific dimension of the design problem on which the early effort has to be focused on; the target audience interested into the problem solution, who has also the key to decide about the "destiny" of that solution; the kind of prototyping technique to use. Specifically, the discussion is focused on early prototypes since they play a key role in orienting design decisions, such as the rejection or approval of an idea.

As underlined in [Holmquist 2005], the prototyping activity itself should be treated with more attention since it is not only a matter of practical nature [Stolterman and Wiberg 2010], but it demands for a more reasoned process whose output is the prototype and whose boundary conditions are the selected dimensions of the problem to represent and the expectations of the target audience. But there is also something more to consider.

When the filtered dimension to represent is related to human aspects the prototyping approaches currently used in industry fail to represent the multisensory context at the basis of the experience of the user with the product. This aspect is well known in the HCI field, but not yet deeply explored in terms of its potential in the engineering design one. The HCI community has already started investing effort in developing new prototyping strategies in order to build flexible prototypes able to let the user perceive different kinds of experience that could be tuned in real-time according to his/her feedback. To this aim, the authors propose the virtual prototypes as a promising prototyping strategy towards the aim of rendering the multisensory experience lived by a user (which involves not only the product but also the context of use). However, technological limitations as well as open research questions are present, which are waiting for solutions from the engineering design community.

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