Exploiting Logarithmic Aesthetic Curves for Proactively Providing 'Design for Emotions' Guidance

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Abstract: Given the indispensability of delivering the user emotional satisfaction, product design engineers need to adopt a Design for emotion (DFe) approach to develop artefacts. A critical literature review of the state-of the-art DFe support, led to the identification of a research gap in providing proactive assistance during the form embodiment design stage. This research therefore aims to develop a computer-based support tool which is capable to predict the lack of emotional value in the evolving form design solution. In view of this context, a set of formal guidelines were developed that relate stakeholders' characteristics, product form characteristics and their impact on aesthetic product emotions. The survey results revealed statistically significant association between emotions elicited and symmetry, high length-to-width ratio and curvature. A system architecture for a computational DFe support tool was developed. Central to this system is the interaction between the analysis of logarithmic aesthetic curves extracted from the evolving form concept and the aforementioned formal guidelines. Based on this system, a proof-of-concept tool integrated in a CAD environment was implemented. Preliminary evaluation results show that the tool proactively supports designers with guidance on how to improve their form concepts such that the emotional value is enhanced.

Key words: CAD Tools, DFX, intelligent support

1. Introduction

It is a challenging task to integrate emotional needs into product design, since emotions are subjective and idiosyncratic. Product experience is not solely dependent on the properties of a product, but also on the global complex human-product interaction. The same product may elicit diverse emotions, majorly determined by the user's individuality, the environment and the period of time at which the interaction occurs since a time period leaves its impressions on culture, fashion and trends [1]. Establishing definite patterns of product properties and the expected emotional response appears to be unattainable; however an underlying principle governing the human-product experience prevails and patterns may be distinguished to help designers facilitate design for emotion [2].

Moreover, emotion-driven industrial design is only at its introductory stage, although recent years have seen an increase in interest and the development of formal processes and tools. Nonetheless as described in section 2 of this paper, there is still a lack of active assistance, whereby a design for emotion support tool predicts an absence of emotional value in the design and suggests or applies modifications in the initial stages of product development.

Within this context, the aim of this research is therefore to develop a computer-based support tool which is capable to predict the lack of emotional value in the evolving form design solution.

Based on this introduction, the rest of this paper is organized as follows. Section 2 describes logarithmic aesthetic curves. Section 3 critically reviews the state-of-the-art DFe support and identifies a research gap. Section 4 discloses results of a questionnaire carried out to investigate the relationships between product and stakeholder characteristics and emotional responses. This was required to formulate a set of guidelines, thereby providing the foundations of an emotional knowledge database of the system architecture described in section 5. Details of the implementation of this system in a proof-of-concept tool are provided in Section 6. Preliminary evaluation results follow in section 7, which are then discussed in the subsequent section. Conclusions on the contribution of this paper are finally drawn in section 9.

2. Logarithmic Aesthetic Curves

Product emotional stimuli include acoustical, visual, tactile and aromatic stimuli. Although every product emotional stimulus is important and affects the stakeholder equally, the focus of this research work is upon aesthetic product emotional stimuli. Pictorial stimuli are particularly important, in particular logarithmic aesthetic curves. ‘Aesthetic curves’ were proposed by Harada [3], where natural aesthetic curves such as birds’ eggs and butterflies’ wings along with artificial aesthetic curves like Japanese swords and automobiles’ key lines, are curves whose logarithmic curvature histograms (LCH) are almost linear [4,5,6]. Aesthetic curves provide another aesthetic principle that is universal and does not vary from one stakeholder to another or across time. LCHs are generated by the following algorithm [7, 8]:

1. The x, y and z coordinates of a curve are extracted
2. A cubic spline in piecewise polynomial form is fitted along the curve coordinates and an equation for the spline is obtained
3. The first (y'), and second (y'') derivative for each point are obtained
4. The curvature, $K = |y''|/(1+y'^2)^{3/2}$, is determined for each point; the average K value is computed
5. A cubic spline in piecewise polynomial form is fitted for curvature versus arc length, and its gradient dK/ds is obtained
6. The radius $\rho=1/K$ is determined for each point on the spline and its logarithm, $\log\rho$ is computed
7. $\frac{ds}{d\rho} = \frac{1}{\frac{d\rho}{ds}} = \frac{1}{-\frac{1}{\kappa^2} * \frac{d\kappa}{ds}}$ [7] is calculated and $\log(\rho * ds/d\rho)$ is determined.
8. $\log(\rho * ds/d\rho)$ vs. $R = \log\rho$ is plotted to provide the logarithmic curvature histogram. The slope of the straight line α represents the curvature variation [7].

3. State-of-the-art in Computer-based DFe Support

This section reviews computer-based tools developed specifically to provide Design for Emotions (DFe) support. Fenech [9] has developed a design for emotion assistant, *Demo*, through the collection of DFe knowledge in the form of a set of guidelines which provide active assistance (anticipatory) to the designer. *Demo* provides DFe assistance to the designer, based on the interactions between the *stakeholder*, the *product* and the specific *environment* in which it is used. *RealPeople* [10] is a DVD-based tool which provides the designers with a ‘pleasure resource’, promoting the integration of emotion and ‘pleasure’ in the ergonomics of the design. This tool was developed to inspire designers in the early stages of the design process, by linking target markets and their ‘pleasure’ needs. The [*product & emotion*] navigator [11] is a database designed to offer inspiration and stimulation to designers to understand the elicitation of emotions by specific product characteristics. It is based on a database which consists of 350 photos of products accompanied by their elicited emotions, user's concerns and the reasons why the emotions were elicited i.e. the appraisal. The designer browses through the database by choosing an element and the navigator displays products that are related to the element of choice. *HADRIAN* (Human Anthropometric Data Requirements Investigation and ANalysis) [12] is a computer-based inclusive design tool which utilizes 3D human modelling of differing shapes, sizes and physical, emotional and cognitive abilities to support ergonomic design. This tool encourages designers to accommodate a wide range of users. *HADRIAN* automatically evaluates concept designs in a CAD environment through the combination of individual datasets for particular people with a task analysis tool. Each individual is assigned cognitive and emotional data, along with video clips to evoke empathy towards the stakeholder within *HADRIAN* thus, inducing a humanistic approach of the design process [12]. *HADRIAN* is not an intelligent system i.e. it does not include the user's intention or generate intelligent responses to demands. *Imprint Design* (I.D.) tool [13] directly relates specific physical design attributes and desired emotional experiences of the stakeholder, thus the designer can determine the features a product has or should have through the emotional parameters. Links are created through mapping of mental reactions that create immediate affective impression of the product and product stimuli. Shirahata *et al.* [6] developed a log-aesthetic curve plug-in module in a commercial modeler, aimed at improving the quality and the efficiency of the aesthetic design. However, this plug-in module does not provide DFe support in order to improve the emotional content of the design, based on the target stakeholder characteristics.

As outlined in the above review, there is a research gap in supporting designers to take a DFe approach during the embodiment stage of form concepts in a Computer-Aided Design (CAD) environment, by exploiting logarithmic aesthetic curves. To address this gap, it is of paramount importance to investigate the relationships between product characteristics, in particular its aesthetic curves, the stakeholder characteristics and emotional responses. This was accomplished by carrying out a survey as described next.

4. Relationships between aesthetic curves, stakeholder characteristics & emotions

4.1 Questionnaire design

The questionnaire consisted of three sections. Section 1 concerned questions regarding the respondents' attitudes when purchasing a product and their relationship with their belongings. Section 2 concerned questions relating the respondents' emotional response to images of products and the last section concerned background questions on the respondents themselves. To aid the respondents in exploring their emotions and experiences on a deeper level, verbal questions alone are not enough [14] and thus images of facial expressions known as *Emocards* [15] were included to make it easier for them to describe their emotion. The questionnaire was focused to analyse a category of product form characteristics, namely, symmetry, curvature and length : width ratio. The products chosen were everyday commodities namely smartphones, staplers and bottles that the respondents are familiar with. Eight smart phone models, eight water bottle models and five stapler models were considered for the questionnaire. Images of each model were depicted in the questionnaire and the respondents had to relate an *Emocard* that best describes their emotional response towards that product.

In order to guarantee the validity of this study, the smart phones chosen were all touch screen so that the emotions elicited depended only on the aesthetics of the product and not the functionality. The eight smart phones were selected out of a sample of twenty, and the front end image of each model was reproduced using a CAD package, which eliminated colours and brands to avoid the selection of phones due to these factors rather than form or size. The same applied for the bottles and the staplers.

4.2 Product Analysis

Curvature analysis was implemented on each product considered in the questionnaire by placing a set of work points along the most prominent curve of the design. The coordinates of the work points were exported and inputted into *MATLAB®* [16] where a spline was fitted along the points, and analysed for its average curvature and its logarithmic curvature histogram was plotted and evaluated. The classification of curvature was classified as a small curvature if the value of the average curvature was less than 0.1, a medium curvature if it lies between 0.1 and 0.35, and a large curvature if the average was larger than 0.35. The length : width ratio was measured using the measurement tools provided in a CAD package and the classification of a high or low length : width ratio was determined according to the item being analysed. This is because, for instance, a high length : width ratio for a water bottle is not the same as for a stapler.

4.3 Questionnaire Data Analysis

Social networks and e-mails were chosen as the method of distributing the questionnaire, as it proved to be cheap, fast and effective. Three hundred eighty three (n=383) valid questionnaires were returned. The data collected was analysed in two steps: a qualitative analysis was first executed to give a general perspective of the results followed by a statistical analysis which presented an in depth study of the relationships between product and stakeholder characteristics.

The first analysis included an emotional mapping of each model. For example, Figure 1 presents the emotional maps on a 180 point scale for a sample of water bottles and displays a general perspective of the emotions that the respondents related to them. Emotions to the right of the chart are positive whilst those to the left are negative.

The statistical analysis software *SPSS Statistics* [17] was used to perform a series of *Chi-Square* tests on the data. The tests were divided in two stages: the primary stage tested the association between product characteristics and emotion whilst the second stage included the stakeholder characteristics in relation to product characteristics and the resulting emotions. The statistical evaluation of symmetry and emotion [18], shows that both single and multiple axis symmetry elicit a majority of positive emotions, whilst there exists an association between the type of symmetry and the emotion elicited since both the Pearson Chi-Square (4.410) and the Likelihood Ratio (4.381) were high, whilst the p-values (p=0.036) were less than 0.05. Length : width (L:W) ratio and emotion were also analysed and the results showed that a high L:W ratio elicits positive emotions for a majority greater than 60%, whilst a low L:W ratio elicits positive emotions only marginally. A strong association exists between the L:W ratio and emotion elicited, since a significantly high Pearson Chi-Square (171.17) and Likelihood Ratio (169.588) resulted whilst the p-values (p📻0) were less than 0.05. Results also revealed that small, medium and large average curvatures all elicit positive emotions, however the medium average curvature has a larger percentage of positive emotions. A product form with no curvatures elicits negative emotions. A strong association exists between average curvature and emotion since both the Pearson Chi-Square value (135.564) and the Likelihood ratio (134.722) are high whilst the p-values are minimal (p📻0).

From the secondary stage analysis it emerged that single axis symmetry, high length: width ratio and curvatures elicit positive emotions for any stakeholder characteristic. It was also found out that there is a strong correlation between the negative emotions the respondents exhibited and the lack of curvatures present across the three categories of products included in the questionnaire.

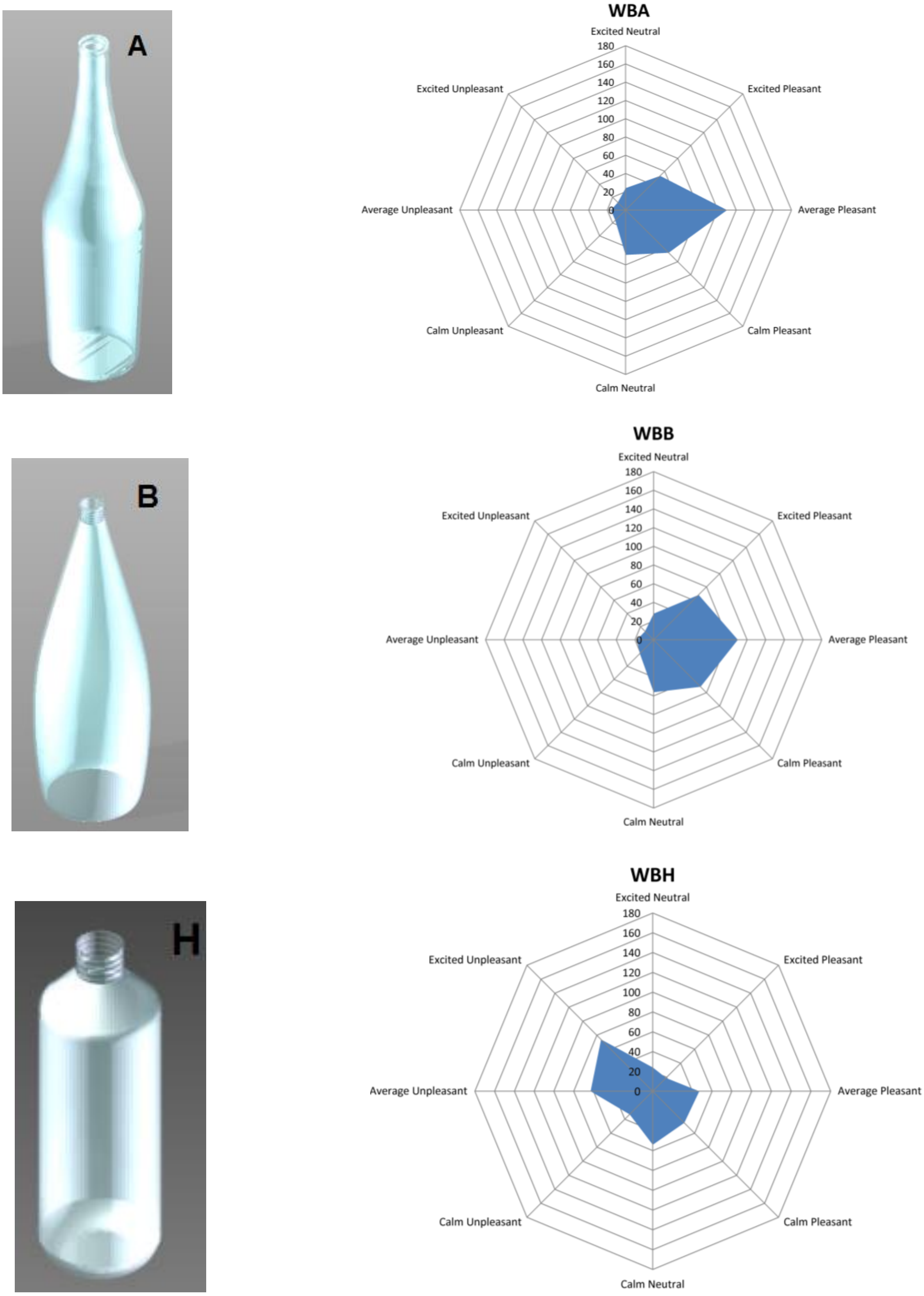


Figure.1 Emotion mapping of a sample of water bottles

5. System Architecture for a DFe support tool which exploits logarithmic aesthetic curves

As illustrated in Figure 2, the system that has been developed is composed of the following three frames:

1. *Form Concept Embodiment* (*FCE*) frame: in this frame, the designer generates form concepts by sketching. The candidate form solution is then transformed into a three-dimensional (3D) virtual model in a CAD environment. To facilitate the transition between sketching on paper and 3D CAD modelling, the *sketching language* described in detail in [19] has been utilized. This language is characterized by symbols which automatically map a form concept sketched on paper into the corresponding 3D virtual model.

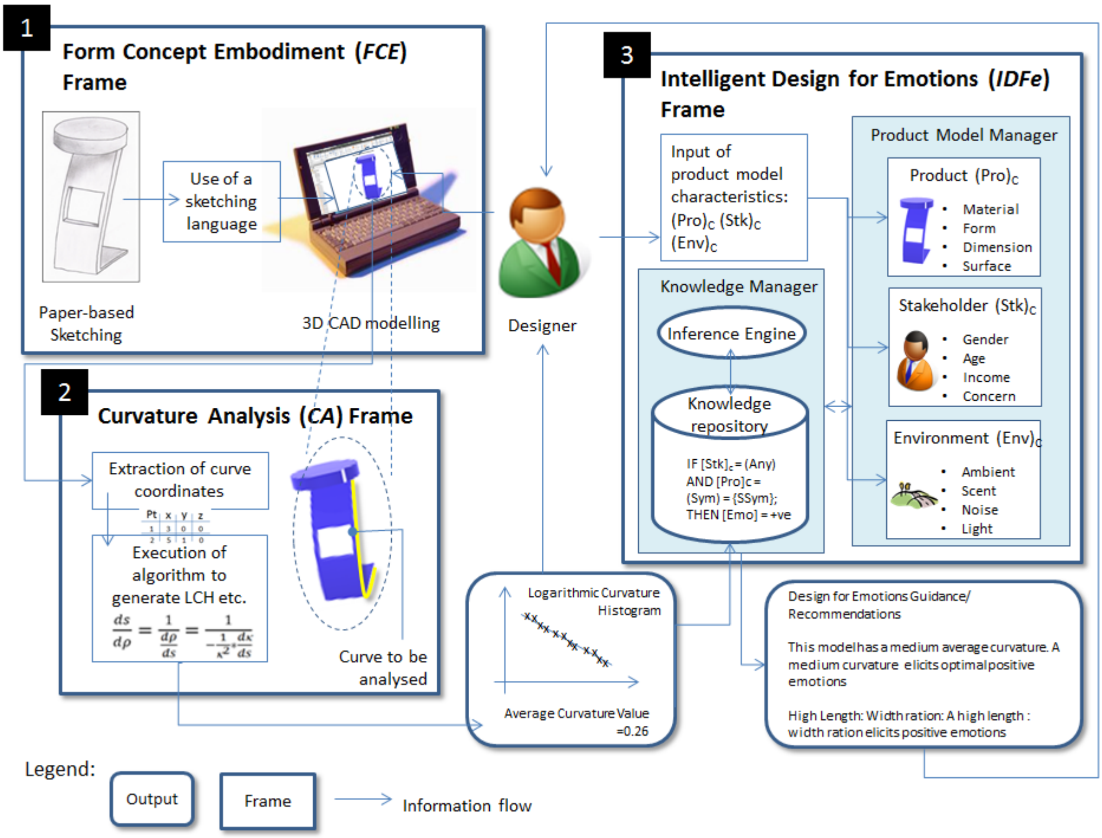


Figure.2 DFe support system

2. *Curvature Analysis (CA)* frame: in which the main curve characterizing the evolving form solution is first highlighted by the designer in the CAD modelling environment. This curve is then subjected to the algorithm described in section 2 in order to derive the logarithmic curvature histogram and subsequently the average curvature value.
3. *Intelligent Design for Emotions (IDFe)* frame: as illustrated in Figure 2, the main elements in this frame are the product model manager and the knowledge manager. The former is based upon Fenech's model [9] which considers the interactions between the stakeholder, the product and the specific environment. In this respect, the designer is required to set the parametric characteristics of the stakeholder (gender, age, income bracket and concern), the product (material, form, dimensions and surface), and the environment (ambient, scent, noise and light) [9]. These characteristics are then inputted in the *inference engine*, which derives a set of DFe recommendations, based on the knowledge captured in the knowledge repository. The knowledge base developed by Fenech [9] has

been augmented with the knowledge generated from the survey results presented in section 4. The captured knowledge has been formalized by employing *IF THEN* rules presented in the form of guidelines. Examples of such guidelines and which were derived from the survey results in section 4 are the following [18]:

$$\boldsymbol{IF}\ [Stk]_c = (Any)\ AND\ [Pro]_c = (L/W) = \{HL/W\}\ \boldsymbol{THEN}\ [Emo] = +ve$$

meaning that for any type of stakeholder characteristic $[Stk]_c$, a product with a high length : width ratio (HL/W) elicits positive emotions

$$\boldsymbol{IF}\ [Stk]_c = (Any)\ AND\ [Pro]_c = (Cur) = \{NCur\}\ \boldsymbol{THEN}\ [Emo] = -ve$$

meaning that for any type of stakeholder characteristic $[Stk]_c$, a product with no curvature (NCur) elicits negative emotions

A set of guidelines are communicated to the designer in order to improve the emotional content of the evolving form design solution.

6. Prototype tool implementation

Based on this system architecture, a proof-of-concept tool was implemented. The salient steps of using this tool are illustrated in Figure 3. *Autodesk* ® *Inventor* [20] has been utilized as the 3D modelling package (step 1).

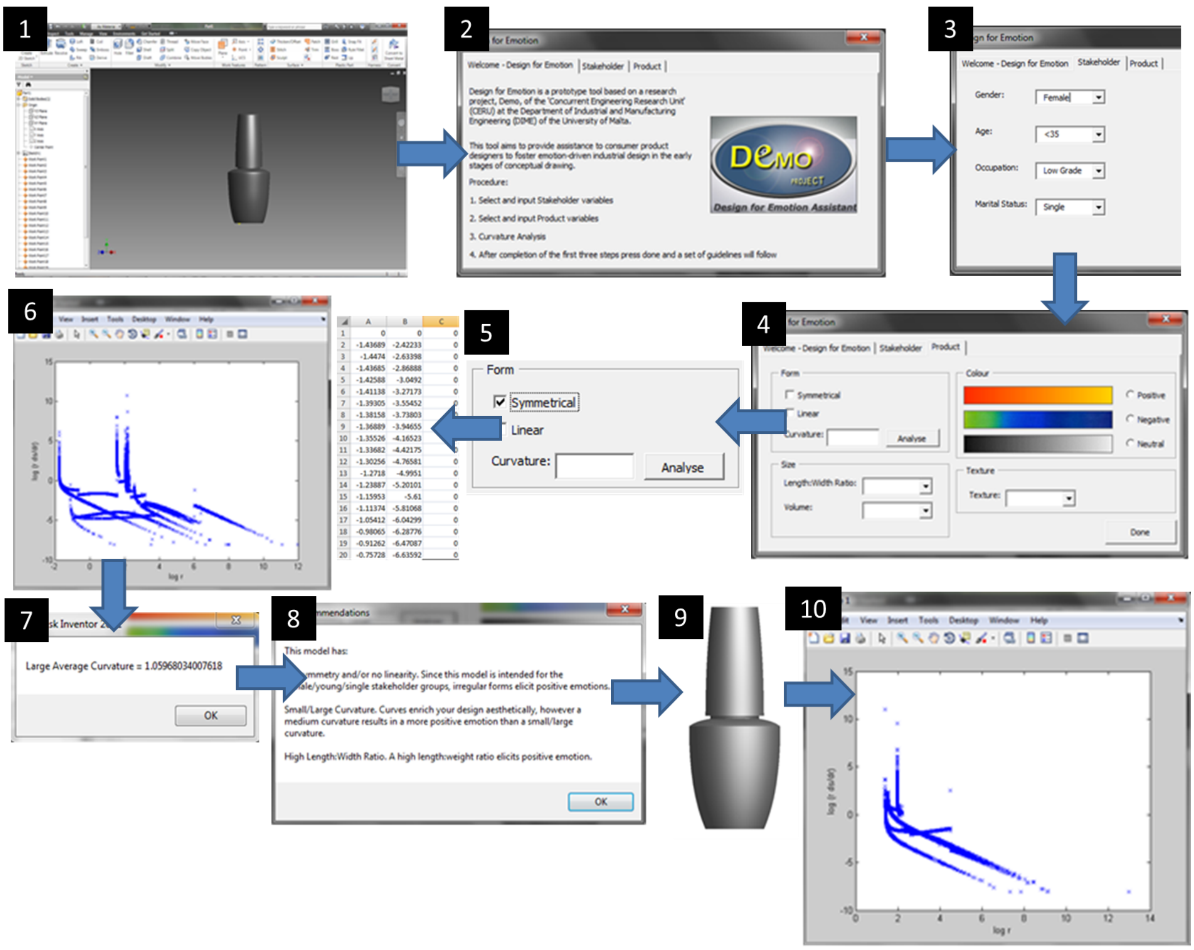


Figure.3 Key steps of using the proof-of-concept tool

The IDFe frame was implemented using the expert system *wxClips* [21]. This frame is invoked in Autodesk® Inventor (step 2), whilst the designer is developing the form concept. This task is accomplished through a macro within Autodesk® Inventor's *Visual Basic for Applications* (VBA). The user then inputs stakeholder and product characteristics through a set of combo and check boxes (steps 3 to 5). The 'analyse' button is then clicked to start the execution of the CA frame. The main implementation limitation concerns the extraction of the coordinates of the curve (step 6), since this is done manually; basically the coordinates of a selected curve are inputted and saved in a *Microsoft Excel* [22] spreadsheet. Another implementation constraint lies in that the implemented tool is limited to planar curves. Given that research efforts have been embarked upon evaluating the system's underlying principle, these limitations were considered as acceptable. *MATLAB*® is automatically launched once the work points are saved. This software was employed to generate LCHs and the curvature value (steps 6 and 7). A set of DFe recommendations are then issued and presented to the designer in Autodesk® Inventor (step 8) so that the model can be improved (step 9). Based on the improved design, the execution of the CA frame is repeated and an updated LCH is issued (step 10).

7. Evaluation

The evaluation approach consisted of two stages. In the first stage the prototype tool was assessed by applying a case study using a nail varnish bottle. After the modifications to the original 3D CAD models were made following the DFe recommendations issued by the tool, the original and the modified designs were compared and assessed by typical end users to verify whether the implemented changes were effective in terms of positive emotions. The second evaluation stage was conducted with a focus group of four industrial engineering students, during the execution of their third year engineering design group project. A live demonstration of the tool was given. The participants were then given time to interact with the tool themselves by evaluating a part designed for their own project. A questionnaire was distributed to each evaluator to fill whilst discussing the tool in a structured focus group. The questionnaire evaluated the importance of DFe, the ease of use, practicality, usefulness, layout, automation, presentation of results of the prototype tool, its adequacy, ease of implementation, degree of support, and the degree of hindrance in creativity of the DFe recommendations. A Likert scale was employed to measure the respondents' attitude.

7.2 Evaluation results from the case study

In the case study product, it was assumed that the range of colours offered by this line of nail varnishes is bright and is intended for young teenage girls. The relevant stakeholder characteristics were inputted as described in section 6. It was observed that the LCH of the original varnish bottle design was a very irregular plot (see Figure 4), which implies that the curve is not log aesthetic and requires modification. Based on the DFe recommendations, the model was modified as illustrated in Figure 4. A smoother plot was attained after this modification (refer to Figure 4). The models prior to modification and after were evaluated through a single question survey. It resulted that 83.3% from a sample of 42 females found the modified design aesthetically pleasing compared to the original model.

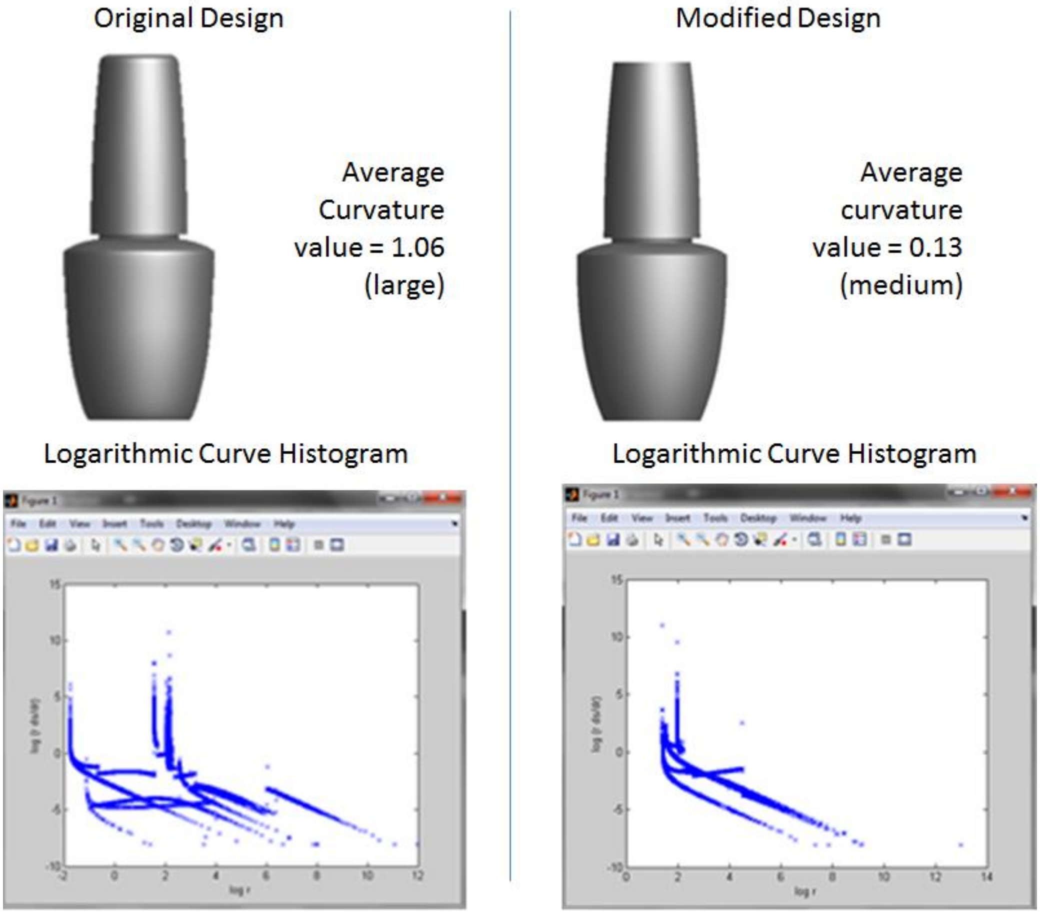
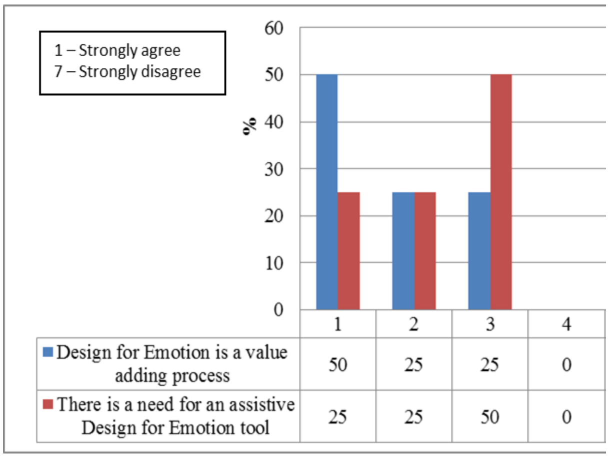


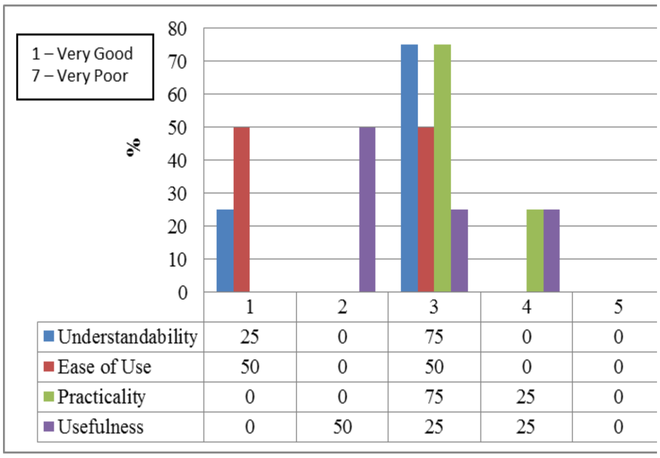
Figure.4 Original and the modified design and the respective LCH of the nail varnish bottle

7.3 Evaluation results from the questionnaire

The results depicted in Figure 5a indicate that the evaluators exhibited a positive attitude towards design for emotion as a value adding process and to have a tool assisting this process. Overall, the evaluators found the tool understandable, easy to use, useful and to a lesser extent practical (see corresponding ratings in Figure 5b). Positive results were also obtained as regards to the tool's user interface, automation and presentations of results (see Figure 5c). The evaluators were satisfied with the level of DFe support the tool offered, its adequacy and ease of implementation (see Figure 5d). Except for one evaluator who gave a rate of 5, the evaluators were of the opinion that the tool does not hinder creativity (see results in Figure 5d). From the qualitative data which was collected, the main advantages of the tool which were highlighted regarded the ability of the tool to guide the designers on the quality of the curves from the emotions point of view, for different stakeholder characteristics. This is reflected in the following comment *"Able to analyze different curves for different segments of people and able to provide valid suggestions for improvements and advice"*. On the other hand, the qualitative data also suggested that the main concerns of the evaluators regarded the fact that the tool is currently constrained to analyse 2D curves only and the manual input of the coordinates rendered the procedure time-consuming.



(a)



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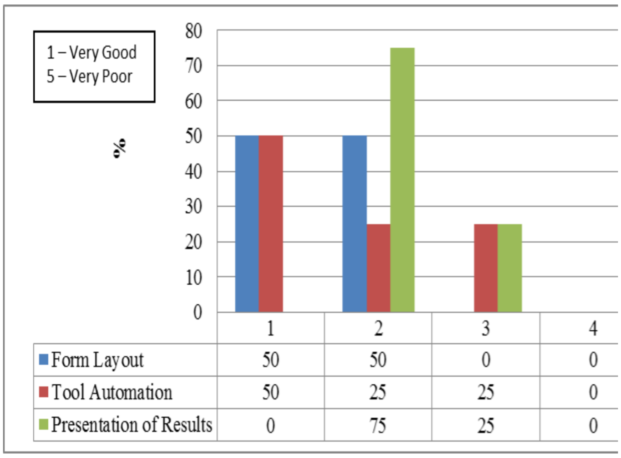
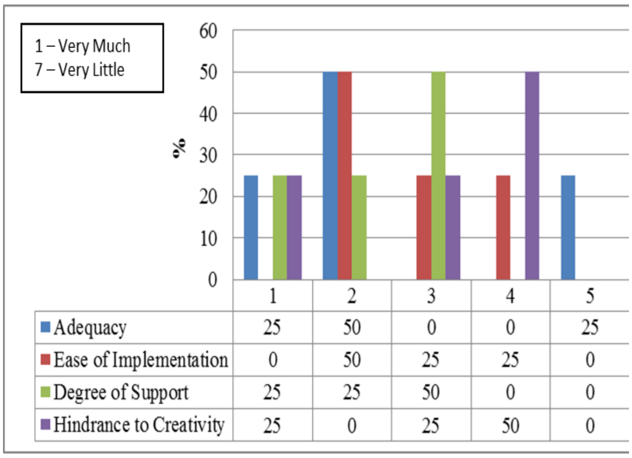


(c)



(d)

Figure.5 Key evaluation survey results

8. Discussion and Future Work

The results obtained in the case study application and the evaluation questionnaire, collectively, gave an indication of the tool's strengths and weaknesses. The results obtained from the case study artefact indicate that curvature modification has a strong effect on the aesthetic emotional value. The survey evaluation results provide a degree of evidence that the evaluators comprehended the tool's operation procedure without difficulty and discerned that the tool's employment was straightforward giving understandability and ease of use high ratings. Thus the prototype tool can be utilized with little training. Practicality and usefulness of the tool were given medium ratings implying that these aspects require improvements not only tool-wise but also by increasing awareness of the importance of DFe and its value adding capabilities, for designers to invest time into improving the emotional value of their products. Providing designers with the DFe recommendations at the initial stages of product development was also highlighted as an advantage by the evaluators. In addition the tool was also appraised with strong potential due to its integration with a CAD package allowing users drawing their design in a CAD environment to also analyse their ideas.

The emotional knowledge database was evaluated as comprehensive however one of the evaluators pointed out that the knowledge should be more product specific and each inherent product characteristic is interpreted accordingly. For example the curve of an automotive design should not be analysed through the same guidelines as the curves of a shampoo bottle. The recommendations provided to the users were supportive, adequate and implementable to their design process although a degree of hindrance to their creativity was experienced by the evaluators as they felt constrained to follow the suggestions. One must also keep in mind that cultures, fashions and trends vary with time thus stakeholders' preferences might change accordingly. Thus the emotional knowledge database has the drawback of being time dependent and requires updating accordingly.

To address the limitations noted from the evaluation, the following main research directions are recommended:

1. introduce a frame in the system architecture such that the emotions database can be maintained;
2. conducting further research to define product specific characteristics e.g. the value to the optimal length : width ratio of a smart phone model differs from that of a water bottle, thus a database defining values and specifying inherent product characteristics would develop a more effective database;
3. improve the practicability of the prototype tool and broaden its applicability by automating the extraction of the curve coordinates and by introducing 3D curves.

9. Conclusions

The main contribution of this paper is a novel DFe system architecture which exploits logarithmic aesthetic curves for proactively supporting DFe guidance in the embodiment design stages. Another key contribution consists of the guidelines derived from the knowledge generated from the questionnaire carried out to investigate the relationships between aesthetic curves, stakeholder characteristics and emotions. It is concluded that the evaluation results collectively indicate that the implemented proof-of-concept tool provides a step in supporting designers with guidance on how to improve their form concepts such that the emotional value is enhanced.

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