Tools for Industrial Design: From Barriers to Enablers of Creativity

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ABSTRACT

This paper presents an innovative tool based on enactive interaction for the industrial design sector. Enactive interaction is based on the action-perception paradigm where users learn how to do things by doing. Recent progresses of the research on haptics have allowed us to build an innovative tool for the modification of the shape of a digital product that includes a haptic strip as interaction device. The tool allows designers to easily and intuitively modify digital shapes just acting on the extremities of the strip. Compared to traditional design tools based on the manipulation of mathematical surfaces through geometrical manipulators and control points, this tool has proved to better exploit designers' skills and creativity.

Keywords: product design, tools for design, enactive interaction, haptics.
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1 INTRODUCTION

Traditionally, the product development process (PDP) consists of three major phases: Design, Engineering and Manufacturing.

Product Design is the phase where concepts and specifications are created and developed, which optimizes the function value and appearance of products. Industrial Designers study both function and form, and also the connection between the product and the users. Typical activities of Industrial Designers include user research where target users and users' needs are investigated and identified, comparative product research where competitors' products and alike products are studied, and the subsequent activities including sketching, model making, prototyping and testing, aiming at representing the concept of the product and performing preliminary studies.

Product Engineering is the phase where the products are specified. Engineers receive product specifications and find solutions that are bounded by constraints. When they receive clear specifications of the products, they know when they have succeeded in the design. Typically, engineers deal with the more technical aspects of the product definition; they identify problems and find solutions, following rules of thumb, numerical tables and books of regulations etc.

Product Design and Product Engineering have traditionally been well distinct: designers design and engineers do the engineering of the product. And the design of a new product goes back and forward between these two phases. The Design and Engineering (D&E) loop is indeed costly, may cause misunderstanding and loss of data and information; eventually, in the attempt of reducing the number of iterations, it may produce products with less quality.

Computer aided tools used since the 70s are software programs that assist designers and engineers in the design of products. Since profiles of designers and engineers are different, they need different tools that at best meet their characteristics. Designers and engineers differ in various aspects, including the methods and techniques they use during the design, the vocabularies they use to address objects and their properties, their world views and histories, and also their demeanors and dress style!

Computer Aided Design (CAD) tools are devoted to engineers, and Computer Aided Styling (CAS) tools are instead used by designers. Tools for engineering have a technical approach that well satisfies the engineers' needs. In fact, these tools implement a technical approach to technical problems. Conversely, tools for aesthetic design are not completely satisfactory for the designers, who would like to use working environments that allow them to better exploit their natural creativity.

This paper analyses issues related to tools for aesthetic product design and suggests new tools that may contribute in better exploiting designers creativity. These tools are based on the concept of enactive knowledge, where perception issues suggest users how to act with systems and environments, and users learn to do things by doing.

2 EVOLUTION OF TOOLS FOR DESIGN

Digital tools for the creation of shapes, CAD (Computer Aided Design) tools or CAS (Computer Aided Styling) tools, support the creation of shapes including their definition, representation and testing. Currently, they have reached very good performances in terms of graphical representation of the digital products. Conversely, their user interface, and then the usability of these tools, has not reached a good quality. This is particularly true for CAS tools that are mainly used by designers, who are creative people with a limited knowledge about the technical aspects related to the representation of surfaces. In fact, CAS tools include curves and surfaces manipulators that allow designers to control the shape of a surface, which underlines a mathematical representation. Although having little knowledge about mathematics of surfaces, designers have to model surfaces through the use of these manipulators. Actually, this may not be the most natural and effective way for designers to create a new object shape by expressing their creativity. For these reasons, still today several designers prefer using clay, wood, cardboard to create a physical representation of their idea of a new shape.

A very important task in the design of complex-shaped products is shape modification applied to fit local/global aesthetic requirements and/or engineering constraints. Shape modification involves different modelling aspects like fairing, local correction, global deformation, shape optimisation, etc. The geometric models supported by most CAD and CAS systems are generally based on curves and surfaces represented by NURBS. Their shape generation and manipulation are obtained by acting on some low level parameters (control points and weights). Although it is still extensively used, this technique is neither sufficiently intuitive for the designers nor definitively adapted for patchworks of trimmed entities (B-rep). Several alternative deformation techniques, based on the extension of feature capabilities to free form modeling, have been developed to provide users with an easier and more intuitive control of the surface shape: [6, 9, 17] and others.

The recent and fast evolution of technology has proposed some systems that attempt to provide better user interfaces oriented to design. Virtual Reality technologies are used for the implementation of these systems. The 3-Draw system [15] allows users to sketch a set of curves and use them to define the skeleton of a surface, as in a wireframe representation, but there was no possibility to create a surface with the curves drawn. JDCAD [10] is a system based on a desktop configurations equipped with a pair of shutter glasses for the stereoscopic vision that supports the creation of 3D primitives and Boolean operations. One of the first modeling applications using immersive Virtual Reality technology was 3DM [5]. It is based on the use of a head mounted display to visualize surfaces modeled by triangle nets. The COVIRDS system [8] tries to combine various multimodal technologies, such as speech input, gesture recognition as 3D input and output, and to develop new interaction techniques for creating and modifying free-form surfaces. Perles and Vance [14] have developed a set of tools that allow users to change the shape of NURBS surfaces in a virtual environment.

Some other advanced modelling tools allow the creation of sketches of products. Particularly interesting are those applications using a physical tape (for example the ShapeTape by Measurand) as curve input device [12]. The manipulation of the tape allows for the creation of 3D digital curves, but has problems regarding precisions in terms of the following aspects: absolute positioning of the starting point of the strip and relative position of the end point, and correct rendering of the 3D shape.

More recently, haptic technology has been integrated into the design tools. Haptic modelling is a term used to indicate modelling of virtual shapes using haptic technologies. Haptic modeling systems allow users to touch, feel, manipulate and model objects in a 3D environment that is similar to a natural setting. Several examples of sculpting systems have been developed based on haptic force associated with dynamic subdivision of solids that give users the illusion of manipulating semi-elastic virtual clay [7, 11]. These applications are based on the use of the point-based PHANToM stylus for interacting with the virtual clay.

The only physically-based shape modeling system commercially available is FreeForm by SenSable Technologies Inc. [16] which is based on the PHANToM haptic device. The FreeForm modeling system uses an internal volumetric representation and associated techniques, so it appears rather difficult and time-consuming to create smooth surfaces and smooth sharp edges or “tense” shapes on models using this system. More recently, the ClayTools has been released by Sensable Technologies Inc., where the PHANToM haptic interface has been integrated into the modeling applications 3ds max, Maya and Rhino. Finally, the T’nD project has developed a haptic system based on a haptic scraping tool and sweep operators for digital material removal [2].

3 DESIGN PROCESS OF AESTHETIC PRODUCTS

The design process in the aesthetic domain can be represented as a spiral that is evolving and moving forward from the initial idea (Fig. 1). The *aesthetic domain* is fuzzy in its boundaries since characteristics like elegance and beauty cannot be precisely and universally defined and perceived. Differently from the engineering domain, it is not possible to define a final target of the solution starting from the initial idea, as well as it is difficult to say how far we have moved from the starting point. It is during the evolution of the initial rough solution that designers understand more clearly in which direction of the solution space they are going and how far they are from the initial point. Furthermore, differently from the engineering domain, the quality of the solution is not measurable through a metrics; in fact, the evaluation of the result is very much subjective and related to the designer’s perception and sensitivity.

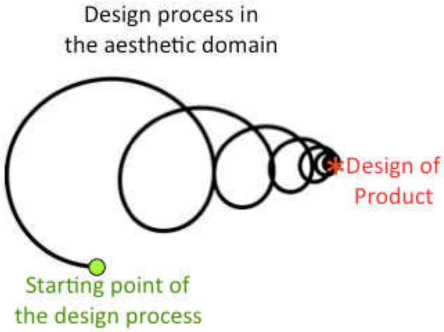


Fig. 1: Design process in the aesthetic domain.

Designers are creative people, often using their hands and manual skills for performing their daily activities. The ability they have in working with their hands depends on the experience they have acquired during their practice, and also on their personal and cultural issues.

Creativity is related to the generation of new ideas and new concepts. Therefore, it is strategic to understand, especially for companies, how to create the best working conditions so that designers can generate more and better ideas, and become more creative. An approach to achieve that is to allow designers to operate using tools that exploit at best their know-how and skills.

In the engineering domain, technology is the enabler of design tasks like computation, analysis, simulation, and supports the quantitative evaluation of the quality of the result (performances etc.). In the industrial design domain, technology is expected to support creativity and to enable the re-use and exploitation of designers' know-how and amplify the knowledge and acquired experience in a shorter time.

If we consider the level of interaction on one axis and the level of exploitation of creativity on the other one, current tools oriented to industrial design have low level of interaction, and therefore the possibility they offer for exploiting designers' creativity is very limited (Fig. 2). In other words, they are barriers actually limiting the designers' creativity. In fact, they are often complex to use and also to learn, and distract designers from their target, and interrupt their creative thinking. One of the more traditional ways of generating new shapes is by building physical prototypes manually. If we observe designers while generating shapes using their hands, we notice that they create and change the shapes many times before reaching a satisfactory final shape. This process is very fluid, and naturally and easily carried out by the designers. Therefore, interfaces of new generation design tools should enable the growth of the level of interaction, being more natural to use for designers, and thus allowing the full exploitation of their creativity and skills.

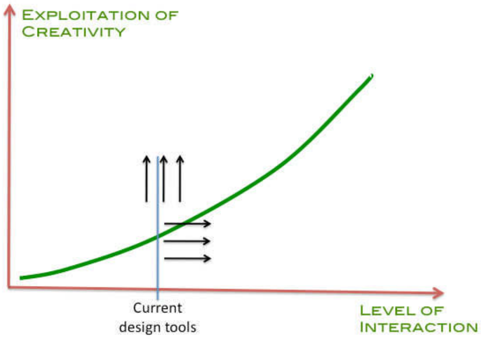


Fig. 2: Level of interaction vs. degree of exploitation of creativity.

4 DIGITAL TOOLS FOR DESIGN

In order to increase the level of interaction, as seen in section 3, we need to develop tools that are more oriented to users and to their needs and profiles. These tools should be built as centered on the designers, and should not be a piece of technology that the designers are called to use. Tools for designers should preserve their personal characteristics and exploit their talent, skills, abilities and know-how.

Consequently, design tools have to be implemented according to a *user-centered design approach* [13], that typically puts the users of a system, designers in this case, at the center of the system design. Requirements of these tools are defined starting from the study of the users' needs and are continuously validated and checked with them during the tool implementation. This would guarantee that the tool at best satisfies the users' expectations and needs. Therefore, the human computer interaction of these tools needs to be well conceived and tested.

4.1 Human Computer Interaction

Traditional human computer interaction is based on symbolic and iconic knowledge, which is related to conventional meaning and cultural significance. User interfaces based on this kind of interaction are basically predictable and deterministic. In contrast, we may think of building user interfaces based on the concept of enactive knowledge [4], which refers to information that the user gains through *perception-action* interaction in the environment. By doing things and performing actions, users learn how to perform and increase their knowledge about the environment and also about the way of doing.

Enactive Knowledge is characterized by a learning process, where humans interact through direct actions and learn by doing.

In an action-perception model of interaction (Fig. 3), the human performs actions on the environment (for example, he grabs a slippery object) and also perceives the effect of the interaction through senses (for example, the feeling that the object surface is slippery). Perception allows the human to take decisions about the action (for example, increase the force applied to the object surface for avoiding that the object slips out of hands). The actions towards the environment are performed through a combination of various modalities, such as gaze, gesture and touch, and also speech. The perception is performed through one or more senses: vision, sense of touch, hearing, sense of smell. Applications implementing this model of interaction are multimodal, since both actions and perception may happen through the implication of various modalities.

This interaction model allows users to learn how to do things by doing those things.

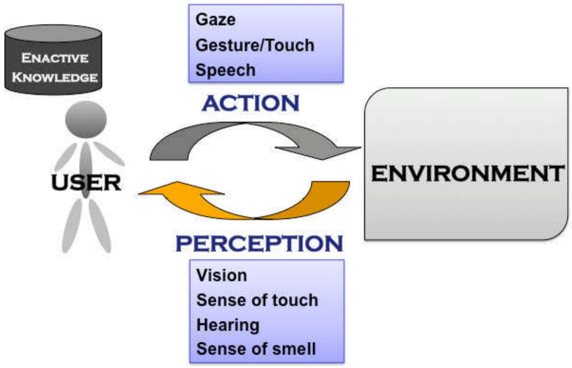


Fig. 3: Action-perception model of human interaction with the environment.

4.2 Enactive Human Computer Interfaces

Enactive Human Computer Interfaces (HCI) are interfaces that are based on the action-perception interaction model. They provide natural and effective ways of interaction, due to the fact that they look very natural to the users. The users, through perception of the system with which they are interacting, decide how to act subsequently. *Enactive Interaction* is driven by users' manual actions, and users' actions are driven by system responses perceived by users through various perceptual senses.

In addition, in respect to traditional HCI, enactive HCIs support physical interaction that generates emotions. This implies a major involvement of users in the use of systems. These interfaces tend to suggest users new ideas in a non-deductive way.

It is interesting to investigate how enactive interfaces can be used and exploited for increasing the level of interaction in tools for product design, which are today still based on traditional interaction modalities. In particular, it should be investigated how to exploit the use of more complex interaction modalities based on visualization, sense of touch and sound, as well as how to use multiple modalities for enhancing the represented information, for complementing the information, for accommodating the perception thresholds that are typical of some senses, and also for coping with limitations of some technological implementations.

4.3 Haptic Perception and the Sense of Touch

Haptic perception refers to perceptual processing of inputs from multiple subsystems, including those in skin, muscles, tendons and joints. Haptic perception is usually active and information seeking: the perceiver explores the world rather than passively receiving it.

There are two basic modes relating perception and action: perception for action and action for perception. In the first case, perception is used for the control of objects during actions. This relies on feedback from mechanoreceptors to ensure appropriate grasp and avoid slippage. The second case is a more active form of perception and involves active exploration of the world through touch. Through actively exploring the environment it is possible to perceive an object's shape, texture, hardness, temperature, size, and weight. However, unlike vision where the object can be perceived almost instantly, touch necessitates exploration over a period of time [18].

In the last years, haptic devices and haptic interaction have been introduced as new modalities for interaction. Haptic systems allow users to interact with virtual objects through the sense of touch. Therefore, they allow users to feel kinestetic feedback and tactile perception during the interaction with the digital environment.

We can classify the haptic devices into two categories:

- Kinesthetic devices, that are commonly named haptic systems, which provide force feedback on users' muscles and tendons when the user gets in contact with the virtual objects.
- Tactile devices, mainly including thermal and vibro-tactile devices that provide tactile sensations on the users' skin.

Kinesthetic devices are generally used for the creation and manipulation of shapes, while tactile devices are used for the perception of the features of digital objects surfaces, like smoothness and roughness.

5 AN ENACTIVE INTERFACE FOR SHAPE MODIFICATION

One of the recurring problems during the conceptual creation of shapes of new products concerns the effectiveness of the tools that support first the creation and then the modification of shapes. In order to be effective, these tools should be natural to use for the designers. With the aim of proposing a new tool, we have studied a system based on the concept of enactive interaction for the modification of aesthetic shapes.

5.1 System Description

The system, named SATIN system, has been developed within the context of a European research project and consists of a Mixed Reality environment where the user can interact with both the virtual and physical representations of an object within a unique working space (Fig. 4) [4]. The user is able to see the virtual object and to both explore and modify the virtual model through the manipulation of the haptic interface. The haptic interface consists of a tangible deformable strip that is inspired by the tape that designers usually place on physical mock-ups for evaluating their characteristics and style lines. A 3D visualization of the shape is super-imposed onto the physical device by means of a stereoscopic display system.

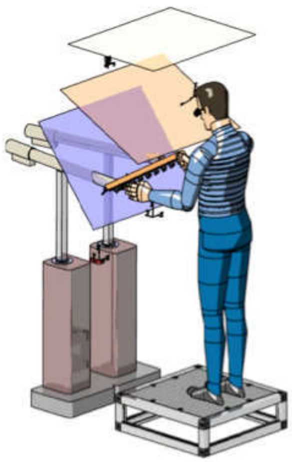


Fig. 4: Conceptual representation of the SATIN system.

The visualization system consists of a DLP projector that projects the light onto and through a set of mirrors and screens forming a 3D image of the virtual object on top of the haptic strip [3]. The projector is located above and on the back in respect to the haptic system, so that it does not occlude the image projected by the projector. The display system is designed in a way that its components do not interfere with the haptic workspace. So, the user can freely move his hands within the interaction space and is able to interact with the system by grabbing and manipulating the physical interface that is positioned under the mirrors.

The haptic device consists of a force sensitive tangible strip, positioned and oriented in space over the simulated virtual object (Fig. 5). The user manipulates a virtual cutting plane for selecting a section, which is a curve, of the virtual model of an object. The strip actively shapes itself for representing the curve, and is placed in the appropriate position and orientation in the workspace by two FCS-HapticMaster systems. The haptic strip is designed as a continuous physical spline that is actuated into the desired shapes by equidistant relative actuators along its length. The haptic interface consists of a geodesic strip of 600 mm length, that can bend and twist, so that it can render any geodesic curve [1]. The strip is equipped with a lighting element in order to improve the strip visibility through the mirror of the visualization system.

Being a haptic device, the tangible strip is an output device in that the strip is an exploration device that can be touched by the user with his full hand. Once conformed to a curve, the user can touch the strip so as to evaluate the quality of its curvature and other geometric features. It is an input device as well, in the sense that the strip behaves as a physical item that can be shaped manually like a physical spline. To be used as input device, the strip extremities have been equipped with sensors.

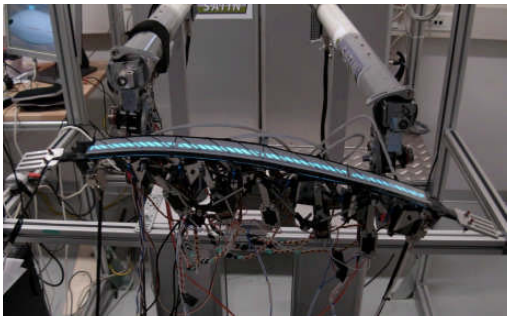


Fig. 5: Haptic strip equipped with sensors at the extremities and with a lighting element.

The shape of the handling extremities have been designers so as to be naturally and simply handled by the users. In order to modify the shape of an object surface, the user first has to select the deformation modality using a graphical menu. Then, moving the haptic strip over the object surface he selects the curve to inspect and modify. Fig. 6 shows the curve selected on top of the surface of a virtual object (the digital model of a vacuum cleaner). The deformation is controlled by the user through the strip extremities. The sensors read the forces applied by the users and translate these values into parameters that globally modify the shape of the object. Actually, the system interprets the users' intent and transforms pushing and pulling actions exerted on the strip extremities into a curvature deformation. The system provides visual and haptic feedback to the users' actions. During the deformation the visual representation of the model is deformed, and at the same time the physical strip shape is updated.

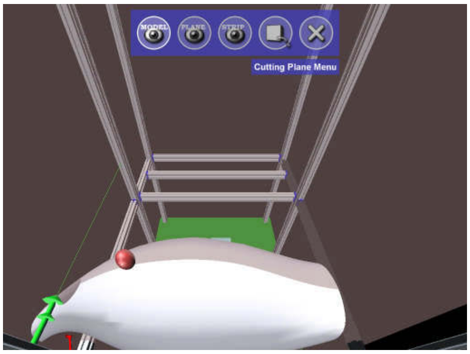


Fig. 6: Curve selected on top of the surface of a virtual object.

The user can cancel or commit the deformation at any time using the small buttons located at the extremities of the trip. Fig. 7 shows two subsequent steps during the modification of a digital shape. When the task is completed, the user can decide to exit the deformation modality, to undo the modification and recover the previous state of the model, or to save the new model for possible comparisons with previous models. For the sake of performance, during the interactive deformation only a tessellated representation of the model is deformed instead of the whole CAD surface model; when the deformation is committed, then the CAD model is updated.

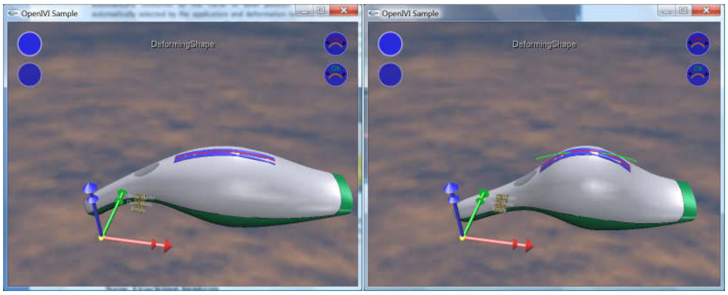


Fig. 7: Two subsequent steps concerning the deformation of a curve, which infers the application of a global deformation to the object shape.

Fig. 8 shows a user while using the haptic strip for deforming the shape of a digital object. The user is interacting with the extremities of the strip. The deformation of the shape is visible in the two pictures. The digital model is also rendered using zebra-lines, in order to increase the global perception of the quality of the shape.

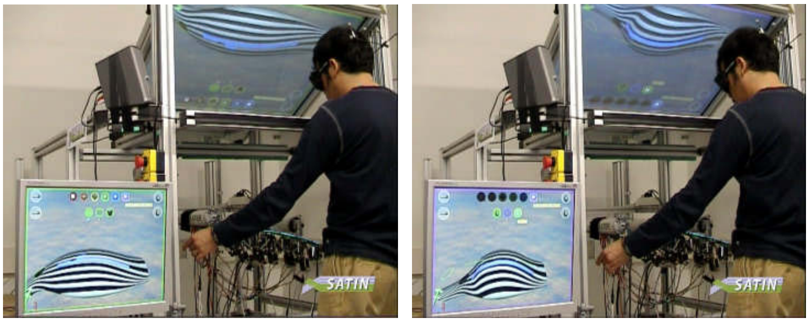


Fig. 8: Designers using the SATIN system for modifying an object shape.

5.2 System Evaluation and Discussion

The system has been tested with some users in order to proof the system concept and check its effectiveness and potentialities. We have organized a testing session where six industrial designers have been invited to evaluate the system. The participants were asked to perform the following tasks:

1. Look at the object through the stereo visualization system;
2. Select a curve of the object surface by using the haptic strip;
3. Evaluate the aesthetic features of the object, through the exploration of the haptic strip;
4. Modify the shape through the manipulation of the strip extremities.

The testing procedure consists of an initial demonstration of the system and its functionality, followed by up to 10 minutes of training performed using the system, and then a variable time frame dedicated to accomplishing exploration, evaluation and modification of the selected model. In order to collect data about the testing sessions, we have made use of video recording and a final questionnaire. The participants were asked to complete a questionnaire after the completion of the tasks. The questions and evaluation results are reported in Tab. 1. The score system proposed has a scale from 1 (which is the most negative value) to 6 (which is the most positive value).

From the analysis of the answers and the free comments given by the designers, we can state that the general impression of the system was good. Overall, all the participants reported a high level of appreciation of the concept of the system. Since the use of 3D stereoscopic visualization and haptic interfaces is a rather new concept, we have allowed the participants to use and play with the system for 10 minutes before performing the tests. The perception of the participants was that the system is quite intuitive and easy to learn. They affirmed that they were able to acquire some dexterity in using it, which makes them confident that they will be able to improve their performance the next time.

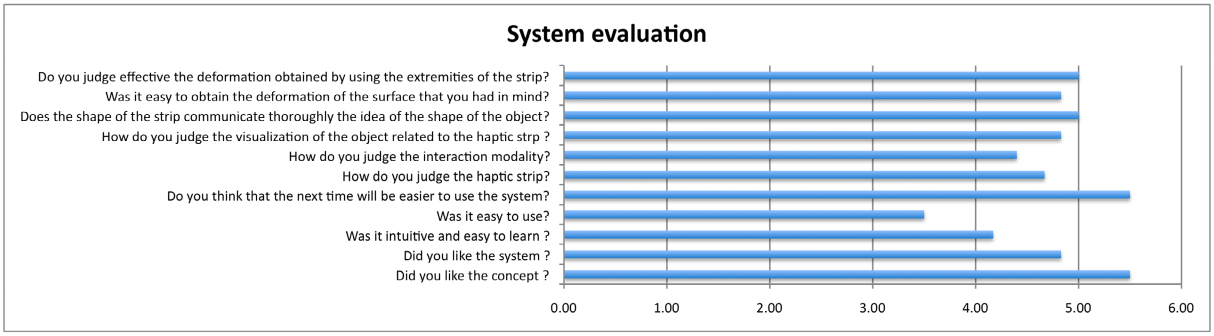
The participants have particularly appreciated the possibilities of exploring the surface by means of the haptic strip. Actually, most of them have asserted that the perception of the surface reflects the visual one. In addition, the participants have recognized the effectiveness of the strip in communicating thoroughly the idea of the shape of the object that they are seeing.

Particularly interesting are the evaluation results concerning the modification modality. The participants appreciated the possibility of quickly applying modifications to the object shape, even if the current implementation of the system does not allow for a fine and precise surface deformation. Anyhow, the possibility of controlling the shape just using the hands and modulating the applied forces has been considered very intuitive and effective.

It can be noticed that the action-perception loop, implemented in our system by the actions performed on the physical strip, i.e. pushing, pulling and twisting the extremities, and the consequent perception of the shape modification is effective and allows the users to quickly understand how to act on the strip in order to obtain certain deformations of the curve. The system implements a level of interaction that is higher with respect to traditional tools for industrial product design. This allows designers to better express their creativity, without bothering too much on technical aspects of the interaction, but rather concentrating on the task and on the aesthetic quality of the shape. In addition, using various senses (specifically, the sense of touch, which is particularly important for designers) for interacting increase the designers' emotional involvement in the creation of new aesthetic shapes.

6 CONCLUSIONS

In this paper we have described an innovative tool based on enactive interaction for the industrial design sector. The tool integrates 3D stereoscopic visualization and haptic device and is used by designers for the modification of digital aesthetic shapes. The haptic device consists of a physical strip that is actuated in order to conform to the shape of a curve selected on a virtual object. The designer can touch with his hands the physical strip in order to check the quality of the curve. The strip is also equipped with some sensors at its extremities that can be handled for applying global deformation to the digital shape. Designers can push, pull and twist the strip extremities for controlling the deformation applied to the shape.



Tab. 1: Results of the system evaluation.

The system has been tested with a set of designers in order to proof the system concept and check its effectiveness and potentialities. From the tests it resulted that the designers appreciated the possibility of using a physical means for interacting with the digital product. The haptic strip has been considered a good starting point towards the development of devices for shape evaluation. In addition, the possibility of controlling the shape of an object very easily and intuitively through a haptic manipulator has been considered powerful and effective.

An important result from the tests is that the action-perception paradigm at the basis of the physical strip is really effective for the designers who can learn how to model the shape and reach the desired form just intuitively acting on the device. This intuitive way of working allows them to concentrate on the shape, rather than on the technological means, and this contributes in allowing the exploitation of their natural skills and creativity.

Future work plans the study of an extension of the haptic strip, investigating the possibility of developing a haptic interface allowing free-hand interaction with a patch of a surface.

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