A mathematical model for computational aesthetics

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Abstract: Computational aesthetics is the research of computational methods that do make applicable aesthetic decisions in a similar fashion as human can. In the context of computer science, it has a direct impact on landscape planning and management, computer aided conceptual design, garment and fashion industry, entertainment industry, architecture, interior design, etc. Inventions done by various researchers have made a significant impact on the development of frameworks and models for computational aesthetics that are of enormous help in the above application areas. This paper studies the existing computational aesthetic techniques and proposes a new approach to investigate the common attributes (parameters) with their weighting factors which give a real impact for a different aesthetic appreciation of an artwork (painting). Further, details of the analysis results have been presented with a view to establish the proposed model.

Keywords: computational aesthetics; aesthetics design; artwork (painting) evaluation; analytic hierarchy process; AHP.

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1 Introduction

Aesthetic characteristics are the most important concerns in several areas where human judgment involves in producing a quality output. It is a subject area that everyone likes as it is inbuilt to human beings. With the technological advancement, the computer is used as a tool to perform different types of tasks efficiently. However, it is needed to introduce particular algorithms depending on the nature of the problem using the available techniques in information technology (IT). Therefore, if any model or approach can be found to compute the aesthetic value of an artwork like a painting, that will be of great use for the efficient and effective evaluation and enhancement of the aesthetic characteristics of such products.

The theory of aesthetics introduced by George David Birkhoff (1933) in his book *Aesthetic Measure* involves a lot of computational methods. It has built a foundation for several other researchers to come up with different frameworks and models for computational aesthetics. Computational aesthetics is the research of computational methods that can make applicable aesthetic decisions in a similar fashion to a human (Florian, 2005). Although several attempts have already been made for assessing and computing aesthetic values, the effort for the enhancement of aesthetic values is still in its infancy. Attempts have been made in the areas of landscape planning and management (Tyrvainen and Tahvanainen, 1999), computer aided conceptual design (Breemen et al., 1998; Knoop et al., 1998; Machado and Cardoso, 1998; Pham, 1999), garment and fashion industry (Helena and Lubbe, 2008; Hethorn, 2005), entertainment industry (Wages et al., 2004), etc. However, only a little research has been done on evaluating and assessing artworks using IT as it involves three basic concepts namely subjectivity, cultural influence and the qualitative evaluation.

The objective of this paper is to conflate various inventions for computing and assessing aesthetics and to propose a new approach using analytic hierarchy process (AHP). Further, this paper discusses the analysis results of the two surveys conducted to establish the proposed mathematical model.

The paper is organised as follows. The first section contains a discussion on what aesthetics is and the importance of computing aesthetics. The second section discusses about the need of aesthetic computing and enhancement for the today's world and it presents an elaboration on its application areas. Next sub section discusses the related work done by other researchers for computing aesthetic value. After that, aesthetic language and the evaluation of an artwork is discussed broadly. Then, proposed approach for computational aesthetics is discussed with details of those steps and two surveys conducted to establish the model. Analysis results are also presented there followed by a discussion and future work, a conclusion and an acknowledgement.

2 Application areas of aesthetics

One of the main reasons for aesthetic design becoming a widespread topic is the fact that we live in a complex world with different entities which requires to concentrate on the functionality as well as on the visual appearance of aesthetics. Accordingly, aesthetic design is used in diverse areas. As mentioned earlier, it shows a high demand from landscape planning and management, computer aided conceptual design, garment and fashion industry, entertainment industry, etc.

Landscape planning and management is one of the areas that highly use aesthetics. Rural landscapes change over time as a consequence of environmental process and human impact. Especially, the visual changes in rural landscape as a result of economic demand and the technological innovations are required to be managed in such a way that a minimum net loss of aesthetics and ecological interest would result. Presently, there aren't efficient and inexpensive tools available in planning and assessing the visual impact of landscape changes. Although, scenic beauty is difficult to be predicted and expressed numerically, the impact of aesthetics for proposed management alternatives can be visualised for decision-makers in planning (Tyrvainen and Tahvanainen, 1999).

It has been that there is great potential in the process of computer aided conceptual design, too. Product designers are highly motivated to integrate specific target customer responses and they communicate their aesthetic intents to target customers by means of shape, composition and physical properties of the designed product (Breeman and Sudijono, 1999).

In the garment and fashion industry, they need to model clothes prior to the manufacturing operations using cloth simulation reducing the production cost and the wastage. In cloth simulation, there is a requirement to map the design variables to the aesthetic characteristics of the clothing so that the user's preferences such as colour, texture and the shape of the final product are covered.

There are some other areas such as entertainment industry, photography, architecture, human computer interaction and interior design in which aesthetic decisions play a major role.

2.1 Related works

Birkhoff (1933) introduced the first quantitative theory of aesthetics in his book, Aesthetic Measure. It is considered as the beginning of computational aesthetics since the involvement of computational methods. The author has developed a definition of a new area of research in computer science that could reflect recently observed interest of researchers in aesthetics.

Tyrvainen and Tahvanainen (1999) proposed a method to assess the scenic impact of changes in landscape management and planning. In their study, they compare the differences in viewer responses for photographs representing rural landscapes with the computer graphics drawings representing the same landscapes. From their study, they have shown the usefulness of computer graphics drawings to illustrate the differences between the present and estimated future state of the rural landscape for practical planning purposes.

Knoop et al. (1998) proposed a novel computer-oriented methodology of design for aesthetics. The authors focus on the issues related to a practical coupling of aesthetic intents and shape characteristics, following an analogy of information communication.

Breemen et al. (1998) has presented a model of design for aesthetics with two directions each having four levels of communication. That model reflects the understanding of the design for aesthetics as a two-way communication between the space of aesthetic characteristics and the space of shape characteristics defined by the designed variables.

Pham (1999) has proposed a systematic approach for exploring interactions of aesthetic properties and design variables by integrating knowledge from other fields such as philosophy, psychology and arts. In his study, a common set of nine principles for achieving aesthetic products in a number of creative disciplines has been identified.

Pham (2000) explored the need for quantitative aesthetic measures for shape. The author has presented a general framework for constructing shape aesthetic measures and discusses how they could be used to enhance computer-supported systems designed for aesthetics.

Machado and Cardoso (1998) proposed a new theory according to which aesthetics depends on biological and cultural issues, namely on visual image processing. They have presented an implementation of this theory where aesthetic value of an artwork is directly connected to image complexity (IC) and inversely connected to processing complexity (PC). By devising estimates for IC and PC they have shown how to compute the aesthetic value of an artwork (image).

3 Aesthetic language and evaluation of an artwork

When the aesthetic characteristics are expressed in a product, different terms are used by people with different meanings. One of the researchers, Goldman proposed a classification of evaluative aesthetic terms into the following eight categories (Goldman, 1995).

- broadly evaluative (e.g., beautiful, ugly)
- formal (e.g., balanced, graceful)
- emotional (e.g., sad, angry)
- evocative (e.g., powerful, amusing)

- behavioural (e.g., sluggish, jaunty)
- representational (e.g., realistic, artificial)
- perceptual (e.g., vivid, dull)
- historical (e.g., derivative, original).

These terms could be used for evaluation and expressing the different views of aesthetic characteristics. However, the important thing is how these terms and the product features are interconnected. Art and aesthetics are different but highly related fields. According to the opinion given by Machado and Cardoso (1998), visual artworks can be evaluated considering two main factors:

- content of the artwork- relates to what is represented by the artwork
- form (visual aesthetic value) – how the content is represented by using the parameters such as colour combination, contrast, brightness, texture, shape, composition, etc.

We are aware that these two factors are not completely independent and the value of the artwork decides upon them and the interactions among them. There may be several instances that the artworks are visually pleasing while the content of them does not give that much of an impact to improve the aesthetic value. Accordingly, it will imply the fact that these two factors are independent while aesthetics focuses mainly on the form of the artwork. Therefore, we are concerning primarily the form of the artwork (painting) in this research.

4 Proposed model for computational aesthetics

4.1 Introduction

As visual aesthetic value depends on several parameters of an artwork, it is required a multi-criteria decision making method for computing it. Thus, a new approach called AHP was discovered during the literature survey and it had been thoroughly studied. AHP is a multi-criteria decision-making method originally developed by Thomas L. Saaty (1980). It can be used to select the best painting with relative weights of its parameters that contributes to the final goal: highest aesthetic value. AHP has become quite popular as a research method due to the fact that its utility expands to the diverse areas of study and it combines both qualitative and quantitative approaches together. It is a hierarchical representation of a system, which is an abstraction of the structure, and it will show different levels of criteria and sub criteria with alternatives at the lowest level.

When dealing with aesthetic decisions in artworks, normally, evaluator or group of evaluators will have to express satisfaction feelings based on the aesthetic quality of the artwork. As the visual aesthetic quality mainly depends on several parameters (design variables) of an artwork, we were able to compute the parameter contribution to the main goal using AHP. In the current research, a set of different image groups (paintings) that can be analysed based on their form (physical attributes, shape, composition, etc.) were selected as a better collection of paintings by referring some reputed painting archives publicly available (Kalwick, 2010; Potter, 2010).

4.2 The AHP method

It has eight steps, which are shown below.

1 defining the decision problem

2 developing a conceptual framework

3 setting up the decision hierarchy

4 collection data from experts

5 employing the pair-wise comparisons

6 estimating relative weights of elements

7 calculating the degree of consistency

8 calculating the mean relative weights.

4.2.1 Defining the decision problem

Following the steps in AHP method, problem was defined as "choose the best painting of highest visual aesthetic value". Then, the conceptual framework was established by decomposing the main objective to criteria and sub criteria (levels and sub levels).

4.2.2 Setting up the decision hierarchy

For the purpose of setting up the decision hierarchy, a preliminary survey was conducted by selecting experts in the subject area and expert knowledge was gathered to establish the mentioned hierarchy.

By consulting experts and by referring some of the research papers, we were able to select the parameters (attributes) that are most significant to the form of artwork (painting). They are colour, contrast, brightness, shapes and texture (brushstroke) (Figure 1).

This survey was useful to identify the diverse existing views about the meaning of aesthetic value and the techniques used by practitioners to enhance the aesthetic value. In addition to the above two findings, it was able to reveal that there are some aesthetic principles which can be balanced using the different contributions of those attributes. According to Pham (1999), nine aesthetic principles have been identified that can fine-tune the interaction between the aesthetic properties and the design parameters. Following table (Table 1) shows those nine principles.

Figure 1 AHP architecture (assumption: comparing three paintings of a particular group)

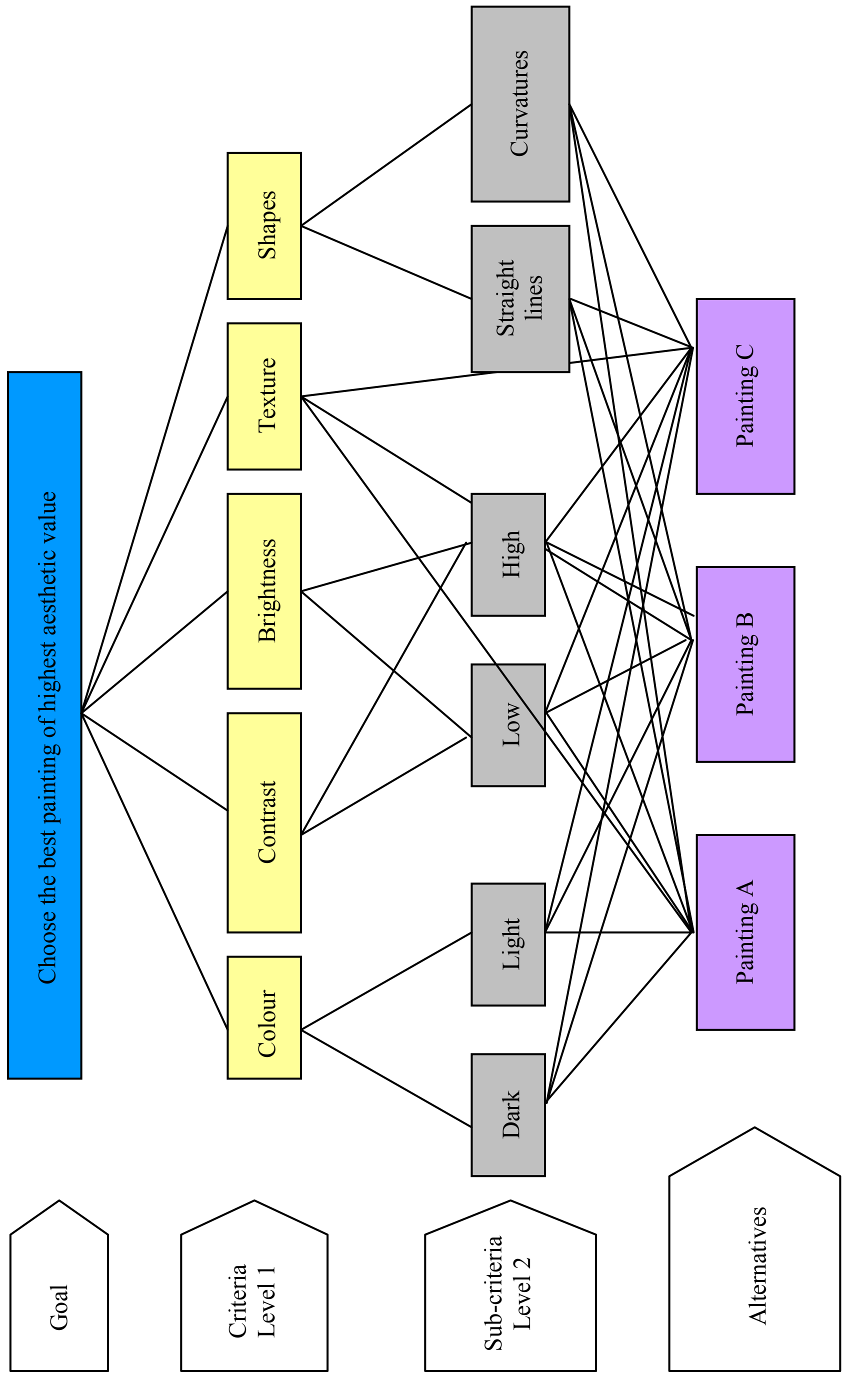


Table 1 Aesthetic principles

Balance
Proportion
Alternation
Continuity
Solidity
Simplicity
Dynamics
Rhythm
Dominance

4.2.3 Data collection

For the purpose of collecting data, we decided to select two major sample categories: IT field category and subject expert category. Here, IT field category was selected as people in this category have a sound knowledge about the enhancement of image quality using IT techniques. Then, the number of sample group for each category was decided by referring to the AHP technique and the statistical theory. Number 50 was selected for IT field category. When referred to the AHP technique, number of subject experts is a very low number in most of the case studies. Accordingly, Number 3 was selected for the subject expert category in our survey. Questionnaire was prepared properly including all the details for the analysis.

4.2.4 Pair-wise comparison

We formed a pair-wise comparison matrix A, where the number in the ith row and jth column gives the relative importance of O_i as compared with O_j (O_i and O_j are two parameters compared). We used a 1–9 scale, with $a_{ij} = 1$ if the two objectives are equal in importance, $a_{ij} = 3$ if O_i is weekly more important than O_j , $a_{ij} = 5$ if O_i is strongly more important than O_j, $a_{ij} = 7$ if O_i is very strongly more important than O_j and $a_{ij} = 9$ if O_i is absolutely more important than O_j . All pairs in each level were compared with respect to the higher level and comparison matrix or adjacent matrix was formulated for each sub criteria (level).Questionnaire was prepared in such a way that comparison matrices are formulated in the data sheet itself. Therefore, these values were directly used for the rest of the calculations in the AHP method.

4.2.5 Analysis results

Steps 6, 7 and 8 are related with calculation of relative weights, calculation of inconsistencies and calculation of mean relative weights. After obtaining pair-wise comparison matrix, a relative weight (priority vector) was calculated. This was done by dividing each element in the matrix by the column sum (normalising) and adding row sum and dividing those values by the number of elements in the row. It is known that people are inconsistent in answering the questions. Therefore, one of the important tasks in AHP is to calculate the consistency using a test defined by the AHP technique.

It is a very tedious task doing these calculations manually as it involves several mathematical calculations. Therefore, we decided to use an efficient IT tool for the rest of the calculations. Again, a research was done to find out a proper tool for this task. It was able to reveal that some software packages for this task are available such as expert choice (Expert Choice, 2010). But, due to the unavailability of free download with all the functionality, we had to find any online tool for this task. It was able to find AHP calculation tool developed by Canadian Conservation Institute (CCI) (Tools, 2010).

Comparison matrix data were directly entered to the above tool and relative local weights and the consistency values were calculated for each and every member in the survey. After getting relative weights (priority vectors) for all members, mean relative weights were calculated using an excel sheet.

4.2.5.1 Painting categories and individual parameter contribution

As our aim is to do the research based on the form of the panting rather than the content, simple themes like animals, flowers and children were selected. Our next target is to calculate global weights for each and every theme under the two major sample groups selected. According to the AHP technique, Global weights for each alternative can be calculated using the following formulae.

Assume that following local weights are obtained for the animal painting theme. Table 2 shows relative local weights with respect to the main goal.

Table 2 Relative local weights with respect to the main goal

Parameter	*Local weights*
Colour	a1
Contrast	a2
Brightness	a3
Texture	a4
Shape	a5

Table 3 shows relative local weights with respect to the Level 1 parameters.

Table 3 Relative local weights with respect to the Level 1 parameters

Parameter	*Local weights*
Dark	b1
Light	b2
Low (contrast)	b3
High (contrast)	b4
Low (brightness)	b5
High (brightness)	b6
Straight lines	b7
Curvatures	b8

Table 4 shows local weights with respect to Level 2 parameters.

Table 4 Relative local weights with respect to Level 2 parameters

Parameter	*Local weights for alternatives: Painting A, Painting B, Painting C*
Dark colour	c1, c2, c3
Light colour	c4, c5, c6
Low contrast	c7, c8, c9
High contrast	c10, c11, c12
Low brightness	c13, c14, c15
High brightness	c16, c17, c18
Texture (*Level 1 parameter*)	c19, c20, c21
Straight lines	c22, c23, c24
Curvatures	c25, c26, c27

Total relative weights (global weights) for Painting A:

$$A = c1*b1*a1 + c4*b2*a1 + c7*b3*a2 + c10*b4*a2 + c13*b5*a3 + c16*b6*a3 + c19*a4 + c22*b7*a5 + c25*b8*a5$$

Total relative weights (global weights) for Painting B and C can also be calculated following the same technique.

Table 5 Parameter contribution of relative weights with respect to the main goal

Alternatives	*Parameter contribution*									*Total relative weights*
	Dark colour	*Light colour*	*Low con.*	*High con.*	*Low bright.*	*High bright.*	*Texture*	*St. Lines*	*Curvatures*	
Paint. A	c1 *b1 * a1	c4 * b2 * a1	c7 * b3 * a2	c10 * b4 * a2	c13 * b5 * a3	c16 * b6 * a3	c19 * a4	c22 * b7 * a5	c25 * b8 * a5	*A*
Paint. B	c2 * b1 * a1	c5 * b2 * a1	c8 * b3 * a2	c11 * b4 * a2	c14 * b5 * a3	c17 * b6 * a3	c20 * a4	c23 * b7 * a5	c26 * b8 * a5	*B*
Paint. C	c3 * b1 * a1	c6 * b2 * a1	c9 * b3 * a2	c12 * b4 * a2	c15 * b5 * a3	c18 * b6 * a3	c21 * a4	c24 * b7 * a5	c27 * b8 * a5	*C*

According to the AHP technique, alternative that gives the maximum relative weight is selected as the best alternative to achieve the main goal.

Following figures (Figures 2, 3 and 4) show the diagrammatic representations of that parameter contribution of alternative for the goal of highest visual aesthetic value.

Figure 2 Parameter contribution for animal theme painting

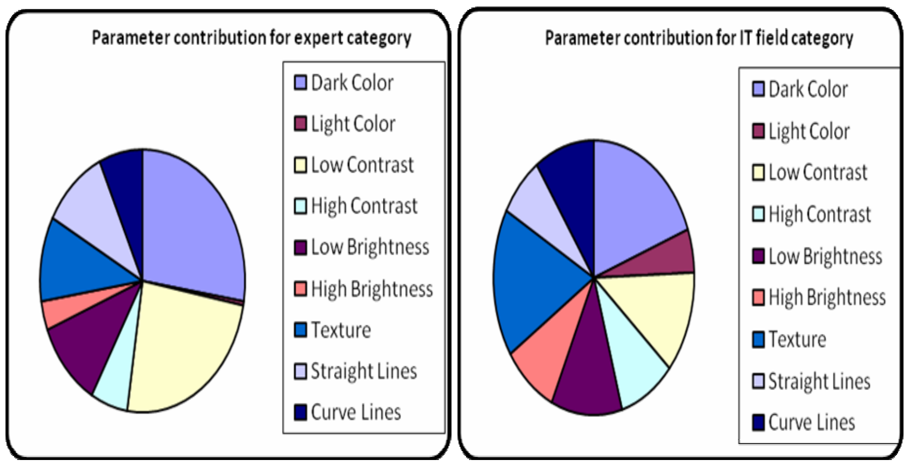


Figure 3 Parameter contribution for children theme painting

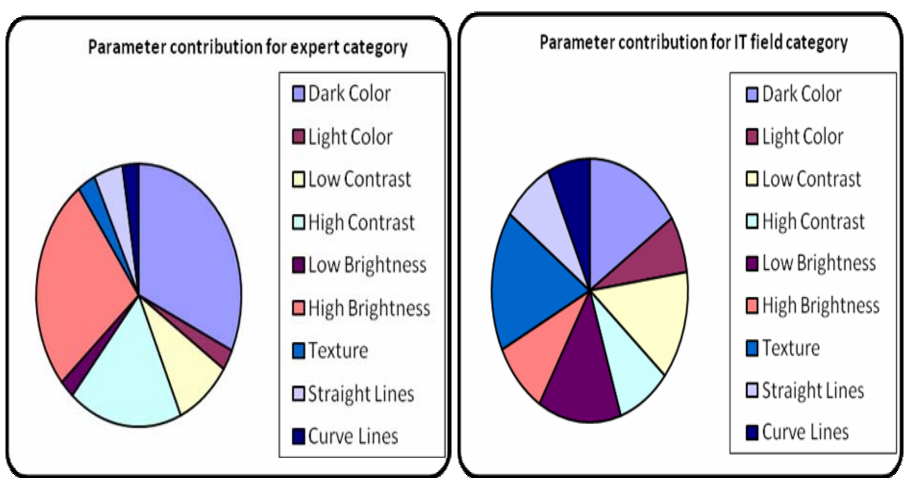
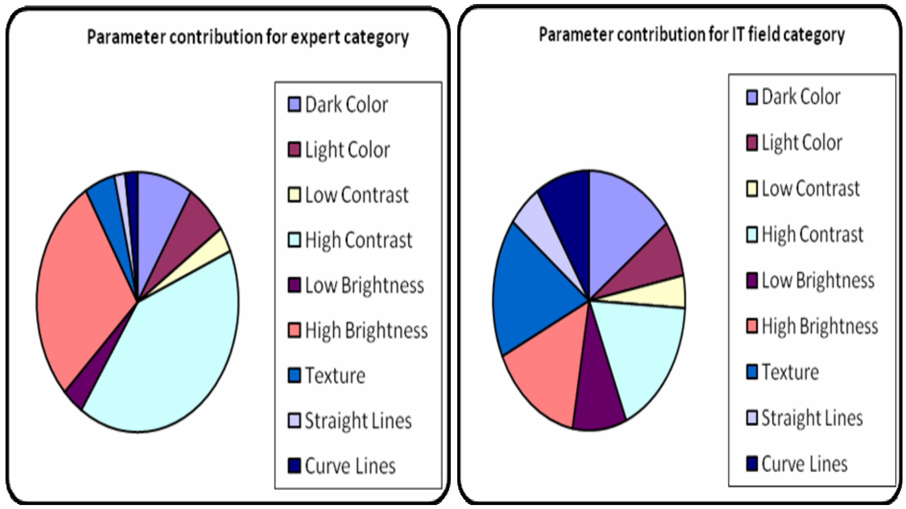


Figure 4 Parameter contribution for flowers theme painting



5 Discussion

According to the AHP technique, maximum relative weight is selected as the best alternative that contributes to achieve the main goal specified. In animal theme painting category, under the IT field category, it has obtained the global weights (total relative weights) 33, 36 and 31 respectively for the three alternatives. Therefore, the highest value is 36 and painting B is selected as the best. In the same category, under the field expert category, it has obtained the global weights 39, 31 and 30 respectively for the three alternatives. Thus, the highest value is 39 and painting A is selected as the best. Irrespective of the painting selected under that category, dark colour design parameter has been selected by them as the highest important parameter. Low contrast and texture are the next important two parameters suggested by them. Therefore, finally, we can decide that irrespective of the content, the dark colour, low contrast and texture are the most significant parameters for aesthetics in order for the animal painting theme. Table 6 presents obtained statistics for the children painting theme.

Table 6 Statistics for the children painting theme

Alternative	*Selected sample category*	
	Field expert category	*IT field category*
Painting A	37	34
Painting B	34	35
Painting C	29	31

For the children painting theme, both categories obtained different parameters. Accordingly, IT field category selected texture is the most important parameter and dark colour and low contrast/low brightness were selected as the next important parameters.

For the field expert category, dark colour is the most important parameter and the high brightness and high contrast were selected as the next important parameters.

Table 7 presents obtained statistics for the flowers painting theme.

Table 7 Statistics for the flowers painting theme

Alternative	*Selected sample category*	
	Field expert category	*IT field category*
Painting A	38	35
Painting B	34	34
Painting C	28	31

For the flowers painting theme, both categories have obtained different parameters. Accordingly, IT field category selected high contrast and texture as the most important parameters and dark colour and high brightness were selected as the next important parameters. For the field expert category, high contrast is the most important parameter and the high brightness and dark colour were selected as the next important parameters.

6 Conclusions and future work

In this paper, we have observed several existing frameworks and models that are used to evaluate and assess aesthetic values of different products. We further discussed the issues of the models and frameworks used by the above mentioned application areas and tried to adapt those to the proposed model for computing and enhancement of the aesthetic value in an artwork. Ultimately, the proposed model (Figure 1) assisted to compute the overall composite weight of each alternative choice based on the weight at different levels for the aesthetic value of an artwork (painting). Based on the results obtained, for each and every group of digital images of given painting themes, one can have a record of physical attribute patterns that totally contribute to the aesthetic appreciation of an artwork.

Next, in future, image processing techniques can be incorporated to establish the acquired common attribute pattern of image for enhancement of the aesthetic value of a given image. This approach can be used to develop a tool that can be used to enhance the aesthetic value of an artwork (painting).

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