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AESTHETICS CONSIDERATIONS IN EVOLUTIONARY COMPUTER AIDED DESIGN

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ABSTRACT: The research described is concerned with establishing the aesthetic and functional evaluation of shape aspects within an evolutionary CAD modelling system. The approach uses genetic algorithms to evolve shapes by the successive 'mating' of objects through crossover and mutation of chromosomes describing geometric, aesthetic and functional aspects of objects. An evolutionary design system based on the genetic algorithm techniques generates shapes and the designer interacts with the system to identify shapes that should be used in the genetic creation of future generations. The current research is aimed at combining formal aesthetic and functional elements within the chromosome description of the objects and to provide computer-based fitness functions to work in conjunction with input from the designer to guide the optimisation of the evolutionary designs.

KEYWORDS: evolutionary design, genetic algorithms.

1. INTRODUCTION

The motivation of this research has come from an interest in evaluating and improving the physical designs of ranges of products, especially the aesthetic and functional elements, with the assistance of computer tools. Currently in the world of computer aided design, the integration of styling and aesthetics into the overall product development process has still not been properly achieved [1]. Computer support of industrial design in the field of aesthetics is still in its infancy partly because there is no methodology available to incorporate aspects such as appearance, pleasantness and human usage of a product [2].

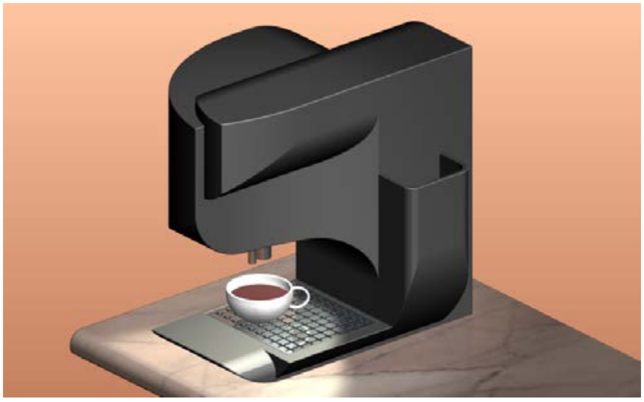

Figure 1. Coffee Machine shape derived from the Evolutionary Form Design system of [6]

It is important that any system that considers aesthetics should be compatible with currently available CAD systems, and as these CAD systems are generally based on geometric and parametric approaches, it is appropriate to define the aesthetics elements in terms of geometric manipulations. It is natural and straightforward to include functional considerations (e.g. surface area, volume, etc) in conventional CAD systems.

A number of researchers have attempted to define aesthetics elements in the form of geometric concepts of the object. Chek and Lian [3] have identified fourteen measures: balance, equilibrium, symmetry, sequence, cohesion, unity, proportion, simplicity, density, regularity, economy, homogeneity, rhythm and order. Although their work was concerned with computer screens, many of these measures have an interpretation for solid products. Fujita et al [4] captured the characteristics of lines, curvatures of free surfaces and their deviation ratios as elements that contribute to the aesthetics features. Giannini and Monti [5] also used a geometric approach with terms such as acceleration, crown, convexity, concavity, sharpness, softness, crispness, tension and lead in.

This research investigates ways of establishing the aesthetic and functional evaluation of shape aspects within an evolutionary CAD modelling system. The work is based on earlier research on an Evolutionary Form Design (EFD) system [6] that was capable of evolving shapes such as that used in the coffee machine of Figure 1. An evolutionary design system based on genetic algorithm techniques generates shapes and the designer interacts with the system to identify shapes that should be used in the genetic creation of future generations. When the designer is satisfied, the generation process is halted and the shape created can be used as the starting point for creating models such as that shown in Figure 1. In this earlier work the objects are defined by chromosomes which express various geometric characteristics such as primitive shape, blending and size. Objects are 'mated' by crossover and mutation of their chromosomes to create a new set of objects. In conventional use of genetic algorithms a fitness function would determine which of the offspring are used to evolve future generations, but here the 'fitness' is determined (visually) by the designer. The current research is aimed at combining formal aesthetic and functional elements within the chromosome description of the objects and to provide computer-based fitness functions to work in conjunction with input from the designer to guide the optimisation of the evolutionary designs.

2. AESTHETICS EVALUATION SYSTEM

The vital tasks in building a Computer Aided Aesthetics and Functions Evaluation (CAAFE) system are first to capture the aesthetic and functional elements. These elements are then quantified using methods such as Concept Scoring/Screening Metrics so that they can be deployed as factors in the genetic algorithm. This needs a good understanding of the accepted criteria of aesthetic values and the engineering functions of objects. To make use of these measures within the genetic algorithm based evolutionary CAD system, it is also necessary to find a way of expressing each of them in terms of the underlying geometric modeller. It is then possible to build a system capable of employing the elements within the fitness functions which control the evolution process [6]. At the current stage of the research a number of measures have been defined for the aesthetic and functional elements. Some have been implemented, the implementation of others is in progress and the remainder are being considered (i.e. methods of quantification and implementation are being sought). Currently implemented are: Simplicity (number of edges/faces); Stability (location of centre of mass); Expandability (capability to expand into a maximum bounding box); Surface Area: Volume: Edge Smoothness (angle between face normals); Face Smoothness (lack of interruption or sudden change in face direction); Surface Characteristics (faces of objects characterised by planar, spherical, cylindrical, conical, revolved or blended surfaces); Softness/Hardness (related to blend radii).

Figure 2 illustrates user assignment of weighting values to each of the 13 implemented measures by the rating of each element on a scale of 0 to 10. The assignment of a zero value means that this aesthetic or functional element should not be considered, whereas a high value indicates that the element is very important. The weightings are used to determine the probability that a shape will be used in the creation of the next generation. Concept scoring matrices are then used to inter-relate the various aesthetic and functional measures. The screen snapshot of Figure 2 also shows the presentation of a complete generation of 14 objects from which the designer chooses those for evolution of the next generation.

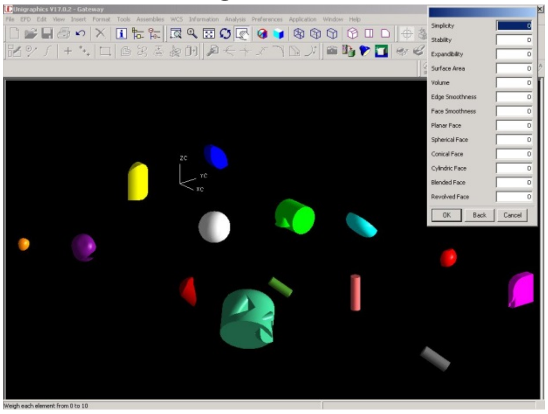

Figure 2. Screenshot – weighting assignment

3. USER SURVEYS

Surveys were conducted as a means of improving the CAAFE-EFD prototype software developed in this research. The survey was conducted twice using the same target users. The results of the first survey were used to suggest improvements to the CAAFE-EFD system, mainly its scoring system. After the improvement to the scoring system, the second survey was conducted to observe the effects or improvements made to the system. The survey was not extensive and it was structured as a source of feedback from observers and users for the improvement of the CAAFE-EFD system and specifically the scoring system. The survey aims to compare the perception or scoring of the observer against the CAAFE system's scoring.

Twelve objects created using the CAAFE-EFD CAD system were evaluated by the survey participants in the first survey. In the second survey, only 10 objects were evaluated, as three of the objects in the first survey were removed, and one new object was included. The objects were removed because the results did not show consistency. Presumably the objects did not present the aesthetic characteristics conclusively enough to be evaluated, since it is sometimes very hard to comprehend an object without a 3D physical prototype. One new object was added just to observe the effect on the rating of a new object.

A list of aesthetic criteria or elements and brief definitions or explanations were given to the participants prior to the evaluation session. The participants were then given ample time to evaluate the objects based on their understanding of the aesthetics elements. The objects were displayed on the university's web pages.

In total, 47 participants participated in the first survey and 30 participants in the second survey. They were students from Loughborough University, most of whom had some exposure to product design from the their engineering and design courses.

The participants were provided with a list of aesthetic elements on which the evaluation was to be based together with brief descriptions. Although there are 13 evaluation elements in the CAAFE system, only 8 were considered in the CAAFE-EFD survey. Functional criteria were omitted as they are totally numerical and the scoring ranges for both of them are relatively easy and straightforward to predict. The evaluations were compared to the scores given by the system scoring. These comparisons were later utilized to construct a scoring system that is more consistent with the observation of the users.

It was not intended in the survey to give the participants the full definition of the aesthetic elements, as it was not the aim for the participants to evaluate the objects numerically or analytically. A brief description was considered to be sufficient for the participants to capture the overall definition of the aesthetic elements, so that they could be evaluated visually. The eight aesthetic elements and abbreviated descriptions given to the survey participants are shown in Table 1.

Table 1. The aesthetic elements

1. Simplicity	Simplicity related to the number of edges and faces
2. Stability	Height of the centre of mass
3. Softness	Soft objects have more blended edges and larger blending radii.
4. Hardness	Hard objects have fewer blended edges and smaller radii.
5. Roundedness	The existence of a large number of 'roundish' faces.
6. Boxiness	The existence of a large number of planar faces.
7. Dominance	Particular types of shapes/faces predominate.
8. Variance	High variety of shape/face types.

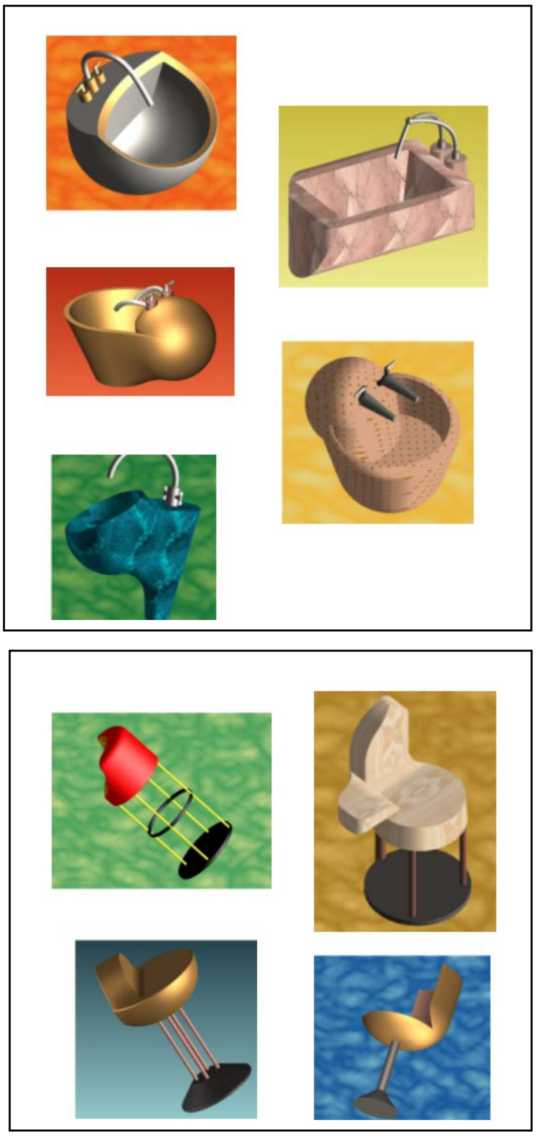

Figure 3. Product Visualisations

The base shapes chosen were given product visualizations based on sink and seat designs (Figure 3) to assist the users in evaluating the aesthetics elements. i.e. only the shape of the main component was generated by the system and the visualization was enhanced by the manual addition of colours, textures, extra items such as taps, etc. All the objects shown in the figures were evaluated by the survey participants by evaluating the extent of the eight aesthetics characteristics (simplicity, stability, softness, hardness, roundedness, boxiness, dominance and variance) on a seven-point scale (none, very little, little bit, average, some, quite a bit, very much). The (computer) system scoring of CAAFE is rated from 0 to 10, but the survey questionnaire was based on a seven-point scale as this was considered to be more suitable for human rating. Mapping between the scales was as shown in Table 2.

Table 2. Scoring table for the surveys

7-Point Scale	0-10 Point Scale
None	$0 \leq x \leq 2$
Very Little	
Little Bit	$2 < x \leq 4$
Average	$4 < x \leq 6$
Some	$6 < x \leq 8$
Quite a Bit	$8 < x \leq 10$
Very Much	

It was intended that the mapping would compensate for the natural inclination of participants who may have been reluctant to select the extremes at either end of the scale, and to be relatively imprecise to reflect the nature of the evaluation of aesthetics.

Figure 4 illustrates the evaluation of the first object in terms of the eight aesthetics characteristics and is typical of the results for all of the objects.

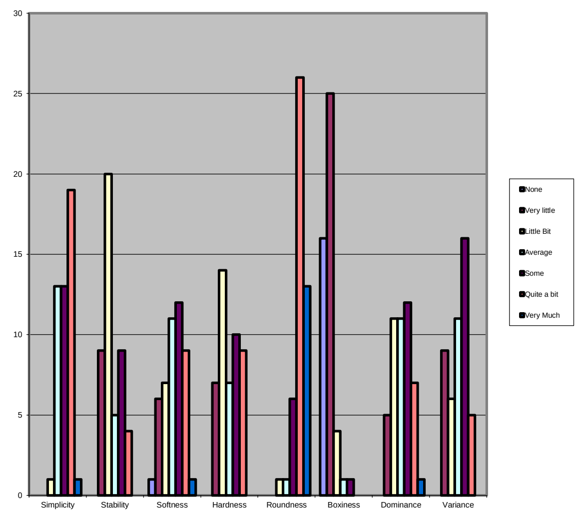

Figure 4 Survey for Object 1.

Most of the evaluations converged to one dominant value for each aesthetic element. The mean and standard deviation values for each evaluated element for each object were determined. The percentage error (Table 3) gives some idea of how large the deviation of the scoring of the human is compared to the scoring given by the CAAFE system and provided some insight and suggestions for improving the scoring system for the CAAFE system.

Table 3. Percentage error in the first survey

	Total Error	Average Error (per Object)
Simplicity	-85.11 %	-9.46 %
Stability	-166.81 %	-18.53 %
Softness	-17.45 %	-1.94 %
Hardness	-46.38 %	-5.15 %
Roundness	162.34 %	18.04 %
Boxiness	-263.83 %	-29.31 %
Dominance	53.40 %	5.93 %
Variance	-31.28 %	-3.48 %

In general, the participants could capture the aesthetics elements presented in the survey. However, because of the subjective nature and broadness of the concept of aesthetics, there are some different scoring trends on particular elements for particular objects in the survey. There are several possible factors affecting the difference between the survey and system developed, including: (i) the description or definition of aesthetics criteria may not be well explained, (ii) participants have their own perception of certain terms used in the aesthetics elements., (iii) some objects may not be suitable for evaluation on certain aesthetics elements as they do not represent the elements clearly enough for the participants, (iv) the 2D representation of objects is inadequate to evaluate the objects in detail., (v) it is noticeable that every time the score is extreme (0 or 10), the results show divergence. It might be the nature of humans to rarely evaluate something to be extreme.

Based on the percentage error analysis presented in Table 3, some suggestions of improvement have been proposed to the scoring system of the CAAFE system. It is observed that simplicity, stability, roundness, and boxiness are on the high side compared to other aesthetic elements. A positive percentage error means that the CAAFE system is underrating the objects. Vice versa, a negative percentage error means that the CAAFE system is overrating the objects. Since other elements exhibit considerably lower percentage errors, it is suggested that only the scoring ranges of simplicity, stability, roundness and boxiness need to be addressed. An element which is underrated by CAAFE will have its values in the scoring table downgraded, and an element that is overrated by CAAFE will have its values in the scoring table upgraded.

Stability, boxiness, and dominance are subject to larger changes in their scoring tables compared to simplicity. The suggested revised and improved scoring tables for simplicity, stability, boxiness, and dominance were subsequently incorporated within the computer system.

A total of 30 subjects participated in the second survey. The second survey was basically conducted in the same way as the first survey with the intention of observing any improvement in the scoring differences between human scoring from the survey and the CAAFE system scoring after improvement have been made to the scoring table as detailed earlier. Figure 5 shows the results for the first object.

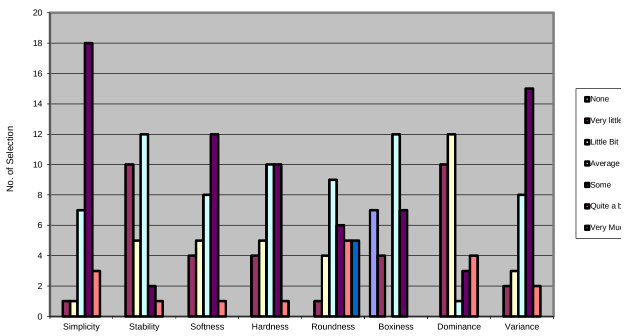

Figure 5. Results of the survey for Object 1.

As predicted, the results from the survey show a similar trend to the first survey where the participants inclined towards a dominant value in the scales for a particular aesthetic element in most of the objects. This shows that the participants have captured and comprehend the aesthetic elements evaluated. In order to determine if any improvement has been made to the CAAFE scoring system, the percentage error was compared to the first survey. The summary for the average error for each aesthetic element is given in Table 4.

From Table 4 it can be seen that the percentage errors for simplicity, stability, roundness and boxiness have improved compared to the situation before the revisions were made to their scoring tables (see Table 3). However, stability and boxiness are still on the high side, and could still be improved. The results from this second survey suggest that the surveys conducted could help to improve the CAAFE system to give a results closer to human scoring and understanding of the aesthetic elements presented.

The upgraded system is more able to produce shapes exhibiting the required aesthetics characteristics. Figure 6 shows a radio CD player that has been evolved with preferences of roundness, hardness and variance, while Figure 7 shows a coffee maker created with preferences for simplicity, stability, dominance and surface area. Once again, only the basic shape shown on the left of each figure has been generated by the evolutionary system and these have been manually enhanced to provide a product realization.

Table 4. Percentage error in the second survey.

	Total Error	Average Error(Per Object)
Simplicity	-72.67 %	-8.07 %
Stability	-141.33 %	-15.70 %
Softness	-56.67 %	-6.30 %
Hardness	46.67 %	5.19 %
Roundness	64.67 %	7.19 %
Boxiness	-158.67 %	-17.63 %
Dominance	46.67 %	5.19 %
Variance	-2.00 %	-0.22 %

4. CONCLUSION

This paper has suggested means of improving the CAAFE scoring system by conducting two surveys. The first survey was conducted to observe deviations from the CAAFE scoring by human scoring from the survey. These observations were then analyzed and any necessary revisions of the CAAFE scoring tables were made. The second survey concludes that improvements have been made to the scoring system although further improvement could still be made. These surveys could be a useful tool to reconcile the CAAFE system to the human understanding of the aesthetic elements presented in the survey. Clearly there is a very considerable amount of work to be done before evolutionary design systems can begin to approach the aesthetic appreciation capabilities of a skilled and trained designer but it is felt that the methods described are a starting point.

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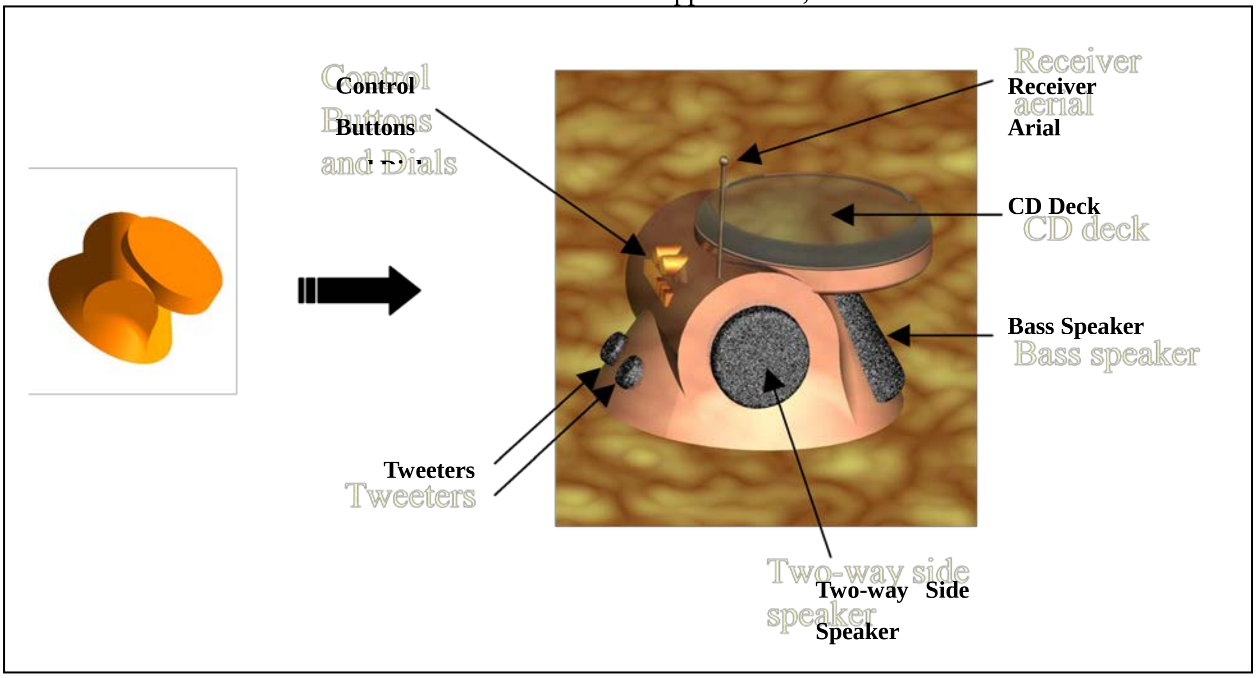

Figure 6. Radio CD player with roundness, hardness and variance preferences

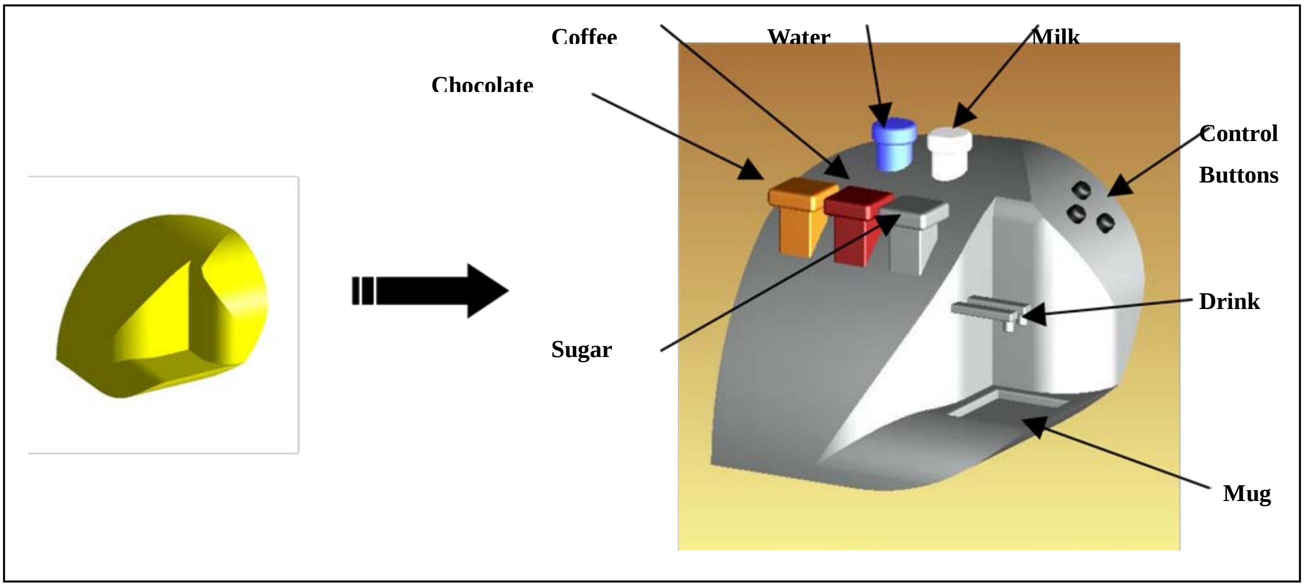

Figure 7. Coffee maker with simplicity, stability, dominance and surface area preferences