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GENERIC GENERATIVE DESIGN SYSTEMS TO IMPRINT PERSONALITIES IN CONSUMER PRODUCTS: PRELIMINARY RESULTS

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Abstract

Generative design is a computer aided design system that automatically or semi-automatically produces design solutions. Generative design systems help designers to save time and labor during the conceptual stage of the design process by providing them with a high number of design alternatives or emergent design patterns the designer can use to further refine the final design solution. They can also be used by non-specialists to quickly generate much needed design solutions. Several generative design techniques for different consumer products have been proposed to date. However, none of them allow imprinting a personality to the product in such a generic way that the method is independent of the product being designed. Given that customers prefer products whose personality is similar to their own, the capability of generating personality-based products is key for their successful introduction to the market. In this paper we present preliminary results of ongoing research on the development of generative design techniques that imprint personalities to consumer products. Unlike previous work, the techniques here explored are generic enough as to be used with any consumer product.

Keywords: Computational design methods, Conceptual design, Generative design, Design process

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1 INTRODUCTION

Generative design techniques help designers to explore a larger design space than that available with traditional paper-based design by leveraging on computational processing. In this way, the design process (or parts of it) is performed by a program - in an automatic or semi-automatic manner, which generates several design alternatives. Depending on the level of automation of the generative design approach, the designer might intervene in intermediate stages of it by controlling the parameters and modifying or selecting generated solutions. As clearly illustrated by a recent video released by Autodesk[1], fully automatic generative design incarnates the idea of "*what if you could tell the computer what you want to accomplish […] the computer can then deliver thousands if not millions of design options*".

Among the advantages of generative design tools are the time and labour saving in the conceptual design stage, where many ideas are explored before proceeding on to the next steps, the much higher number of design alternatives available for the designer to select or to interact with than the traditional paper-based sketching approach and the possibility of identifying emergent design patterns, not envisaged by the designer, to stimulate the creativity process of the designer as well as allowing reformulating the search in the design space.

There are several generative designs techniques that can be used alone or in a joint manner: shape-grammars, genetic algorithms, cellular automata, swarm intelligence, Markov Random Fields and simulated annealing (Singh and Gu, 2011; Jian and Ming-Xi, 2013; Barros et al., 2014). The most used in the design of consumer products have been shape grammars and genetic algorithms.

First proposed in the area of architecture (Stiny and Gips, 1972), shape grammars have been very much used as a tool for generative design. A shape grammar defines a basic set of shapes (vocabulary), a set of non-terminal shapes, an initial non-terminal shape and a set of rules that define the transformations that can be experienced by a shape under development. The first use of a shape grammar to design a consumer product (a coffee maker) was presented in (Agarwal and Cagan, 1998), where it was noticed that all coffeemakers have "*the same functional principles and the same breakdown of form topology*". That is, for products with similar basic layouts, shape grammars are ideal as they partition the product in different topological regions that are built around a given shape. Since then, many works on the use of shape grammars for generative design have been reported, for example: motorcycle design (Pugliese and Cagan, 2002), jewellery (Kieralova, 2015), inner hood panels of vehicles (McCormarck and Cagan, 2002), furniture (Barros et al., 2012) and ethnic embroidery (Jia and Ming-Xi, 2013). The main drawbacks of shape grammars are that a specific grammar must be developed for every different object to be designed and that they might be too restrictive, as the final combination of the basic shapes might be novel but the forms to be combined are predetermined. Thus, really innovative design solutions might not be possible. In an effort to circumvent this limitation in (Jia and Ming-Xi, 2013) a mixture of shape grammars and B-splines is used to produce smooth and natural shapes for design exploration of ethnic embroidery whilst others approaches enter the final solutions obtained with a shape grammar-based method to evolutionary algorithms (Barros et al., 2012; Granadeiro, 2013; Kieralova, 2015).

Genetic algorithms, where design alternatives are generated by following the rules of evolution over an initial population of solutions, have also been used to design consumer products. In (Fung, 2014) a genetic algorithm is used to design a mobile phone that complies with being "handy". The vector that codifies a mobile phone solution is made of 8 design parameters (corresponding to physical aspects): Top shape, bottom shape, function button shape, layout, body length, body width, body thickness and border width. The fitness function is built according to mined rules – obtained specifically for mobile phones - that determine how handy a mobile phone is in terms of the 8 mentioned parameters. Cluzel et al. (Cluzel et al., 2012) use an interactive genetic algorithm to design car silhouettes with an intended personality (friendly and sportive). Silhouettes genes are coded after using a Fourier decomposition of

[1] https://www.youtube.com/watch?v=E2SxqUvtpIk

the shape contour and a human evaluates the fitness function in every generation. In (Kim, 2014) a genetic algorithm is applied to create 3D rings according to the preferences of the users in terms of feminine/masculine; complex/simple; ordinary/unique traits. The coding of the chromosome has 4 parts: band generation (circular, spiral), stone addition (form, size and edge of the stone), cutting-off (location, direction, interval, depth, form and size) and general transformations of size, area and shape.

To the best of the author's knowledge, no automatic generative design technique has been used to design consumer products with a given personality (that is, with an attribute related to the human perception of objects, not easily quantifiable) in a generic way that allows it to be applied to any object. The efforts are based mainly in methods that finally lie in the designer experience to decide the shapes that better built the final product form that match the intended concept or personality (Ortiz, 2011; Govers, 2004; Mugge, 2009). As it has been shown that customers prefer products whose personality is similar to their own (Su et al., 2015; Dumitrescu, 2010; Govers and Shoormans, 2005), the ability of designing personality-based products is key for their successful introduction to the market. Although (Cluzel at el., 2012) use a genetic algorithm to design car silhouettes with an intended personality, the fitness function is performed by a human, who has to evaluate up to 100 solutions per generation. In (Kim, 2014) a fully automatic process is performed to design rings with either a feminine or masculine personality. However, the process was specifically developed for rings, not applicable to other objects.

In this paper, we present preliminary results on three proposals for generative design systems focused on supporting designers in imprinting a personality to any product shape during the conceptual stage of the design process. Unlike previous research, the proposed process is generic enough to be applied to any shape. Note that aspects as texture, colour or the context of use, that are important in the design of the final solution are not considered in this paper, where the focus is on the form of the object, represented as a 2D shape.

The first method is based on a genetic algorithm. To be able to use this evolutionary strategy without human intervention in the fitness evaluation stage, first the main shape features of a given product personality should be detected, in such a specific way that it can be expressed by means of a mathematical formula; next a descriptor able to detect whether a given personality is present in a product shape needs to be defined to then use it in a genetic algorithm to explore a high number of different shapes and select the one most representative of the desired personality.

The second method is based on the Grasshopper plug-in for the Rhinoceros CAD software. Two objects are entered as input to a developed morphing module. The first is a neutral shape of the object to be designed. The second is an "essential shape" representing the required personality in its most abstract expression. The module then performs a morphing process between both objects. By adjusting the control points and the morph factor, several design solutions with the intended personality can be generated.

The third method is a hybrid system where the input to the Grasshopper system corresponds to the best individual generated by the genetic algorithm-based generative technique.

The rest of this paper is as follows: firstly, the method used to detect the main features of objects with a given personality is presented to then obtain the "essential shape" and the mathematical descriptor for a "*cute*" personality (Section 2), then the genetic algorithm-based and the Grasshopper-based methods are described in Sections 3 and 4, respectively. Preliminary results obtained with a given personality by the 3 methods (Genetic, Grasshopper and Hybrid) are then presented in Section 5. Finally, conclusions and extensions to the present work are discussed in Section 6.

2 PRODUCT PERSONALITY AND SHAPE FEATURES

To be able to use any generative design technique that intends to imprint a personality in the generated design solutions it is necessary to have a formal, generic description of the main attributes of a shape with such personality. In the case of a genetic algorithm, such formal description must then be transformed into a mathematical formula that evaluates the fitness of a solution. In the case of a visual technique, as the one based on Grasshopper, an "essential shape" representative of the personality must be identified.

The method proposed to obtain such formal descriptions is made of the following 4 steps:

Concept definition: the intended personality must be defined in natural language. This description is key to guide the efforts of the second step. For example, for a cute personality, the Oxford dictionary presents the following description: *Attractive in a pretty or endearing way*.

Referent analysis: referents with a shape representative of the previous definition must be analysed. Referents can be artificial or natural products as well as gestures of people matching the concept. Once a set of referents is selected, the set of representative and relevant geometric features (e.g. types of lines) of all the products sharing the concept must be extracted. To do so, observation and abstraction of the types of lines present in the referents is performed. As a way of an example, Figure 1 shows a summary of this process. The first column of Figure 1 shows an example of a sub-set of referents (only artificial products) for the concept *cute*. Columns B-E show the evolution of the process of extracting their relevant geometric features: first, colour images are transformed into black and white images (column B), next the main lines separating the white and black zones are obtained (column C) to then discard the lines that do not give significant information about the shape of the object (column D). Finally, only the main contour lines are kept (column E).

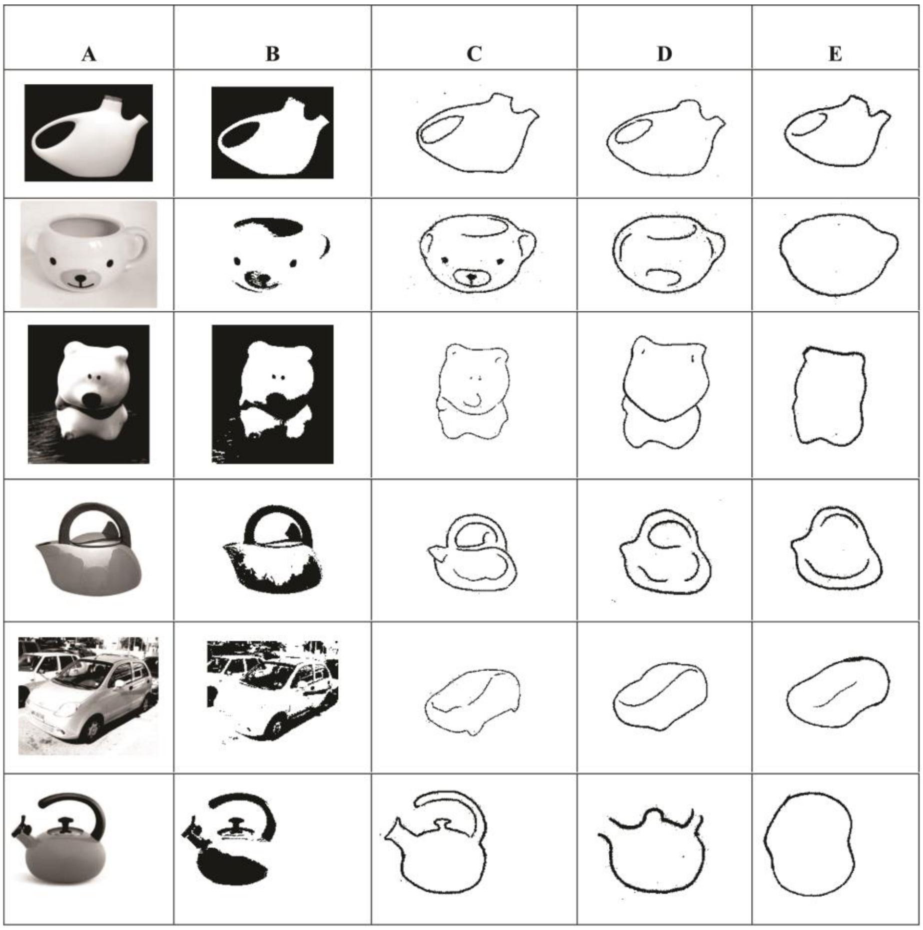


Figure 1. Extraction of relevant geometric features for cute objects

Shape description: The result of the previous step is made more explicit by using natural language to describe the significant shape features (e.g. types of lines or curves) identified in the previous step. From the visual information of column E (using the objects shown in Figure 1 as well as natural objects and gestures), two senior designers agreed on the following textual description of the significant features of a cute shape: *A cute shape is compact, rounded, made of sinuous curves that change direction smoothly*.

Essential shape and shape descriptor: The description obtained in the previous step is key to detect the "essential shape" of a given personality. For example, based on the previous description of a cute shape, the following "essential shape" can be derived:

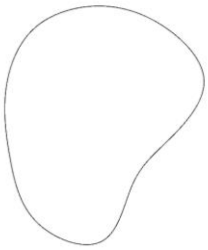


Figure 2. Essential shape for a cute personality

Note that there are several "essential shapes" that comply with the definition of a cute form. The one shown in Figure 2 is just one possibility.

In the search for an initial mathematical descriptor for a cute form, we used a curve characterization technique know as the osculating circle (Gray, 1997; Coeurjolly et al., 2001). The osculating circle of a curve C at a given point P is the circle that has the same tangent as C at point P as well as the same curvature. That is, the osculating circle is the circle that best approximates the curve at P (Gray, 1977, p.111), as shown in Figure 3.

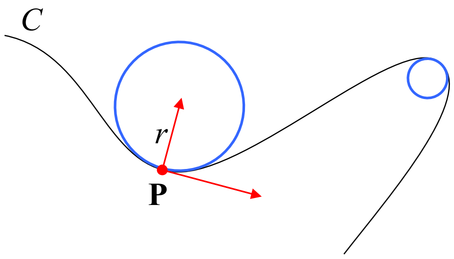


Figure 3. Osculating circle example

The osculating circle is defined by the value of its radius, *r*. By calculating the inverse of the radius, 1/*r*, a curve can be characterized as shown in Figure 4. The left image shows a 160-point curve built

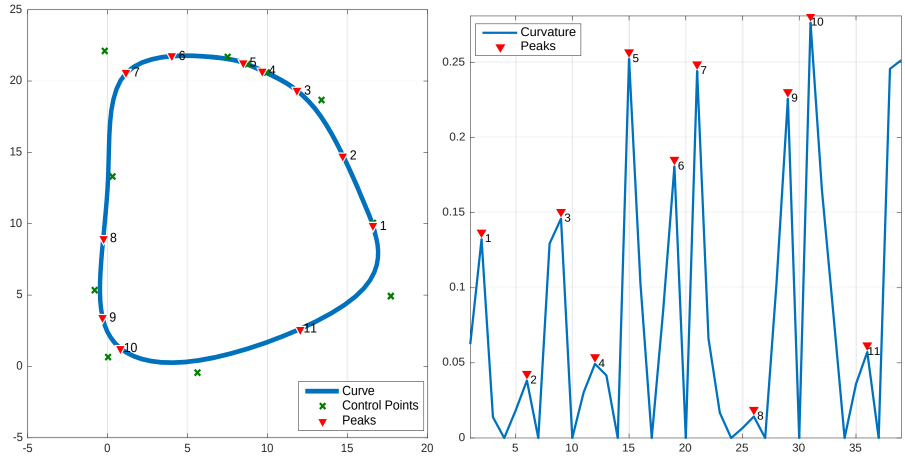


Figure 4. Left image: Cubic B-spline curve, its 8 control points shown as crosses. Right image: Function 1/r, maximum values highlighted with triangle markers

from a cubic B-spline with 8 control points (shown with crosses). The right image shows the curvature function, made of the values of $1/r$, estimated over 4 continuous points of the original curve, leading to 40 values for $1/r$. The number and height of peaks in the right curve give information about the deformation intensity of the curve.

As a cute form must have sinuous, smooth curves, a first simple attempt for a descriptor of a shape that focus on its curvature is as follows:

$$d_{cute} = \frac{1}{P} \sum_{i=1}^{P} p_i \quad (1)$$

where P is the number of peaks of the curvature function and p_i the value of the i-th peak. A peak is defined as a point in the curvature function whose value is higher than its left and right neighbour points. By minimizing the value of d_{cute} on an already compact and closed curve, a shape made of soft curves could be detected. Note that this descriptor does not evaluate compactness and it is only one possible among several that could be used to define a cute shape. Naturally, for other personalities, different descriptors able to capture the shape definition of such personalities must be derived.

3 GENETIC-BASED APPROACH

The genetic algorithm was implemented using the AG Toolbox of Matlab v7.3. The algorithm takes a seed image as an input. This image is a shape representing the object to design, with no intended personality.

To generate the individuals of the initial population, 20 points out of the original points making the contour of the seed image are randomly selected. These 20 points are the control points of a bicubic B-spline that represents one individual. By using a representation based on the control points of a B-spline, we ensure algorithmically that such points are sequentially ordered and thus, the shape deformation is not as extreme as to diverge from the original object (that is, the original object can still be recognized after applying the evolutionary process). The vector coding each individual is an array of 20 elements. Each element represents the coordinates of each point. We repeat these procedure 100 times, to generate 100 individuals.

In every generation, mutation and cross-over operators are applied and 100 new individuals are generated. This procedure is repeated until the system converges. The descriptor presented in Equation (1) is used as a fitness function: the lowest the value of d_{cute}, the higher the fitness of an individual.

4 GRASSHOPER-BASED APPROACH

Figure 5 shows the components of the morphing process developed in Grasshopper, where two shapes are entered as input: an initial shape (Curve 1) where the object to be designed can be recognized and an "essential shape" (Curve 2) representing the personality to be imprinted in the object represented by the initial shape. The input shapes can be given in a .txt file listing the control points of the B-spline defining the shape. Both shapes are then re-built with the same amount of control points and entered to the morphing process. The number of control points of the shapes, the morph factor as well as the degree of the output shape can be varied to achieve different resulting shapes. In the figure, both the

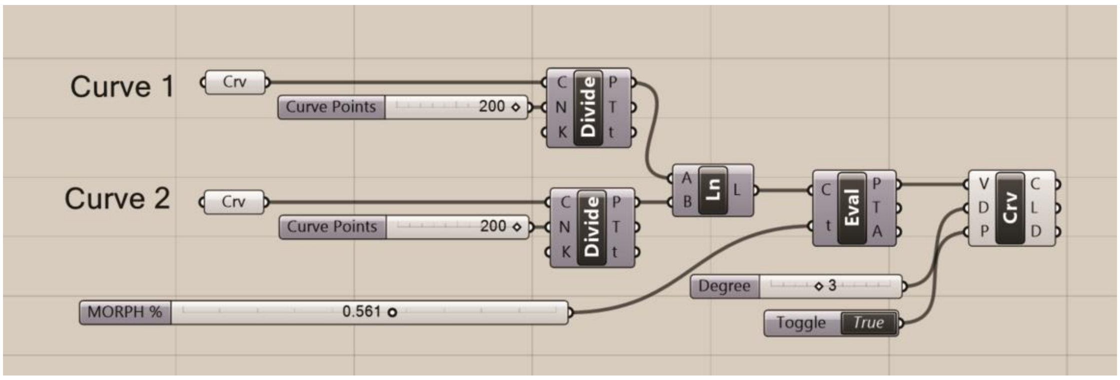


Figure 5. Morphing process in Grasshopper

initial an the essential shapes are set to 200 control points, the morphing factor is equal to 0.561 and the degree of the output shape is 3.

5 PRELIMINARY RESULTS

In this section we present preliminary results obtained after applied the genetic-based approach, the Grasshopper-based approach and the hybrid system. In the three cases, the goal is imprinting a "*cute*" personality to a wine glass.
We used the image shown in Figure 6 as a seed image for the genetic algorithm-based approach. The seed image was made of 2737 points. It has no intended personality, but it has the compact property on it as in this first attempt we focus only on the rounded form of a cute object.

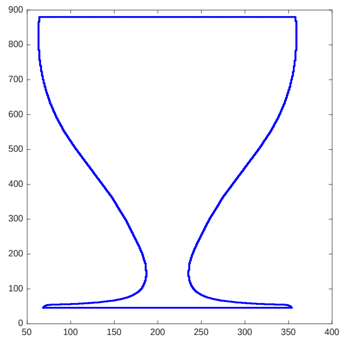
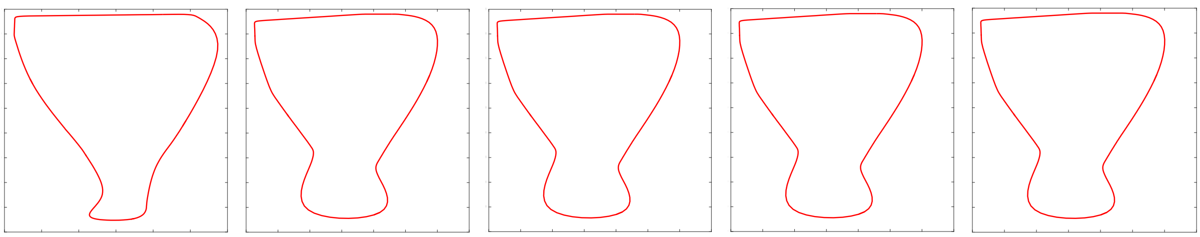


Figure 6. Seed image for a wine glass

The genetic algorithm converged very quickly, as shown in Figure 7, where the best individual from generations 2, 6, 10, 14 and 18 are presented.



2 6 10 14 18

Figure 7. Best individuals from generation 2, 6, 10, 14 and 18

It can be seen that, except for the upper left corner, the final solution has rounded/sinuous curves, as required by the definition of cute. This preliminary result is promissory in terms of achieving a shape that does not resembles the seed shape and that hints a cute personality. Naturally, further research with different descriptors, objects and personalities must be pursued.

In the next experiment, we morphed the initial image (Figure 6) with the "essential shape" of a cute object (Figure 2) using the morphing module developed in Grasshopper. Figure 8 shows 8 design solutions obtained from the morphing process for different morphing factors (the morphing factor, MP, can vary from 0 to 1). The number of control points for each shape was set to 200.

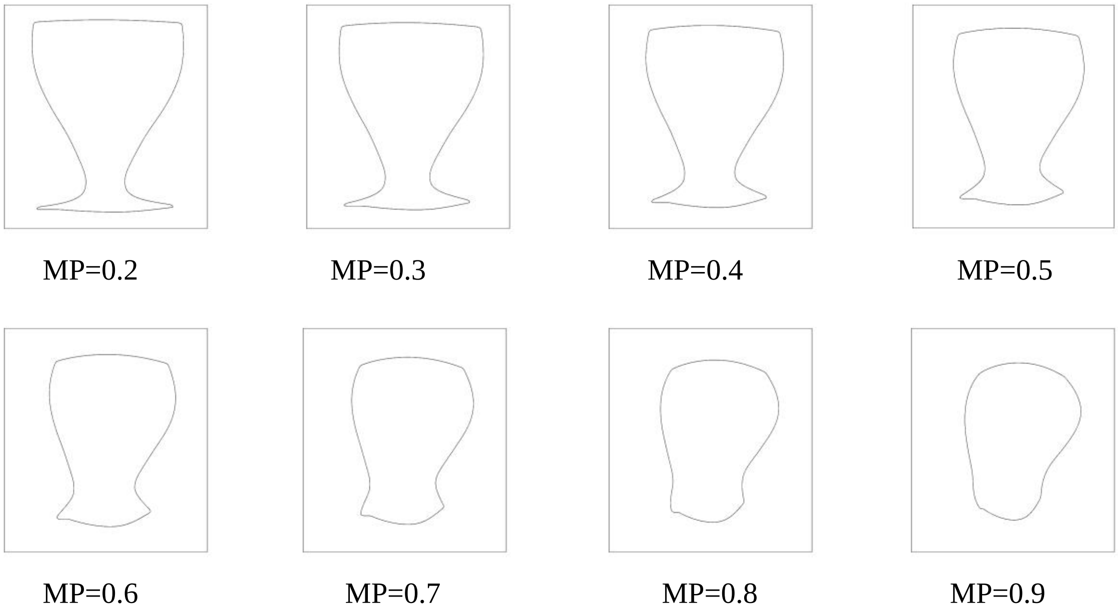


Figure 8. Design solutions obtained from the morphing between the seed shape and the essential shape of the cure personality for morphing factor

It can be seen that, although the shape of the seed image becomes more rounded, the recognition of the original object (glass wine) is more difficult for high morphing factors (higher than 0.7). For intermediate values of the morphing factor (0.5-0.6) the wine glass gets closer to a cute shape, but still further design work is required.

Finally, to verify whether a set of design solutions better representing the concept of a cute personality could be obtained by using a different initial image, in the hybrid approach we used as an initial image the shape obtained by the genetic algorithm (rightmost shape of Figure 7). Figure 9 shows 8 design solutions obtained from this new morphing process.

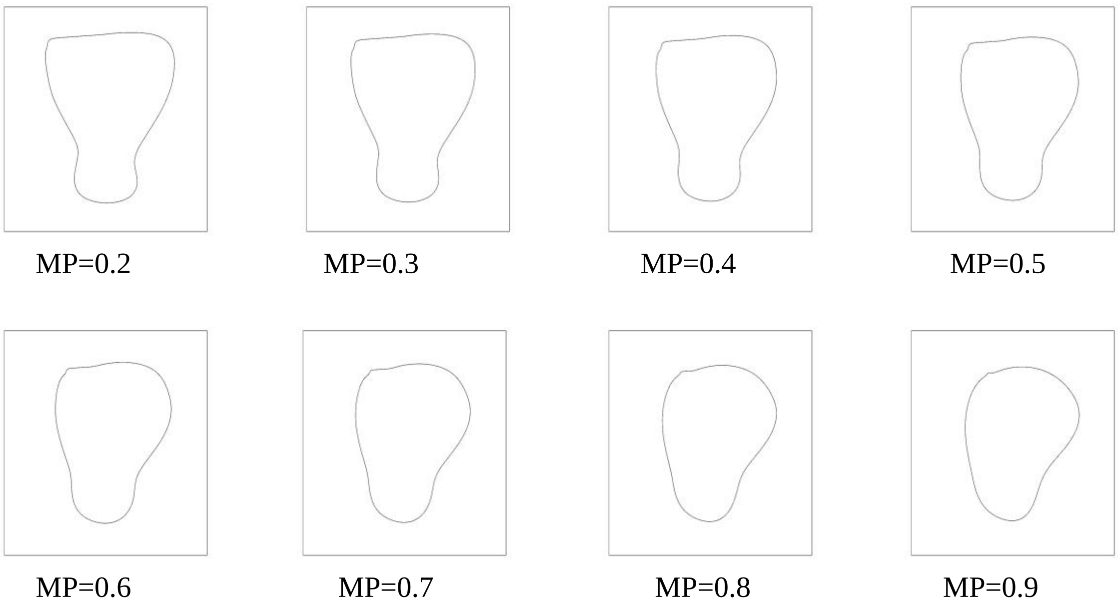


Figure 9. Design solutions obtained from the morphing between the shape generated by the genetic algorithm and the essential shape for the cute personality

It can be seen that by starting with a shape that already has some cute traits incorporated, figures closer to the cute personality are obtained with lower values of morphing factors (0.3-0.4) than the previous case.

Both cases (Grasshopper-based and hybrid) show that the figures in the middle of the morphing process allow recognizing the product whilst exhibiting some traits of the intended personality. Further research with different objects, alternative essential shapes and modifications of the morphing process is still required.

6 CONCLUSIONS

In this paper, preliminary results on 3 generative design systems to imprint personalities in consumer products were presented: an evolutionary one, a Grasshopper-based one and one hybrid method mixing evolutionary results with Grasshopper processing. Unlike previous work, the systems are generic enough as to be able to work with any product. The keys for the generic property of the systems are: firstly, the definition of the personalities in generic geometric terms, not dependent of the physical characteristics of any product but rather on the geometric features present across several objects that share a given personality. Secondly, the use of B-splines to represent the shapes, instead of shape grammars that are specific to a given product or chromosome coding that represent parts of specific products.

The systems were preliminary tested for the *cute* personality with promissory results. However, further research is necessary in:

Shape descriptions: Further validation of the natural language description of the geometric characteristics of the shapes representing different personalities must be carried out. Expert and non-expert opinion (leveraging on the “wisdom of crowds”) should be considered.

Descriptors: the initial descriptor used for the cute personality requires refinement to be able to evaluate the compactness of a form. Several alternatives must be also tested to verify whether different ways of measuring rounded forms can be attained. Finally, descriptors for other personalities must be derived.

Essential shapes: there is no unique “essential shape” for a concept. Exploring the impact that different “essential shapes” have on the final design solution is part of future research.

Products: a high variety of consumer products must be evaluated. As the systems were developed to work with any product shape, this is the next natural step to carry out in our research. Also, products made of several distinguishable parts (e.g. internal and external parts of a city car) should be studied.

Personalities: a wider range of personalities (e.g. elegant, kind, rough, aggressive, etc.) must be studied to be included in the research.

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