Shape Aesthetic Measures and Their Potential Uses

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ABSTRACT

This paper first explores the needs for quantitative aesthetic measures for shape and analyses previous work in this area. We then present a general framework for constructing shape aesthetic measures, and discuss how they could be used to enhance computer-supported systems for design for aesthetics.

Keywords: *aesthetics, design for aesthetics, quantitative measures, evolutionary programming, fitness functions.*

INTRODUCTION

The concept of aesthetics has been extensively analysed by philosophers for the last three centuries and opposing views may be grouped into two main types: *rationalistic* or *romanticist* (e.g. [1,2,11,14,25,26]). The former view argues that aesthetic appeal lies with the quality of objects, while the latter believes aesthetics exists only in the eye of the observer. The notion of aesthetic measures, although worth exploring, is a contentious one and may not be well received by some sectors, especially from artistic disciplines. Despite this, we cannot deny that there is an increasing demand to produce visually pleasing products, and aesthetic appeal plays a significant role in the marketing of products, especially cars, office and household products. A number of "design for X" paradigms have recently emerged with the aim to improve the quality and efficiency of design and production. However, most recent work has been focused on X being manufacturing, testing or analysis (e.g. [15]), while little attention is paid to design for aesthetics. To support such activities and ensure that a designed product is not only functional but also optimal in terms of aesthetics, we need appropriate and robust models and representations.

In an early attempt to formalise a computational model for aesthetic appreciation and evaluation, Birkhoff [2] introduced a simple aesthetic measure based on the classical Greek idea of beauty which believes that *"beauty is order in complexity"*. His aesthetic measure was expressed as a ratio of the number of elements of *order* and the number of elements of *complexity*. To study the aesthetic characteristics of polygonal forms, he defined the complexity of a polygon as the number of indefinitely extended lines that contain all of its sides. The elements of orders are defined as the vertical symmetry, rotational symmetry, equilibrium and relation to a Cartesian coordinate system. Birkhoff also acknowledged that different elements of order could exert different influence on the object's beauty and solved this problem in a very limited way by introducing weights which are pre-determined by trial-and-error. He also applied this technique to examine the aesthetics of ornaments, musical harmony and melody, and also poetry. Moon and Spencer [13] later used a similar approach to derive aesthetic measures for colour harmony. In this case, the elements of order are the similarity and contrast of hue, value and chroma, and the balance of areas of colour. The complexity is expressed as the sum of the number of colours and the number of pairs of colours having hue difference, value difference and chroma difference. To improve on Birkhoff's pre-defined weights for the elements of order, Moon and Spencer carried out subjective experiments to obtain individual weights. This method provides a quantitative rating scheme for evaluating the aesthetic merit of any combination of colours. A pertinent question is how to deal with individual subjective preferences or the suitability of specific applications.

More recently, a few researchers have attempted to define simple aesthetic measures for specific design applications. Furuta [6] considered the aesthetics of bridges in terms of their structural configurations, functional characteristics, balance and slenderness. Aesthetic measures based on these factors were subsequently defined in terms of the length of vertical and horizontal components of the bridge parts over and under the road surface, as well as the area of the bridge and of the clearance. These measures were also used as fitness functions in genetic algorithms to produce optimal bridge designs. Similarly, Reich [20] developed a design support system for cable-stayed bridge and based the judgement of aesthetics on good proportion. He introduced aesthetic measures in terms of the dimension and number of decks, towers, stays, spans and clearance distance. To address a problem in car design, Pham and Zhang [17] defined aesthetic measures in terms of the degree of smoothness of curves and surfaces in order to generate optimal reflection lines on car surfaces, using genetic algorithms. The aim of this paper is to find a more systematic framework to construct viable aesthetic measures for designed objects.

We argue that the traditional Greek view of beauty that underlies Birkhoff's aesthetic measure is too restricted to be useful for specific areas of design. The essence of aesthetic judgements very often depends not only on the number of elements of order, but on the degree in which each element of order is achieved. We believe that to be viable, aesthetic measures have to be defined within the context of a specific design problem, and furthermore, taking into account the subjective views of designers and users of products. In previous papers [3,12,16-19], we have shown how knowledge from various fields involving different aspects of aesthetics, can be integrated in order to construct a systematic framework to link design variables in terms of shape, composition and physical properties to aesthetic properties, judgements and responses. This paper extends this work and presents a method for constructing shape aesthetic measures, and discusses how they could be used to enhance computer-supported systems for design for aesthetics. Future directions for research are also covered.

SHAPE AESTHETIC MEASURES

On judicious examination of basic principles for designing aesthetic products in areas such as painting, graphic design and industrial design (e.g. [7,9,20,22,23,28-30]), we have found that there is much overlap in individual sets of such principles. We therefore have grouped these main principles into four categories which convey the sense of *opposing forces*, *resolution of conflicts*, *movement* and *global impression* of a design.

Opposing forces: *balance, contrast, proportion*
Resolution of conflicts: *dominance, harmony, composition*
Movement: *rhythm, gradation, dynamics*
Global impression: *simplicity, solidity*

For each principle for achieving aesthetic product, we identify concrete and computable properties of products that may be varied so that different degree of fulfiment of that particular aesthetic principle is achieved. This in turn would induce different responses that can be expressed in a range of aesthetic evaluative terms. Table 1 gives examples of how design variables in shape, composition and physical properties link with the aesthetic principles *balance* and *dominance*. The full list can be found in [19].

Our intention is to make sure that a variety of aesthetic judgements and emotional responses are obtained not at random, but in a more controlled and exhaustive manner which exert the most impacts. Thus, a concrete scheme for constructing objective aesthetic measures for shape design has emerged from this table, by using the normalised values of the corresponding design variables for each aesthetic principle. Furthermore, the combined effects of different aesthetic principles can also be explored using this method by manipulating these variables simultaneously or in a sequential manner. To simplify the explanation on physical properties, we choose to deal only with a few aspects relating to colour and tone. However, similar reasoning can be easily applied to other physical properties such as texture and material. One thing worth noting is that there is an inherent limitation on the extent to which aesthetic quality can be evaluated by examining variations in individual characteristics of a product because the expressive character of a volume is perceived not only as a combination of its features such as edges, planes and surfaces, but also as a whole entity. Despite this limitation, we believe that this systematic framework will add much useful knowledge towards computer-supported design for aesthetics in a number of ways. By manipulating the identified design variables in terms of shape, composition and physical properties of a given designed product, aesthetic judgements and responses can be explored. Similarly, aesthetic evaluation of alternative designs can be achieved by comparing the values of these variables for each design to see how well it has fulfilled each principle. In other words, evaluation being carried out this way, resembles that performed by professional critics. These variables can also be manipulated at the finishing stage when an initial design is checked and further refined to improve its aesthetic appearance.

Aesthetic Principles	**Shape**	**Composition**	**Physical Properties Colour / intensity**
Balance	• degree of asymmetry about centre of mass, major axes, and planes of reference (frontal, profile, median) • comparative size and spacing of features	• degree of symmetry of arrangements of objects about centre of mass, major axes and planes of references of the whole product	relative location, area coverage and variations of • complementary and opponent colours • different luminance intensity, hue, or saturation
Dominance	• major orientation • smoothness of curvature • convexity of shape • global shape characteristics of smallest convex polygonal enclosing object • surface types: plane, single curved, double curved, warped	presence of distinct patterns of arrangements • orientation • path • grouping pattern (number of objects, positions within a group), e.g. triangular, pyramid, radiation, circular	presence of • prevalent colour • distinct colour • highlight (can work with hue, saturation and value separately or with their combination in terms of colour)

Table 1.

Furthermore, by allowing selective inclusion of principles and variations of their weights, this scheme can also cater for the subjective aspects of shape appreciation such as personal shape preferences which are essential for individual creativity in art. For example, a particular designer may place more emphasis on the *simplicity* of a design than its *solidity* by using a larger weight on the former. Our framework for linking design variables with aesthetic characteristics therefore would facilitate the identification of relevant contributing factors to a viable aesthetic measure for a specific type of product, as well as the investigation of the relative weights of these factors. Examples of contributing factors to aesthetic measures given by Furuta, Reich, Pham and Zhang (as mentioned above), thus may be seen as special cases drawn from a more comprehensive list of contributing factors provided by this framework.

Another important factor to be considered is that aesthetic judgements may change with time, experience and culture, and any scheme for constructing aesthetic measures should allow such measures to be updated with further knowledge. Our framework while provides a starting point to support the design of products which are considered aesthetic when viewed from a generic perspective, could also offer scope for further refinement to cater for specific views of aesthetics if such needs arise. For example, an ultra modern design approach might even abandon the principles of *balance*, *harmony*, and *proportion* in favour of a new principle called *chaos* which is expressed in terms of the degree of randomness in relative spacings of objects, size, area, volume and physical properties. Thus, in this case, aesthetic measures would be expressed in terms of such degrees of randomness.

A more exciting prospect, however, would be to deploy these aesthetic measures in automatic reasoning schemes to provide a more extensive support system for design for aesthetics. We deal with these methods in the next section.

POTENTIAL USES OF AESTHETIC MEASURES

Geometry-based design provided by many existing CAD systems has a number of limitations. Although the local characteristics of objects can be modelled in detail, it is much harder to obtain their more global or high-level characteristics such as the relationships between their components, which in turn, may induce certain aesthetic merits. The demand to include more knowledge to support design has created the impetus to integrate artificial techniques in these systems (e.g. [24). Heuristic knowledge and automatic reasoning can relieve designers of many laborious and time-consuming tasks such as checking the satisfaction of design constraints. They can also help to support design at different levels of abstraction or to identify and search the space of possible designs. Once relevant design variables that influence the fulfillment of each aesthetic principle are identified, and aesthetic measures are constructed, they may be used in many tasks of design in a similar manner as that used for other types of knowledge such as engineering and manufacturing constraints.

The first useful application of aesthetic measures is to evaluate the aesthetic merit of a design, or to compare alternative designs based on the variation of these values. Designers very often wish to re-use previous successful designs as starting points for new designs. Thus, the aesthetic measures of good designs may be computed and stored in a knowledge-based system for future use. This body of knowledge is useful not only for future designs but also for training of novices. These measures may also be used for strategic planning with the aim to discover good designs by devising schemes to automatically check the inconsistencies of aesthetic constraints, to identify design possibilities and to warn designers of unsuitable ones. It is worthwhile to note that as aesthetic merit and appreciation are fuzzy in nature, it is more appropriate to represent these measures in a fuzzy representation (e.g. interval arithmetic or fuzzy sets), rather than an exact representation. Thus, in some way, we can say that aesthetic constraints are more forgiving than many other types of design constraints. Management of inconsistencies can be achieved by using forward and backward inferencing techniques. Thus, such a system can provide active support to experienced designers by relieving them of mundane tasks as well as novice designers by providing some guidance and feedbacks.

Another important application is to use an evolutionary approach such as genetic algorithms to automatically generate a set of designs which are considered optimal under certain criteria.

Designers then can select from this set those designs for their own use or for further refinement. The intention here is not to replace the creativity of designers by an automatic system, but rather to use designs generated this way as an aid to stimulate further creative thoughts. In this case, designers firstly select those aesthetic principles that they wish to explore or achieve and their relevant design variables. Each chromosome is represented by a single design expressed in terms of a vector containing the corresponding values of these variables. A fitness function is then constructed using aesthetic measures in terms of these variables. A population of chromosomes may be generated by selecting values of these vectors at random, or with known values from previous designs. The rules for reproduction, crossover and mutations are constructed according to the purpose of the investigation. To inspire more creative ideas in designers, it would be better to keep the initial population small while allowing a high mutation rate to obtain designs with a higher degree of variations.

It would be very useful to have a graphical user interface that enables designers to view the evolution of designs. This may serve as a mechanism to stimulate creative thoughts, but furthermore, designers would be able to exert more control on the system in various ways. Some interim results may catch their attention and they may wish to keep these results as possible designs. They may also wish to change the way the shapes are being evoluted by replacing current weights, crossover and mutation rules with new ones.

CONCLUSION AND FUTURE WORK

The concept of aesthetic measures for shape has been discussed and a systematic framework for constructing these measures has been presented. This has been achieved by drawing knowledge on how to produce aesthetic products from a number of fields to obtain a rational view of aesthetics. It has also been shown that these shape aesthetic measures can be used in computer-supported design for aesthetics in a number of ways: to evaluate a design, to compare alternative designs, to explore the effects of different design variables and to automatically generate designs that satisfy certain aesthetic constraints.

To provide further insight into the understanding and design of shapes, we plan to integrate the concept of aesthetic measures into a shape taxonomy. A 2D shape taxonomy based on factors concerning the geometry, topology and morphology of a shape has been given by Gomes and Middleditch [9]. We plan firstly to integrate the concept of aesthetic measures to this 2D shape taxonomy. We then investigate a 3D shape taxonomy by extending Gomes and Middleditch's work and also explore the integration of aesthetic measures to this 3D shape taxonomy.

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