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Novel Interaction Methods for Product Design

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Abstract

This paper describes the first results of a research project aiming at developing a system based on shape manipulators and haptic tools for the creation, modification and evaluation of shapes of industrial design products. The paper describes how the users' requirements have been studied and analyzed, and subsequently used for the definition of the interaction modalities and tools of the system. The system architecture is described, and a first prototype built for evaluating the system concepts is presented. Finally, some scenarios showing the short-term and long-term evolution of the system are presented.

1 Introduction

In the industrial design sector the practice of hand-made physical prototyping is extensively used with two main purposes: 1) representing the conceptual idea of the product; 2) testing and evaluating the idea, the styling features of the product, and assessing it. Common practice is the following: the designer has an idea of the product in mind that translates into a sketch on a piece of paper. The sketch gives a rough idea of the product. It often consists of few styling lines, that do not fully and comprehensively represents the object the designer has in mind. Then, the sketch is given to a modeler who studies it, constructs a mental model of the object, and eventually builds a physical prototype (Yamada, 1997). The modeler is a highly skilled craftsman who uses her hands directly, or some tools like a rasp and sand paper, to shape an object out of an initial piece of plastic material. The obtained object is expected to truly represent in 3D the content of the sketch, and therefore the designer's idea of the product. Unfortunately, this is not the case and is due to the fact that the information contained in the sketch is too few to convey a clear and unique idea about the object. Therefore, the physical prototype requires to be reviewed. It is given to the designer who looks at it, touches it, and requires the modeler to perform some modifications. The modification/evaluation tasks iterate several times before the designer accepts the design, which happens when it is exactly the one she had originally in mind. The production of physical prototypes and their modifications require long time, and then is an expensive practice. Therefore, this practice can be considered effective but not efficient because of the just mentioned critical aspects.

A common trend of companies operating in the industrial design sector is finding alternative practices in order to reduce the number of physical prototypes required in the lifecycle development process. The current level of evolution of CAS (Computer Aided Styling) tools supporting the product conceptual styling phase is such that companies have started using those tools for building virtual prototypes of products. Actually, designers are not fully comfortable using these tools since they often find them too technical and much more oriented to engineers than to creative people. Since creative people lack the kind of technical training that the engineers are given, they spend a considerable amount of time trying to find out the appropriate procedures to reach the desired solutions. Another major criticism about these tools concerns the lack of physical contact and continuous tactile interaction with objects that are being modeled. Moreover, despite the fact that the visual realism that can be reached using current modeling and rendering techniques is very good, designers still like, prefer and require physical prototypes to assess the final product. Therefore, also in this case physical prototypes -even if fewer in respect to the previous case- are built with the consequent disadvantages already mentioned. An additional issue to consider is related to the integration of physical prototypes into the digital lifecycle of the product. In fact, the downstream phases of the product development process make use of tools, like CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) that operate on digital models of the product. The former types of tools are used for detailing the product design, the latter for defining its manufacturing. That implies that the physical models built for representing or for testing the ideas are in some way converted into the equivalent digital models. The practice commonly used is named Reverse Engineering and consists of building 3D digital models of physical objects acquiring a data set of points of the object surface using 3D scanning techniques and reconstructing mathematical representations of the surface from the point data set. This practice is complex, long and requires skilled operators.

The research work presented in this paper aims at providing a system that improves the design process performances by reducing the necessity of building several physical prototypes, and by tightly integrating the digital and physical prototypes. The research work carried out within the context of the project *T'nD – Touch and Design* (*www.kaemart.it/touch-and-design*) financially supported by FP6 IST Programme of the European Union proposes a new practice based on the concept of *Virtual & Haptic Prototype*. The project is developing a system based on shape manipulators and haptic tools for the creation, modification and evaluation of shapes. The system aims at offering intuitive ways of working with hands for shape creation and evaluation that resemble the ways modelers operate in their daily work. The use of the system is expected to reduce the number of physical prototypes, and to get a more efficient and less costly design process. The project is coordinated by Politecnico di Milano (expert in shape modeling, haptics and system integration), and involves two technology providers think3 (provider of shape modeling technology) and FCS-CS (provider of HapticMaster system), two academic partners Universitè Aix-Marseille I (expert in cognitive ergonomics) and Universitat de Girona (expert in product design sector), and three end-users Pininfarina (end-user operating in car design sector), Alessi and Eiger (end-users operating in the domestic appliances and household articles design sector).

2 Hand-made prototyping

The aim of the research work presented in the paper is to develop a system supporting ways of interaction that are easy, intuitive and pleasant to use for both modellers and designers so as to convince them to adopt the system as a daily working tool. Therefore, great attention has been put on the usability and on intuitiveness aspects of the interaction modalities with physical models (Bowman et al., 2004). The idea is to provide a system that resembles the manual way of working that is typical of modellers. Therefore, the initial activity of the project has consisted in observing modellers while modelling physical prototypes of products using their hands, and subsequently deriving some specifications for the system.
Cognitive psychologists participating to the research project have observed and analyzed the modellers' skill while molding physical prototypes using their hands. Modellers of industrial partners of the project have been video recorded and interviewed while creating physical models of some selected objects (a vacuum cleaner and a car C-pillar) by working malleable materials (like clay, foam material, etc.) with their hands. Subsequently, the collected data have been quantitatively and qualitatively analyzed in order to understand the advantages derived from using hands when creating shapes, and to understand the modellers' knowledge that is in their hands. That knowledge is often tacit and difficult to identify. It is indeed useful to capture it in order to reproduce it into the system. The analysis of the acquired data has produced the identification and classification of the tools used (manual tools, machines) and of the gestures and hand motions performed (for shaping the object, for feeling the surface quality). In addition, we have identified the hand-prototyping process tasks that consist of: template preparation, preliminary material removal, precise sculpting, surface finishing, comparison and measurement, visual and tactile assessment. Through interviews to modellers and designers we have also identified the most critical aspects of the process, in order to understand if and how the new system may improve the process performance.

The analysis of hand gestures has highlighted the fact that visual, tactile and kinaesthetic feedbacks are equally important in the shape creation and evaluation process. The skilled hand motions performed by the modellers allow for a precise creation of the shape; the tactile interaction with the object helps in comparing adequacy of the physical prototype with the drawings, in providing early clues about shape features, and in improving the 3D mental representation of the shape. From this analysis we have pointed out the most recurrent, common and effective users' hand operations. These are the actions that are going to be reproduced in the system: *scarping, surface quality testing and finishing* (Figure 1).

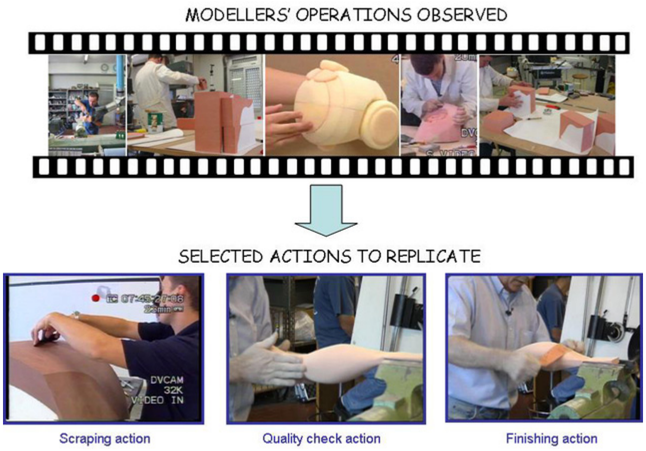

Figure 1: Capturing modelers' operations and analysis of actions to reproduce in the system.

3 System description and development

The system we intend to develop aims at overcoming the drawbacks of physical and virtual prototyping practices. Physical prototyping is a common practice used for design evaluation. The production of virtual prototypes requires considerable amount of time and is quite expensive; physical prototypes are made by skilled modellers who interpret designers' concepts with several difficulties and uncertainties; finally, reverse engineering is applied in order to reconstruct a digital model from the physical one. Conversely, virtual prototyping is a practice mainly used by designers for representing directly in the digital world a new product. The practice requires designers that are expert in using CAS tools, which are not so many. Besides, the design process using virtual prototyping requires anyway the production of physical prototypes in order to evaluate the design aspects of the new product. The proposed new system is based on the concept of *virtual hand-made prototyping* and aims at providing some functionality for creating digital models using hand-operated tools that resemble the common way of operating of modellers (Figure 2).

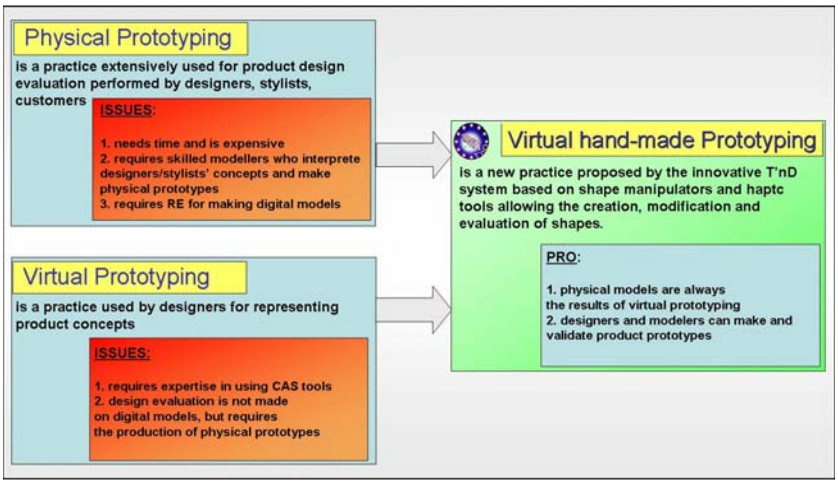

Figure 2: Virtual hand-made prototyping proposed by the project.

The following sections present the interaction tools and modalities studied for the new system. Moreover, the sections describe the system architecture, show the first prototype developed for evaluating the research concepts, and finally discuss how the system is expected to improve the design process.

3.1 Interaction tools and modalities

The interaction modelling tools and modalities are required to provide an environment and a set of tools for modelling object surfaces by removing material from an initial shape, and for finishing the surface and testing its quality. According to the analysis of modellers' operations, as described in § 2, the system has to provide tools like rasps and sand papers that allow the users to feel, touch and model the object surface. The sense of touch in virtual environments is provided by haptic devices (Burdea, 1996). Haptic devices are subdivided in force feedback devices, and tactile devices. Within the context of our project, only force feedback devices are considered at the moment. They are gradually penetrating commercial market segments. The past five or ten years have seen a considerable increase in the number of commercially available force feedback products. Besides, several prototypes have been studied in research labs. In order to identify and specify the appropriate force feedback tool satisfying our system requirements, an overview of state-of-the-art devices has been performed, also considering recent developments of haptics and applications (Laycock et al., 2003).

The PHANToM devices produced by SensAble Technologies, Inc. (www.sensable.com) have been the first commercial haptic products and are still the most popular devices. They are point-based devices having from 3 to 6 d.o.f. and using stylus or thimble as haptic interface. The working space is rather limited, at least in the standard model, and the maximum feedback force is low (10N). Some other similar devices have been developed like the HapticMaster device developed at the University of Tsukuba actuating three fingers. Rather recent more industrial oriented point-based devices are the HapticMaster produced by FCS-CS (www.fcs-robotics.com) and VIRTUOSE produced by Haption (www.haption.com). The HapticMaster is a bi-directional 3 d.o.f. I/O device. The feedback force supported is high (250N) and its working space is much larger than the one supported by most of the competitors' commercial products. That allows using the device to develop industrial applications like the welding application developed by FCS-CS in a research project (see FCS-CS web site for details). A different class of devices covers exoskeletons on user's hand, like the Sarcos Dextrous Arm Master (www.sarcos.com), the PERCRO device (www.percro.org) and actuated gloves like the CyberForce device produced by Immersion Corp. (www.immersion.com). Actually, these devices are quite cumbersome, difficult to wear and to operate, and therefore little effective and seldom used. Some benchmarking has been performed on current available technology, considering haptic performance indicators such as workspace, position resolution, stiffness, nominal forces, and tip inertia, and also some non-dimensional performance indicators (Hayward et al., 2004). Details about the state-of-the-art analysis can be found in a report available on the project web site (*www.kaemart.it/touch-and-design*).

There are very few haptic systems developed for sculpting virtual shapes. At the moment, the most popular is FreeForm by SensAble (www.sensable.com). Using the system, users can see and feel the shape of the object they model, and can also have a feeling of the type of material they are molding (clay, foam material, hard material, etc.). This system simulates a spherical sculptor's tool used to remove or add "matter" from/onto an initial block of matter. Its major limit considering the project requirements is that the high aesthetic quality level required by several industrial design sectors (like, the car industry or high-end customer products) –named class A surfaces- is not reached since the spherical tools provided by the system are not sufficient for complex models. This technique is anyway promising and it would be interesting combining this innovative user interface with a more aesthetic intent driven process.

Since the objective of the project is to create an interface that allows designers to interact haptically and graphically with virtual models of products including a true size car body, purely point-based haptic interaction that is provided by most of the haptic devices is not sufficient to appreciate and modify the surfaces in an intuitive way. Designers wish to interact either with the full hand, or with a virtual version of typical material modelling tools. Satisfactory full hand interfaces (haptic gloves) have not been built so far, despite a number of attempts and one commercial product (the Immersion CyberGlove). This is probably a bridge too far at the current state-of-the-art.

On the basis of the force feedback devices overview, the final conclusion we draw is that an extended version of the FCS HapticMaster (www.fcs-robotics.com) is the most appropriate hardware solution for the project. In fact, the device provides an adequate workspace (66 litres) and rendered force (250 N). Currently, the device provides from 3 to 4-d.o.f. (degree of freedom). Within the context of the project, the FCS HapticMaster is planned to be used as basic platform, equipped with a strong and stiff 6 d.o.f. device carrying simulated clay modelling tools. The interaction haptic tools are currently under development. They are conceived as two handle devices used for scraping materials, and as flat thin metal plates used for finishing the surface and for testing its quality.

3.2 System architecture

On the basis of the analysed users' requirements the system has been conceived and its functionalities have been defined. The system consists of a hardware component (the HapticMaster system) that is controlled by a software module that computes and renders the geometrical model of the object, and computes the response forces to be actuated by the haptic device. The architecture of the system is shown in Figure 3. It consists of the following main components:

- the FCS HapticMaster is operated by the user. The device is going to be equipped with innovative haptic tools that are oriented to design and modeling operations. In response to the collision with the virtual object the device renders appropriate contact and reaction forces. The rendered forces depend on the type of collision and on the type of material being simulated.
- the haptic rendering system includes a collision detection module for detecting contacts between the virtual representation of haptic interface (avatar) at position X and the virtual object; a force response module that returns the interaction force between the avatar and the virtual object; and the control module that returns a contact force to the user (that is the ideal interaction force approximated to the haptic device capabilities).
- the simulation system updates the geometric and haptic model of the object on the basis of the shape, position and speed of the haptic tool.
- the visual rendering system renders the graphic representation of the object on the screen.

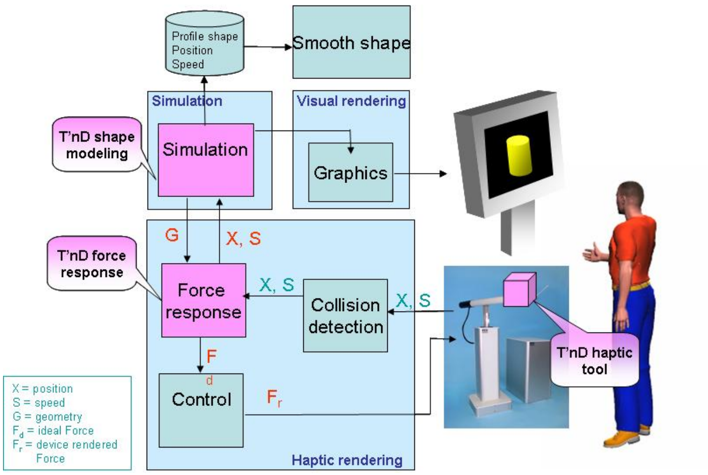

Figure 3: System architecture.

3.3 System prototype and evaluation

The idea of using a haptic tool for modeling objects in the industrial design field is quite new. Therefore, we have considered very important testing the concepts and interaction modalities proposed by the research with designers in order not to build a system that users won't like, and consequently won't use. Therefore, in order to test the concept of haptic "scraping" in the virtual environment, we have developed a prototype that can be evaluated by end-users.

The system set-up consists of an initial version of the scraping haptic tool driven by two integrated HapticMaster devices (so as to have a 4-5 d.o.f. haptic system), and a monitor showing the object virtual model. The developed example aimed at just validating the general idea. Therefore, in this first implementation the system shows a simple geometric object. The user handles the haptic tool with two hands like in the real case when using a scraping tool, and moves it for removing material (Figure 4). When the haptic tool gets in contact with the virtual object, it gives back the user a haptic feedback. The tool is equipped with some buttons on its back side that allow the user to change some physical parameters of the models. The two buttons placed on the right hand side of the tool allow the user to set the stiffness of the material. The two buttons on the left hand side allow changing the resistance of the material when scraped.

Some users have been invited to try and evaluate the prototype. They consist of designers and CAS/CAD engineers. They all agree on the fact that the system is suitable for rough shape creation. Conversely, few of them seemed not fully satisfied concerning the possibility of creating precise shapes. For what concerns this comment it is important to underline the fact that the current implementation of the system does not provide a graphical feedback of the result of the actions of the users, and also no stereo vision has been yet implemented. That might indeed limit the possibility to interact precisely with the object model. In general, all the testers have expressed the opinion that the system might be a very helpful tool both for modelers and designers. They all seem quite positive in the possibility of integrating this new tool with other modeling tools within the design process. At the moment, testers do not see the possibility to replace 2D sketching or 3D CAS tools, but rather they confirm the effective use of this tool for substituting the physical model making. Concerning the system usability, they all agreed in confirming its extreme intuitiveness for creating shapes, also because of the intrinsic naturalness of the hand gesture. An important achievement to be noted is that all participants considered the motion they were making and the forces implied of extreme good quality, absolutely similar to the ones of the physical clay model making.

Figure 4: End users testing the first prototype of the system.

3.4 New product design process and benefits

Hereafter, we describe the new product design process and the benefits that are expected compared to the current process implemented in industrial design companies.
The new developed system addresses two types of users:

- Modelers who are skilled in using hands for creating/modifying shapes, but who are not able to use digital tools.
- Designers who are skilled in using CAS/CAD tools but do not have expertise in hand making prototypes.

Figure 5 shows the new design process based on the use of the proposede *virtual hand-made prototyping* system. The system is used by designers and modellers for creating, modifying and evaluating new product concepts. Initially, users use the system for creating shapes starting from initial ideas and concepts. The system provides in output models that are physical and digital (high quality surface) at the same time. To note that in the proposed process physical models are always the results of virtual ones.

The new design process based on the use of the developed system has the following main features, and consequent benefits:

- Design and testing activities are carried out in one *unique task*, performed by a *single user* (designer/modeler), using the innovative system. Therefore, in the laps of time available for new products conceptual phase more design solutions may be evaluated. Besides, the user makes a first version of the product, starting from her concepts and ideas, and can continuously and directly test and modify it. The model is created, tested and modified by the same user, without the necessity to depend on other practitioners. In this way, delays among the activities performance are reduced or completely eliminated, and the number of creating/evaluating iterations is also reduced.

- The system provides a unique environment where physical and virtual model can be created and evaluated. The output is a virtual/physical model that is represented by high quality surfaces, and therefore no surface reconstruction or reverse engineering (RE) techniques are required. The product model developed using the proposed system is unique and coherent: it is at the same time a virtual and physical model.
- The CAD engineer intervenes only at the end of the process, using the available CAD model that is provided by proposed system in a high quality format, for refining and detailing the model, and for making only few or even better only one final version of physical prototype of the product using a rapid prototyping (RP) technique. The data exchange from CAS to CAD model is not required any more, since the designer is expected to directly produce a high quality surface model; and also the reconstruction of CAD models from physical models using expensive reverse engineering techniques has less impact on the process.

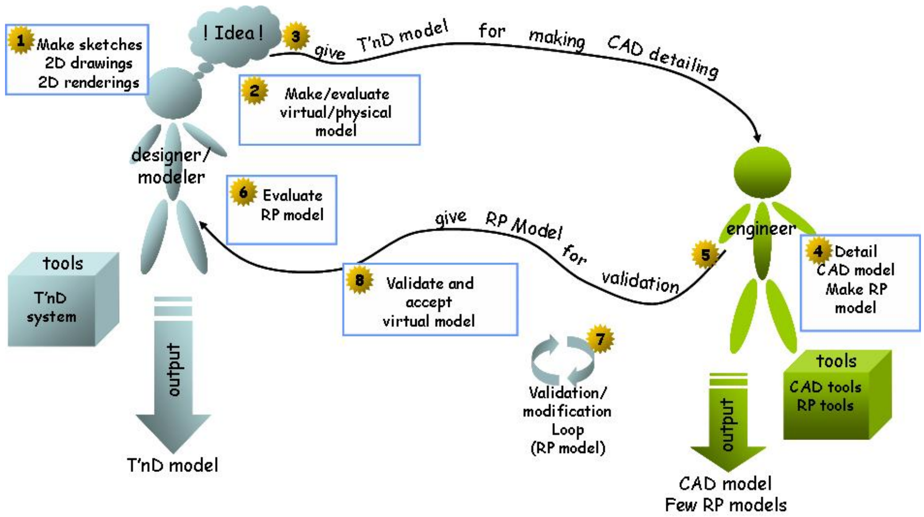

Figure 5: New design process using the new proposed system.

4 Scenarios

In order to validate the system concepts, to show how the system will work once implemented, some Scenarios have been developed (they are available on the project web site). A Scenario describes the environment, the hardware components of the system, and how the system is operated by users. Scenarios are defined on the basis of system requirements and short-term and long-term technological goals. Two types of scenarios are proposed. The first one is a *short-term scenario* that demonstrates the use and performances of the proposed system for shape creation and evaluation. The scenario shows improvements in the process and in the ways of doing things, and exploiting skills due to the integration of shape modeling and haptic technologies extended with novel interaction metaphors and devices. An animation has been developed showing a user scraping an initial piece of material, manipulating a haptic tool simulating a scraper, and also evaluating the shape surface using a haptic tool that is aimed to allow users to feel directly the contact with the surface using their hand (Figure 6).

The second one is a *long-term scenario* that describes how a shape modeling system based on haptic interaction might be according to IT providers' long-term vision about technological evolution in the two addressed fields. The scenario is based on haptic feedback provided by more friendly, natural and easy to use tools that support a better exploitation of designers' skills they have when creating shapes by hands (Figure 7). The envisaged haptic tool might be an evolution of the tactile devices and haptic windows that are at the moment only available as academic prototypes (Iwata et al., 2001). The long-term scenario is going to be used to check if the evolution trend of technology is such that users' expectations will be fully or partially satisfied. This is useful to understand if technology functionalities and users' requirements are going to converge at a certain point in the near future.

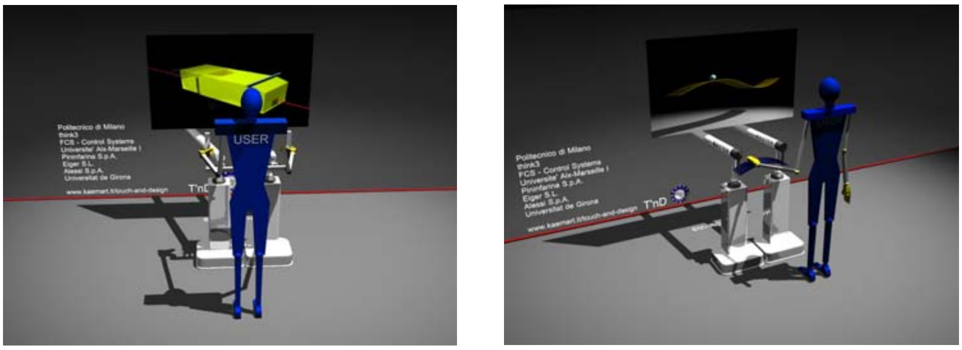

Figure 6: Snapshots of animations showing short-term Scenarios.

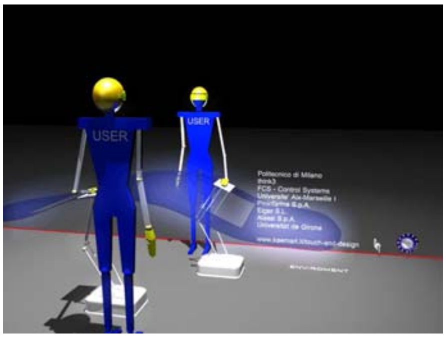

Figure 7: Snapshot of animation showing long-term Scenario.

5 Conclusions

The paper has presented the initial results of the research project T'nD funded by the European Union. The paper describes the motivations that justify the project, the objectives and relevance of the research topics in the industrial design sector, the requirements collected by interviewing and observing designers and modelers at work, and the analysis performed for designing the system. Furthermore, the paper presents the first achieved results that consist in the identification of the system functionalities resembling ways of operating of designers and modelers, the study of the haptic tools and of the shape modeling techniques, and the system architecture. A prototype of the system has been built in order to test with end-users (designers, modelers and CAD/CAS engineers) the concepts proposed by the research. Finally, some scenarios are described presenting the characteristics and use of the system, and longer vision about evolution of shape modeling systems based on the used of haptic tools. The system under development is expected to be a major improvement for industrial design companies that will be able to shorten product design lifecycle, improving design quality, while preserving valuable skills of operators.

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