Design intent-oriented modelling tools for aesthetic design

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ABSTRACT
The paper presents the outcome of an international research project, aimed at identifying and implementing an innovative approach in computer aided aesthetic design. Despite the availability of sophisticated modelling tools, there are still critical issues to be faced in order to get functionality really suited to the creative users mentality. The presented results are based on the analysis of the design activities carried out with stylists and *surfacers* (Computer Aided Styling operators) both in the automotive field (BMW, Pininfarina, Saab), and in household supplies field (Alessi and Eiger). Some of the identified aesthetic features, used by designers to judge the shape, are discussed. In particular the free–form modelling tools for curve modification driven by aesthetic properties perception will be presented.

Keywords
Aesthetic design, aesthetic features and properties, shape perception, geometric modelling.

1. INTRODUCTION
Styling is a creative activity where the designer's goal is to define a product that evokes a certain *emotion* while satisfying the imposed constraints, both ergonomics and engineering. Currently, the adopted computer aided design tools offer functionality mostly based on low level geometric elements: often, to know which elements have to be changed and how to obtain the desired model modifications, a deep understanding of the underlying mathematical representation may be required.

The objective of the project is to improve the industrial design workflow by the definition of innovative digital tools more adhering to the mentality of creative users and able to support them in easier attaining a model with a certain emotional character and in its preservation during the required model modifications. In order to identify a proper class of properties, linked to geometry but more directly connected to the design intent, the possible relationships between shape geometry and aesthetic character have been investigated. The formalization of these links could offer many advantages at different levels. First of all, a better understanding of human reactions may lead to an easier comprehension of market wishes and tastes. Furthermore, the formalization of these relations as items of knowledge to be processed by a computer system may allow the designers' aesthetic intent to be communicated through a product's shape and non-shape (e.g. colour and material) characteristics.

Several studies aiming at identifying the links between a product's shape characteristic and its emotional message have been carried out. These relationships have been analysed from different perspectives including perceptual psychology [Luh94, Leb00], design and computer science [Wal93, Bre98, Hsi98, Yos98, Che98, Smi00]. In literature, results of experiments are shown about the possibility of categorizing products in classes sharing

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some aesthetic character terminology [Bre99, Don99, Ish97]. However, all these experiments are quite limited in the number of analysed objects and interviewed persons as well as in the results. No systematic and precise specification of a correspondence between product elements and emotional terms has ever been provided. Also the problem related to the use of terms has not been fully addressed; terms have the disadvantage of being subject to personal interpretation, mainly depending on cultural environment and personal experience; an universal code, mapping a set of words to a set of lines or shapes, is undoubtedly attractive but questionable, as aesthetics and trends are highly variable, depending on time and places and the verbal expression of the emotional aspects is subject to changes accordingly. Furthermore the differences of languages have to be considered. This implies that some possibility of adapting or customizing the connections between terms, describing geometric characters, and aesthetic properties has to be taken in account. A formalization that could be processed by a computer program requires the identification of direct relationships between the geometric elements of an object and its aesthetic characters. Ideally, the mapping specifies those values of shape characteristics and parameters that correspond to the design model conforming to the intention. Van Bremen and his colleagues at Delft University [Bre98] provided some examples of possible, but not tested, associations between aesthetic and shape parameters without proving an effective feasibility of the mapping process. They conclude that such an association is rather difficult and it is not a simple mapping, since the same aesthetic parameters can be associated to different shape parameters. For this reason, it is not possible to give an absolute definition of an aesthetic character, but it is preferable to specify how to increase or decrease the object's already given characters. In addition, it was shown that the choice of the aesthetic variable type depends on the product. Therefore, an effective system needs to incorporate subject dependency, possibly by introducing subject-specific relations or weighting functions. At the same time, they also indicate a way for identifying aesthetic characteristics and their correspondence with shape properties.

In the European Project FIORES-II (Character Preservation and Modelling in Aesthetic and Engineering Design) [FIO02] a wide research has been carried out to identify possible relationships among shape geometry and emotional character: fourteen partners have been involved, whose expertises range from geometric modelling theory and algorithm development, multi-criteria optimisation and artificial intelligence methods, to cognitive psychology and styling. A big quantity of papers, brochures, and company briefing describing products from an aesthetic and emotional point of view has been analyzed. After that, a set of web questionnaires and person to person interviews have been performed mainly addressed to designers, with the dual objective of

- identifying those terms used in styling activities to describe the aesthetic aspects of a product and of those terms used in marketing to describe product from an emotional point of view
- identifying the main elements characterizing a product (i.e. character lines, silhouettes, light lines and other significant curves)

The research done in this perspective has brought to the identification of a two level mapping (see Fig. 1):

- The 1st level links geometric properties with styling terms
- The 2nd level links styling terms with those expressing the emotional character.

Different from the first link, the second one can only have contextual valence, as it is conditioned by fashions, trends and therefore can be coherently defined only within a specific cultural and temporal context. To overcome such problem, in the project the learning capabilities of CBR (Case Based Reasoning) [CBR02a, CBR02b] technology are applied to deduce the existing relationships [Sta01].

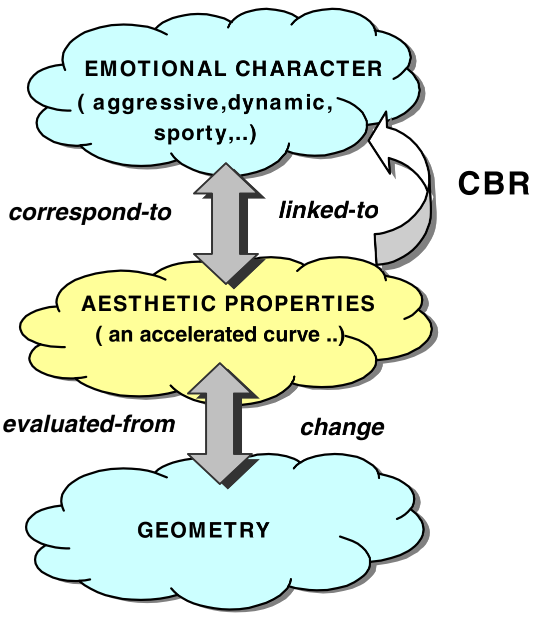


Figure 1. The FIORES II approach for defining the link between geometry and aesthetic character

The paper will concentrate on the first link and in particular on the modelling operators defined and implemented in correspondence of the styling terms.

2. PROJECT BACKGROUND

With aesthetic character it is meant the global impression the product suggests. It could be related to emotional feelings or reveal the belonging to a specific producer and family of products. For instance in the automobile field, designers normally recognize a company style from few curves because of some characteristics and their evolution. The example in Fig.2, provided by SAAB, shows the few lines which are sufficient to provide the company feeling for the depicted car.

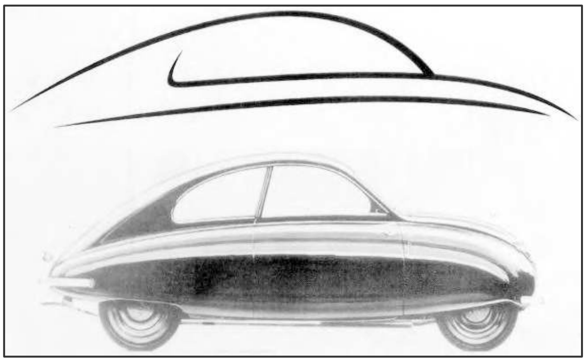


Figure 2. Examples of characterising curves (Courtesy of SAAB).

Understanding which are the underlying curves characteristics that provide such information to an expert eye is not so easy: stylists are able to see and recognize the characters but not to describe them in elements and terms which could be directly coded in a software tool. On the contrary they use a more restricted set of specific terms to describe curves and to explain their "recognition" procedure. Similarly, they use the same terms when they modify the shapes to achieve products with a desired specific aesthetic character.

From the various interviews carried out with the designers of the partner companies, it emerged that stylists use different languages when they speak with marketing people and when they work at the definition of the digital model with *surfacers*. In the former they use terms related to emotional aspects, expressing somehow the objective, in other words, the character that the final product must have; in the latter they adopt a restricted set of terms, corresponding in some way to shape properties, to provide instructions on which elements have to be changed to enforce/modify a certain character to fulfill marketing directives. It results that the link between aesthetic character and the underlying geometry could be better achieved by understanding and using the geometric properties underlying the terms used by designers when judging and changing the shape. In the remaining of the paper, these terms are indicated as aesthetic properties.

When stylists try to impress a specific character to a shape, they not only decompose curves in parts, but they also look at how the curve evolves within a certain area [Pod01]. In these cases, they normally talk about modifying certain properties of the curve itself, for instance *tension* and *acceleration* or the *lead-in* of a curve into another. Even if some of the terms used have a direct mathematical counterpart, the meaning is not exactly the same; for example not all the curves in which the second order derivative increases are necessarily perceived as *accelerating* curves. Currently the styling directives expressed in these terms are executed by *surfacers* which are able to translate them into the expected results throughout sequences of modelling operations, not directly linked with the target properties. This is possible thanks only to a great skill both in modelling and in the adopted tools, but often requires a time-consuming trial-and-error loop; in fact, the operators do not know exactly with which sequence of operations the goal is achieved, since there is not an explicit relationship between the target property and the geometric handles managed by users. Therefore, it is clear which advantages may be provided by offering the possibility of specifying directly the desired property values to automatically obtain the corresponding surface modification.

To this aim, the project has worked on the identification of the most meaningful aesthetic properties, which are recurrent during the surface model refinement. In correspondence of them, innovative modelling functionality have been defined and implemented.

3. AESTHETIC PROPERTIES

The aesthetic properties used by stylists to evaluate shape are closely related to their perception of shape, therefore a trivial and immediate translation in geometric properties is not possible. When looking at a drawing or a 3D digital model, designers concentrate on how specific important characterizing lines (both real or defined by the light effects) behave, imagining how it results in the real 3D concretisation; they take advantage of their experience in physical prototype creation for modifying the shape, very frequently simulating in the CAD system what they would do, for instance, in clay modelling.

In order to understand which properties are important, we deeply analysed the process followed by designers and CAD operators for achieving the desired product. The rational behind was analysed through the person-to-person interviews. Some of the terms, which they normally use to indicate how to act on several geometric properties simultaneously, have been selected. Even if they correspond to the English translation of the terms commonly used in their native language, some harmonisation work has been needed to ensure a common understanding, mainly due to the differences of the considered application fields. The following properties have been selected for the prototype development:

-Acceleration

-Convexity/Concavity

-Softness/Sharpness

-Tension

Based on the value of these properties in comparison with the neighbour area and with the whole object, additional qualitative judgment is normally performed. For instance the roof of a car can become *flat* if the value of the tension is too high with respect of the dimension, or similarly a concave section can appear *hollow* if its concavity is too small with respect to the whole section. These limit situations are not treated at present; anyhow using the CBR tool with a sufficient number of example cases could make possible the identification of their ranges. Moreover, from the end-user activity analysis it emerged that additional very common operations occur for aesthetic reasons, which have been considered worthwhile to be defined and implemented in the project:

-Crown

-Lead in

In the following a brief description of the selected properties and operators is given [Pod02].

Acceleration

The acceleration is related to how much the deviation of the tangent to the curve is balanced along the curve. The more this deviation is closer to an extremity the more designers perceive it accelerates. Symmetric curves are perceived as having no acceleration at all.

Convexity/Concavity

Generally speaking, a curve is *convex/concave*, if the curvature along the curve has the same sign. In our case, it has a more specific meaning. From the interviews done to the end-users, it comes out that when designers are making a curve more convex, they are ideally moving towards a semi-circle.

Sharpness / Softness

Used to describe transitions between curves or surfaces. The sharpness between surfaces (resp. curves) is due to the emergence of a visible edge (resp. point) on it. The softness between surfaces around an edge (resp. a point on curve) increases with the lower emergence of the edge (resp. point) on it.

Tension

Tension, under some constraints at curve extremities and in the modification mode, can be understood as the physical analogy of applying tension to a steel spline: the more is the tension applied, the closer is the curve to a straight line.

Crown

To make a part more crown results in raising a certain *part* of a curve according to a given direction without *changing* the end points. Similarly to *tension*, it can be better understood from the physical analogy of blowing up the curve. This operator can be used also for eliminating oscillations on curves.

Lead-in

Lead-in is a particular way to connect two edges/surfaces. Designers talk about creating a Lead-in when they want a better transition: to "prepare the eye to the shape that follows" as they say.

4. AESTHETIC PROPERTIES MODIFIERS

The twofold objective of the identification of the above described properties is, on the one hand, the formalization of aesthetic features, characterising shape from the stylist point of view, and on the other hand, the development of modelling tools (in the following indicated as *modifiers)* that directly act on the related properties. Using the modifiers, CAD operators have the possibility of acting simultaneously on several properties of a given curve at the same time, thus avoiding cumbersome sequences of modelling operations.

As previously mentioned, it turned out that these aesthetic property could also represent a meaningful tool for shape comparison purposes. This leads us to define an evaluation measure for each of them. By controlling their evaluated values, it is possible to control the combination of the associated geometric properties and hence, by specifying their changes, to control the shape. To define and implement such design functionality, the following problems had to be solved for each considered property :

- Definition of its meaning from the designer point of view: what shape is the designer expecting when the *modifier* value changes for the considered entity? Which are the geometric properties that are affected by the *modifier*?
- Evaluation of a measure of the aesthetic property.
- Specification of the mathematical function producing the expected shape modification and the related domain of application, i.e. hypothesis /

restrictions on the curve in order to have the possibility of applying the modifier.

- Identification of the required parameters to be provided by the user or automatically specified by an algorithm in case of character preservation. This also includes the specification of which parameters can be used within the optimisation process and in which way.

In the following, as an example, will be illustrated the definition of a measure function for the *convexity* property.

4.1 The Convexity Modifier Measure

From the interviews done to the end-users, it comes out that when designers are making a curve more convex, they are moving towards the semi-circle; i.e. considering the chord between the two extremes of a curve, the most convex curve on that chord, in the user opinion, is the semicircle with diameter equal to the chord (*ideal convex curve).* Judging a curve more or less convex depends on several factors: above all the symmetry, the roundness, and the curvature variation. Many of these factors depend in turn on mathematical properties that can be calculated on the curve and compared to the corresponding values of the *ideal convex curve* in order to determine how much the curve is distant from the most possible convex curve. The *ideal convex curve* is the semi-circle or an arc of circle if the imposed constraints are compatible with, otherwise it is the curve satisfying the given continuity constraints at the extremities and presenting the lowest variation in curvature. A convexity measure criterion, which takes in account all the factors that are implicitly considered by the users, is obtained by measuring the distance of a vector of curve attributes from the corresponding vector computed on the *ideal convex curve*. To evaluate the vector distance it has been adopted the normalized Minkowsky measure, applied to a vector of values of selected properties of the curve and of the area (lamina) delimited by the curve and the corresponding chord. The main attributes considered meaningful for the convexity are:

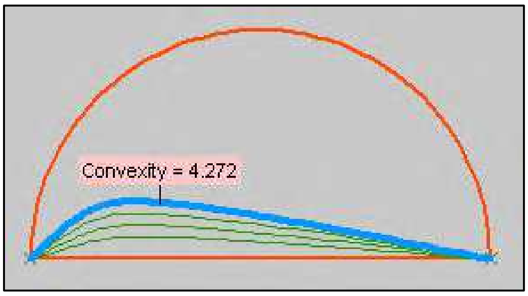
- Length.
- Area.
- Coordinates of the gravity centre of the lamina.
- Momentum of inertia of the lamina with respect to the axes of the coordinate system local to the curve.

Let

$\mathbf{V}^C = \{ v_i^C \}$ the vector of attributes of the curve and $\mathbf{V}^Q = \{ v_i^Q \}$ the vector of attributes of the *ideal convex curve*: the convexity measure is given by

$$\sum_{i=1}^{k} w_i \frac{| v_i^C - v_i^Q |}{D_i}$$

The maximum of convexity is then given by a measure value equal to zero. The normalization factor D_i is necessary to guarantee that scaled curves present the same measure; we use the values of the properties evaluated for the correspondent semicircle in the case of the length, area, y component of the centre of gravity, momentum of inertia with respect to the x-axis, momentum of inertia with respect to the y-axis. While for the x component of the centre of gravity we use the radius. The factor w_i is the weight of the i^{th} attribute. It has been experimented that the considered properties provide good information regarding the key characteristics of convexity like roundness and symmetry; nevertheless, after the evaluation of the users feedback on several measure combinations, it emerged that attributes have different weights on the perception of convexity and in particular the most important ones seem to be curve symmetry and roundness. For that reason a vector of weights W has been stated and used in the computation of the measure. Different values have been assigned to the vector of weights, in order to find measure values as close as possible to the users expectations and at the same time able to discriminate between the different situations. In Fig. 3 some examples of the results obtained with the weights vector W = {1, 1, 3, 1, 1.2, 2} are shown. In the pictures, the convexity measure indicated is the one corresponding to the orange curve (the one with the maximum thickness), i.e. the curve to be modified. The green curves (the ones with minimum thickness) are obtained making the curve more/less convex by considering G0 continuity conditions at the extremes.



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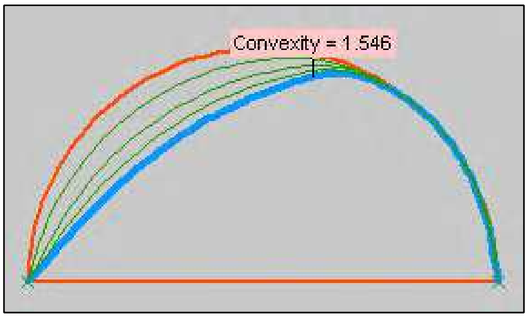

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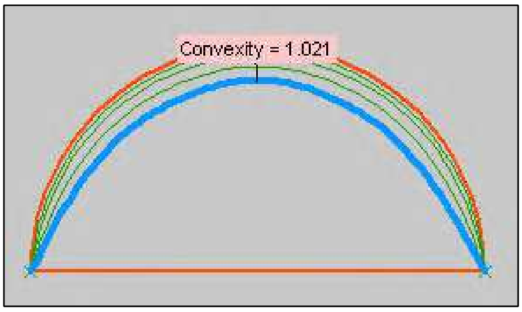


(c)

Figure 3. Examples of measured convex curves

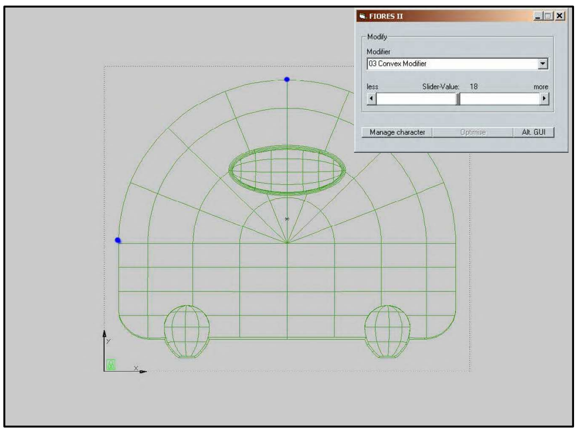
Even if the test results are quite encouraging, the proposed measure, to be used for evaluation, needs to be further tested, in order to be sure that it is really discriminatory. Anyway it has to be noticed that since it is given by a set of mathematical properties it can be further improved by including additional properties. The function implemented to apply the *convexity* modifier, is based on the method to modify the original curve to tend to the *ideal convex curve*, or to the least convex one, e.g. the straight line, when possible, or it turns to use another modifier: *tension*. From the user point of view, to apply the modifier he/she has to chose:

- any planar curve (aesthetic property) of a shape on which the modifier will be applied,
- the preserving conditions at each boundary i.e. how much a curve extremity must be preserved (position, tangency or curvature),
- positive or negative increment; this parameter has a default value that the user can tune if necessary.

The study has been restricted to planar curves; this is not a tough limitation because users typically prefer to act on curves having a specific meaning within the shape, that are normally judged in a planar view (paper or CAD screen). Nevertheless, since the final aim is always to change the 3D model, the modification has to be propagated to the related surfaces.

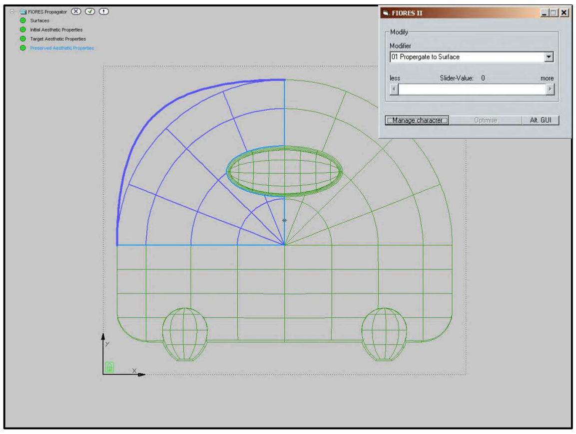
5. THE SOFTWARE PROTOTYPE

In the following figures (Fig. 4a-d) a practical example illustrates the use of the already implemented operators applied to a real case developed in Alessi [www.alessi.it]. It consists in the development of a new toaster from a breadbox that has to belong to the same product family. To do it, the upper part of the original breadbox (see Fig. 4-a) is first modified to change the dimension, in order to guarantee the positioning of the internal mechanism for heating (see Fig. 4-b). This is done by changing the convexity of the half section, which will be then mirrored when the modification is completed. Once the desired convexity is reached, the modification is propagated to the whole surface by using the Global Shape Modelling tool of the host system used as the prototype platform [thinkDesign ™, copyright of think3 www.think3.com] (see Fig. 4-c). Next the designer decides to add acceleration to the longitudinal section (see Fig. 4-d) and finally he/she adds tension to the middle section to guarantee the maintenance of the character (Fig. 4-e).



(a)

Figure 4.-Continue-



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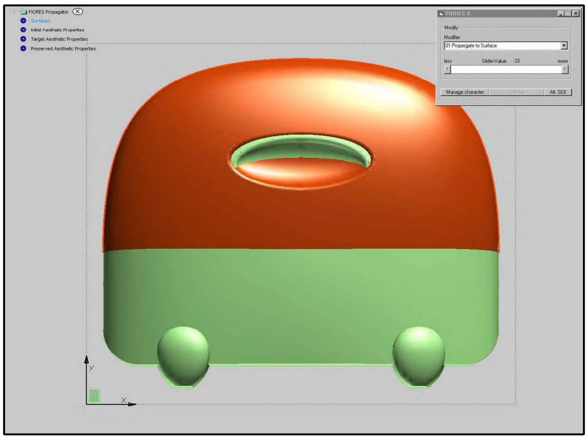

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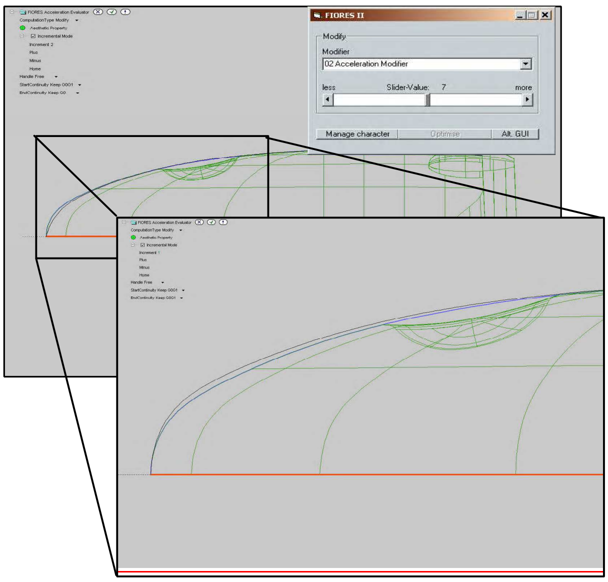

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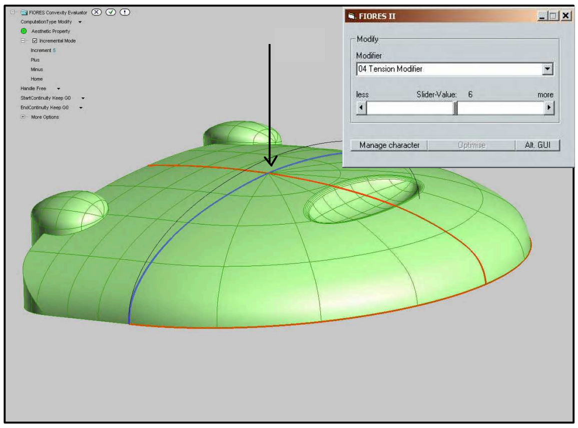

(e)

Figure 4. An example of application of modifiers (Courtesy of Alessi)

The objective is reached in a much more direct way than using the traditional functionality of most computer aided design tools.

The development of the software prototype is almost completed. It is composed by several components operating through a common user interface and can be connected via Product Data Channel (PDC) to other CAD system; the current implementation is based on thinkdesign ™ [thinkdesign is copyright of think3, www.think3.com].

6. CONCLUSIONS

In this paper, part of the objectives of the European Project FIORES-II and its current results have been described, with particular emphasis to the identified and formalized aesthetic properties and to the developed modelling tools for their modifications.
Currently the developed software prototype is under testing at the user sites. The preliminary results of the adopted approach, which links different disciplines such as mathematics and cognitive psychology, confirm its potential from different perspectives:

- for providing end-users with aesthetic features manipulators for better and faster achieving the desired changes in the geometric model, conforming to their intent;
- for a deeper comprehension of the geometric characteristics influencing the perception of shapes and of their similarities from an aesthetic point of view.

In accordance with the identified standpoint, further activities are foreseen in order to validate the defined measures of the aesthetic properties and to develop their usage for defining a proper aesthetic similarity criterion.

7. ACKNOWLEDGMENTS

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